R.I. RENEWABLE ENERGY SITING PARTNERSHIP
FINAL REPORT

VOLUME 2
TECHNICAL REPORTS

RESP

RENEWABLE ENERGY SITING PARTNERSHIP

VOLUME II. TECHNICAL REPORTS

Table of Contents

RESP TECHNICAL REPORT #1

THE STRUCTURE OF RENEWABLE ENERGY FINANCING IN RHODE ISLAND
AN OVERVIEW OF 2011 ENACTMENTS

By

Ken Payne

June, 2012

In 2011, the RI General Assembly comprehensively amended to laws pertaining to renewable energy financing. The year was a watershed. Now the structure of renewable energy financing in RI can only be described in terms of the 2011 enactments.

The components of the comprehensive suite of enactments are as follows:

- Net-metering: Public Laws of 2011, Chapters 134 and 147,
- Distributed generation-long term contracting: Public Laws of 2011, Chapters 129 and 143,
- Interconnection studies and charges: Public Laws of 2011, Chapters 140 and 144,
- Systems benefit charge: Public Laws of 2011, Chapters 19 and 28,
- Renewable Energy Coordinating Board: Public Laws of 2011, Chapter 222.

Net-metering

Until the 2011 enactments, Public Laws of 2011, Chapters 134 and 147, net-metering was a subsection of Rhode Island's renewable energy standard law, RIGL Chapter 39-26. This was awkward. Net-metering had become an increasingly important and complex topic with its own definitions and purposes. The 2011 enactments made net-metering a freestanding chapter of the General Laws, and provided critical definitions:

"Eligible Net Metering System" means a facility generating electricity using an eligible net metering resource that is reasonably designed and sized to annually produce electricity in an amount that is equal to or less than the renewable self-generator's usage at the eligible net metering system site measured by the three (3) year average annual consumption of energy over the previous three (3) years at the electric distribution account(s) located at the eligible net metering system site. A projected annual consumption of energy may be used until the actual three (3) year average annual consumption of energy over the previous three (3) years at the electric distribution account(s) located at the eligible net metering system site becomes available for use in determining eligibility of the generating system. The eligible net metering system must be owned by the same entity that is the customer of record on the net metered accounts. Notwithstanding any other provisions of this chapter, any eligible net metering resource: (i) owned by a municipality or multi-municipal collaborative or (ii) owned and operated by a renewable generation developer on behalf of a municipality or multi-municipal collaborative through municipal net metering financing arrangement shall be treated as an eligible net metering system and all municipal accounts designated by the municipality or multi-municipal collaborative for net metering shall be treated as accounts eligible for net metering within an eligible net metering system site.

"Eligible Net Metering System Site" means the site where the eligible net metering system is located or is part of the same campus or complex of sites contiguous to one another and the site where the eligible net metering system is located or a farm in which the eligible net metering system is located. Except for an eligible net metering system owned by or operated on behalf of a municipality or multi-municipal collaborative through a municipal net metering financing arrangement, the purpose of this definition is to reasonably assure that energy generated by the eligible net metering system is consumed by net metered electric service account(s) that are actually located in the same geographical location as the eligible net metering system. Except for an eligible net metering system owned by or operated on behalf of a municipality or multi-municipal collaborative through a municipal net metering financing arrangement, all of the net metered accounts at the eligible net metering system site must be the accounts of the same customer of record and customers are not permitted to enter into agreements or arrangements to change the name on accounts for the purpose of artificially expanding the eligible net metering system site to contiguous sites in an attempt to avoid this restriction. However, a property owner may change the nature of the metered service at the accounts at the site to be master metered in the owner's name, or become the customer of record for each of the accounts, provided that the owner becoming the customer of record actually owns the property at which the account is located. As long as the net metered accounts meet the requirements set forth in this definition, there is no limit on the number of accounts that may be net metered within the eligible net metering system site.

"Renewable Net Metering Credit" means a credit that applies to an Eligible Net Metering System up to one hundred percent (100%) of the renewable self-generator's usage at the Eligible Net Metering System Site over the applicable billing period. This credit shall be equal to the total kilowatt hours of electricity generated and consumed on-site during the billing period multiplied by the sum of the distribution company's:

(i) Standard offer service kilowatt hour charge for the rate class applicable to the net metering customer;
(ii) Distribution kilowatt hour charge;
(iii) Transmission kilowatt hour charge; and
(iv) Transition kilowatt hour charge.

"Excess Renewable Net Metering Credit" means a credit that applies to an eligible net metering system for that portion of the renewable self-generator's production of electricity beyond one hundred percent (100%) and no greater than one hundred twenty-five percent (125%) of the renewable self-generator's own consumption at the eligible net metering system site during the applicable billing period. Such excess renewable net metering credit shall be equal to the electric distribution company's avoided cost rate, which is hereby declared to be the electric distribution company's standard offer service kilo-watt hour (kWh) charge for the rate class and time-of-use billing period (if applicable) applicable to the distribution customer account(s) at the eligible net metering system site. Where there are accounts at the eligible net metering system site in different rate classes, the electric distribution company may calculate the excess renewable net metering credit based on the average of the standard offer service rates applicable to those on site accounts. The electric distribution company has the option to use the energy received from such excess generation to serve the standard offer service load. The commission shall have the authority to make determinations as to the applicability of this credit to specific generation facilities to the extent there is any uncertainty or disagreement.

"Municipal net metering financing arrangement" means arrangements entered into by a municipality or multi-municipal collaborative with a private entity to facilitate the financing and operation of a net metering resource, in which the private entity owns and operates an eligible net metering resource on behalf of a municipality or multi-municipal collaborative, where: (i) The eligible net metering resource is located on property owned or controlled by the municipality or one of the municipalities, as applicable, and (ii) The production from the eligible net metering resource and primary compensation paid by the municipality or multi-municipal collaborative to the private entity for such production is directly tied to the consumption of electricity occurring at the designated net metered accounts.

For ease of administering net metered accounts and stabilizing net metered account bills, the electric distribution company may elect (but is not required) to estimate for any twelve (12) month period:

(i) The production from the eligible net metering system; and

(ii) Aggregate consumption of the net metered accounts at the eligible net metering system site and establish a monthly billing plan that reflects the expected credits that would be applied to the net metered accounts over twelve (12) months. The billing plan would be designed to even out monthly billings over twelve (12) months, regardless of actual production and usage. If such election is made by the electric distribution company, the electric distribution company would reconcile payments and credits under the billing plan to actual production and consumption at the end of the twelve (12) month period and apply any credits or charges to the net metered accounts for any positive or negative difference, as applicable. Should there be a material change in circumstances at the eligible net metering system site or associated accounts during the twelve (12) month period, the estimates and credits may be adjusted by the electric distribution company during the reconciliation period. The electric distribution company also may elect (but is not required) to issue checks to any net metering customer in lieu of billing credits or carry forward credits or charges to the next billing period. For residential eligible net metering systems twenty-five kilowatts (25 kw) or smaller, the electric distribution company, at its option, may administer renewable net metering credits month to month allowing unused credits to carry forward into following billing period.

If the electricity generated by an eligible net metering system during a billing period is equal to or less than the net metering customer's usage during the billing period for electric distribution company customer accounts at the eligible net metering system site, the customer shall receive renewable net metering credits, which shall be applied to offset the net metering customer's usage on accounts at the eligible net metering system site.

If the electricity generated by an eligible net metering system during a billing period is greater than the net metering customer's usage on accounts at the eligible net metering system site during the billing period, the customer shall be paid by excess renewable net metering credits for the excess electricity generated beyond the net metering customer's usage at the eligible net metering system site up to an additional twenty-five percent (25%) of the renewable self generator's consumption during the billing period; unless the electric distribution company and net metering customer have agreed to a billing plan.

The amount of net metering was capped at: (1) The maximum allowable capacity for eligible net metering systems, based on nameplate capacity, shall be five megawatts (5 mw), and (2) The aggregate amount of net metering in Rhode Island shall not exceed three percent (3%) of peak load, provided that at least two megawatts (2 mw) are reserved for projects of less than fifty kilowatts (50 kw). The previous limitation on eligible net metering resources to solar and wind projects was eliminated.

The Acts also, within their renewable energy standard sections, separated the definition of eligible renewable energy resources from a requirement that such resources be used to off-set the electricity generation from non-renewable resources.

Distributed Generation-Long Term Contracting

Distributed generation-long term contracting: Public Laws of 2011, Chapters 129 and 143, is a new mechanism under Rhode Island law. The purpose of the law is "to facilitate and promote installation of grid-connected generation of renewable energy; support and encourage development of distributed renewable energy generation systems; reduce environmental impacts; reduce carbon emissions that contribute to climate change by encouraging the local siting of renewable energy projects; diversify the state's energy generation sources; stimulate economic development; improve distribution system resilience and reliability; and reduce distribution system costs."

If the function of the net metering law is to facilitate customers meeting their own electrical power needs from eligible renewable energy resources, the function of the distributed generation-long term contracting law is to facilitate the development of eligible renewable energy resources that provide electricity from eligible renewable energy resources to the grid serving the distribution area that includes Rhode Island.

The amount of generation subject to distributed generation-long term contracting is capped at aggregate amount of at least 40 MegaWatts name plate capacity; and the maximum individual project size is set at 5 MW name plate capacity, larger projects are eligible for enrollment in the long-term contracting provisions of RIGL chapter 39-26.1.

The distributed generation standard contract board [or in the absence of the board, the OER] "shall set ceiling prices and annual targets for each renewable energy class of distributed generation for the 2011 program year and make a filing with the commission pursuant to this chapter recommending such prices and targets. <u>Thereafter annually by no later than October 15 of each year, the board shall make filings with the commission to recommend the standard contract ceiling prices and annual targets for each renewable energy class of distributed generation facility.</u> The ceiling price for each technology should be a price that would allow a private owner to invest in a given project at a reasonable rate of return, based on recent reported and forecast information on the cost of capital, and the cost of generation equipment. The calculation of the reasonable rate of return for a project shall include where applicable any state or federal incentives including, but not limited to, tax incentives. In setting the ceiling prices, the board also may consider: (1) Transactions for newly developed renewable energy resources, by technology and size, in the ISO-NE region and the northeast corridor; (2) Pricing for standard contracts received during the previous program year; (3) Environmental benefits, including, but not limited to, reducing carbon emissions, and system benefits; and (4) Cost effectiveness. The board shall in performing this assessment involve representation from its advisory council, if applicable, and from the office of energy resources, the electric distribution company, and the energy efficiency and resources management council. The board shall hold, with at least ten (10) business days' notice, a public community review meeting. The board shall issue a report of its findings from the assessment process recommending standard contract ceiling prices for the upcoming program year."

As of 2012, there are to be at least four classes of projects, at least two for solar generation, at least one for wind, and one other.

Eligibility for the ceiling price at the small distributed generation is set at 500 KW solar, and 1.5 MW wind.

The "Standard contract" means a contract with a term of fifteen (15) years at a fixed rate for the purchase of all capacity, energy, and attributes generated by a distributed generation facility. A contract may have a different term if it is mutually agreed to by the seller and the electric distribution company and it is approved by the commission. The terms of the standard contract for each program year and for each renewable energy class shall be set pursuant to the provisions of this chapter.

The "Standard contract ceiling price" means the standard contract price for the output of a distributed generation facility which price is approved annually for each renewable energy class pursuant to the procedure established in this chapter, for the purchase of energy, capacity, renewable energy certificates, and all other environmental attributes and market products that are available or may become available from the distributed generation facility.

The standard contracts would be applicable for various technologies for both small and large distributed generation projects. The standard contracts should balance the need for the project to obtain financing against the need for the distribution company to protect itself and its distribution customers against unreasonable risks. The standard contract should be developed from contracting terms typically utilized in the wholesale power industry, taking into account the size of each project and the technology. The standard contracts shall provide for the purchase of energy, capacity renewable energy certificates, and all other environmental attributes and market products that are available or may become available from the distributed generation facility. However, the electric distribution company shall retain the right to separate out pricing for each market product under the contracts for administrative and accounting purposes to avoid any detrimental accounting effects or for administrative convenience, provided that such accounting as specified in the contract does not affect the price and financial benefits to the seller as a seller of a bundled product. The standard contract also shall:

> (i) Hold the distributed generation facility owner liable for the cost of interconnection from the distributed generation facility to the interconnect point with the distribution system, and for any upgrades to the existing distributed generation system that may be required by the electric distribution company. However, a distributed generation facility owner may appeal to the commission to reduce any required system upgrade costs to the extent such upgrades can be shown to benefit other customers of the electric distribution company and the balance of such costs shall be included in rates by the electric distribution company for recovery in the year incurred or the year following incurrence;
>
> <u>(ii) Require the distributed generation facility owner to make a performance guarantee deposit to the electric distribution company of fifteen dollars ($15.00) for small distributed generation projects or twenty-five dollars ($25.00) for large distributed generation projects for every renewable energy certificate estimated to be generated per year under the contract, but at least five hundred dollars ($500) and not more than seventy-five thousand dollars ($75,000), paid at the time of contract execution;</u>
>
> (iii) Require the electric distribution company to refund the performance guarantee deposit on a pro-rated basis of renewable energy credits actually delivered by the distributed generation facility over the course of the first year of the project's operation, paid quarterly;
>
> (iv) Provide that if the distributed generation facility has not generated the output proposed in its enrollment application <u>within eighteen (18) months after execution</u> of the contract, the contract is automatically voided and the performance guarantee is forfeited. Any forfeited performance guarantee deposits shall be credited to all distribution customers in rates and not retained by the electric distribution company;
>
> (v) Provide for flexible payment schedules that may be negotiated between the buyer and seller, but shall be no longer than quarterly if an agreement cannot be reached;
>
> (vi) Require that an electric meter which conforms with standard industry norms be installed to measure the electrical energy output of the distributed generation facility, and require a system or procedure by which the distributed generation facility owner shall demonstrate creation of renewable energy credits, in a manner recognized and accounted for by the GIS; such demonstration of renewable energy credit creation to be at the distributed generation facility owner's expense. The electric distribution company may, at

> its discretion, offer to provide such a renewable energy credit measurement and accounting system or procedure to the distributed generation facility owner, and the distributed generation facility owner may, at its discretion, use the electric distribution company's program, or use that of an independent third party, approved by the commission, and the costs of such measurement and accounting are paid for by the distributed generation facility owner.

After 2011, there are three enrollments periods annually through 2014.

Interconnection

The interconnection law setting standard timetables and fee schedules for interconnection studies and charges, Public Laws of 2011, Chapters 140 and 144 was the result of frustration with an interconnection process that was unpredictable and frequently time consuming and expensive.

The General Assembly found "expeditious completion of the application process for renewable distributed generation is in the public interest. For this reason, certain standards and other provisions for the processing of applications are hereby set forth to assure that the application process assists in the development of renewable generation resources in a timely manner."

Standard fee schedules and schedules are statutorily set for higher level "feasibility studies" and more detailed "impact studies." This is done by the size of the project:

(1) Residential applicants for interconnections of distributed generation that is twenty-five kilowatts (25 kw) or less,

(2) Residential applicants for interconnections of distributed generation that is greater than twenty-five kilowatts (25 kw),

(3) Non-residential applicants for interconnections of distributed generation that is one hundred kilowatts (100 kw) or less,

(4) Non-residential applicants for interconnections distributed generation that is two hundred fifty kilowatts (250 kw) or less,

(5) Non-residential applicants for interconnections of renewable distributed generation that is greater than two hundred fifty kilowatts (250 kw), and

(6) Non-residential applicants for interconnections of renewable distributed generation greater than one megawatt.

Demand Side Management Fee

The demand side management fee, a systems benefit charge of .3 mills per kilowatt hour-hour delivered was continued by Public Laws of 2011, Chapters 19 and 28, through 2018; the fee currently generates about $2 million annually and supports the Renewable Energy Fund at the Economic Development Corporation.

The Renewable Energy Coordinating Board

Recognizing that there was a need for on-going strategy and coordination of the State's effort to obtain the benefits of renewable energy development, the General Assembly created the Renewable Energy Coordinating Board, Public Laws of 2011, Chapter 222.

The board has five (5) members: (1) The director of the department of administration, who shall serve as chairperson of the board; (2) The commissioner of the office of energy resources; (3) The executive director of the economic development corporation; (4) The director of the department of environmental management; and (5) The director of the coastal resources management council.

There is also an advisory council with (15) members. Each board member shall select three (3) advisory council members, provided that the advisory council includes members with experience in the following areas: (1) Renewable energy development; (2) Energy regulation and law; (3) Environmental issues pertaining to renewable energy; (4) Business association or chamber of commerce; (5) Green trades; (6) Residential energy consumers; (7) Low-income energy consumers; (8) Small business relating to renewable energy; and (9) Commercial/industrial energy consumers.

On or before November 15, 2011, the board shall adopt the strategic plan. The board may amend the strategic plan as necessary; and on March 15 and September 15 of each year, commencing in 2012, the board shall issue the strategic plan biannual report, which shall be made available to the public and transmitted to the governor; the senate president; the speaker of the house; and state agencies.

RESP TECHNICAL REPORT #2

SITING OF WIND ENERGY FACILITIES IN RHODE ISLAND

By

Annette Grilli, Malcolm Spaulding, Chris Damon, and Christopher O'Reilly

University of Rhode Island,

Narragansett Bay Campus

June, 2012

Table of Contents

List of Figures

List of Tables

Abstract

To facilitate selection of sites for wind energy facilities (100 kW to several MWs) in Rhode Island a multi-step screening process was developed and implemented on a high resolution grid (30 m by 30 m) covering the state. The goal of the effort was to develop a simple, user friendly method to help guide site selection and as the initial step in site evaluation. The first step in the analysis was to characterize the wind resources at elevations of 30, 50, and 80 m, corresponding to wind turbine sizes of approximately 100 kW, 250-500 kW, and 1.5 MW or larger, respectively using a validated meteorological model that provided mean annual wind speeds. The model was validated with available wind observations. Wind speed thresholds (economic viability) were selected and areas removed from further consideration if the wind speeds fell below 4.5 (30 m), 5.5 (50 m), and 6.5 (80 m) m/sec. A series of potential constraints to facility siting were identified and put in the form of spatial distribution maps. The constraints included: FAA restricted areas around airports, population density, wetlands, water bodies, rivers and large streams, impervious surfaces, State/federal/ NGO protected areas, historic sites and cemeteries, habitat diversity, bird habitats, threatened and endangered bird species, background noise level and communications towers. Whether all or some of these variables are constraints is dependent on the municipality wind energy siting guidelines. Many may also be amenable to some type of mitigation. An analysis was performed to determine the number of potential constraints for each grid, assuming each had equal value. A second analysis was performed where the constraints were weighted by level of importance scores provided by representatives of RI municipalities interested in wind energy development, with scoring ranging from little to very important. The number of constraints, at a given location, was summarized on a grid and the municipal weighted scores were similarly presented in the form of a development viability index, ranging from low to high. Finally the wind thresholds for the three elevations were overlaid on the constraint score and development viability index maps. A review of the maps provides a rapid method to assess the viability of siting throughout the state. The approach allows the user to investigate the potential constraints at any particular site and to identify these early in the siting process. The study found that the viability of siting wind facilities is strongly dependent on turbine size with a decreasing number of viable areas with increasing wind power output. For smaller turbines siting is viable in inland areas while for larger turbines only sites that are close to the ocean have significant potential. The combined maps indicate that siting is highly site specific and each potential site may have one or more constraints that will need to be addressed. The maps also suggest that siting of large scale facilities in RI is likely to be restricted to individual or several turbines and not wind farms.

1. INTRODUCTION

To facilitate the siting of wind energy facilities in Rhode Island, a multi-step screening analysis to assess the suitability of sites was developed, implemented, and presented in this report. Grilli et al (2012), in a companion report, provide an assessment of the wind resources in the state, including a detailed comparison of meteorological model based estimates to observations, the overarching framework for energy facility siting, a summary of the analysis presented here, and recommendations for setbacks from facilities for blade failure/ice and blade throw, acoustic noise, and shadow flicker.

2. MULTI-STEP SCREENING ANALYSIS

To set the stage Figure 1 shows the RI study area, with associated topography. The map also shows the location of meteorological observation towers and existing wind turbines that have been previously sited. The analysis begins with the characterization of wind resources at selected elevations. Elevations of 30, 50 and 80 m were selected for analysis since they are consistent with commercial scale developments for turbines with power production ranging from 100 kW (30 m), 500 kW (50 m) to 1.5 MW (80 m) and greater. The wind data used in this analysis was obtained from AWS True Winds and generated using their MesoMap meteorological modeling system. The modeling study area included the southern New England states (Rhode Island, Massachusetts, and Connecticut) and adjacent coastal waters. The data were provided on a 200 m by 200 m resolution grid. AWS validated the model predictions by comparison to 33 stations located in southern New England. The maps show the annual average wind speeds at each elevation. Details on the modeling approach, application and validation are provided in Brower (2007). Figures 2, 3, and 4 show the annual mean wind speed contours for elevations of 30, 50, and 80 m, respectively. It has been assumed that commercially viable development will require wind speeds greater than 4.5, 5.5, and 6.5 m/sec for 30, 50, and 80 m elevation winds, respectively. These wind speed thresholds for development will clearly restrict the areas suitable for wind energy development in the state.

The pattern of the mean wind speeds is dominated by the topography (Figure 1), the land cover (Figure 5) and roughness (Figure 6). In general higher wind speeds are observed at higher elevations. Areas, with forest land cover, have a larger roughness than urban areas with significant cleared areas (Figure 6). Both topographic relief and land cover (roughness) are used as input to AWS's MesoMap model and hence reflected in their model estimates.

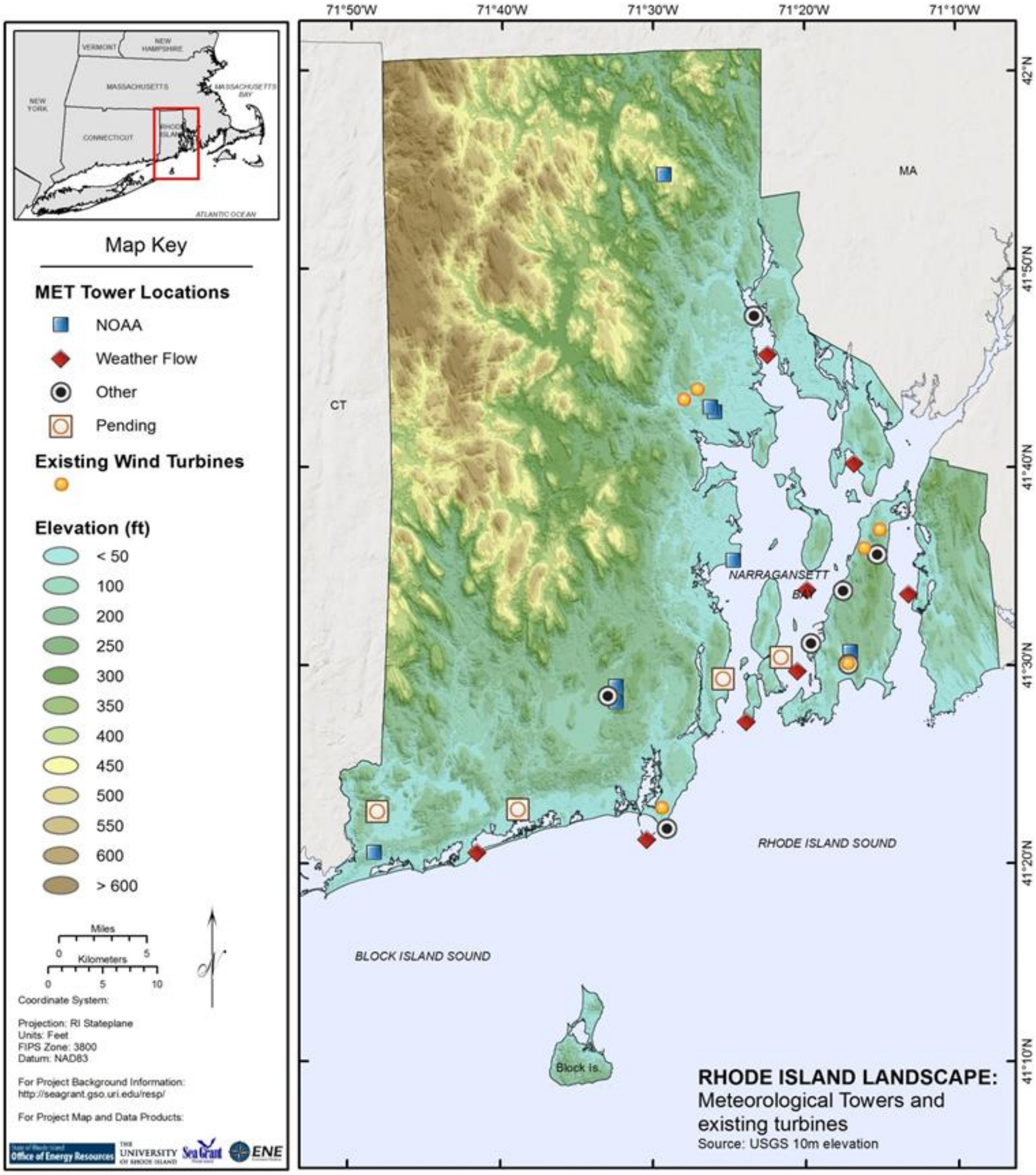


Figure 1. Renewable Energy Siting Plan (RESP) study area with USGS topography as the background. The locations of existing meteorological observation stations from NOAA/ NWS, Weather-Flow (a private firm), and other sources are provided. Locations of existing wind turbines are also provided.

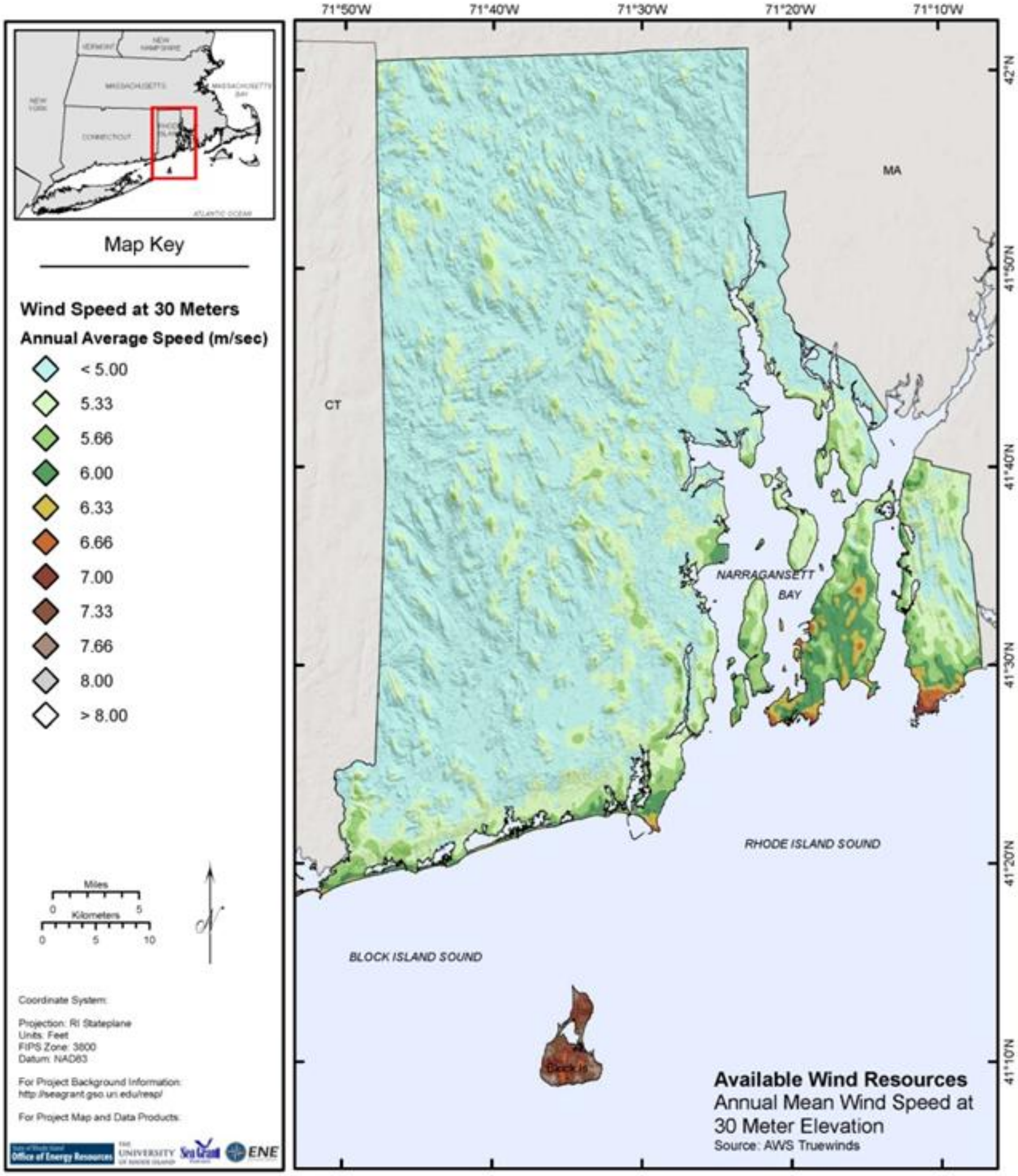


Figure 2. Predicted annual average wind speeds at 30 m elevation from AWS TrueWind.

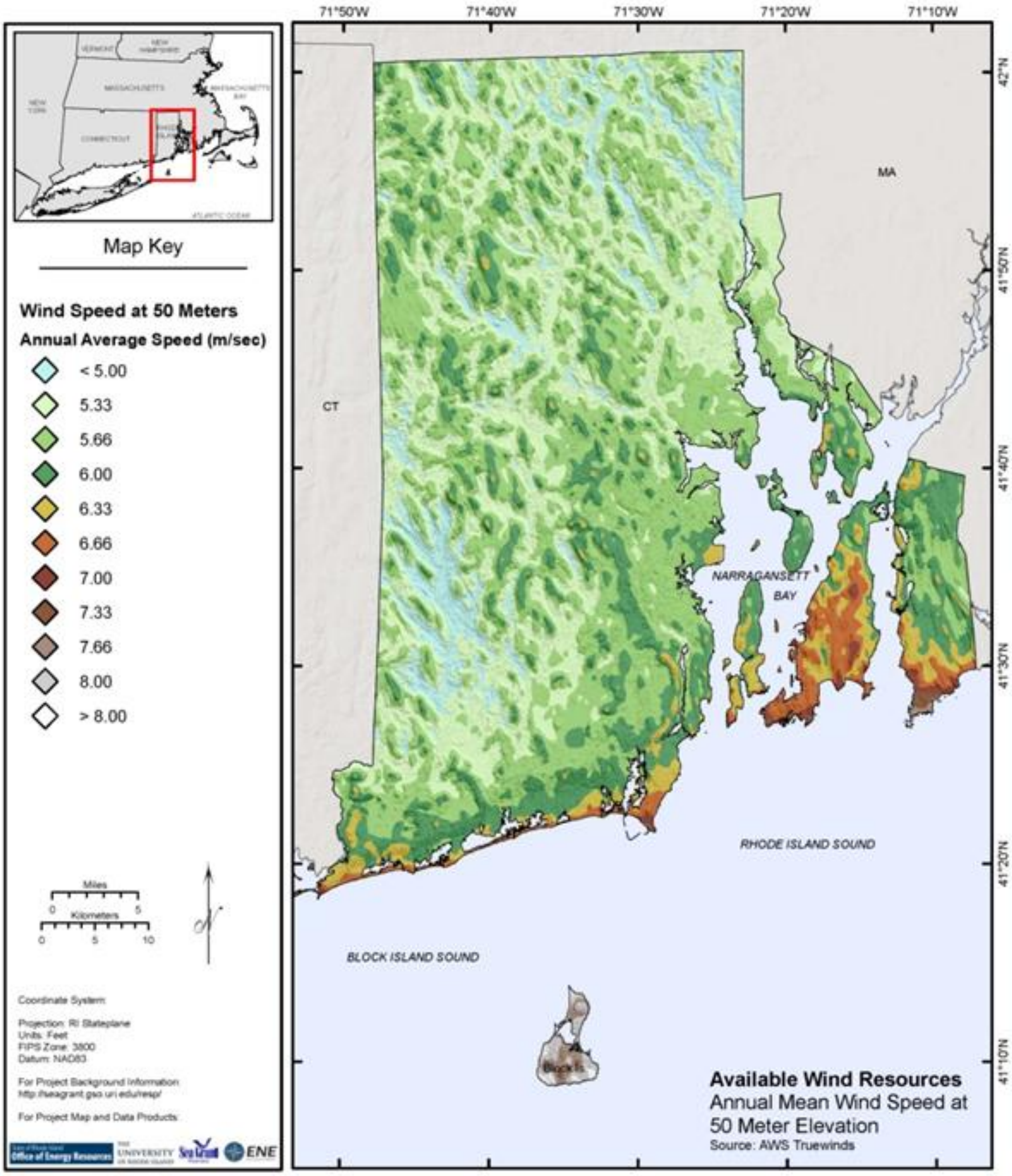


Figure 3. Predicted annual average wind speeds at 50 m elevation from AWS TrueWind.

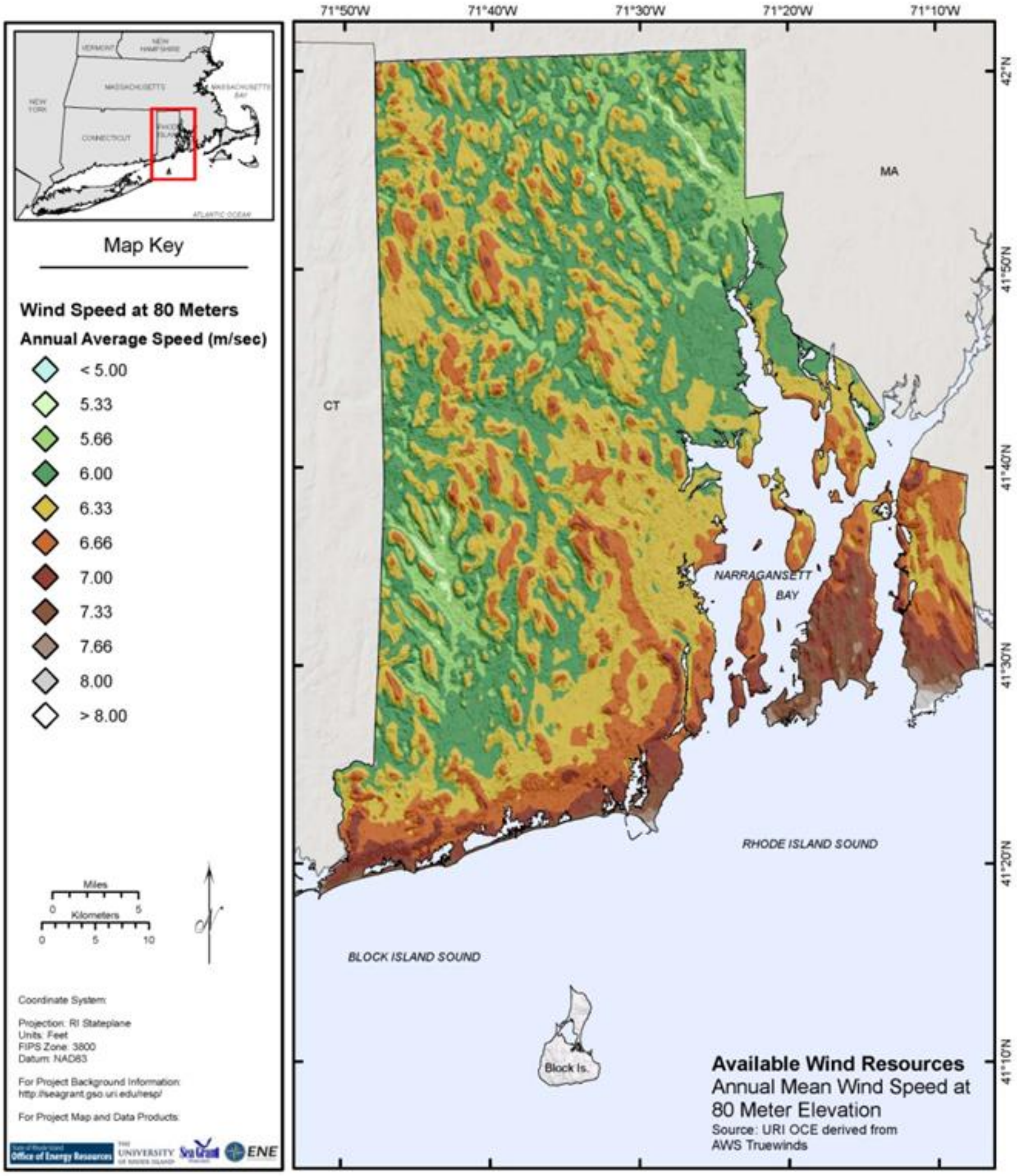


Figure 4. Predicted annual average wind speeds at 80 m elevation from AWS TrueWind.

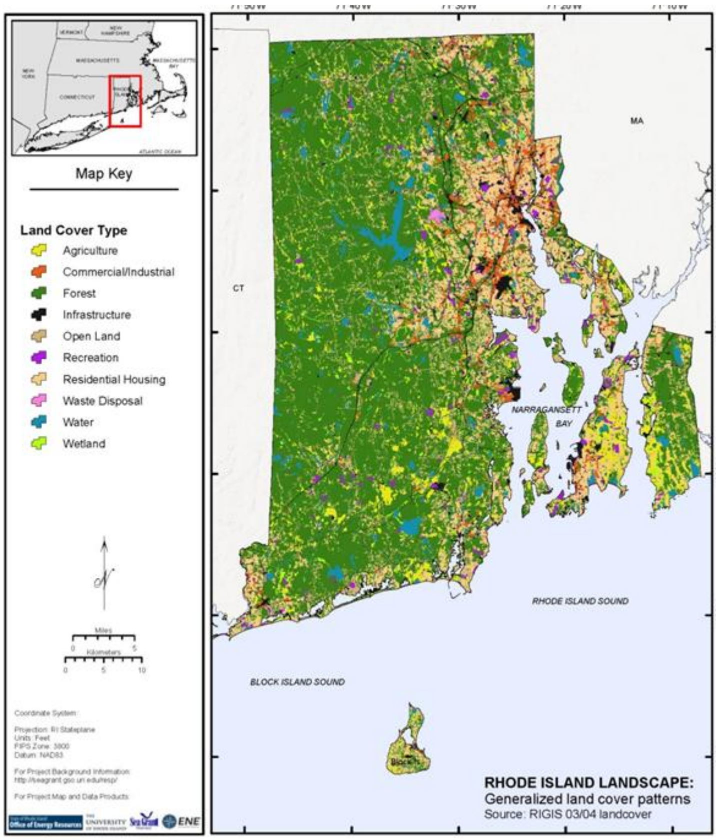


Figure 5. Land-cover for RI from RIGIS -3/04 data base. Cover type is noted in the legend.

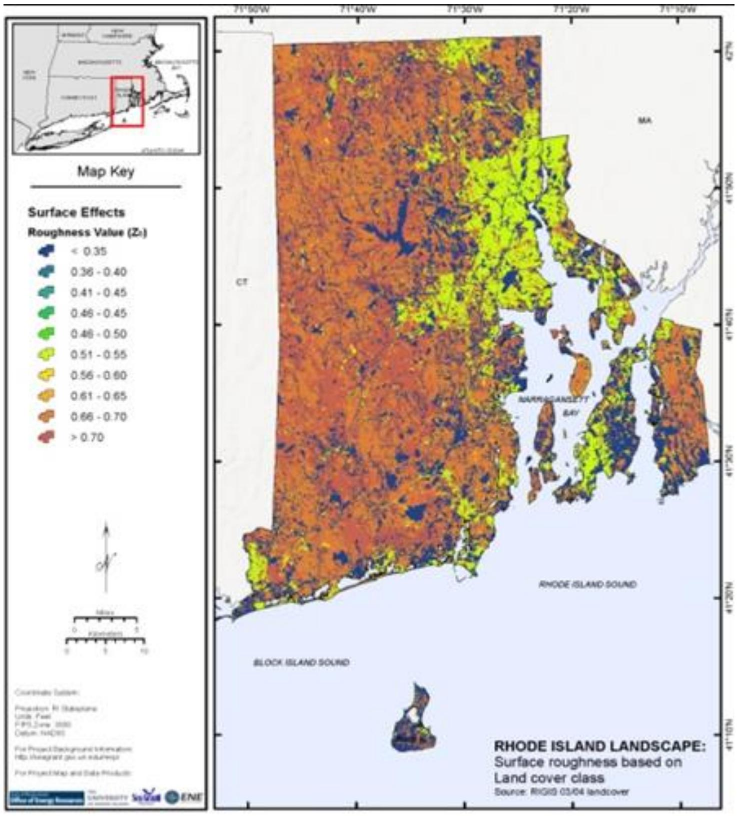


Figure 6. Surface roughness (z_0) based on land cover (Figure 5).

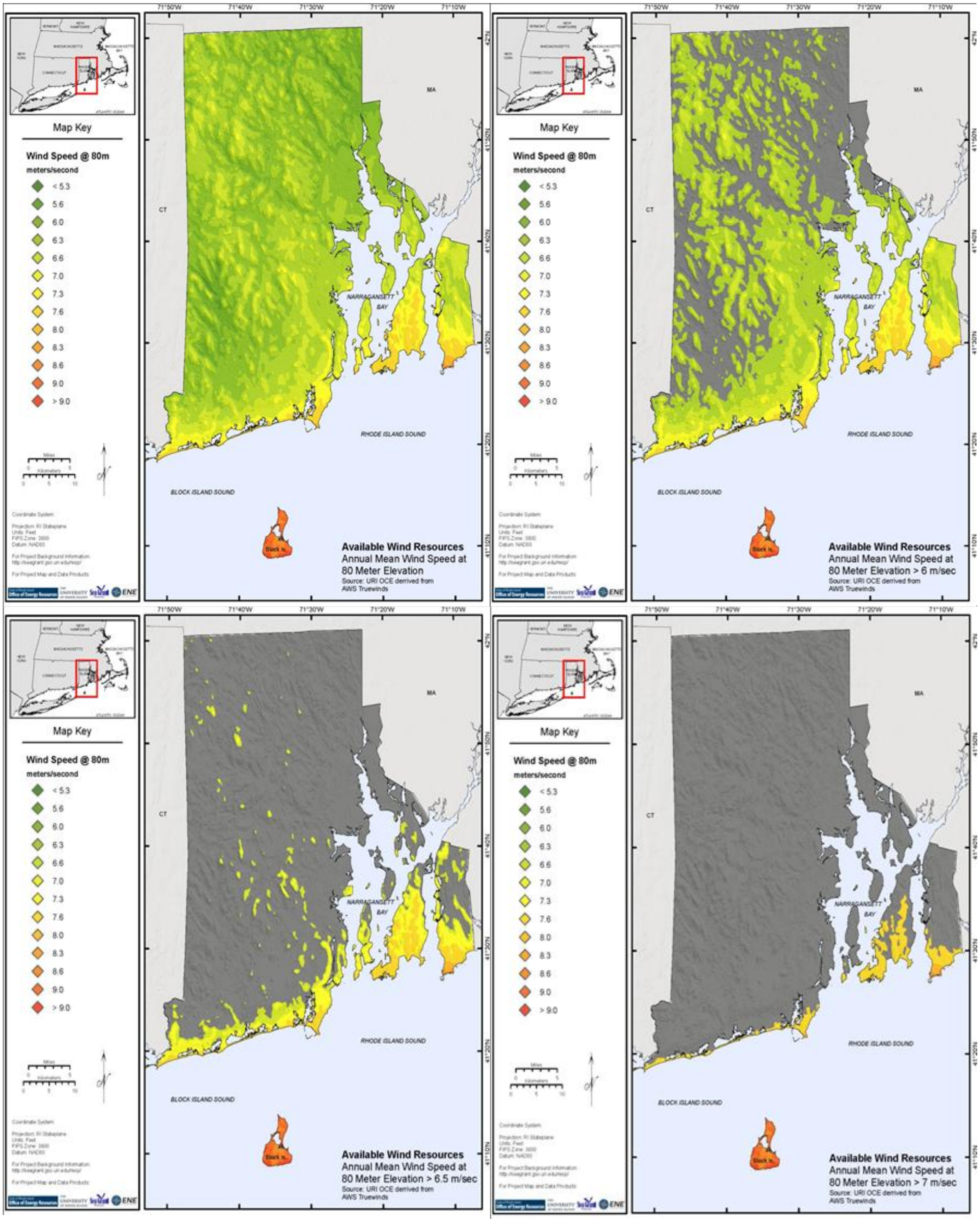


Figure 7. (a) Upper left, (b) upper right, (c) lower left, and (d) lower right. Annual mean wind speed at 80 m (a), showing areas with winds greater than (b) 6 m/sec, (c) 6.5 m/sec, and (d) 7 m/sec.

To illustrate the impact of assuming various wind energy thresholds on siting of wind energy facilities, Figure 7 shows contours of mean wind speed at 80 m assuming thresholds of (a)6 m/sec, (b) 6.5 m/sec and (c) 7 m/sec, respectively. Areas in grey are eliminated since the mean wind speed is below the threshold. Seven (7) m/sec is often used to represent the threshold of economic viability for wind turbines with hub heights of 80 m.

As the threshold value is increased the area suitable for development is dramatically reduced, with the highest elevations in the interior of the state and a narrow margin along the coast and Narragansett Bay being the only viable sites. If a 7 m/sec threshold is assumed only a very narrow band along the southern RI shoreline and southeast portion of the east bay communities is viable.

The next step in the process was to determine any potential constraints to the siting of wind facilities. Ideally this would be done in terms of hard constraints, indicating things that would absolutely preclude development, and other constraints that might indicate a concern but not necessarily a barrier to development. Initial application of variables that might be considered hard constraints showed that there were very few sites suitable for development. Discussion of the constraints with municipal officials from towns interested in wind energy development indicated that they had considerably varying views on the importance of various constraints.

Given this observation a total of fourteen maps were developed and implemented in GIS format, providing geospatial representations of potential constraints to siting. The constraint layers are summarized in Table 1 and GIS layers are provided in Figures 8 through 20. Detailed information on the source of the data for each constraint and any information on the processing that was used to generate the GIS layers is provided in the figure legends. The maps have various resolutions depending on the data source and methods used for processing. The goal was to have a nominal resolution of 30 m x 30 m covering the entire state.

Table 1. Potential constraints for wind facility siting.

Potential Constraints for Wind Facility Siting
FAA restricted areas around airports (setbacks based on runway lengths)
Population densities (greater than individuals per km^2)
Wetlands (with buffers)
Water bodies, rivers and large streams (with buffers)
Impervious surfaces (highways, highly developed
State, federal, and NGO protected areas
Historic sites and cemeteries (point locations)
Ecological Land Units (ELUs) - habitat diversity- number of ELUs per 30 m grid
Habitats (birds) (forests, grasslands, and shrubs) (with buffers)
Threatened and endangered bird species (with buffers)
Background noise level (land use, highways)
Communication towers

The rationale for selecting the various constraints listed in Table 1 is broadly summarized below.

FAA restricted areas around airports (setbacks based on runway lengths) (Figure 8)

Siting of wind turbines requires a case by case determination by the FAA as to site location given turbine characteristics. The map provides some guidance on the areas that are not likely to be acceptable.

Population densities (greater than individuals per km^2) (Figure 9)

Population density maps show the distribution of individuals in the state based on 2010 Census data. Areas with high population density are not likely to be suitable for development given proximity of turbines to individuals and the setback requirements normally implemented in facility siting.

Wetlands (with buffers) (Figure 10)

Development in wetlands and associated buffers is normally prohibited by either the RI Department of Environmental Management (RI DEM) or the RI Coastal Resources Management Council(RI CRMC). Permitting challenges are likely to be very significant.

Water bodies, rivers and large streams (with buffers) (Figure 11)

Development in water bodies, rivers, and streams and associated buffers is normally prohibited by either the RI Department of Environmental Management (RI DEM) or the RI Coastal Resources Management Council (RI CRMC). Permitting challenges are likely to be very significant.

Impervious surfaces (highways, highly developed areas, etc) (Figure 12)

Development in areas with impervious surfaces may or may not be considered for development. It is likely that areas with extensive buildings and road and highway networks will not be suitable for development but parking lots may be appropriate.

State, federal, and NGO protected areas (Figure 13)

Development in state, federal, and NGO protected areas may be prohibited by law or the permitting process may be very difficult.

Historic sites and cemeteries (point locations) (Figure 14)

Development in historic sites and cemeteries is likely to be prohibited or the permitting process challenging.

Ecological Land Units (ELUs) - habitat diversity- number of ELUs per 30 m grid (Figure 15)

Ecological Land Units (ELU) have been shown to provide a good indication of the biodiversity of given segments of land; the higher the number of ELUs the greater the biodiversity (http://www.edc.uri.edu/elu/Biodiv101.html). Areas with a high number of ELUs are preferred for land conservation and hence might not be preferred for uses that potentially interfere with that goal, such as wind energy development.

Habitats (birds) (forests, grasslands, and shrubland) (with buffers) (Figures 16, 17, and 18)

Maps of forest, grasslands, and shrubland provide an indication of the location of various bird habitats. Siting of wind energy facilities need to consider that potential impacts on bird species who use these habitats.

Threatened and endangered bird species (Figure 19)

Siting of facilities that might adversely impact threatened and endangered bird species is likely to be prohibited or permitting extremely challenging.

Background noise level (land use, highways) (Figure 20)

A map of the average background noise was generated based on land use types. The map shows the noise levels in dBA. Some communities may wish to give preference to siting in areas with higher background noise levels. The counter argument is that areas with higher background noise levels are most likely to be areas with higher human use (e.g. roads, developed areas, etc.)

Communications towers (Figure 21)

Siting of wind turbines could be prohibited in close proximity to communication towers to minimize the interface of the turbines with communications. Communication towers are located on Figure 21. New European standards specify specific setbacks regarding this issue, and we could seek some guidance from those.

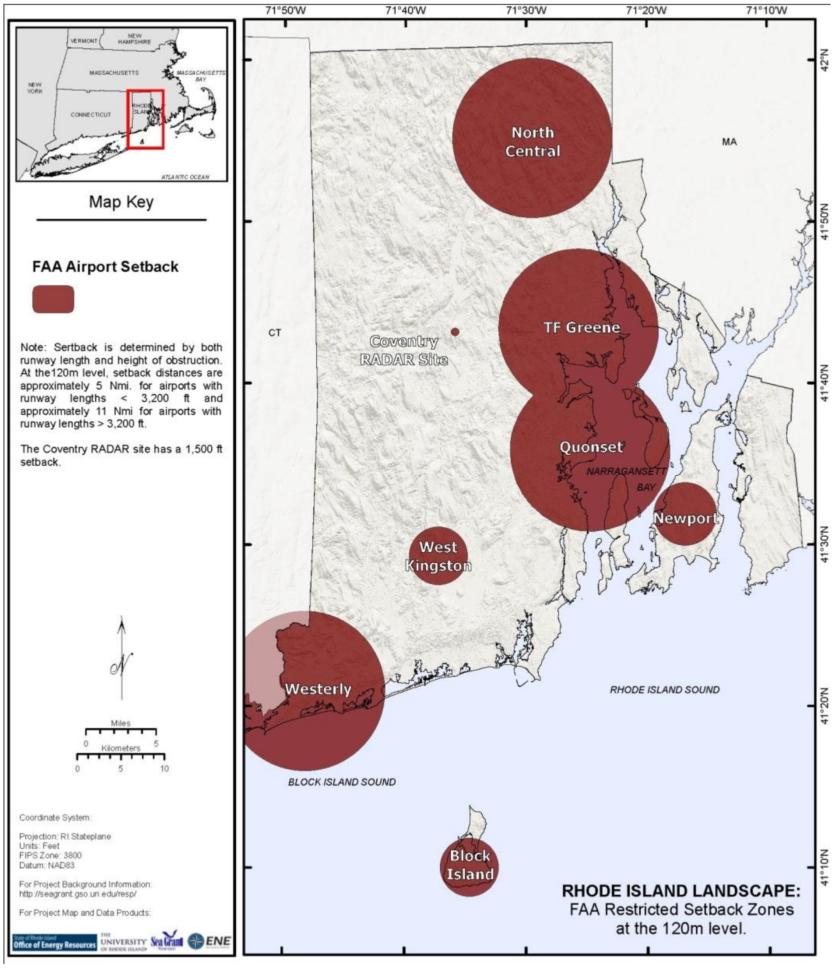
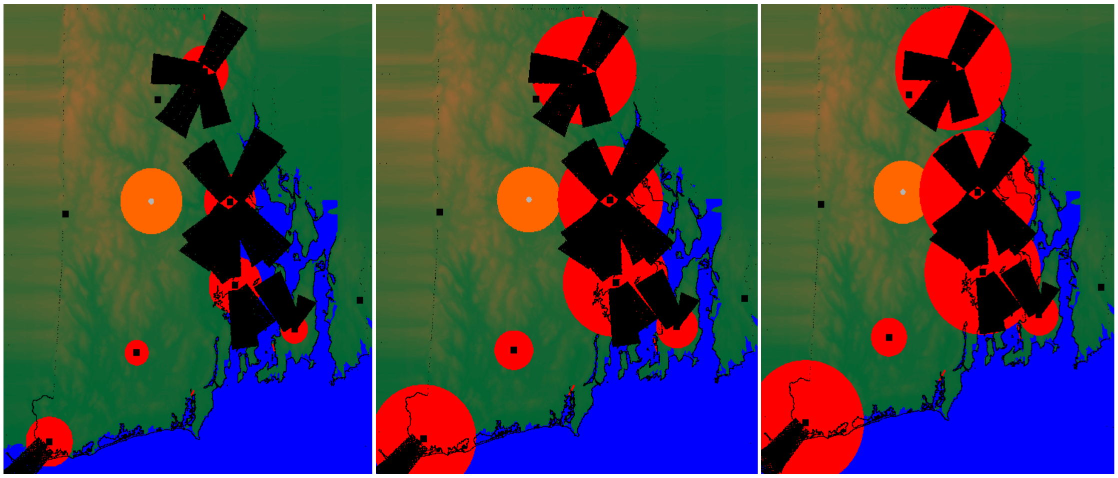


Figure 8a. FAA restricted areas around airports (setbacks based on runway lengths).
Figure 8b. (Below) FAA restrictions by elevation, (left) 60 m, (center) 120 m, and (right) 150 m. These correspond to turbines with hub heights of 30, 50, and 80 m, respectively.

FAA Exclusion Zone Chart Legend	
Airport or Heliport Zone	🟥
Approach Zone	⬛
Surveillance Radar Zone (Close)	▨
Surveillance Radar Zone (Far)	🟧



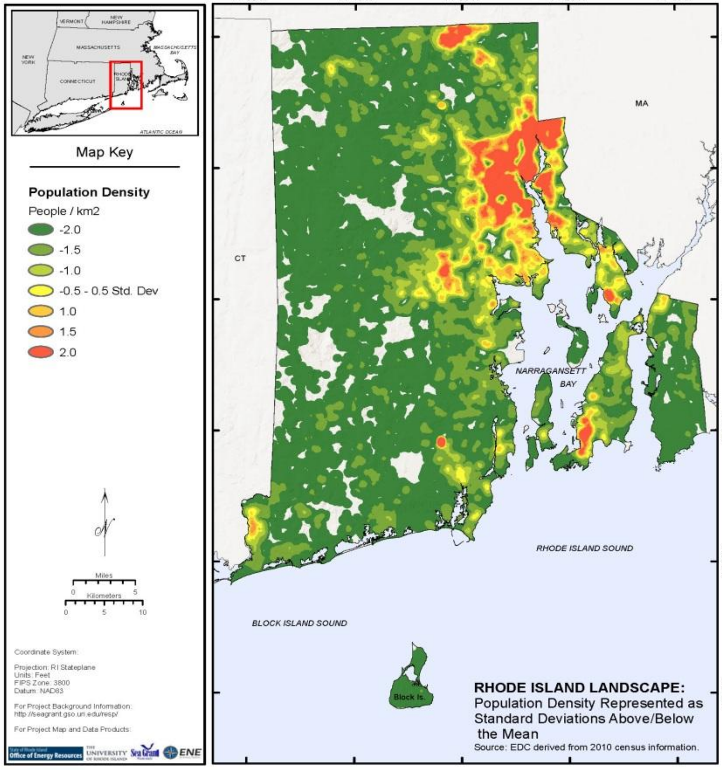


Figure 9. Population densities, in standard deviations above and below the mean, from the 2010 Census.

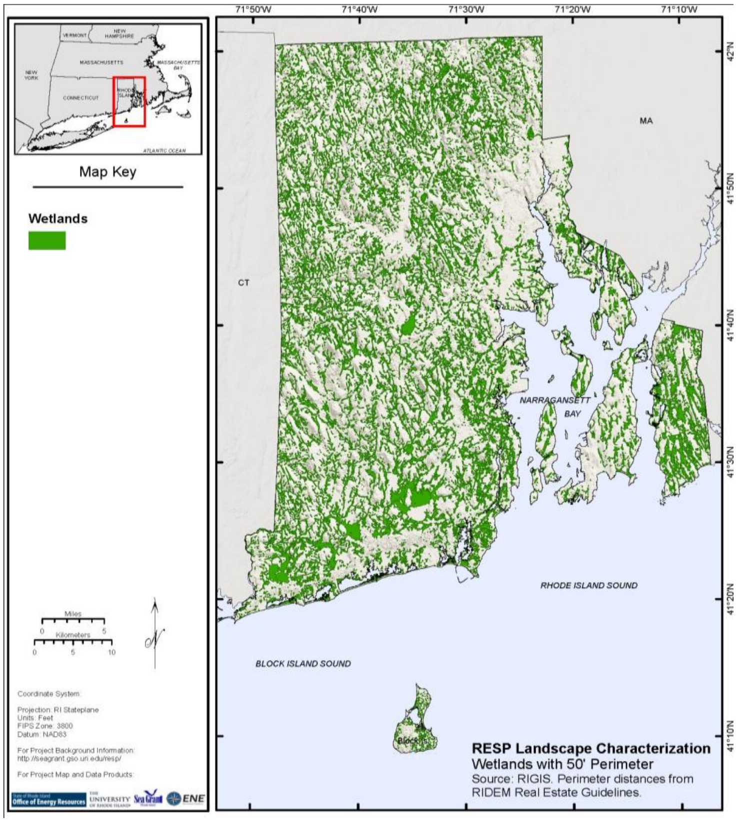


Figure 10. Wetlands, with 15.2 m (50ft) buffer.

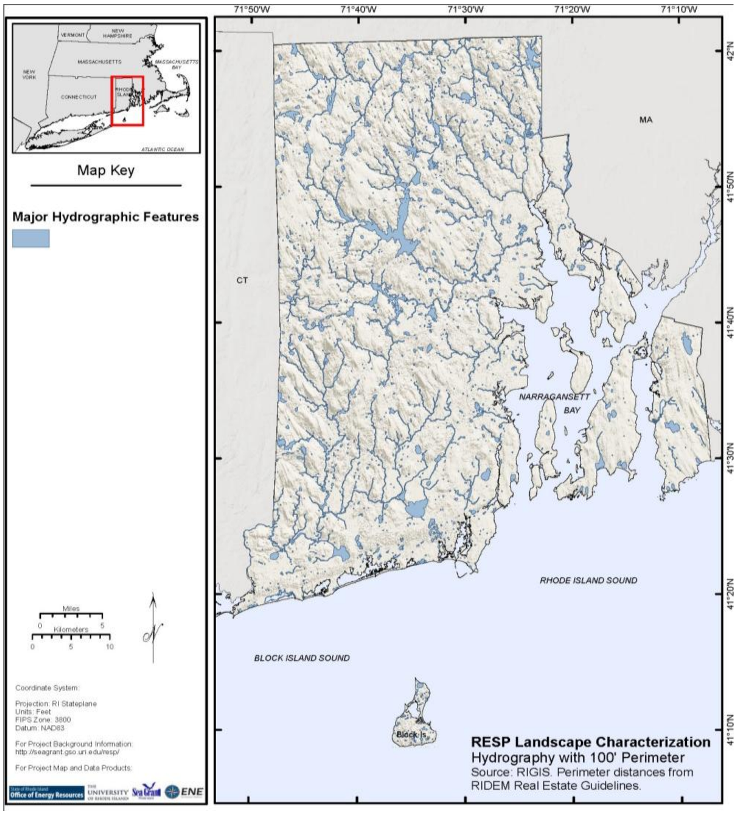


Figure 11.Water bodies, rivers, and large streams, with 30.5 m (100ft) buffer.

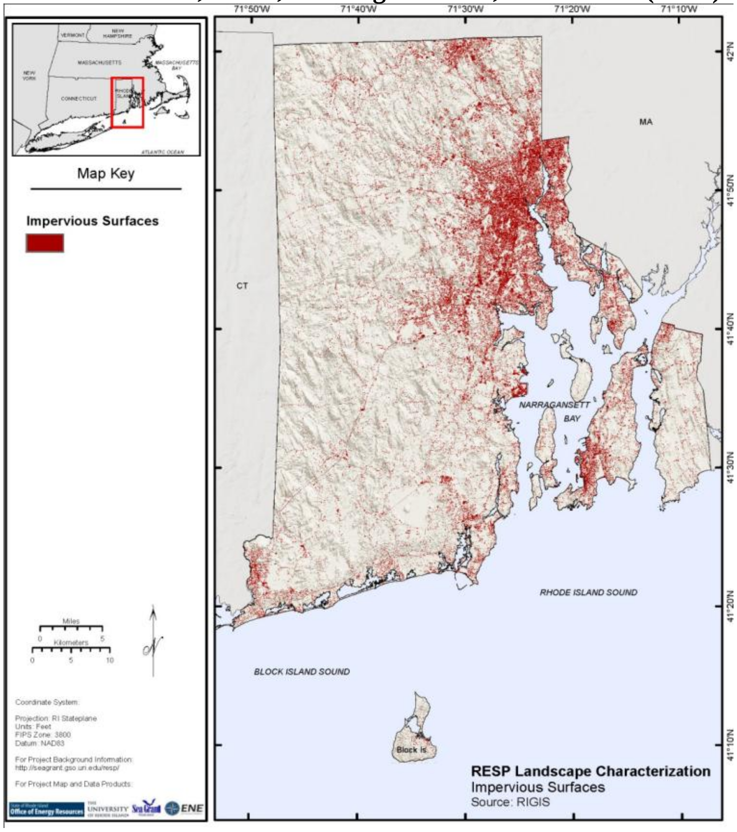


Figure 12. Impervious surfaces (highways, highly developed areas, parking lots, etc.).

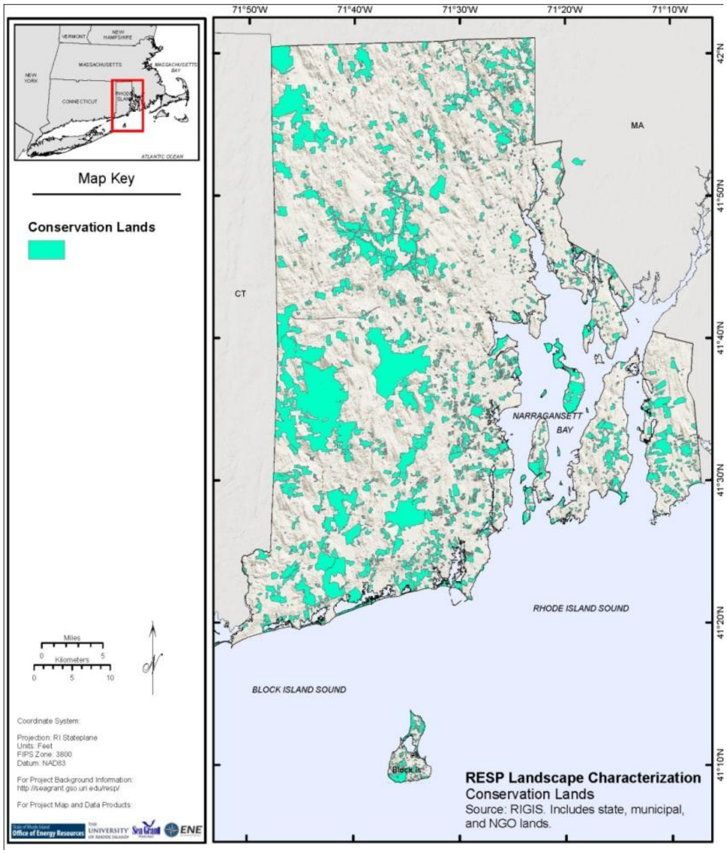


Figure 13. State, federal, and Non-Governmental Orginizations (NGO) conservation lands.

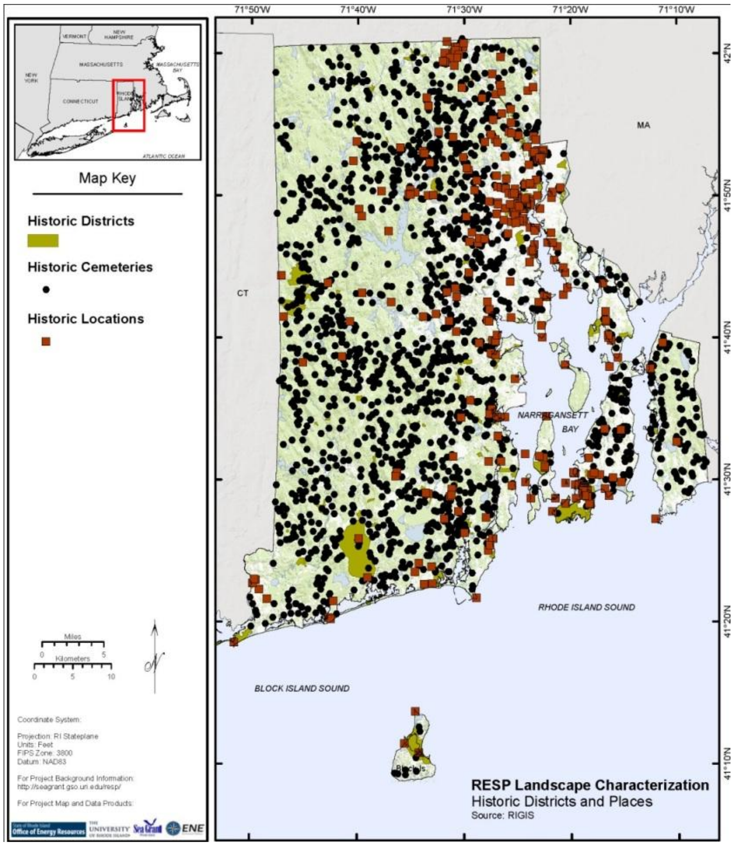


Figure 14. Historic districts, locations, and cemeteries (point locations).

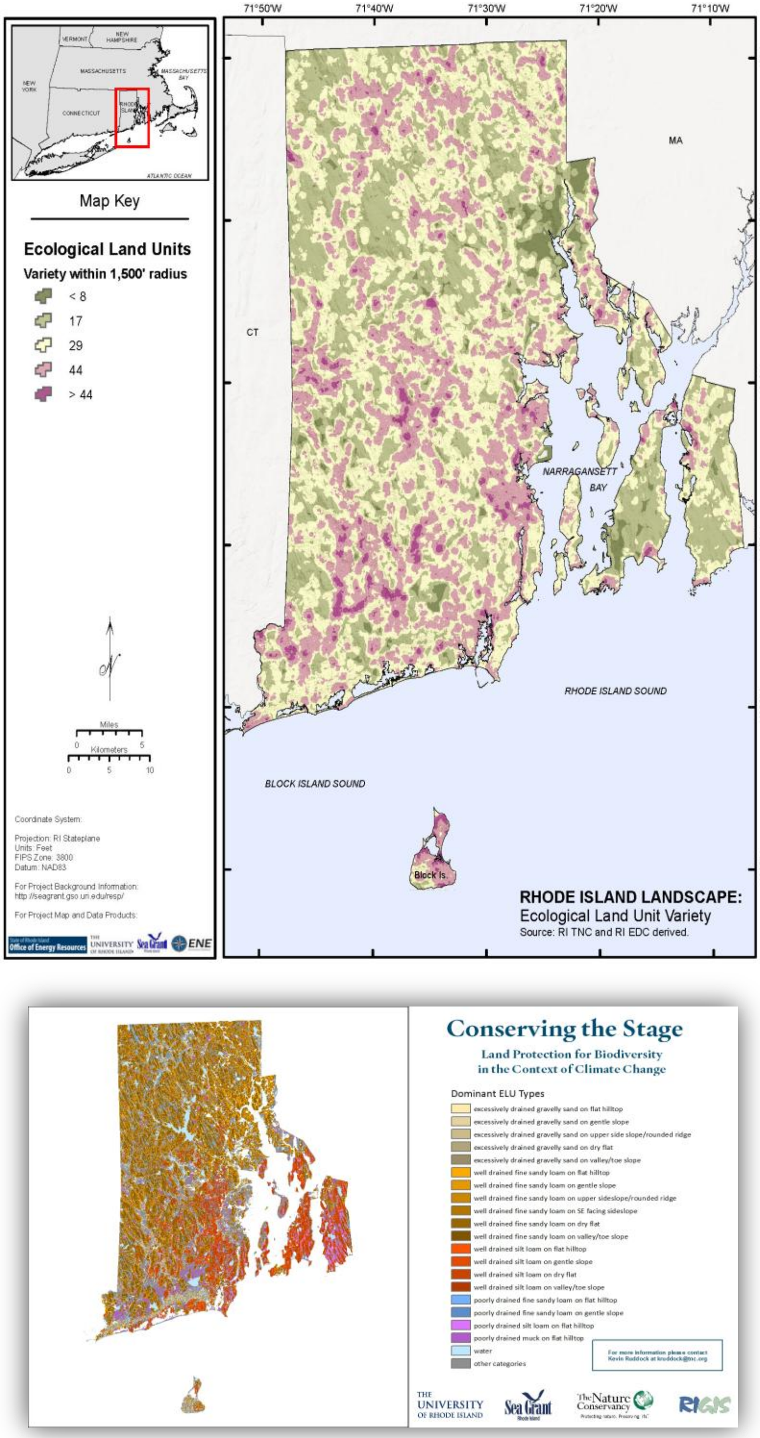


Figure 15. Number of Ecological Land Units (ELUs) - habitat diversity- within a 460 m (1500 ft) radius of the center point of a grid with 30 m by 30 m resolution (a, upper panel) and dominant ecological units for the state (b, lower panel) (Source: http://www.edc.uri.edu/elu/).

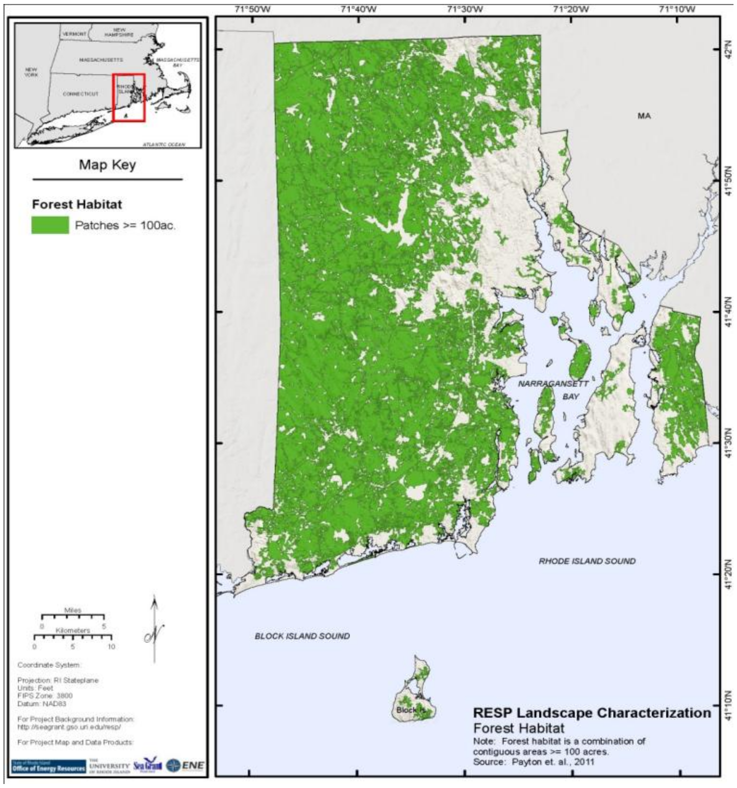


Figure 16. Forest habitat (birds), with contiguous areas greater than 40 hectares (100 acres).

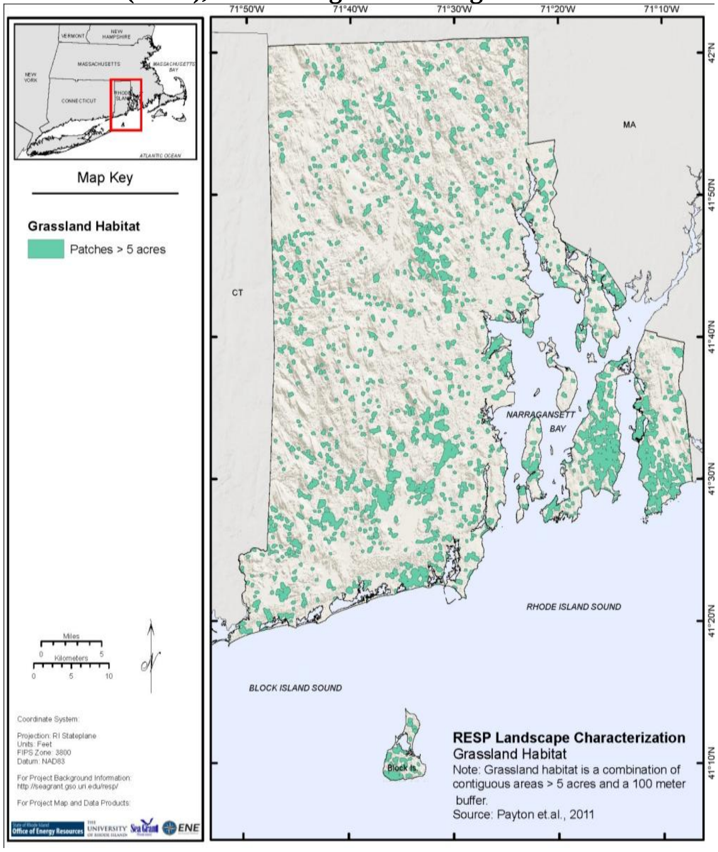


Figure 17. Grassland habitats (birds), with contiguous areas greater than 2 hectares (5 acres) and 100 m buffer.

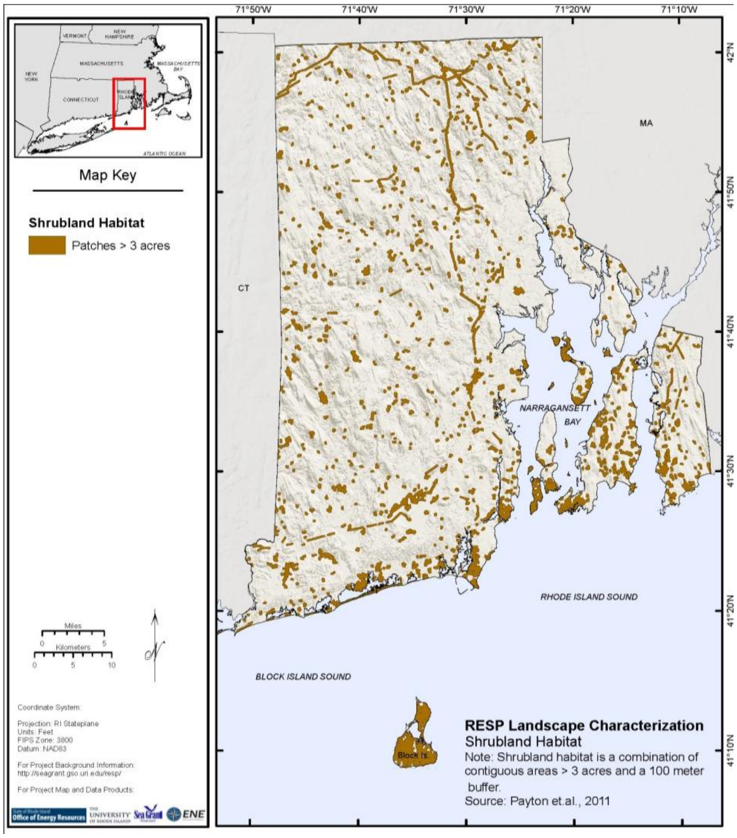


Figure 18. Shrubland habitats (birds), with contiguous areas greater than 1.2 hectares (3 acres) and 100 m buffer.

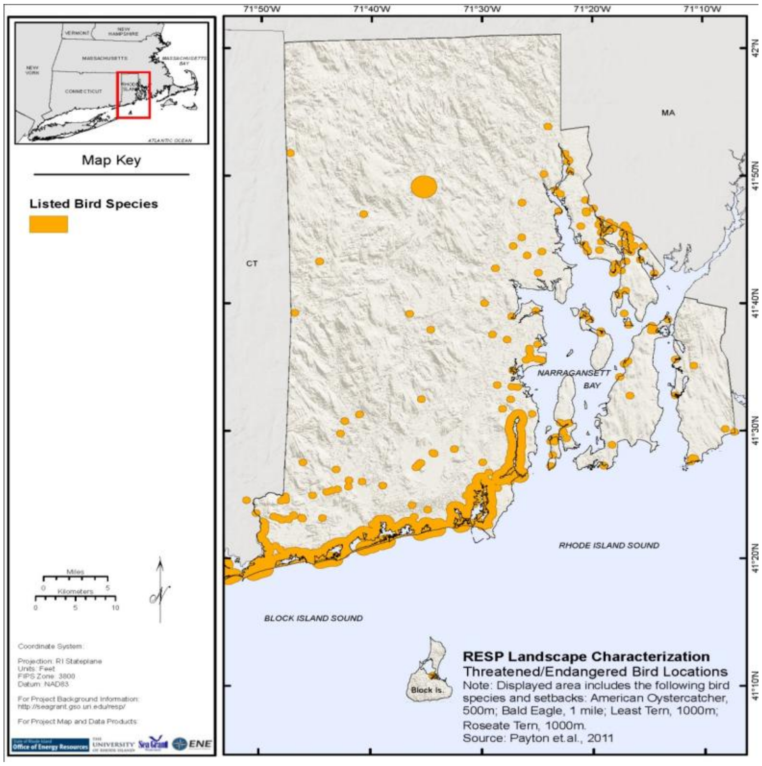


Figure 19. Threatened and endanger bird locations, with setbacks dependent on species noted in legend.

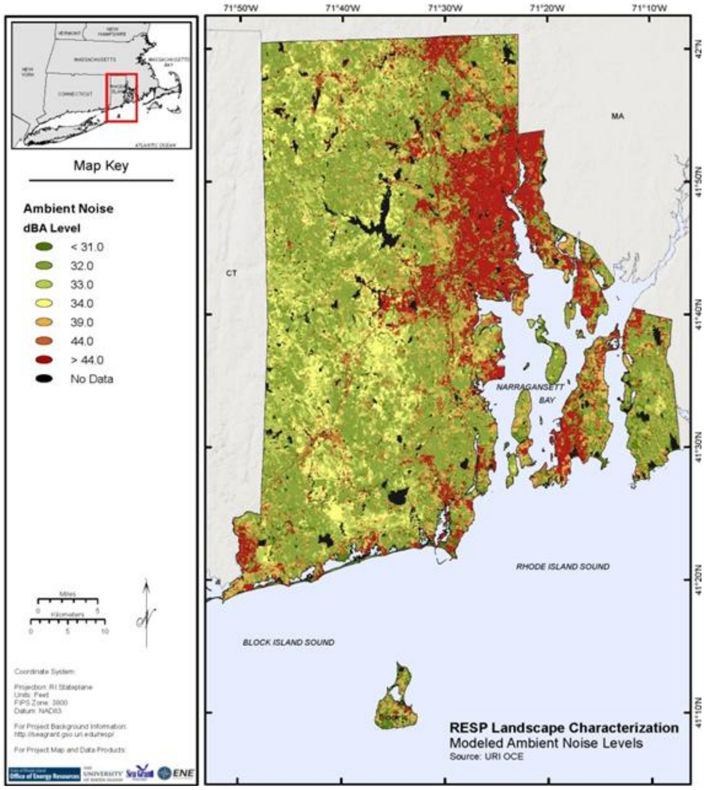


Figure 20. Estimated background noise levels in dBA, based on land use.

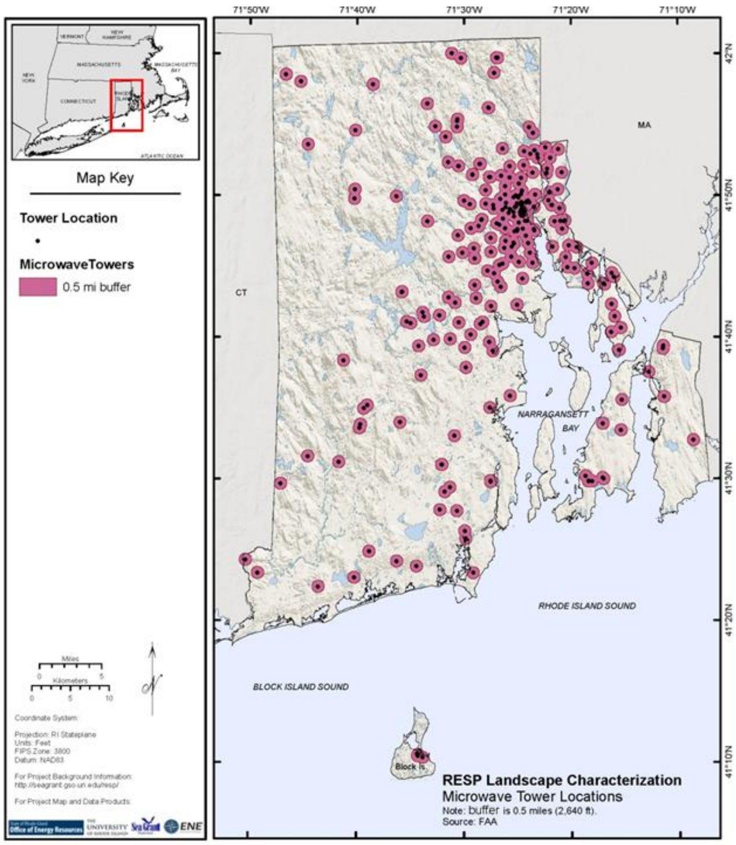


Figure 21.Communication (microwave) towers with 765m (0.5 mile) buffer.

3. RESULTS

The constraints, as provided in Figures 8 through 21, were overlaid on a 30 m by 30 m grid for the entire state and the number of constraints for each grid was determined (Figure 22a). The maximum number of constraints is typically 5 to 6, with the largest number located in areas with the highest levels of development (population, impervious surfaces, etc). The lowest numbers, 1 to several, are in rural areas distant from the coast in the center to the northwestern portion of the state.

It is clear that the constraints should have different weights depending on their importance to those responsible for the siting process. As an example, the constraint for FAA restricted areas is enforced by FAA while the importance of constraints for siting in bird habitats is clearly more subjective. To develop an assessment of the importance that key individuals in the siting process place on the constraints a group of representatives from the municipalities in RI were asked to provide a score of the importance of the individual constraints. The constraint layers were provided to them and the source and rationale for including each were discussed. They were asked to score each constraint from 0 to 5; with 0 representing no importance to the siting process to 5 indicating that the constraint was extremely important. A total of 13 individuals, representing the municipalities who were interested in wind energy development in their towns completed the survey. The mean score for each of the constraints is provided in Table 2. The average score over all constraints was 3.07. The highest score was for FAA constraint, while the lowest was for impervious surfaces. The reasoning behind this low score is that siting in parking lots and the like was deemed to be a minor constraint. Ecological constraints scores were typically in the 2.4 to 2.8 range, while all others were rated at about 3.

A weighted score was generated for each 30 m by 30 m grid and then converted into a siting viability index, progressing from low to high. Figure 22b provides a map of the index. This can be compared to the un-weighted map provided in 22a. Highly developed areas around the bay(Warwick, Cranston, Providence, East Providence, Woonsocket) and centers of large communities (Westerly, Newport/Middletown, and Kingston) have the lowest index scores while inland sites in the north and western portions of the state have the highest scores.

The GIS implementation of the constraints analysis allows one to determine the constraints that make up the score at any individual location. As an example, Figure 23 shows the constraints for a site at Castle Hill, south of Newport and noted by the star in the figure. The site has 5 constraints, which are listed on the insert to the figure. This capability provides a powerful tool to screen sites and determine the potential constraints for each.

Figures 24, 25, and 26 show the (a) un-weighted and (b) weighted (in the form of development viability) constraints with wind speed cutoffs of 4.5 (30 m), 5.5 (50 m), and 6.5 (80 m) m/sec, respectively. The underlying figures are exactly the same as in Figure 23. Figure 27 shows all three cutoffs, side by side, to make direct comparison simpler to visualize. The figures show that the number of viable sites decreases dramatically as wind speed cutoffs increase (hub elevation). Inland sites are generally viable for small scale systems (100 kW) if they are at higher elevations but only near coast sites are viable for larger scale systems (1.5 MW). It is clear from the constraint maps that most sites have some potential constraints that need to be addressed in the siting process. The GIS layers provided here should be very helpful in that process.

Table 2. Potential Constraints for Wind Facility Siting listed in Table 1 with Municipal Working Group Scores. Score: 0 - constraint is unimportant to 5 - constraint is very important. Average score is provided.

Score	**Potential Constraint for Wind Facility Siting**
4.85	FAA restricted areas around airports (setbacks based on runway lengths)
4.0	Population densities (greater than individuals per km^2)
2.85	Wetlands (with buffers)
3.00	Water bodies, rivers and large streams (with buffers)
1.85	Impervious surfaces (highways, highly developed areas, etc)
3.08	State, federal, and NGO protected areas
2.92	Historic sites and cemeteries (point locations)
2.46	Ecological Land Units (ELUs) - habitat diversity- number of ELUs per 30 m grid
2.46	Habitats (birds) (forests, grasslands, and shrubs) (with buffers)
3.31	Threatened and endangered bird species (with buffers)
3.31	Background noise level (land use, highways)
3.1	Communications towers
3.01	MEAN SCORE (all constraints)

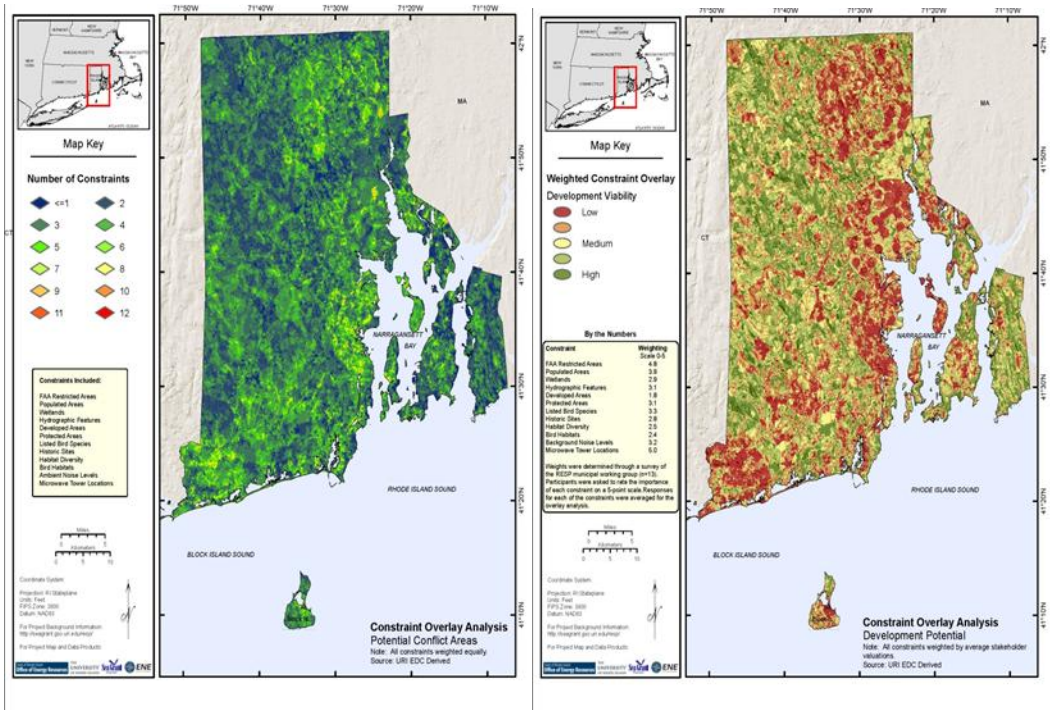
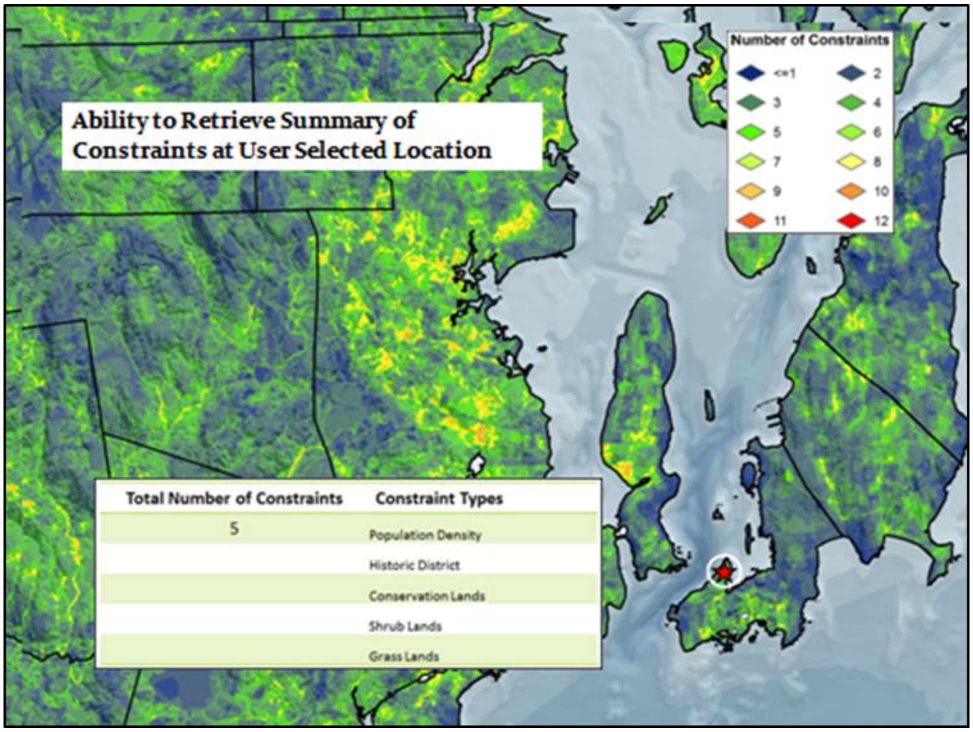
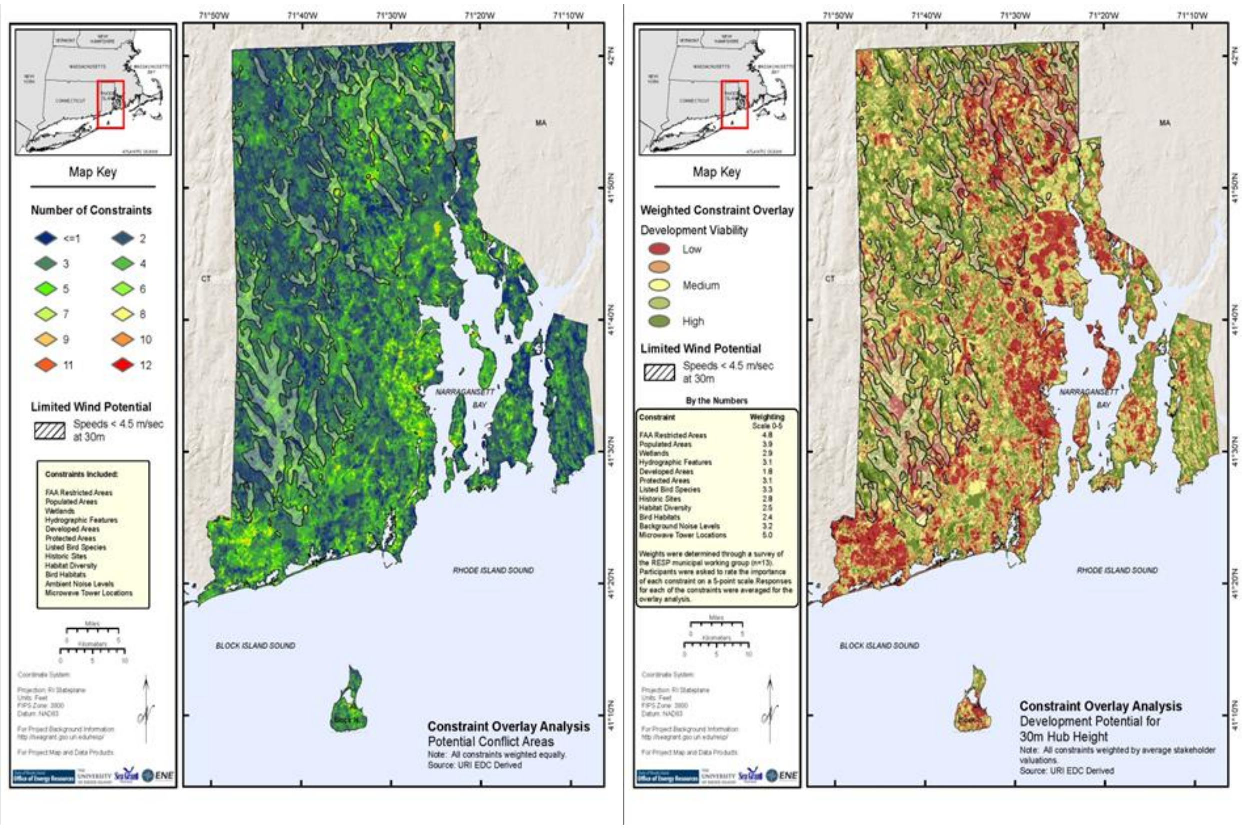


Figure 22. Number of constraints (a, left) and weighted constraints (b, right)(in the form of development viability) for wind energy siting.



Total Number of Constraints	Constraint Types
5	Population Density
	Historic District
	Conservation Lands
	Shrub Lands
	Grass Lands

Figure 23. Determination of constraints for selected site south of Newport.



Constraints Included:

FAA Restricted Areas
Populated Areas
Wetlands
Hydrographic Features
Developed Areas
Protected Areas
Listed Bird Species
Historic Sites
Habitat Diversity
Bird Habitats
Ambient Noise Levels
Microwave Tower Locations

Constraint Overlay Analysis
Potential Conflict Areas
Note: All constraints weighted equally.
Source: URI EDC Derived

By the Numbers

Constraint	Weighting Scale 0-5
FAA Restricted Areas	4.8
Populated Areas	3.9
Wetlands	2.9
Hydrographic Features	3.1
Developed Areas	1.8
Protected Areas	3.1
Listed Bird Species	3.3
Historic Sites	2.8
Habitat Diversity	2.5
Bird Habitats	2.4
Background Noise Levels	3.2
Microwave Tower Locations	5.0

Weights were determined through a survey of the RESP municipal working group (n=13). Participants were asked to rate the importance of each constraint on a 5-point scale. Responses for each of the constraints were averaged for the overlay analysis.

Constraint Overlay Analysis
Development Potential for
30m Hub Height
Note: All constraints weighted by average stakeholder valuations.
Source: URI EDC Derived

Figure 24. Number of constraints (a, left) and weighted constraints (b, right) (in the form of development viability) with 4.5 m/sec (30 m) overlay.

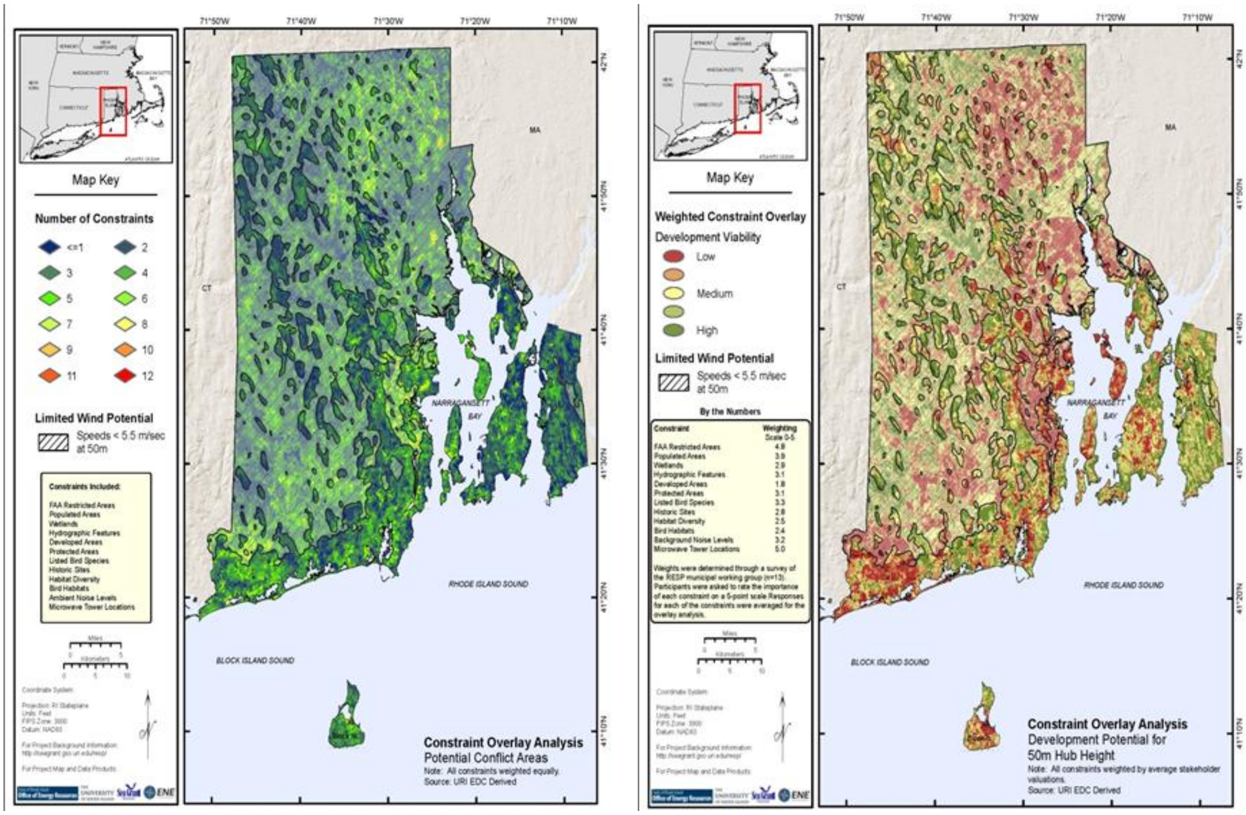


Figure 25. Number of constraints (a, left) and weighted constraints (b, right) (in the form of development viability) with 5.5 m/sec (50 m) overlay.

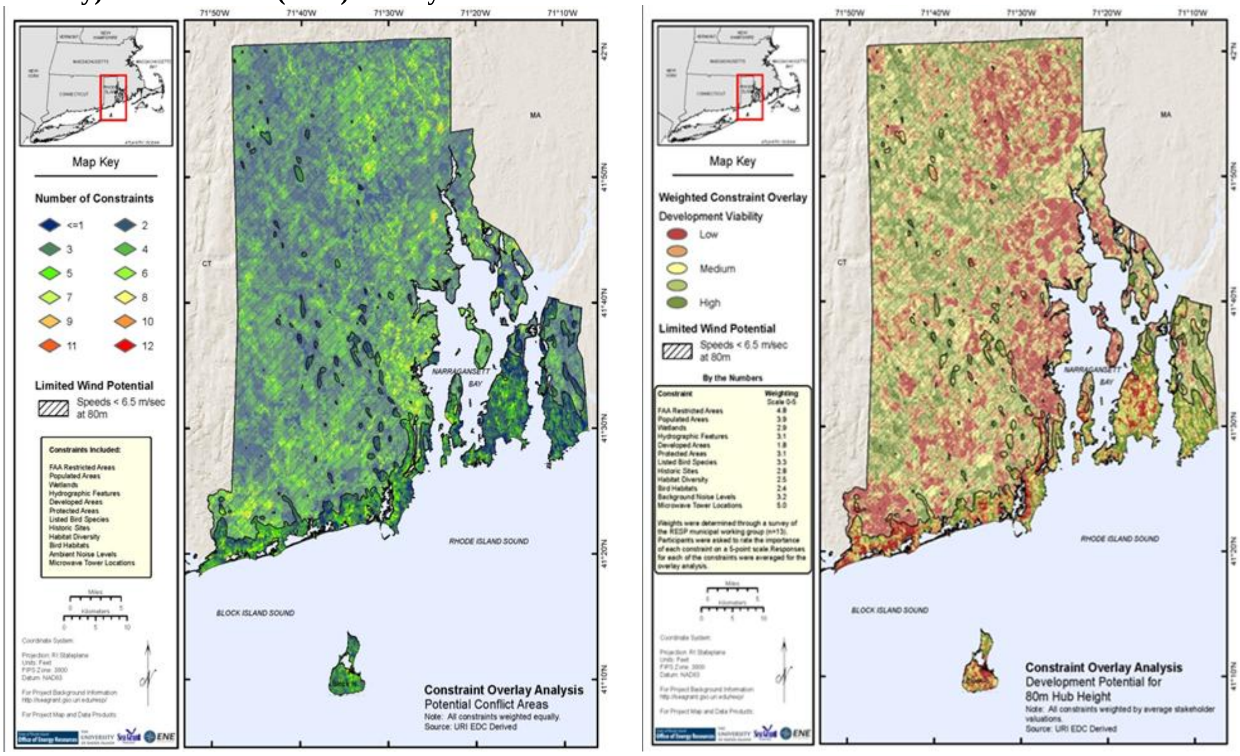


Figure 26. Number of constraints (a, left) and weighted constraints (b, right)(in the form of development viability) with 6.5 m/sec (80 m) overlay.

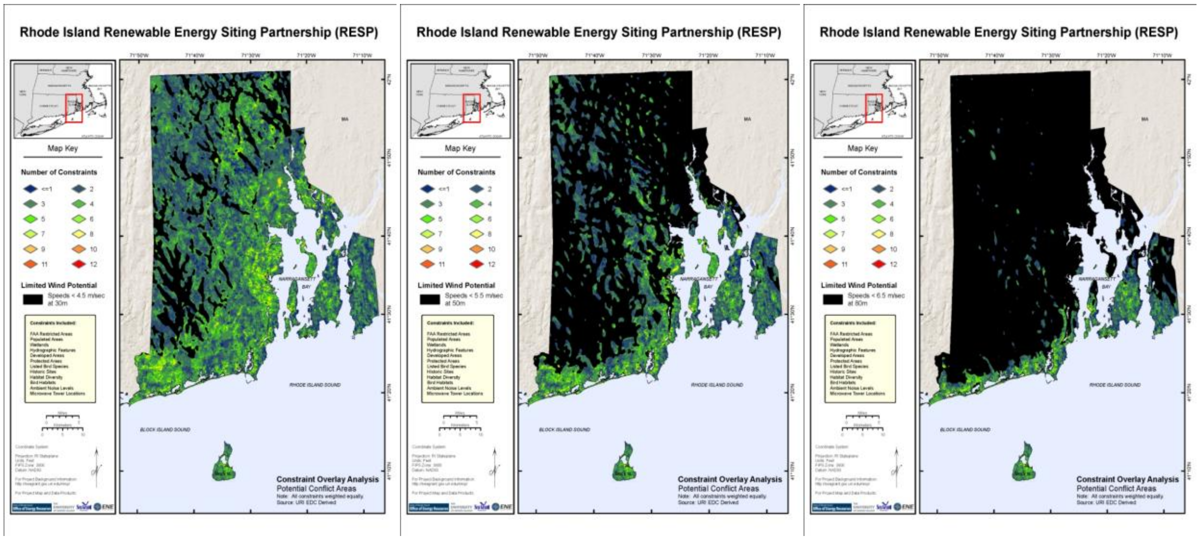


Figure 27. Number of constraints with 4.5 (a, left); 5.5 (b, center); and 6.5 (c, right) m/sec wind speed cutoffs overlaid.

4. SUMMARY

A statewide analysis has been performed to identify wind resources at three vertical elevations (30, 50, and 80 m). This analysis shows that wind speeds are generally modest because of the limited variations in topography and the extensive amount of the state that is forested. Wind speeds increase with elevation with a vertical profile that is locally dependent on land cover and type. Highest mean winds are found in a narrow band following the southern RI coast line, around the shoreline of Narragansett Bay, and then into southeastern RI (Newport, Tiverton). This is a direct result of proximity of these locations to the large water bodies where winds are generally stronger due to lower surface roughness. The viability of siting wind facilities is strongly dependent on turbine size with a decreasing number of viable areas with increasing wind power output. For smaller turbines siting is viable in inland areas while for larger turbines only sites that are close to the ocean have significant potential.

A number of variables that might constitute constraints to wind siting were developed and put in the form of GIS layers. The constraints included human, ecological, land and cultural and historical uses. A constraint analysis was performed on 30 m by 30 m grid covering the entire state and identified the number of constraints for each grid square. A weighted version of the constraints analysis was performed based on scoring from municipal representatives in the state. The weighted constraint maps were converted into development viability maps (low to high). Both weighted and un-weighted constraint (development viability) maps were developed with minimum mean annual wind speeds of 4.5, 5.5, and 6.5 m/sec, reflecting wind turbines at elevations of 30, 50, and 80 m above ground, respectively. These maps allow one to identify areas most viable for development for various turbine sizes. The combined maps indicate that siting is highly site specific and each potential site may have one or more constraints that will need to be addressed. The maps also suggest that siting of large scale facilities in RI is likely to be restricted to individual or several turbines and not wind farms. The tools and GIS layers developed during this study should help developers, municipal officials, and interested citizens to perform initial screening of sites quickly and efficiently. It will also serve to highlight any critical constraints early in the siting process.

5. REFERENCES

Brower, M., 2007. Wind resource maps of Southern New England, prepared by True Wind Solutions, LLC, 10 p

Grilli, A., M. Spaulding, C. Damon, C. O'Reilly, and G. Potty, Wind resource assessment and siting of wind energy facilities in Rhode Island, RI Renewable Energy Siting Partnership Technical Report, May 2012.

RESP TECHNICAL REPORT #3

WIND RESOURCE ASSESSMENT AND SITING FOR WIND ENERGY FACILITIES IN RHODE ISLAND

By

Annette Grilli, Malcolm Spaulding, Christopher Damon,

Christopher O'Reilly, and Gopu Potty

University of Rhode Island,

Narragansett Bay Campus

June, 2012

Table of Contents

List of Figures

List of Tables

Executive Summary

A statewide analysis has been performed to identify and evaluate land based wind resources in Rhode Island (A prior analysis performed in the context of the SAMP project has assessed offshore wind resources). The present report is designed to establish a progression from *theoretical* wind resource assessment towards *technical* and finally, *practical* wind resource assessment; In brief, the general philosophy is to provide an assessment as accurate as possible of the wind resource, as provided by the wind (*theoretical* resource), but more precisely, to provide an assessment of the extractable power by a wind turbine (*technical* resource), and even more practically, to provide guidance towards the practical resource, which reflects the potential sites where wind turbines could *feasibly* be deployed considering the current social and ecological constraints (*practical* resource).

The Continental Rhode Island wind climate is characterized by a theoretical wind resource that is relatively modest compared to offshore area, with expected mean wind speed on the order of 4 to 6.5 m/s at 30 meters height and of the order of 5 to 7.5 m/s at 80 meters height, versus 8 to 9.5 m/s offshore, at 80 meters, showing a spatial variability primary due to topography and coastal proximity. Highest mean winds are found in a narrow band following the southern RI coastline, around the shoreline of Narragansett Bay, and then into southeastern RI (Newport, Tiverton). This is a direct result of proximity of these locations to the large water bodies where winds are generally stronger due to lower surface roughness.

Mapping theoretical and technical power shows that the technical power, is approximately half the theoretical power, and its spatial variance is slightly reduced. For example, at 30 meters height, the expected technical power is on the order of 100 W/m^2 in the most sheltered inland areas (forested valley) and 200 W/m^2 in coastal areas , while the theoretical power is on the order of 200 W/m^2 and 500 W/m^2, respectively. The viability of siting wind facilities is strongly dependent on turbine size with a decreasing number of viable areas with increasing wind power output. For smaller turbines siting is viable in inland areas while for larger turbines only sites that are close to the ocean/BAY have significant potential as shown by mapping the capacity factor for selected generic turbine.

The resource assessment analysis is performed in terms of expected mean power and its uncertainty around this mean value. It is shown that if the mean wind speed between 10 and 30 meters height can be estimated with uncertainty on the order of 3% around the mean value, the expected mean power carries an expected uncertainty of 10 times this order of magnitude, order of 30 % around the mean value, in a 95 % confidence interval. The current deployment of towers and SODAR measurement by the URI team (Merrill and Knorr, 2012) will provide additional wind speed time series, which will contribute to estimate and reduce the uncertainty associated with the current estimations at elevation.

Major ecosystem services are identified as social or ecological “constraints” to the siting of a wind turbine.

A resulting geography of the “practical area” showing feasible (eliminating exclusionary areas) and optimal area is developed. A companion report provides a GIS based constraint analysis. In identifying feasible area, FAA exclusionary area were carefully mapped and excluded. User interactive software was developed to identify FAA exclusionary zones based on turbine’s specification (tower height and blade diameter) (O’Reilly, 2012).

An interactive tool was developed to estimate setback distance from a deployed turbine. If noise and flicker setback distances are in agreement with the current best practice usage, the proposed setback distance recommended to prevent accident from potential blade or piece of blade breaking and being thrown, is based on a combination of ballistic theory and risk assessment, and is therefore function of the wind turbine’s specifications (angular velocity and blade radius). The resulting proposed setback distances are slightly larger than the setback distances previously proposed in Rhode Island, but are however, in close agreement with most setback distances adopted in Europe.

A GIS interactive tool is developed with which a user can query any site in Rhode Island and obtain relevant information in terms of wind resource, expected theoretical or technical power, capacity factor for a given turbine, potential social and ecological constraints, expected vertical wind profile and therefore power estimation at any level, proposed setback distance for given turbine ‘specifications, corresponding noise level spatial spreading zone, and the expected flicker spatial zone of influence.

1. BACKGROUND AND STUDY OBJECTIVES

The RI Winds study (ATM, 2007) demonstrated that Rhode Island has substantial opportunities for the development of offshore wind resources for large grid scale power production (100 MW or more). The land side analysis showed more limited opportunities for municipal, large industry, and community based users (1.5 MW or greater) to meet local needs. Although there is great demand by municipalities and state agencies to promote this new industry on land, there is no formal management or regulatory guidance for the state. To facilitate decision making on renewable energy development, the RI Statewide Planning Program (RI-SPP) is undertaking an initiative to develop renewable energy facility siting standards and guidelines for Rhode Island.

The Rhode Island Office of Energy Resources (OER) has contracted the University of RI (URI) to provide both targeted research as well as develop a public education and engagement process to support the Statewide Planning effort. The overarching goal of this project is to provide technical support to the State of Rhode Island to facilitate the siting and permitting of land based commercial (100 kW) to municipal scale (1.5 MW) renewable energy facilities in the State of Rhode Island. This support will result in the development of a Rhode Island Renewable Energy Chapter that, using the best available science and applying an integrated public process that fosters and engages a well informed and well represented constituency, provides the state with guidelines and standards to better manage and regulate this new industry. Once completed, RI-SPP will incorporate this chapter into the Rhode Island Energy Plan.

The objective of this component of the larger effort is to develop and implement protocols and tools to facility siting of land based, wind energy facilities in RI. The strategy is to determine site suitability on the board scale and then to have tools that can be implemented to determine setbacks from selected turbine sites. The report begins with an assessment of wind resources in the state (Section 2) and includes results of meteorological model predictions and associated validation with observations. The theoretical framework of an ecosystem services constraints assessment methodology is presented and then implemented in the form of a constraints based methodology (Section 3). Methods are then presented for determining setbacks for proposed wind energy facilities (Section 4). To facilitate access to both the constraints analysis and setback tools a web based system has been implemented by RPS- Applied Science Associates (RPS-ASA). An overview of the web-based system is provided in Section 5. Study conclusions are presented in Section 6 and references in Section 7.

2. WIND RESOURCE ASSESSMENT

Providing a spatial coverage of the wind resource in Rhode Island was motivated by the lack of an accurate wind resource assessment at a relevant spatial scale for wind turbine development, either at individual or utility scale. In order to do so, a full spatial coverage of the state wind resource is investigated and a resulting wind resource assessment is provided on a 100 meter resolution grids for 3 vertical levels, 30, 50 and 80 meters, corresponding to the approximate hub heights of 500 kw, 750 kw and 1.5 MW turbines, respectively. In addition, an interactive tool is provided to extract the relevant information at any given location in Rhode Island (Section 5). This assessment is based on meteorological model predicted data (AWS Truewind; Bowers, 2007) as well as measured data at several stations. Those data are described in detail in the following. In view of the many definitions found in the literature to define wind "resource" precise definitions adopted in this report are first introduced.

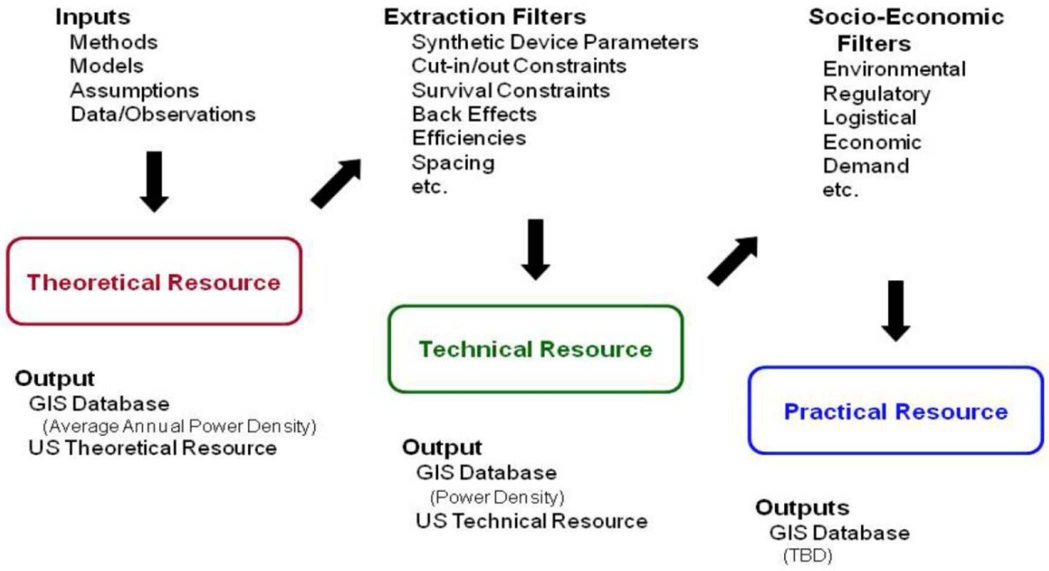


Figure 1. Conceptual Framework. Source: Assessment of Marine and Hydrokinetic Energy Technology. Interim Letter Report. http://www.nap.edu/catalog.php?record_id=13202

2.1 Terminology and conceptual framework

The Department of Energy recently requested a Marine Hydrokinetic (MHK) Energy assessment: (1) for the entire US coast for wave and tidal power; (2) for all US Rivers for in-stream power and (3) for the world oceans and seas for OTEC (Ocean Thermal Energy Conversion) power . In 2009 the National Academies of Science created the MHK energy committee, appointed for 2 years, with the task to evaluate the quality, interest and caveat of MHK energy assessments. One of the main findings emerging from comparing those studies was a lack of consistency in the terminology and the associated physics behind the concepts discussed. The committee proposed a conceptual framework to guide the renewable energy assessment teams towards a common terminology (Figure 1). The conceptual framework is largely based on European marine energy community practice (European Marine Energy Centre ; EMEC; http://www.emec.org.uk/standards.asp).

This framework, is perfectly suitable for wind energy, since it deals with identical concepts. The lack of consistency in the wind terminology and, as for MHK, the lack of clear definition of wind *resource* (Da Rosa, 2010; Hennesey, 1977; Bailey B., and J. Freedman, 2008) led to adoption of the MHK framework, as a conceptual framework.

The *<u>Theoretical Resource</u>* is the power density (P [W/m^2]) provided by the wind at any point in space. This is defined as the power per square meter of cross sectional area to the incident wind. This theoretical resource is the standard value used in the wind industry and the quantity predicted in the AWS Truewind report (Figure 2).

The *<u>Technical Resource</u>* is the maximal power density (P_T [W/m^2]) available once a turbine is placed at a given location. A turbine operates over a range of wind speeds,. A turbine extracts wind power between *cut-in* and *cut-out* wind speeds. Below the minimum threshold (cut-in) and above the maximum threshold (cut-out), the turbine is shut down and produces no power; below the cut-in the turbine would need power to operate and above the cut-out, the risk of failure of the structure is so high the turbine is shut down. The turbine has a third threshold, the *rated speed*: the wind speed at which the turbine produces its maximum power, or rated power (P_R). Above this rated speed, the turbine output power is constant independent of the wind speed. These three thresholds define *Usable Power* (P_U), as defined by Hennessay (1978).

In addition to those three technical thresholds, Betz's law (maximum energy extractable from a fluid moving through an actuator) constitutes a fourth constraint, which limits the available power to the turbine to 59.4 % of the power contained in the wind. This is based on physical principles and is demonstrated by the Froude-Rankine theorem. The technical power, include those four constraints and represents the maximum extractable power assuming a 100% efficiency of the device.

(1)

$$P_U = \int_{cut-in}^{rated\ speed} P + \int_{rated\ speed}^{cut-out} P_R$$

(2)

$$P_T = 0.59 * P_U$$

with P_U defined as the usable power and P_T defined as the technical power.

This analysis assumes only one device and does not consider the wake effect behind the turbines, which would reduce the available power due to the presence of other turbines.

The Practical Resource constitutes the technical resource in the spatial context of "acceptable area", according to socio-economic filters, or ecosystem services constraints (in the terminology of ecosystem based management conceptual framework). Ecosystem service constraints are developed in Section 3.

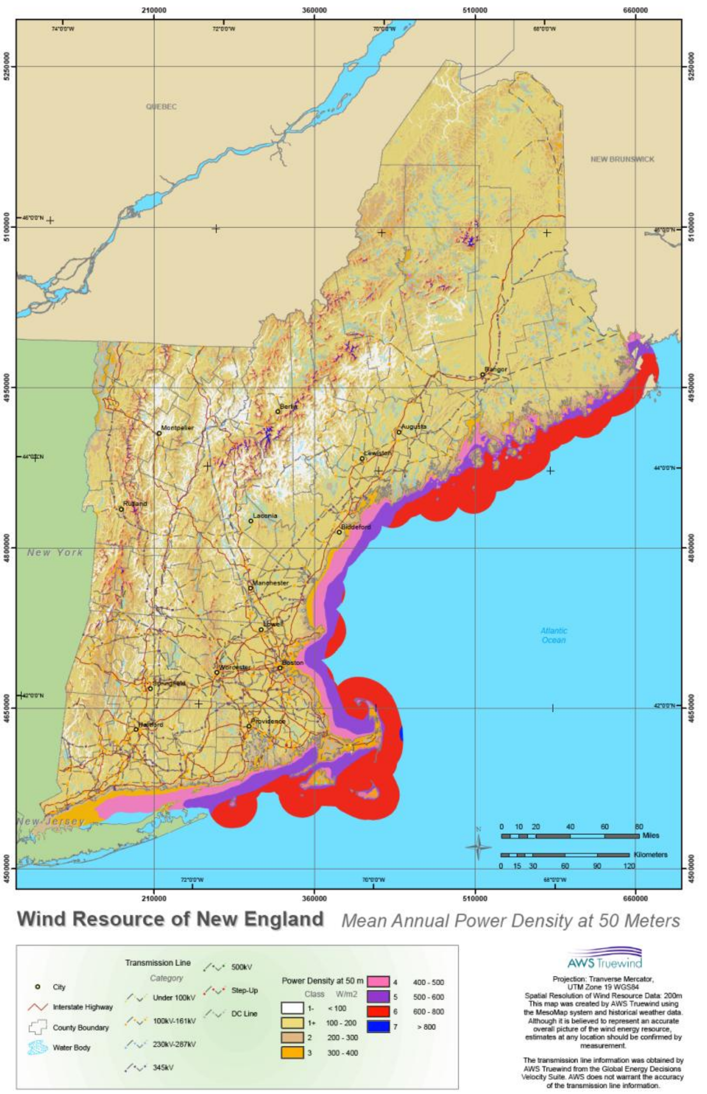


Figure 2. Theoretical Wind Resource estimated from AWS Truewind, Bower, 2007. Mean annual power density at 50 meters.

2.2 Theoretical background

In this section, standard formulations expressing the relationship between wind speed and wind power are provided, at wind speed measurement level as well as their extrapolation to higher elevations. The methodology used to estimate the technical power is also presented.

Theoretical Power

The total energy flux of a uniform air stream of speed U and density ρ, passing through a turbine of cross-sectional area A is:

(3)
$$E = \frac{1}{2}\rho A U^3 \quad (W)$$

The mean kinetic energy flux density or mean power density,

(4)
$$\overline{P} = \frac{\overline{E}}{A} = \frac{1}{2} r \overline{U^3} \qquad (\mathrm{W/m^2})$$

is the standard parameter used to quantify the wind power resource. Assuming a constant air density, the wind power is only a function of the wind speed distribution (da Rosa, 2009). The wind speed frequency distribution is shown to follow a Weibull distribution. The three-parameter Weibull distribution, f, is defined as (Rinne, 2009),

(5)
$$f(U|c,k,\gamma) = \frac{k}{c}\left(\frac{U-\gamma}{c}\right)^{k-1} exp\left(-\left(\frac{U-\gamma}{c}\right)^{k}\right)$$

With, U , the wind speed, k the Weibull shape parameter, c the Weibull scale parameter, and γ the Weibull location parameter. If the location parameter, $\gamma=0$ (likely the case in RI wind speed distributions), the distribution is reduced to the two-parameter Weibull distribution. The scale parameter has units of speed and is directly related to the mean wind speed $\overline{U}$ (by the gamma function, Γ, since the first moment of the distribution is defined as,

$$E(U|c,k,\gamma) = \gamma + c\,\Gamma\left(1+\frac{1}{k}\right)$$

and

(6)
$$\overline{U} = E(v|c,k,\gamma)$$

The shape factor is dimensionless and varies in the range [1-3]. It is inversely related to the variance σ^2 of the wind speed about the mean. Typically, offshore locations yield distributions with a shape parameter very close to k=2. With this value, the distribution corresponds to a particular case of the Rayleigh distribution for which both components of the wind speed vector are Gaussian. The higher the k value, the more sharply peaked the distribution is, and the closer the probability of occurrence of higher wind speeds, to the median value of the distribution, is.

The expected value of the distribution's 3rd non-centered moment is defined as,

(7)
$$E(U^3) = \gamma^3 + 3\,\gamma^2 c\,\Gamma\left(1+\tfrac{1}{k}\right) + 3\,\gamma c^2\,\Gamma\left(1+\tfrac{2}{k}\right) + c^3\Gamma\left(1+\tfrac{3}{k}\right)$$

which, for a two-parameter Weibull distribution, reduces to the last term on the right hand side and provides a convenient way to calculate the expected *theoretical wind power* by combining Equations 4 and 7 (and assuming γ=0).

(8) $$\overline{P} = \frac{\overline{r}}{2} c^3 \Gamma\left(1 + \frac{3}{k}\right)$$

Wind at elevation

Assuming wind speed U_1 is measured at height z_1 , we introduce a vertical wind velocity profile to express wind speed U_2 at hub height z_2 . Using a standard power law,

(9) $$U_2 = U_1 \left(\frac{z_2}{z_1}\right)^{r}$$

where r is the *shear coefficient*.

The shear coefficient depends on both the atmospheric stability and ocean/land surface roughness z_0. An alternative, standard formulation for the vertical wind profile is the law of the wall, or so called “log-law” (Charnock, 1955). The “log-law” assumes, (1) an average neutral atmosphere, (2) a logarithmic vertical profile during neutral conditions, and (3) a profile dependency on the surface “surface roughness”, which would control the height of the wind speed reduced to the friction velocity. The surface roughness is based on the land cover. The log-law is defined as:

(10) $$U_2 = \frac{U_*}{K} \log\left(\frac{z_2}{z_0}\right)$$

with K the von Karman constant and, U_* the friction velocity.

Combining Eqs. (4), (7), and (9), the mean wind power density at hub height is found analytically (Sedefian, 1980) as,

(11) $$\overline{P}_2 = \frac{\overline{r}}{2} c_1^3 \Gamma\left(1 + \frac{3}{k_1}\right)\left(\frac{z_2}{z_1}\right)^{3r}$$

where k_1 and c_1 are the Weibull distribution parameters when fitted to the U_1 data.

The wind speed at elevation z_2 (hub height) is thus a function of the Weibull shape and scale parameters (of the U_1 wind speed data) and of the local shear coefficient.

Similarly the theoretical wind power at elevation z_2 can be calculated using the log-law. In that case:

(12)

$$\frac{U_2}{U_1} = \frac{log\left(\frac{z_2}{z_0}\right)}{log\left(\frac{z_1}{z_0}\right)}$$

(13)

$$\bar{P}_2 = \frac{\bar{\rho}}{2} c_1^3 \Gamma\left(1 + \frac{3}{k_1}\right)\left(\frac{log\left(\frac{z_2}{z_0}\right)}{log\left(\frac{z_1}{z_0}\right)}\right)^3$$

Technical Power

The concept of technical power results in a wind speed distribution truncated with cut-in and cut-out thresholds, and adjusted for the rated speed threshold. By *adjusted,* it is meant that all the occurrences of wind speed higher than rated speed are assumed to be at rated speed, which corresponds to standard turbine specifications. Indeed, a standard turbine extracts a maximal power at rated speed and keeps extracting the same amount of power above the rated speed, up to the cut-out wind speed value, when the turbine is shut down and stops extracting energy. The analytical formulation for expected power is therefore not applicable in its original form. An alternative method to the analytical formulation to estimate the wind power is by using a Monte Carlo method to simulate the effective input distribution at the turbine. A previous study in the Ocean SAMP demonstrated the accuracy of the method (Grilli and Spaulding, 2010). The principle of the Monte Carlo method is to generate a large number of random wind speeds associated with a given Weibull distribution, specified by its mean wind speed and shape parameter k, corresponding to simulating a time series representative of the given Weibull distribution. The instantaneous power corresponding to each wind speed is calculated and averaged to determine the expected mean power. The advantage of the method is that it is suitable for arbitrary distributions, and easily accounts for the adjustments in the distribution indicated above. This method is therefore used to estimate the Technical Power in this effort. In addition to the 3 thresholds, , once a turbine is introduced into the environment, the wind field is modified in such a way that only a fraction of the available power is available to the turbine (maximum of 59.3 %). The concept of technical power accounts for this power reduction due to aerodynamics principles.

2.3 Data sources

The analysis is based on two types of wind data: data resulting from model simulations and data measured at wind stations. Each of these sources is described hereafter.

Model simulated wind data

Model simulated mean wind speed data were obtained from AWS Truewind. This data covers the entire state on a 200 by 200 m grid. Mean values result from averaging simulations over 366 historical days randomly selected over a 15-years period, on a 2.5 by 2.5 km grid (Bower, 2007). AWS Truewind used a numerical weather model (MASS, Mesoscale Atmospheric Simulation System, 2.5 by 2.5 km grid) coupled to a simpler wind flow model, WindMap to refine the spatial resolution of MASS and account for simple localized effects of terrain and surface roughness. AWS Truewind provides results in terms of mean wind speed on a 200 m grid at 4 elevations levels, 30 , 50, 70 and 100 meter, as well as the Weibull distributions on the 2.5 km grid at 50 m.

WindMap uses the local topography and the local surface roughness based on the 30 m USGS elevation grid (National Elevation Dataset, USGS) as well as the 30 m land cover USGS grid (National Land Cover Dataset derived from Landsat imagery) as input.

In converting land cover to surface roughness length to displacement height, AWS Truewind has assumed that the displacement height was 10 times the surface roughness length, which corresponds to approximately 7.5% of the vegetation height. For deciduous forests with a roughness length of 0.9 m, this resulted in a displacement height of 9 m. The model predictions of the mean annual wind speed were compared to observations (33 stations in New England; 1 in RI) and show that the model under-predicts measured wind speeds by 0.4 m/s for the annual average at measurement elevation.

Wind observations

The AWS Truewind modeling approach provides valuable theoretical wind resource estimations, at national and regional scales. At local scale, however, it is difficult to assess the accuracy of the model with the lack of measurements stations in RI used in the validation study. An accurate wind assessment at the local scale requires additional validation with local measurements.

Local stations, criteria of station selection and analysis are discussed in Section 2.4 and 2.5. Section 2.5 focuses on an assessment of the accuracy. A companion report, focusing in detail on the data description and analysis, in particular stations with multiple levels observations is provided in Merrill and Knorr (2012).

2.4 Wind resource spatial variability

In this section we investigate the spatial wind variability in Rhode Island, in particular the factors or variables controlling the power variability at hub height; the wind speed distribution parameters controlled by the topography and surface roughness (Weibull scale parameter or mean wind speed; Weibull shape parameter), and the wind speed vertical profile defined by the shear coefficient and controlled by the surface roughness.

This results in a state "wind geography " map, providing wind "regions" in the state. This section is based on gridded data on a 30 m grid (topography, land use and roughness) or a 200 m grid (wind speed) re-interpolated on a 100 m grid, which is established as the reference spatial grid for this analysis.

The expected mean power can be determined at any elevation. Results are presented for theoretical and technical wind power at 30, 50, and 100 m.

Wind speed distribution parameters

As discussed in the theoretical section, the wind speed is Weibull distributed and one needs only two parameters of the distribution to estimate the expected power: the scale parameter and the shape parameter. One can accurately predict the expected theoretical mean power at a given elevation knowing only the mean wind speed and the shape parameter at that elevation.

Mean Wind speed

Wind speed values were extracted at 30 m, 50 m, 70 m, and 100 m height from AWS TrueWind on their 200 m grid data base and were re-interpolated on the 100 m grid. The spatial interpolation method used is a kriging algorithm. The vertical interpolation uses the shear coefficient determined from AWS data at those four elevations. Results are shown for wind at 30, 50 and 80 m in Figure 3a, 3b,3c.

Shape parameter

AWS TrueWinds provided predicted Weibull distribution, scale and shape parameter for 30 degrees directional wind sector roses, on a 2.5 km grid. The wind frequency, of each 30 degrees sector, in combination with the Weibull parameters is used to re-calculate a global Weibull distribution using a Monte Carlo method in which a number of wind vectors, proportional to their frequency of occurrence, is drawn from each directional sector probability distribution in order to reconstruct a global probability distribution (yearly average - all wind sectors). This results in a map of the Weibull shape coefficient on a 100 m grid. The Weibull shape coefficient is assumed constant, (lacking any data to indicate otherwise) through the vertical profile. A contour map of the shape parameter is shown in Figure 4.

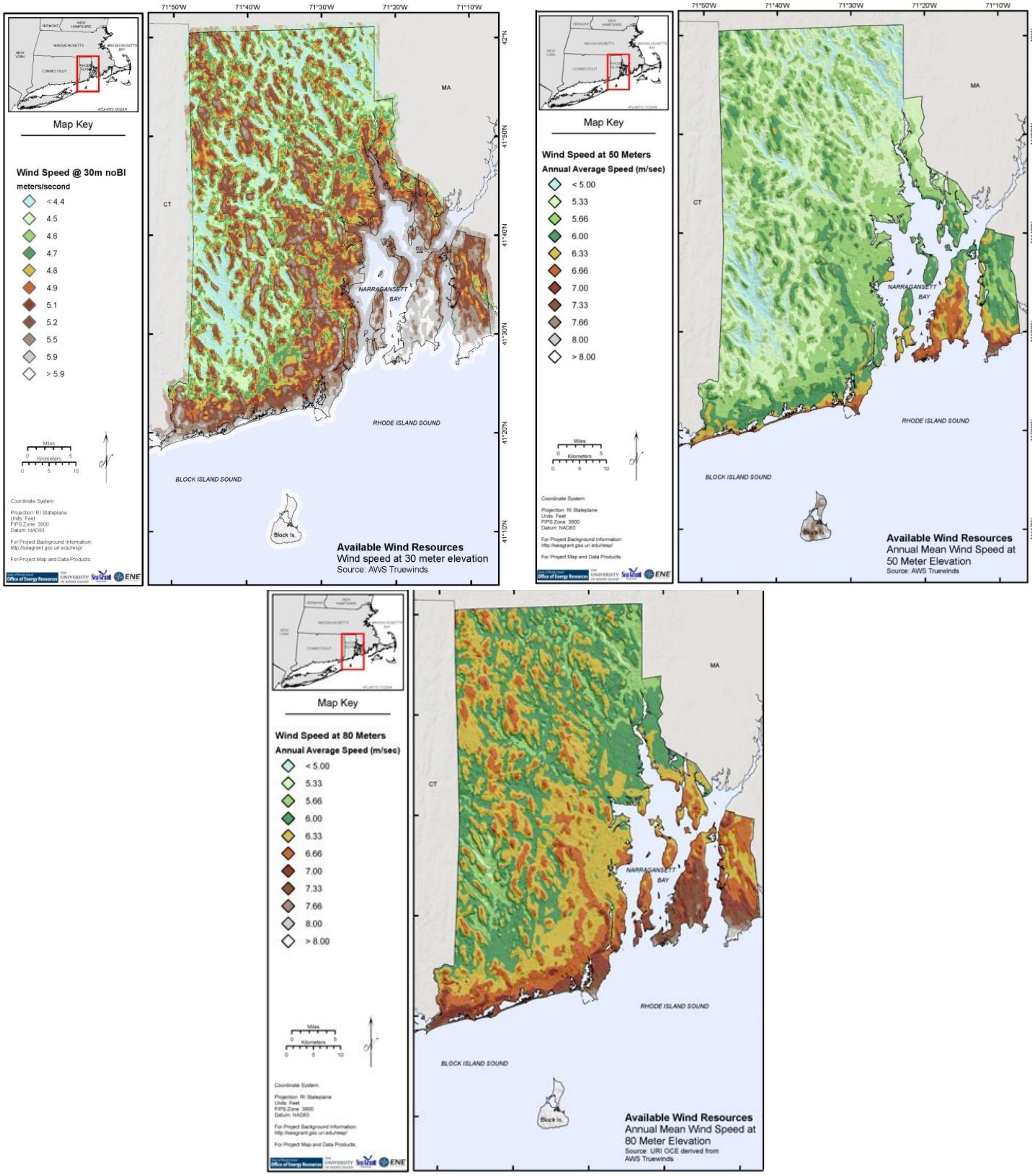


Figure 3. 3a (above left), 3b (above right), 3c (lower left) Mean Wind Speed at 30, 50 and 80 meters –Data source: AWS Truewind.

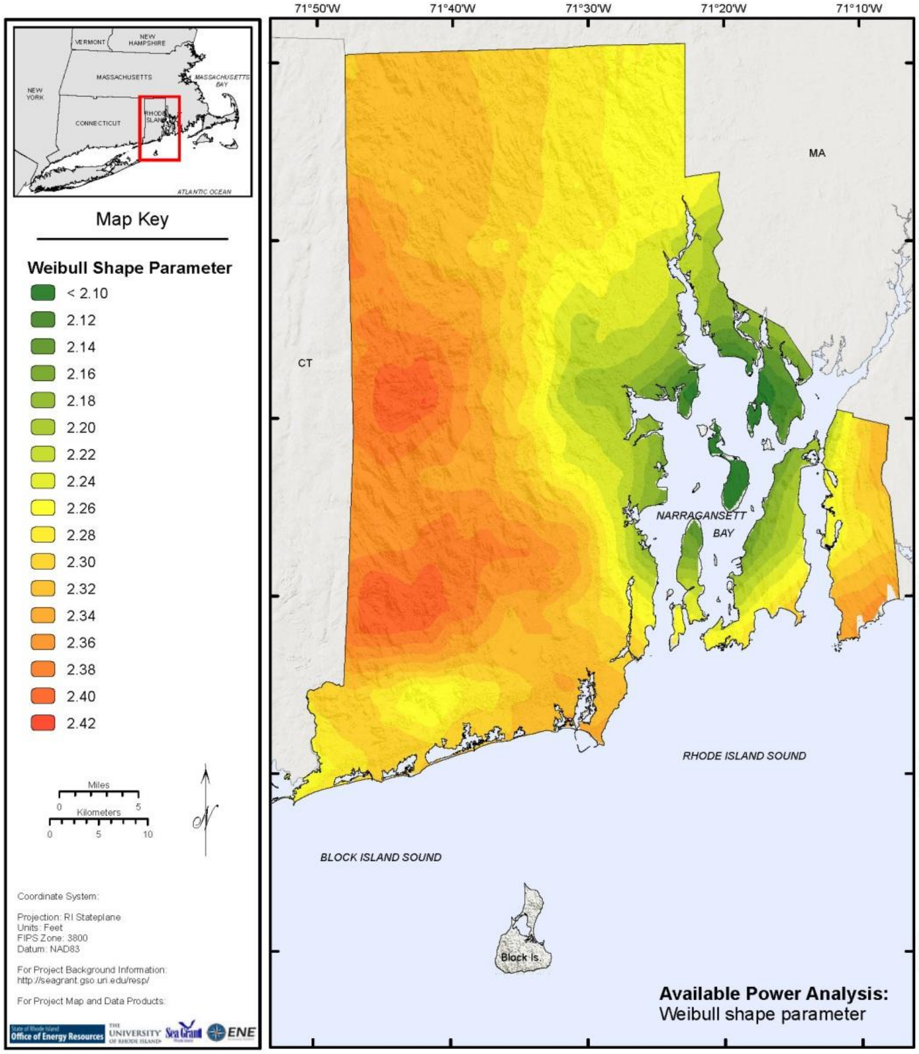


Figure 4. Weibull shape parameter.

Wind speed vertical profile

To estimate the wind speed at any elevation, one can either use the Charnock formula (Eq.10; Section 2.4.4) based on land roughness, or the "*power law*" based on the shear coefficient (Eq.9).

Power law and Shear Coefficient

The power law constitutes the most commonly accepted standard. The shear coefficient is determined from AWS Truewind estimates at four levels for each grid point using a nonlinear fit between wind speeds at those elevation points.

In summary, starting with the power law, $U_2 = U_1\left(\frac{z_2}{z_1}\right)^{r}$, with U_1 and U_2 the mean wind speed at two different levels z_1 and z_2, respectively and setting, $\beta = r; X_i = \frac{z_i}{z_1}; C = U_1; Y = U_i$, so that the fit is simply expressed as , $\hat{Y} = C * X^{\beta}$, where the value of β is selected to minimize the error between $Y \, and \, \hat{Y}$. Using a standard least–square method, results provide a shear coefficient for each grid point. A contour map of the predicted shear coefficients is shown in Figure 5.

Note that AWS Truewind wind speed estimations at 100 m height are assumed to be the most reliable of their four level estimations (30, 50, 70 100 m), since those velocities are generated directly from the meso-scale model simulations. These simulations are expected to have a higher accuracy at higher elevation, away from the surface aerodynamic characteristics (roughness), and from the local topographic effects. Therefore the 100 m level wind speed constitutes the reference for any alternative elevation extrapolation (z_1 in Eq. 9).

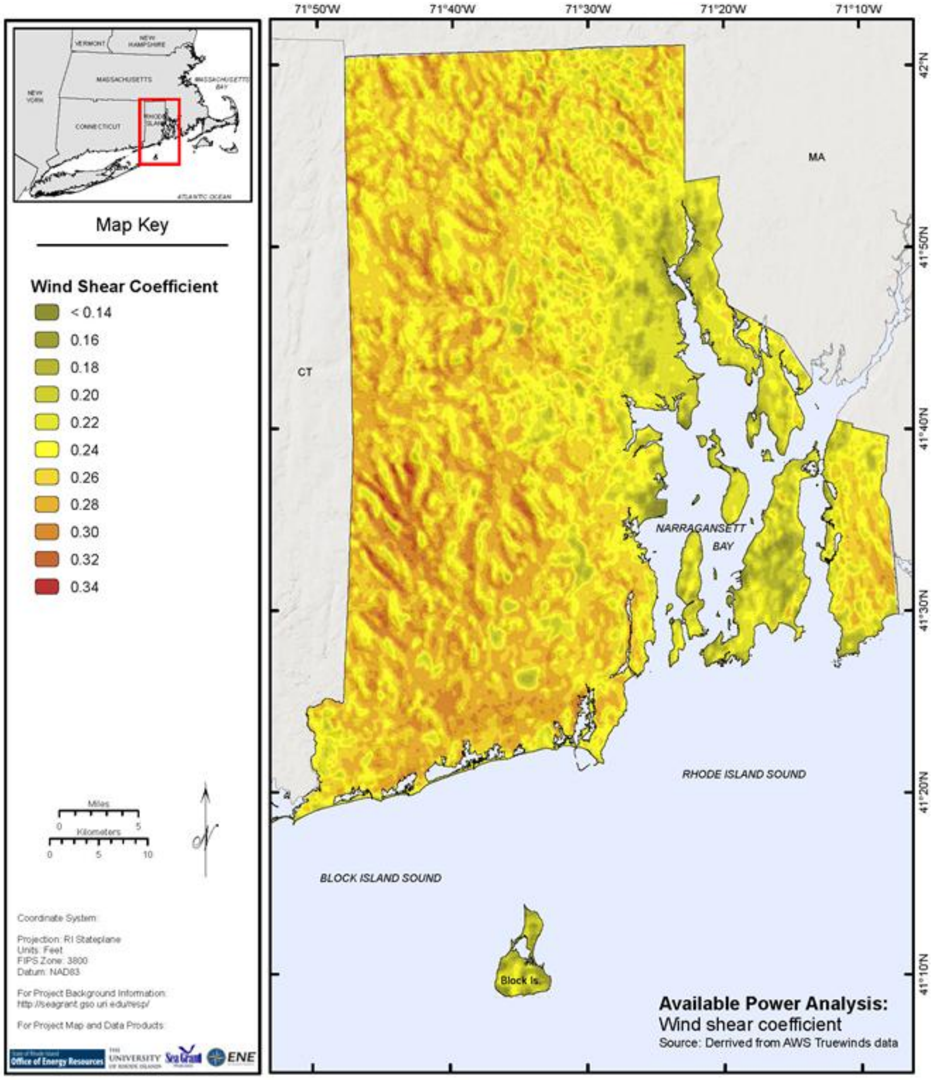


Figure 5. Shear coefficient inferred from AWS Truewind data.

Charnock log-law and Surface Roughness

As described in the theoretical section, the land use directly determines the surface roughness, which in turn determines the vertical wind profile. This is explicit in Charnock law (Eq. 10), which constitutes an alternative model to the power law (Eq.9) to estimate the vertical wind profile. Both profiles have been compared to give a sense of the variance between the methods. Application of both methods and results are described in Section 2.4.8. We expect to eventually have good measurements at elevation from towers and SODAR to validate those vertical extrapolations. Unfortunately measurement at elevations will be available after the submission deadline for this report (Merrill and Knorr, 2012).

Table 1 presents the surface roughness length corresponding to the local land use classes. Results are available on a 30 m grid and on a 100 m grid. Land use and corresponding roughness length is mapped on Figure 6 and Figure 7, respectively.

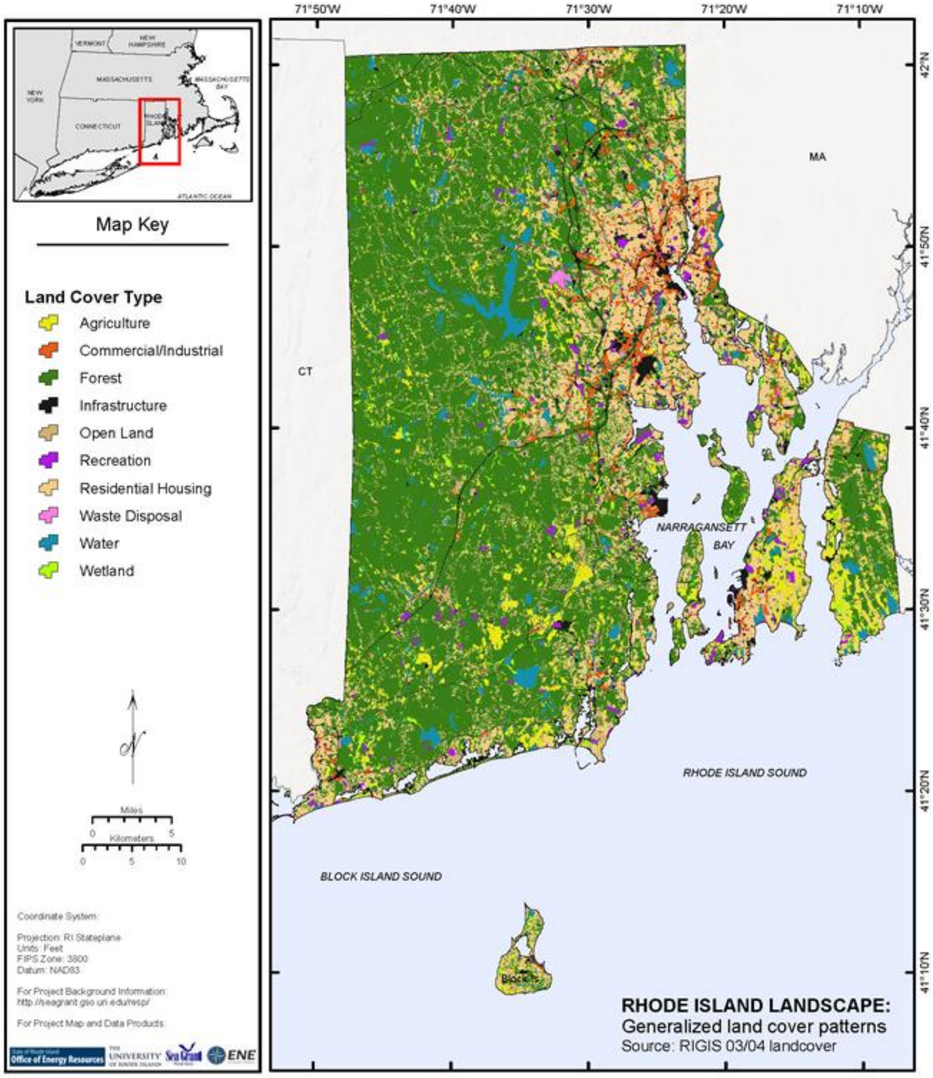


Figure 6. Land cover from RIGIS landcover.

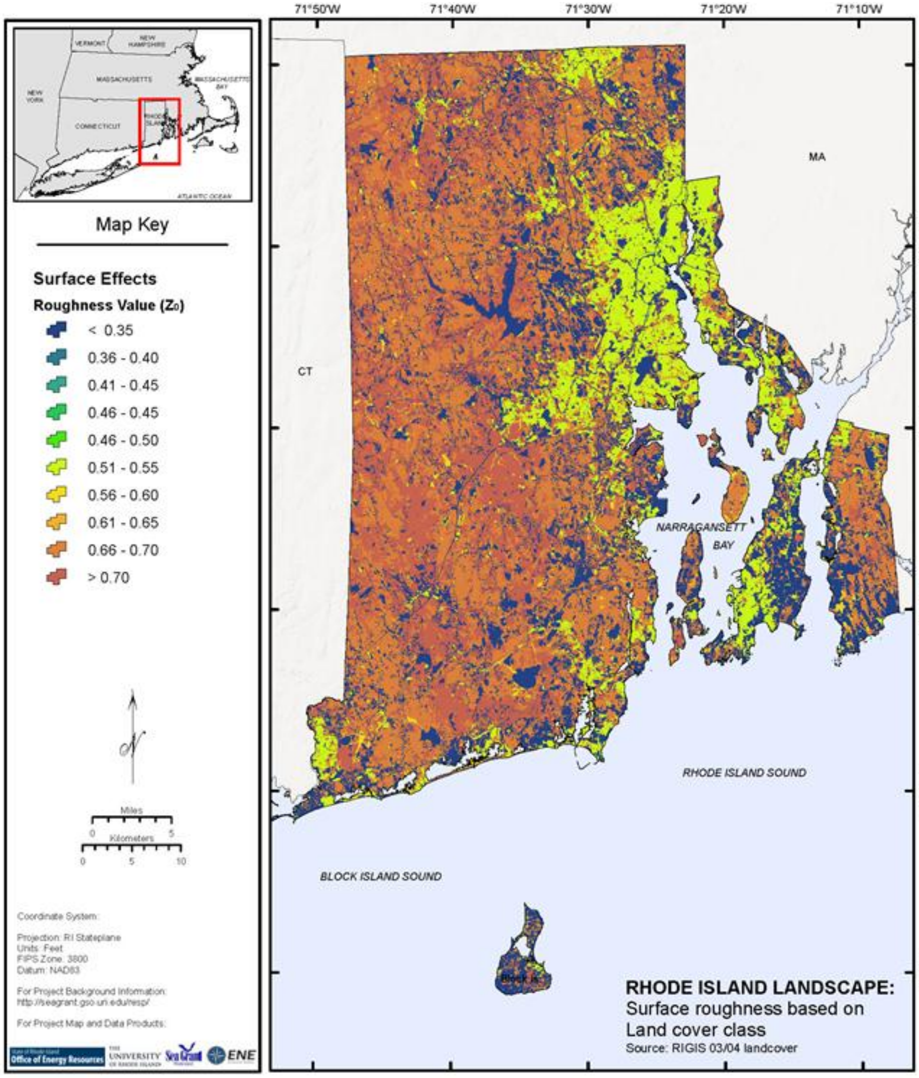


Figure 7. Roughness length Z_0 (m).

Table 1. Roughness length based on land use (Spruce, Berglund and Davis. NASA, 2004).

RIGIS LULC	RIGIS CODE	ROUGHNESS CLASS	
Water	500	Open Water	0.01
Medium Density Residential (1 to 1/4 acre lots)	113	Low Intensity Residential	0.33
Medium Low Density Residential (1 to 2 acre lots)	114		
Low Density Residential (>2 acre lots)	115		
High Density Residential (<1/8 acre lots)	111	High Intensity Residential	0.53
Medium High Density Residential (1/4 to 1/8 acre lots)	112		
Commercial (sale of products and services)	120		
Industrial (manufacturing, design, assembly, etc.)	130		
Commercial/Residential Mixed	151		
Commercial/Industrial Mixed	152		
Institutional (schools, hospitals, churches, etc.)	170		
Roads (divided highways >200' plus related faci	141	Commercial Industrial Transportation	0.35
Airports (and associated facilities)	142		
Railroads (and associated facilities)	143		
Water and Sewage Treatment	144		
Waste Disposal (landfills, junkyards, etc.)	145		
Power Lines (100' or more width)	146		
Other Transportation (terminals, docks, etc.)	147		
Beaches	710	Bare Rock/Sand/Clay	0.09
Sandy Areas (not beaches)	720		
Rock Outcrops	730		
Mines, Quarries and Gravel Pits	740	Quarries/Strip Miines/Gravel Pits	0.18
Vacant Land	162	Transitional	0.20
Transitional Areas (urban open)	750		
Mixed Barren Areas	760		
Deciduous Forest (>80% hardwood)	410	Deciduous Forest	0.68
Softwood Forest (>80% softwood)		Evergreen Forest	0.73
Orchards, Groves, Nurseries	230	Mixed Forest	0.71
Mixed Forest	430		
Brushland (shrub and brush areas, reforestation)	300	Shrubland	0.12
Pasture (agricultural not suitable for tillage)	210	Grassland/Herbaceous	0.04
		Pasture /hay	0.05
Cropland (tillable)	220	Row Crops	0.05
		Small Grain	0.06
Idle Agriculture (abandoned fields and orchards)	250	Fallow	0.04
Developed Recreation (all recreation)	161	Urban Recreational Grasses	0.03
Cemeteries	163		
Wetland	600	Woody Wetlands	0.58
		Emergent Herbaceous Wetlands	0.09

Wind geography

In this section, the objective is to establish a RI wind geography providing a map of wind "regions" in terms of wind climate. Regional variations, within the state, in wind speed depend mostly on (1) topographic effects, blocking or accelerating, (2) variation in surface roughness, and (3) exposure to sea breeze.

Using the three variables to define the wind characteristics: mean wind speed (Figure 3), vertical profile shear coefficient (Figure 5), and Weibull shape coefficient (Figure 4), and two major controlling variables in the wind micro-climate surface roughness (Figure 7) and topography (Figure 7), a very general regional geography of the RI wind climate based on multivariate statistical analysis, a combination of principal component and cluster analysis (Zuur, 2009) has been established.

The analyses identify five major wind regions (Figure 9):

Region 1: The close to shore windiest region characterized by a sea-breeze re-enforcement in the summer; very little topographic effects and a lower shear coefficient characteristic of a lower displacement length due to a relatively "smooth surface".

Region 2: An intermediate inland region, more inland, less windy; higher surface roughness and higher shear coefficient.

Region 3: A "slope" region, further inland than *region 2*, and in the lee of the highest elevation; this lesser exposed region is also characterized with high surface roughness and therefore high shear coefficients.

Region 4: The highest elevation region, relatively windier than other inland areas. However, high surface roughness and therefore high shear coefficient.

Region 5: This final region is interesting since it highlights inland regions with very small surface roughness and therefore low shear coefficients. Those areas can expect to have relatively higher wind velocities at lower elevation. Most of those surfaces are lakes and ponds.

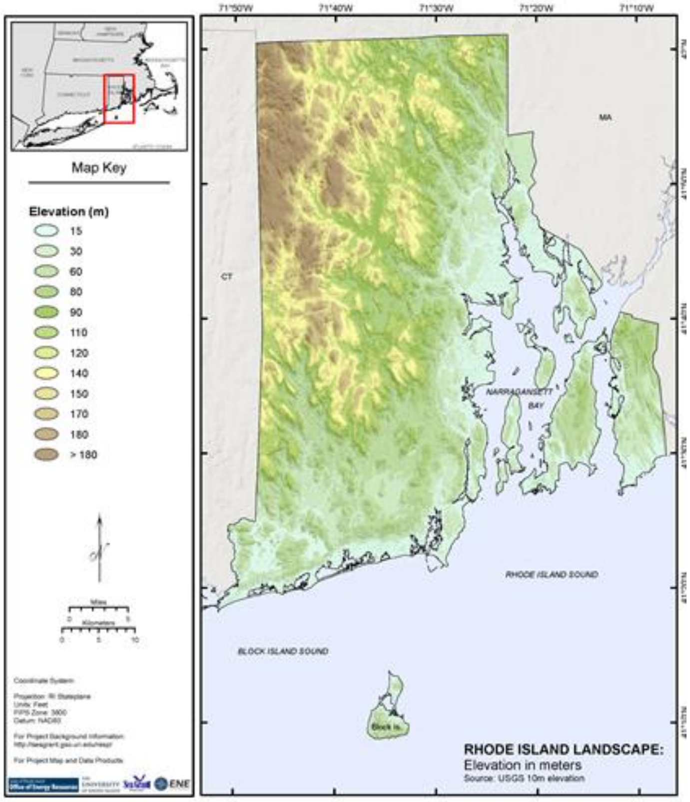


Figure 9. Elevation (m).

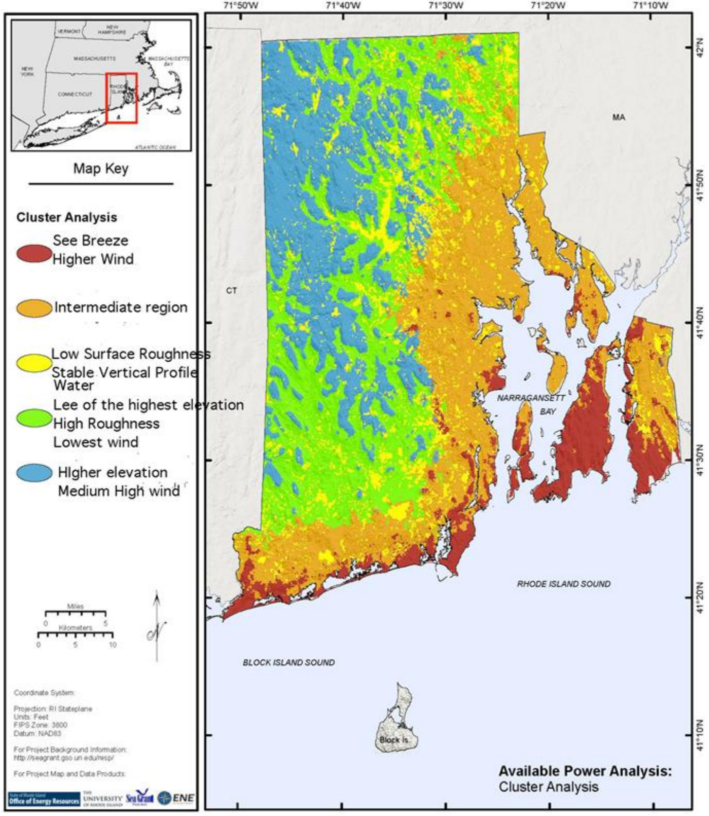


Figure 8. Wind Geography based on cluster analysis.

Mean expected theoretical wind power

At this point, we have a good grasp of the wind geography in Rhode Island and have defined all the elements to calculate the expected mean theoretical wind power at any height in the vertical profile.

The theoretical power is calculated at each grid point using the analytical formulation (Eq.8). Maps are provided for 30 m, 50 m and 80 m height (Figure 10a,b,c). However the interactive tool available on the GIS allows estimation of the expected power at any elevation (see next sub-section) and at any specific location (Section 5). Higher theoretical power is found as expected closer to the shore and at the highest elevations.

The wind power is determined at any elevation assuming a wind velocity vertical profile, or a shear coefficient (Eq.9). This one is determined at each grid point from AWS Truewind data (see Section 1.4.2).

In an attempt to understand the order of magnitude of the expected power uncertainty associated with the vertical extrapolation, comparisons were made for the expected mean wind speed at 30 m considering the two wind profile formulations:

- The power law using the shear coefficient estimated from AWS Truewind data at four levels.
- The log law (Charnock law) using a roughness length based on land use.

The difference between the mean wind speed at 30 m, using the power law versus the log-law is mostly contained between +0.2 m/s and -0.1m/s. The difference is largest above water surfaces. This wind speed sensitivity to the wind profile formulation is mapped on Figure 11a. The transfer of this small uncertainty in mean wind speed translates into a small variance in the mean power uncertainty for most part of the state (<4%). Forested sloppy area and water areas show a slightly higher potential underestimation of the expected power using the power law versus the log law (order of 6 to 9 %) (Figure 11b).

Both model show consistent results. The only way to validate those profiles is to compare them to actual data. Merrill and Knorr (2012) have the deployed two measurement towers equipped with anemometers, as well as a mobile SODAR. Only those measurements will give an accurate estimation of the expected power uncertainty due to the uncertainty in the wind profile.

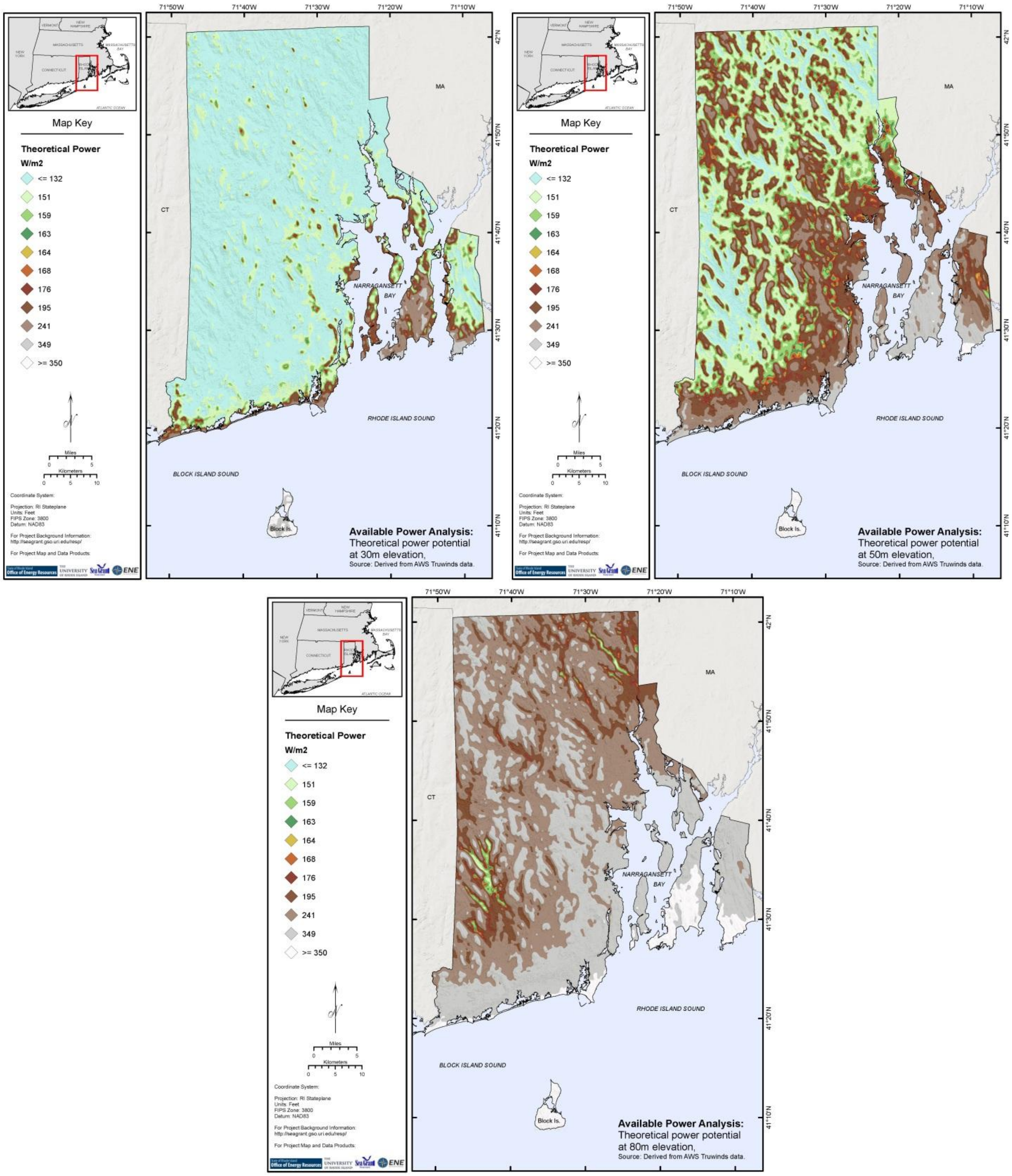


Figure 10. 10a, 10b, 10c Mean Theoretical power at 30 m, 50 m, and 80 meters.

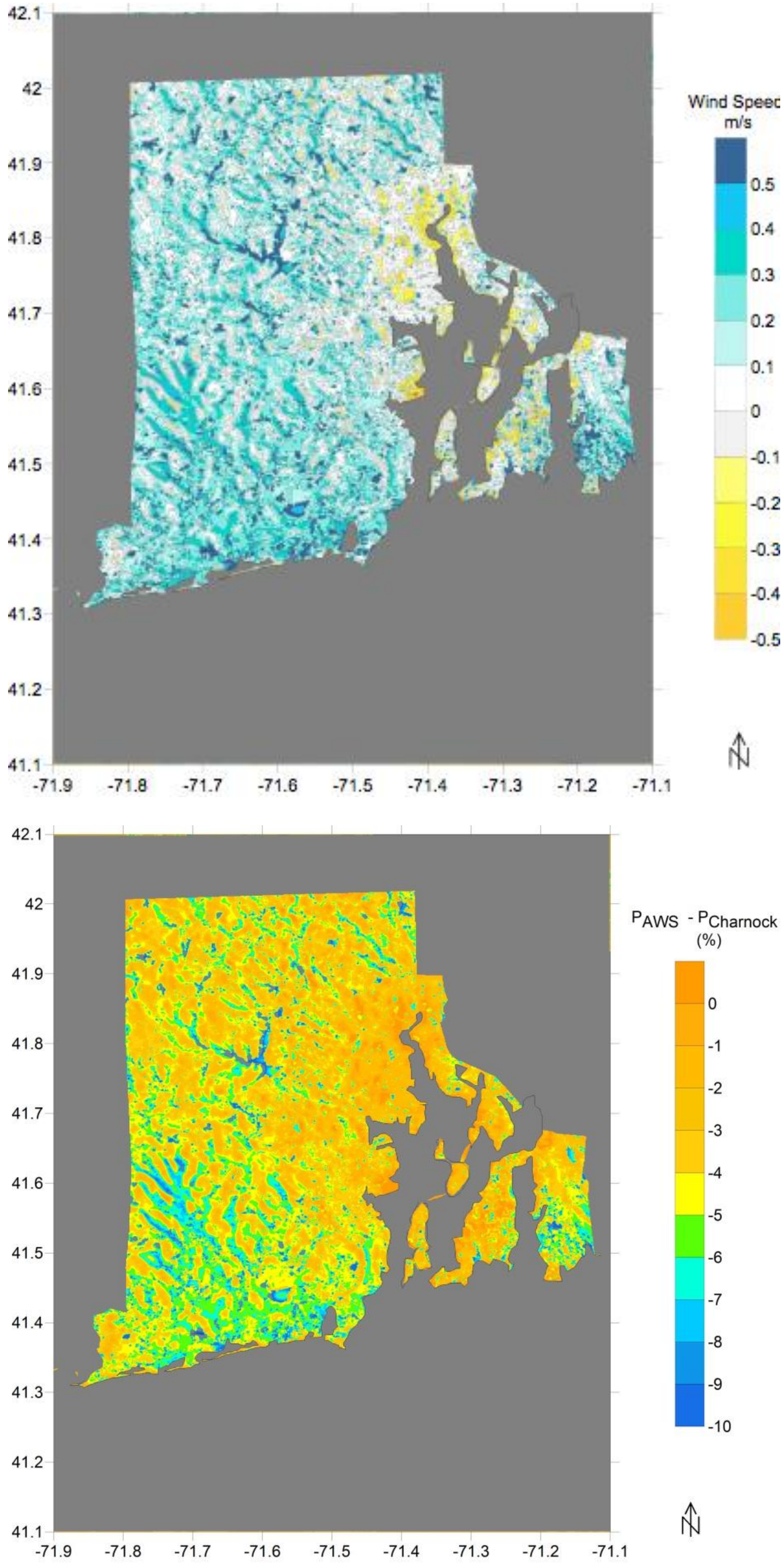


Figure 11. Wind speed (11a) and Theoretical power (11b) sensitivity at 30 m to Charnock law versus power-law in vertical profile definition in m/s and percentage of expected power respectively (%).

2.5 Expected technical power spatial variability

As discussed in the theoretical section, once a turbine is introduced in the environment the wind field is modified in such a way that only a fraction of the available power is available to the turbine (maximum of 59.3 %). In addition the turbine specifications, cut-in, cut-out and rated speed define the maximum extractable power. Those restrictions define the technical power.

Mean expected technical power

In the following we assume a turbine with cut-in and cut-out, of 3.5 and 25 m/s respectively. Note that the expected power is relatively insensitive to any small variations around those cut-off values (since this affects the tails of the wind speed distribution). However, it is more sensitive to the rated speed value. We chose a rated speed of 14 m/s for our base case maps, which will represent an expected upper limit for technical power (maximum value).

The technical power is calculated at the three standard elevations. It is mapped on Figure 12a, b, c at 30, 50 and 80 m. It can also be calculated interactively at any elevation for any spatial specific location with the GIS tool (Section 5). Note that the technical power is on the order of half of the theoretical power, (mostly due to the inclusion of Betz's law in the formulation). It also shows less spatial variance in the expected wind resource (due to the inclusion of the rated speed in the formulation, which reduces the impact of the high winds on the available resource). This results in a spatial variance on the order of 2 between minimum and maximum technical power regions, versus an order of 2.5 between minimum and maximum theoretical power regions.

Capacity factor

The capacity factor is the ratio of the mean output of a turbine over a period of time (usually a year or a number of years) and its potential mean output if it had operated at full nameplate capacity the entire time. This concept is standard in the wind industry and is an indicator of the viability of a wind project. If the capacity factor is too low, the cost of the project might be larger than the revenue from the expected extracted power. For example siting a turbine with rated capacity of 14 m/s in an area where the median wind speed at hub height is around 7 m/s at 80 m (e.g.: Point Judith, 7.3 m/s) would result in a capacity factor on the order of 0.22 (Table 2). If the rated speed decreases to 12 m/s, the turbine operates more often at full capacity and the capacity factor would increase to 0.32. This example is detailed on Table 2, as well as two other, arbitrary selected sites, slightly less windy, Jamestown and Portsmouth.

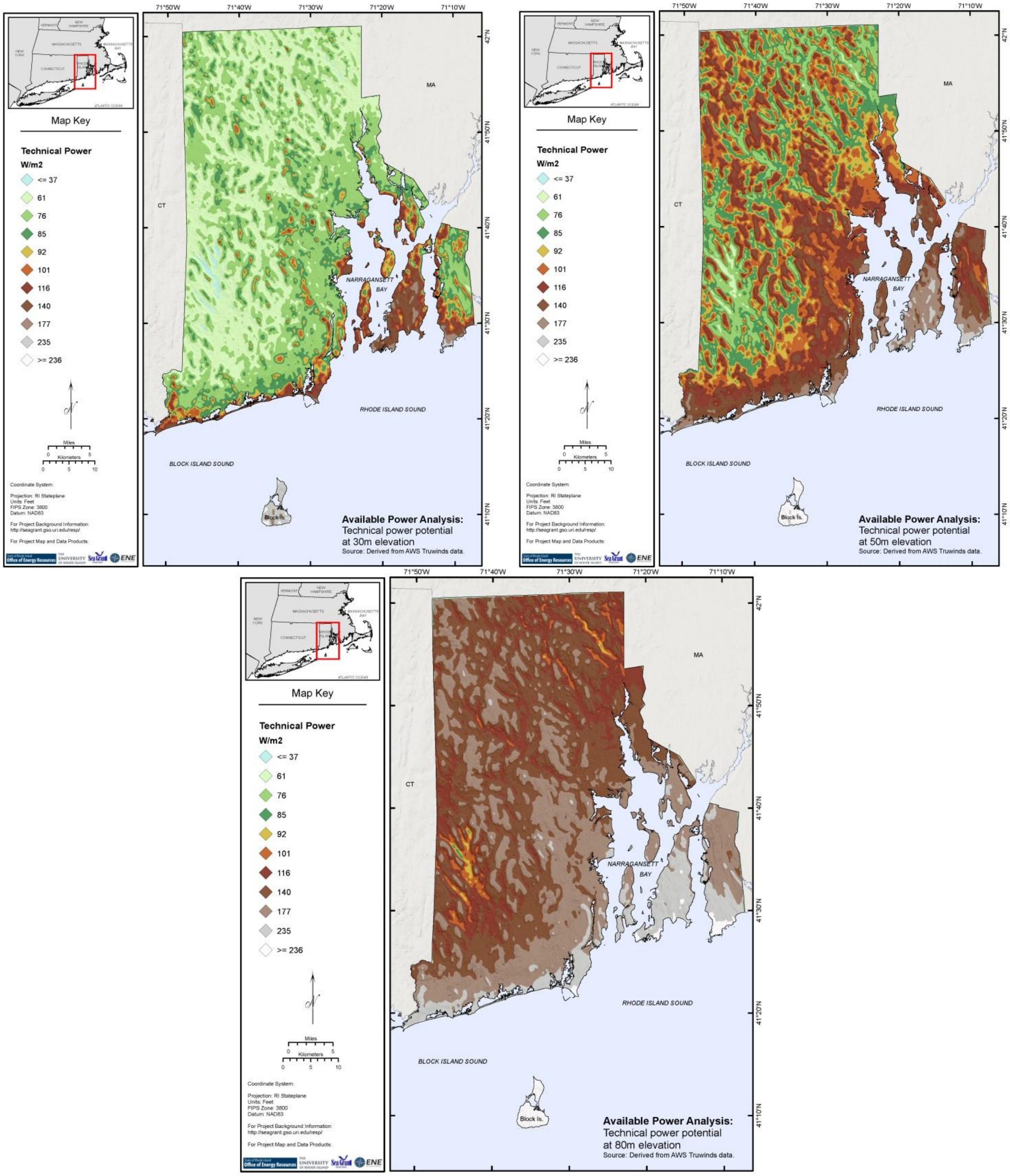


Figure 12. 12a, 12b, 12c Technical power at 30 m, 50 m, and 80 m for 14 m/s rated speed, cut in and cut out, 3.5 and 25 m/s.

Table 2. Capacity factors at 3 sites, for 3 turbines (at each site), characterized by the following specifications: cut-in and cut-out are 3.5 m/s and 25 m/s and rated speed of 10 m/s, 12 m/s and 14 m/s, respectively. Each site is defined by its mean wind speed at 80 meters height. Theoretical power as well as technical power are also calculated.

Location	U_{80} (ms^{-1})	P_{Th} (Wm^{-2})	Turbine Technical Chararacteristics	U_r (ms^{-1})	Resulting Technical Power and Capacity Factor	P_T (Wm^{-2})	CF
Pt Judith	7.3	399		10		164	0.45
Jamestown	6.8	338		10		146	0.40
Porthmouth	6.5	315		10		135	0.37
				12		201	0.32
				12		176	0.28
				12		160	0.26
				14		223	0.22
				14		190	0.19
				14		176	0.18

The theoretical formulation of the capacity factor is defined in the following. The instantaneous power output is defined as,

$$P_i = \frac{1}{2}\rho A u_i^3 \beta\eta \tag{14}$$

with,
P_i Instantaneous power density (W/m^2)
u_i Instantaneous wind speed (m/s)
ρ Air density
A Swept area (m^2)
β Betz coefficient (0.59)
η Efficiency
and the subscript i referring to time;
The power output when operating at full nameplate capacity:

$$P_i = \frac{1}{2}\rho A u_R^3 \beta\eta \tag{15}$$

with, u_R the rated wind speed (m/s) (speed at which the turbine works at full capacity).

Therefore, the capacity factor, for a period of time between t_1 and t_2, is defined as,

(16)

$$C = \frac{\int_{t1}^{t2} \frac{1}{2} \rho A u_i^3 \beta \eta}{\int_{t1}^{t2} \frac{1}{2} \rho A u_R^3 \beta \eta} = \frac{\int_{t1}^{t2} u_i^3 \eta}{\int_{t1}^{t2} u_R^3 \eta}$$

Assuming a constant efficiency, independent of the wind speed, this expression reduces to:

$$C = \frac{\int_{t1}^{t2} u_i^3}{\int_{t1}^{t2} u_R^3}$$

Alternatively it can be expressed in the frequency domain, as,

(17)

$$C = \frac{\int_{cut\ in}^{Rated\ speed} f_k * u_k^3 + \int_{Rated\ speed}^{cut\ out} f_k * u_R^3}{\int_0^\infty f_k * u_R^3}$$

where f_k is the frequency of the velocity u_k (the subscript k refers to a velocity k).

The capacity factor was estimated at each grid point in the study area using Eq. 17, assuming that the efficiency of the turbine is independent of the wind velocity. The frequency distribution is the Weibull distribution determined from AWS Truewind mean wind speed and shape parameters. The integration is calculated by a Monte Carlo method using 100,000 independent draws.

The simulations were performed at 80 m for a set of rated speed between 11 and 15 m/s. In the GIS tool, the user can enter the actual power curve of any specific turbine, and therefore implicitly the efficiency curve, so that in that case the capacity factor estimation is performed exactly using Eq. 17 (Section 5) Note that differences between the value of the capacity factor, calculated assuming a constant efficiency factor, and the exact efficiency curve is very small. The expected capacity factor is mapped on Figure 13a, 13b, 13c for rated speeds of 12, 10 and 14 m/s.

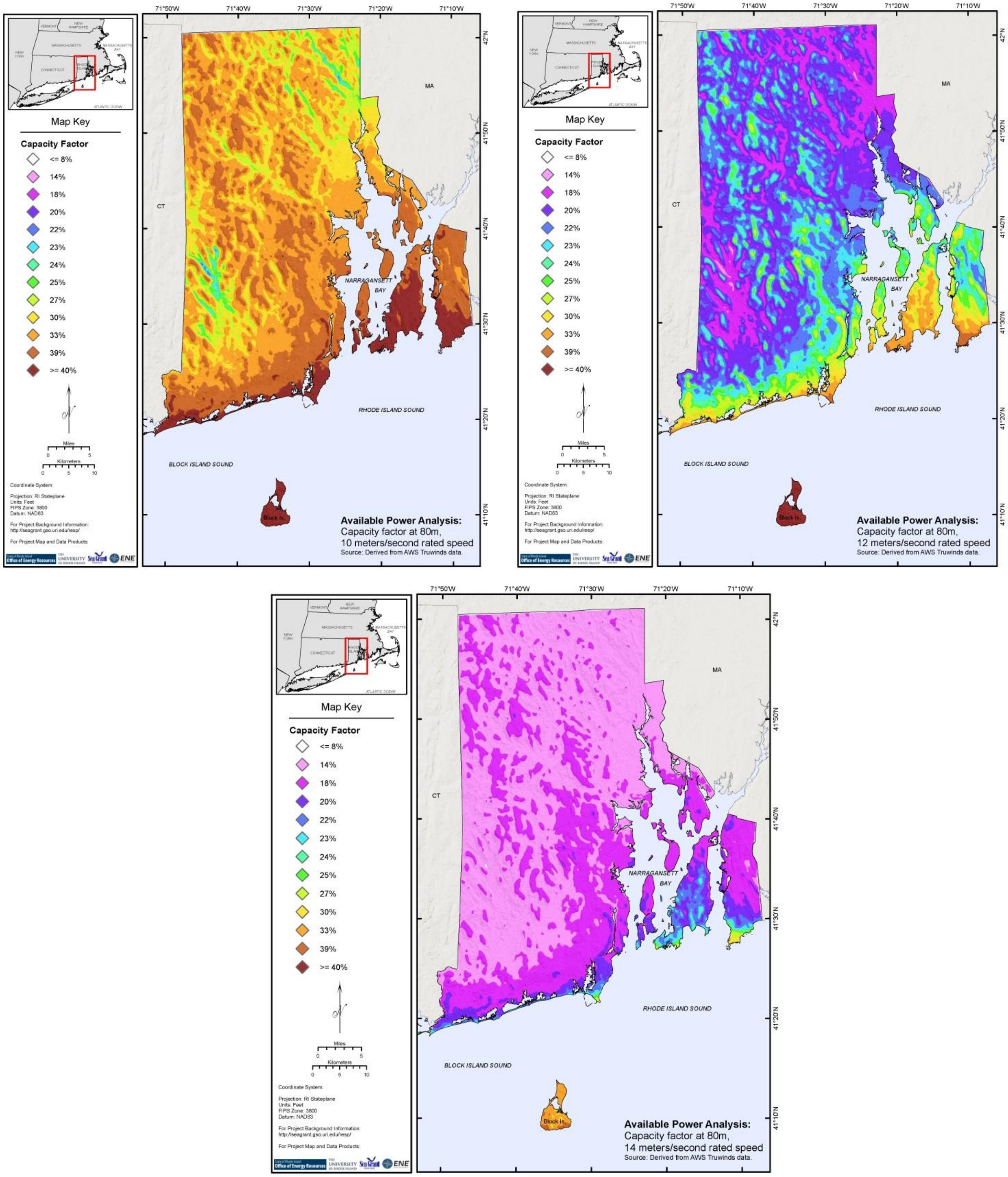


Figure 13. 13a, 13b, 13c Capacity Factor at 80 m for 10 m/s, 12 m/s, and 14 m/s rated speed.

2.6. Wind measurement at stations

Local wind records are used to estimate the uncertainty associated with the expected theoretical power. Wind speeds measured at local stations are compared to model predicted wind speeds, and the differences between them are used to estimate the expected uncertainty on the mean theoretical power.

In addition, local wind stations provide wind direction (wind rose) and wind speed time series. No spatial inference of the wind roses is provided in this report. Wind rose and wind power roses are provided, in addition to the Weibull distribution, as standard output, at the wind stations location, only. The vertical profile is included, calculated based on surface roughness characteristics, and compared to the expected profile from model predicted wind data. Wind time series are summarized in seasonal time series, showing the monthly averaged values over the years present in the records.

Local wind records were obtained from a variety of sources: NOAA stations, Green Airport data, Weather Flow Stations and a few other local stations. A selection from 22 potential sources, primarily based on quality control, reduced the number of stations to 8 for the uncertainty analysis. (Section 2.7). Table 3 lists those selected stations and their location (Figure 14). Length of the records is shown in Figure 15.

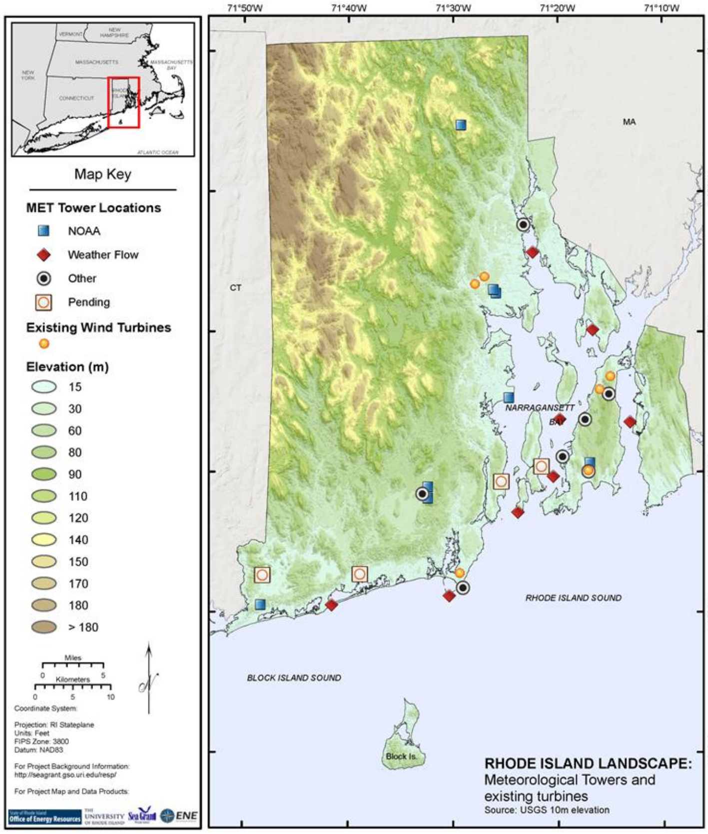


Figure 14. Wind station locations.

Table 3. Selected measurement station locations.

Station	Latitude	Longitude	Source	Anemometer Height
Half Way Rock	41.5637	-71.33138	WeatherFlow	8.53
Point Judith	41.354	-71.507	WeatherFlow	16.46
Sabine Point	41.762	-71.374	WeatherFlow	8.53
Rose Island	41.49554	-71.3418	WeatherFlow	10.67
TF Green	41.722	-71.433	NOAA	10
North Central State	41.917	-71.500	NOAA	7.9
Camp Cronin	41.3666	-71.4833	DEM	30
Newport	41.51945	-71.31053	Naval Station	25

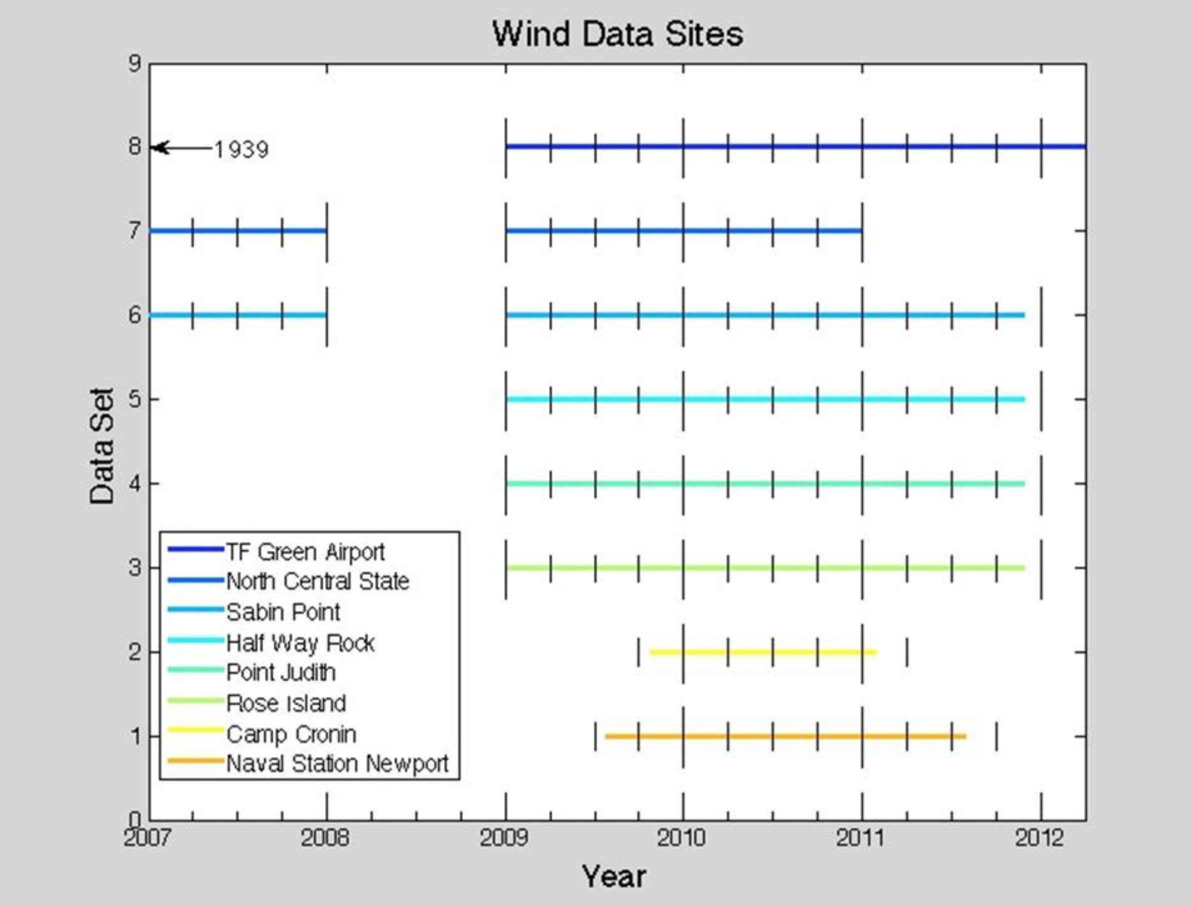


Figure 15. Selected measurement length for stations shown in Table 3 (Merrill and Knorr, 2012).

Available data were verified and compiled into consistent hourly time series for wind speed and direction. The quality check included :(1) outliers were removed; (2) missing data were checked for two criteria: (i) not exceeding the accepted threshold of 15% of zeros (3) frequency consistent through seasons such that it does not bias the seasonal representation; (4) Weibull parameters not "outliers" in their probability distribution.

Weibull distributions, wind roses, power roses, monthly average wind speed are presented in Figures 16, 17 and 18 for Point Judith at 16.5 m elevation. Similar plots for the other stations and are available on the website : RI Energy.org.

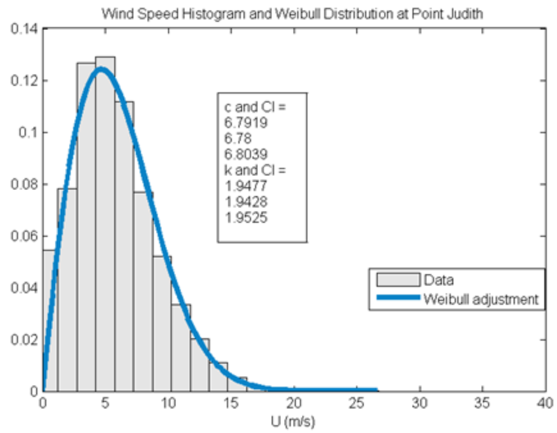


Figure 16. Weibull distribution with scale(c) and shape parameter (k) and their confidence interval at anemometer height (16.5 m) at WeatherFlow Point Judith Station (location in Table 3 and Figure 14).

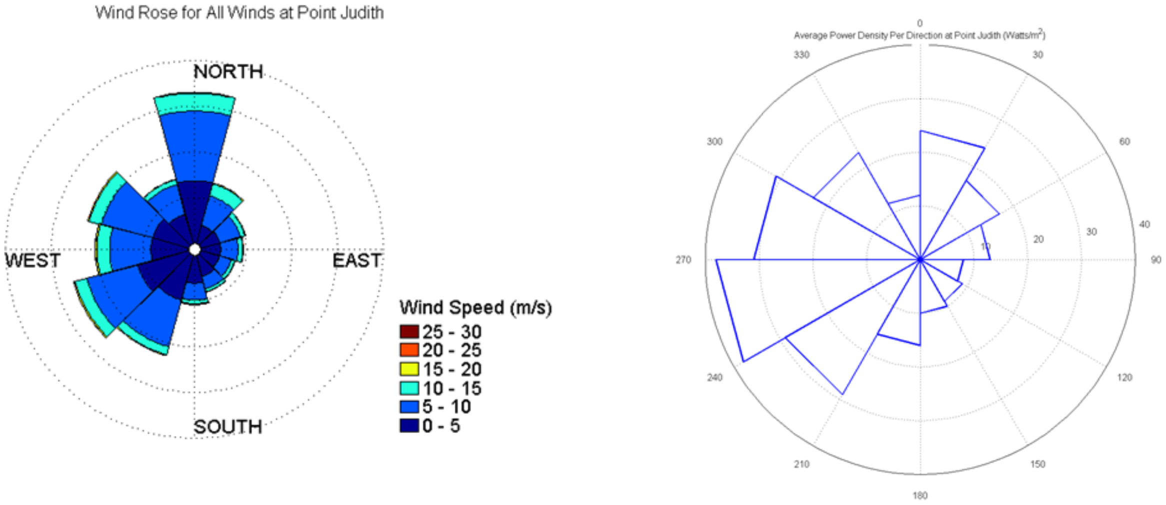


Figure 17. Wind speed directional frequency distribution (wind rose) and theoretical power directional frequency distribution (power rose) at anemometer height (16.5 m) at WeatherFlow Point Judith Station (location in Table 3 and Figure 14).

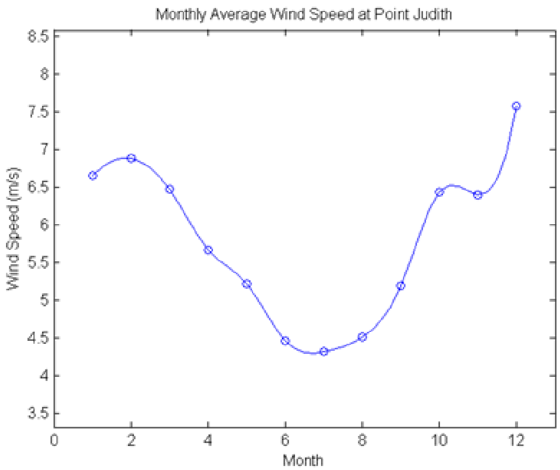


Figure 18. Monthly mean wind speed at anemometer height (16.5 m) at WeatherFlow Point Judith Station (location in Table 3 and Figure 14).

2.7 Wind and power uncertainties estimates

Availability of wind speed measurements at stations (Table 3) allowed assessing the uncertainty associated with AWS Truewind wind speed predictions, and therefore provide a range of confidence to the mean power estimations as shows in Figures 10 and 11.

Comparison between observed and simulated wind speed at stations at anemometer height

AWS Truewinds data were, as described earlier, validated with 33 measurements stations across New England. Few stations in RI however were available at the time (1 at our knowledge was used for calibration). In view of the larger number of currently available local wind speed records, the accuracy of the AWS predicted winds is re-assessed for RI. Selected stations for the analysis are listed in Table 3.

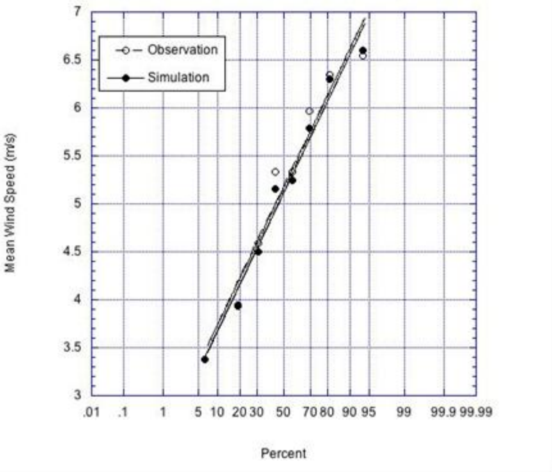


Figure 19. Simulated (AWS) and observed mean wind speed at measurement stations probability distribution. Stations are listed in Section 2.5, Table 3.

Comparison of mean wind speed at measurement stations and anemometer level shows a similar Gaussian distribution for AWS Truewind modeled wind speed and measured wind speed (Figure 19) . A t-student statistical test demonstrates that the two distributions are statistically similar and therefore, from a statistical point of view, considered identical.

Uncertainty in mean wind speed

However, one can extract more information from those distributions and evaluate the uncertainty associated with the mean values and define the confidence interval around the mean value, or the expected reasonable range of variation of mean the wind speed.

Differences between model predicted and measured wind speed at each station are Gaussian distributed (Figure 20). The differences are not significantly different from zero as shown from a t-student test (no significant difference between measurement and modeled data, confirming the result obtained above). One can expect a mean slight underestimation of AWS model predicted wind speed, on the order of 1 %, (-1%) with a confidence interval at 95 %, of that mean value varying between 0 and -2%. At a specific location, one might expect the actual mean wind speed value varying from AWS Truewind prediction in a range between - 4.5 % to 2.5 %, at a 95 % confidence interval (integrating the uncertainty due to the small number of stations used for the comparison).

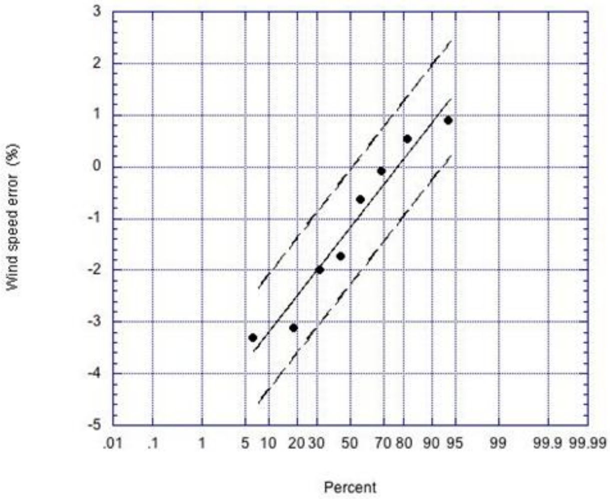


Figure 20. Mean wind speed relative difference between AWS Truewind values and observations at stations (%). Probability distribution and confidence interval at 95 %.

Uncertainty in mean power assuming accurate shape parameter

The uncertainty in expected power associated with the uncertainty in mean wind speed can be expressed as:

$$\varepsilon_P = \frac{1}{2}\rho\,[(U+\epsilon_u)^3 - U^3\,] \qquad (18)$$

Where ε_u and ε_p, are the uncertainties associated with mean wind speed, (U) and mean wind power, (P), respectively.

The sensitivity of the expected power to the wind speed uncertainty is plotted in Figure 21 for a range of potential relative errors in wind speed. The relative uncertainty in power varies between -15 % and 5 %, when the mean wind speed relative uncertainty varies between -4.5% and 2.5% . This assumes that the shape coefficient of the Weibull distribution is known deterministically (no uncertainty). However, in reality the shape coefficient is also a random variable whose values are expected to vary over a certain range.

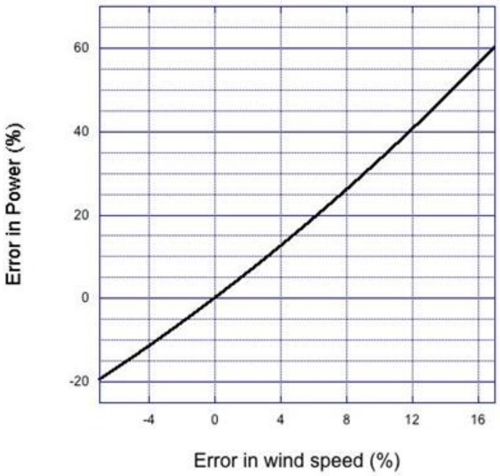


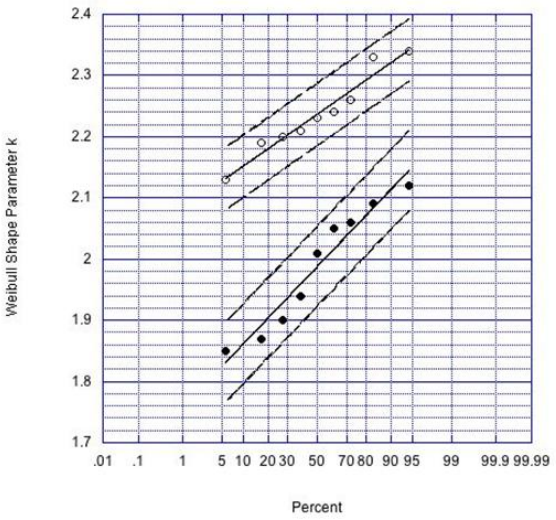
Figure 21. Sensitivity of the expected theoretical power to the wind speed uncertainty.

Uncertainty in shape parameter

As discussed in Section 2 the wind speed is Weibull distributed, which is defined by the scale (c) and shape parameter (k) . Mean wind speed and scale parameter are directly related assuming a constant shape parameter. The shape parameter however is also a random variable slightly varying around a value on the order of 2.

The probability distribution of the shape parameter at measurement stations indeed shows a Gaussian distribution, with k varying spatially between 1.8 and 2.3, within a 95 % confidence interval. The shape parameter values, determined from AWS Truewind data, show less variance around the mean but have a higher average value, 2.2. A t-student test demonstrates a significant difference between the two sets of data (Figure 22).

The probability of the differences between AWS Truewind determined shape parameter and observed shape parameter is Gaussian distributed with a mean value of 0.25 and a 95% confidence interval of the mean value varying between 0.18 and 0.32 (Figure 23).



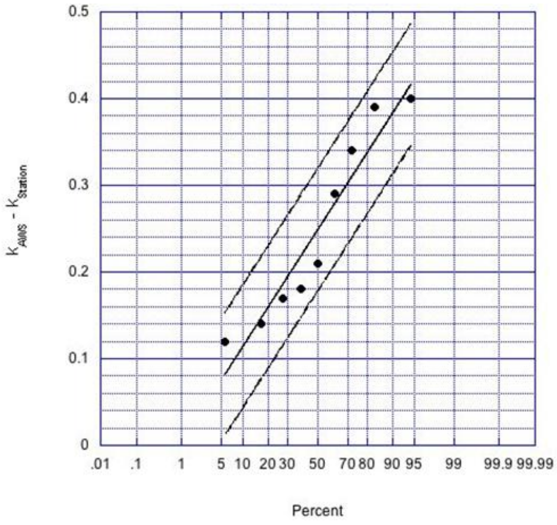


Figure 22. Weibull shape parameter distributions for observed data at stations (black dots) and corresponding values inferred from AWS Truewind data (open circles).

Figure 23. Probability distribution of the differences in Weibull shape coefficients between observations and AWS Truewind values at stations.

The difference in elevation between the anemometer (6.1 m to 30 m) and AWS Truewind estimates (50 m) might be responsible for the significant systematic difference between observations and AWS Truewind values. The shape coefficient is currently assumed constant throughout the profile, although one might expect its value to increase with elevation (Merill and Knorr, 2012). There is however insufficient data to perform a systematic variance analysis which would extract the variance due to geographic variability, vertical variability and random error.

Therefore, we elected to perform the sensitivity analysis for two sets of shape parameter variance assumption (1) First, we assume that the shape parameters values inferred from AWS Truewind data, carry a systematic bias due to the elevation, which is a therefore a true bias reflecting reality. This bias has therefore to be removed before performing the sensitivity analysis. (2) Second, we assume that the total variance of the differences between the two sets of data is representative of the expected variance at any spatial point and any level.

The uncertainty analysis including mean wind speed and shape parameter variance is developed and presented in the next section. To have a feeling of the order of magnitude of the shape parameter variability impact on power estimates, Figure 24 presents, the sensitivity of the theoretical power (in relative value, %) to a variation of the shape parameter. The figure shows that an increase in shape parameter value from 2 to 2.2 (assuming identical mean wind speed), results in a drop in the mean power of about 9%.

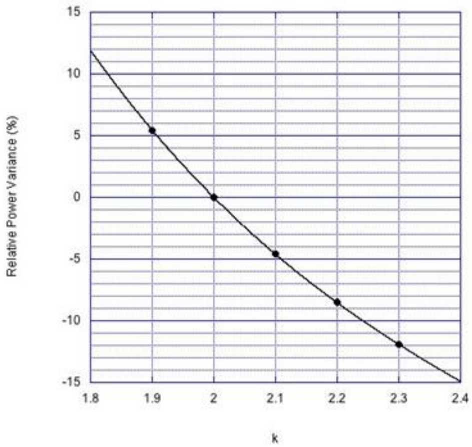


Figure 24. Sensitivity of the expected theoretical power to the shape parameter (k) value. Relative variance in percentage from the expected power when k=2.

Uncertainty in mean power assuming stochastic Weibull parameter

The expected uncertainty in power combining both uncertainties, mean wind speed and shape parameter uncertainties, can be expressed as:

$$\varepsilon_P = \frac{\partial p}{\partial U}\,\varepsilon_U + \frac{\partial p}{\partial k}\,\varepsilon_k \qquad (19)$$

where, $\frac{\partial p}{\partial U}$ and $\frac{\partial p}{\partial k}$ are the derivatives of the expected power with respect to the mean wind speed U and the Weibull shape parameter k $\varepsilon_P, \varepsilon_U, \varepsilon_k$ are the total uncertainties associated with the power, the mean wind speed, and the shape parameter.

Since both uncertainties, associated with the mean wind speed and Weibull shape parameter, are random variables, the total uncertainty is estimated stochastically using Monte Carlo random simulations from the probability distribution of $\varepsilon_U, \varepsilon_k$. 100000 random simulations were performed.

As an example, the probability distribution of the uncertainty associated with the mean wind speed is plotted in Figure 25.

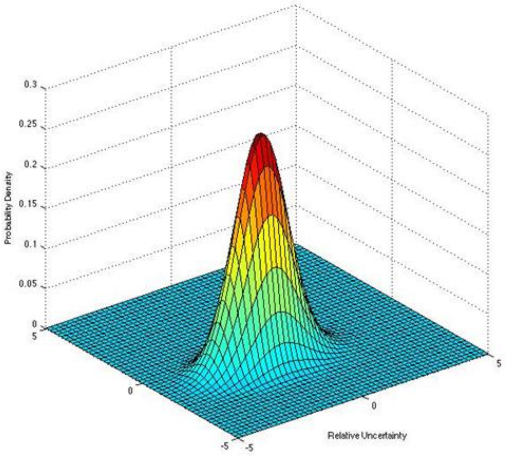


Figure 25. Mean wind speed relative uncertainty probability density.

The uncertainty is calculated at each grid cell of the study area. Results are first presented in terms of the statistics for the entire area in Figure 26. The expected mean uncertainty, ε_P, on the theoretical expected power calculated using Eq. 19, and using a stochastic estimation of ε_U and ε_k, is of the order of -3.5%, assuming no bias in the shape parameter value and -8 %, including the bias in shape parameter value. From the discussion in the previous section, the no-bias assumption would be valid at "higher", elevations (from ~ 50 m). Results are summarized on Figure 26, where the red and orange boxes indicate the second and third quartiles (50 % of the most likely cases), the black line indicates the maximum and minimum values, and dots are classified as outliers.

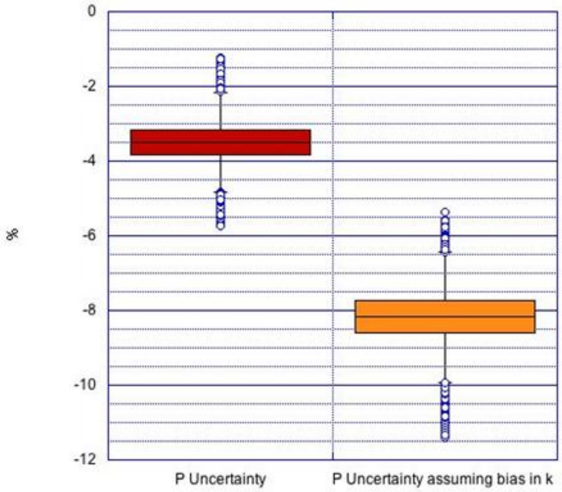


Figure 26. Expected mean theoretical power relative uncertainty (%) including the uncertainty on the mean wind speed and shape parameter, assuming no bias in the shape parameter (red box), or assuming a bias in the shape parameter (orange box). The AWS Truewind data would underestimate, on average, the mean wind speed by 3.5 or 8 % according to the shape parameter assumption.

The red and orange boxes represent the expected interval of variation of the uncertainty among all the spatial grid points. The small box width indicates that the expected mean uncertainty does not vary very much spatially, and can almost be assumed constant in relative value: -3.5 % (assuming no bias in k/or in other words accepting bias as correct from 30 m above ground). In absolute value, therefore one expected higher uncertainty in W/m^2 in the windiest area as shown on Figure 28.

Now, at each individual spatial point the mean uncertainty varies in a specific confidence interval. The expected confidence interval is represented in Figure 27 with the red and green arrows, for uncertainties. without or with bias in the shape parameter, respectively. Because of the combination of uncertainties, and the small number of stations available for comparison, the confidence interval is relatively large, varying between an interval on the order of +/- 25 %. This means that, statistically, if on average the true expected power as the highest probability of being higher by 3.5 % that the estimated mean expected power from the wind speed maps, however, one could still expect a higher or lower power, up to the order of +35% or - 25 %, within a 95 % confidence interval.

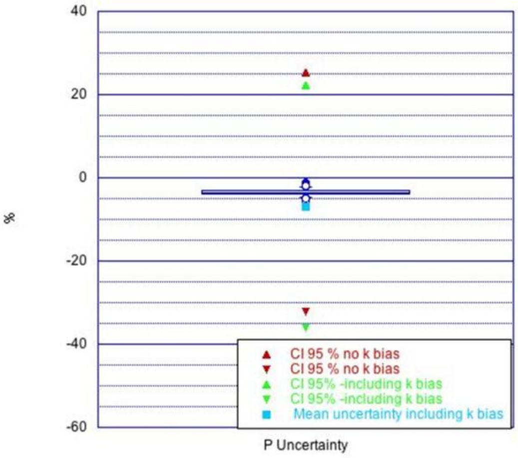


Figure 27. Expected mean relative theoretical power uncertainty including the confidence interval at 95 %.

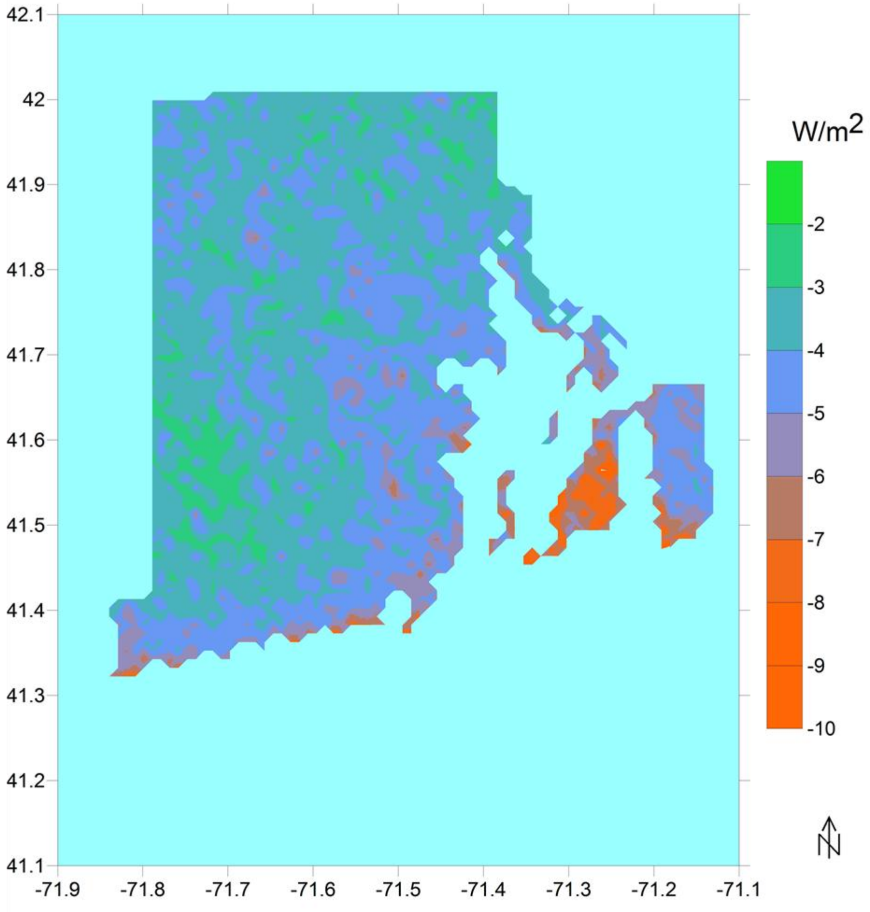


Figure 28. Mean uncertainty of the mean power value inferred from AWS Truewind data in absolute value (W/ m2) at 30 m including mean wind speed and shape parameter uncertainties. AWS Truewind underestimates the average wind power by 3.5 % in average. The confidence interval at 95 % is of this uncertainty is [25% ;-35%].

It is important to note that the power uncertainty due to the uncertainty in vertical wind profile is not included in this version of the report, since the relevant data were not available at the time of publication.

3. PRACTICAL WIND RESOURCE AND ECOSYSTEM SERVICES CONSTRAINTS

As defined in Section 2.1 the practical power refers to the “sustainable” power, the power that can be extracted according to the physical and technical constraints but also to the sociological and ecological constraints. The Rhode Island Coastal Resources Management Council (CRMC) had been leading in the past years an Ocean Special Area Management Plan (SAMP) aimed at zoning the state’s coastal waters to accommodate offshore wind farm developments. In earlier SAMP related work (Spaulding et al, 2010), the offshore wind farm siting issue was considered in a cost model approach, as the solution of an optimization problem between wind resources and technological constraints. This approach led to the development of a technological development index (TDI) defined as a non-dimensional ratio between technological constraints, associated with a specific site (e.g., water depth, geology, distance to the grid), and the wind resource at the site. Subsequently, the additional effects of ecological and social constraints on wind farm siting, were explored by expanding the set of technological constraints, or the standard concept of cost, to ecosystem services constraint (or cost) (Grilli et al, 2011). This results in a more general protocol for optimizing offshore wind farm siting, by way of a Wind Farm Siting Index (WiFSI). The method was tested in the SAMP area in Rhode Island (Grilli et al, 2012). A similar conceptual framework is proposed for the land wind farm siting and outlined below.

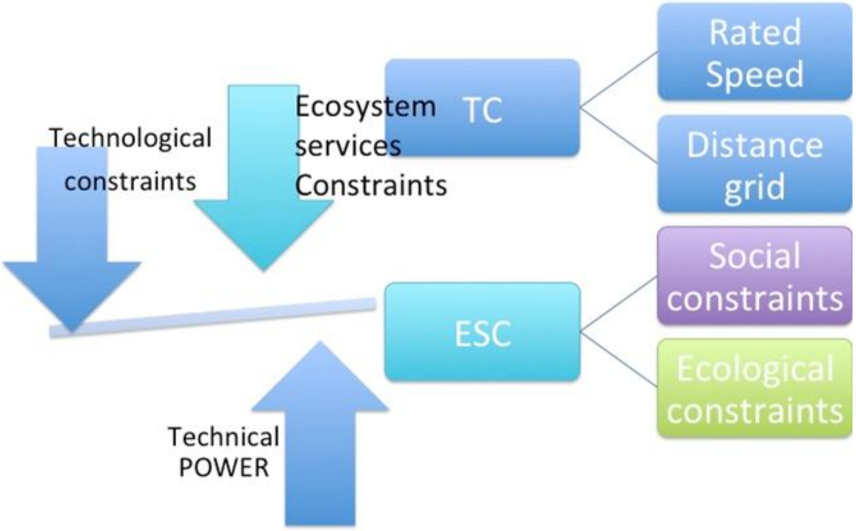


Figure 29. Siting approach based on ecosystem services optimization.

The ecosystem services conceptual approach has been extensively described and developed in the ecosystem based management (EBM) literature, providing a clear definition and a classification system (e.g., McLeod and Leslie, 2009; Arkema et al. 2006; Lester et al., 2010). In the current analysis, McLeod and Leslie's (2009) ecosystem services definition is adopted: *the services the ecosystem provides to human beings*, and follow the general terminology as listed in Table 4, Column 1, as originally published by McLeod and Leslie (2009) and subsequently modified by Oumeraci (2011).

In Column 2, the ecosystem services constraints are listed, which are both, considered relevant to the wind farm siting optimization in RI, as well as quantifiable. Those services could also be referred as social and environmental constraints; both are adding weight to the traditional technological cost in a traditional cost benefit analysis.

- Column 3 describes the data used to describe the corresponding service.
- Column 4 defines the method used to assess the service in terms of constraints.
- Column 5 indicates if the constraints can be mitigated or not: *hard* constraints define exclusionary area; *soft* constraints can be mitigated, and are therefore included in the optimization approach.

Each spatial grid point is described by a set of variables, which can be grouped into three categories:

1. Wind Resource (W/m^2). This concept and the associated value is described in Section 1.
2. Presence or absence "hard" constraints excluding a priori the area in the siting, and therefore in the optimization.
3. "Soft" ecosystem services constraints.

Those can be divided into 2 subcategories:

- The tangible costs, potentially expressed in money value (e.g., cable cost), but not necessary. Those cost constitutes the traditional technological costs (in a standard cost/benefit approach).
- The intangible costs, not defined in money value but as an index [0-1]

Since the optimization combines tangible and intangible costs, units are non-dimensional and "costs" are expressed in indices varying between [0-1]; the relative importance of each service is expressed through a weighting system. Ultimately, the weighting scheme could be established using an econometric Stated Preference approaches, such as Choice Modelling approach (Hanley and Barbier, 2009).

Table 4. Ecosystem Services terminology and categories addressed in the constraint analysis; variables addressed in the state of the present study are indicated either by X or by their range of variation: a continuous variable varying between 0 and 1 is indicated as [0-1]; a binary variable is indicated as [0/1].

Ecosystem Services Constraints				
Ecosystem Services Components	**Categories addressed**	**Representative variables**	**Sensitivity to impact Methodology**	**Variables addressed in this study**
Provisioning services	Air Transportation Energy transferability to grid	FAA regulation rules Distance to transmission line	Exclusionary area based on FAA rules Cost proportional to Euclidian distance to transmission line	X --
Cultural services	Recreation: parks and beaches Historical patrimony Landscape Aesthetic Environmental integrity	Park and beaches Historical sites -- "Quietness"	Binary variable (absence/ presence) Binary variable (absence/ presence) Sensitivity inversely proportional to background noise (decibel)	0/1 0/1 0-1 --
Regulating services	Population residence Ecological service	Population density Biodiversity Birds richness Birds rarity Forest non-fragmentation Natural parks	Sensitivity proportional to population density Sensitivity proportional to biodiversity Sensitivity proportional to richness Binary variable (absence/ presence) Sensitivity proportional to non-fragmentation Binary variable (absence/ presence)	0-1 0-1 0-1 0/1 0-1 0-1

The constraints can be divided into "hard" and "soft" constraints. The hard constraints are not mitigatible and preclude any wind turbine siting. Removing those area refine the feasible area, for a wind project. Optimizing the soft constraints can help identifying the optimal area for turbine siting.

Feasible siting area

The Federal Aviation Administration (FAA) has established a number of rules in proximity of airport preventing the siting of any elevated constructions, which could obstruct the flight zone. This legislation is elaborated and extended and involves complex setback "volumes" (combination of spatial distances and elevations) from the airport, as well as from landing and take off pathways. The legislation varies according to the airport classification level, as well as for heliport.

In this study an exhaustive analysis of those restrictions was implemented in a interactive software, allowing to map all the exclusionary area in Rhode Island associated to a turbine specification (Tower height and blade radius). The complex methodology is part of the work proposed in a Master Thesis, Ocean Engineering, University of Rhode Island (O'Reilly, 2012). An example of the output is given in Figure 30.

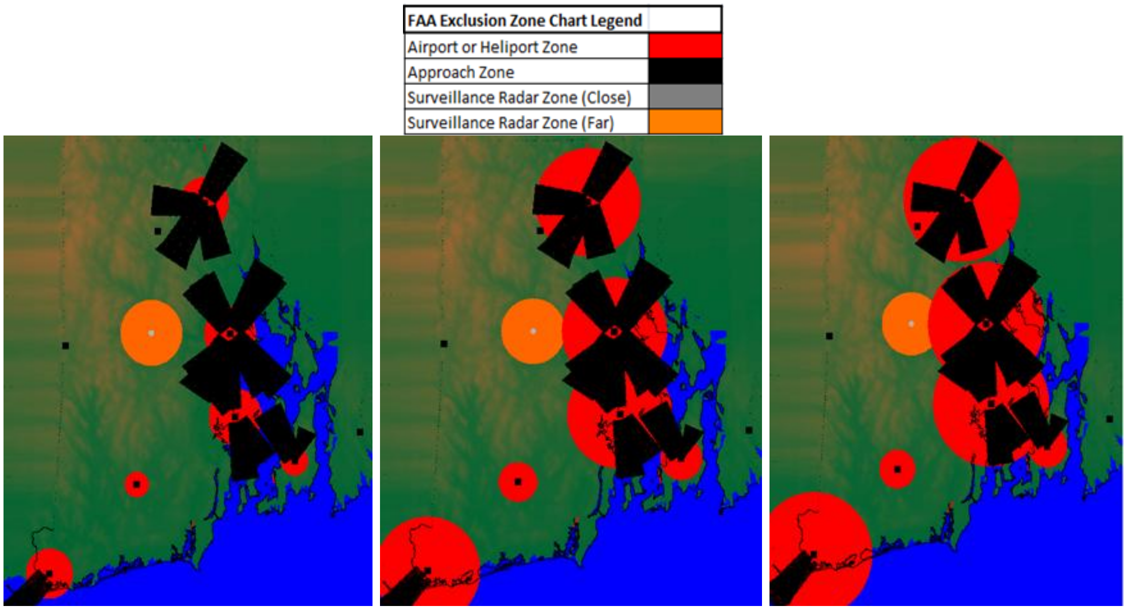


Figure 30. FAA restrictions by elevation, (left) 60 m, (center), 120 m, and (right) 150 m elevations. These correspond to turbines with hub heights of 30, 50, and 80 m, respectively.

Optimal Siting Area

Once the feasible area is defined one can find optimal area based on a balance between constraints and resources.

Towards such an optimization approach of resources and constraints, a constraint analysis was tentatively developed (within the budget and time frame constraints of this project) and is presented in the companion report: Siting of wind energy facilities in Rhode Island (Grilli et al., 2012).

4. SETBACKS FOR SITING OF WIND ENERGY FACILITIES

A literature review of the current setback distances from wind turbines established in North America and Europe, resulted in a large range of legal set back distances (100 to 1500 m), based on a variety of rules, associated to a similar variety of variables, most commonly turbine height or background noise (Oteri F. 2008 ; Whiteford J., 2008 ; Larwood S. and C.P. van dam, 2006).

In view of no clear unanimously accepted legislation in terms of setback distance, our analysis has separated the sources of risks and impacts driving the setback distances into three primary physical processes:

- The structural failure, blade and ice throw
- The Noise impact
- The flicker effect

Each of those three processes driving the setback is evaluated separately.

4.1. Structural failure, blade and ice throw

A literature review of setback distances based on structural failure, blade and ice throw risks has shown a large range of regulations and resulting associated setback distances; a common agreement however emerges from the recent literature proposing the use of a standard ballistic approach as a scientific basis to the regulation scheme. Canada and California have both provided an extensive report on the issue deploring the lack of scientific basis on the currently adopted setback distances in United States (Larwood S. and C.P. van dam, 2006; Whiteford J., 2008). California recommends the use of an explicit ballistic approach to define the probability of impact of a potential piece of blade such as the one developed by the Danish Riso laboratory. In the current project a protocol is suggested and implemented, which closely follows the methodology developed by Rogers et al. (2011), to estimate the optimal setback distance from a turbine.

The methodology is based on a ballistic model coupled with a probabilistic approach of the risk of a broken piece being thrown a certain distance from the turbine (Slegers N., et al., 2009).

It is shown that, when those extreme events occur, the probability of a portion of a blade falling in a certain radius from the turbine is mostly driven by the release velocity of the broken part and, therefore, by the angular velocity of the rotor, the size of the blade and the position of the breaking point on the blade.

Rogers et al. (2011) assume a wind climate characterized by a Weibull distribution defined by a 8.5 scale parameter and a shape parameter value of 2 (corresponding to 7.7 m/s mean wind speed value) as well as “normal” operations of the turbine. Although some accidents have occurred in the past when the rotor over-speeds, those critical conditions are not included in

Rogers et al. estimated setback distance because of their very low probability of occurrence, 5 10^{-6}, versus the probability of blade fragment release, 2.6 10^{-4} or an entire blade failure 8.4 10^{-4}.

The total risk or probability of a blade being thrown a distance, D, from a turbine (Eq. 21), P1, is represented as the product of the probability of the blade falling at a given distance from the turbine if a blade failure occurs (P3) and the probability of blade failure (P2).

$$P1 = P2*P3 \tag{21}$$

It is assumed that total acceptable risk, P1, is established by the regulator. It should also be noted that this value does not assess the probability of a person being struck by a blade, but instead the probability of the blade falling within a certain distance from the turbine. The probability of striking any moving object, as an individual driving or riding his bicycle, could subsequently be estimated and would be significantly lower. It should also be mentioned that by accepting the risk associated with this new source of energy, other risks related to the extraction/production of traditional forms of energy will be reduced.

Using the methodology developed in Rogers et al. (2011), examples of estimates of setback distance for three levels of accepted risk of fall outside the setback limit; two scenarios are presented: (1) the entire blade fails, is thrown and falls; (2) the tip of the blade fails, is released and falls. In the later case the blade is assumed to fail at 2 m from the tip of the blade. Failure at this location has the largest throw distance because it has the largest angular momentum.

The three levels of accepted risk ranked from 1 to 3, with 1 representing the most conservative scenario, and 3 the most risky: (1) one chance in a million (10^{-6}); (2) one chance in 20 000 (5 10^{-5}); (3) one chance in 10 000 (10^{-4}) were evaluated. To illustrate the meaning of risk associated with these probabilities, one can set these numbers in a scale of involuntary risk of dying: the risk associated with Scenario 2 is similar to the risk of dying in a car accident; the risk of dying by lightning is 10^{-7} (Wilson and Crouch 1982). An interesting reflection on the concept of risk can be found in Wilson (1979).

The risk of blade failure is defined for two types of failure: failure of the entire blade, or release of a blade fragment. Those probabilities have been estimated in previous studies based on observed turbine failure to be 8.4 10^{-4}, for the entire blade and 2.6 10^{-4}, for a blade fragment (Radermakers and Braam, 2005).

The probability of an entire blade failing is therefore on the order of 3 times greater than the probability of a blade fragment being released. The ballistic theory predicts that when an entire blade fails, it is projected to a shorter distance from the tower than when the tip of the blade breaks. However, since the frequency of occurrences of the entire blade failure is larger than the frequency of blade fragment being released, one can expect that the safety distance associated with the entire blade failure increasing to a larger safety radius than expected if those type accidents would occur with an identical probability to blade fragment failure. The safety radius associated with the entire blade failure is therefore getting closer to the larger safety radius associated with the far flying tip of blades .

Calculations were performed for two generic turbine characteristics defined in Table 5. Results of the two scenarios for the two generic turbines are given in Table 6 for the three levels of accepted risk. There were selected because their size matches those likely to be installed in RI and because they show the impact of higher rotation rates for the smaller turbine.

Table 5. Turbine Characteristics of two generic turbines used in the setback failure examples.

	Turbine #1 660 KW	Turbine #2 1.5 MW
Rotor Height (m)	50	80
Blade Radius (m)	23.5	35
Angular velocity (rad. /sec)	2.98	2.3

Table 6. Set back distance based on an accepted risk of fall beyond that distance for two generic turbines (Table 5) and three potential choices of accepted risk.

Set back distance (m) based on an accepted risk of fall beyond that distance			
Type of failure	*Most conservative Risk 1: 10^{-6}*	*Medium risk Risk 2: $5\ 10^{-5}$*	*Least conservative Risk 3: 10^{-4}*
Turbine #1 660 kW			
Entire blade	438	412	386
Tip of the blade	561	455	347
Turbine #2 1.5 MW			
Entire blade	507	477	447
Tip of the blade	655	531	404

4.2. Noise and Flicker

Setback distances should be driven by noise and flicker impacts, besides the probability of being in a probable impact area, in case of failure or blade and ice thrown. Noise and flicker setbacks are discussed in details in Potty (2012). An interactive tool is provided on the GIS where the user can visualize on a map the noise area of influence as well as flicker sensitive areas if a specific turbine would be installed at any location (Section 5). Table 7 and 8 summarizes the accepted threshold for three scenarios, for noise and flicker recommended setback respectively. For example, one can imagine that we would adopt the most conservative scenario in terms of noise impact in a residential area and we could be less conservative in an industrial area and we discuss the general best practice recommendation in the following.

Recommendation for noise setbacks

After extensive review of literature (Potty, 2012) it is recommended that the following guidelines be used. They can be customized for each community based on the site specific conditions such as land use (residential, commercial, industrial), density of population (urban or rural), and community acceptance. The guidelines are specified as least conservative, average, or most conservative. Upper, mid, and lower bounds have been suggested to allow communities a range of options to meet their individual needs.

Table 7. RESP Noise Guidelines.

Least Conservative	Average	Most Conservative
Not more than 5 dB **above ambient noise	Not more than 3 dB above ambient noise	Not more than 1 dB above ambient noise
Based on daytime equivalent ambient noise in vicinity of turbine	Based on day-night average ambient noise in vicinity of turbine	Based on night time equivalent ambient noise in vicinity of turbine

"Vicinity of turbine" implies the closest point of interest such as a residential building, school, commercial or industrial building. Thus these guidelines specify the location of the wind turbine which will introduce a noise level according to one of the above suggested levels at the nearest receive location such as residential building, school, commercial or industrial building

There are different ways to measure the background noise levels. One common background noise descriptor, recommended by ISO 1996/1, is LAeq,T, the equivalent continuous dB(A) level which has the same energy as the original fluctuating noise for the same given period of time T. LAeq,T is an excellent criterion for studying long-term trends in ambient noise. However, it does not convey any measure of environmental noise variations which is also an important factor when considering human response. To overcome this ISO 1996/1 recommends measuring percentile levels, LAN,T, i.e. that dB(A) level which is exceeded for N% of a stated time period T. Percentile levels reveal maximum and minimum noise levels. They are used in baseline studies and in environmental impact statements to protect against new highways and new industrial plants degrading the acoustic quality of the environment. It is suggested that the A-weighted sound pressure level of the residual noise at the assessment position that is exceeded for 90 per cent of a given time interval, T. (LA90, T) as a measure of the ambient noise level.

No recommendation is provided regarding low frequency and infrasound noise or tonals. Research in this area is still ongoing and yet to result in any adoptable criteria. It is suggested that in the event of any complaints of low frequency or infrasound noise or tonals a detailed investigation be conducted and appropriate remedial steps be taken.

Recommendation for shadow flicker setback

After extensive review of literature (Potty, 2012) it is recommended that the following guidelines be used by each community to set their own regulations based on the site specific conditions such as land use (residential, commercial, industrial), density of population (urban or rural) and community acceptance. The guidelines are specified as least conservative, average, or most conservative. As seen in Table 8, most of codes specify a limit of 30 hours per year as the maximum limit for the shadow flicker incidence. It is recommended that 30 hours be the least conservative limit per year. On the other hand, the most conservative criterion suggests no impacts on any residence or business in the area of interest. Considering the fact the calculations (which assumes most favorable conditions for flicker, such as no cloudy days, turbine always facing the receiver, turbine always turning, and no barriers) will always estimate at least a minimum amount of shadow flicker occurrence (since dilution of the shadow with distance is not taken into account) a limit hours of shadow incidence per year.

Table 8. Recommendations for shadow flicker (hours per year).

Least conservative	Average	Most conservative
Duration of flicker- 30 hours per year	Duration of flicker - 20 hours per year	Duration of flicker 3 hours per year
		No impacts on any residence or business in area

Recommendation for signal interference setback

No setback distances are generally provided to counter signal interferences. Many regulations require interference to considered and minimized. For example regulations:

Henry County, Illinois (Oteri, 2008) specifies that:

> *the owner of a wind energy system must take such reasonable steps as are necessary to prevent, eliminate, or mitigate any interference with cellular, radio, or television signals caused by the wind energy system.*

Huron County, Michigan requires that:

> *no large-scale WECS shall be installed in any location where its proximity with existing fixed broadcast, retransmission, or reception antennas for radio, television, or wireless phone or other personal communication system would produce electromagnetic interference with signal transmission or reception. No large-scale WECS shall be installed in any location along the major axis of an existing microwave*

> *communications link where its operation is likely to produce electromagnetic interference in the links operation.*

Fillmore County, Minnesota stipulates that:

> *the applicant shall minimize or mitigate interference with electromagnetic communications, such as radio, telephone, microwaves, or television signals caused by WECS. The applicant shall notify all communication tower operators within 2 miles of the proposed WECS location upon application to the county for permits. No WECS shall be constructed as to interfere with County or Minnesota Department of Transportation microwave transmissions.*

No specific recommendation for specific setback distances with regards to signal interference is proposed. It is suggested that the wind turbine not interfere with signal transmission or reception of existing fixed broadcast, retransmission, or reception antennas for radio, television, or wireless phone or other personal communication system. Also care should be taken not to place a turbine along the major axis of an existing microwave communications link where its operation is likely to produce electromagnetic interference in the links operation. It is suggested that a check for all communication towers within 2 miles of the wind turbine for any interference with their operation be made.

5. WEB BASED ACCESS TO WIND RESOURCE, CONSTRAINTS AND SETBACK SITING TOOLS

Many of the results of the analysis are currently accessible though a web site:

http://www.RIenergy.org

The web site provides three types of information: maps, siting tools, and a query tool.

Rhode Island Maps

Rhode Island Wind resource and wind expected power mapped on a 100 m grid is available on the GIS: Landscape and ecosystem services constraints are mapped on a 30 m grid; synthetic maps are mapped on a 100 m grid. In summary 5 types of maps are available:

Rhode Island Landscape
Rhode Island Wind Resource
Rhode Island Wind Technical Power
Rhode Island Ecosystem Services Constraints
Rhode Island Synthetic Maps

A siting tool providing specific information at any grid point

The user can select any geographical point and query the area for information. The software provides at any geographical point wind resource information the 100 m grid and constraints information the 30 m grid. Each of the listed concept follows closely their description in the previous sections of this report.

Wind resource

- Mean Wind speed
- Weibul distribution
- Vertical Profile
- Theoretical mean power
- Expected uncertainty

Technical expected power

- Technical mean power
- Capacity factor

Feasible area (hard constraints)

- FAA set back constraints
  Structural failure and ice throw setback distance
- Noise setback distance
- Flicker setback distance

Ecosystem Services Constraints

- Number of ecological and social constraints
- List of the ecological and social constraints

A query tool at measurement stations providing directional and seasonal information

At each selected measurement station the query tool provides, in addition to the standard outputs, wind directional information as well as seasonal information, specifically

Wind rose

Wind power roses

Seasonal time series

The specific siting software were designed and developed at the University of Rhode Island, Ocean Engineering and the user interactive interface was implemented by a consulting company, RPS-Applied Science Associates (RPS-ASA).

6. CONCLUSION

The present analysis has provided a statewide resource assessment for Rhode Island on a fine spatial resolution (100 m to 30 m). Resources are presented in terms of mean expected theoretical power, as well as mean technical power in order to provide an assessment of the truly extractable power. A geography of Rhode Island wind resources (continental RI; offshore area have been evaluated in the context of the SAMP project, SAMP 2008) identifies the coastal area and state's highest elevations area, as the most promising in terms of theoretical resource, with mean wind speed of the order of 5.5 to 6.5 m/s at 50 meters height (popular hub height for a 750 kW turbine) in high elevations and along the coastline respectively; this corresponds to 6 to 7 m/s at 80 meters height (popular hub height for a 1.5 MW turbine) at the corresponding locations; few of hot-spots reach 7.5 to 8 m/s at 80 meters height, such as Point Judith or Tiverton. However, the ability of a wind turbine to extract the wind power is such that the contrast between high and low wind resource area does not appear as pronounced once one maps the extractable power (technical power), versus the theoretical power. Maximum extractable power values (technical power) ranges between 100 W/m2 to 200 W/m2 , versus, 200 to 500 W/m2 for available theoretical power, across Rhode Island. Maximal technical power resource still remains in coastal areas benefiting from summer sea-breezes and the low surface roughness. Highest elevations are a secondary good choice, and in third position are the low roughness areas, mostly water surface (however, very low practical interest).

The mean power estimations were evaluated from AWS Truewind simulated wind speeds. Comparison of the AWS estimations with the currently available wind speed data (8 stations) showed a slight mean under-prediction of the simulated wind speeds (as reported by AWS Truewind), translating into a mean underestimation of the order of 3.5 to 8 % on average of the theoretical power at anemometer level (between 8 and 30 m). The 95 % confidence interval varies between values of an order of +25 to -35 %. This means that at a given location, one have the highest probability underestimating the mean wind speed, by an order of 5%, however one have 95% of chance to be between +25 to -35 % (overestimate by 25% or underestimate it by 35 %), with those extreme values having the least probability of occurrence. Note that this large confidence interval is the expected consequence of the small number of wind stations used in the analysis (and does not reflect a poor agreement).

The vertical profile could not be validated against measurement at this stage because of a lack of vertical profile data at the time of this report publication. This step should be accomplished in the near future once data at the new observation stations will be available. This is discussed in the companion report (Merrill and Knorr, 2012). A comparison of the two vertical profile formulations, power-law and log-law, results in a very small variance in expected wind power at 30 meters height. Differences are < 4% in most parts of the state, reaching a maximum of 6 to 9% in forested sheltered area and inland water surface.

The constraint analysis compiles a large database of potential constraints, social and ecological such as restricted area resulting of compliance to FAA rules, population density, ecological diversity, background noise. A preliminary constraint analysis is presented in the companion report “Siting of Wind Energy Facilities in Rhode Island”, by the same authors.

A careful “setback” review and analysis was performed and resulted in proposing an alternative approach for setbacks. The structural/blade failure setback should be evaluated as a function of the potential released velocity of a blade fragment (which depend on the angular velocity of the blades and their length) and the accepted risk one is willing to accept that a piece of blade could be thrown in a given area. The noise setback should be based on a threshold above the ambient noise, which could vary between 1 to 5 db according to the absolute value of this background noise or to specific social considerations (proximity of an hospital or retirement home). This analysis provides a map of ambient noise, locating the critical quiet area. Detailed reports for the noise and flickers setback are provided (Potty and Miller, 2012; Potty, 2012)

A GIS and a fully interactive siting tool is developed and should help developers, municipal officials, and interested citizens to perform initial screening of sites quickly and efficiently. It will also serve to highlight any critical constraints early in the siting process.

7. REFERENCES

Bailey, B., and J. Freedman, 2008: A regional assessment of the U.S. offshore wind energy resource through the use of mesoscale modeling. *Marine Tech. Soc. J.*, **42**, 8-18.

Brower, M., 2007. Wind resource maps of Southern New England, prepared by True Wind Solutions, LLC, 10 p

Charnock, H., 1955: Wind stress on a water surface. *Q. J. Roy. Meteor. Soc***. 81**, 639-640.

da Rosa, A.V., 2009: *Fundamentals of renewable energy processes*. Elsevier. 844 pp.

Dinman, B.D. , 1980. The reality and acceptance of risk. Journal of the American Medical Association, 244-11.

Garvine, R.W., and W. Kempton, 2008: Assessing the wind field over the continental shelf as a resource for electric power. *J. Mar. Res*. **66**, 751-773.

Hennessey, J. P., 1977: Some aspects of wind power statistics. *J. Appl. Meteor.*, **16**, 119–128.

Larwood, S. and C.P. van dam, 2006. Permitting setback requirements for wind turbines in California. Pier Interim Project Report, prepared for California Energy Commission by California Wind Energy Collaborative.

Morgan, E. C., M. Lackner, R.M. Vogel, and L.G. Baise, 2010: Probability distribution of offshore wind speeds. *Energy Convers. Manage*., **52**, 15-26.

McLeod, K., and Leslie, H. , 2009. "Why ecosystem-based management ?" In: *Ecosystem-Based Management for the Oceans*, pp. 3-6 McLeod, K., and Leslie, H., (eds.), Island Press, Washington, DC.

O"Reilly, C. , 2012. Integration of wind farm macro and micro-siting optimization. Master thesis in preparation. Department of Ocean Engineering. University of Rhode Island.

Oteri, F. 2008. An overview of existing wind energy ordinances. Technical Report. National Renewable Energy Laboratory, Golden Colorado.

Oumeraci, H., Jensen, J., Gönnert, G., Pasche, E., Kortenhaus, A., Naulin, M., Wahl, T., Thumm, S., Ujeyl, G., Gershovich, I., and A. Burzel, 2009. Flood risk analysis for a megacity: The German XtremRisK project, *Proc. Conference on Road Map towards a Flood Resilient Urban Environment*, Paris, France, 8 p.

Radermakers, L. and H. Braam, 2005. Analysis of risk-involved incidents of wind turbines. In *Guide for risk- based zoning of wind turbines*. Energy Research Center of the Netherlands.

Rinne, H. , 2009 . The Weibull distribution. *A handbook. CRC Press, Chapman andHall. PP. 784.* Boca Raton, Fl.: CRC Press, Chapman & Hall.

Rogers, J. , Slegers N. and M. Costello, 2011. A method for defining wind turbine setback standards. *Wind Energy*.

SAMP, 2008. http://seagrant.gso.uri.edu/oceansamp/documents.html

Spruce, J., Berglund, J., and B. Davis. 2004. Developing Coastal roughness map using ASTER and Quickbird data sources. NASA. Presentation at Workshop High Spatial Resolution Commercial Imagery Workshop. Virginia , 2004.

Sedeflan, L. 1980. On the vertical extrapolation of mean wind power density. *Journal of Applied Meteorology*, 1980: 488-493.

Slegers, N., Rogers, J., Costello, M., Puga, M. and P. Arons , 2009. Modeling the risk of a failed wind turbine blade impacting a power transmission line. Wind Engineering, 33-6,587-606.

USGS. National Elevation Dataset.

USGS . National Land Cover Dataset derived from Landsat imagery.

Wilson, R. and Crouch, E., 1982. Risk/Benefit analysis, Cambridge, Ballinger.

Wilson. ,R., 1979. Analyzing the daily risks of life. Technology Review, 81.

Wind-Watch.org

Whiteford J., 2008. Model wind turbine provisions and best practices for New Brunswick municipalities, rural communities and unincorporated areas. Report prepared for the Department of Energy, New Brunswick, Canada.

Zuur, A.F., Ieno, E.N., Smith, G.M. , 2007. “Analyzing Ecological Data”, Springer, NY.

RESP TECHNICAL REPORT #4

WIND RESOURCE ASSESSMENT

By

John Merrill and Kelly Knorr

University of Rhode Island,

Narragansett Bay Campus

June, 2012

Table of Contents

List of Figures

List of Tables

Background and Introduction

An objective of the Renewable Energy Siting Partnership, sponsored by the Rhode Island Office of Energy Resources with funds from the US Department of Energy, is to provide access to wind observations at sites in Rhode Island. We participated in the compilation of available wind data and in their analysis, and have assisted in making the data readily available. In this Report we focus on vertically-resolved wind data collected at onshore sites in Rhode Island over the last decade. We enumerate the sites where tower or profiler data have been acquired. We discuss in some detail, for some but not all sites, the annual variation of the wind, the observed vertical shear and its annual variation. Finally, we make a brief comparison of the observed wind profiles and results of model simulations of the distribution of wind speeds with height.

1. PROFILE SITE LOCATIONS AND CHARACTERISTICS

Near-surface wind observations are commonly available at only a single level; at these sites a single anemometer provides wind data at one height, typically in the range of 3 -10 meters, but in some cases higher above the surface. In this report we focus instead on sites with tower-mounted anemometers, and at one site an acoustic wind profiler, providing wind estimates at multiple vertical levels. All of the wind data outlined here are time resolved, event-specific, instrumental data.

Table 1. Location of tower and SODAR wind profile observations.

Source	Site	Period	Notes
NBC	Fields Point, Providence	200703-200711 200801-200903	20-30-40 m 30-P42-P49 m
URI	West Kingston	200710-200807	30-40-50 m
DEM	Camp Cronin/Narragansett	200911-201102	30-40-50 m
Northeast Engineers	Newport/Easton Pond	200903-200907	P27-P35 m
Northeast Engineers	Portsmouth/Quaker Hill	200910-201010	P27-P35 m
Naval Station	Newport	200908-201108	24-P40-47.5-P58 m
Naval Station	Newport, Tank farm 4	201003-201104	25-P40-50-P58 m
Charlestown	Ninigret Park	201103-201201	P30-P40-P50 m
Jamestown	Taylor Point	201105-201112	40-60 ··· 200 m

The data sets available for this analysis are summarized in Table 1. A graphical summary of the sites and periods of observation is shown in Fig. 1. The observed data and all of the results discussed here are to be made available on the Web-based Renewable Energy Siting Tool. The underlying data are in a variety of formats because a number of different data logging systems were used. The data in the archive will be in a common format.

In Table 1 the period of observation is indicated by the year and month beginning and ending the data set. These are relatively short-term data sets, in some cases less than a year in duration. The levels at which wind observations were made is indicated in the Notes column; heights are in meters above ground level, and paired anemometers at a given level are indicated by the P designation. In only a few cases are wind data aloft accompanied by temperature or static stability (temperature gradient) estimates, and these data are not used here.

The data from two periods of observation at the Fields Point site were provided by the Narragansett Bay Commission. Different towers and instrumentation were utilized, and here we limit the analysis to the second, longer period when a taller tower was used. The wind measurements at the Camp Cronin site were acquired from the RI Department of Environmental Management (DEM). Of the two sites where measurements were made for the Naval Station,

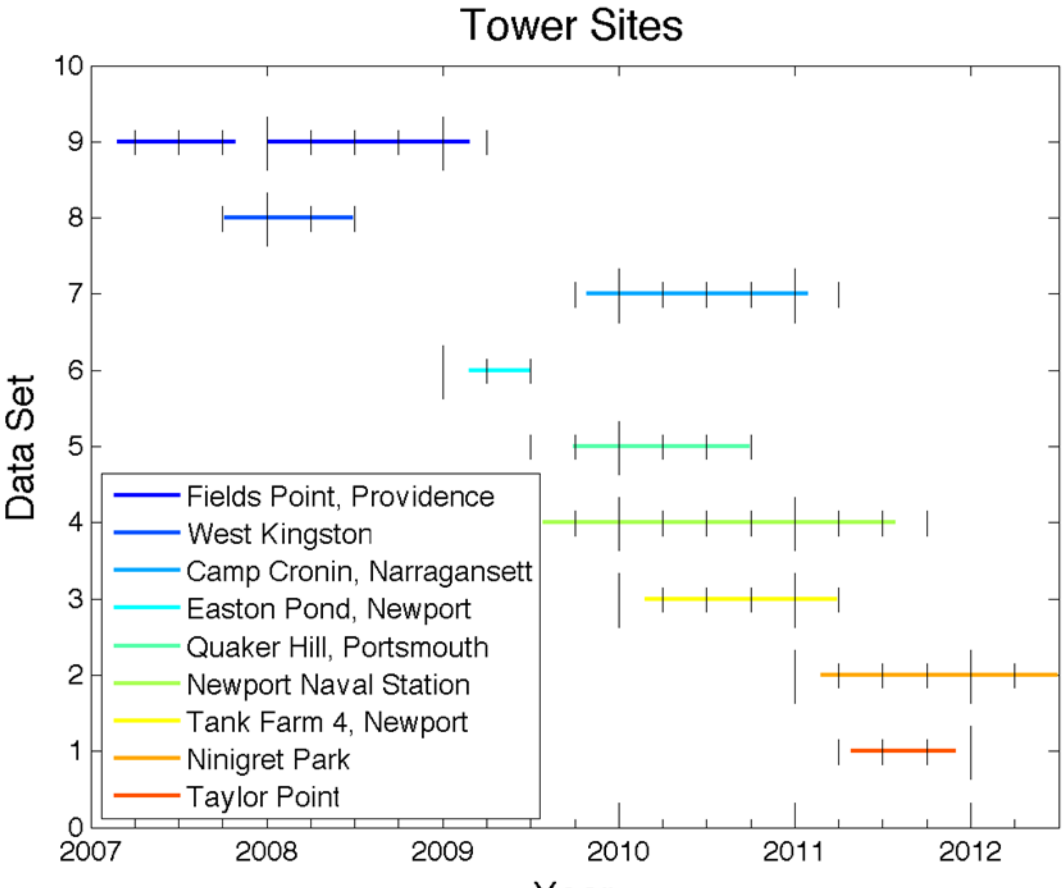


Figure 1. Sites vs. time periods where wind profile observations are available.

Newport, we here analyze data from the first site, near Coddington Cove, where a longer period of data is available. An acoustic profiling SODAR system has been used to obtain wind profile data at a site at Taylor Point for the Town of Jamestown, and we include an analysis of these data here. (Data collection has continued, but our analysis is based on a limited time period; the analysis will be extended to include additional months of data.) In this report we do not make use of the data from the other sites listed in the Table, because of the brevity of the record, the modest height of the tower or other limitation.

The vertical profiles of the wind speed, averaged over the period of observation are shown in Figures 2 and 3. The profile at the Fields site indicates that the winds are somewhat weaker there, while at the Camp Cronin site the winds are somewhat stronger than at the other sites. The latter is to be expected, given the Atlantic Ocean exposure of the Camp Cronin site and its proximity to the shoreline. The Naval Station and Taylor Point sites have intermediate wind speeds. The Naval Station profile indicates a strong gradient in the wind speed near the surface, but the least rapid variation of speed with height above 20 m, as discussed below in the section on wind shear. At the Taylor Point site the observations extend well above the 100 m range shown, although the percentage of time when accurate estimates were obtained decreases with height. The fitted curves reflect the entire observed profile.

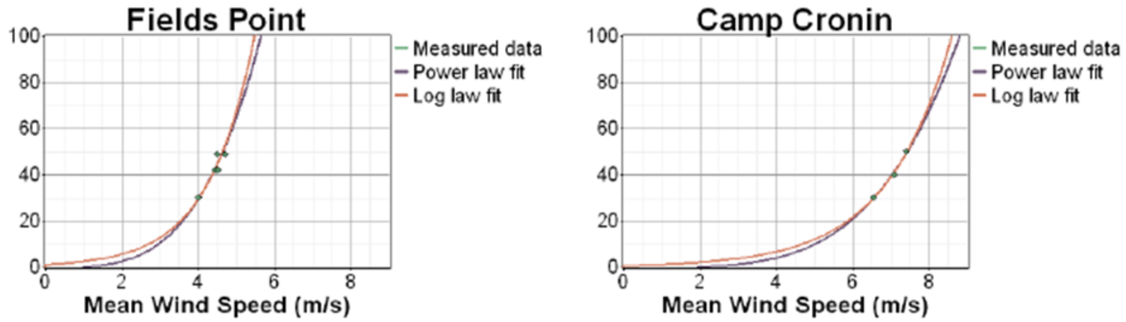


Figure 2. Vertical profiles of wind speed at the Fields Point and Camp Cronin tower sites, averaged over the period of record. The green diamond indicates the average speed at each level, and the curves indicate the variation following the log profile and power law distribution.

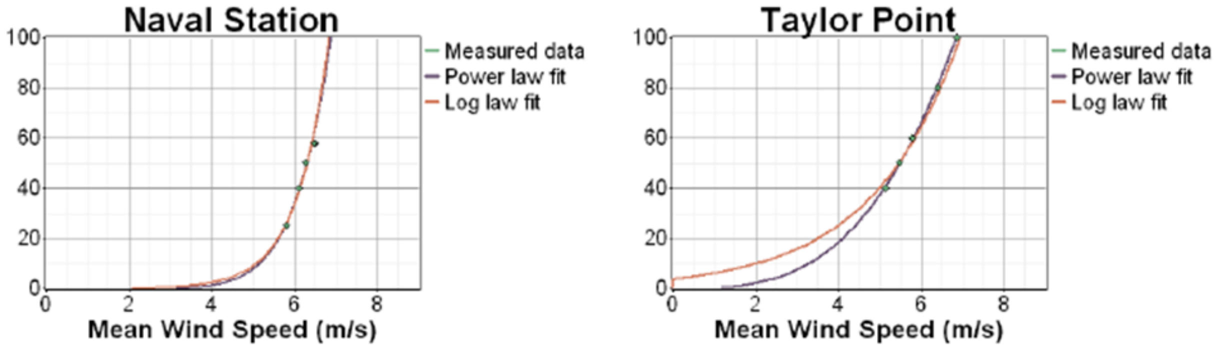


Figure 3. Vertical profiles of wind speed at the Naval Station and Taylor Point sites, averaged over the period of record. Symbols as in Fig. 2.

The fitted curves in these and other figures indicate the variation according to the logarithmic and power law profiles, which are analytical representations of the variation of the speed with height used to represent average conditions. The log wind profile can accurately represent the vertical variation of the wind in the turbulent lowest layers of the atmosphere, below about 30 m. A clear discussion of the log law in the context of the mixing length approach to modeling the surface layer is in Holton (2004), section 5.3.5. The log law can be formulated to account for the effects of static stability and instability using the Monin-Obukhow similarity theory (e.g. Businger, 1973). Here the emphasis is on the power law, which applies over a greater height range and which is commonly used to give an overall characterization of average conditions in wind resource assessment. In this approach the average wind speed U at height z_2 is given by

$$U(z_2) = U(z_1)(z_2/z_1)^{\alpha}$$

where α, a nondimensional number, is designated the **shear coefficient** (e.g. Touma, 1977; Peterson and Hennessey, 1978), and $U(z_1)$ is the speed at height z_1. In neutral static stability conditions, corresponding to a well-mixed atmospheric boundary layer, the value of α is close to $1/7 \cong 0.143$. There are a number of reasons why this theoretical value is not observed to apply very often. Well-mixed conditions are common in strong wind situations and are frequently observed in the marine environment, but profiles at specific times typically deviate from this form owing to variations in the stability of the boundary layer, which is modulated or can be controlled by the synoptic-scale meteorological variability. In inland areas conditions alternate between statically stable (nighttime) and convectively unstable (daytime) stratification, with near-neutral conditions during transitions, which are common near dawn and dusk. Vertical shear is greater in stably stratified conditions and weaker in convectively mixed situations. In coastal areas the effects of stratification are greater during persistent offshore flow situations and reduced during sustained onshore flow.

The fitting process yields an estimate of α and also a measure of the goodness of fit. The latter provides little additional information here because of the short period over which data are available. The use of the power law formulation with α assumed constant above the range of observation is an approximation, but one whose use is necessitated by the substantial cost of increasing the height of the tower or otherwise extending the range of measurements.

2. ANNUAL VARIATION OF WIND

The annual variation of the vertically-resolved wind speed, averaged over the period of observation is shown in Figures 4 and 5. As expected, the common pattern is of somewhat weaker winds during the warmer months, especially the summer, with the strongest winds in the spring and fall and intermediate speeds during the winter. The strongest winds are observed in March in these relatively short records. There is a larger variation through the year at the Camp Cronin and at the Naval Station sites that at other sites with weaker winds during April – September. A much smaller variation is observed at Fields Point, in an overall weaker wind environment as noted above. The apparently unusual variation in the spring time at the Taylor Point site should be discounted. The stronger than expected winds in the month of May are likely an artifact of inadequate statistics; there is less than half a month of data available then, as the observations started on the 17th of the month.

The very limited time interval over which these observations extend puts significant constraints on the representativeness of the results. It is well established that the uncertainties in

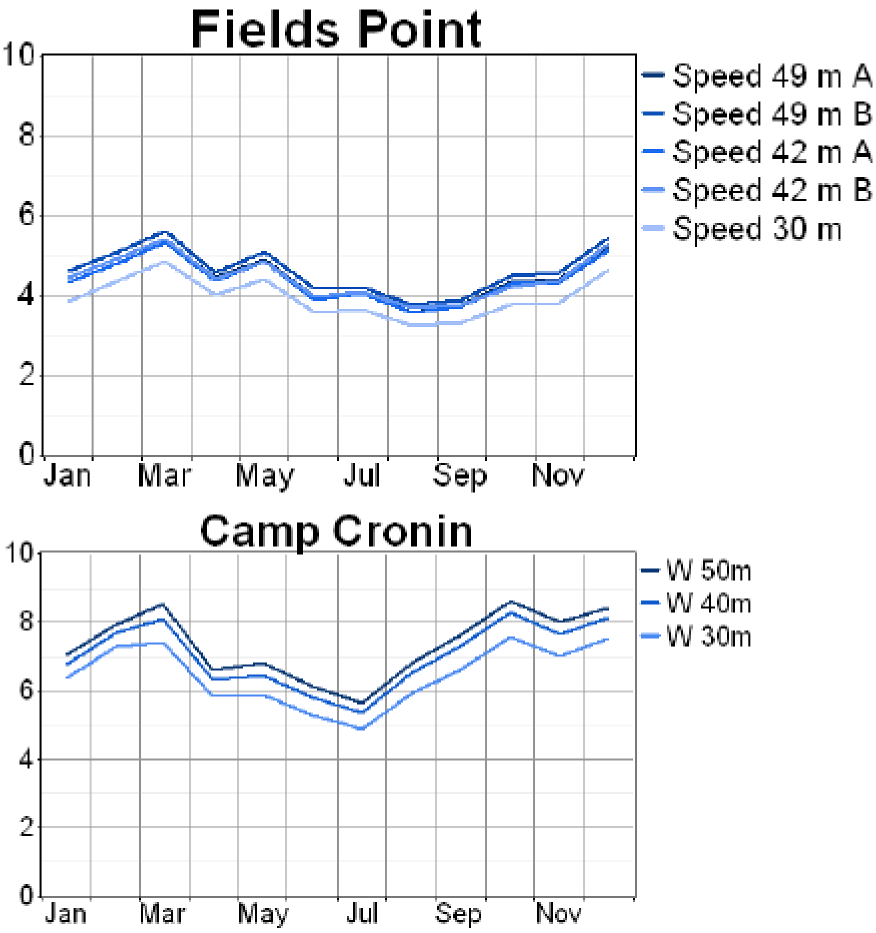


Figure 4. Annual variation of the vertically-resolved wind speed at the Fields Point and Camp Cronin sites, averages over the period of record. At the Fields Point site, the data from the paired anemometers are displayed separately, and at Camp Cronin, the speed from a single anemometer at each level is shown.

resource assessments depend, in part, on the length of available data records. This and related factors are discussed elsewhere in this series of reports (e.g. Grilli and O’Reilly, 2012). We note that analysis of longer-term near surface wind observations at a few sites has led to the hypothesis that there are temporal trends in the wind speed. For example, Pilson (2008) examined a graph of the monthly-mean wind speed at T.F. Green Airport, in Warwick, RI from 1964 to 2004, showing an apparently significant downward trend in the speed, especially after 1990. However, examination of the record at more than a single station is needed, as is examination of ancillary factors such as changes in prevailing wind direction and thus in the upwind terrain, or changes in the local conditions such as the surrounding vegetation or the built environment could introduce apparent trends unrelated to the wind field itself. There are, to date, no published studies establishing significant trends in wind speeds.

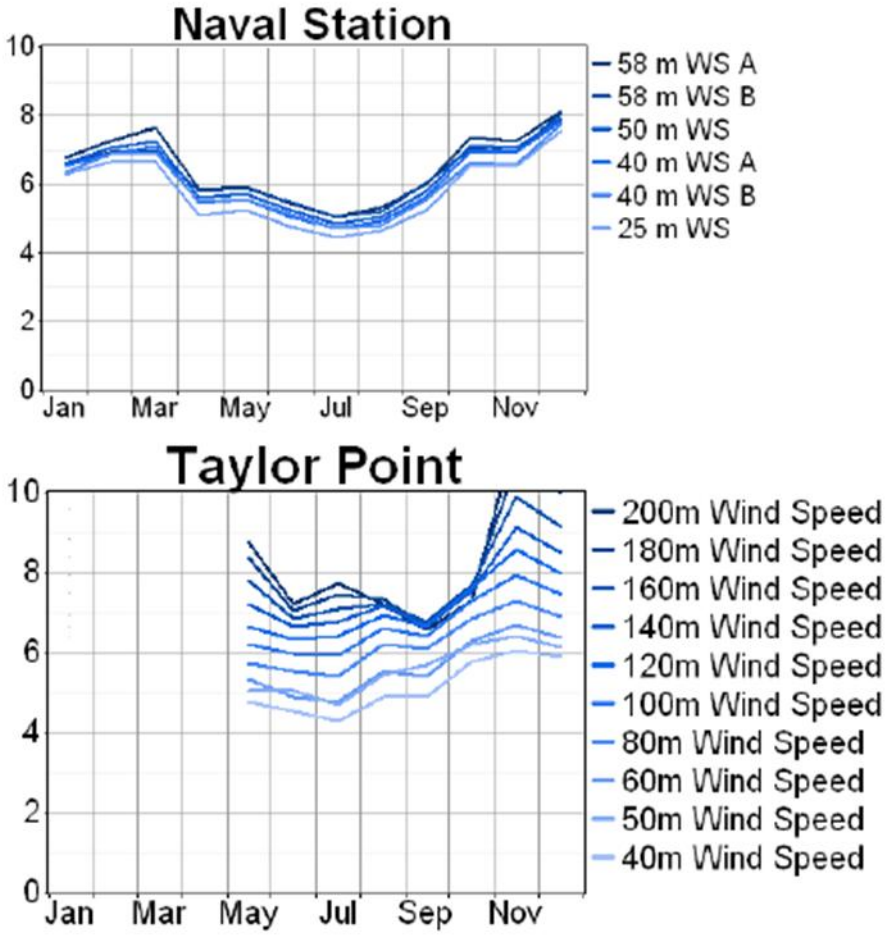


Figure 5. Annual variation of the vertically-resolves wind speed at the Naval Station and Taylor Point sites, averaged over the period of record.

3. DIEL VARIATION OF WIND SPEED

The variation with hour of the day in the observed wind speed at four sites is shown in Fig. 6 and 7. The anticipated behavior is observed at three of the four sites: winds freshening during the late afternoon hours as onshore flow in the sea breeze/land breeze cycle typically augments the prevailing winds from the southwesterly direction. At the Camp Cronin and Naval Station sites the variation with hour of the day is very small. In contrast, the variation is greatest at the Fields Point site, with about twice the change in wind speed between the minimum and maximum values of that observed at Camp Cronin and the Naval Station. This is consistent with the expectation that the variation caused by the sea breeze/land breeze cycle would gradually increase from the Atlantic shoreline toward inland areas. It may be surprising that this analysis seems to apply, as winds from the northwest are almost as common as are winds from the southwest at these sites. There does not appear to be a change, in the mean, of the vertical shear of the wind with the hour of the day at the Fields Point or Camp Cronin sites. At the Naval Station site there is a noticeable decrease in the vertical shear below the 40 m level in the mid-day hours, but it is not known whether this is significant. It is also not clear whether the strongly-varying vertical shear observed at the Taylor Point site relates to sheltering of the winds by the island or some other factor, or indeed whether the variation in the shear shown here is fully representative, largely because of the shortness of the data interval.

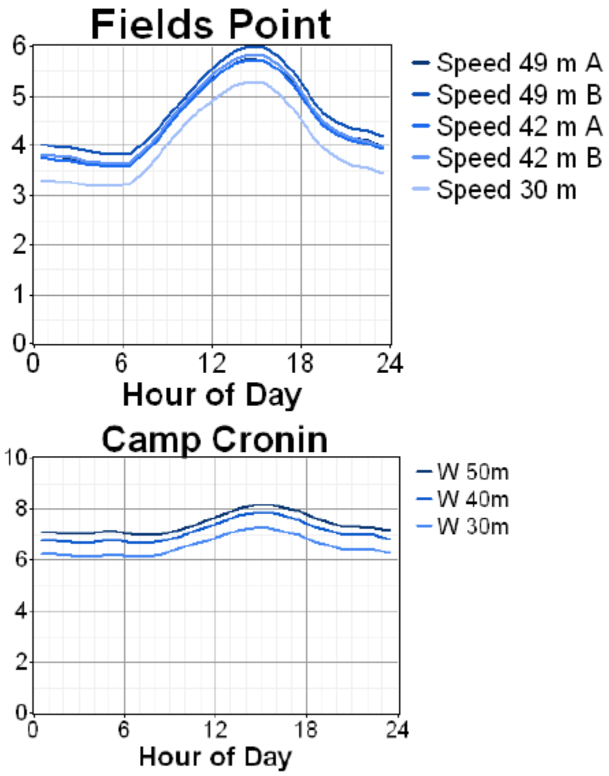


Figure 6. Diel variation at the Fields Point and Camp Cronin tower sites, averaged over the point of record.

4. ANNUAL VARIATION OF SHEAR

The annual variation in the power law exponent or shear coefficient, α, at four sites is shown in Fig. 8 and 9. Acquiring an accurate and representative estimate of α is a primary goal of wind profile observation, as the power law profile is used in extrapolating estimates of wind speed and available wind energy resources to heights above the range of observation. At the Fields Point site the value of α changes very little through the year. Neither the minimum, which is close to 0.25, nor the maximum of 0.34 differ very substantially from the annual mean value of 0.28. At the Camp Cronin and Taylor Point sites the variation in α is significantly greater. At Camp Cronin the value of α is between 0.24 and 0.30 during the months from March to November, but falls below 0.20 during the coldest months of the year. At Taylor Point the values of α are generally higher, with values above 0.30 except in August, September and October. The α values at the Naval Station site are generally lower than at the other sites, with the values in all but two months below 0.15, and an average value of 0.125. This is consistent with the weaker vertical gradient in the wind at this site, noted in Section 1. Obstructions to wind flow, such as nearby trees and buildings, cause the formation of an internal boundary layer with reduced wind speeds near the ground. This can be accounted for with the introduction of an offset or displacement height in the profile analysis. Such an analysis can improve wind resource estimates, but because of limitations in the available data record we did not include this in our analysis.

5. COMPARISON OF OBSERVED WIND CHARACTERISTICS WITH MODEL RESULTS

A limited comparison with the model-based analysis reported by Grilli and O'Reilly (2012) is possible. In their work shear coefficients and wind distribution parameters estimated from multi-year simulations of near surface meteorological fields are examined in the context of siting considerations for wind energy systems in Rhode Island. The distribution parameters used are the shape and scale factors, k and c, for a Weibull distribution of wind speeds, available on a state-wide spatial grid at the 30 m level. Because the model-based estimates of the shape factor, k, vary little from site to site, ranging only from 2.19 to 2.33, the emphasis here is on the scale factor, c, which is in ms^{-1}. At the Fields Point site their estimate for α is 0.13, while the best-fit value for the observations analyzed here is about 0.28. The Weibull c value in the model results is 5.96 m s^{-1}, substantially higher than the profile-based estimate of 4.50 m s^{-1}. At the Camp Cronin site, their results give an α value of 0.21, while the observations are best fit with a value of 0.25. The Weibull scale factor 7.05 m s^{-1} in the model-based analysis and the profile-based estimate of 7.39 m s^{-1} agree quite well. At the Naval Station site the model results indicate that α is close to 0.21; the observations analyzed here yield an α of 0.125 at a height of 25 m. The Weibull scale factor 6.31 m s^{-1} in the model-based analysis at the Naval Station site and the profile-based estimate of 6.31 m s^{-1} are identical, but the profile estimate is for a 25 m height, lower than the 30 m level used in the model calculations. Finally, at the Taylor Point site the model simulations yield α of 0.17, while the limited profile data used here are best fit with an α of 0.32. The corresponding Weibull scale factor estimates are 6.5 m s^{-1} from the model-based analysis, and 5.96 m s^{-1} at the 40 m level based on the wind profiles analyzed here.

As noted earlier, the limited duration of the wind profile observations available for analysis here presents a significant challenge, limiting our certainty in the representativeness of the results. Only additional data can overcome this challenge, and efforts are underway to acquire such data.

6. REFERENCES

Businger, J. A., 1973, Turbulent transfer in the atmospheric surface layer, *Workshop on Micrometeorology*, pp 67-100, Haugen, D. A., (Ed.), Amer. Meteor. Soc.

Grilli, A. and C. O'Reilly, 2012, Siting of wind energy facilities in Rhode Island, Technical Report, Renewable Energy Siting Partnership, Narragansett, Rhode Island.

Holton, J. R., 2004, *An Introduction to Dynamic Meteorology*, Elsevier Academic Press.

Peterson, E. W. and J. P. Hennessey, Jr., 1978, On the use of power laws for estimates of wind power potential, *J. Appl. Meteor*., 17, 390-394.

Pilson, M.E.Q. 2008. Narragansett Bay amidst a globally changing climate. In: *Science for Ecosystem-Based Management: Narragansett Bay in the 21st Century*, pp. 35-46. Desbonnet, A., and Costa-Pierce, B.A., (Eds.), Springer Publishing, New York.

Touma, J. S., 1977, Dependence of the wind profile power law on stability for various locations, *J. Air Pollut. Control Assoc.*, 27, 963-866.

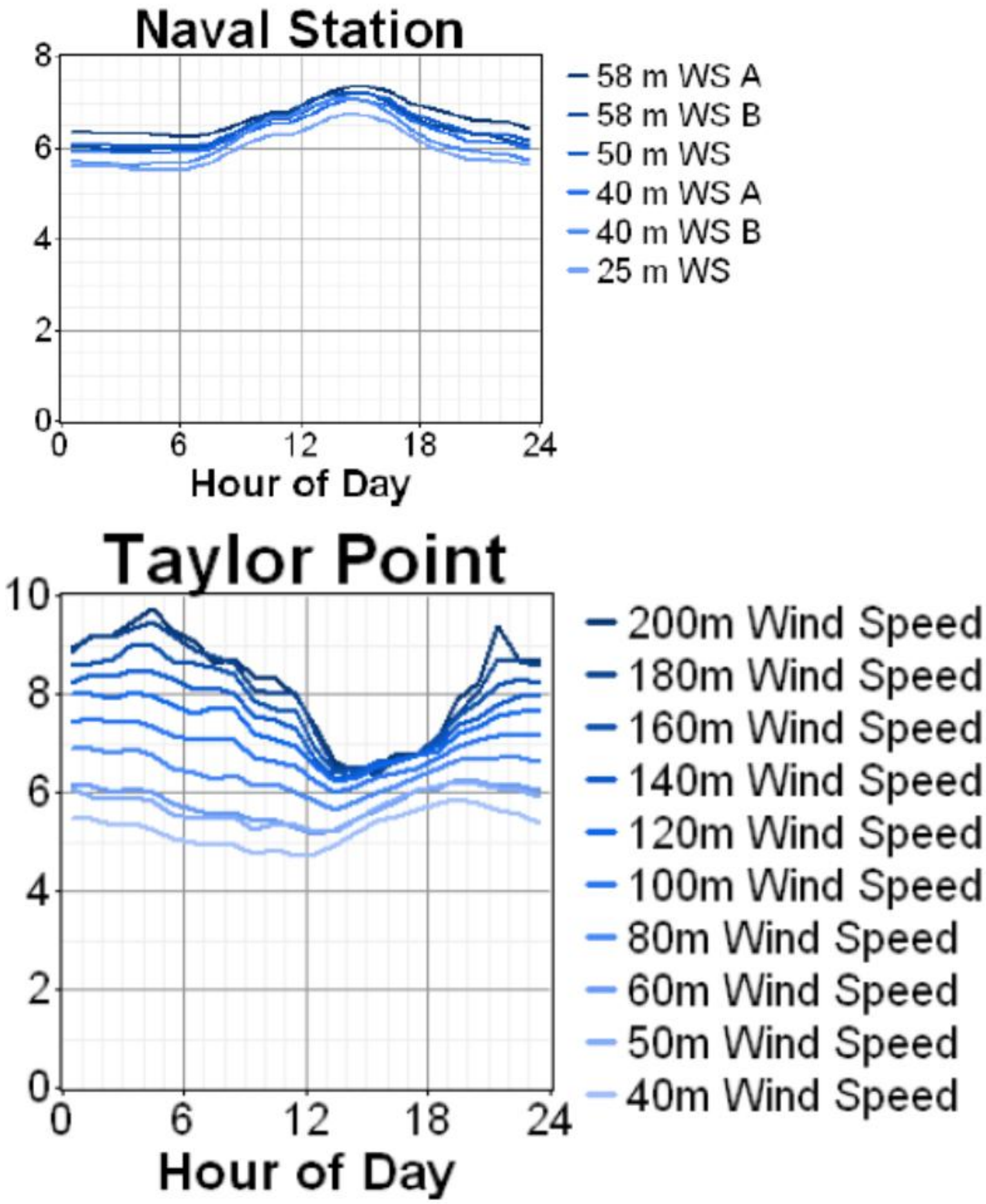


Figure 7. Diel variation at the Naval Station and Taylor Point sites, averaged over the period of record.

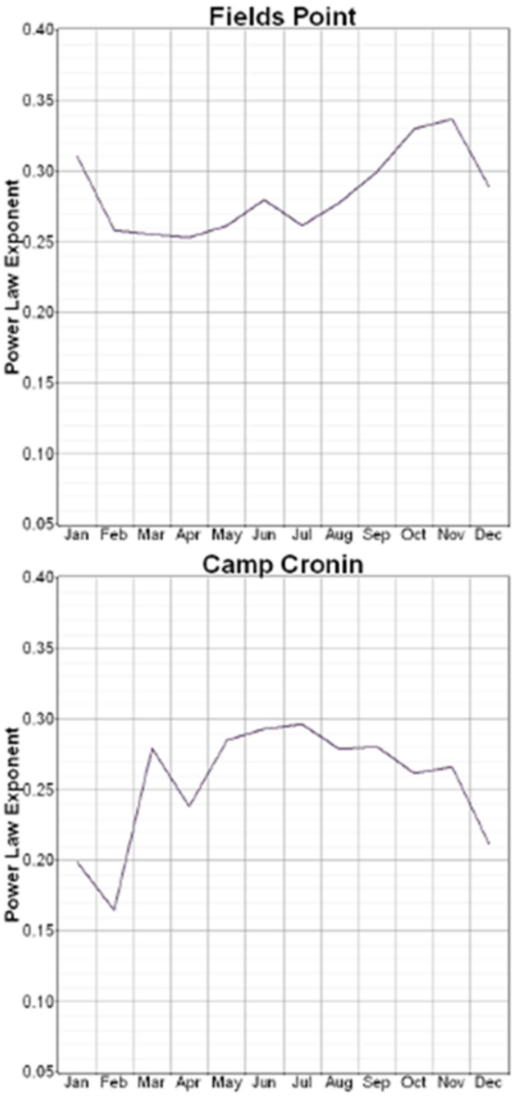


Figure 8. Annual variation of shear coefficient at the Fields Point (top) and Camp Cronin (bottom) sites.

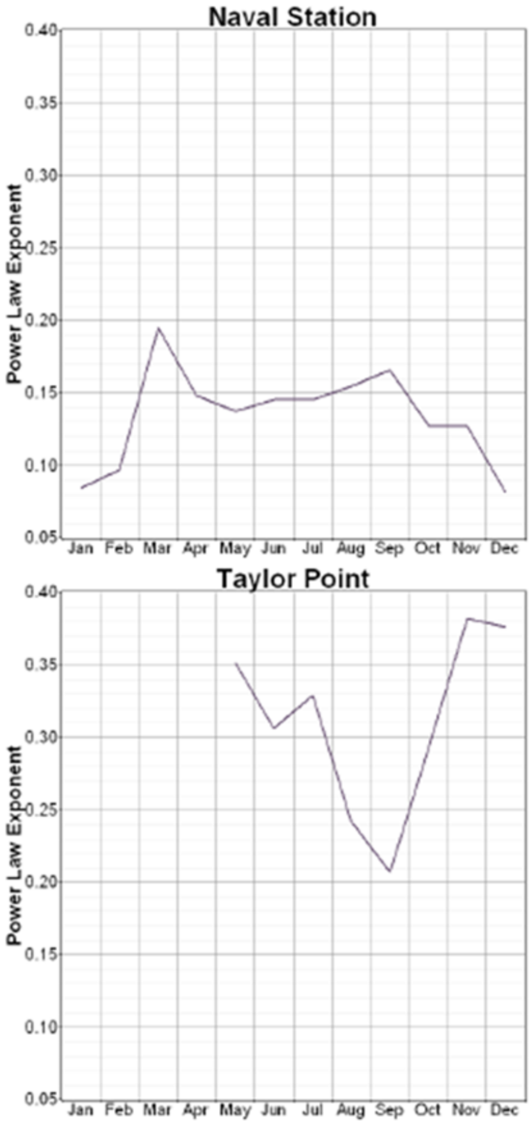


Figure 9. Annual variation of the shear coefficient at the Naval Station (top) and Taylor Point (bottom) sites.

RESP TECHNICAL REPORT #5

THE EFFECTS OF TERRESTRIAL WIND FARMS ON BIRDS AND BATS LITERATURE REVIEW FOR RHODE ISLAND'S RENEWABLE ENERGY SITING PARTNERSHIP PROJECT

By

Peter Paton, Sarah Butler, and Corrie Heinz

Department of Natural Resources Science

University of Rhode Island

June, 2012

Table of Contents

List of Figures

List of Tables

1. EXECUTIVE SUMMARY

- This document provides a detailed literature review on the effects of wind turbines on birds and bats based on research conducted throughout the North America. This review also provides information on our current understanding of the distribution and abundance of birds and bats in Rhode Island.
- Available evidence suggests there are four potential impacts of wind turbines on wildlife populations: 1) collision risk, 2) displacement, 3) barrier effects, and 4) habitat loss.
- Collision risk appears to be greater for bats than birds based on our review of the peer-reviewed literature and technical reports. Based on our review of 28 publications and technical reports from throughout North America, avian mortalities average 2.9 deaths/turbine/year and range from 0 – 12.7 deaths/turbine/year. Bat fatalities average 8.4 deaths/turbine/year and range from 0 – 63.9 deaths/turbine/year. These estimates were corrected for search efficiency and scavenging rates. None of these collision studies occurred at wind facilities at coastal sites in New England.
- Vulnerability is thought to be related to species abundance and behavior. Among bats, “tree-roosting” species have the highest mortality rates at wind facilities (e.g., eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), and silver-haired bat (*Lasionycteris noctivagans*)), which rank among the most abundant migratory bats in Rhode Island. Among birds, songbirds (passerines) and diurnal raptors (hawks and eagles) tend to be the most prevalent taxa killed by wind turbines.
- Radar studies suggests that migratory birds typically fly at altitudes between 137 - 833 m (averaging 428 m), which is above the rotor sweep zone of most wind turbines. However, in coastal areas where birds stop to rest and feed, they can drop down and take off around turbine height. Inclement weather can also lower the flight altitude of birds and cause mortality events. Available evidence suggests weak relationship between turbine height and wildlife mortality rates.
- Because there are few land-based wind turbines in coastal New England states, no studies have been conducted in coastal areas similar to the ecological conditions that exist in Rhode Island. Thus developers should proceed cautiously with large wind facilities near the coast until we learn more about the impact of wind turbines on bats and birds in the coastal zone.
- Slower wind and blade speeds are correlated with higher bat fatality rates, with the greatest bat fatality events occurring when wind speeds are below 6 m sec^{-1}.
- Lighting affects avian mortality rates at wind turbines, but apparently not bat fatality rates. Structures that have constant lighting attract nocturnally migrating birds, while flashing lights are not attractive. Current US Fish and Wildlife Service guidelines recommend minimal lighting, but when lighting is necessary - red or dual red/white strobe or flashing lights are recommended on a portion of the turbines in wind projects.

- Development of wind facilities can cause habitat loss, habitat fragmentation and increases in edge effects for birds and bats. Thus, fragmentation of contiguous habitat should be avoided.
- Bird and bat fatalities are often most likely to occur during migration periods, thus gaining a clear understanding of migration phenology is critical for baseline studies.
- Most migratory birds typically fly above the height of the most turbines.
- There are 388 species of birds that have documented in Rhode Island, of which 166 species nest in the state.
- Twenty-eight percent of breeding birds in the state are of state and federal concern, including the federally-listed piping plover. Twenty-nine breeding bird species are experiencing a significant regional population decline.
- Eighty-six percent of Rhode Island's birds are migratory. We use bird banding data to describe the abundance and phenology of birds migrating through Rhode Island and radar data to describe flight altitudes and seasonal and diel variation in migration for birds and bats.
- Fifty-seven percent of Rhode Island's birds winter in the state. The most common groups of birds to winter in the state include waterfowl, gulls, sparrows and finches. Coastal habitats provide important habitat for many species in winter. The Christmas Bird Count and the Great Backyard Bird Count provide spatially and temporally explicit data about wintering birds in Rhode Island.
- Because spatially-explicit data is not available describing the abundance and distribution of every species of bird and bat in Rhode Island, we can identify important habitats and the birds and bats that typically occupy to allow developers to focus survey efforts on the appropriate groups of bird or bats when siting a renewable energy development.
- There are 55 species of birds in Rhode Island that are either state or federally-listed as either endangered, threatened, or of concern. The two federally-listed species (Endangered: Roseate Tern [*Sterna dougallii*]; Threatened: Piping Plover [*Charadrius melodus*]) are protected by the Endangered Species Act of 1973. There are 8 State Endangered, 5 State Threatened, and 33 species of concern in Rhode Island.
- We recommend developers follow the USFWS land-based wind energy guidelines (2012) when siting and installing wind facilities in the state. We have modified these guidelines specifically for Rhode Island, based on the distribution of sensitive species and habitats. Information contained in this technical report is intended for consultants conducting pre-construction planning (Tier 1 and Tier 2 in the USFWS guidelines).
- We recommend that the first step in pre-construction monitoring should be to determine if priority habitat for important species occur near the potential turbine(s) location.
- Bald Eagles (*Haliaeetus leucocephalus)* are no longer a federally-listed species, but are protected by federal legislation under the Bald and Golden Eagle Act of 1962, with a recommended 1.6 km (1 mile) buffer around nest sites.

- For threatened and endangered birds in Rhode Island, as well as species of concern, we developed a series of voluntary buffer distances around the nests and foraging/roosting sites. We recommend that 1-km buffer around known nesting beaches used by Piping Plovers (federally-listed as threatened), a 1-km buffer surrounding coastal ponds used by nesting Pied-billed Grebes, American Bittern, Least Bitterns, a 1-km buffer around roosting sites used by Roseate Terns (federally-listed as endangered), and 0.5 km buffer around nests of Peregrine Falcons, American Oystercatchers and Ospreys.
- Twenty-six percent of land in Rhode Island is protected. This land provides critical habitat for birds and bats, and plans to develop wind turbines or other types of renewable energy sources should consider potential impacts on these protected lands before developing detailed plans. In particular, coastal National Wildlife Refuges provide key conservation lands for birds and bat and we recommend a 1-km buffer around these properties.
- At least 22 species of birds in Rhode Island use grassland habitat. Many grasslands are converting to shrub or forest dominated habitats, and, as a result, the associated grassland species are experiencing significant population declines. We recommend that wind turbines should not be constructed within 0.1 km of grasslands over 5 acres in size, particularly if a trained biologist determines than any grassland-associated species are documented nesting in the habitat patch during the breeding season in May and June.
- At least 36 bird species associated with scrub-shrub habitats in Rhode Island. Regionally, species that use scrub-shrub habitat have declining population declines. This habitat also provides vital food and cover for many species of songbirds during migration. We recommend that no wind turbines be constructed with 0.1 km of large blocks (3 acres or larger) of scrub-shrub habitats in Rhode Island.
- At least 75 species of birds in Rhode Island nest or forage in forested habitats. A majority of the forest species in Rhode Island are classified as of conservation concern regionally. However, in Rhode Island, forest habitat has increased in recent years, resulting in more stable population trends. We recommend not fragmenting forest patches that are over 100 acres in size when feasible. We also recommend not placing wind turbines with 0.1 km of forest patches >100 acres in size. This will help to minimize impacts on area sensitive species and to minimize edge effects.
- There 78 species of shorebirds in Rhode Island. A number of shorebirds of conservation concern use intertidal mudflats as stopover habitat; therefore, we recommend no wind turbines be located within a 1-km buffer of these key sites.
- There are 13 species of wading birds in Rhode Island. Given the conservation concern for the most of the colonial wading birds in Rhode Island, we recommend not constructing any wind turbines within 0.5 km of known wading bird colonies.
- Coastal ponds in southern Rhode Island provide important habitat to many species that are of conservation concern in the region. Given the importance of coastal ponds on

estuaries to local, regional, and national avian conservation concerns, we recommend a 1-km buffer for all wind turbine development near these critical wetlands.

- There are 9 species of bats that are year-round residents or migrants through Rhode Island. Unfortunately, relatively little is known about the bat abundance, distribution and behavior in the state. Thus, at this point it was challenging to develop recommendations until we learn more about the spatial distribution of breeding bats, and distribution and abundance of migratory bats in Rhode Island.
- We recommend not fragmenting forest tracts > 100 acres in size, where the more vulnerable tree-roosting bat species inhabit, for wind facility development. However, as we learn more about bat migration in the region, these recommendations could be modified.
- Because we know so little about bat movement ecology in the region, we recommend pre-construction monitoring for bats at any proposed wind facility, particularly during fall migration (mid- July through the end of October), to assess number of bats using the area. In addition, we recommend post-construction monitoring of bat collision rates for wind turbines constructed in Rhode Island that should include searcher efficiency and carcass removal correction factors for bats.
- We recommend bat mitigation methods for wind facilities operating in Rhode Island to decrease the probability of bat fatalities. During nights with high potential for bat migration, and hence bat mortality, the operational wind speed for wind turbines should be 11 miles per hr (6 m per sec), rather than 8-9 miles per hour to start power generation. This would result in a <1% reduction in power production, yet could result in up to a 93% reduction in bat mortality.
- Until we have a clearer understanding of mortality rates of birds and bats at wind facilities in Rhode Island, particularly in coastal habitats, we recommend carcasses searches be conducted for a minimum of one year following construction of the turbine. This means conducting search within a minimum of a 50 m radius around the turbine at least every three days. There should be focused efforts during fall migration when the number of migrants passing through the state is greatest.
- Although other fauna (e.g., butterflies, dragonflies and damselflies) or flora (rare plants) could be impacted by development of wind turbines in Rhode Island, those other taxa are not covered in this report. However, developers should consult with local experts on these other taxa before considering the development of specific sites.

2. DOCUMENTED EFFECTS OF TERRESTRIAL WIND TURBINES ON BIRDS AND BATS

There has been considerable research on the potential impacts of terrestrial wind turbines on birds and bats. These potential impacts can be segregated into four general categories: 1) collision risk, 2) displacement, 3) barrier effects, and 4) habitat loss (Drewitt and Langston 2006). Direct mortality from colliding with wind turbines is just one anthropogenic source of mortality facing avian and bat populations in the United States (Fig. 1; Erickson et al. 2005).

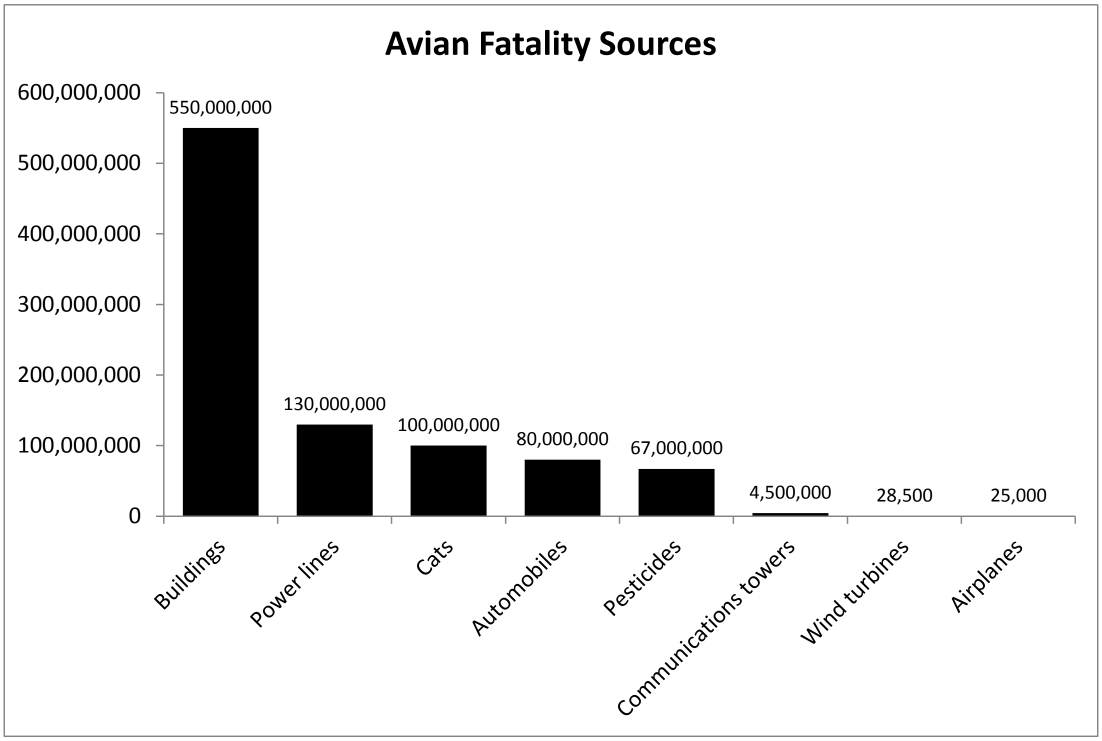


Fig 1. Estimated number of birds killed annually in the United States from various anthropogenic sources based on Erickson et al. (2005).

2.1 Collisions

Collision mortality is the most well documented effect of wind facilities on birds and bats. Available evidence suggests that avian and bat mortality rates at most wind farms in the United States tend to be relatively low, but occasionally mortality rates can be much higher. However, high mortality rates of birds and bats at some terrestrial wind facilities on some days have raised concerns about the potential impact of wind facilities on wildlife populations (Drewitt and Langston 2006). In the early 1980s, researchers documented thousands of bird deaths, primarily raptors, at the Altamont Pass Wind Resource Area in California (Orloff and Flannery 1992). Since this initial research was conducted, numerous studies have investigated collision mortality rates of birds at wind facilities across the United States and throughout Europe (Drewitt and Langston 2006, Kerlinger et al. 2010). Similarly, in 2000, researchers recorded thousands of bat deaths at the Buffalo Mountain Wind farm in Tennessee (Fielder 2004, Fielder et al. 2007). These high mortality rates were a cause for concern and initiated bat mortality research at wind facilities across the country and internationally (Johnson et al. 2004, Nicholls and Racey 2007, Horn et al. 2008, Piorkowski and O'Connell 2010).

While some facilities have experienced relatively high mortality rates (Fielder 2004, Smallwood and Thelander 2005, 2008; Fielder et al. 2007), there are many operational wind facilities where bird and bat mortality rates are relatively low (Osborn et al. 2000, Howe et al. 2002, Reynolds 2006). Reported bird and bat fatalities are largely a result of direct collisions with wind turbines, although recent evidence suggests that rapid air-pressure reduction near moving turbine blades can kill bats by barotrauma (Baerwald et al. 2008). By identifying and avoiding or minimizing the factors that can potentially lead to negative impacts on bird and bat populations, terrestrial wind facilities can be a viable alternative energy source with minimal impact on wildlife populations for the future.

Collisions can occur with the rotors and towers, as well as the associated structures such as guy wires and transmission lines (Drewitt and Langston 2006). While there are some sampling issues regarding carcass recovery such as searcher efficiency (Smallwood 2007, Arnett et al. 2008b) and scavenger removal of carcasses (Crawford and Engstrom 2001) collision rates can generally be readily quantified at terrestrial wind facilities and are among the most visible effect of wind facilities on birds and bats. The impact of collisions on population viability certain bird or bat species is uncertain, particularly for long-lived birds and bats with low reproductive rates and endangered or threatened species. However, there is some evidence to suggest that collision rates with anthropogenic sources can impact local avian populations, although these negative impacts did not occur at wind facilities (Drewitt and Langston 2006).

Based on our review of the peer-reviewed literature and technical reports, bird collision fatalities at terrestrial wind facilities average 2.9 deaths/turbine/year and range from 0 – 12.7 deaths/turbine/year (Table 1). These estimates are corrected for scavenging and searcher efficacy. Recent evidence suggests that bats generally have higher mortality rates at terrestrial wind facilities than birds, especially during their peak migration periods and at night (Kunz et al. 2007). Bat fatalities average 8.4 deaths/turbine/year and range from 0 – 63.9 deaths/turbine/year (Table 1). Collision mortality rates for both birds and bats vary as a function of location, facility specifications (e.g., tower height and rotor size (Barclay et al. 2007), layout, orientation lighting (Kerlinger et al. 2006), species, and local weather.

In general, bird fatalities that result from collision with a terrestrial wind turbine are low compared to other documented anthropogenic sources of bird casualties such as communication towers, transmission wires, vehicles, and other buildings or structures (Erickson et al. 2001, Erickson et al. 2005). This is due to the fact that there are relatively few wind turbines compared to the other anthropogenic mortality sources (e.g., buildings, cars, etc).Additionally, bird and bat fatalities at wind facilities are lower per KW hour than other energy sources (Sovacool 2009). Bat fatalities at wind facilities were not well documented until after 2001, largely because carcass searches focused on birds and not bats (Kunz et al. 2007). However, since researchers have started to focus searches on bats, estimates of collision rates have increased, particularly at larger terrestrial wind turbine facilities. Available evidence suggests that migratory tree-roosting bat species in forested areas of the eastern United States are the species most vulnerable to collision risk (Fielder et al. 2007, Kunz et al. 2007). The following sections describe the impacts of various factors on bird and bat mortality rates at wind farms.

2.1.1 Are certain species more vulnerable to collision risk?

Some species of birds and bats appear to be more prone to turbine-related mortality than others (National Research Council 2007). Vulnerability is thought to be related to species abundance (Kuvlesky et al. 2007) and behavior (National Research Council 2007). In areas where bird or bat populations are high, there is a greater risk of collision. However, some species are more vulnerable to turbine-related deaths than others of similar population densities. For examples, some species of birds and bats are potentially attracted to turbines, increasing their chances of collision.

Table 1. Summary of studies that have investigated bird and bat collision rates at terrestrial wind facilities in North America. Only studies that included mortality estimates corrected for scavenging and searcher efficiency are included.

Wind facility location	Date of study	Corrected bird mortality rate turbine/yr	Corrected bat mortality rate turbine/yr	Reference
Altamont Pass, CA	3/98 - 9/01	0.79	0.01	Smallwood and Thelander 2005
Biglow Canyon, OR	9/09 - 9/10	12.73	6.24	Enk et al. 2011
Buffalo Mountain, TN	2005	1.80	63.90	Fiedler et al. 2007
Buffalo Mountain, TN	9/00 - 9/03	7.28	20.82	Nicholson et al. 2005
Buffalo Mountain, TN	9/00 - 9/03	na	20.80	Fiedler 2004
Buffalo Ridge, MN Phase 1	3/96 - 11/99	0.98	0.26	Johnson et al. 2000
Buffalo Ridge, MN Phase 2	3/98 - 11/99	1.14	0.89	Johnson et al. 2000
Buffalo Ridge, MN Phase 3	3/00 - 11/99	5.93	2.04	Johnson et al. 2000
Diablo Winds, CA	3/05 - 2/06	1.40	na	WEST Inc 2006
Eurus Combine Hills , OR	2/04 - 2/05	2.56	1.88	Young et al. 2006
Foote Creek Rim, WY	11/98 - 00	1.49	1.04	Young et al. 2003
Green Mtn. Searsburg, VT	6/97 - 10/97	0.00	0.00	Kerlinger 2003
High Winds, CA	8/03 - 7/05	2.45	3.63	Kerlinger et al. 2006
Hopkins Ridge, WA	1/06 - 12/06	2.21	1.13	Young et al. 2007
Kewaunee County, WI	1998-2001	1.29	4.26	Howe et al. 2002
Klondike, OR	na	1.42	1.16	Johnson et al. 2003b
Klondike, OR	10/07- 10/09	5.33	1.96	Gritski et al. 2010
Maple Ridge Wind park, NY	4/07 - 11/07	4.71	11.65	Jain et al. 2009b
Mars Hill Wind Farm, ME	4/07 - 9/07;	1.32	2.28	Stantec Consulting 2008
Mountaineer, WV	4/03 - 11/03	4.04	47.50	Kerns and Kerlinger 2004
Natl Wind Center, CO	5/01 - 5/02	na	0.00	Schmidt et al. 2003
Nine Canyon Project, WA	9/02 - 8/03	3.59	3.21	Erickson et al. 2003
Noble Bliss Eagle, NY	4/08 - 11/08	1.90	11.71	Jain et al. 2009
Pickering, Ontario	01 - 12 2002	4.00	10.70	James 2002
Stateline, WA	7/01 - 12/03	1.93	1.12	WEST Inc. 2004
Top of Iowa, IA	4/03 - 12/04	0.65	8.04	Jain 2005
Vansycle Ridge, OR	1/99 - 12/99	0.63	0.74	Erickson et al. 2000
Wild Horse Wind facility, WA	1/07 - 12/07	2.79	0.70	Erickson et al. 2008
Max		**12.73**	**63.90**	
Min		**0.00**	**0.00**	
Average		**2.86**	**8.43**	

2.1.1.2 BIRDS

In general, available studies conducted to date suggest that avian populations are not significantly impacted by terrestrial wind facilities (Drewitt and Langston 2006, Kuvlesky et al. 2007); however, turbines placed near critical bird habitat or along migration routes have the potential to increase mortality rates for some species. In addition, collision–caused mortality of species with long life spans, low productivity and slow maturation rates could significantly affect populations (Drewitt and Langston 2006, Carrette et al. 2009).

Songbirds (order Passeriformes) are the most common birds in most terrestrial systems, and they are usually the most reported avian group for turbine-related bird deaths (Kuvlesky et al. 2007, National Research Council 2007, Erickson et al. 2002). We summarized 34 studies across United States and determined that passerines comprised 49% of identified bird fatalities (Tables 2, A1.1; Fig. 2). Excluding California, where raptors comprise a large percentage of fatalities, passerines accounted for 72% of all identified bird fatalities (Tables 2, A1.1; Fig. 2). Of six studies conducted in the eastern United States, passerines were consistently the dominant species detected during carcass searches at wind facilities, accounting for 71% of all identified birds (Tables 2, A1.1; Fig. 2).

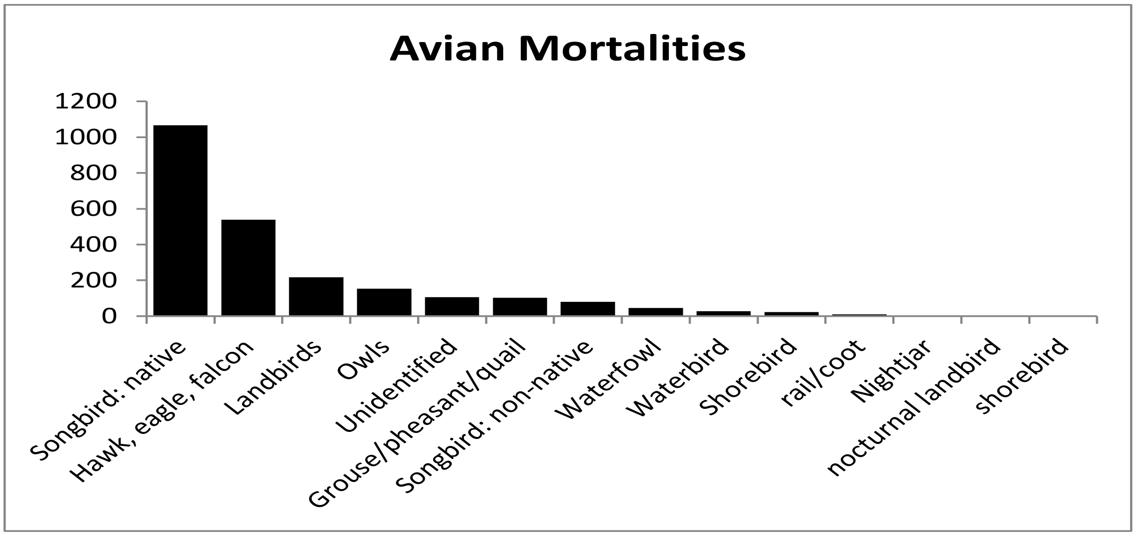


Figure 2. Total number of avian mortalities, by taxonomic group, documented at terrestrial wind facilities based on 34 studies across the United States (see also Tables 2, A1.1).

Table 2. Total number of fatalities by various groups of birds and bats documented in peer-reviewed articles and technical reports across the United States (34 studies), in the United States excluding California (26 studies), and only in the eastern United States (6 studies).

Bird/Bat group[a]	U.S. (N=34)	U.S. excluding CA (N=26)	Eastern U.S. (N=6)
Bat	2001	1874	874
Grouse/pheasant/quail	103	96	3
Hawk, eagle, falcon	538	61	10
Landbirds	217	45	9
Nightjar	4	4	0
Owls	153	5	0
Shorebirds	22	6	1
Songbird: native	1067	756	145
Songbird: non-native	79	36	8
Unidentified	105	59	37
Waterbird	28	14	1
Waterfowl	45	16	3
Sum of bird fatalities	**2361**	**1098**	**217**
Sum of bat fatalities	**2001**	**1874**	**874**
Sum of fatalities	**4362**	**2972**	**1091**
Bird fatalities (% of total)	**54**	**37**	**20**
Bat fatalities (% of total)	**46**	**63**	**80**

[a] Groups:landbirds (non-passerines; doves (Columbiformes), cuckoos (Cuculiformes), woodpeckers (Piciformes), swifts (Apodiformes)), shorebirds (Charadriiformes), songbirds: native (all Passeriformes except non-native species), songbirds: non-native (some Columbiformes (Rock Pigeon), Passeridae (House Sparrow) and Sturnidae (European Starling)), unidentified (species not determined), waterbird (Pelecaniformes, Ciconiiformes, Gruiformes), and waterfowl (Anseriformes).

Raptors and vultures have also experienced high mortality rates in some areas (Erickson et al. 2001, Anderson et al. 2004, Barrios and Rodriguez 2004, Smallwood and Thelander 2004,). In California, diurnal raptors account for a large portion (up to 41%; Erickson et al. 2001) of bird fatalities associated with wind facilities (Erickson et al. 2002, Anderson et al. 2004, Smallwood and Thelander 2005). In a study of collision-caused fatalities at a wind facility in Spain, Griffon Vultures (*Gyps fulvus*) and Common Kestrels (*Falco tinnunculus*) had the highest mortality rates (Barrios and Rodriguez 2004). In both areas, the author's suggested that the fatalities were related to topographic position of the wind turbines as well as prey abundances. Many of the turbines in these areas are located on hill slopes where there are strong wind updrafts. Raptors and vultures often use wind gusts for soaring, increasing their risk of collision with the turbines on slopes (Barrios and Rodriguez 2004, Smallwood and Karas 2009). Areas of high prey densities, primarily small mammals, also led to high mortalities for raptors in California and the Common Kestrel in Spain.

Bird behavior may also affect mortality rates, but little research has examined why certain taxonomic groups are more prone to turbine-related mortality than others (National Research Council 2007). For example, in the mid-western United States, common grassland species (Horned Lark, Vesper Sparrow, Bobolink) often exhibit aerial courtship displays that take them into the rotor-sweep zone where they are vulnerable to collisions (National Research Council 2007). Howe et al. (2002) found that the fatalities of birds at wind facilities in Wisconsin were species-specific, and the most common species did not necessarily have the highest mortality rates (Howe et al. 2002). Similarly, raptors at the Altamont Pass Wind Resource Area in California were more prone to collisions than other similarly abundant species (Smallwood and Karas 2009). Researchers suggested that a raptors' focus on prey apparently made them less likely to notice and avoid turbine blades, increasing risk of collisions (Smallwood and Karas 2009). However, in three similar wind facility sites in California, raptor fatalities were highest where raptors were more abundant, likely related to prey densities (National Research Council 2007). Based on these and various other studies (Barrios and Rodriguez 2004, de Lucus et al. 2008), mortality seems to be related to both specific bird behavior and abundance. Additionally, migration routes of birds are largely species-specific, and thus turbine placement will likely affect migrating species differently (National Research Council 2007).

2.1.2.2 BATS

The life history of bats makes them unique from birds. Most bats in the temperate zone mate in autumn and the winter, with pregnant females often migrating in the spring to different habitats and regions of North America than those used by males in the summer (Cryan 2011). In addition, bats have high adult survival rates with many individuals living to be 10 to 20 years old (Cryan 2011). The trade-off for this high survival rate is that they have low reproductive rates, with only one to two young produced annually (most species of bats in North America have one offspring per year, but 'tree-roosting bats" usually have two offspring annually; Cryan 2011), therefore the ability of populations to recover from perturbations is diminished.

Bat mortality from wind turbines is one of the key emerging issues in wind energy development in the United States. Current estimates of bat fatalities average 11.6 bats per MW per year (Cryan 2011). With an estimated 40,000 MW of installed turbines in North America, this suggests that over 450,000 bats may be killed annually in North America by turbines (Cryan 2011).

In the eastern United States, bat mortality rates are much higher than those reported in the western United States (National Research Council 2007, Arnett et al. 2008b), which may be related to the species present in the eastern US versus the western US (Table A1.2; Fig. 3). Bats comprise 80% of all fatalities reported in 6 studies in the eastern United States (Table 2). In the eastern United States, a majority of reported bat fatalities were detected during migration periods from mid-summer through fall (Erickson et al. 2002, Howe et al. 2002), while very few fatalities occur in the spring and summer, even when there are large local populations of breeding bats near wind turbines (Erickson et al. 2002, Howe et al. 2002). A majority of these fatalities were the so called, “tree-roosting bats”, which include eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), and silver-haired bat (*Lasionycteris noctivagans*) (Kunz et al. 2007; Arnett et al. 2008b; Cryan 2008, 2011) (Table A1.2; Fig. 3). In other parts of the United States, fatalities are also associated with wind facilities near breeding areas of local populations of bats, specifically the Brazilian free-tail bat (*Tadarida brasiliensis*)) (Piorkowski and O’Connell 2010) (Table A1.2; Fig. 3). Bat fatalities are also common in certain areas of Europe that are thought to be likely related to species abundances near wind facilities (Brinkmann and Schauer-Weisshahn 2006).

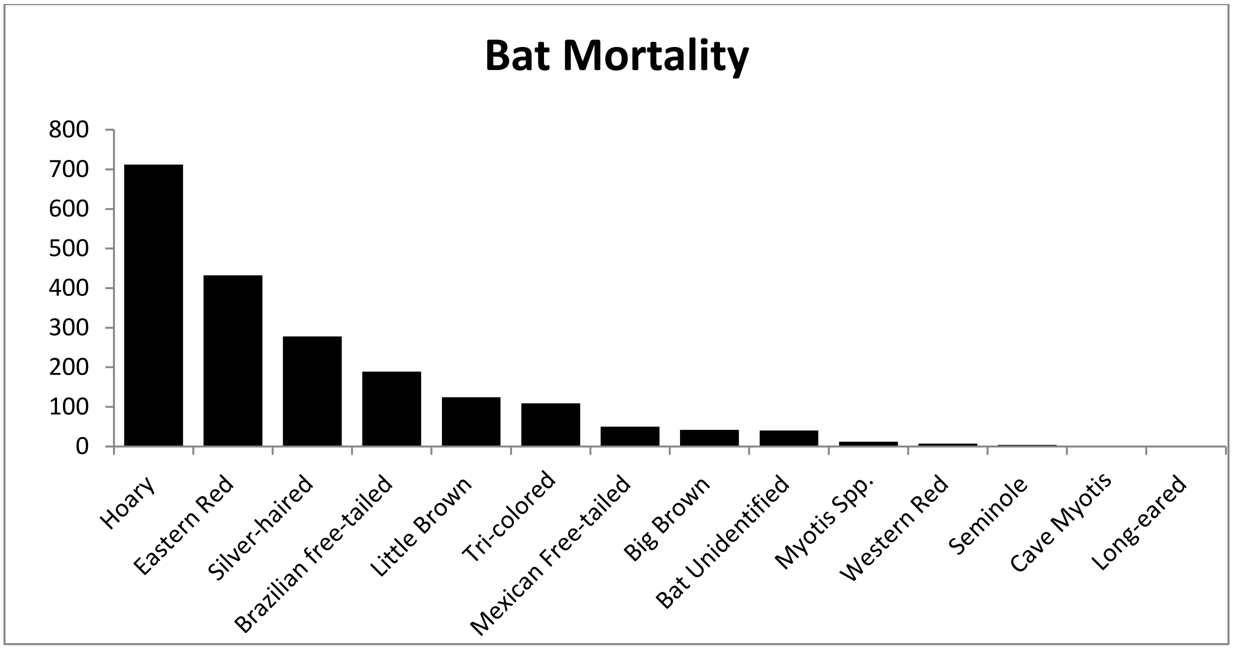


Figure 3. Interspecific variation in total bat mortalities (total number of individuals killed) for 15 species documented at wind facilities in the United States from 34 studies.

Some research has shown that bat mortality is related to seasonal migrations, but species-specific behavior during migration windows may also play a role in high mortality rates. Cryan (2008) suggested that bats are attracted to the turbines in the same way they are attracted to tall trees during mating, which occurs in the fall migration window for the eastern red, hoary and silver-haired bats. In Europe, the bat mortality rate is also are strongly linked to migration patterns, as well as species-specific roosting, foraging and mating behavior around turbines (Brinkmann and Schauer-Weisshahn 2006).

2.1.2 Factors affecting collision risk at wind facilities

Several factors related to wind turbine facilities have been found to directly impact the mortality rates of birds and bats. Understanding how topography, habitat type, habitat resources, migration routes and facility specifications such as facility size, turbine height, blade size and speed and lighting, affect bird and bat mortality would help policy makers create guidelines to reduce collision deaths (Erickson et al. 2002, National Research Council 2007, Kunz et al. 2007).

2.1.2.1 TOPOGRAPHY

2.1.2.1.1 Birds

For some species, primarily soaring birds that use updraft winds for flying, fatalities have been correlated with topography (Orloff and Flannery 1992, Barrios and Rodriguez 2004, Hoover and Morrison 2005, Insignia Environmental 2009). Diurnal raptors tend to follow ridgelines during fall migration presumably to take advantage of thermals, while available evidence suggests that the migration pathways of nocturnal passerines are less likely to be affected by topography (National Research Council 2007). When examining sites with varied topography, turbines located on peaks or hill slopes tend to have the most soaring bird fatalities (Orloff and Flannery 1992, Barrios and Rodriguez 2004). Updrafts are more frequent on steeper slopes, and the increased winds likely will result in greater collision rates for diurnal raptors and other birds that soar in thermals. However, little research focused on other bird species or geographical locations has been done examining the effects of topography on wind turbine placement and bird mortality (National Research Council 2007).

2.1.2.1.2 Bats

Although data are relatively limited, reported bat mortality rates are highest along ridge tops in the eastern United States, likely because these bats forage, mate, roost and migrate along ridge tops (Kunz et al. 2007, National Research Council 2007). However, Cryan (2011) suggests there is no relationship between bat fatality rates at wind turbines and local topography (see also Arnett et al. 2008a).

2.1.2.2 HABITAT TYPE

2.1.2.2.1 Birds

Mortality rates of birds and bats could be related to habitat composition at the wind facility, if the habitat attracts species that are especially vulnerable to collisions. In Belgium, a wind facility was built along the North Sea coast near a breeding colony of gulls and terns, where birds often flew through the wind facility to reach their foraging grounds (Everaert and Stienen 2007). In general, the birds did not alter their breeding or foraging patterns to avoid turbines, which resulted in relatively high mortality rates of terns (*Sterna hirundo, Sterna* *sandvicensis, Sterna albifrons*) and gulls (Everaert and Steinen 2002, Everaert and Stienen 2007).

Wind facilities located in critical habitat for certain species of birds are more likely to lead to elevated mortality rates. Horned larks, a grassland species, are the most commonly reported fatality (10% of 2361 reported fatalities) of all species examined across the United States in 34 studies (Table A1.1). However, in 6 studies in the eastern United States, where many of the wind facilities are surrounded by forest, no horned lark fatalities reported, which is not unexpected since this species is a grassland specialist (Table A1.1). In the eastern United States (6 studies examined), Red-eyed Vireo, a forest specialist, is the most commonly reported fatality (11% out of 217 reported fatalities) (Table A1.1).

2.1.2.2.2 Bats

Bat mortality at wind facilities may also be related to habitat composition when turbines are placed in critical foraging or roosting areas. For example, constructing a facility in forest habitat along a bat migration route may interfere with foraging and roosting behaviors. Horn et al. (2008) found that bats are actually attracted to turbines for roosting, apparently because they are resemble large trees and snags that are more typical natural, roosting structures.

Studies examining the effect of habitat type or topography within a single facility have found that bat fatalities are not significantly related to variation of habitat type within one turbine facility (Johnson et al. 2004, Brinkmann et al. 2006).

2.1.2.5 FACILITY SPECIFICATIONS

2.1.2.5.1 Facility size

Larger facilities result in proportionally larger mortality rates of birds, simply because a greater number of wind turbines lead to more opportunities for collision (Kingsley and Whittam 2005). Thus, larger facilities have the potential to affect more birds. The Altamont Pass Wind Resource Area in California, one of the largest terrestrial wind facilities in the world, has experienced some of the highest mortality rates documented (Smallwood and Thelander 2008). To our knowledge, little research has focused on examining the effect of facility size on bat mortality rates. While size of a facility is important, turbine location may have a larger impact on bird and bat mortality than facility size, so siting terrestrial facility in areas with the potential for low impact may lead to fewer deaths than numerous small poorly-sited wind facilities (Kingsley and Whittam 2005).

2.1.2.5.2 Turbine height

Turbine and rotor heights have generally increased in recent years as engineers manufacture turbines at a height to capture the most stable and consistent winds (Kingsley and Whittam 2005). Turbine heights from 25 terrestrial studies across the United States average 58 m, with a range from 27.3 – 138.5 m (Table 3).

Table 3. Wind turbine characteristics (nameplate power, tower height, rotor diameter, total height) at terrestrial wind facilities in the United States.

Wind facility Location	Nameplate capacity (MW)	Tower height (m)	Rotor diameter (m)	Total height (m)	Reference
Altamont Pass, CA	na	18.3	18.0	27.3	Howell and DiDnato 1991
Altamont Pass, CA	na	24.0	18.0	33.0	Smallwood and Thelander 2005
Altamont Pass, CA	na	24.4	18.0	33.4	Howell and DiDnato 1991
Altamont Pass, CA	na	40.7	18.0	49.7	Howell and DiDnato 1991
Buffalo Mountain, TN	0.66	65.0	47.0	88.5	Fiedler 2004
Buffalo Mountain, TN	0.66	65.0	47.0	88.5	Nicholson et al. 2005
Buffalo Mountain, TN	0.66 - 1.8	78.0	84.0	120.0	Fiedler et al. 2007
Buffalo Ridge, MN	0.75	37.0	33.0	53.5	Johnson et al. 2000
Buffalo Ridge, MN	0.34	50.0	47.0	73.5	Johnson et al. 2000
Castle River, Alberta	0.66	50.0	47.0	73.5	Brown and Hamilton 2002
Eurus Combine Hills Turbine Ranch, OR	1.00	53.0	61.4	83.7	Young et al. 2006
Exhibition Place, Ontario	0.75	94.0	48.0	118.0	James and Coady 2003
Foote Creek Rim, WY	0.60	40.0	42.0	61.0	Young et al. 2003
High Winds, CA	1.80	60.0	80.0	100.0	Kerlinger et al. 2006
Hopkins Ridge Wind Project, WA	1.80	67.0	80.0	107.0	Young et al. 2007
Kewaunee County WI	0.66	65.0	45.0	87.5	Howe et al. 2002
Klondike, OR	1.50	65.0	70.0	100.0	Johnson et al. 2003b
Maple Ridge Wind park, NY	1.65	80.0	82.0	121.0	Jain et al. 2009b
Nine Canyon Wind Energy Project, WA	1.30	60.0	62.0	91.0	Erickson et al. 2003
Oklahoma Wind Energy Center, OK	0.10	100.0	77.0	138.5	Piorkowski and O'Connell 2010
Pickering, Ontario	1.80	78.0	78.0	117.0	James 2002
Stateline, WA	0.66	50.0	47.0	73.5	WEST Inc. and 2004
Top of Iowa, IA	0.90	71.6	52.0	97.6	Jain 2005
Vansycle Ridge, OR	0.66	50.0	47.0	73.5	Erickson et al. 2000
Wild Horse Wind	1.80	67.0	39.0	86.5	Erickson et al.

Wind facility Location	**Nameplate capacity (MW)**	**Tower height (m)**	**Rotor diameter (m)**	**Total height (m)**	**Reference**
facility, WA					2008
Max		**100.0**	**84.0**	**138.5**	
Min		**24.0**	**18.0**	**33.0**	
Average		**59.8**	**52.9**	**86.2**	

2.1.2.5.2.1 Birds

Available evidence based on radar studies suggests that migratory bird and bats typically fly at altitudes between 137 - 833 m (averaging 428 m) in the eastern United States (Table 4). While there is some overlap, research suggests that birds generally fly well above the height of most wind turbines, and studies have found that bird fatalities do not generally increase with increased turbine height (Barclay et al. 2007). In an analysis of 15 radar studies done in the eastern United States at the sites of proposed wind facilities, 3-20% (averaging 12%) of birds or bats flew below the proposed turbine height (120 – 135 m) (Table 4). However, during inclement weather such as cloud cover, rain, snow and wind, birds often fly at much lower altitudes, resulting in a higher risk of turbine collision (Johnson et al. 2002, Kingsley and Whittam 2005, Saidur et al. 2011). We analyzed the results of 24 studies across the United States with tower height and bird fatality estimates to see if there was a significant relationship. We found a weak (R^2 = 0.25) but significant (p = 0.01) positive relationship between bird fatality and turbine height (Fig. 4).

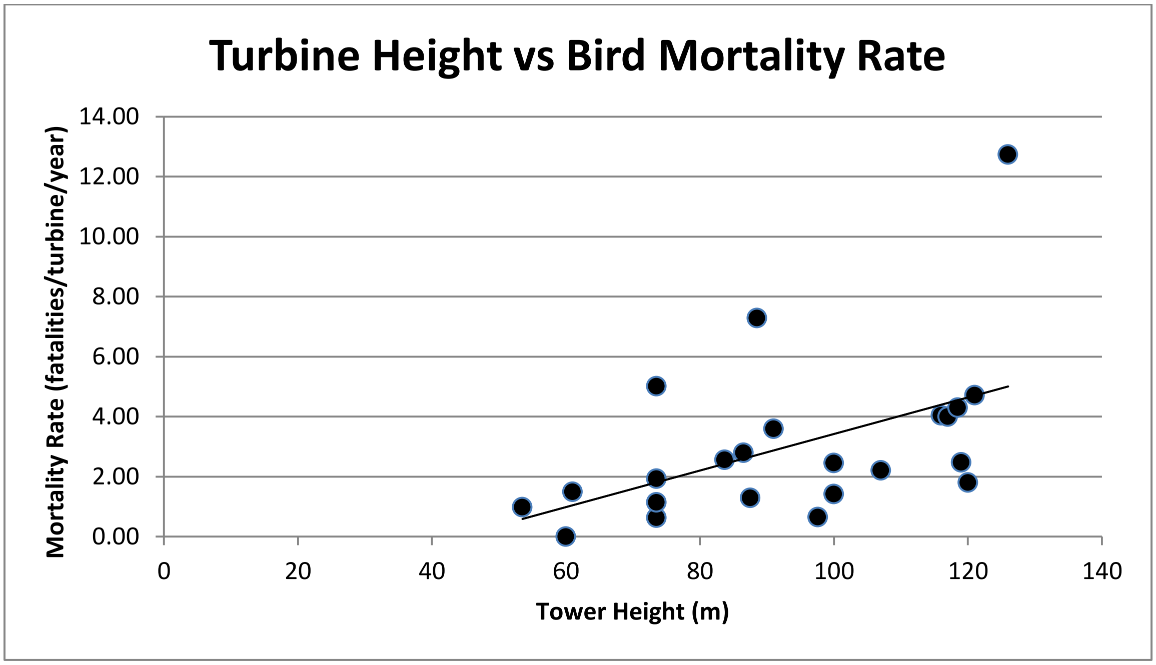


Figure 4. Turbine height is significantly related to bird mortality rate (fatalities/turbine/year) (R^2 = 0.25, p = 0.01).

2.1.2.5.2.2 Bats

Bat fatalities generally increase with increasing turbine height, especially for turbines greater than 65 m tall, with no evidence that inclement weather changes the flight altitude of bats during migration (Barclay et al. 2007, Arnett et al. 2008a, 2008b). The higher mortality rates of bats near taller towers suggest that bats have a lower flight altitude than most birds (Barclay et al. 2007). We analyzed the results of 24 studies across the United States with tower height and bat fatality estimates to see if there was a significant relationship. We found a weak ($R^2 = 0.23$) but significant ($p = 0.01$) positive relationship between bat fatality and turbine height (Fig. 5).

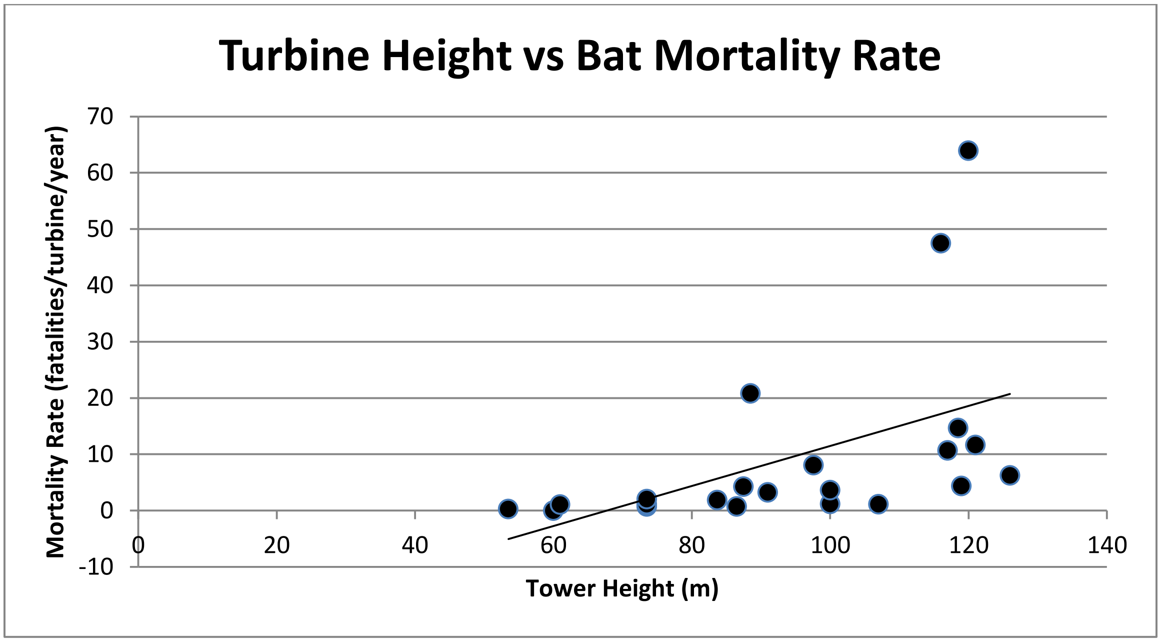


Figure 5. Turbine height is significantly related to bat mortality rate (fatalities/turbine/year) (R2 = 0.25, p = 0.01).

2.1.2.5.3 Blade size and speed

Blade size and speed has also changed as wind technology advances. From 1980 to 2000, rotor heights have increased from 15 to 66 m (Bansal et al. 2002), with more modern designs incorporating larger turbine blade (Kingsley and Whittam 2005).

2.1.2.5.3.1 Birds

Larger turbine blades have a slower speed along most of the blade, making them more visible to birds (Kingsley and Whittam 2005). Bird fatalities do not seem to be affected by size of the rotor-swept area (Brinkmann and Schauer-Weisshahn 2006, Barclay et al. 2007).

2.1.2.5.3.2 Bats

Bat fatalities are not typically affected by size of the rotor-swept area (Brinkmann and Schauer-Weisshahn 2006, Barclay et al. 2007). However, slower wind and blade speeds are correlated with higher bat fatality rates (Jain 2005, Arnett et al. 2008b, Horn et al. 2008). The largest bat fatality events occur when wind speeds are below 6 m sec^{-1}. Lower wind speeds are favorable for foraging and migration, and bats are more active during these weather conditions, resulting in higher chances of collision (Arnett et al. 2008b).

Table 4. Flight altitudes of targets (birds and bats) in the northeast United States based on radar studies.

Wind facility location	Survey method	Season	Habitat	Topography	Average flight altitude (m)	Range of flight altitude (m)	% flying below proposed turbine height	Proposed turbine height (m)	Reference
Allegheny Front, WV	nocturnal radar	fall	forest	mountain	410	214 - 769	na	na	Mabee et al. 2006
Chautauqua Wind Energy Facility, NY	nocturnal radar	fall	agriculture, forest, wetlands	ridgeline	532	na	4	125	Cooper et al. 2004
Chautauqua Wind Energy Facility, NY	nocturnal radar	spring	agriculture, forest, wetlands	ridgeline	528	na	4	125	Cooper et al. 2004
Chautauqua Wind Energy Facility, NY	diurnal radar	spring	agriculture, forest, wetlands	ridgeline	372	na	17	125	Cooper et al. 2004b
Chautauqua Wind Energy Facility, NY	nocturnal radar	spring	agriculture, forest, wetlands	ridgeline	528	na	17	125	Cooper et al. 2004b
Clayton Wind Project, PA	nocturnal radar	fall	forest, agriculture	flat	516	190-727	3	125	Woodlot alternatives 2005b
Clayton Wind Project, PA	nocturnal radar	spring	forest, agriculture	flat	370	225 - 667	16	125	Woodlot alternatives 2006
Flat Rock wind power project, NY	nocturnal radar	fall	agriculture, pasture, wetlands	rolling hills	415	194 - 691	8	125	Mabee et al. 2005
Highland New Wind Development Project, VA	nocturnal radar	fall	pasture, agriculture, forest	ridgeline	442	211 - 721	11	125	Plissner et al. 2006
Kingdom Community Wind Project, Lowell, VT	nocturnal radar	fall	forest	ridgeline	350	na	16	135	Stantec 2010
Kingdom Community Wind Project, Lowell, VT	nocturnal radar	spring	forest	ridgeline	298	na	16	135	Stantec 2010
Mars Hill Wind Farm, ME	nocturnal radar	spring	forest, agriculture	ridgeline	312	137 - 443	18	130	Stantec 2007
Mount Storm Wind Power Development, WV	nocturnal radar	fall	reclaimed coal strip, forest	ridgeline	410	na	13	125	Mabee et al. 2004
Top Notch wind project, NY	nocturnal radar	fall	agriculture, forest	rolling hills	516	303 - 800	4	125	Woodlot alternatives 2005 c
Top Notch wind project, NY	nocturnal radar	spring	agriculture, forest	rolling hills	419	160 - 833	20	125	Woodlot alternatives 2005 d
Max					**532**	**833**	**20**		
Min					**298**	**137**	**2.6**		
Average					**428**	**.**	**11.9**		

2.1.2.5.4 Turbine Lighting

2.1.2.5.4.1 Birds

In general, steady (constant) lighted turbines attract nocturnally migrating birds, while flashing lights are less like to attract birds to turbines (Johnson et al. 2002, Kingsley and Whittam 2005, Kerlinger et al. 2010, Saidur 2011). The largest mortality event at a terrestrial wind-facility was the death of 33 passerines during heavy fog in West Virginia at a substation lit with sodium vapor lights (Kerns and Kerlinger 2004) reported in National Research Council (2007). Subsequently these lights were turned off and no further mortalities were reported. Based on research examining the effects of lighted communication towers on bird mortality (Gerhring et al. 2009), the US Fish and Wildlife Service developed recommendations that suggest that lights to be kept to a minimum (including duration and intensity), preferably red or dual red/white strobe or flashing lights and avoiding non-flashing red lights to minimize light-caused avian mortality at turbines (USFWS 2012, see also Kerlinger et al. 2010).

2.1.2.5.4.2 Bats

Although there has been some speculation that lighted turbines attract insects that, in turn, attract bats (National Research Council 2007), studies we examined have found no statistically significant relationship between bat fatalities and turbine lights (Arnett et al. 2008a, Horn et al. 2008).

2.2 Barotrauma in bats

In addition to direct collisions causing mortality in bats, barotrauma, or the rapid changes in air pressure causing internal tissue damage, could be a significant cause of mortality in some species (Baerwald et al. 2008). Researchers in Alberta, Canada, found 90% of turbine-related fatalities had evidence of injuries related to barotrauma, and over half of the deaths were likely caused by barotrauma (Baerwald et al. 2008). Barotrauma is not a significant source of fatality in birds, likely because they have smaller hearts as more rigid lungs than bats. The greater effect of barotraumas on bats may contribute to higher mortality rates of bats at many wind facilities (Baerwald et al. 2008).

2.3 Habitat alteration

2.3.1 Birds

Development of wind facilities can cause habitat loss, habitat fragmentation and increases in edge effects for birds and bats (National Research Council 2007). In Europe, habitat loss is considered to be a greater risk for bird mortality than direct collisions (Kuvlesky et al. 2007). Studies have shown species abundances were lower in areas with wind turbines than adjacent areas with no turbines in similar habitats (Osborn et al. 1998, Leddy et al. 1999, Pearce-Higgins et al. 2009), and that some species directly avoid wind farm areas as well as a buffer zone surrounding the turbines. Madsen and Boertmann (2008) found that Pink-footed Geese (*Anser brachyrhynchus*) kept approximately 200 m from an active wind facility in Denmark. This response is likely to be species and habitat-specific, as some studies show that turbines have little or no effect on bird abundances near wind turbines as compared to reference areas (Howe et al. 2002, Devereux et al. 2008). Habitats may also significantly change, if, for example, a forested habitat is converted to a grassland habitat during wind facility development (National Research Council 2007), causing changes in species composition.

Changes in predator or prey densities or species could also affect birds near wind facilities. For example, at the Altamont Wind Resource Area in California, Red-tail Hawk mortality was correlated to increased gopher densities near turbines. Gophers tended to cluster near edges created by facility construction, and hawks were attracted to these clusters for prey (Thelander et al. 2003). The increase in gopher clusters as a result of the change in habitat type caused increases in bird fatalities at the wind facility.

2.3.2 Bats

The effect of wind facilities on bat habitat is also likely to be species- and habitat-specific, although very few studies directly assess this potential impact (National Research Council 2007, Cryan and Brown 2007). Altering the landscape to install wind turbines could potentially influence bat roosting sites and prey abundances, although the degree to which this may happen is largely unknown in most habitats and for most bat species in North America (National Research Council 2007). Horn et al. (2008) predicted that the increase in forest edges surrounding wind turbines could lead to increases in insect densities, which they found were positively related to bat activity near wind turbines. In one European study, bats were more abundant in reference areas than in turbine areas (Brinkmann and Schauer-Weisshahn 2006). It is unclear if this is due to differences in habitat or bats negatively reacting to the turbines.

3. SEASONAL IMPACTS OF WIND TURBINES ON BIRDS AND BATS

Bird and bat fatalities are often most likely to occur during spring and fall migration periods in North America and Europe (Howe et al. 2002). Depending on the location and species, available evidence suggests that higher fatalities could occur during the breeding season, spring or fall migrating season, or the wintering season. Seasonal patterns of migration and local population use of a specific area vary from year to year, making longer-term studies necessary for limiting bird and bat fatalities when turbines are sited (Piorkowski and O'Connell 2010).

3.1. Breeding season

3.1.1 Birds

In general, direct collision fatalities of breeding birds living near wind turbines are much lower than for migrating birds (Kingsley and Whittam 2005). This is possibly because birds nesting near the wind farms become familiar with locations the turbines and learn how to navigate around them. Exceptions include areas where a wind facility was constructed in an area of high bird abundance and where the species do not tend to avoid the turbines, such as the Altamont Pass Wind Resource Area in California (Smallwood and Thelander 2005; Smallwood and Karas 2009, 2007). Here, there is a high mortality rate for local breeding raptors, which is thought to be largely related to high prey densities and topographic conditions of the wind facility (Smallwood 2007). Similarly, terns and gulls along the North Sea coast in Belgium do not alter their behaviors around turbines (Everaert and Stienen 2007). Terns at this colony foraged daily out at sea, and crossed through wind turbine facility during their daily foraging trips. Everaert and Stienen (2007) found that the number of breeding bird pairs was directly correlated to fatality rates at this coastal site.

Direct collision mortality rates for breeding birds may be relatively low in most areas because some species are apparently displaced by the wind facility and avoid the area (Pearce-Higgins et al. 2009). In the United Kingdom, breeding bird populations of 12 species were examined at 12 large wind facilities. Most species (58%; 7 of the 12) tended to avoid turbines up to 800 m (Pearce-Higgins et al. 2009). The effects of displacement on populations of species with a tendency to avoid turbines are unknown; however, it could be significant if suitable habitat was not abundant for these species.

3.1.2 Bats

Studies have found low rates of turbine-based mortality for most species of bats examined in the breeding season (Reynolds 2006, Arnett et al. 2008b). Yet, Piorkowski and O'Connell (2010) found local breeding populations of Brazilian free-tail bats were affected by wind turbines in the late spring and early summer. However, many studies of bat mortality have focused on the migrating season, potentially missing fatalities occurring in the breeding season (Kunz et al. 2007, Arnett et al. 2008b).

3.2 Spring and fall Migration

3.2.1 Birds

Every year in North America, birds and most species of bats migrate northward in the spring and southward in the fall. The most bird fatalities reported around wind turbines happen during migration season in the United States (Kingsley and Whittam 2005, Mabee et al. 2005). Migration pathways are not static, and most birds migrate over broad fronts (National Research Council 2007). There are species-specific trends though, such as eastern raptors using ridges and mountains as migration pathways (National Research Council 2007). Most migrants fly well above the height of the average turbine, but inclement weather can force birds to fly at a lower altitude and cause large mortality events (Johnson et al. 2002, Kingsley and Whittam 2005, Saidur 2011). In addition, when birds stop to rest or feed during migration, they drop down and take off around the height of wind turbines (Kingsley and Whittam 2005).

3.2.2 Bats

The highest rates of bat mortality are reported in mid-summer through early fall in the United States and Europe, which corresponds to fall migration for many species (Brinkmann 2006, Arnett et al. 2008b). Studies have also reported fatalities of certain species (primarily silver-haired bat) in the spring, also corresponding to migration windows (Arnett et al. 2008b). Migration is highly variable in the eastern United States, with large migration events often related to low wind speeds and weather fronts moving through a region (Reynolds 2006, Horn et al. 2008, Arnett et al. 2008b, see Smith and McWilliams 2012 below). Similarly, migration in the western United States also corresponded to low wind speeds as well as dark phases of the moon and low cloud cover (Cryan and Brown 2007). Higher fatalities associated with slow wind speeds are likely related to increases in insect activity during these weather conditions (Kunz et al. 2007, Horn et al. 2008). It is also possible that bats tend to fly at lower altitudes in these weather conditions, increasing their risk of turbine collisions (Cryan and Brown 2007).

3.3 Wintering

3.3.1 Birds

During the winter, most bird activity in North America is generally reduced. Having lower densities of birds generally leads to lower turbine-based fatalities (Kingsley and Whittam 2005). However, turbines could still affect local populations of birds if they are located in areas of high bird use. For example, in the Altamont Wind Resource Area in California there are documented high mortality rates for Red-tailed Hawks (*Buteo jamaicensis*) in the late fall and winter when their use of the area peaked (Smallwood and Karas 2009). Similarly, at the Hopkins Ridge Wind Energy Facility in Washington, the most fatalities occurred in the winter (37%) (Young et al. 2007).

3.3.2 Bats

Little research has been done evaluating bat fatalities in winter. Many temperate species either migrate south to warmer climates or hibernate in the winter.

4. MITIGATION

4.1 Birds

The Altamont Wind Resource Area in California is one of the largest wind facility in the United States (which had up to 6700 small wind turbines in 29 square miles; Rhode Island is 1,212 square miles), with operating wind turbines since the 1980s (Smallwood and Karas 2009). Thousands of bird fatalities, primarily raptors, have been recorded at this site in the past 20 years. The fatalities have been attributed to high prey densities in this area and turbine locations (Smallwood and Karas 2009). In 2005, wind companies implemented various mitigation methods to attempt to reduce the bird fatalities by at least 50%. However, fatality rates for most species increased, despite power generation from the turbines decreasing (Smallwood and Karas 2009). Mitigation methods included leaving deactivated turbines at row ends to divert birds from flying close to active turbines. However, it is possible that birds used the inactive turbine towers to perch on, attracting other birds and causing more fatalities (Smallwood and Karas 2009). Mitigation methods also included leaving broken and inactive turbines in the facility, causing gaps between rows of active turbines that could have drawn more birds into the wind facility, and resulting in more collisions (Smallwood and Karas 2009). In addition, companies were required to shut down turbines for 2 months in the winter. However, the reactivation of these turbines corresponded with peak utilization rates of Red-tailed Hawks, likely increasing fatalities of this species (Smallwood and Karas 2009).

In addition to implementing these mitigation methods to attempt to reduce fatalities at the Altamont Wind Resource Area, a set of mostly nonfunctioning turbines were replaced by more modern turbines spaced farther apart with taller, smoother towers, larger blade sizes, slower blade speeds and higher power outputs than the older generation models at the facility. These new turbines caused significantly lower mortality rates for most species (an 85% reduction in mortality for all birds) than the older generation turbines (Smallwood and Karas 2009).

4.2 Bats

Because bat mortality rates generally increase during low wind speeds (Arnett et al. 2009, Horn et al. 2009), Baerwald and Barclay (2009) examined how altering turbine rotation speeds in low winds would affect bat fatalities at a wind facility in Alberta, Canada during peak migration period. Manipulating the turbines so that they were idle during low wind speeds significantly decreased mortality rates of hoary and silver-haired bats (Baerwald et al. 2009). This is mitigation technique that may not work for other areas where other species are more common.

Installing electromagnetic radiation devices has also been suggested to divert bats from certain areas. Nicolls and Racey (2007) found that bat activity significantly decreased in areas with high electromagnetic field strength (>2 volts/meter). However, exposure to electromagnetic radiation could potentially be harmful to bats, increasing their body temperature and causing hypothermia or decreasing their ability to echolocate (Nicolls and Racey 2007).

5. ENVIRONMENTAL ASSESSMENT GUIDELINES

Several countries have guidelines in place that attempt to limit bird and bat fatalities when new turbines are being constructed (Anderson et al. 1999, Kingsley and Whittam 2005, Scottish National Heritage Guidelines 2005, Rodrigues et al. 2008, USFWS 2012). This section describes the various guidelines for pre- and post-construction monitoring of turbines. Many European countries have used guidelines suggested by the United States Fish and Wildlife Service (2003) to monitor the effect of wind facilities on birds, and the group Eurobats (Rodrigues et al. 2008) have outlined guidelines for reducing bat fatality in Europe. An abbreviated guide to pre- and post-construction monitoring protocols can be found in Appendix 4.

5.1 Pre-construction monitoring

Many monitoring guidelines begin with assessing the pre-construction populations and use of birds and bats in a localized area. This allows any threatened or sensitive species and habitats to be identified, and ensures that the siting of any future wind facility is located where impacts to birds and bats are minimized. Pre-construction monitoring guidelines typically suggest focusing on estimating potential losses from collision, barotrauma, habitat loss, displacement and behavioral changes using existing resources and conducting habitat, bird and bat surveys (USFWS 2012).

5.1.1. Habitat evaluation

5.1.1.1 UNITED STATES

The United States Fish and Wildlife Service (USFWS 2012) guidelines recommend that the first step in pre-construction monitoring should include a survey of the potential facility location in relation to priority habitats for important species. This includes federally-protected areas, as well as areas identified as important for wildlife by local conservation agencies such as the Audubon Society and The Nature Conservancy. When siting a potential wind facility location, USFWS (2012) guidelines recommends documenting known habitats of maternity roosts, nesting, hibernacula, migration stopovers and routes, wintering ranges, and coastal migration drop-out zones. In addition, guidelines include identifying and assessing documenting areas of intact habitat around the potential facility location to determine the degree at which installing a wind facility will cause habitat fragmentation. These guidelines should be used at the landscape scale as well as a more localized level using pre-existing knowledge (USFWS 2012).

5.1.1.2 EUROPE

Similarly, many European guidelines suggest pre-construction habitat evaluation to assess the potential effects of a new wind facility on bird and bat communities (e.g., Langston and Pullan 2003, Cook et al. 2008, Rodrigues et al. 2008, Scottish National Heritage 2009).

5.1.2 Movement ecology in study area

5.1.2.1 RADAR

5.1.2.1.1 US

USFWS (2012) recommend using radar technologies to examine nocturnal bird and bats activities prior to initiation of construction. Common radar technologies include NEXRAD radar and marine radar (Strickland et al. 2011). NEXRAD radar is weather surveillance radar operated by the National Weather Service. These radars provide information at a large spatial and temporal scale, allowing daily assessments of bird and bat migratory passages (Strickland et al. 2011). However, NEXRAD radars cannot filter out noise from insect passages, and they cannot assess the migration passages at the height of the wind facilities.

Marine radar units, X-band and S-band, were initially designed for boats, but they have been used successfully to collect data on passage rates, flight patterns, paths, direction and altitude (Mizrahi 2010, Strickland et al. 2011). X-band radar can detect targets out to 6 km, but there is often interference with insect passages and precipitation. S-band radars are less prone to interference of insects and precipitation, but they often cannot detect small birds and bats. In addition, the marine radar data cannot distinguish among species based on nocturnal targets.

5.1.2.1.2 Europe

Using X-band and S-band radar technology has also recommended by many European reports to better understand the patterns of nocturnal bird and bat activities around areas of potential or installed wind facilities (Langston and Pullan 2003, Rodrigues et al. 2008, Scottish National Heritage 2009).

5.1.2.2 DIRECT OBSERVATIONS

5.1.1.2.1 US

5.1.1.2.1.1 Birds

Point-count surveys, transect surveys, hawk watch surveys, territory mapping, raptor nest surveys, radio telemetry and acoustic monitoring are some recommended methods to determine bird and bat use of a potential site (National Research Council 2007, Strickland et al. 2011, USFWS 2012). Point-count surveys record species use in an established plot over a defined time period. These surveys record abundance, species composition, behavior, flight path, spatial distribution and habitat use. This data can be used to determine best placement of turbines to avoid high usage areas as well as determine displacement after turbines are installed (Strickland et al. 2011). Similar information can be obtained from transect surveys, which are more commonly done in more open grassland or cropland (Strickland et al. 2011). Hawk watch surveys focus on migrating raptors, which researchers have determined to be particularly vulnerable species. These surveys are similar to point-count surveys, but the defined time period of surveying is longer than point-count surveys (1-2 hrs vs. 10-40 min) (Strickland et al. 2011). Hawk counts are often focused during the spring and fall migration periods. Territory mapping, in which researchers record bird location, sex, age, behavior and habitat multiple times a day, is used to determine details about bird breeding pairs in a proposed wind facility site. More specific nest mapping can be done for identified vulnerable breeding birds in the area, such as raptors. Researchers search for nests to determine species, occupancy, substrate and condition (Strickland et al. 2011). Additional surveys can also be done focusing on the known behavior of identified vulnerable species in the site of the proposed wind turbines. Radio telemetry, which involves capturing individuals and attaching a transmitter that tracks its location over time, can be used to determine how a proposed wind facility might impact a threatened or endangered species of bird or bat (Strickland et al. 2011).

5.1.1.2.1.2 Bats

Bats activity is monitored by roost searches, mist-netting and acoustic monitoring. Mist-netting and roost searches can provide some estimate of abundance as well as bat species, sex, age and reproductive condition (Strickland et al. 2011). Acoustic monitoring is often used for determining bat species composition, activity and relative abundance in an area. These methods of surveying bats are best used together to limit sampling biases.

5.1.2.2.2 Europe

Similar direct observations are recommended for bird and bat detection in Europe (e.g., Langston and Pullan 2003, Cathrine and Spray 2009, Cook et al. 2008, Rodrigues et al. 2008, Scottish National Heritage 2009).

5.2 Post-construction monitoring

Post-construction monitoring should assess impact of wind turbines on the collision rates, barotrauma, habitat loss, displacement and behavioral changes of birds and bats spatially and temporally (USFWS 2012). In addition, post-construction monitoring can provide insight into potential mitigation techniques that could be implemented to reduce wind facilities' impacts on birds and bats.

5.2.1 Assessing mortality rates

Assessing mortality rates is important in understanding the impact that turbines are having on birds and bats. Mortality rates can be compared to studies in similar landscapes to determine if rates are low, moderate or high. These rates can be determined for all species in addition to species of high concern, such as threatened or endangered birds and bats.

5.2.1.1 DIRECT MORTALITY – TADS

5.2.1.1.1 US

Thermal Animal Detection Systems (TADS) uses infra-red cameras to detect individuals flying near wind turbines (Drewitt and Langston 2006). This system can provide information on species, flock size, flight altitude and flight behaviors (Desholm et al. 2006, Drewitt and Langston 2006). This technology has not yet been used for detecting birds in the United States. Horn et al. (2008) used thermal image cameras to examine the behaviors of bats around turbine blades at a wind facility in Pennsylvania.

5.2.1.1.2 Europe

TADS, developed in Denmark, have been used to examine the collision patterns at the offshore wind facility, Nystad (Desholm et al. 2006). No collisions have been reported using TADS, which may be a result of bird avoidance of offshore wind facilities (Desholm et al. 2006). In addition, the field of view on the camera is relatively narrow, resulting in a low probability of documenting collisions, and there was currently only one camera on one turbine tested during this study (Desholm et al. 2006). In Germany, Brinkmann and Shauer-Weisshahn (2006) examined the bat activity at two wind facilities and a reference site using thermal image cameras. The thermal image cameras determine swarming behaviors as well as differences in bat activities at various locations, times and wind speeds.

5.2.1.2 SEARCH AREA AROUND TURBINES

5.2.1.2.1 US

Studies in the United States have used a variety of methods to search for bird and bat carcasses around turbines. Typically, they involve searching transects within a defined plot around a turbine. The percentage of turbines searched and the area around each turbine varies considerably among studies. In addition, carcasses found often only represent a portion of total birds or bats killed by direct collision. Many carcasses are missed by searchers or are removed by predators. To account for both searcher inefficiencies and carcass predation, researchers should perform carcass removal studies (Smallwood 2007).

5.2.1.2.2 Europe

Similar searching techniques are recommended for bird and bat detection in Europe (e.g., Langston and Pullan 2003, Cathrine and Spray 2009, Cook et al. 2008, Rodrigues et al. 2008, Scottish National Heritage 2009).

5.2.1.3 ASSESSING CARCASS RETENTION RATES

5.2.1.3.1 US

Researchers use carcass removal studies to adjust for searcher inefficiency and carcass predation (Smallwood 2007). To estimate searcher inefficiency, marked carcasses are randomly placed within the search area, and the percentage of these carcasses found by searchers is then determined. To estimate carcass predation, marked carcasses are placed randomly in the sampling area and revisited every 1-2 days to determine the average amount of time a carcass remains in the area (Strickland et al. 2011). These studies should be made using a variety of sizes of birds as well as bats (Arnett 2006) in all seasons, as the correction factors are likely to vary by size and time of year (Strickland et al. 2011).

5.2.1.3.2 Europe

Similar searching techniques are recommended for assessing carcass retention rates in Europe (Rodrigues et al. 2008, Scottish National Heritage 2009).

5.2.1.4 LENGTH OF STUDY

5.2.1.4.1 US

Many studies focus their mortality assessments on a specific time of year. For example, Johnson et al. (2004) report mortality rates of bats at Buffalo Ridge Wind Resource Area during the fall migration season. However, these studies may miss fatalities of local wintering or roosting populations affected by the turbines. The USFWS (2012) recommends bird and bat fatality monitoring should occur in all seasons in order to capture the effects of turbines on different species, their migration patterns and their local populations.

There is often spatial and temporal variation in migration patterns, breeding and wintering habitat from year to year. Multiple year studies have found variations in mortality rates from year to year (e.g., Johnson et al. 2004, Kerlinger et al. 2006). The USFWS recommends multi-year assessments to capture temporal variation in mortality rates and displacement (USFWS 2012).

5.2.1.4.2 Europe

Various time frames are suggested for monitoring studies done in Europe, but most recommend multi-year assessments on wind facility impacts on birds and bats (e.g., Langston and Pullan 2003, Rodrigues et al. 2008, Scottish National Heritage 2009).

5.2.2 Assessing movement ecology near turbines

5.2.2.1 RADAR

5.2.2.1.1 US

Two types of radar are generally used to detect birds and bats: x-band and s-band. X-band radar uses short wavelengths to detect targets vertically. Data regarding height distributions and rates of passage overhead can be gathered. X-band data provides good resolution of passerine-sized targets; however, this type of radar often confuses insect clouds with bird or bat targets. S-band radar uses long wavelengths to detect targets, but S-band data often cannot detect passerine-sized targets; however, this type of radar differentiates between insect clouds and bird or bat targets.

Using radar to assess the movement ecology of birds and bats near turbines can determine if birds are being displaced or avoiding turbine areas. There is an energetic cost to flying around wind facilities; however, the extent to which this significantly affects bird or bat populations is likely species specific (USFWS 2012).

Radar can also determine how birds and bats are responding the turbines. Arnett et al. (2005) documented the behavioral responses of bats to turbines in West Virginia using radar. They determined that slower blade speeds increase fatalities at this facility; therefore, mitigation techniques could be applied to decrease these direct collisions (Horn et al. 2008).

5.2.2.1.2 Europe

Radar technology installation is also recommended by many European reports to better understand the patterns of nocturnal bird and bat activities around areas of installed wind facilities (Langston and Pullan 2003, Rodrigues et al. 2008, Scottish National Heritage 2009).

5.3 State Guidelines

States vary in their wind power usage, ranging from no wind power in seven states to over 10,000 MW of wind-generated electricity in Texas (Table A1.3). States with environmental voluntary assessment guidelines include Arizona, California, Indiana, Iowa, Kansas, Maine, Massachusetts, Michigan, Montana, Nevada, New Mexico, New York, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, South Dakota, Texas, Vermont, Washington, Wisconsin and Wyoming. There are no states with mandatory bird/bat guidelines that we could find.

5.4 Summary of USFWS (2012) Recommended Guidelines

We have abbreviated the USFWS (2012) recommended guidelines below, however our recommendation is that all wind development in Rhode Island should follow using all guidelines listed on the official 2012 guidelines. The guidelines consist of five potential tiers of evaluation before and after a wind facility is constructed minimize negative impacts on bird and bat populations and their habitats. Within each tier, data are collected that is then refined and expanded upon in the next tier. At each tier, a list of questions is provided as well as the metrics and methods best used to answer those questions. Below is a brief explanation of each tier.

Tier 1: Preliminary evaluation or screening of potential sites

In Tier 1, USFWS (2012) guidelines recommend developers work with the USFWS and other local agencies to determine areas that are inappropriate for wind energy development based on the risks to wildlife and their habitats. Developers and agencies should take into consideration the following points when evaluating the potential wind facility site in the initial stages: what potential or known wildlife resources are in the potential wind facility site; if there are bat maternity roosts, hibernacula, avian staging areas wintering ranges, nesting sites, migration stopovers, coastal migration drop-out zones, leks, or other areas of significance; if there are important intact habitats at the potential site in which habitat fragmentation would be detrimental to the wildlife present; or is the site important for the recovery of a listed species; are there important plant species present. Developers and agencies should use local resources to address the above points before moving on to the Tier 2 guidelines. Developers could use this report for sites in Rhode Island for the initial screening of sites. If none of the above points are compromised, the developer should move on to Tier 2 considerations. If the developers find that any of the above points will be compromised if a wind facility is constructed in the given area, they should consider finding an alternate location or implementing mitigation techniques in order to preserve the wildlife and its habitats in the area.

Tier 2: Site characterization

In Tier 2 of the process, the developer should narrow their search to specific sites, addressing many of the same points as in Tier 1, but with a specific location chosen. In addition, the developer should do some initial field-based evaluations of the appropriateness of the specific site for wind facility development. The same points should be considered at this stage as were considered in Tier 1. However, a wildlife biologist or botanist should visit the site in all seasons and conditions to address the points in addition to using maps, reports and other resources from the USFWS and other local agencies. If none of the above points are compromised, the developer should move on to Tier 3 considerations. If the developers find that any of the above points will be compromised if a wind facility is constructed in the given area, they should consider finding an alternate location or implementing mitigation techniques in order to preserve the wildlife and its habitats in the area.

Tier 3: Pre-Construction monitoring and assessments

Tier 3 is where scientifically rigorous and quantitative evaluations of the wind facility site begin. At this stage, the developer evaluates the site to determine how the facility should be designed, constructed and operated to minimize the effects to wildlife; established compensation measures if wildlife or its habitat will unavoidably be compromised due to wind facility development; and determine the duration and intensity of pre- and post-construction surveys. In Tier 3, the affected species' distribution, site use and behavior are quantified, as well as the potential risks to local and migration populations. A variety of assessment and monitoring tools are recommended at this stage including an in-depth literature search of the selected site, baseline surveys, and risk models for species and habitat. If the developer determines there is low risk to species and habitat with the installation of a wind facility, the developer should move on to Tier 4 considerations. If the developer finds that the species or habitat will be compromised if a wind facility is constructed in the given area, they should consider finding an alternate location or implementing mitigation techniques in order to preserve the wildlife and its habitats in the area.

Tier 4: Post-construction monitoring of effects

After construction of the wind facility has commenced, fatality and other effects are monitored in Tier 4. Carcasses searches and searcher efficacy studies should be conducted to determine how actual mortality rates compare with predicted rates. In addition, fatality patterns should be examined to determine if certain aspects of the wind facility, such as location of certain towers or other features, or if other factors, such as season or weather, are contributing to higher rates of mortality than others. The developer can then assess the need for modifications to the wind facility to minimize fatalities at the site. In addition, any adverse effects to habitat or species behavior should also be identified in this step. The type, duration and intensity of monitoring will depend on the fatality rates as well as factors identified in Tiers 1-3.

Tier 5: Research

Research should be conducted when Tier 3 highlights potential high risk for species or habitats and there is some uncertainty regarding effective mitigation techniques or Tier 4 assessments resulted in higher than predicted mortality rates. Developers would design experiments and research projects to address any issues that arose in the operation of their wind facility.

6. POTENTIAL EFFECTS OF TURBINES IN RHODE ISLAND

6.1 Documented studies

There are no published studies that we know that have investigated effects of operational terrestrial wind turbines on birds or bats in Rhode Island. However, there are two known assessments of the potential effects of proposed terrestrial wind turbines on local populations of birds and bats on Conanicut Island, Jamestown (Mendelsohn et al. 2009) and the Point Judith area (Raithel 2008). In addition, a 100 kW, 117-foot turbine that was installed by RI DEM at Fishermen's Memorial State Park in mid-September 2011 is currently undertaking an ongoing bird monitor effort (Table 5).

In addition, offshore wind facilities are proposed south of Block Island. As part of the environmental review process for these turbines, terrestrial surveys (i.e., radar studies at the SE lighthouse, raptor surveys and bats surveys with acoustic monitors) have been conducted, but no data or analyses from this research were available at the time of this report, thus we could not provide information from these studies.

Table 5. Summary of nine wind turbine facilities currently active in Rhode Island as of May 2012.

Name	Output (MW)	Installation Year	Height (m)	Manufacturer
Easton Pond Business Center	100 kw	2009	-	Northern Power Systems
Fisherman's Memorial State Park and Campground	100 kw	2011	54	Northern Power Systems
East Matunuck State Beach	19 KW	2012	36	NA
New England Tech	100 kw	2010	48	Northern Power Systems
Portsmouth Abbey	660 kw	2006	82	Vestas
Salty Brine Beach Bath House	10 kw	2010	30	NA
Shalom Housing	100 kw	2011	48	Northern Power Systems
Town of Portsmouth at High School	1.5 MW	2009	102	AAER
Field's Point (3 turbines)	1.5 MW	2012	110	Goldwind

6.2 Birds of Rhode Island

There have been approximately 388 species of birds that have been documented in Rhode Island (Desante and Pyle 1986, August et al. 2001), of which 166 species nest in the state (Enser 1992) (Table A2.1). Of the breeding species in the state, 53 species are considered common, 10 species are fairly common, 56 species are uncommon and 47 species are rare (Table A2.1). Of the species that do not breed in Rhode Island but that occur in the state during the summer months, 5 species are considered common (e.g., Great Shearwater which nests in the southern hemisphere), 6 species are uncommon, 32 species are rare and 8 species accidental (Table A2.1).

We classified 185 species as migrants that dispersed through Rhode Island between their breeding grounds and wintering areas, of which 25 species we classified as common, 20 species are fairly common, 53 species are uncommon, 34 species are rare, 52 species are accidental and 1 species is extinct (Table A2.1).

We classified 115 species as wintering, but not nesting, in Rhode Island (Table A2.1), of which 15 species are common, 4 species are fairly common, 34 species uncommon, 38 species are rare and 24 species are accidental. Of the 102 species that nest and winter in Rhode Island (resident species), 27 are common, 6 are e fairly common, 43 are uncommon, 23 are rare and 3 are accidental in winter.

In the following sections, we summarize the habitat associations and movement ecology of the 55 federally- and state-listed species, and those species associated with specific habitats (grasslands, shrub-scrub, forested habitats, and coastal ponds) in Rhode Island. We also discuss data sources that would be useful to biologists interested in conducting impact assessments for the potential development of wind turbines or other renewable energy sources in Rhode Island. Finally, we discuss guidelines for wind turbine development in Rhode Island based on existing state and federal guidelines.

6.3 Data sources

We quantified the abundance and distribution of birds using terrestrial habitats in Rhode Island from a variety of sources including the RI Breeding Bird Atlas (Enser 1992), the Breeding Bird Survey (http://www.mbr-pwrc.usgs.gov/bbs/), Christmas Bird Counts (http://birds.audubon.org/historical-results), the Great Backyard Bird Count (http://gbbc.birdsource.org/gbbcApps/report), and the Avian Knowledge Network (http://www.avianknowledge.net/content/). In addition, we summarized data from three local constant-effort bird banding stations (Kingston Wildlife Research Station, Block Island Banding Station, and Ninigret Banding Station).

To examine the distribution and abundance of breeding landbirds in the state, we used data from Enser (1992) and USGS Breeding Bird Survey (BBS) (http://www.mbr-pwrc.usgs.gov/bbs/). To our knowledge there are no recent systematic, statewide surveys that have quantified breeding landbirds in Rhode Island. Enser (1992) coordinated a Breeding Bird

Atlas survey from 1982-1987 based on subdividing the state into a 25-km^2 grid system. For Enser's (1992) research, he enlisted volunteers to document possible, probable and confirmed nests for each species within each grid cell based on systematic criteria. We used these data to examine the distribution and abundance of all breeding birds in the state, including grassland, forest and shrub specialists, as these were the most current, widespread surveys designed to document the distribution of birds throughout Rhode Island.

The Breeding Bird Survey (BBS) was initiated in 1966, and it is the primary large-scale monitoring program used to document population trends for breeding birds in North America. This survey uses volunteers to conduct point counts along pre-determined 24.5 mile-long road-based routes, with observers stopping at 0.5 mile intervals to count every bird seen or heard during a 3-minute survey period during early morning surveys. To maintain consistency, the same routes and the same methods are followed every year. In North America, there are approximately 3000 routes. All data collected during these surveys are available on a website maintained by USGS biologists (http://www.mbr-pwrc.usgs.gov/bbs/), which allowed us to analyze data using tools developed by these biologists. We choose to utilize the data for most birds at a regional scale (e.g., New England and the mid-Atlantic Coast) because too few routes are conducted in Rhode Island to detect precise estimates of population trends. For species with low detection rates at a regional scale, we used the survey-wide dataset. The BBS is primarily designed for diurnal passerines, and other species are poorly tracked. We present estimates of annual rates of change and species with significant rates of decline that are of concern.

We used the Christmas Bird Count (http://birds.audubon.org/historical-results) and the Great Backyard Bird Count (http://gbbc.birdsource.org/gbbcApps/report) datasets to examine the relative abundance of wintering birds in Rhode Island. The Christmas Bird Count is a one-day annual citizen science based survey of birds in early winter (from December 14 – January 5) administered by The Audubon Society. Active circles have changed through the years in Rhode Island. The first one in Rhode Island occurred in Glocester in 1902, and currently there are active count circles in South Kingstown, Block Island, Napatree and Newport.

The Great Backyard Bird Count, administered by The Audubon Society, The Cornell Lab of Ornithology and Bird Studies Canada, is an annual one-day survey that takes place over President's Day weekend, where citizens count and identify birds and submit their data online. We used data from 1998 – 2011 from various participating towns to determine the spatial distribution of wintering birds in decline in Rhode Island, as determined by the USGS BBS.

The Avian Knowledge Network (http://www.avianknowledge.net/content/), funded by the National Science Foundation, is a partnership between many governmental and non-profit groups and largely administered by the Cornell Lab of Ornithology. The Avian Knowledge Network is a compilation of over 50 bird observation datasets from around the world, including eBird, Great Backyard Bird Count, Project Feederwatch, North American Breeding Bird Survey, and Hawk Watch datasets. As a part of this record, eBird observers send in their observations. This is not a systematic survey, thus it provides information on the presence of a species on a particular date at a specific point. However, there is a tendency for just rare species to be reported, thus eBird records should be considered as one tool to begin to assess the distribution of birds in the state.

To assess the current distribution of wading bird colonies and other colonial nesting birds in Rhode Island, we used surveys initiated by Ferren and Myers (1998) and continued by C. Raithel (RI DEM, unpubl. data). These surveys document the distribution and abundance of colonial breeders (egrets, herons, terns, cormorants, gulls, oystercatchers) throughout coastal regions of Rhode Island, with an emphasis on Narragansett Bay. Department of Environmental Management (DEM) observers visit colonies annually, where they attempt to count every nest (see Ferren and Meyers 1998).

To understand the distribution of Piping Plovers in Rhode Island, we contacted Erin King (USFWS, RI Refuge Complex, Charlestown RI) to obtain the most recent survey data conducted by USFWS biologists. Since the early 1990s, USFWS biologists have surveyed Piping Plover nesting colonies both on refuges and non-refuge lands. Biologists visit all potential nesting beaches at least weekly (and sometimes daily) throughout the breeding season to document the number of nesting pairs and productivity on each beach. This represents the most comprehensive, spatially-explicit dataset on any species of bird nesting in the state.

We also summarized data from constant-effort bird banding stations to describe the abundance of migratory landbirds in Rhode Island. There are three active banding stations in Rhode Island: Kingston Wildlife Research Station (41° 28’ 40”N, 71° 30’39”W) - operated by URI biologists on a 82-acre Audubon Society of Rhode Island property; Block Island Banding Station (41° 12’ 34”N, 71° 33’30”W) on the north end of Block Island – operated at the Lapham property by Kim Gaffet, with data management by Steve Reinert; and Ninigret National Wildlife Refuge banding station (41° 21’ 40”N, 71° 35’55”W) – operated by USFWS biologists, which is located on north-central side of Ninigret Pond adjacent to restored runways.

To assess conservation status of birds, we used several sources. First, to determine federal status, we searched the website maintained by the US Fish and Wildlife Service that list Threatened and Endangered species (http://www.fws.gov/endangered/species/). Second, the State of Rhode Island Natural Heritage program maintains a Threatened and Endangered Species list (Rhode Island Natural Heritage Program. 2006), which has not been updated since 2006 to our knowledge.

There are also two national efforts designed to prioritize conservation plans for birds in the United States. Another scheme to prioritize conservation issues for birds was developed for Bird Conservation Regions by the North American Bird Conservation Initiative (http://www.nabci-us.org/bcrs.htm). Rhode Island is located within Bird Conservation Region

(BCR) 30, which covers New England and the mid-Atlantic coast. Under this prioritization scheme, species are classified as either: **Highest Priority** (i.e., they have high BCR Concern and Responsibility and either High or Moderate Continental Concern), ***High Priority*** (High continental concern and Moderate BCR responsibility OR Moderate BCR Concern and High BCR responsibility OR High BCR concern and moderate BCR responsibility OR non-breeding High continental concern species whose primary area of spring or fall migration overlaps the BCR) or ***Moderate Priority*** (Moderate BCR Concern and Moderate BCR responsibility OR High Continental Concern and Low BCR Responsibility OR High BCR Concern and Low BCR Responsibility and Regionally Threatened Species (PIF Tier IIC, see below) OR High BCR Responsibility and Low BCR Concern or Sub-species of Regional Importance).

Partners in Flight (PIF; http://www.partnersinflight.org/) have also developed a prioritization scheme, with a North American Landbird Conservation Plan (Rich et al. 2004; http://www.partnersinflight.org/cont_plan/#Part1). For this report, we focused on the Eastern Avifaunal Biome (http://www.blm.gov/wildlife/table_09.htm). PIF developed their conservation strategies based on an assessment of six factors, (1) population size, (2) breeding distribution, (3) non-breeding distribution, (4) threats to breeding, (5) threats to nonbreeding, and (6) population trend. This quantitative assessment was conducted on landbirds in North America to assess continental and regional conservation issues. PIF categorizes the conservation statuses of birds into tiers as follows: Tier I A: High Continental Priority - High Regional Responsibility, Tier I B: High Continental Priority - Low Regional Responsibility, Tier II A: High Regional Concern, Tier II B: High Regional Responsibility, Tier II C: High Regional Threats, Tier III: Additional Watch List, Tier IV: Additional Federally Listed, Tier V: Additional State Listed.

6.4 Species of high concern, federal and state listed species

There are two federally-listed species and 53 state-listed species in Rhode Island. There are currently two species of birds listed by the US Fish and Wildlife Service as either Threatened or Endangered that occur in Rhode Island, as of 9 January 2012 (USFWS 2012). These include Roseate Tern (Endangered) and Piping Plover (Threatened; Table 6; see species accounts below), which both occur in coastal habitats. In addition, there are eight species listed as State Endangered, five species listed as State Threatened, six species listed as State Historical, and 34 species listed as State Concern (Rhode Island Natural Heritage Program 2006).

Of those eight species listed as State Endangered (Table 6), two are rare species that breed in coastal ponds surrounded by persistent, emergent vegetation (Pied-billed Grebe and American Bittern), one prefers anthropogenic structures for nesting, but migrates in coastal areas (Peregrine Falcon), three primarily occur in grassland habitats (Northern Harrier (breeds on Block Island, winters in coastal Rhode Island), Barn Owl (breeds on Block Island and isolated areas on mainland Rhode Island), Upland Sandpiper (extirpated as a breeding bird in RI, but still is occasional observed in larger grasslands during spring and fall migration), one occurs rarely in shrub habitats (Yellow-breasted Chat is a rare breeding bird in the state and detected primarily during fall migration in coastal shrub habitats), and one rare forest specialist (Cerulean Warbler is extirpated as a breeding bird and occasionally detected during migration periods now).

Of the five State Threatened species (Table 6), two species are restricted to coastal beaches and coastal ponds (Least Bittern and Least Tern) during the summer months where they nest and forage, and three species (Northern Parula, Black-throated Blue Warbler and Blackburnian Warbler) nest in a few isolated forest stands in Rhode Island (hence the reason for their listing), but they are common migrants throughout the state (particularly during fall migration), and one species (Grasshopper Sparrow) is a rare breeding bird in isolated grasslands throughout the state.

Of the six State Historical species (Table 6), Sharp-shinned Hawk is an uncommon breeding bird in the state, but a common migrant – particularly during fall migration in coastal areas. Common Moorhen is at the northern limits of their breeding range. The other four species are occasionally detected as migrants in the state, but they presumably no longer breed in Rhode Island.

Of the 33 species listed as State Concern (Table 6), eight are colonial-breeding birds, (Great, Snowy, and Cattle Egret, Little Blue Heron, Glossy Ibis, and Black-crowned and Yellow-crowned Night-Heron). There are four species of waterfowl that rarely nest in the state, but are much more common as wintering birds (except Blue-winged Teal). Of the listed diurnal raptors, Osprey and Cooper’s Hawk are much more abundant in 2012 than when this list was developed, and their status should be reconsidered, while Northern Goshawk is still a rare bird in the state. Five species that breed in coastal ponds are uncommon in marshes with extensive persistent, emergent vegetation (King and Clapper Rail, Sora, and Marsh Wren), or saltmarsh habitats (Willet). American Oystercatchers nest on islands throughout Narragansett Bay and in Little Narragansett Bay. Of the nocturnal species, Long-eared Owl is a rare species, while Northern Saw-whet Owl is much more common than previously thought, particularly during fall migration (P. Paton, unpubl. data). Of the remaining species, seven species are forest specialists that are rare breeding birds: Pileated Woodpecker, Winter Wren (more common as a wintering bird in RI), Acadian Flycatcher, Prothonotary Warbler (southern species spreading north), Worm-eating Warbler (southern species spreading north), White-throated Sparrow, and Dark-eyed Junco. White-throated Sparrow and Dark-eyed Junco are abundant migrants with tens of thousands wintering throughout Rhode Island. Horned Lark is a grassland specialist that breeds in a few grasslands throughout the state, and is more common in winter.

Table 6. Birds that occur in Rhode Island that are either federally-listed at threatened or endangered by the US Fish and Wildlife Service (USFWS 2012) or are listed by the state of Rhode Island as a species of concern (Rhode Island Natural Heritage Program 2006).

Species	Status[a]	Species	Status
Pied-billed Grebe	SE	Willet	C
American Bittern	SE	Upland Sandpiper	SE
Least Bittern	ST	Roseate Tern	FE/SH
Great Blue Heron	C	Least Tern	ST
Great Egret	C	Barn Owl	SE
Little Blue Heron	C	Long-eared Owl	C
Snowy Egret	C	Northern Saw-whet Owl	C
Cattle Egret	C	Common Nighthawk	C
Black-crowned Night Heron	C	Pileated Woodpecker	C
Yellow-crowned Night Heron	C	Acadian Flycatcher	C
Glossy Ibis	C	Horned Lark	C
Green-winged Teal	C	Cliff Swallow	SH
Blue-winged Teal	C	Winter Wren	C
Gadwall	C	Marsh Wren	C
Hooded Merganser	C	Golden-winged Warbler	SH
Bald Eagle	C*	Northern Parula	ST
Osprey	C	Black-throated Blue Warbler	ST
Northern Harrier	SE	Cerulean Warbler	SE
Sharp-shinned Hawk	SH	Blackburnian Warbler	ST
Cooper's Hawk	C	Prothonotary Warbler	C
Northern Goshawk	C	Worm-eating Warbler	C
Peregrine Falcon	SE	Yellow-breasted Chat	SE
King Rail	C	Vesper Sparrow	SH
Clapper Rail	C	Henslow's Sparrow	SH
Sora	C	Grasshopper Sparrow	ST
Common Moorhen	SH	Seaside Sparrow	C
Piping Plover	FT	White-throated Sparrow	C
American Oystercatcher	C	Dark-eyed Junco	C

[a] Status: FT = Federally Threatened, FE = Federally Endangered, SC = State concern (rare or vulnerable), SH = State Historical (currently not known to occur in RI), ST = State Threatened (likely to become State Endangered), SE = (State Endangered, imminent danger of extirpation in RI). *Bald Eagle is no longer a federally-listed species.

Based on our analysis of mortality studies at existing wind facilities throughout North America (Table 1), including an assessment of which species have been documented as being killed by turbines, we considered which species might be vulnerable to wind turbines in Rhode Island. We primarily focused on state or federally-listed species, as their populations are possibly the most vulnerable (Fig. 6).

Based on fatality studies in the literature (Table 1), species that nest or forage in grassland habitats appear to be particularly vulnerable to fatalities from wind facilities. This includes Horned Lark, Barn Owl, Grasshopper Sparrow, Vesper Sparrow and Northern Harrier (Fig. 6). Documented fatalities of Horned Larks, Grasshopper and Vesper Sparrows primarily occurred in mid-western states during the breeding season where they are abundant, and because these species have aerial courtship displays that make them vulnerable to collisions. Barn Owls and Northern Harriers hunt for small mammals in grasslands, often within the elevation of the rotor sweep zone, again, making them vulnerable. Due to the paucity of suitable grassland habitat in Rhode Island, and the fact that these species are all rare in the state, we suggest that wind turbines not be located in grasslands due to the vulnerability of these species (see Grassland account below, section 6.8.1).

Of the other species listed in Fig. 6, we do not believe wind turbines pose a major threat to forest specialists. For example, although Dark-eyed Juncos are a rare breeding bird in Rhode Island (coniferous forests in western Rhode Island), the state is at the edge of their extensive breeding range. During winter, thousands of juncos winter throughout Rhode Island and are a widely dispersed bird in the region, thus we feel this species' population is not vulnerable to wind turbines at this time.

Most species of concern in Rhode Island (Table 6) tend to have low fatality estimates at wind turbines (Fig. 6), thus populations of most of these species probably will not be affected by wind energy developments in the state. However, there have been very few studies on the effects of turbines on birds in areas similar to Rhode Island. Therefore, once wind facilities are installed in the state, the effects on birds and bats should be assessed to populations are not more vulnerable to turbine fatalities than what is reported in the literature to date.

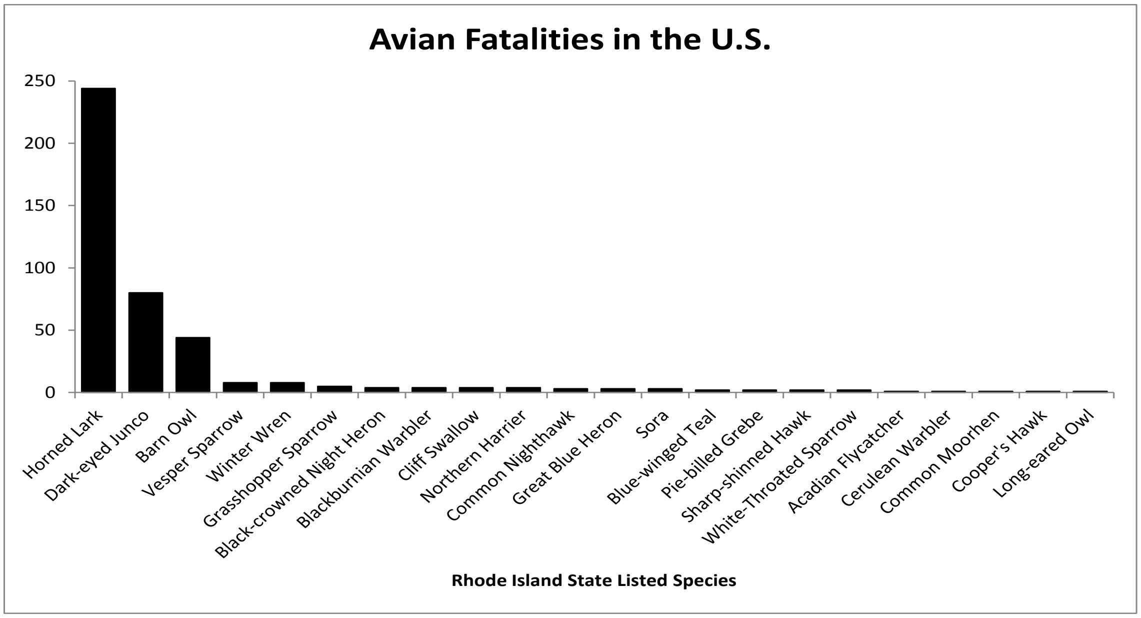


Figure 6. Total number of documented mortalities of birds at wind facilities in North America for species that are listed as conservation concern in Rhode Island based on a literature review (Table 6).

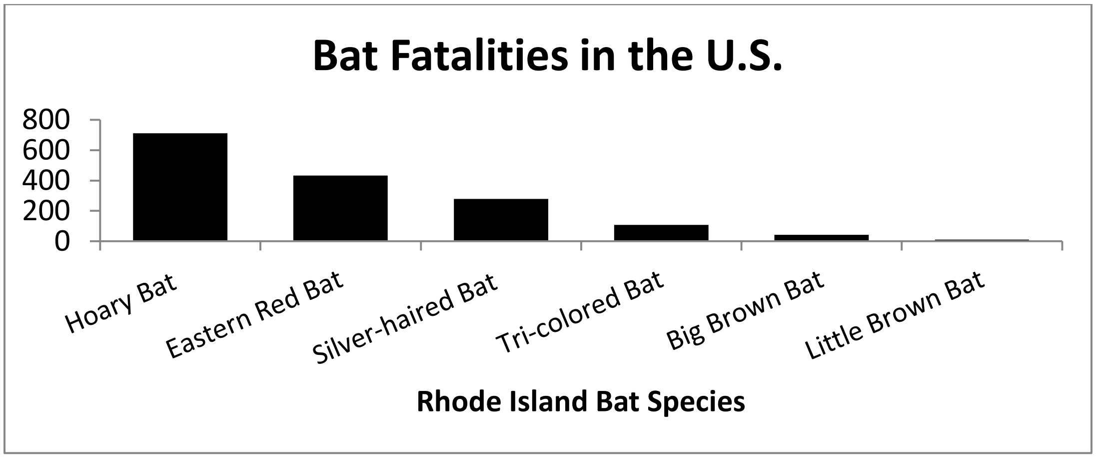


Figure 7. Total number of bat fatalities documented in the peer-reviewed literature and technical reports for species that occur in Rhode Island. Hoary, Red and Silver-haired Bats are migratory, non-hibernating tree-roosting bats, while Tricolored, Big Brown and Little Brown Bats are species that hibernate and are affected by White-nosed Syndrome.

Available evidence suggests that migratory, tree-roosting bats (e.g., Hoary, Red, and Silver-haired Bats) are more vulnerable to collision risk than cave-roosting bats (e.g., Tri-colored, Big Brown and Little Brown) (Fig. 7). However, these cave-roosting bats are vulnerable to White-nosed Syndrome, with their populations declining by 100% in some caves in the northeast (see section 7.1).

6.4.1 Federally-listed species

According to the most recent listing decisions by the US Fish and Wildlife (www.fws.gov/endangered/species/; accessed 9 January 2012), there are currently two federally-listed species of birds that occur in Rhode Island, Roseate Tern (Endangered) and Piping Plover (Threatened), thus these species are afforded special protection under the federal Endangered Species Act of 1973. This law requires federal agencies, in consultation with the U.S. Fish and Wildlife Service, to ensure that actions they authorize, fund, or carry out are not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of designated critical habitat of such species. The law also prohibits any action that causes a "taking" of any listed species of wildlife.

Bald Eagles were formerly federally-listed as threatened, but they were removed from the endangered species list in 2007. However, eagles are protected under the Bald and Golden Eagle Protection Act of 1962, which prohibits anyone from ‘taking’ an eagle without a permit. This also includes disturbance that may result from human-induced changes to the traditional nest sites as such changes may interfere or interrupt their normal behavior. The USFWS includes wind turbines in the interpretation of this law; hence, we include a discussion of eagles below.

6.4.1.1 PIPING PLOVER (*CHARADRIUS MELODUS*)

Piping Plovers nesting in Rhode Island are currently regulated by the USFWS as a Threatened species (USFWS 2012), and they are protected under the Endangered Species Act of 1973. Piping Plovers are only in Rhode Island during the breeding season (Fig. 8) and nest only beaches in southern Rhode Island and on Block Island (Table 7; Fig. 9). Piping Plovers are classified as highest priority for conservation in Bird Conservation Region 30 and a Tier IA (***High Continental Priority - High Regional Responsibility***) species by Partners in Flight (Table A2.2). Piping Plovers are a migratory species, occurring in Rhode Island from mid-March through the end of September, primarily on beaches where they nest and coastal stopover sites such as mudflats in coastal ponds (Fig. 9). In the 1980s, less than 10 pairs nested along coastal Rhode Island, and by 2011 their numbers had increased to 87 pairs (http://www.fws.gov/ninigret/complex/images/ARS_plover2011.pdf). Nesting Piping Plovers are primarily restricted to sandy beaches in southern Rhode Island (Table 7; Fig. 9). They forage in the intertidal zone along beaches and also on mudflats of coastal ponds (e.g., Ninigret Pond, Maschaug Pond, Trustom Pond, and Quicksand Pond). During migration, Piping Plovers use stopover habitat in coastal ponds and the intertidal zone of beaches. Given the importance of coastal beaches to Piping Plovers, we recommend that no wind turbines be constructed directly on the coast, particularly near beaches where plovers are managed by the USFWS and have exhibited evidence that successful reproduction has occurred (Table 7). In addition, we recommend that wind turbines be placed at least 1 km inland from beaches where Piping Plovers are known to nest in order to reduce the possibility of Piping Plovers colliding with turbines.

To our knowledge, the USFWS does not recommend specific buffer distances from plover nests for wind turbines. The state of New Jersey recommends a 400-m buffer near plover nests (http://www.nj.gov/dep/cmp/windreport090908f.pdf), but suggests a larger (1 km) buffer around major shorebird concentration areas. Given that we know little about migratory movements of Piping Plovers or foraging flights during the breeding season, we recommend a more conservative 1000-m buffer that this time to minimize the potential that plovers are affected by wind turbines. As biologists learn more about plover movement ecology, these buffer recommendations could be modified.

Table 7. Annual variation in the mean (Standard Deviation [SD]) number of Piping Plover pairs and productivity (number of chicks per pair) at various beaches throughout Rhode Island from 2000 to 2011.

	Number of pairs		Productivity	
Beach	**Mean**	**SD**	**Mean**	**SD**
E. Beach Watch Hill	15.3	6.1	2.1	0.8
Napatree	5.8	2.6	0.7	0.7
Quonchotaug	7.9	2.6	1.6	0.7
Ninigret	8.9	2.9	0.9	1
Ninigret NWR	2.9	2	0.7	1.2
Charlestown	0.3	0.5	0.3	0.8
Green Hill	0.6	0.8	0.8	1.4
Trustom	9.2	2.8	1.5	0.9
East Matunuk	0.8	0.5	0.8	1.1
Narrow River	1.3	0.7	2.6	1.3
Sachuest	0.8	0.6	1	1.6
Block Island	0.6	0.7	0.2	0.6
Sandy Point	1.4	1.7	0.5	0.8
Briggs Beach*	6.1	1.5	1.2	0.8
Goosewing Beach*	7.7	1.5	1.3	0.6

*Data from 1998 - 2009

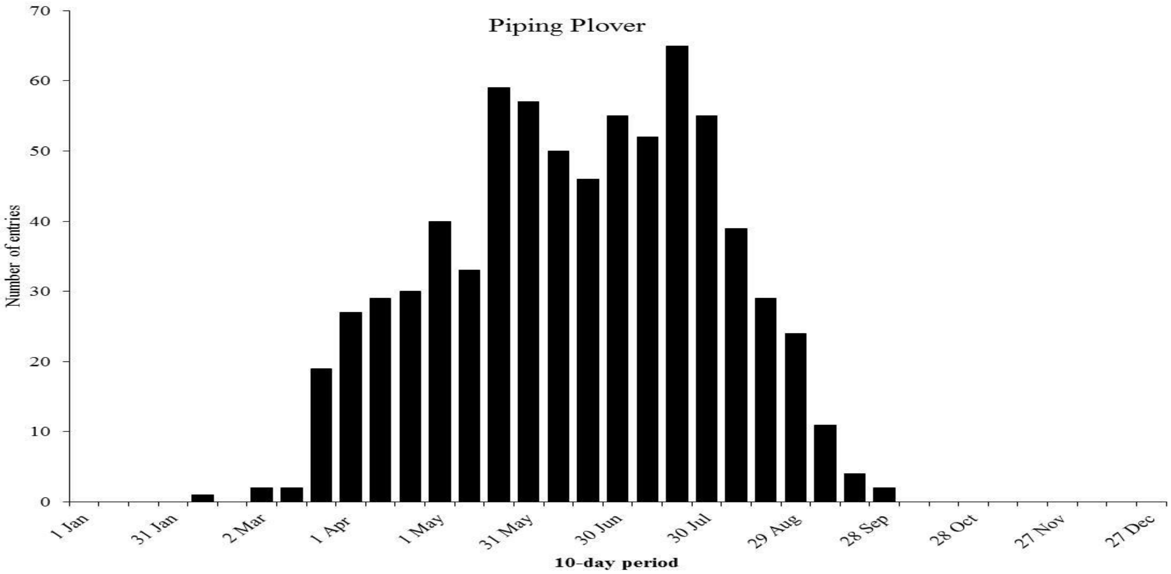


Figure 8. Phenology of Piping Plover occurrence in Rhode Island based on observations of the Avian Knowledge Network.

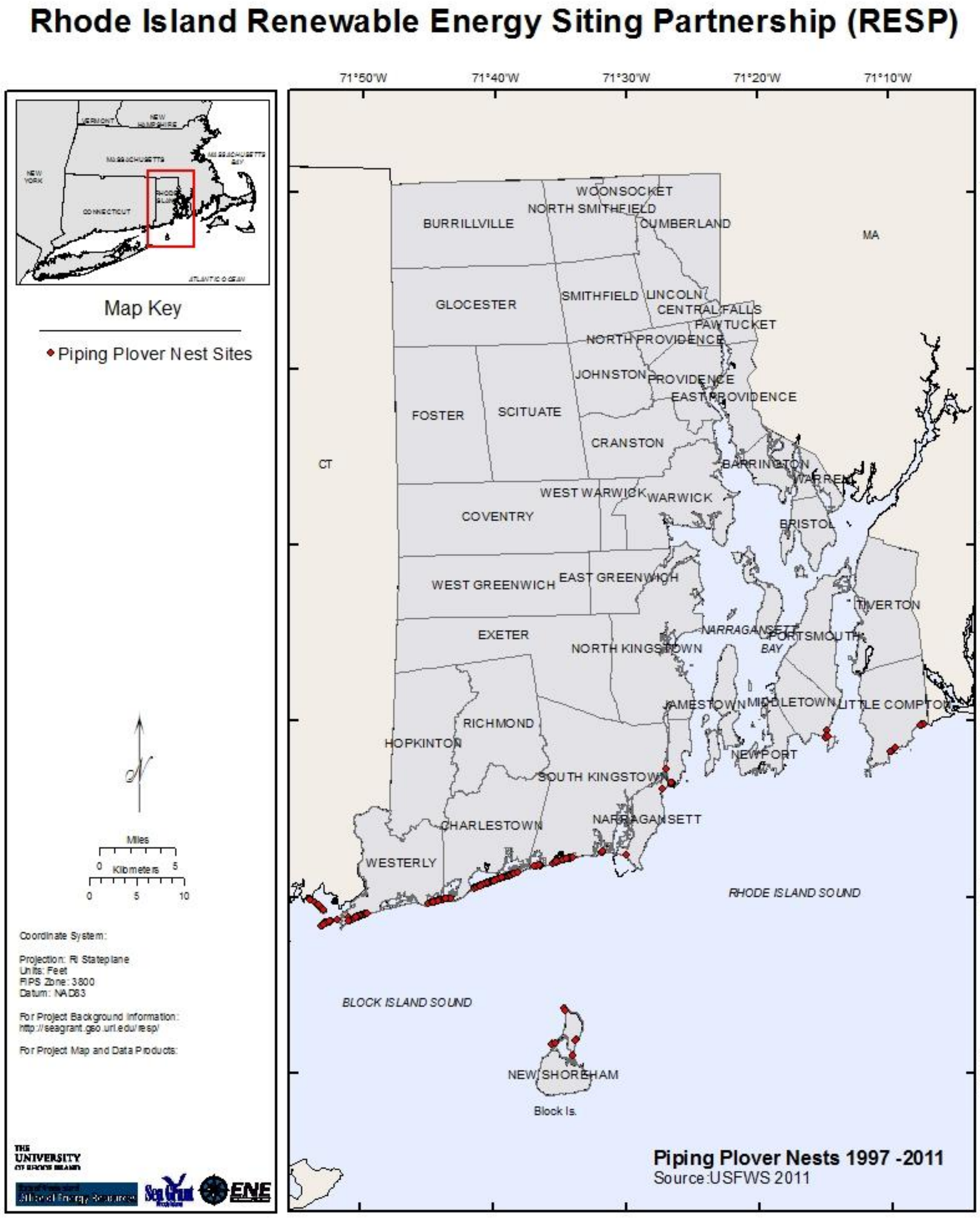


Figure 9. Distribution of Piping Plover nest locations (red circles) from 1997 – 2011 in Rhode Island, documented by the US Fish and Wildlife Service (USFWS 2011, unpubl. data).

6.4.1.2 ROSEATE TERN (*STERNA DOUGALLII*)

Roseate Terns were listed as endangered by the US Fish and Wildlife Service in 1987 under the Endangered Species Act of 1973. Roseate Terns are classified as highest priority for conservation in Bird Conservation Region 30 and a Tier IV (Federally listed) species by Partners in Flight (Table A2.2). Roseate Terns historically nested in Rhode Island, but now only occur in the state as migrants, with larger numbers documented in Rhode Island primarily during the post-breeding period (Paton et al. 2010). In Rhode Island, Roseate Terns primarily occur in nearshore, shallow habitats in the western part of the state where they forage on sand lance (*Ammodytes* sp.). Most individuals have been documented near Little Narragansett Bay including Sandy Point, Napatree Spit (C. Raithel, pers. comm.), and Watch Hill Lighthouse, with some individuals using mudflats as far east as Ninigret Pond. In addition, they roost on exposed sandflats, such as Napatree Spit, Sandy Point, or Great Salt Pond on Block Island (Paton et al. 2010). The largest Roseate Tern colony in North America is on Great Gull Island near Fisher's Island, New York, which close enough to Rhode Island to be within the foraging range (30 km) of breeding birds. In addition, based on observations of banded birds from Great Gull Island, large numbers of Roseate Terns are known to disperse east from Great Gull Island to Cape Cod after the breeding season (B. Harris, Mass. Audubon Society, pers. comm.). The exact dispersal route of birds between these two points is uncertain, but they presumably disperse through Rhode Island waters.

Based on our current understanding of Roseate Tern movement ecology in Rhode Island, this species primarily uses nearshore waters, with occasional use of coastal beaches in the western part of the state and Block Island as roosting/staging habitat. Roseate Terns occur in Rhode Island primarily from early May through late September (Fig. 10), thus any surveys for this species should occur during this time window. To minimize the probability of collisions, we recommend no wind turbines are constructed within 1 km of nearshore coastal beaches in the western part of the state where Roseate Terns have been documented roosting (i.e., Napatree Spit, Sandy Point, and mudflats in Quonochontaug Pond, and Ninigret Ponds, shores of Great Salt Pond).

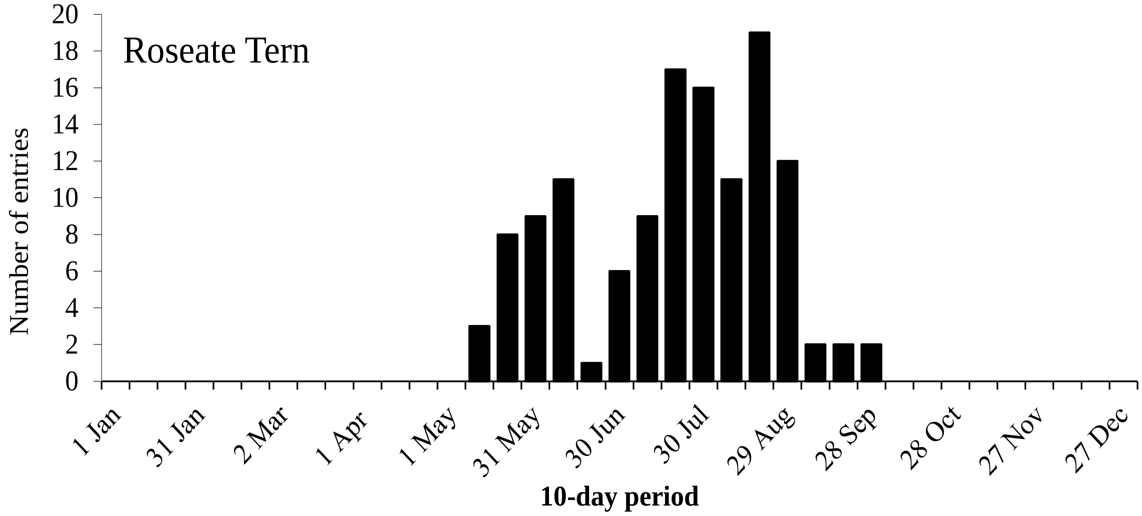


Figure 10. Phenology of Roseate Tern occurrence in Rhode Island based on observations from the Avian Knowledge Network.

6.4.1.3 BALD EAGLE (HALIAEETUS LEUCOCEPHALUS)

Bald Eagles were listed under the Federal Endangered Species Act of 1973, but they were de-listed in 2007; however, eagles are an issue for wind turbine development in Rhode Island because they are protected by the Bald and Golden Eagle Act of 1962. Their populations declined dramatically throughout North America in the 1940s and 1950s due to DDT, but they have since started to increase exponentially since DDT was banned in the United States in 1972. Their population reached a low of 487 pairs in the US.

In Rhode Island, there is currently one nesting pair of Bald Eagles on the Scituate Reservoir (as of 2012) (41°49’03.30” N; 71°35’17.47”) (Fig. 11). Bald Eagles are now a relatively common migrant in Rhode Island, primarily during fall and spring (Fig. 12). Bald Eagles generally nest in large trees adjacent to large bodies of water (lakes or rivers) where they have close access to fish prey to feed their young. Therefore, there is probably limited eagle nesting habitat in Rhode Island, although it is likely that more nests might detected on the Scituate Reservoir in the future.

In Massachusetts, there were 17 nesting pairs in 2010, with nests on Quabbin Reservoir, along Connecticut and Merrimack Rivers, and lakes in Plymouth County (www.massaudubon.org; Figs. 13 and 14). Connecticut had 18 nesting pairs in 2012 (www.ct.gov), with territorial pairs in 6 of 8 counties (Fig 14). In addition, in Massachusetts, Bald Eagles maintain their nests during December to February, incubate eggs March to April, and raise their chick until September (http://www.mass.gov/dfwele/). Occasionally, migratory Golden Eagles are detected in Rhode Island, but they are rare in eastern North America, particularly in coastal Rhode Island.

Current USFWS guidelines suggest that wind turbines should not be located within 1.6 km (1 mile) of a Bald Eagle nest based on their interpretation of the Bald and Golden Eagle Act. Thus, plans for any turbine near the Scituate Reservoir should take into consideration this nest site. Also, any plans of installing a wind facility near the border of Connecticut or Massachusetts near large water bodies should contact state wildlife agencies to insure there are no nest Bald Eagles nearby.

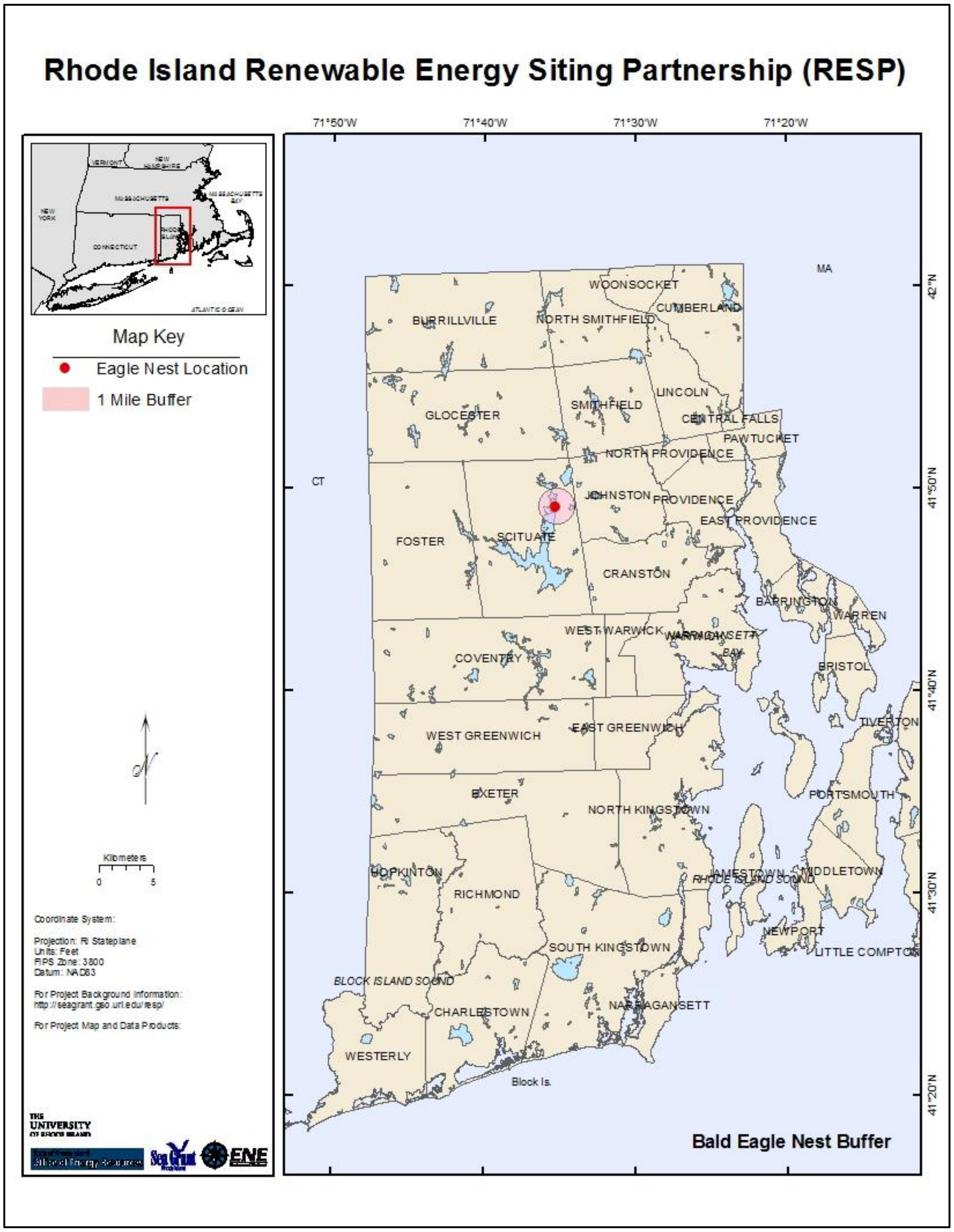


Figure 11. Location of only currently active Bald Eagle nest in Rhode Island (red circle) on the Scituate Reservoir and recommended 1.6 km buffer around the nest (pink circle).

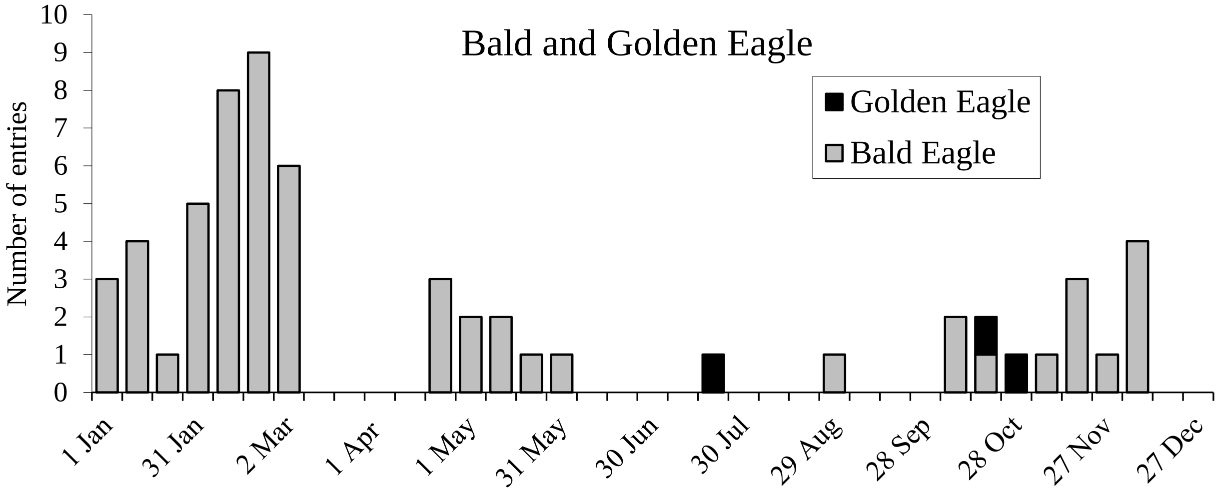


Figure 12. Phenology of Bald and Golden Eagle occurrence in Rhode Island based on records in the Avian Knowledge Network.

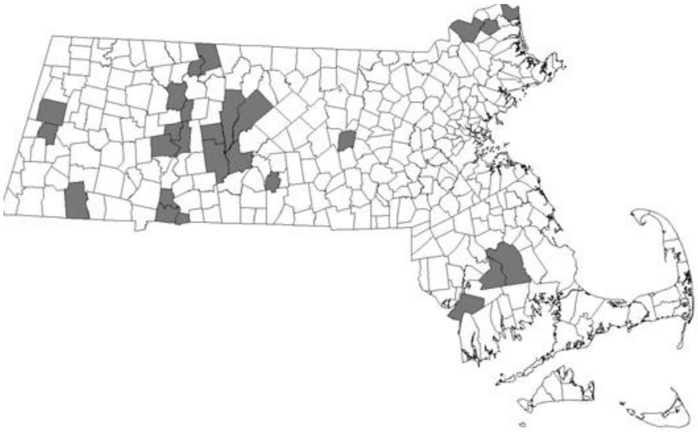


Figure 13. Areas with Bald Eagle nests in Massachusetts from 1978 to 2008 (MA Fish and Wildlife).

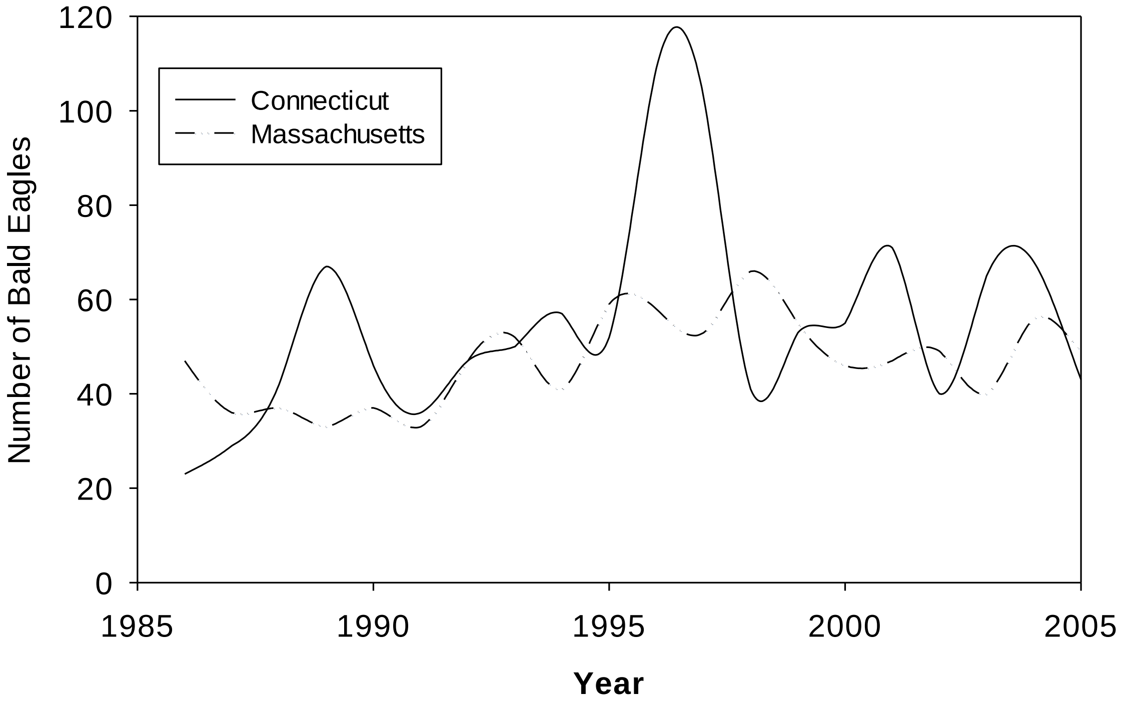


Figure 14. Number of Bald Eagles detected in Connecticut and Massachusetts during mid-winter Bald Eagle

6.4.2 State-listed Species

6.4.2.1 STATE ENDANGERED SPECIES

There are eight species in Rhode Island that are listed as State Endangered by the Natural Heritage Program (Rhode Island Natural Heritage Program 2006), which has not been modified since 2006. Species listed as State Endangered in Rhode Island are native species that are in imminent danger of extirpation from the state and meet one or more of these criteria: 1) formerly considered by the USFWS for Federal listing as Endangered or Threatened, 2) only 1-2 known populations in Rhode Island, or 3) apparently globally rare or threatened due to ≤ 100 populations range-wide. For birds, status is based on breeding populations in Rhode Island.

6.4.2.1.1 Pied-billed Grebe (Podilymbus podiceps)

This rare, migratory species is primarily restricted to coastal ponds in the southern part of the state (e.g., Maschuag, Quonochontaug, Ninigret, Trustom, Point Judith, and Quicksand ponds). This species is also State listed in Massachusetts, Connecticut, and New Jersey. Regional trend estimates for this species are not available from the BBS. There is a small nesting population in the state, again in coastal ponds (primarily Trustom Pond) where there is minimal disturbance. Given the rarity of this species in the state, wind turbines are probably not much a threat to this species. However, because coastal ponds are so important to local avian biodiversity, we recommend no turbines are constructed within 1 km of coastal ponds.

6.4.2.1.2 American Bittern (Botaurus lentiginosus)

This rare migratory species occasionally winters in Rhode Island. This species is State listed in Massachusetts, Connecticut, and New Jersey. This species might still breed in the state (possibly on Block Island, Enser 1992), but there are few recent records suggesting this species nests in Rhode Island. This species is poorly sampled by BBS survey, with regional trend estimate for eastern North America suggesting a decline from 1966 to 2009 (-0.68 annual rate of decline; 95% CI = -3.18 to 1.30). American Bitterns prefer large stands of persistent, emergent vegetation, which are restricted to a few coastal ponds in Rhode Island (e.g. Maschaug, Quonochontaug, Ninigret, Trustom, Point Judith, Quicksand and Great Salt Pond on Block Island). Wind turbines should not be located with 1 km of key coastal wetlands to protect this species and other species that use coastal ponds.

6.4.2.1.3 Northern Harrier (Circus cyaneus)

Northern Harrier is classified at State Endangered in Rhode Island. This species is State listed in New York. In eastern North America, this species is in decline based on BBS survey results, with a -1.73 annual rate of decline (95% CI = -3.22 to -0.49) from 1966 – 2009. There is a small nesting population on Block Island (Enser 1992). In addition, this species is a fairly common migrant through Rhode Island, primarily during fall and spring migration along the southern, mainland coast. In addition, harriers winter in Rhode Island, where they forage in grassland/shrub habitat, again primarily along the southern coast and Block Island (Fig. 15). As with other grassland specialists, we recommend not locating wind turbines or other renewable energy devices within 100 m of prime grassland foraging habitat, particularly along the southern coast of mainland Rhode Island and Block Island.

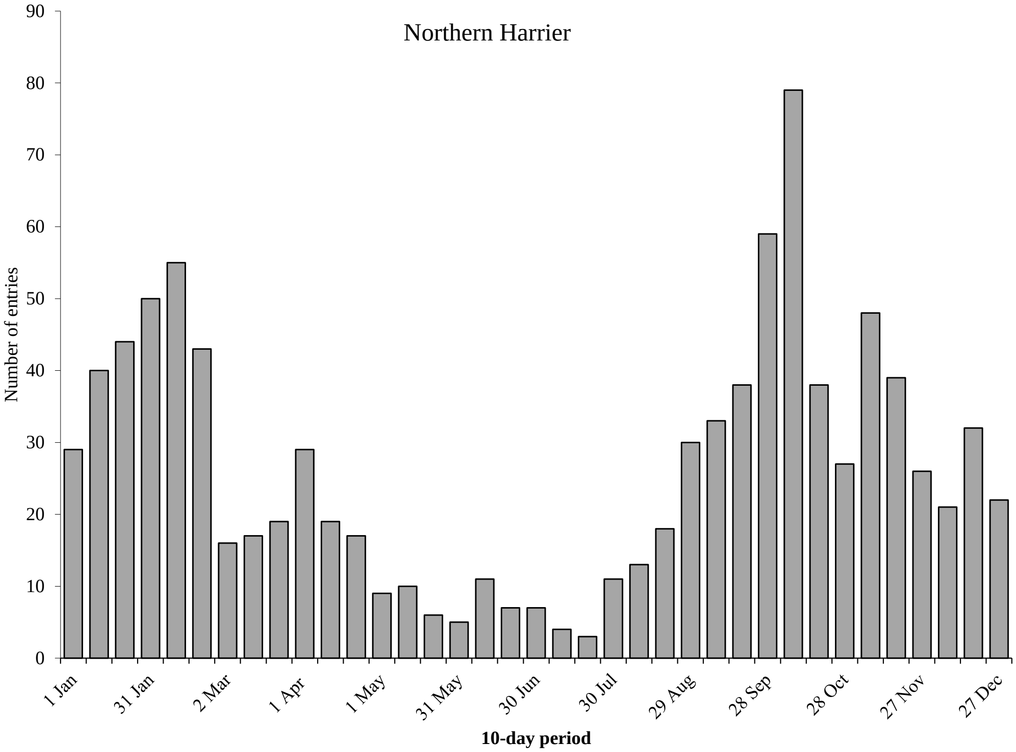


Figure 15. Phenology of Northern Harrier occurrence in Rhode Island based on eBird observations from the Avian Knowledge network.

6.4.2.1.4 Peregrine Falcon (Falco peregrines)

Peregrine Falcons are current classified as a State Endangered species. This species declined due to issues with DDT in 1940s and 1950s, which as banned in the US in early 1970s. Since then, Peregrine Falcon populations have subsequently recovered, and they were de-listed as Federally Endangered under the Endangered Species Act in 1999.

In Rhode Island, there is a small breeding population with birds nesting in Providence, the Mt. Hope Bridge, and the Newport Bridge. In addition, this species is a fairly common migrant through the state, particularly during fall migration (Fig. 16), although Peregrines can be detected virtually year-round in coastal area. In fall, Peregrines are most likely to be detected along the southern coast or on Block Island. Peregrines usually prey on ducks or shorebirds, so are most likely to be detected where these potential prey congregate.

Available evidence suggests that wind turbines are a minimal threat to Peregrine Falcons in Rhode Island as long as they are not located 1) within 500 m of known nesting locations to reduce the probability that birds collide with turbines during foraging flights, or 2) not located along known migration concentration sites in the state (i.e., SW corner of Block Island, SW coastline of mainland RI).

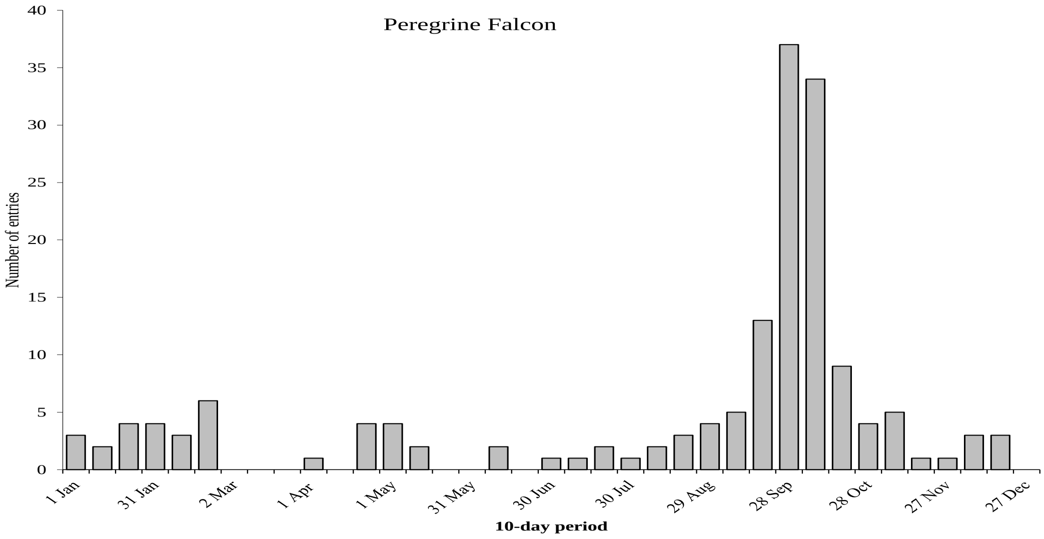


Figure 16. Phenology of Peregrine Falcon occurrence in Rhode Island based on eBird observations from the Avian Knowledge network.

6.4.2.1.5 Upland Sandpiper (Bartramia longicauda)

This grassland specialist used to nest in the state, but it is now just a rare migrant during spring and fall migration (Fig. 17). This species is listed by Partners in Flight as a Tier 1B species (High Continental Priority - Low Regional Responsibility). This species is declining throughout eastern North America (-3.00 annual rate of decline; 95% CI = -4.75 to -1.83) from 1966 to 2009) based on BBS regional trends for eastern North America. Upland Sandpipers are classified as moderate conservation concern in Bird Conservation Region 30 (Table A2.2). They are usually detected in large turf fields in the southern half of Rhode Island (e.g., Richmond, South Kingstown, and North Kingstown). Other rare shorebird species are also often detected foraging in turf fields during migration including American Golden Plovers, Buff-breasted Sandpipers, Pectoral Sandpipers, and Baird’s Sandpipers. On their breeding grounds, they prefer grasslands that are over 40 acres (http://www.gpnc.org/upland.htm).

Because larger turf fields provide foraging habitat for some rare species of shorebirds that forage in upland habitats, we recommend not locating wind turbines within turf fields that are over 40 acres.

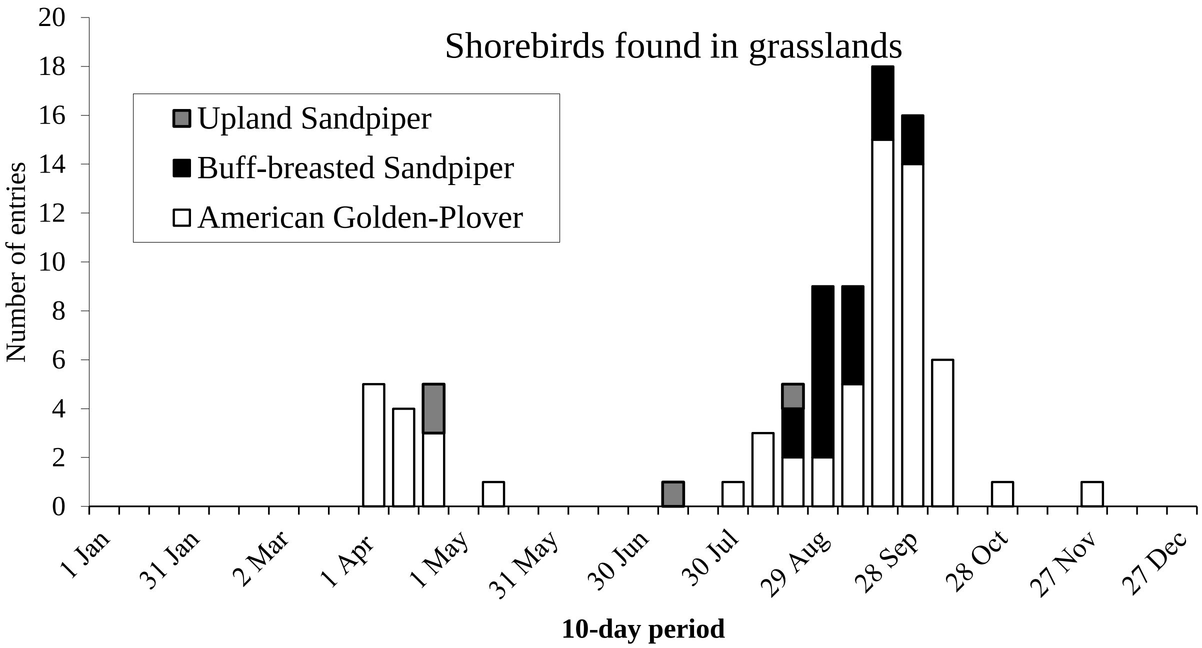


Figure 17. Phenology of shorebirds that use large grasslands in Rhode Island based on eBird observations from the Avian Knowledge Network.

6.4.2.1.6 Barn Owl (Tyto alba)

This rare permanent resident primarily occurs in coastal Rhode Island near grassland habitats. This species is State listed in Connecticut, Massachusetts and New York. Regional population trends are not available for this nocturnal species, as the BBS only conducts early morning surveys. On Block Island, Barn Owls nest on bluffs on southeast corner of the island. They also nest near Trustom Pond NWR and possibly occur on Aquidneck Island. Barn Owls primarily forage in grasslands, which should not have wind turbines within 100 m of potential foraging habitat.

6.4.2.1.7 Cerulean Warbler (Setophaga cerulean)

This species is listed by Partners in Flight at a Tier 1B species (High Continental Priority - Low Regional Responsibility). Cerulean Warblers are extirpated as a breeding species in the state, and they are declining at a precipitous rate throughout New England based on BBS survey results (estimated -2.98 annual rate of decline; 95% CI = -3.92 to -2.06) from 1966-2009 in eastern North America. This migratory species is occasionally detected during spring or fall migration, but it is extremely rare in the state. Breeding Cerulean Warblers now occur farther to the west and south (http://www.birds.cornell.edu/cewap/cewaspec.htm). The species prefers deciduous forests with large, mature trees, usually near stream bottoms or near lakes or rivers (http://www.birds.cornell.edu/cewap/cewaspec.htm). Available evidence suggests that wind turbines will have minimal impact on Cerulean Warblers in Rhode Island, because it is primarily a rare migrant in the state, thus this species is not of concern when considering placement of wind turbines or other renewable energy sources in Rhode Island at this time. However, because this species nests in large contiguous forested habitat, we recommend that forest patches over 100 acres in size not be fragmented by the construction of wind turbines.

6.4.2.1.8 Yellow-breasted Chat (Icteria virens)

This shrub specialist is declining throughout the region and is probably extirpated as a breeding bird in Rhode Island. In eastern North America, this species has a significant annual rate of decline (-0.8%; 95% CI = -1.05 to -0.52) based on BBS surveys from 1966 – 2009. However, small numbers are detected each year in Rhode Island, primarily during fall migration – principally along the southern coast in shrub habitats such as Ninigret and Sachuest NWRs. Due to the importance of shrub habitats to a wide variety of migratory birds, including this species, we propose that no wind turbines be constructed with 100 m of large blocks (3 acres or larger) of shrub habitats in coastal Rhode Island.

6.4.2.2 STATE THREATENED SPECIES

There are six species of birds that are listed at State Threatened in Rhode Island. In Rhode Island, State Threatened species are native species that are likely to become State Endangered in the future if current trends in habitat loss or other detrimental factors remain unchanged. These taxa have three to five known or estimated populations and are especially vulnerable to habitat loss. For birds, status is based on breeding populations in Rhode Island.

6.4.2.2.1 Least Bittern (Ixobrychus exilis)

This is an extremely rare species in Rhode Island, primarily detected in coastal ponds with persistent emergent vegetation. This species is State listed in New York. Because coastal ponds are so important to local avian biodiversity, we recommend no turbines are constructed within 1 km in all directions of coastal ponds.

6.4.2.2.2 Least Tern (Sterna antillarum)

This uncommon, migratory species nests on coastal beaches (Fig. 18) and forages in nearshore marine waters and coastal ponds. This species occurs in Rhode Island from May through September (Fig. 19). This species is State listed in New York, New Hampshire, Connecticut, and Massachusetts, and listed as a species of high priority for conservation in Bird Conservation Region 30 (Table A2.2). Their habitat associations are similar to the federally-listed Piping Plover. Because Least Terns often nest near Piping Plovers, we recommend a 1 km buffer inland for any wind turbines constructed near potential Least Tern nesting habitat.

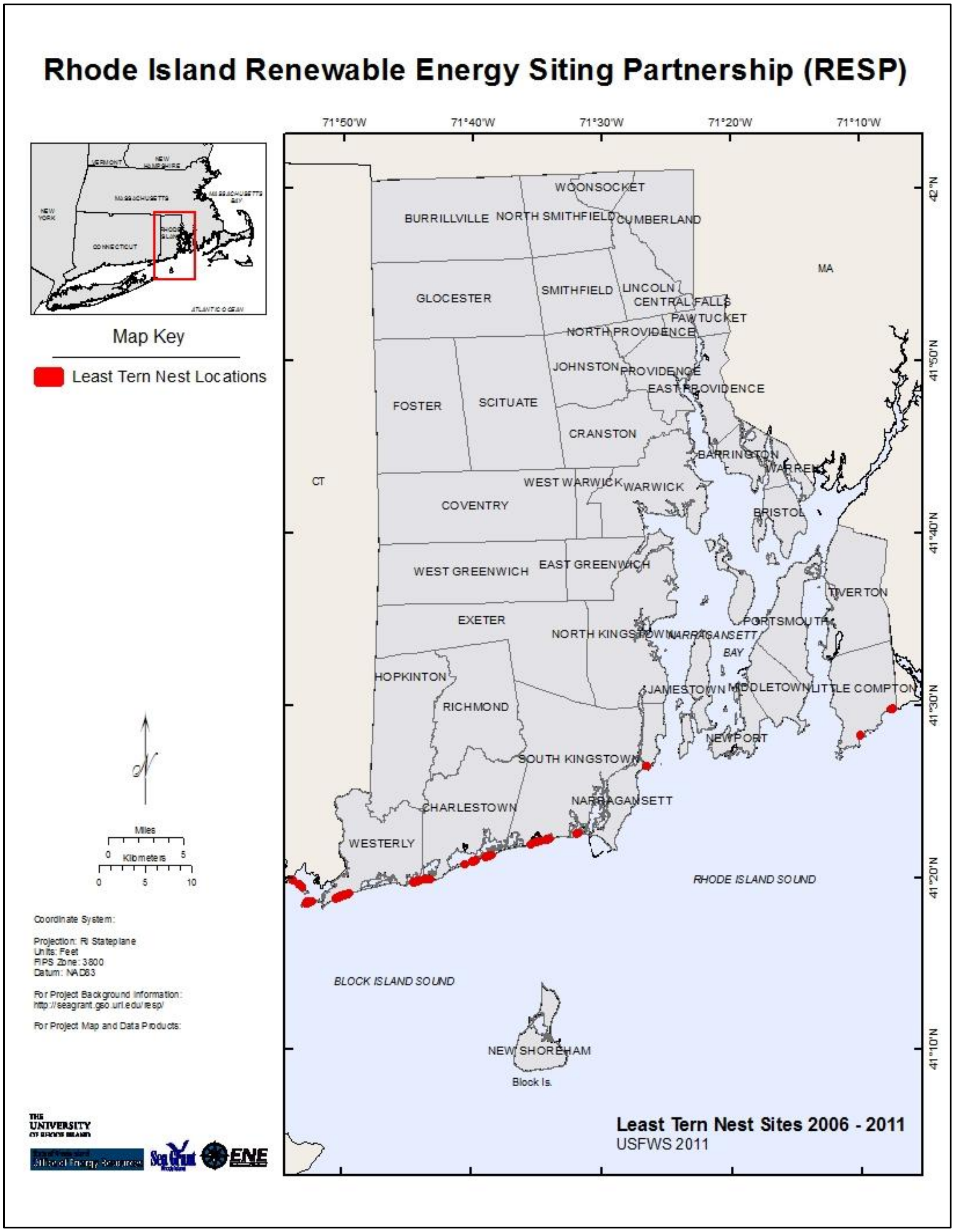


Figure 18. Distribution of Least Tern nest locations documented from 2006 – 2011 in Rhode Island based on surveys conducted by the US Fish and Wildlife Service (USFWS unpubl. data).

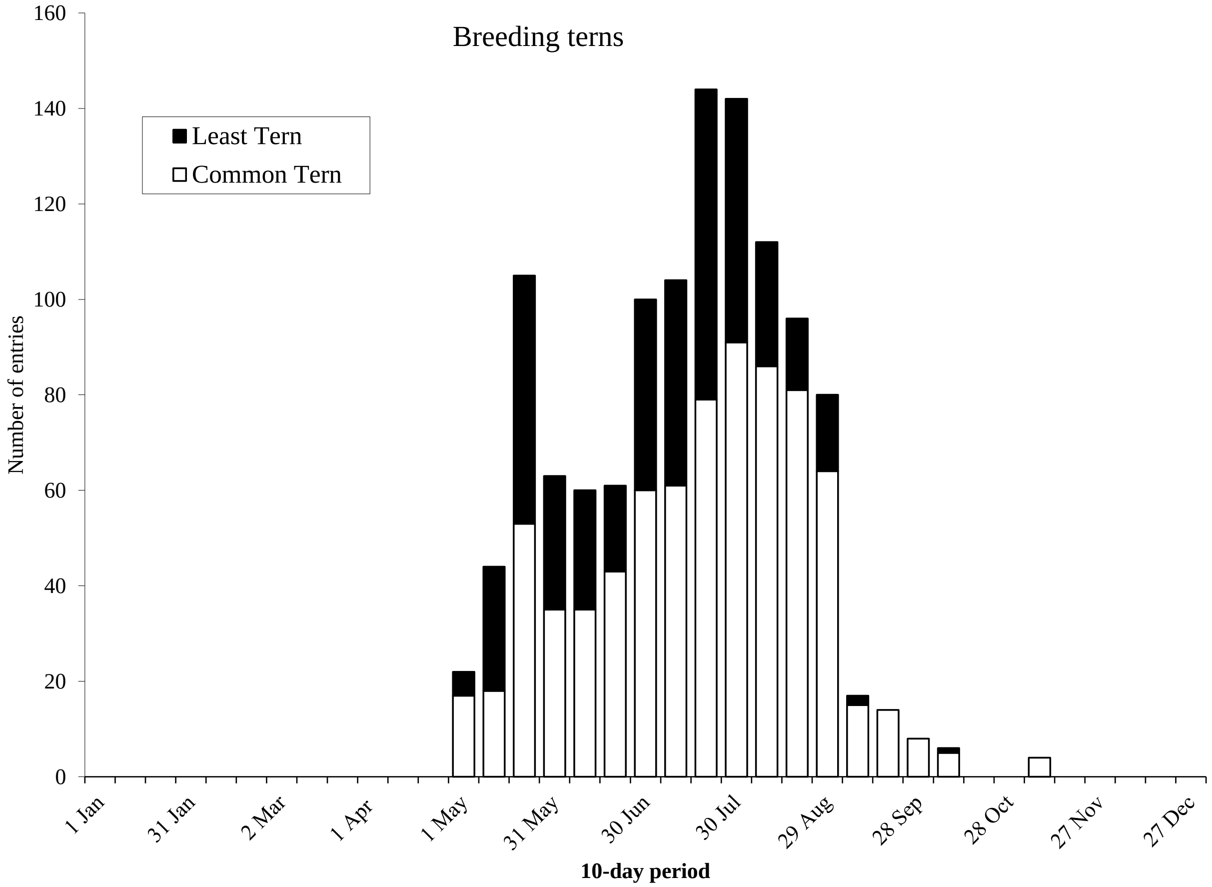


Figure 19. Phenology of Least and Common Tern occurrence in Rhode Island based on eBird observations from the Avian Knowledge network.

6.4.2.2.3 Northern Parula (Setophaga americana)

This uncommon migratory warbler is listed at State Threatened because there are only three to five known breeding locations for this species in Rhode Island. However, available evidence suggests this species is significantly increasing in eastern North America based on BBS survey results, with a 1.1 annual rate of increase (95% CI = 0.64 to 1.58) from 1966 to 2009. This species has specific requirements for nesting habitat consisting of mature forests with epiphytic moss (e.g., beard moss). Available evidence suggests that wind turbines are not a threat to this species, as long as turbines are not constructed in mature forest stands.

6.4.2.2.4 Black-throated Blue Warbler (Setophaga caerulescens)

This uncommon migratory warbler is listed at State Threatened because there are only three to five known breeding locations for this species in Rhode Island. This species is listed by Partners in Flight at a Tier 1B species (High Continental Priority - Low Regional Responsibility). Available evidence suggests this species is significantly increasing in eastern North America, with a 2.38 annual rate of increase (95% CI = 1.21 to 3.51) from 1966 to 2009 based on BBS survey results. This species nests in coniferous forests, and Rhode Island is located at the southern edge of their breeding range (Sibley 2003). This species is an uncommon migrant in the state during spring and fall migration, where they probably could be detected in forested areas throughout the state (Fig. 20). Available evidence suggests wind turbines in Rhode Island would not pose a threat to their population at this time, as long as they are not constructed in mature deciduous or mixed coniferous-deciduous woodlands with a thick understory in northern, hilly parts of the state.

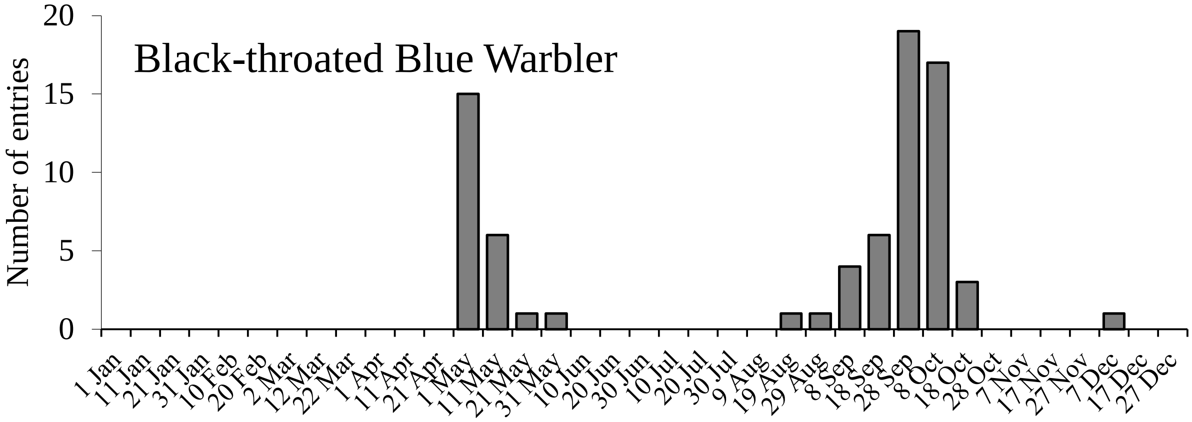


Figure 20. Phenology of Black-throated Blue Warbler occurrence in Rhode Island based on observations from the Avian Knowledge network.

<u>*6.4.2.2.5 Blackburnian Warbler (Setophaga fusca)*</u>

This migratory warbler is State Threatened because there are less than five coniferous forest stands in the state where this species potentially nests. This species is listed by Partners In Flight at a Tier IIC species (High Regional Threats). Available evidence suggests this species significantly increasing in eastern North America, with a 0.93 annual rate of increase (95% CI = 0.01 to 1.88) from 1966 to 2009 based on BBS survey results. However, Rhode Island is on the southern edge of their breeding range (Sibley 2003), thus provides little breeding habitat for this species. Blackburnian Warbler is an uncommon migrant in the state during spring and fall migration, where they can be detected in forested areas throughout the state (Fig. 21). Available evidence suggests wind turbines in Rhode Island would not pose a threat to their population at this time as long as wind facilities were not constructed in mature coniferous forest stands in the northern portions of the state.

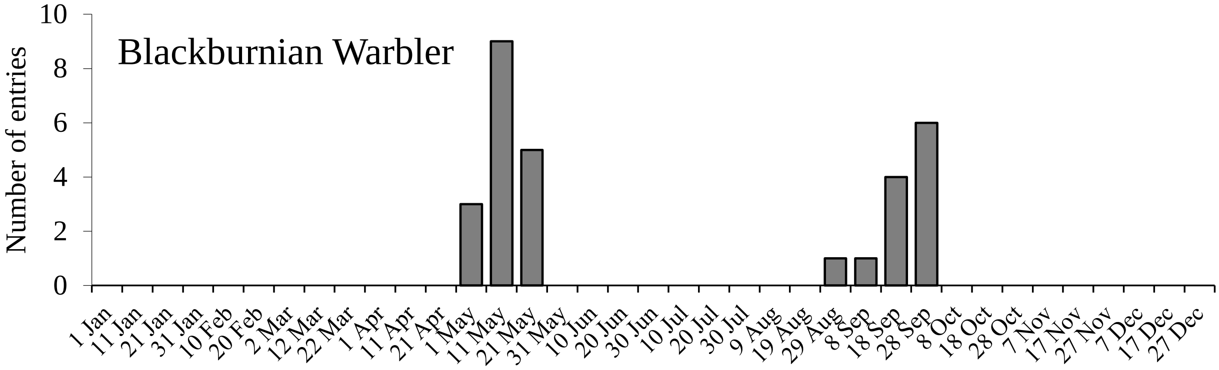


Figure 21. Phenology of Blackburnian Warbler occurrence in Rhode Island based on observations from the Avian Knowledge network.

6.4.2.2.6 Grasshopper Sparrow (Ammodramus savannarum)

Grasshopper Sparrow is classified as State Endangered, primarily because there are probably less than five grasslands in Rhode Island where this species now nests. Regionally, this species is doing very poorly, with BBS routes in eastern North America conducted from 1966 to 2009 suggesting a -4.70 annual rate of decline (95% CI = -7.86 to -4.19). They are a grassland specialist and there are few remaining suitable nesting sites for this species in the state. This species requires relatively large grasslands (over 30 acres) with short bunch grasses (height 4-12 inches) and minimal litter and ground cover. Sites that meet these criteria should be surveyed by trained biologists in May and June to determine the occurrence of Grasshopper Sparrows. If detected, we recommend wind turbines be constructed a minimum of 100 m from the edge of the grasslands used for nesting.

6.4.2.3 STATE SPECIES OF CONCERN

There are 33 species State listed as species of concern in Rhode Island (RI Natural Heritage Program 2006). These are native species not considered to be State Endangered or State Threatened at the present time, but are listed due to various factors of rarity and/or vulnerability. Species listed in this category may warrant endangered or threatened designation, but status information is presently not well known. We discuss a few of these species of concern, primarily because regional conservation efforts have highlighted these species.

6.4.2.3.1 American Oystercatcher (Haematopus palliatus)

There is considerable interest in eastern North America in this species because their population is small enough (11,000 birds from New Jersey to Texas) to warrant special consideration (http://amoywg.org/amoy-working-group/). American Oystercatchers are categorized as the highest priority of conservation concern in Bird Conservation Region 30 (Table A2.2). This species is listed by Partners in Flight at a Tier 1A species (High Continental Priority - High Regional Responsibility). In Rhode Island, this rare migratory species nests primarily on islands and peninsulas in Narragansett Bay and Little Narragansett Bay (Fig. 22), where there were probably less than 30 nesting pairs in 2011 (USFWS, unpubl. data). Given the conservation concerns with this species from the American Oystercatcher working group and the scarcity of nesting pairs in the state, we recommend a buffer distance of 500 m from all current and future oystercatcher nests to minimize disturbance and reduce collision risk.

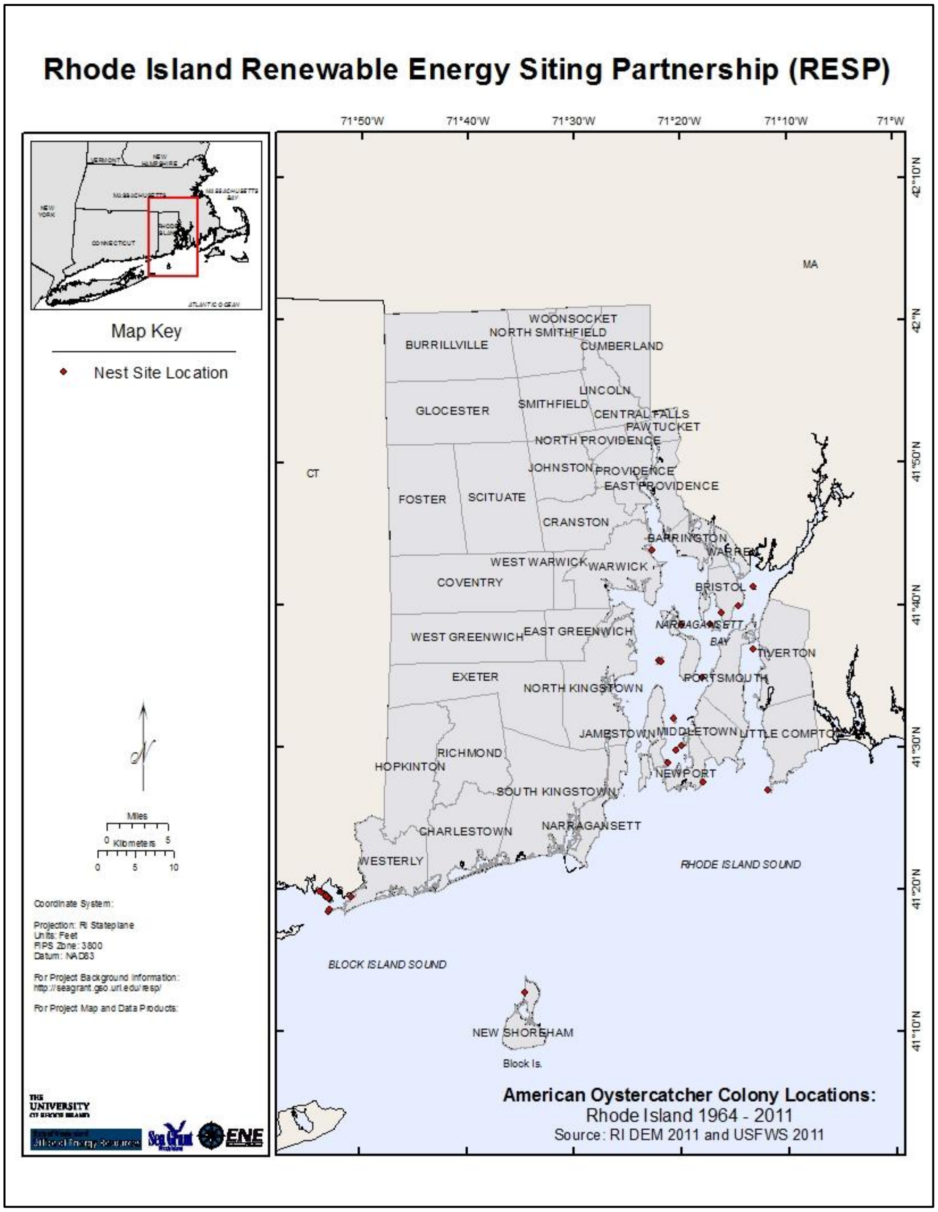


Figure 22. Distribution of American Oystercatcher nests (red circles) in Rhode Island based on systematic surveys by USFWS (unpubl. data) and RI DEM (unpubl. data).

6.4.2.3.2 Osprey (*Pandion haliaetus*)

As with other predatory birds at the top of the food chain, Osprey populations declined dramatically in the 1940s and 1950s due to egg shell thinning from DDT. Their populations have subsequently increased with the ban on DDT use in the United States in the 1970s. This species is State listed in New York. There has been a strong effort to restore osprey populations in Rhode Island; hence they are a charismatic species that is a focal point for conservation efforts. In fact, Ospreys are pictured on the state conservation license plate. Thus we recommend strong efforts to minimize impacts to their nesting efforts in Rhode Island. RI DEM and now Audubon Society of Rhode Island have led efforts to restore the number of breeding Ospreys by erecting nesting platforms throughout the state. In 2008, there were 104 active nests in the state (Fig. 23; http://www.dem.ri.gov/programs/bnatres/fishwild/pdf/osprynew.pdf). In addition, researchers have learned much about the migration ecology of Osprey by using satellite transmitters to monitor their movements from Conanicut Island to their wintering grounds in South America (http://www.conanicutraptors.com). This migratory species occurs in Rhode Island from April through November (Fig. 24). Efforts to document the presence of Ospreys at nesting platforms should take place during the breeding season from May through August.

Given the importance of this flagship species, we recommend no wind turbines are erected with 500 m of an active Osprey nest to minimize disturbance and reduce the probability that adults collide with turbines on foraging flights or young collide with turbines on as they learn to fly. The recommended buffer distance is approximately the distance between the new (2011) 100-kW turbine at Fisherman’s Memorial State Park and an Osprey tower in Galilee Bird Sanctuary.

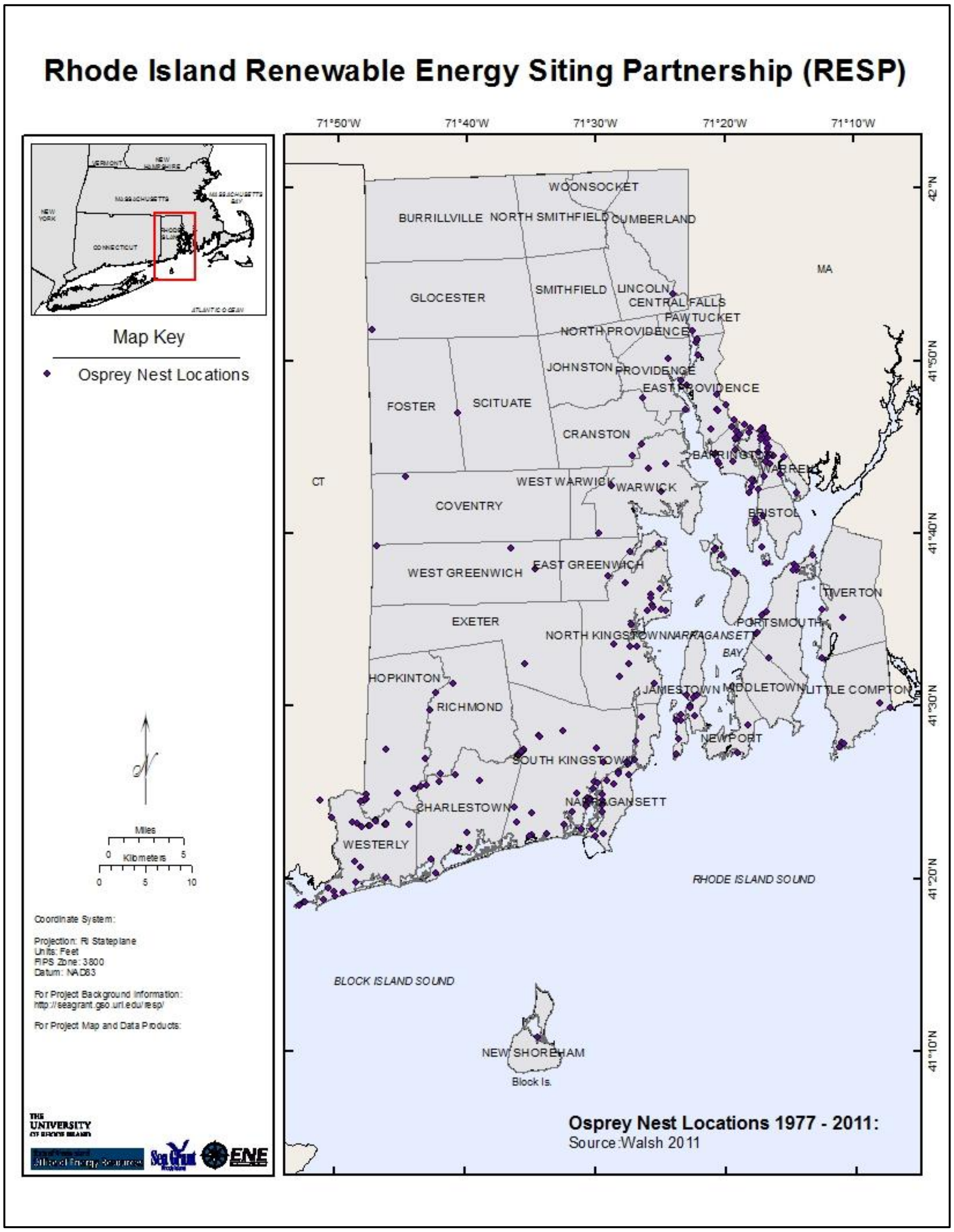


Figure 23. Distribution of Osprey nest locations from 1977 – 2011 in Rhode Island based on data from RI DEM and Audubon Society of Rhode Island (Audubon Society of Rhode Island, unpubl. data, 2011).

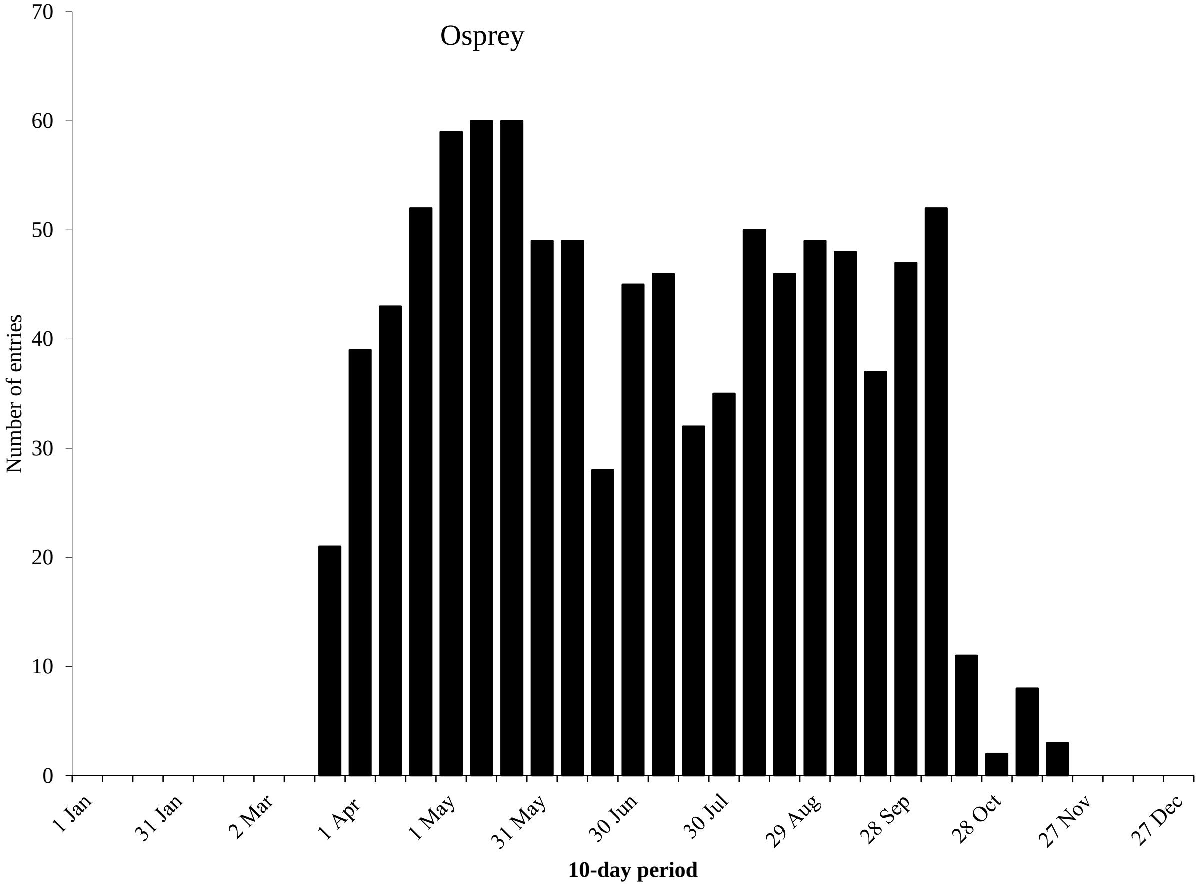


Figure 24. Phenology of Osprey occurrence in Rhode Island based on eBird observations from the Avian Knowledge network.

6.4.3 Protected Lands in Rhode Island

There are currently 179,784 acres (26% of the state) in Rhode Island that are protected for conservation purposes by state and federal agencies (e.g., RI DEM, USFWS), non-government entities (Audubon Society of Rhode Island, The Nature Conservancy), and local land trusts (Fig. 25; Table 8). Any plans to develop wind turbines or other types of renewable energy sources should consider potential impacts on these protected lands before developing detailed plans.

At the federal level, the USFWS (The Rhode Island National Wildlife Refuge Complex) manages 5 National Wildlife Refuges in Rhode Island, which are primarily located in coastal regions in the southern part of the state and on Block Island (Fig. 26).

Table 8. Acreage of government (State and Federal lands) and nongovernment (NGO: local conservation societies and land trusts) conservation lands in Rhode Island (http://www.edc.uri.edu/rigis/: accessed January 2012).

Town	Town (acres)	NGO agencies (acres)	Government (acres)	NGO agencies (%)	Government (%)
BARRINGTON	5500	996	252	18	5
BRISTOL	6320	1013	573	16	9
BURRILLVILLE	36456	4319	7238	12	20
CENTRAL FALLS	825	30	28	4	3
CHARLESTOWN	24454	6509	4707	27	19
COVENTRY	39972	4039	3472	10	9
CRANSTON	18505	959	1088	5	6
CUMBERLAND	18078	3816	808	21	4
EAST GREENWICH	10438	991	181	9	2
EAST PROVIDENCE	8953	510	64	6	1
EXETER	37371	3458	10233	9	27
FOSTER	33261	3597	1395	11	4
GLOCESTER	36373	4139	4646	11	13
HOPKINTON	28250	2316	4347	8	15
JAMESTOWN	6187	1818	814	29	13
JOHNSTON	15573	1360	1021	9	7
LINCOLN	12141	2054	1316	17	11
LITTLE COMPTON	14458	3033	1439	21	10
MIDDLETOWN	8447	1686	384	20	5
NARRAGANSETT	9118	1348	761	15	8
NEW SHOREHAM	6378	2006	524	31	8
NEWPORT	5177	470	279	9	5
N. KINGSTOWN	28268	6136	1800	22	6
N. PROVIDENCE	3708	101	46	3	1
N. SMITHFIELD	15927	1152	304	7	2
PAWTUCKET	5670	493	81	9	1
PORTSMOUTH	15103	3197	3056	21	20
PROVIDENCE	12037	875	57	7	0
RICHMOND	26074	1484	5123	6	20
SCITUATE	35077	11167	399	32	1
SMITHFIELD	17669	1902	664	11	4
S. KINGSTOWN	39225	6558	5751	17	15
TIVERTON	19421	2125	2385	11	12
WARREN	4000	479	284	12	7
WARWICK	22971	1576	828	7	4
WEST GREENWICH	32779	5638	13108	17	40
WEST WARWICK	5178	184	33	4	1
WESTERLY	19666	3522	2620	18	13
WOONSOCKET	5048	566	53	11	1
Statewide	**690,056**	**97,622**	**82,162**	**14.1%**	**11.9%**

The Rhode Island DEM also manages over 82,000 acres of protected lands in the state that include Wildlife Management Areas and State Parks, which are located throughout the state (Table 8; Fig. 25). Towns with the largest acreage of protected lands are West Greenwich (13,108 ac), Exeter (10,233 ac), and Burrillville (7,238 acres).

Non-government agencies, such as Audubon Society of Rhode Island and The Nature Conservancy, as well as local land trusts, own or manage over 14% of Rhode Island (97,622 ac). Towns with the most local protected lands include Scituate (11,167 ac), South Kingstown (6,558 ac) and Charlestown (6,509 ac).

6.4.4 Management Implications

With over 26% of Rhode Island managed as protected lands, any plans to develop wind turbines need to consider the potential impact to conservation lands. Plans to erect wind turbines on currently conserved lands should be compatible with the conservation objectives of the land parcel. If the land under consideration has large patches of grassland, scrub-shrub, or forested habitats, then management guidelines we list elsewhere should be considered.

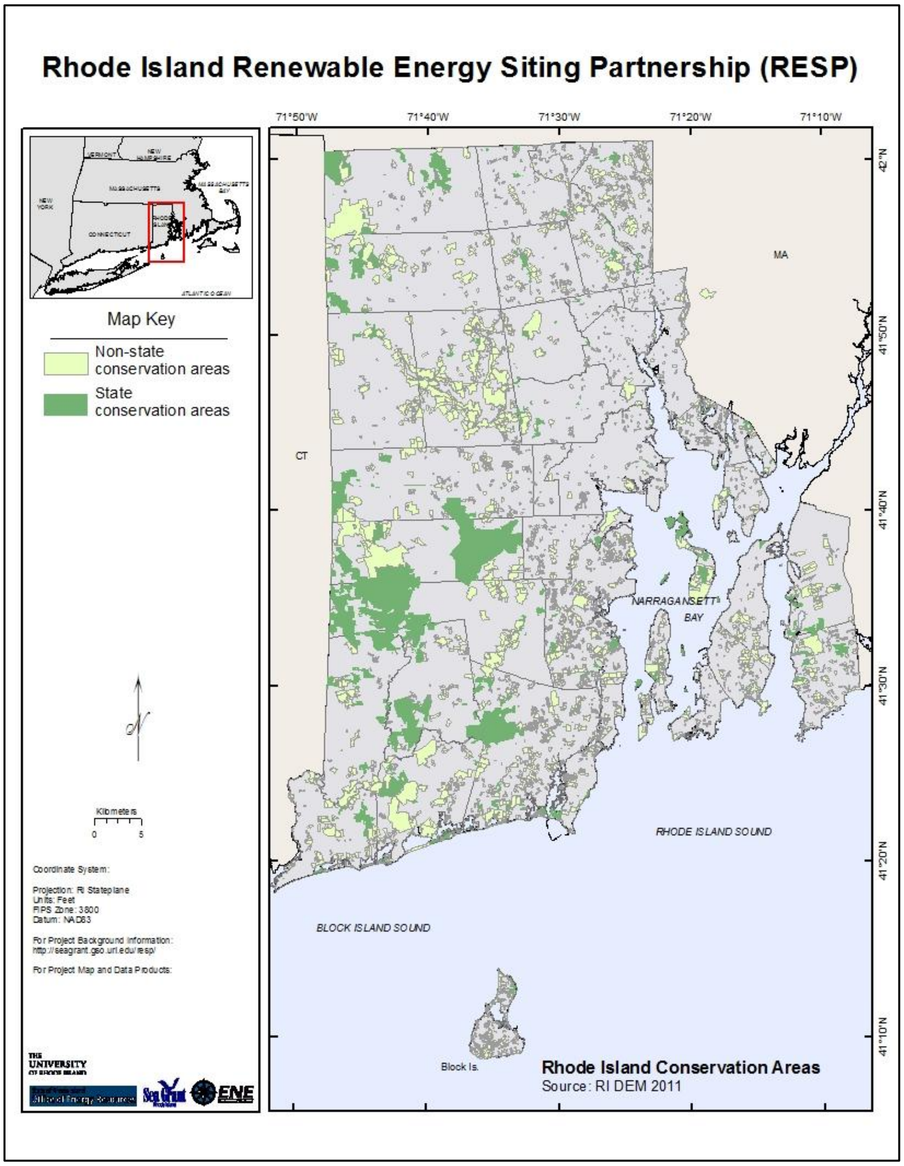


Figure 25. Distribution of conservation areas in Rhode Island. These include lands managed by RI DEM Fish and Wildlife, US Fish and Wildlife Service, non-government agencies (e.g., Audubon Society of Rhode Island, The Nature Conservancy), and town land trusts.

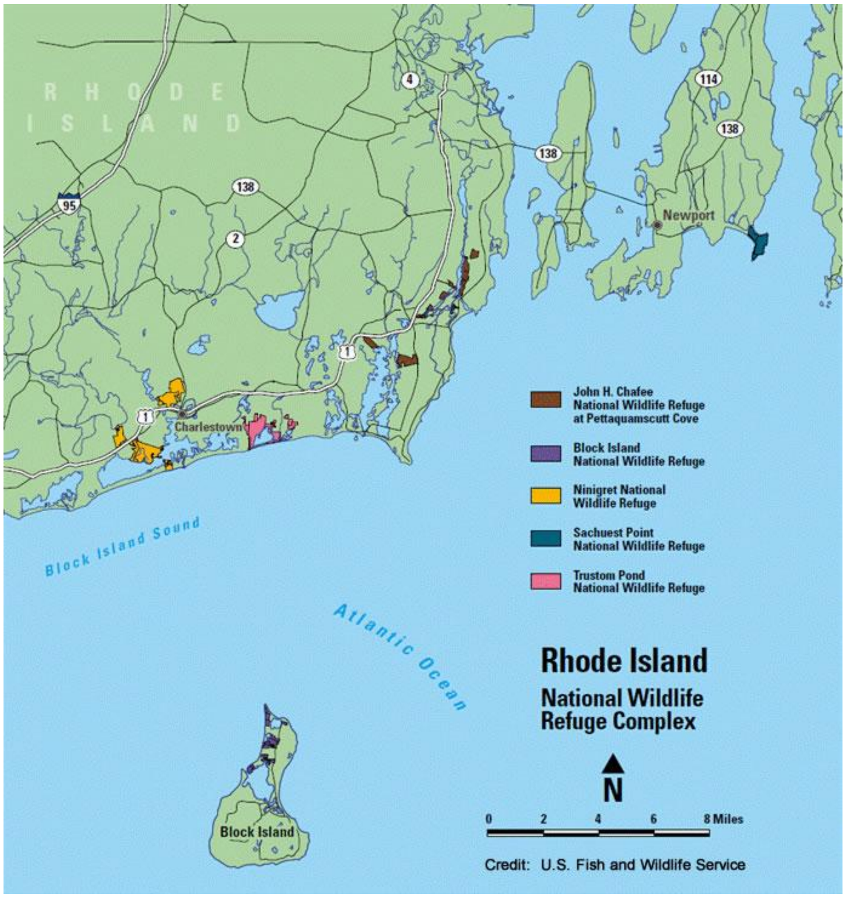


Figure 26. Location of lands owned and managed by the US Fish and Wildlife Service in Rhode Island.

6.5 Breeding Birds

Of the 166 species of birds that nest in Rhode Island (Table A2.3), 47 species are a conservation concern based on state and federal classification schemes (Tables 6 and A2.2), with one federally-listed species (Piping Plover), five State Endangered species (Pied-billed Grebe, American Bittern, Northern Harrier, Peregrine Falcon, and Barn Owl), four State Historical (formerly nested in Rhode Island; Sharp-shinned Hawk (although they probably nest in RI again), Cliff Swallow, Vesper Sparrow), five State Threatened (Least Bittern, Least Tern, Northern Parula, Black-throated Blue Warbler, and Grasshopper Sparrow), and 32 species of State Concern (Tables 6 and A2.2; Rhode Island Natural Heritage Program 2006).

Based on population trend estimates from the BBS, 29 species are exhibiting a significant annual rate of population decline at a regional scale (Table A2.3), 50 species exhibited a non-significant rate of population decline, 33 species are experiencing a significant rate of population increase, 49 species are exhibiting a non-significant rate of increase, and five species have insufficient data to model their population trajectory.

Of the species that are exhibiting significant rates of decline based on an analysis of BBS regional trends 9A2.3), 14 species are forest specialists, two species are grassland specialists, seven species prefer early successional habitats, two species prefer urban areas, and two species prefer wetlands. Of the species exhibiting significant increasing in annual population trends, two species nest on bay islands, 19 species mainly use forested habitats, two species are grassland specialists, one species uses mixed grasslands, four species use early successional habitats, and four.

Using Enser's (1992) Breeding Bird Atlas survey results, we mapped the overall spatial distribution of breeding birds in Rhode Island (Fig. 27). Patterns are difficult to discern based on these surveys. However, there is a tendency for more species to be detected in inland blocks in the western half of the state, away from urban areas.

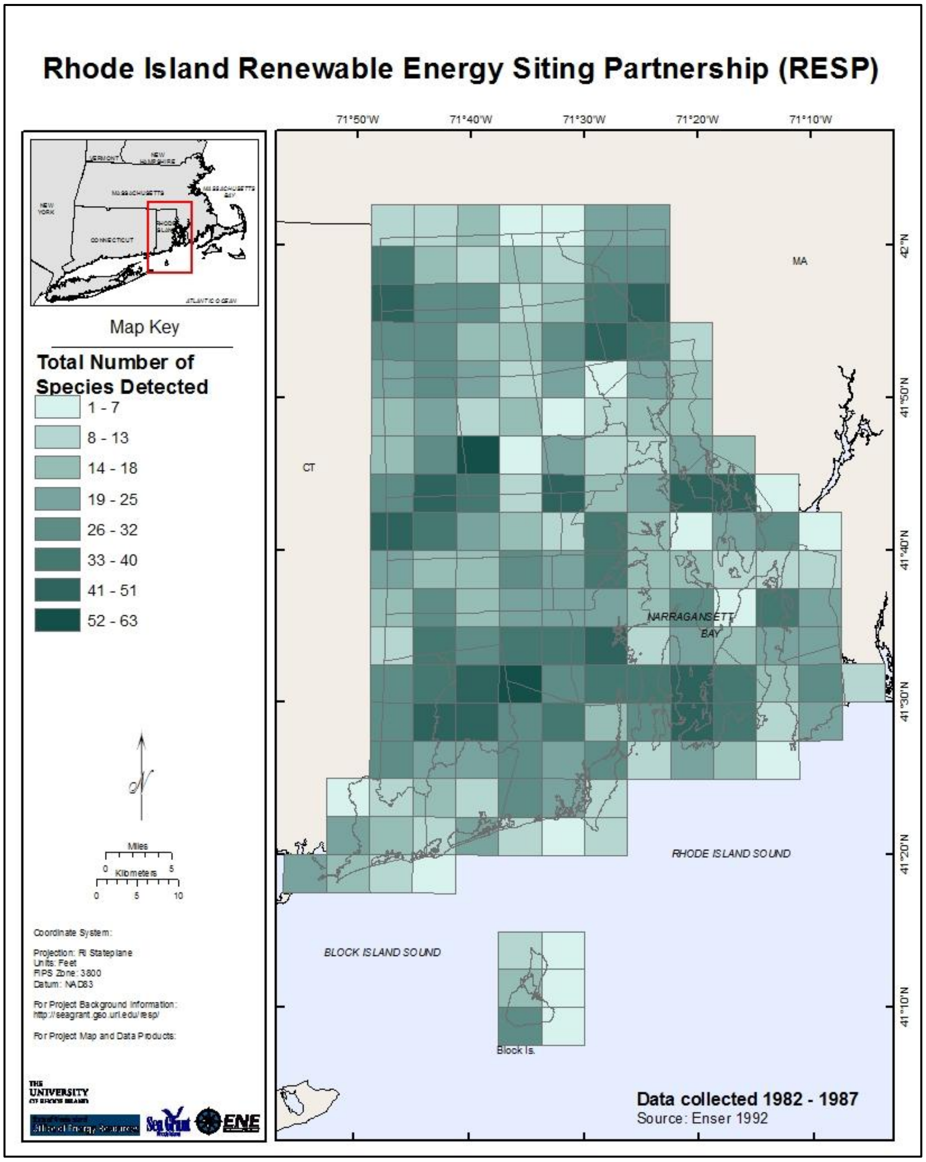


Figure 27. Occurrence of breeding birds in Rhode Island based on surveys conducted from 1982 - 1987 (Enser 1992). Shown are the total number of species of birds with a confirmed nest in each grid cell (25 km^2), thus this figure represents spatial variation in breeding bird species richness throughout Rhode Island.

6.6 Migratory Birds

The vast majority of birds in Rhode Island are migratory species (86%; 334 of 388 species; Tables A2.4 and 9). The primary habitats these species use are forests (114 species), wetlands including lakes/ponds (60 species), coastal areas (68 species), offshore waters (22 species), grasslands (22 species), and early successional/scrub habitats (26 species). We have devoted separate sections of this report to various habitat categories, where these species are likely to be detected (see below).

Of the migratory species, 83 species are considered common, 35 species are fairly common, 113 species are uncommon, 50 species are rare, and 52 species are accidental (Table A2.4).

Table 9. Total number species of migratory birds, by family, in Rhode Island. Numbers represent the number of species, by relative abundance category based on Desante and Pyle (1986)^{A}.

Bird Group	Common	Fairly Common	Uncommon	Rare	Accidental	Extinct	Total
Loons	2		1	1			4
Grebes		1			2		3
Shearwaters and allies	1	1		1	2		5
Pelican and allies	2		1		4		7
Herons and allies		5	2	5	2		14
Waterfowl	13	9	9	4	1		36
Diurnal raptors and vultures	5		8		2		15
Turkey and grouse	1		1		1		3
Rails and allies	1		2	4	3		10
Shorebirds	9	4	17	6	5	1	42
Gulls, terns, jaegars	5	1	9	7	7		29
Alcids`	3	2	1				6
Pigeons and Doves	2					1	3
Cuckoos			2				2
Owls	1		2	1	4		8
Nightjars			2	1			3
Swift			1				1
Hummingbird	1						1
Kingfisher			1				1
Woodpeckers	2	1	1		2		6
Flycatchers	2		5	2	3		12
Larks			1				1
Swallows	2		3	2			7
Jays and allies	3			1	1		5
Chickadees	2						2
Nuthatches	1						1

Bird Group	Common	Fairly Common	Uncommon	Rare	Accidental	Extinct	Total
Creeper	1						1
Wrens	2		2	1	1		6
Kinglet	2						2
Gnatcatcher			1				1
Thrush and allies	1	4	3		1		9
Mimic Thrush	2		1				3
Pipit		1					1
Waxwings	1				1		2
Starling	1						1
Phainopepla					1		1
Vireos	1		4	1			6
Warblers	7	7	17	5	1		37
Tanagers			1	1	1		3
Sparrows and allies	6	1	11	5	6		29
Blackbirds and allies	3		2	2	2		9
Orioles			2				2
Finches	2		2				4
Total number of species	83	35	113	50	52	1	334

[A] Desante and Pyle (1986) definitions: few individuals encountered on >90% of days (common); 50-90% (fairly common); 10-50% of days (uncommon); <10% of days (rare); Occurring outside of its range (accidental); unrecorded in last 50 years (extinct); or many individuals encountered on >50% of days (common); 10-50% of days (fairly common); >10% of days (uncommon).

6.6.1 Bird banding data

There are three active bird banding stations in Rhode Island: Kingston Wildlife Research Station (41° 28' 40"N, 71° 30'39"W) in Kingston - operated by URI biologists on a 82-acre Audubon Society of Rhode Island property, Block Island Banding Station (41° 12' 34"N, 71° 33'30"W) on the north end of Block Island – operated at the Lapham property by Kim Gaffet, with data management by Steve Reinert, and Ninigret National Wildlife Refuge banding station (41° 21' 40"N, 71° 35'55"W) – operated by USFWS biologists, which is located on north-central side of Ninigret Pond adjacent to restored runways. Available habitats at each station determine which species will be captured at each site.

Kingston Wildlife Research Station was opened in 1958 by Douglas Kraus, with active banding operation really starting in 1960, making it one of the longest banding operations in the United States. From 1960 through 2010, over 33,000 individuals from 110 species were captured at Kingston (Fig. 28, Fig A2.5). At Block Island Banding Station, almost 100,000 individuals were captured from 146 species from 1967 to 2010. The most recent station to open was Ninigret, which has captured over 6,000 individuals from 73 species from 2008 - 2010.

Capture data from the stations can be used for a number of purposes. First, the relative abundance of birds captured gives us some idea about which species are most common at each site. For example, Gray Catbird, Yellow-rumped Warbler, White-throated Sparrow, Common Yellowthroat, and Black-capped Chickadee tend to be among the most commonly captured species at each station (Fig. 28). Second, captures at these stations can be used to assess migration phenology in fall for migratory species (Table A2.5). Finally, they can be used to estimate the total number of migratory species at each site. For example, species accumulation curves suggest more migratory species use Block Island than mainland banding stations (Fig. 29), with about 115 species expected at Kingston and Ninigret versus over 140 on Block Island.

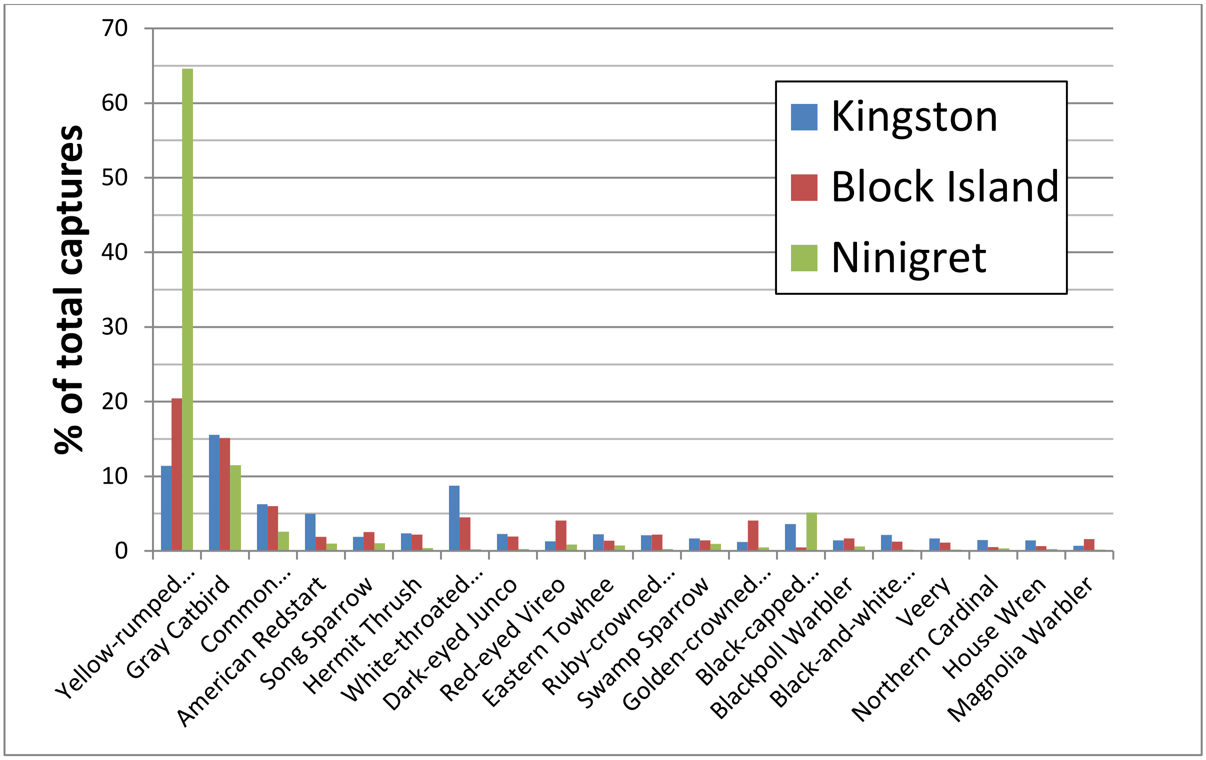


Figure 28. Relative abundance of the most commonly captured species at three bird banding stations in Rhode Island.

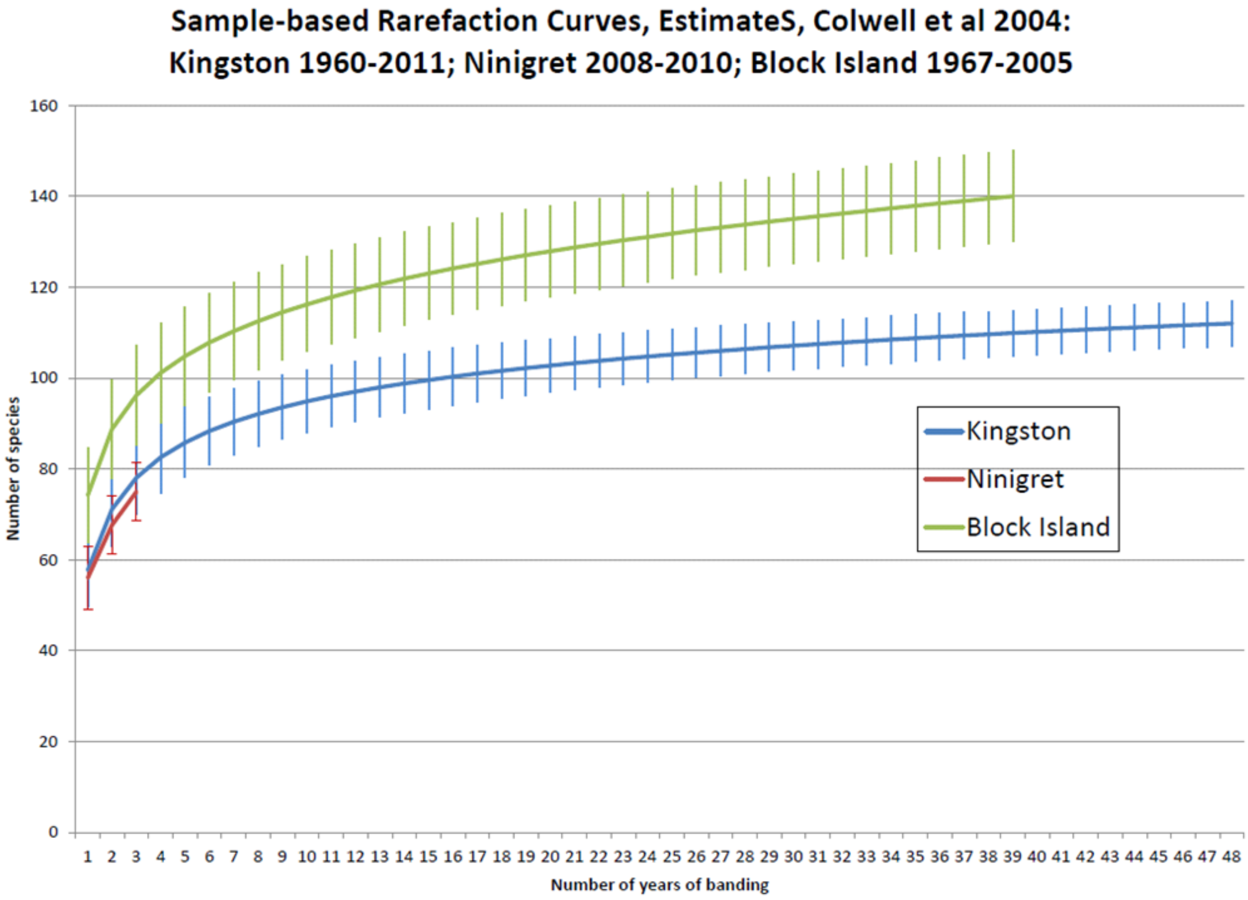


Figure 29. Species Accumulation Curves from banding station data collected at three stations in Rhode Island.

6.6.2 Movement Ecology of Birds on Block Island based on Radar Studies

From 19 March to 15 December, 24 hours per day, 7 days per week in 2009, Mizrahi et al. (2010) monitored avian movement ecology at two sites on Block Island using a dual mobile marine radar system. Their system consisted of two 25 kW X-band marine radars with 6.5’ open array antennas, with one antenna operating in the vertical plane (used to determine the number of targets; undifferentiated between birds and bats) and flight altitude of targets) and one in the horizontal plane (used to assess flight direction of targets). This study provided the first quantitative estimates of flight altitude of bird and bats in the state. Additional radar studies are being conducted by Detect and Tetratech for the Deepwater offshore wind turbines, but those studies’ results were not available at the time we prepared this report. Several interesting patterns were evident from Mizrahi’s research.

Altitude of migration: On Block Island, data were recorded in 100m strata, with the number targets declining asymptotically above 500 m (Mizrahi et al. 2010). The number of targets flying < 100 m in altitude was highest in spring (13% of all targets) compared to summer and fall (11% of targets). Mizrahi et al. (2010) suggested a higher proportion of birds flew <200 m attitude over Block Island than comparable studies conducted over the mainland. Put in other words, large number of targets were potentially flying in the rotor sweep zone on Block Island, thus results were similar to studies conducted in the North Sea; this was probably due to the large numbers of waterfowl, gulls, and herons recorded near the radar unit on Block Island

Seasonal variation: There were more targets passing by Block Island during fall (16 August – 15 December, mean = 408.89 ± SE 48.40 targets) compared to spring (19 March – 31 May, mean = 161.72 ± SE 17.75 targets). The number of targets passing over Block Island during night in the fall was lower than estimates for Cape May, New Jersey where birds from several flyways are concentrated (Mizrahi et al. 2010). In addition, movement rates of birds were greater in the mid-Atlantic Appalachian Mountains suggesting that "overland migration is greater in magnitude than that occurring across Long Island Sound and the Block Island vicinity" (Mizrahi et al. 2010). Most interestingly, large numbers of targets passed over Block Island on only four to five nights (Fig. 30), thus this is not a constant, steady stream of birds flying over Block Island.

Diel Movement Patterns: The number of targets was significantly greater at night (mean = 439.86 ± SE 46.94) than during the day (mean = 172.53 ± SE 17.19). More targets flew <100 m altitude during the day (15%) compared to night (8%). During the night, there was a dramatic increase in the number of targets within the first hour of sunset, with peak movements occurring one to four hours after sunset, with most birds flying between 300 to 800 m altitudes (Figs.31 and 32). Numbers gradually decreased until the following morning. During the day period, there was peak in movements six to eight hours after sunrise, except in fall when the pattern was bimodal, with most birds flying 300-800 m altitude (Fig. 30). Interestingly, there were many targets airborne just before sunset, which Mizrahi et al. (2010) suggested were possibly movements of birds to roosting areas or bats initiating foraging flights. In the fall, large numbers of targets were moving just after sunrise. Similarly, this could be movement of birds from roosting areas or the reorientation of nocturnally-migrating birds after a night of migration.

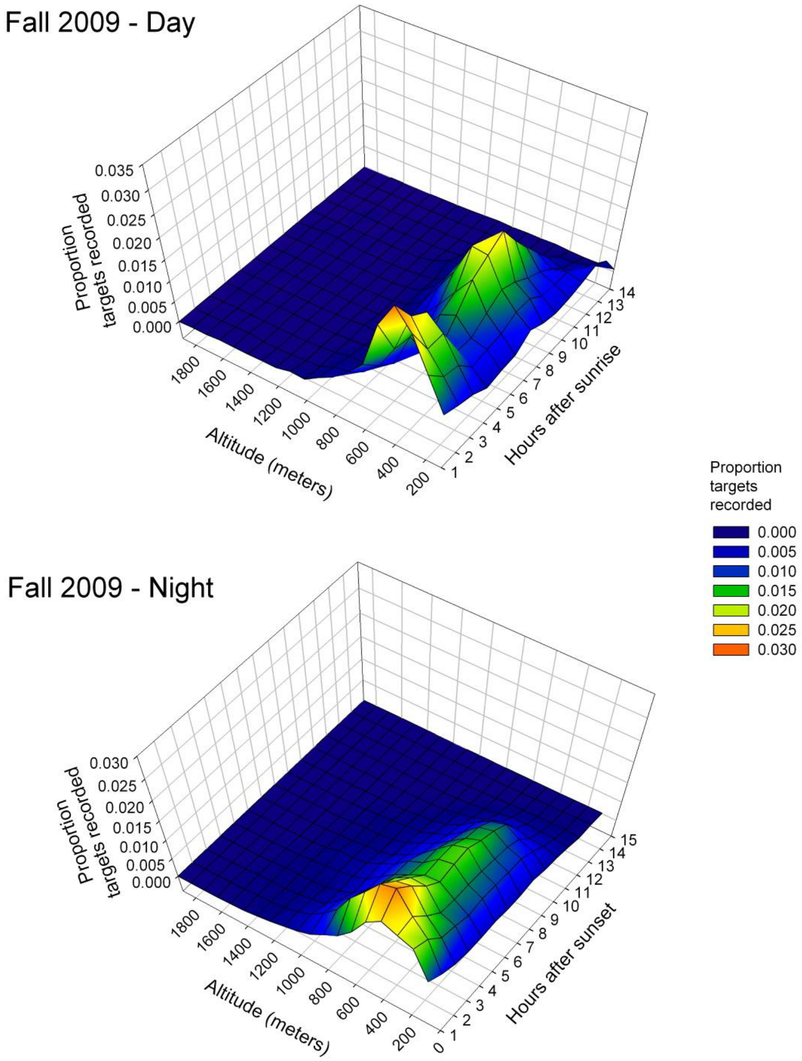


Figure 30. Diel variation in flight altitude of targets (birds/bats) detected on Block Island during the day and at night from March to Dec 2009 by Mizrahi et al (2010).

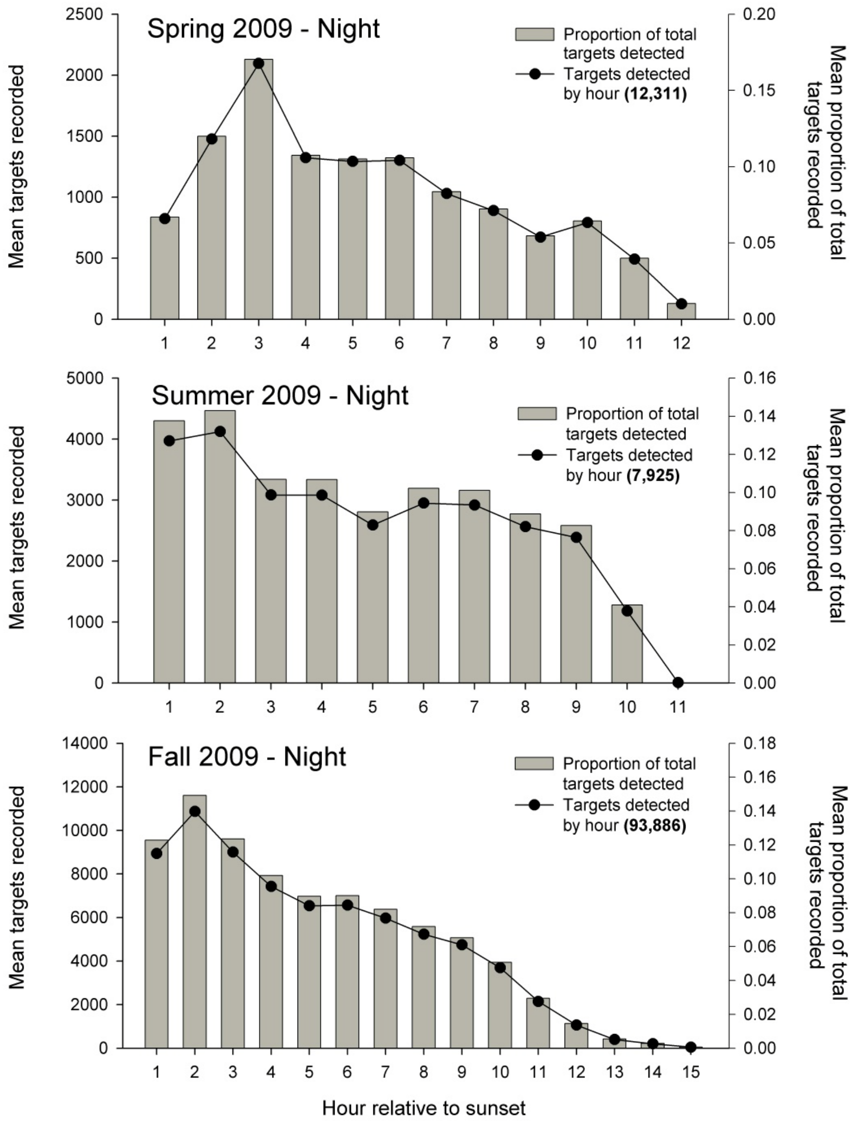


Figure 31. Seasonal variation in the number of targets detected by a vertical X-band radar on Block Island as a function of hours after sunset (Mizrahi et al (2010). Peak movement rates were 3 hrs after sunset in Spring vs. 2 hrs after sunset in Fall. Also, note >12,000 targets were detected in the spring vs. over 93,000 in the fall.

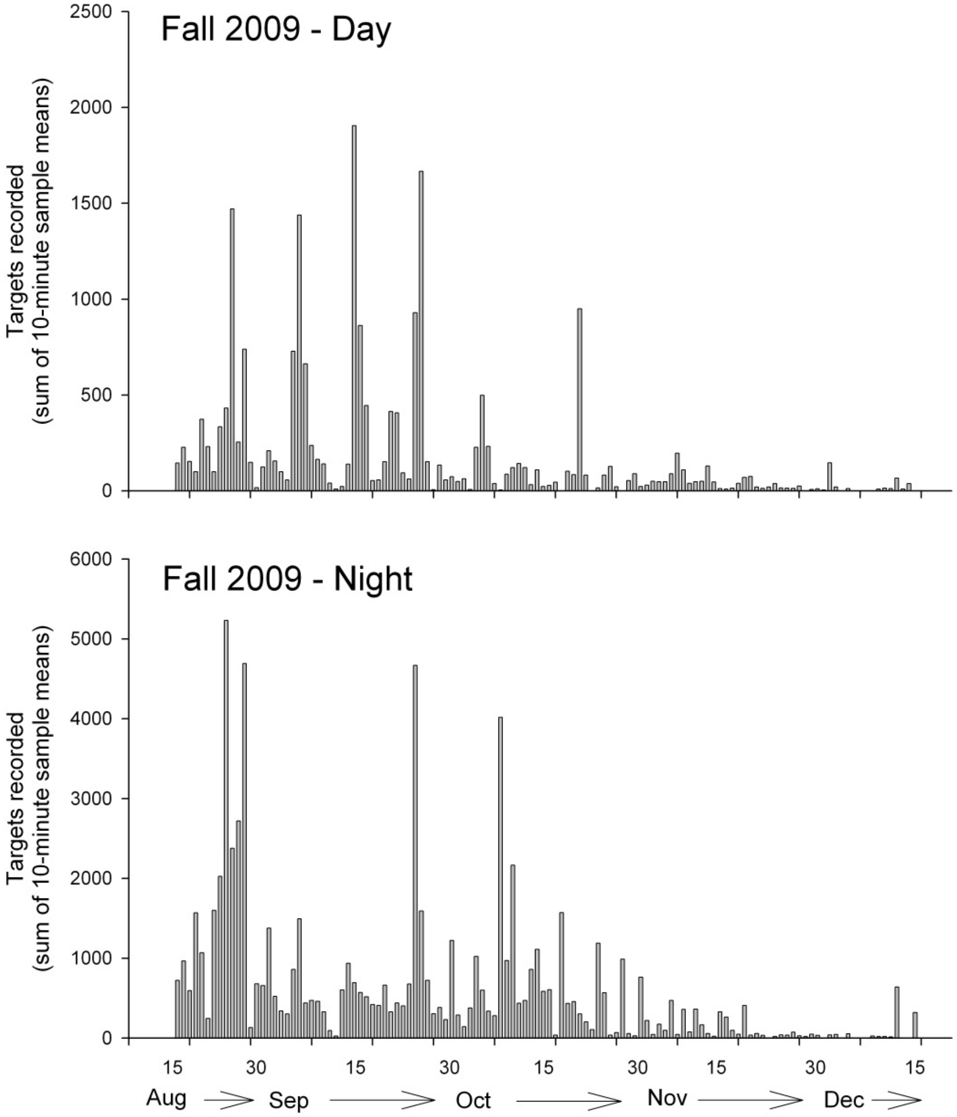


Figure 32. Daily variation in the number of targets passing over Block Island during the day and night in the fall 2009 based on a radar study by Mizrahi et al. (2010). Only on few nights were relatively large numbers of targets (probably mainly migratory passerines) passing over the island.

6.7 Wintering Birds

There are approximately 222 species of birds that winter in Rhode Island (Table 10 and A2.6). Based on Desante and Pyle (1986), most species (77 of 222) are classified as uncommon, while 41 species are common, 10 species are fairly common, 61 species are rare, and 30 species are accidental (Table 10).

At least 26 species primarily occur in offshore marine waters during winter, thus are unlikely to be affected by terrestrial wind farms. Of the remaining species, at least 20 species tend to be most abundant in grasslands, 60 species are forest specialists, 32 species are associated with a variety of terrestrial habitats including forests and grasslands (classified as mixed), over 40 species occur in wetlands (ponds, lakes, streams, and marshes), 11 are shorebirds that use the intertidal zone in wetlands, and 16 species occur in nearshore waters (e.g., Narragansett Bay).

The most common types of birds to winter in Rhode Island include waterfowl (peak abundance is in winter for many species), diurnal raptors (although most are uncommon or rare in the winter), shorebirds (again most are uncommon or rare in winter), gulls (peak abundance for many species is in the winter), alcids (peak abundance is in winter), sparrows (peak abundance is in winter for many species), and finches (peak abundance is in winter for many species)(Table A2.6).

Table 10. Total number of bird species, by family, that winter in Rhode Island. Given is the number of species, by relative abundance based on Desante and Pyle (1986) [A].

Group	Common	Fairly Common	Uncommon	Rare	Accidental	Total
Loons	**2**			**1**		**3**
Grebes		1	2		2	5
Tubenose			1			1
Cormorants and allies	1		2			3
Herons and allies			2	2	2	6
Waterfowl	14		11	10	1	36
Raptors / vultures	1	1	6	8		16
Grouse and allies	1		3			4
Rails			1	3	3	7
Shorebirds			4	9	2	15
Gulls, terns, jaegars	3	1	3	3	4	14
Alcids	1		3	2		6
Doves	2					2
Owls			7		2	9
Kingfisher			1			1
Woodpecker	2		2	3	1	8
Flycatcher			1		1	2
Larks			1			1
Swallows				1		1
Jays and allies	2		2			4
Chickadees	2			1		3
Nuthatches	2					2
Creeper			1			1
Wrens	1		1	2	1	5
Kinglet		1	1			2
Thrushes and allies	1		3		2	6
Mimic thrush			1	1		2
Pipit			1			1
Waxwing		1		1		2
Starling	1					1
Shrikes			1	1		2
Warblers		1	1	4	2	8
Sparrows and allies	4		8	5	5	22
Blackbirds and allies			4	2	2	8
Finches and allies	1	4	3	2		10
House Sparrow	1					1
Total	41	10	77	61	30	220

[A] Desante and Pyle (1986) definitions: few individuals encountered on >90% of days (common); 50-90% (fairly common); 10-50% of days (uncommon); <10% of days (rare); occurring outside of its range (accidental); unrecorded in last 50 years (extinct); or many individuals encountered on >50% of days (common); 10-50% of days (fairly common); >10% of days (uncommon).

6.7.1 Christmas Bird Count

Christmas Bird Counts provide some information on annual variation in the relative abundance of birds wintering in Rhode Island. There are four counts that are still active in the state: Newport, Block Island, South Kingstown, and Napatree (Fig. 33).

These data provide useful information on population trends of wintering birds over the time span of surveys (e.g., 1902-1950 in the case of the Providence count), however we did not conduct any trend analyses for this report. These surveys also provide some indication of species that might be vulnerable to collisions with wind turbines in the winter, assuming there is a relationship between abundance and collision rates. For example, in Newport, the most abundant species detected is European Starling (an average of over 11,000 birds per year per survey), followed by Canada Goose, Herring Gull, American Robin and American Black Duck (Table A2.7). On Block Island, Herring Gulls were the most commonly detected (>1,600 per yr per survey), followed by Red-breasted Merganser, Great Black-backed Gull, European Starling, and Yellow-rumped Warbler. South Kingston had American Robin as the most common species, followed by Canada Goose, European Starling, Herring Gull, and Red-breasted Merganser. Thus, the same species tend to the most abundant in all these coastal sites.

Over the years, 181 species have been detected on the Newport count from 1981-2010, 153 species on Block Island from 1981-2010, 181 species at South Kingstown from 1981-2010, and 82 species in Providence from1902-1950. This information might be useful to planners located in Newport, Block Island, or South Kingstown, as it provides a rich source of baseline information on avian diversity along the southern coast of Rhode Island.

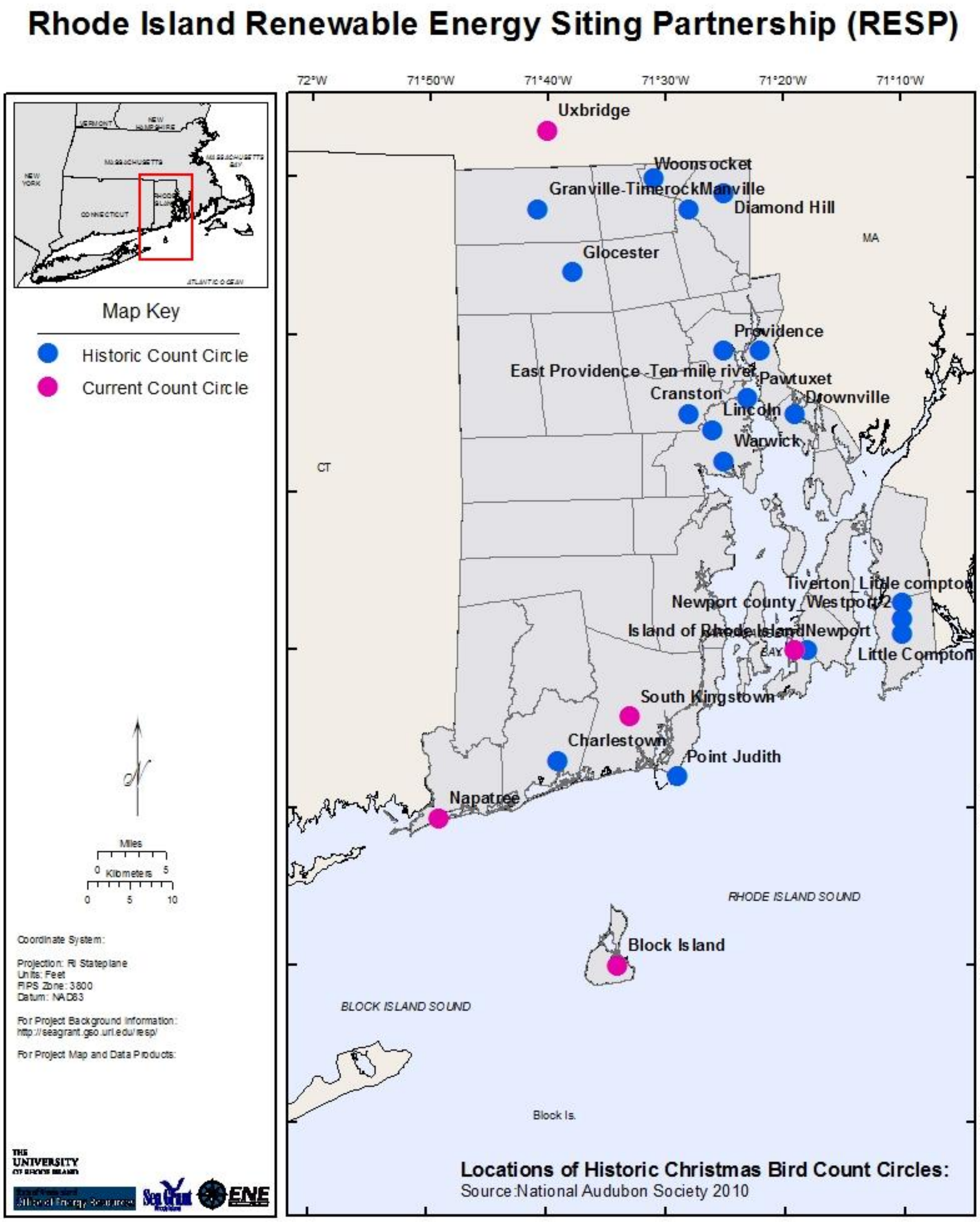


Figure 33. Distribution of sites where Christmas Bird Counts have been conducted in Rhode Island based on records from the National Audubon Society (2010). Surveys are no longer conducted at most sites shown here (blue circles), with active counts conducted primarily in southern Rhode Island (pink circles).

6.7.2 Backyard Bird Count

The Great Backyard Bird Count is an annual survey where volunteer observers count all the birds in a location one day in late February. On useful aspect of this dataset is that it is spatially explicit, so that biologists interested in the distribution of wintering bids in a particular town can go to this database to pull up records for a specific area (Table A2.8). Also, the Great Backyard Bird Count provides information on annual variation in birds, particularly for those species that use feeders. For example, annual variation in the abundance of irruptive species at bird feeders is clearly shown with these types of data.

6.8 Habitats

There are a number of habitats in the region that are conservation priorities. Partners In Flight has highlighted these habitats and discusses in depth which species are associated with each habitat (http://www.blm.gov/wildlife/table_09.htm). In Rhode Island, those habitats include: (1) maritime marshes, (2) beach/dune, (3) mature forests, (4) early successional shrub/pitch pine barren, (5) grassland/agricultural, (6) urban/suburban, and (7) freshwater wetland, river, and lake. Within each habitat, a set of representative species with conservation concerns have been identified, with a summary of actions levels (I = crisis; recovery needed; II = immediate management or policy needed range-wide; III = management to reverse or stabilize populations; IV = long-term planning to ensure stable populations; V = research needed to better define threats; VI = monitor population changes only).

Rhode Island covers approximately 690,057 acres, with 397,254 acres of forest, 23,003 acres of shrubs, 124,381 acres of grasslands, and 26,286 acres of ponds, lakes, and rivers (Table 11). There are 39 towns in Rhode Island that range in size from Central Fall (825 acres) to Coventry (39,972 acres). The top three towns in terms of acreage of forest are: Exeter (30,646 ac), Glocester (29,078 ac), and Burrillville (28,785 ac). Early successional/shrub habitat acreage is greatest on New Shoreham (Block Island; 2305 acres), followed by Portsmouth (1749 ac), and South Kingstown (1653 acres). Grasslands acreage is greatest in Warwick (14,409 ac), followed by Providence (10,375 ac) and North Kingstown (8,517 ac).

Table 11. Summary of habitat acreage in 38 towns in Rhode Island based on Buffum (2012).

Town	Town (ac)	Forest (ac)	Shrub (ac)	Grassland (ac)	Water (ac)	Forest (%)	Shrub (%)	Grassland (%)	Water (%)
BARRINGTON	5501	1082	47	0	193	20	1	0	4
BRISTOL	6320	1824	124	0	21	29	2	0	0
BURRILLVILLE	36456	28785	739	0	1324	79	2	0	4
CENTRAL FALLS	825	43	13	0	53	5	2	0	6
CHARLESTOWN	24454	16880	1236	18	1019	69	5	0	4
COVENTRY	39972	27575	527	1	2181	69	1	0	5
CRANSTON	18505	5647	310	0	341	31	2	0	2
CUMBERLAND	18078	9541	561	0	1138	53	3	0	6
E. GREENWICH	10438	5999	176	0	59	57	2	0	1
E. PROVIDENCE	8953	1744	174	2	294	19	2	0	3
EXETER	37371	30646	678	0	650	82	2	0	2
FOSTER	33261	27891	571	0	727	84	2	0	2
GLOCESTER	36373	29078	446	3109	1692	80	1	9	5
HOPKINTON	28250	21803	562	2860	940	77	2	10	3
JAMESTOWN	6188	1889	917	2118	50	31	15	34	1
JOHNSTON	15573	7194	355	5710	541	46	2	37	3
LINCOLN	12141	5759	337	4813	552	47	3	40	5
LITTLE COMPTON	14458	5664	1042	2423	1260	39	7	17	9
MIDDLETOWN	8448	577	889	4110	268	7	11	49	3
NARRAGANSETT	9118	2675	1186	3985	166	29	13	44	2
NEW SHOREHAM	6378	196	2305	1705	303	3	36	27	5
NEWPORT	5177	198	529	3479	214	4	10	67	4
N. KINGSTOWN	28268	15026	937	8517	483	53	3	30	2
N. PROVIDENCE	3708	456	25	3051	80	12	1	82	2
N. SMITHFIELD	15927	10509	642	3120	606	66	4	20	4
PAWTUCKET	5670	567	22	4686	75	10	0	83	1
PORTSMOUTH	15103	3721	1749	5037	329	25	12	33	2
PROVIDENCE	12037	755	17	10375	236	6	0	86	2
RICHMOND	26074	19259	684	2588	403	74	3	10	2
SCITUATE	35077	25122	668	3662	4226	72	2	10	12
SMITHFIELD	17669	10518	434	4775	907	60	2	27	5
S. KINGSTOWN	39225	21535	1653	7851	2539	55	4	20	6
TIVERTON	19421	10975	563	4352	572	57	3	22	3
WARREN	4000	986	111	1680	28	25	3	42	1
WARWICK	22971	5477	447	14409	409	24	2	63	2
W. GREENWICH	32779	27677	523	2380	651	84	2	7	2
W. WARWICK	5178	1433	50	3344	152	28	1	65	3
WESTERLY	19666	9228	667	6807	486	47	3	35	2
WOONSOCKET	5048	1320	87	3414	122	26	2	68	2
Statewide	**6900567**	**397254**	**23003**	**124381**	**26286**	**58**	**3**	**18**	**4**

6.8.1 Grassland Birds

There are at least 22 species of birds in Rhode Island that use grasslands during part of their annual cycle (Table 12), with 15 of these species nesting in Rhode Island (Figs. 34 and 35). A few species nest only in grassland habitats, thus this habitat provides a critical resource for these grassland-obligate species (i.e., Horned Lark, Grasshopper and Savannah Sparrows, Bobolink, Eastern Meadowlark, and Upland Sandpiper). Other species nest in adjacent habitats and actively forage in grassland habitats (Cattle Egret and Glossy Ibis, American Kestrel, Northern Harrier and Barn Owl, Common Nighthawk). Finally, some species use grasslands during migration (American Golden and Black-bellied Plover, Buff-breasted Sandpiper, Vesper Sparrow) or on their wintering grounds (Canada Goose, North Atlantic Population).

Compared to other habitats in Rhode Island, avian populations that are grassland specialists are doing poorly. Based on Breeding Bird Survey population trend estimates, 14 of 18 species with BBS trends available have declining populations, with 11 of 14 exhibiting significant negative declines. Of the three species with apparently increasing populations, only Eastern Bluebird is showing a significant population increase (Table 12). This is primarily because the amount of grassland habitat is diminishing as forests become reestablished throughout the region. Of the 22 grassland-associated species we identified in Rhode Island, five are State Listed, eight species are priority bird species for Bird Conservation Region 30, and ten species are classified as conservation concerns of various levels by Partners in Flight (Table 12).

Overall, the assemblages of bird species that use grasslands for breeding and/or foraging have declined more than any other habitat associated group (Knopf 1994). Based on trends along BBS routes, populations Eastern Bluebirds have increased across parts of their breeding regions, largely due to management practices. However, most obligate grassland species are declining throughout their range based on BBS results (Table 12). For the past few centuries, both natural and human-altered grasslands provided habitat for grassland birds in southern New England. However, with grasslands reverting back to shrublands and forests, due to declines and changes in agricultural practices and increases in the human population, grassland habitat has drastically declined across the region and so have the avian species associated with grasslands (Vickery and Dunwiddie 1997).

Based on available land cover maps, there are over 124,000 acres of grassland habitat in Rhode Island. Grasslands include pasture, idle pasture, lawns, turf farms, and developed recreational areas (Fig. 36); therefore, many areas depicted are probably not viable breeding or foraging habitat. Therefore, without on the ground visits by a trained biologist to determine if the site is potential grassland that provides wildlife habitat, the habitat maps provided in this report are of limited value and merely present potential design considerations. Towns with the largest acreage of potential grasslands include Warwick (14,409 ac), Providence (10,375 acres), North

Kingstown (8,517 ac), and South Kingstown (7,851 acres). Towns with the high percentage of available lands include Providence 86%, Pawtucket 83%, and North Providence 82% (Table 11).

Table 12. Twenty-two species of birds associated with grassland habitats in Rhode Island (Degraaf and Yamasaki 2001). Given are habitat associations at nests and foraging habitat. In addition, information on their conservation status is given and their annual population trends based on Breeding Bird Surveys (BBS) from 1966-2009.

	Habitat			**BBS Trend[C]**	
Species[A]	**Nest habitat**	**Foraging**	**Conservation Status[B]**	**Annual rate**	**95% CI**
Cattle Egret	Trees on islands	Upland fields with cows		**-5**	**-10.8 to -1.2**
Glossy Ibis	Trees on islands	Grasslands	High, Tier V	-1.3	-6.1 to 3.7
Canada Goose (Atlantic population)	wetlands	grasslands, uplands	Highest	NA	NA
Killdeer	grasslands, barren areas	Various- field, stream, beach		-0.3	-1.1 to 0.5
American Golden Plover	Tundra	Grasslands	High	NA	NA
Black-bellied Plover	Tundra	Grasslands	High	NA	NA
Upland Sandpiper	Grasslands > 150 acres	Grassland including airports	SE, Moderate, Tier I B	**-3**	**-4.8 to -1.8**
Buff-breasted Sandpiper	Tundra		High	NA	
American Kestrel	Cavity	Grasslands		**-4.9**	**-6.3 to -3.7**
Northern Harrier	Shrubs	Open fields/ coastal areas	SE, Tier V	-0.1	-4.3 to 3.6
Barn Owl	Structures, cliffs	Fields, grasslands	SE, Tier V	4.9	-3.2 to 14.1
Short-eared Owl	Grasslands	Grasslands	Tier II C	NA	
Common Nighthawk	On ground in open field	Fields and edges	Tier V	**-4.8**	**-26.7 to -0.4**
Northern Bobwhite	Grasslands	Open fields	High	**-8.1**	**-8.7 to -7.5**
Ring-necked pheasant	On ground in tall grass	Open fields		**-5.5**	**-7.4 to -3.7**
Horned Lark	Grasslands	Open fields/airports	C, Tier V	0.8	-0.3 to 1.9
Eastern Bluebird	Natural cavity or nest box near grassland	Open fields		4.3	3.3 to 5.4
Vesper Sparrow	On ground in open field	Prairie/meadow roadsides	Tier V	**-4.4**	**-6.7 to -2.5**
Savannah Sparrow	Grasslands >10 acres	Open fields	Tier V	**-3.7**	**-6.7 to -0.7**
Grasshopper Sparrow	On ground in open field	Grassland/bare ground	ST, Moderate	**-4**	**-5.0 to -3.0**
Bobolink	Grasslands >5 acres	Grassland	Tier III	**-2.1**	**-3.5 to -1.0**
Eastern Meadowlark	Grasslands >15 acres	Grassland		**-6.4**	**-7.2 to -5.7**

[A] Species documented breeding in Rhode Island (Enser 1992) are given in bold.

[B] State of Rhode Island classification: SE = State Endangered, ST = State Threatened, C = Concern; Bird Conservation Region 30 categories: HH = Highest Priority, H = High priority, M = Moderate priority; Partners in Flight categories: Tier I A: High Continental Priority - High Regional Responsibility, Tier I B: High Continental Priority - Low Regional Responsibility, Tier II A: High Regional Concern, Tier II B: High Regional Responsibility, Tier II C: High Regional Threats, Tier III: Additional Watch List, Tier IV: Additional Federally Listed, Tier V: Additional State Listed.

[C] BBS trends in bold are significant

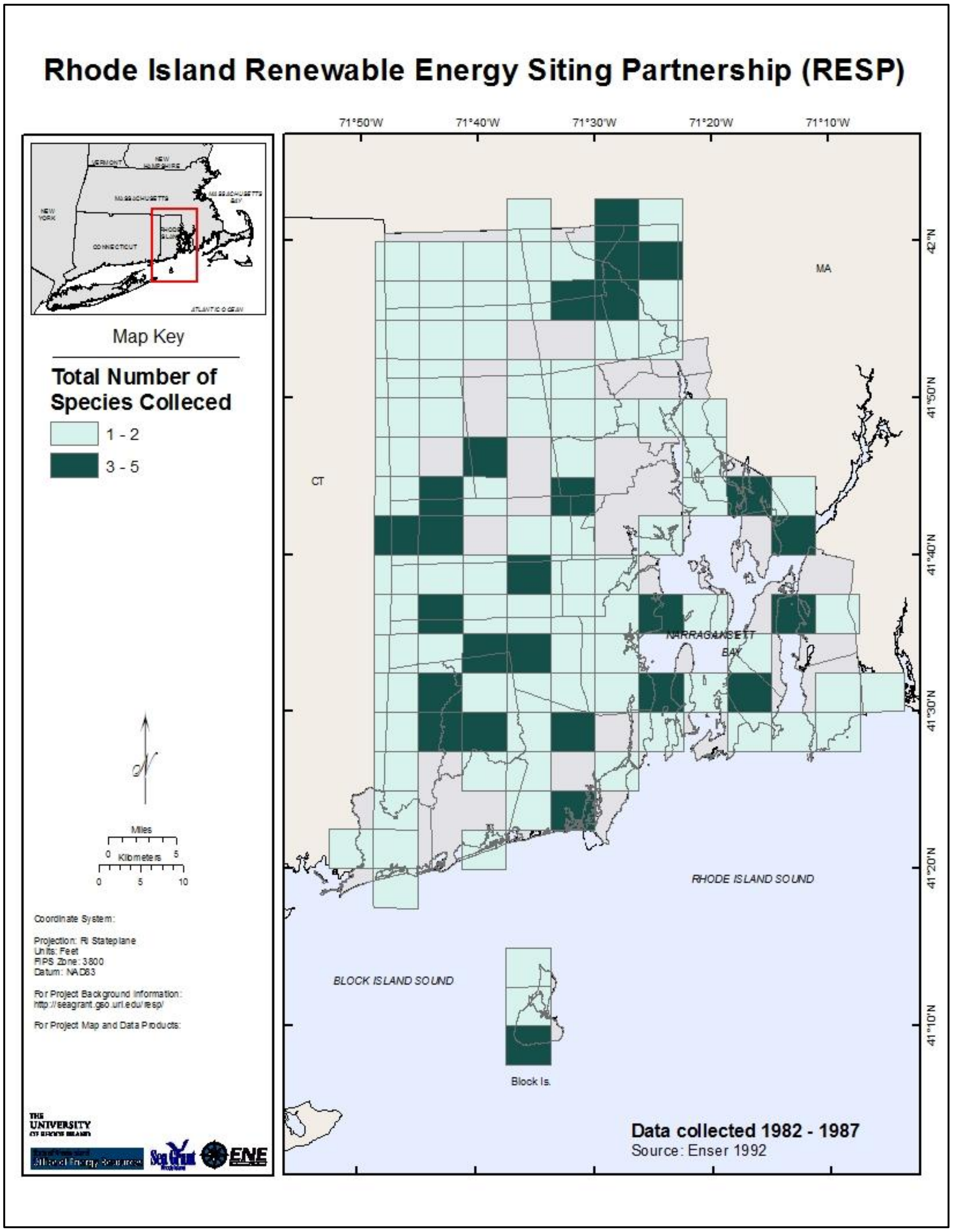


Figure 34. Distribution of breeding birds that primarily nest in grasslands in Rhode Island based on surveys conducted from 1982-1987 (Enser 1992). Shown is the total number of species of grassland- specialist birds with a confirmed nest detected in each 25 km^2 grid cell. Species that nest primarily in grassland habitats are given in Table 12.

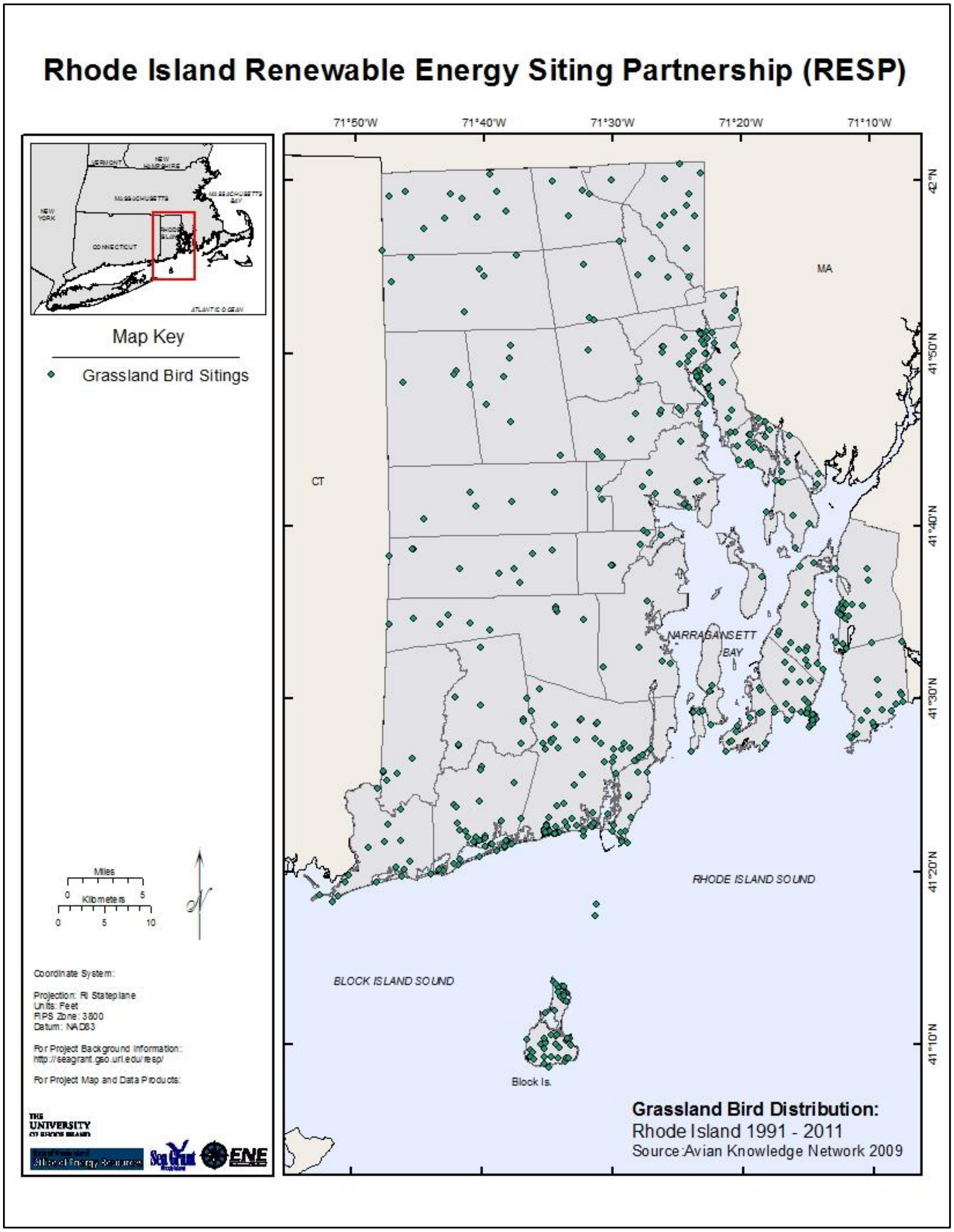


Figure 35. Reports of birds that are grassland specialists that were detected from 1991-2011 in Rhode Island based on the eBird records in the Avian Knowledge Network.

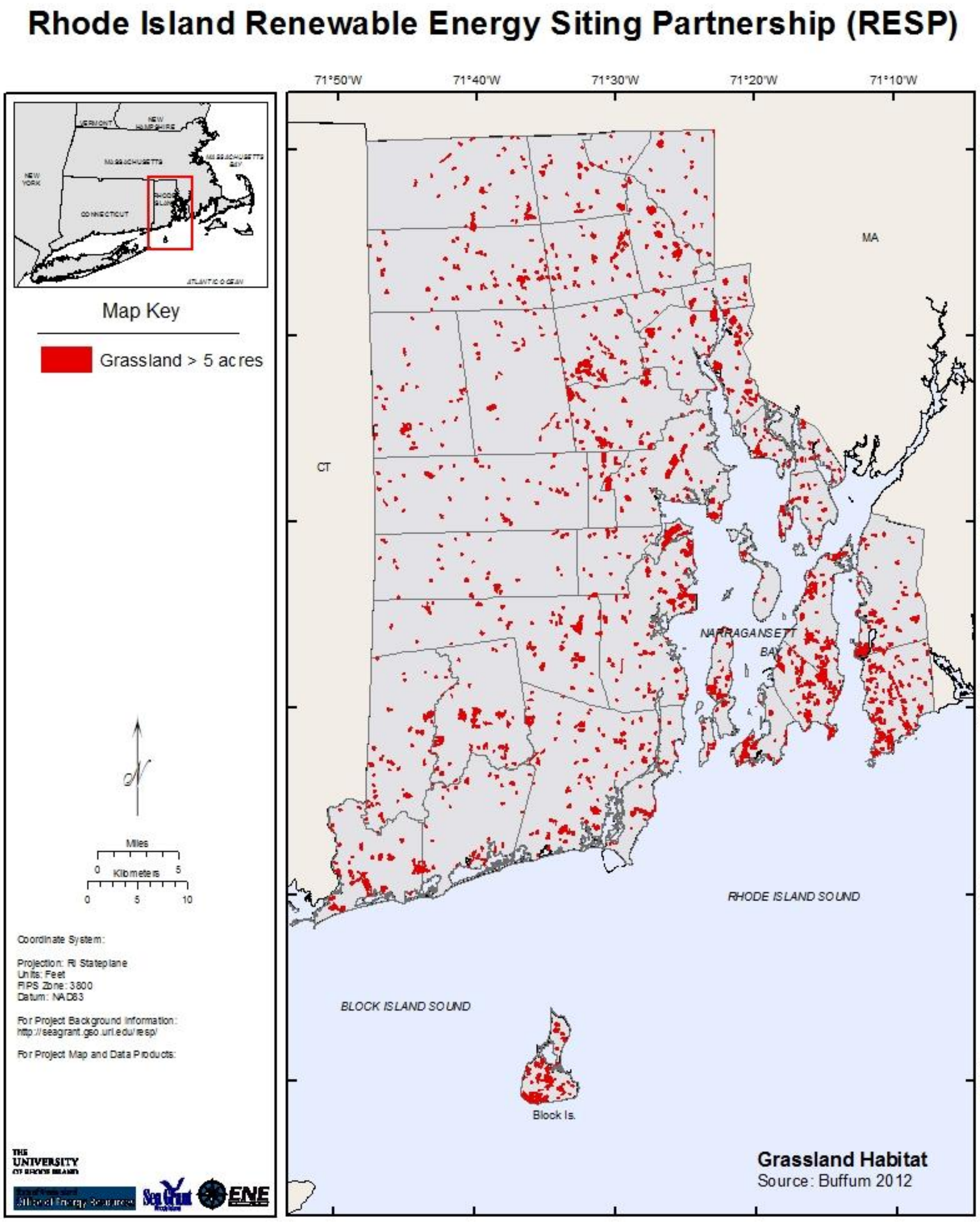


Figure 36. Distribution of potential grassland habitat > 5 acres in Rhode Island based on work by Buffum (2012). Grasslands shown on this map include pasture, idle pasture, lawns and developed recreational areas, thus many areas depicted here are probably not viable breeding or foraging habitat for most species of birds that specialize in grasslands. There currently are no current maps available showing viable grassland habitat for grassland birds in Rhode Island, therefore individual parcels will have to be inspected by a biologist to determine if it provides suitable habitat for grassland specialists (see Table 12).

Birds that use grasslands in Rhode Island fall into two major categories – migrants that nest only in Rhode Island and winter farther south and species that breed and winter in Rhode Island. Nesting migrants include Bobolink and Grasshopper Sparrow (Fig. 37), which occur in Rhode Island from early May to the end of October. Dickcissels do not nest in Rhode Island, but pass through during migration, primarily in the fall. Other species nest and winter in Rhode Island (e.g., Eastern Meadowlark, Horned Lark), but now these species are more likely to be detected here in the winter months – presumably from more northerly breeding populations that only winter in Rhode Island. Ipswich Savannah Sparrows only winter in Rhode Island.

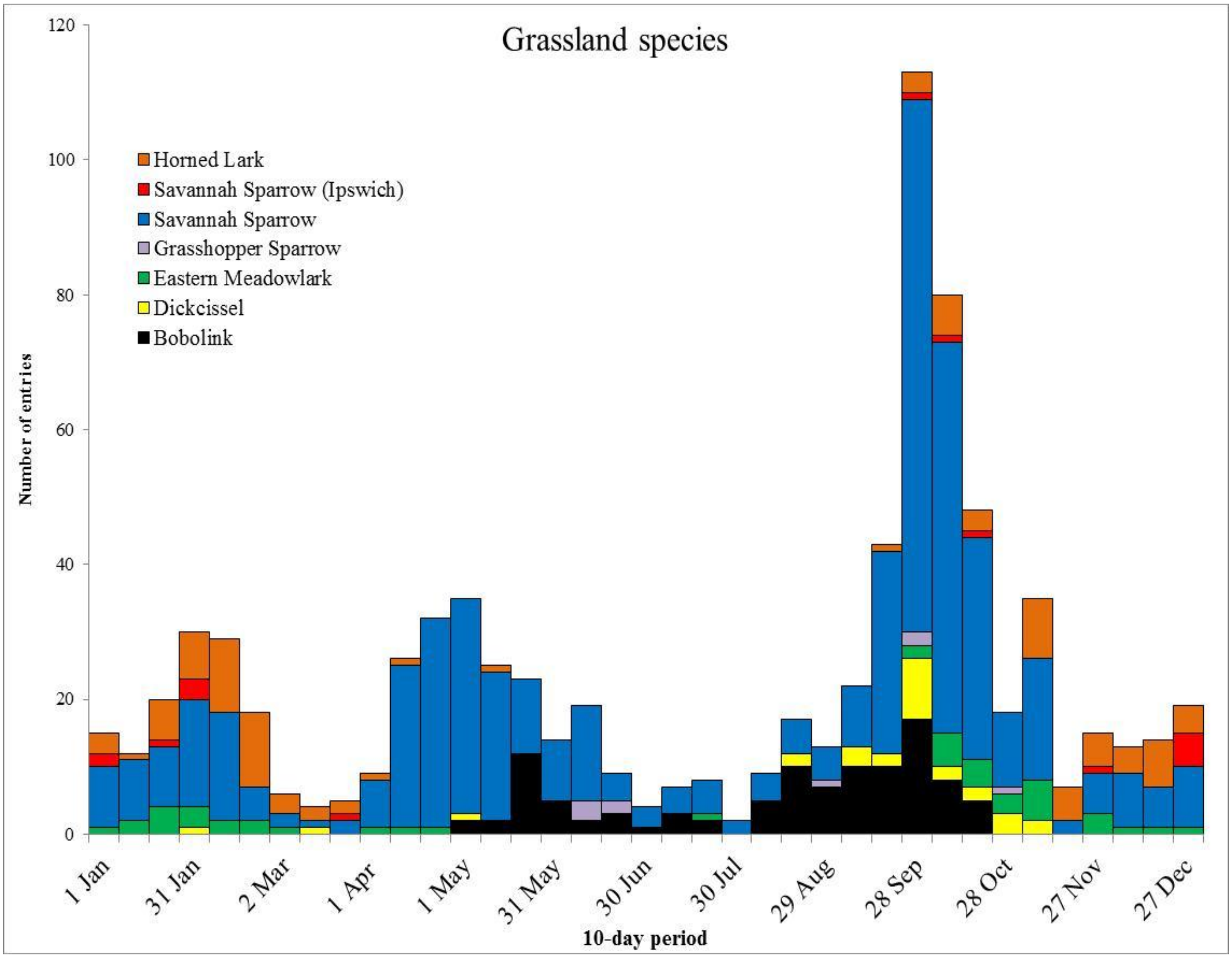


Figure 37. Phenology of observations of bird species associated with grasslands in Rhode Island based on eBird observations in the Avian Knowledge Network.

6.8.1.1 MANAGEMENT IMPLICATIONS

Studies have shown that small, isolated grasslands are not suitable for local breeding grassland birds such as Upland Sandpiper and Grasshopper Sparrow (Jones and Vickery 1997). These species require large contiguous tracts of land for breeding; however, these sites do provide summer breeding habitat for Eastern Meadowlarks, Bobolinks, Northern Bobwhite, and Savannah Sparrow. In the fall, these fields provide food for many of the mentioned migrating species (Rothbart and Capel 2006).

Upland Sandpipers, Grasshopper Sparrows, and Northern Harriers (all listed as threatened or endangered in most northeastern states) nest in large contiguous fields that contain a mosaic of mowed areas, tall grass meadow, and wildflowers. Furthermore, these habitats provide foraging and resting places for migrating species (sparrows, warblers, waterfowl, and sometimes shorebirds such as yellowlegs and killdeer). The open grasslands are also imperative to birds of prey such as American Kestrel and Short-eared Owls (Rothbart and Capel 2006).

For many species, size of the grasslands determines whether or not the species will use the habitat patch. For example, Jones and Vickery (1997) found that Upland Sandpipers will not nest in grasslands less than 150 acres, while Bobolinks will not nest in grasslands less than five to ten acres in size (see also Vickery et al. 1997). Therefore, we recommend that wind turbines not be constructed within 100 m of grasslands over 5 acres in size, particularly if a trained biologist determines than any grassland-associated species (Table 12) are documented nesting in the habitat patch during surveys conducted during the peak of the breeding season in May and June.

6.8.2 Scrub/shrub Birds

There are at least 36 bird species associated with scrub/shrub habitats in Rhode Island (Table 13). Shrubs habitats are dominated by landbirds including two species of cuckoos, a hummingbird, and 32 species of songbirds including seven species of warblers (Table 13, A2.10).

Based on Breeding Bird Surveys, 19 species associated with shrubs are declining (9 significantly) and 17 species are increasing (9 significantly; Table 13). Species with greatest rates of annual decline include: White-throated Sparrow, Least Flycatcher, and Eastern Towhee, while species with the greatest rate of annual increase include Cedar Waxwing, Northern Mockingbird, and Willow Flycatcher (Table 13).

No species using shrub habitats in Rhode Island is federally-listed as Threatened or Endangered, but three species are state listed (Table 6). Two species are State Endangered (Northern Harrier, and Yellow –breasted Chat) and one State Concern (White-throated Sparrow). Based on Bird Conservation Region (BCR) conservation prioritizations, Blue-winged Warbler and Prairie Warbler are classified as **Highest Priority** and Eastern Towhee, Brown Thrasher, and Field Sparrow are **High Priority** species. Partners in Flight (PIF) classified four species among their highest conservation category (Tier IA): Blue-winged and Prairie Warbler, Brown Thrasher, and Black-billed Cuckoo. Eastern Towhee was also classified as a conservation concern (Tier IIA), and Northern Harrier and Yellow-breasted Chat (Tier V) were listed by some states in the New England/ New York region.

According to Brawn et al. (2001), 39% of scrub-shrub breeding birds have declined in recent decades. In contrast, only 20% of species that nest in forests have declined. Furthermore, 70% of the scrub-shrub species in eastern North America show population decreases (Hunter et al. 2001). Of the ten endangered songbirds in the continental United States, seven breed in scrub or other early-successional habitats (U.S. Fish & Wildlife Service 2006). None of these species breed in Rhode Island, but they use the shrub habitat during migration stopovers or wintering in the state.

Table 13. Thirty-six species of birds associated with scrub/shrub habitats in Rhode Island (Degraaf and Yamasaki 2001). Given are habitat associations at nests and foraging habitat. In addition, information on their conservation status is given in Bird Conservation Region 30 (BCR 30) and Partners in Flight, and their annual population trends based on Breeding Bird Surveys (BBS) from 1966-2009.

	Habitat			BBS[B]	
Species	**Nesting**	**Foraging**	**Conservation Status[A]**	**BBS Annual Trend**	**Trend Data Origin**
Northern Harrier	Shrub	Grassland	Tier V	0.4	NE
Black-billed Cuckoo	Forest, shrub,	Forest, shrubs	Tier I A	**-3.4**	NE
Yellow-billed Cuckoo	Forest	Dense shrub		-1.9	NE
Ruby-throated Hummingbird	Forest	Mixed		**2.9**	NE
Willow Flycatcher	Moist, shrubs	Mixed open	H	**3.9**	NE
Eastern Phoebe	Structure	Mixed open		-0.3	NE
Least Flycatcher	Forest, shrub	Mixed		**-5.2**	NE
Tree Swallow	Open Forest	Mixed open		1.2	NE
House Wren	Cavity	Mixed open		-0.4	NE
Carolina Wren	Forest	Mixed		**3.4**	NE
Eastern Bluebird	Cavity	Mixed open		**3.1**	NE
American Robin	Tree/shrub	Various		-0.3	NE
Cedar Waxwing	Tree/shrub	Shrub/tree		**5.7**	NE
White-eyed Vireo	Shrub	Open forest		-1.8	NE
Warbling Vireo	Tree/shrub	Open forest		**3.2**	NE
Gray Catbird	Shrub	Mixed		0.4	NE
Northern Mockingbird	Shrub	Mixed		**3.9**	NE
Brown Thrasher	Shrub	Mixed	H, Tier IA	-2.1	NE
American Redstart	Tree/shrub	Mixed		0.2	NE
Chestnut-sided Warbler	Shrub	Mixed		**-2.9**	NE
Blue-winged Warbler	Shrubs	Mixed	HH, Tier IA	-1.5	NE
Common Yellowthroat	Forest/shrub	Mixed		**-1.7**	NE
Nashville Warbler	Shrub	Mixed		-6.5	NE
Prairie Warbler	Shrub	Mixed	HH, Tier IA	**-1.1**	NE
Yellow Warbler	Shrub	Mixed		-0.3	NE
Yellow-breasted Chat	Shrub	Mixed	Tier V	-1.9	NE
Field Sparrow	Shrub	Mixed	H	**-4.4**	NE
Song Sparrow	Mixed	Mixed		**-1.1**	NE
Chipping Sparrow	Shrub/ forest	Mixed		**1.3**	NE
Northern Cardinal	Shrub	Mixed		**2.4**	NE
White-throated Sparrow	Shrub	Mixed		**-9.4**	NE
Indigo Bunting	Shrub	Early successional		0.7	NE
Eastern Towhee	Shrub/bramble	Mixed	H, Tier IIA	**-5.1**	SW
Orchard Oriole	Tree	Early successional		0.2	NE
Brown-headed Cowbird	Successional	various		0.8	NE
American Goldfinch	Successional	Mixed		1	NE

[A] Bird Conservation Region 30 categories: HH = Highest Priority, H = High priority, M = Moderate priority; Partners in Flight categories: Tier I A: High Continental Priority - High Regional Responsibility, Tier I B: High Continental Priority - Low Regional Responsibility, Tier II A: High Regional Concern, Tier II B: High Regional Responsibility, Tier II C: High Regional Threats, Tier III: Additional Watch List, Tier IV: Additional Federally Listed, Tier V: Additional State Listed.

[B] BBS trends in bold are significant

Habitat availability is one of the most important factors limiting bird populations (Newton 1998). Scrub-shrub is relatively uncommon in southern New England (which ecologists define as Rhode Island, most of Connecticut, the eastern two-thirds of Massachusetts, coastal New Hampshire, and south-coastal Maine) (Schlossberg and King 2007). In Rhode Island, New Shoreham (Block Island) has the most acreage of shrubland (2,305 acres), followed by Portsmouth (1,749 ac), and South Kingstown (1,653 acres) (Fig. 38). Transmission line right-of-ways provide some of the most important scrub-shrub habitat in the state.

Populations of many species migratory songbird have declined over the past few decades (Askins et al. 1990; Peterjohn et al. 1995). In the past, the most emphasis has been placed on conservation of songbird populations in breeding and wintering areas; however, protecting important migratory stopover points has proven to be a critical piece for conservation of species. Migration can result in mortality rates 15 times higher than during breeding and wintering seasons (Sillett and Holmes 2002), thus maintaining critical stopover areas is crucial. Coastal Rhode Island is part of an important migration corridor for songbirds along eastern North America and provides critical stopover habitat for many species that utilize maritime scrub-shrub (Smith et al. 2007).

Maritime scrub-shrub occurs in coastal areas, including critical upland areas around Rhode Island’s coastal ponds. This habitat provides vital food and cover for migratory songbirds. Many migratory songbirds, even those previously considered insectivores, consume nutrient-rich berries from shrubs to fuel for their long migration (Smith et al. 2007). These birds need foods with sufficient protein in order to ensure a successful migration. The maritime shrubs along the coast provide these vital fruits. The availability of high-quality fruits in coastal regions is important for successful migration of songbirds (Smith and McWilliams 2011).

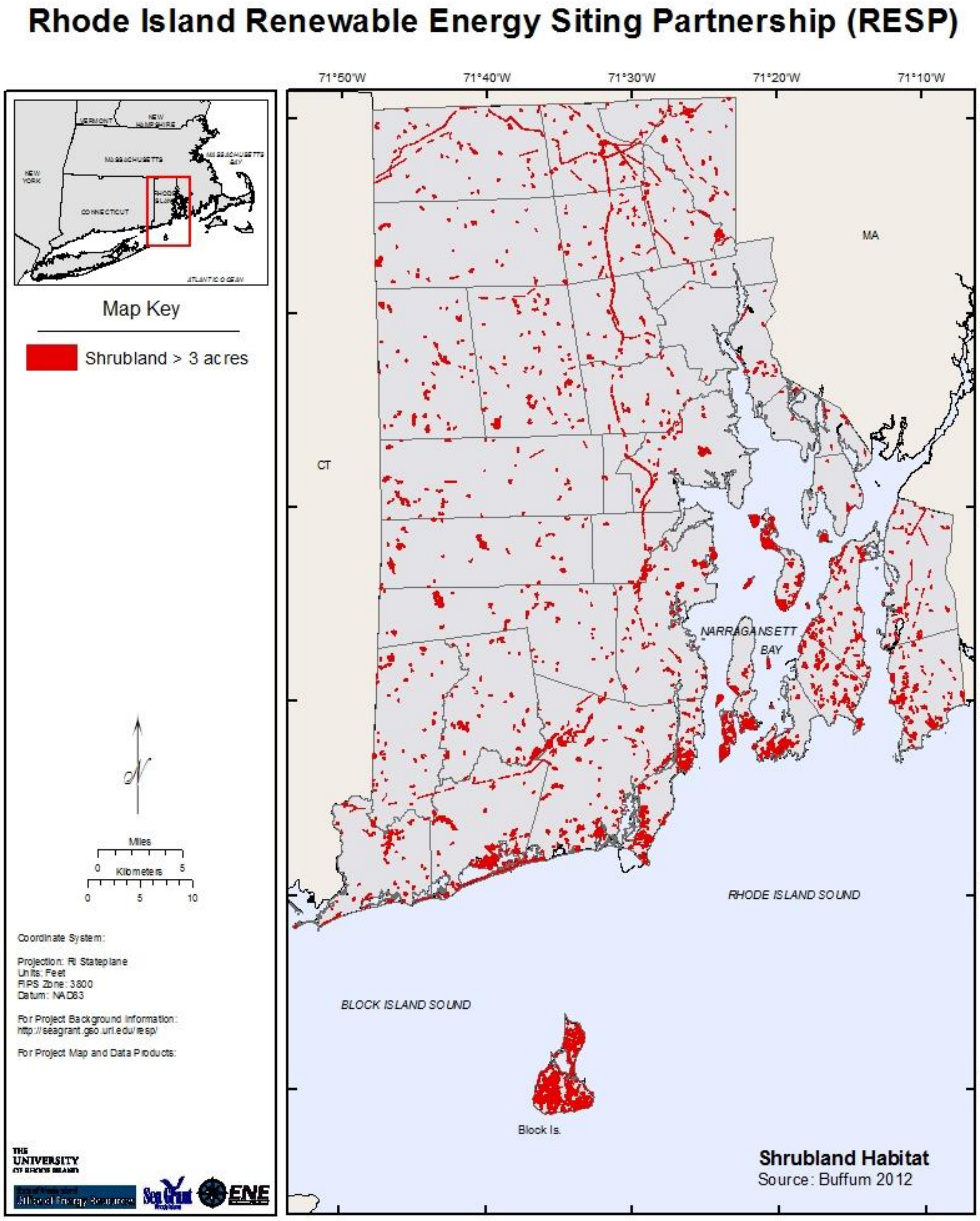


Figure 38. Distribution of potential scrub/shrub habitat > 3 acres in Rhode Island based on Buffum (2012).

Because scrub-shrub habitats are widely distributed around the state, these species are also found throughout Rhode Island (Figs. 39 and 40). Areas with potential concentrations of scrub-shrub birds are found throughout Rhode Island. However, there is some indication that scrub-shrub specialist tend to be concentrated in the maritime scrub-shrub zone near coastal areas (Fig. 39).

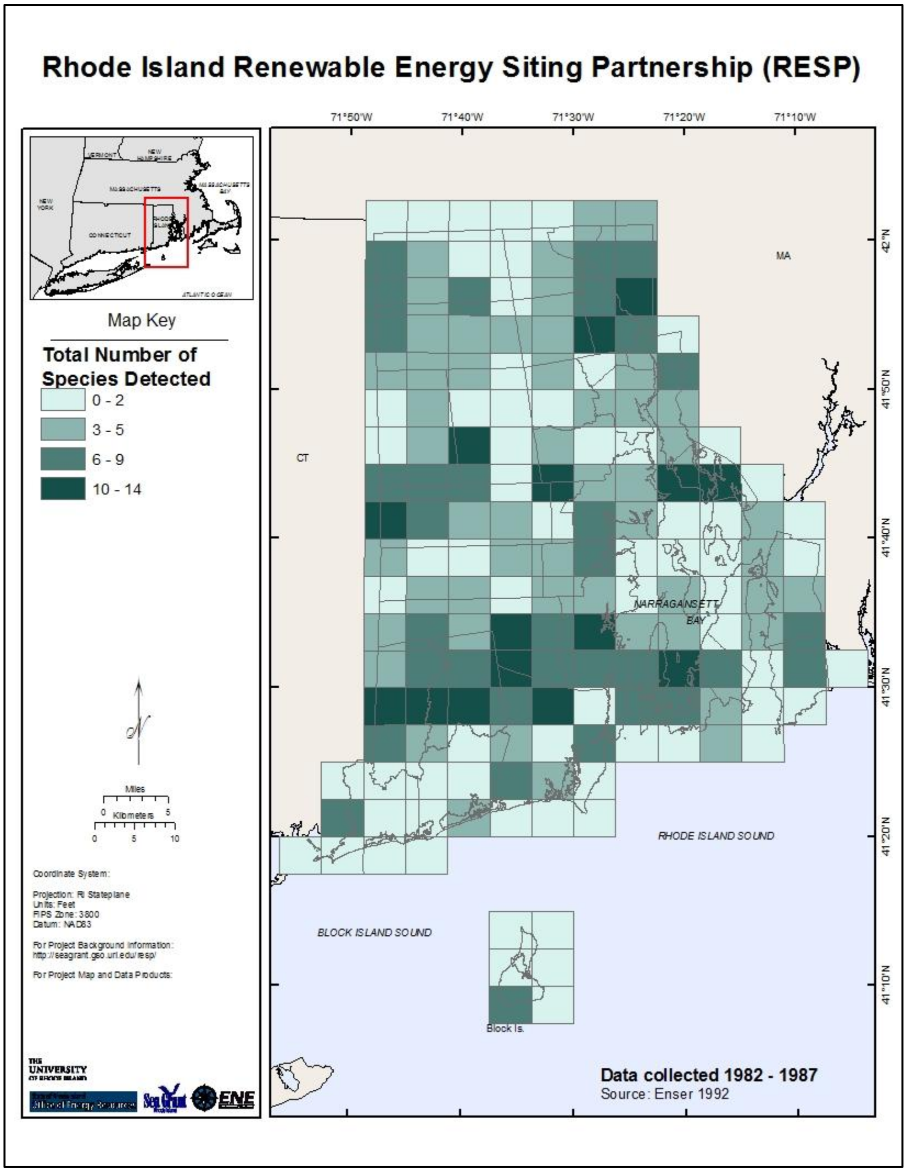


Figure 39. Distribution of breeding birds that primarily nest in shrublands in Rhode Island based on surveys conducted from 1982-1987 (Enser 1992). Shown are the total number of species of shrubland-specialist birds with a confirmed nest detected in each 25 km^2 grid cell. Species that nest primarily in shrubland habitats are given in Table 13.

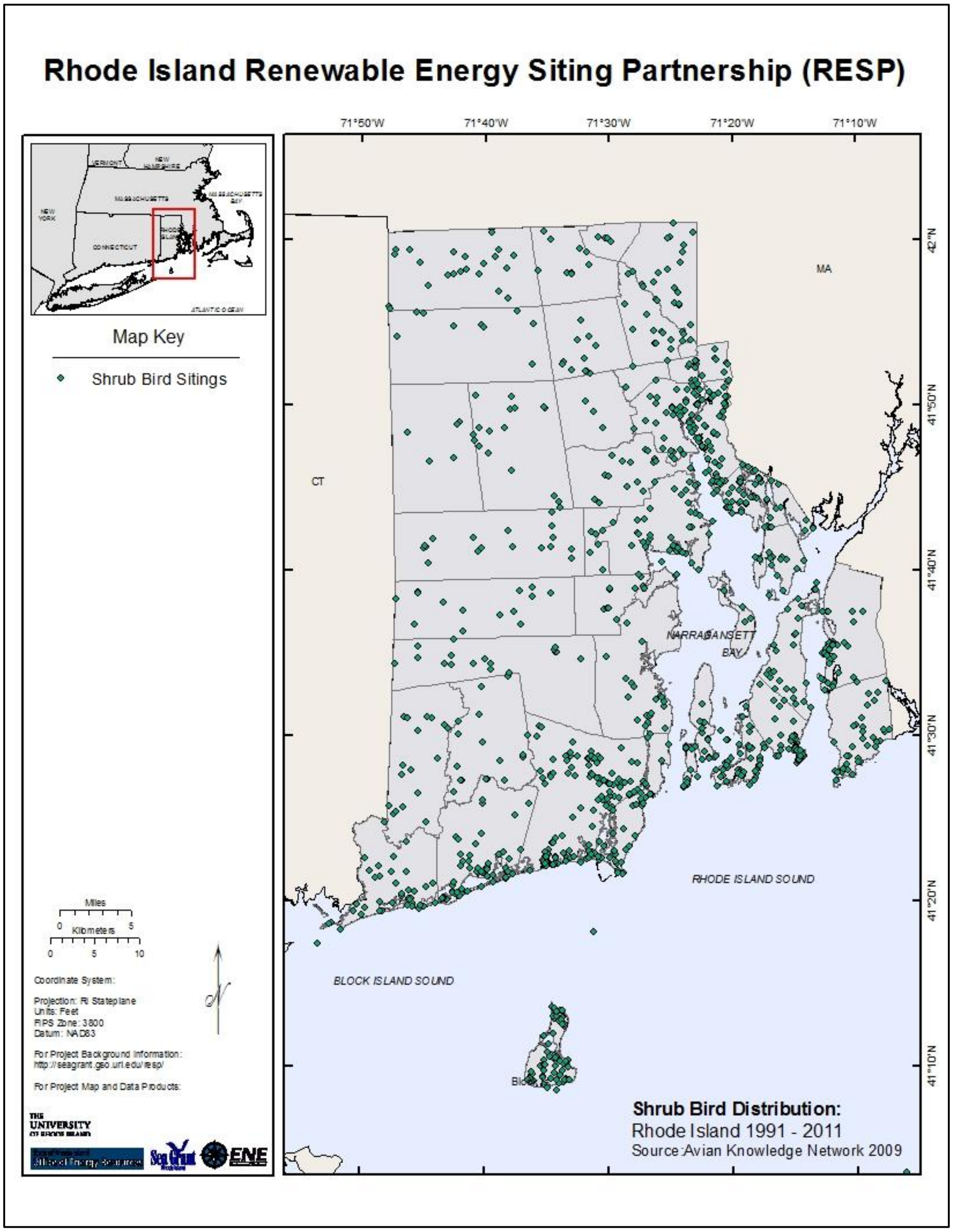


Figure 40. Reports of birds that are scrub/shrub specialists (Table 13) that were detected from 1991-2011 in Rhode Island based on the eBird records in the Avian Knowledge Network (AKN 2009).

6.8.2.1 MANAGEMENT IMPLICATIONS

We define scrub-shrub habitat as areas with little or no tree canopy and dense shrubs and saplings within the first 2m above ground. Most scrub-shrub associated birds prefer habitat patches greater than 2.5 to 10 acres (1-4 ha) that have regular shapes, with birds often avoiding irregular edges (Schlossberg and King 2007).

Due to the importance of shrub habitats to a wide variety of migratory and nesting birds, we propose that no wind turbines be constructed with 100 m of large blocks (3 acres or larger) of shrub habitats in Rhode Island. This would include electrical transmission right-of-ways that account for over 3 acres.

6.8.3 Forest Birds

There are at least 75 species of birds in Rhode Island that nest or forage in forested habitats (Table 14). Based on Breeding Bird Survey population trend estimates for 72 species, primarily using trend estimates for the New England/mid-Atlantic region, 46% (33 of 72 species) had negative population trends, with 58% of species (19 of 33) exhibiting significant annual declines. Forest species with the greatest rates of decline included White-throated Sparrow (-8.5% annual decline), Purple Finch (-6.0% annual decline), Ruffed Grouse (-5.4% annual decline), Canada Warbler (-5.4% annual decline), and Least Flycatcher (-5.2% annual decline). Of the 54% of species with apparent population increases in New England based on BBS surveys, 16 of 39 species (41%) exhibited significant rates of increase. Species with the greatest rate of increase included Evening Grosbeak (17.1%, an irruptive species that is uncommon in southern New England), Bald Eagle (11.8% annual increase, formerly listed as Threatened by USFWS, delisted in 2007), Cooper’s Hawk (10.9% annual increase, but listed as a Species of Concern in Rhode Island), and Worm-eating Warbler (4% annual increase – southern species spreading north).

Although 25% of species (19 of 76) exhibited significant negative annual rates of decline, a majority (51%) of species are classified as conservation concerns, either within Rhode Island or regionally. Based on Rhode Island listing considerations (Rhode Island Natural Heritage Program 2006), there is one State Endangered species (Cerulean Warbler – extirpated as a breeding bird in the state; -2.5% annual decline in New England from 1989-2009, -3.0 annual decline survey wide from 1966-2009, focus of regional conservation efforts – see http://www.birds.cornell.edu/cewap/), one State Threatened species (Black-throated Blue Warbler; non-significant annual population increase from 1989-2009 based on BBS routes survey wide), and 10 State Species of Concern (two raptors, an owl, a wading bird, and six songbirds; Table 14).

Regionally, based on conservation status within Bird Conservation Region 30 (http://www.acjv.org/bcr30.htm), one species (Wood Thrush) is ranked as a Highest Conservation Priority, 11 species are ranked as High Priority (Bald Eagle, Baltimore Oriole, Black-and-white Warbler, Broad-winged Hawk, Great Crested Flycatcher, Louisiana Waterthrush, Northern Flicker, Prothonotary Warbler, Whip-poor-will, Worm-eating Warbler, and Yellow-throated Vireo), while three species (Blackburnian Warbler, Cerulean Warbler, and Red-headed Woodpecker) are considered Moderate Conservation Priorities.

Partners In Flight (http://www.partnersinflight.org/) has another conservation prioritization plan: there are seven species that are of high continental importance and high regionally importance that use forested habitats in Rhode Island (Tier 1A: Worm-eating Warbler, American Woodcock, Black-billed Cuckoo, Wood Thrush, Baltimore Oriole, Scarlet Tanager, and Louisiana Waterthrush); there are two species that are of high continental importance and low regionally responsibility (Tier 1B: Cerulean Warbler and Black-throated Blue Warbler); six species of high regional concern (Tier IIA: Eastern Towhee, Black-and-white Warbler, Rose-breasted Grosbeak, Chimney Swift, Hairy Woodpecker, and Eastern Wood-Pewee); three species of high regional threat (Tier IIC: Canada Warbler, Blackburnian Warbler, and Red-headed Woodpecker); and eight additional State-listed species (Table 14).

Compared to species that specialize in grassland or scrub-shrub habitats, forest specialists tend to be doing relatively well in Rhode Island and the region based on BBS trend analyses (Table 14). This is due in large part to the fact that habitats the region are converting to forested habitats, and existing forested habitats are maturing (Foster 1992). However, there are some forest specialists that could be affected by the fragmentation of habitats for the construction of wind turbines. There are least 12 species of forest birds are highly sensitive to forest fragmentation (http://www.npwrc.usgs.gov/resource/birds/manbook/areareq.htm; Table 14). For example, forest tracts larger than 100 acres will only have a 20% probability of being occupied by highly area sensitive species, while this probability increases to about 70% for contiguous forest tracts over 1000 acres. For species with moderate area sensitivity, forest tracts >100 acres have a 60% probability of being occupied, while tracts >1000 acres have a >90% probability of being occupied.

Table 14. Summary of birds associated with forests in Rhode Island (Degraaf and Yamasaki 2001). Information is provided on nesting habitat, foraging habitat, conservation status based on priorities for Bird Conservation Region 30 (BCR30) and Partners in Flight (PIF). In addition, the annual trend for each species is given based on Breeding Bird Surveys from 1989-2009 (species with significant trends are shown in bold) and BBS area where trends were analyzed (NE - New England, SW – survey-wide).

	Habitat			BBS[C]	
Species[A]	**Nesting**	**Foraging**	**Conservation Status[B]**	**Annual Trend**	**Trend Region**
Great Blue Heron	Woodland	Wetland	SC, Tier V	**3.1**	NE
Turkey Vulture	On ground in leaf litter or soil	Mixed		3.8	NE
Bald Eagle	Forest adjacent to water	Lakes, rivers, coastal bays with large trees	H	**11.8**	NE
Sharp-shinned Hawk	Forest usually with conifers	Mature coniferous or mixed with clearing	SH, Tier V	4	SW
Cooper's Hawk	Mature coniferous or deciduous	Woodlots away from nest area/ open areas	SC, Tier V	**10.9**	NE
Northern Goshawk	Forest	Forest	SC, Tier V	0	SW
Red-shouldered Hawk	Riparian deciduous with tree	Wooded Swamps or woodland openings	Tier V	3.9	NE
Broad-winged Hawk (H)	Continuous deciduous or mixed	Forest openings, meadows and wetlands	H	-1.1	NE
Red-tailed Hawk	Various from scrub desert with trees, urban parks, pastures with trees	Short-meadow grasses, open pastures		**4**	NE
American Woodcock	Needs scrub-shrub for mating		Tier 1A	-4.1	
Ruffed Grouse	Ruffed Grouse	On ground at base of tree, stump, or rock		**-5.4**	NE
Black-billed Cuckoo (M)	Black-billed Cuckoo	Various mixes of woodland	Tier 1A	**-3**	NE
Yellow-billed Cuckoo (M)	Yellow-billed Cuckoo	Second growth deciduous		3.3	NE
Eastern Screech Owl	Cavity in open deciduous and woodlots	Wooded field margins, marshy streams		0.5	NE
Great Horned Owl	Large cavity, or large birds nest	Forest with openings, edges, woodlots		-3.6	NE
Barred Owl	Moist mature forest/ large cavity trees	Forest, bogs, muskegs, and fields	Tier V	0.4	NE
Long-eared Owl	Dense, usually coniferous forest	Dense forest adjacent to open grassland	Tier V	NA	SW
Northern Saw-whet Owl	Forest/old tree cavity or nest box	Dense, moist forest adjacent to open grassland	SC	NA	SW
Common Nighthawk	Barren ground	aerial		NA	

	Habitat			**BBS[C]**	
Species[A]	**Nesting**	**Foraging**	**Conservation Status[B]**	**Annual Trend**	**Trend Region**
Whip-poor will	Open, dry deciduous or mixed/nests on ground	Open, dry deciduous or mixed	H	-3.2	NE
Ruby-throated Hummingbird	Mixed deciduous and coniferous	Plants that provide tubular nectar-bearing/mixed variety		**3.9**	NE
Chimney Swift			Tier IIA	**-2.1**	NE
Red-headed Woodpecker	Various mixes of woodland	Most omnivorous woodpecker-foraging various places	M, Tier IIC	2.3	NE
Red-bellied Woodpecker	Extensive open, mature woodland with dead trees cavities	Lowlands and upland forest edges		**3.7**	NE
Downy Woodpecker	Nest trees at least 6" in diameter	Woodlots, forest edges/parks, cemeteries		0.6	NE
Hairy Woodpecker (M)	Nest trees at least 10" in diameter	Various forest mixes	Tier IIA	-0.5	NE
Northern Flicker	Tree cavities in open woodland or forest edges	Forest, lawn, pastures, cornfield	H	-0.6	NE
Pileated Woodpecker (H)	Mature deciduous mixed, coniferous near water	Decaying wood in forest or at edges	SC	4.5	NE
Eastern Wood-Pewee	Deciduous at edges or openings	Woodland clearing, edge of fields, marshes	Tier IIA	-0.5	NE
Acadian Flycatcher (M)	Mature, closed canopy, deciduous woods near water	Understory of forest	SC	0.4	NE
Least Flycatcher (H)	Open, mature deciduous and mixed	Various areas with flying insects		**-5.2**	NE
Great Crested Flycatcher	Hardwood woodlots	Forest canopy or edge	H	**0.7**	NE
Blue Jay	Deciduous and mixed/esp. oak forest near edges	Almost anywhere		**-2.6**	NE
Fish Crow	Low coastal areas, esp. wooded marine	Tidal flats, shoreline, brackish rivers		**3.2**	NE
Black-capped Chickadee	Various mixes of woodland	Pine grooves, and adjacent oak woods		0.4	NE
Tufted Titmouse (M)	Deciduous or mixed	Forest with dense canopy		**2.5**	NE
Red-breasted Nuthatch	Prefers coniferous	Coniferous forest		0.3	NE
White-breasted Nuthatch (M)	Mature deciduous/ mixed	Forest dead trees /feeder		**2.2**	NE
Brown Creeper	Dense, mature coniferous,	Standing dead trees with loose bark		3.3	NE

Species[A]	Habitat: Nesting	Habitat: Foraging	Conservation Status[B]	BBS[C] Annual Trend	BBS[C] Trend Region
	deciduous, and mixed				
Winter Wren	Dense , moist undergrowth of coniferous or mixed	Ground in forest	SC	-1	NE
Golden-crowned Kinglet	Dense coniferous forests and plantings	Boreal forest habitats		1.9	SW
Blue-gray Gnatcatcher	Various mixes of deciduous trees	Prefer high canopy of forest with abundant supply of arthropods		**2.6**	NE
Veery (H)	Moist woodland with thick understory	Ground in forest		-0.5	NE
Hermit Thrush	Extensive, dense coniferous or mixed	Ground in forest		-1.9	NE
Wood Thrush (M)	Mature, moist deciduous or mixed -closed canopy	Leaf litter in forest	HH, Tier 1A	**-2.4**	NE
Gray Catbird	Low, dense shrubby vegetation	Open woodland, leaf litter, understory		0.4	NE
Blue-headed Vireo	Extensive coniferous or mixed	primarily in lower and middle canopy		1.5	NE
Yellow-throated Vireo (H)	Mature, moist deciduous with partially open canopy	Upper part of canopy	H	1.8	NE
Warbling Vireo	Scattered mature deciduous or riparian	Middle or upper canopy		**3.2**	NE
Red-eyed Vireo (M)	Deciduous trees	Middle or upper canopy		**-0.7**	NE
Northern Parula (M)	Mature forest near fresh water with lichen *(Usnea)*		Tier V	**1.5**	SW
Black-throated Blue Warbler	Northern hardwood forests with thick understory	In upper branches in shrub or subcanopy	ST, Tier 1B	0.5	SW
Yellow-rumped Warbler	Coniferous tree	Broad range of microhabitat, insects and fruit		1.5	NE
Black-throated Green Warbler	Mixed woodland/ esp hardwood-hemlock	Coniferous trees/evergreens		2.1	SW
Blackburnian Warbler	Mature coniferous forests	forest	M, Tier IIC	-0.9	SW
Pine Warbler	Pine forest/ esp. open pitch pine forest			**2.3**	NE
Cerulean Warbler (H)	Extensive (>250ha) mature deciduous trees	Forest	SE, M, Tier 1B	**-2.5**	SW

Species[A]	Habitat		Conservation Status[B]	BBS[C]	
	Nesting	Foraging		Annual Trend	Trend Region
Black-and-white Warbler (H)	Deciduous and mixed esp. immature and scrubby	Forest - branches	H, Tier IIA	**-2.9**	NE
American Redstart (H)	Moist second growth forest	Foliage gleaner		0.2	NE
Canada Warbler			Tier IIC	**-5.4**	NE
Prothonotary Warbler	Tree cavity	Bark Forager	SC, H	0.4	NE
Worm-eating Warbler (H)	Deciduous or mixed with ravines/hillsides	forest leaf litter	SC, H, Tier 1A	**4**	NE
Ovenbird (H)	Contiguous mature deciduous	Debris on forest floor		-0.4	NE
Northern Waterthrush	Dense thickets along edges of deciduous	Woodlands with flowing water		-0.8	NE
Louisiana Waterthrush (M)	Extensive deciduous or mixed forest with water	Woodlands with flowing water	H, Tier 1A	1.3	NE
Hooded Warbler	Low , dense deciduous woody			-0.2	NE
Scarlet Tanager (M)	Mature deciduous of mixed	Open canopy of forest	Tier 1A	**-1.2**	NE
Rose-breasted Grosbeak	Deciduous/mixed woodlands typically near edge		Tier IIA	**-2.7**	NE
Dark-eyed Junco	Edges and opening in coniferous or mixed forest	Ground in various habitats	SC	**-2.6**	NE
Common Grackle	Open habitat, agricultural fields, suburbs, parks forest edge	Open areas with water adjacent to woodlots		**-1.8**	NE
Song Sparrow	Woodlands with shrub understory	Open woodlands		**-1.1**	NE
White-throated Sparrow			SC	**-8.5**	NE
Eastern Towhee			Tier IIA	**-4.3**	NE
Baltimore Oriole	Leafy deciduous near edge of habitat	semi-opened	H, Tier 1A	**-2**	NE
Purple Finch	Moist, cool coniferous forest edges	Various wooded habitat		**-6**	NE
Evening Grosbeak	Conifers	Forest and feeders		**17.1**	NE

[A] Sensitivity to forest fragmentation (http://www.npwrc.usgs.gov/resource/birds/manbook/areareq.htm); H – high sensitivity, M – moderate sensitivity.

[B] State of Rhode Island classification: SE = State Endangered, ST = State Threatened, C = Concern; Bird Conservation Region 30 categories: HH = Highest Priority, H = High priority, M = Moderate priority; Partners in Flight categories: Tier I A: High Continental Priority - High Regional Responsibility, Tier I B: High Continental Priority - Low Regional Responsibility, Tier II A: High Regional Concern, Tier II B: High Regional Responsibility, Tier II C: High Regional Threats, Tier III: Additional Watch List, Tier IV: Additional Federally Listed, Tier V: Additional State Listed.

[C] BBS trends in bold are significant.

The dominant habitat type in Rhode Island is forests, with approximately 57% of the State (almost 400,000 acres) classified as forested (Table 11). Coniferous forests are most abundant in the western sections of the state (Fig. 41), while deciduous and mixed forests are found throughout Rhode Island (Figs. 42 and 43). Towns with the largest acreages of forested habitat are in western Rhode Island and include Exeter (37,371 ac), Glocester (29,078 ac) and Burrillville (27,785 ac), while Newport (198 ac) and New Shoreham (196 ac) have the smallest acreages of forest of towns in Rhode Island.

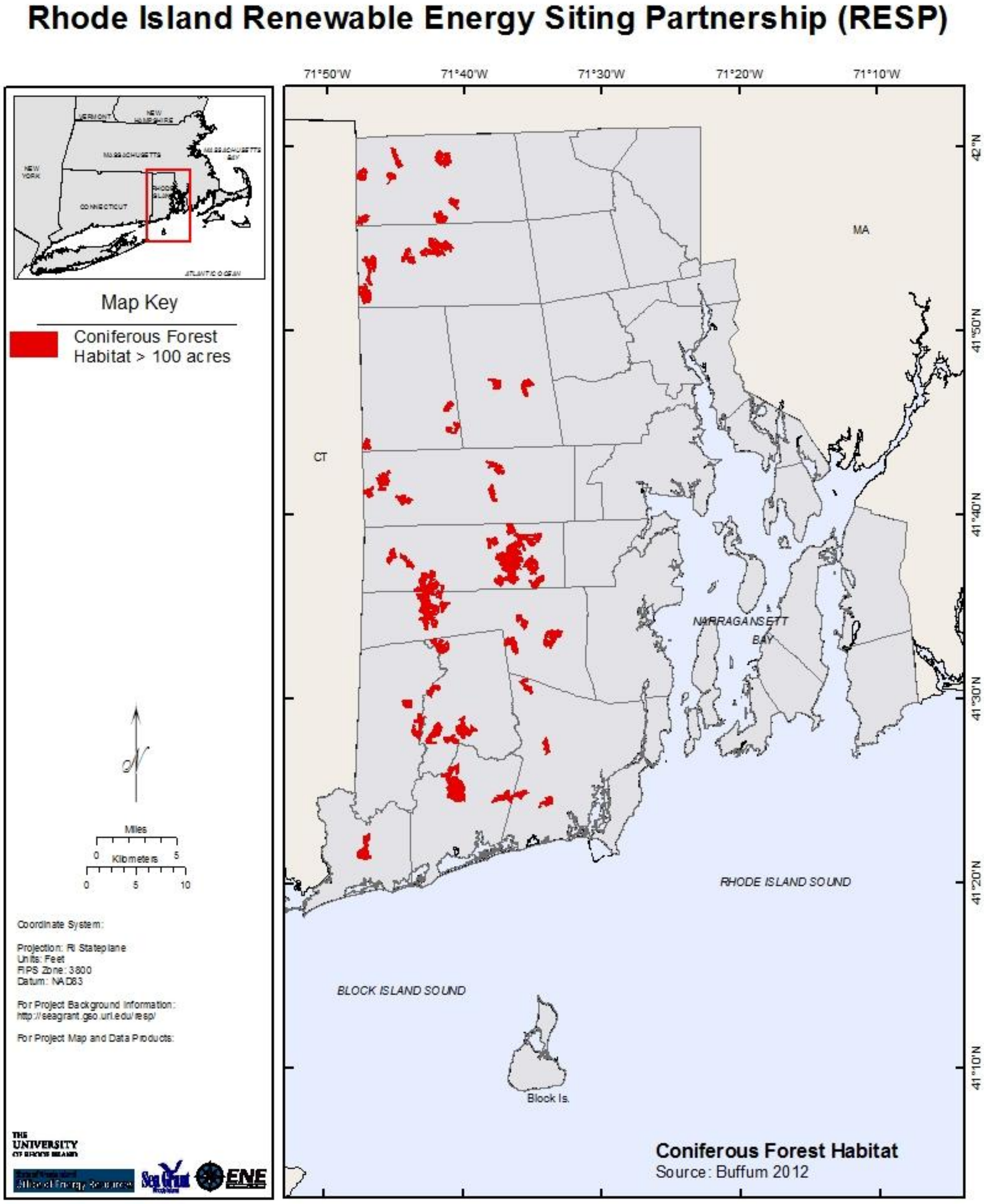


Figure 41. Distribution of potential coniferous forested habitats in Rhode Island in tracts larger than 100 acres based on Buffum (2012).

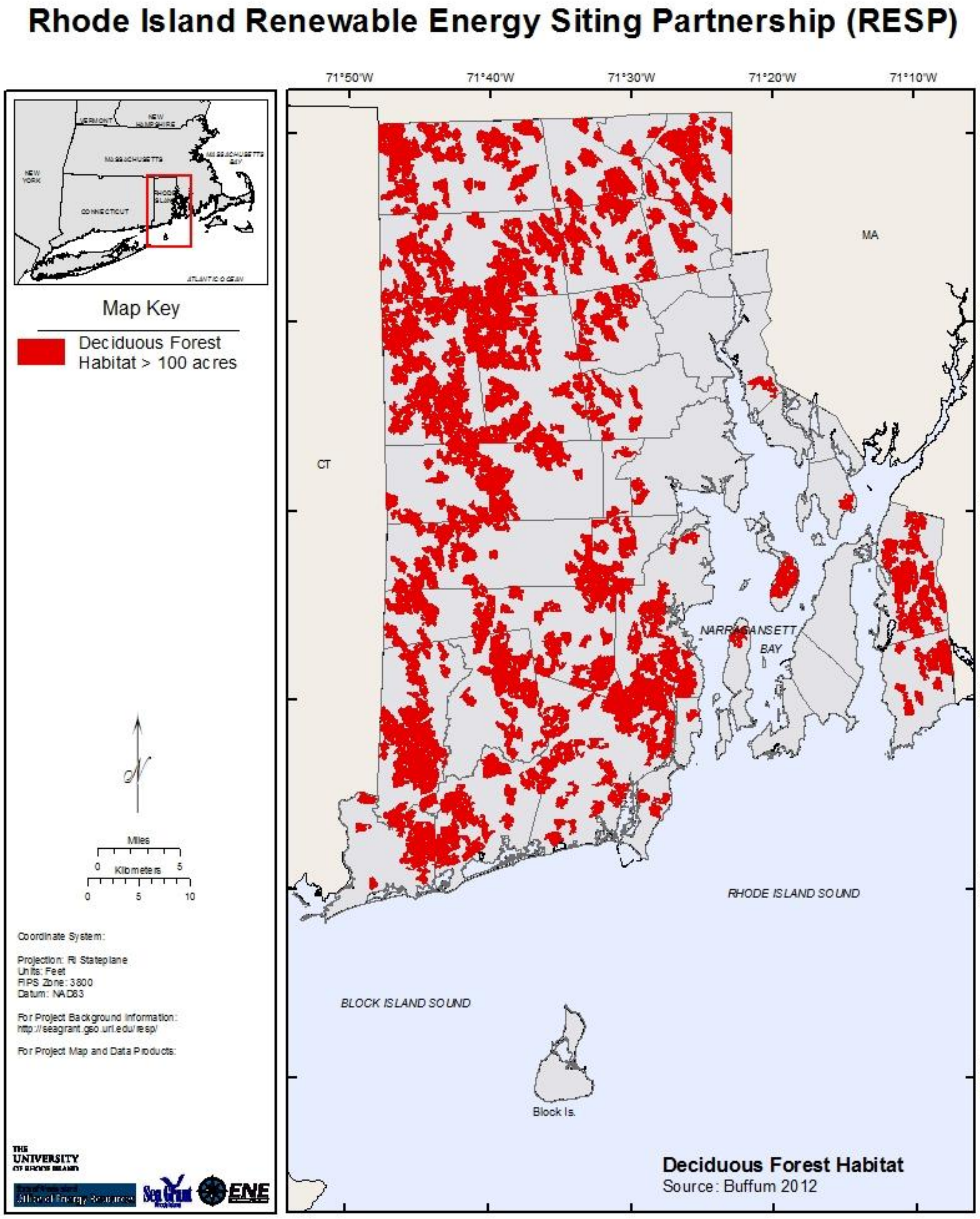


Figure 42. Distribution of potential deciduous forested habitat in Rhode Island in tracts larger than 100 acres based on Buffum (2012).

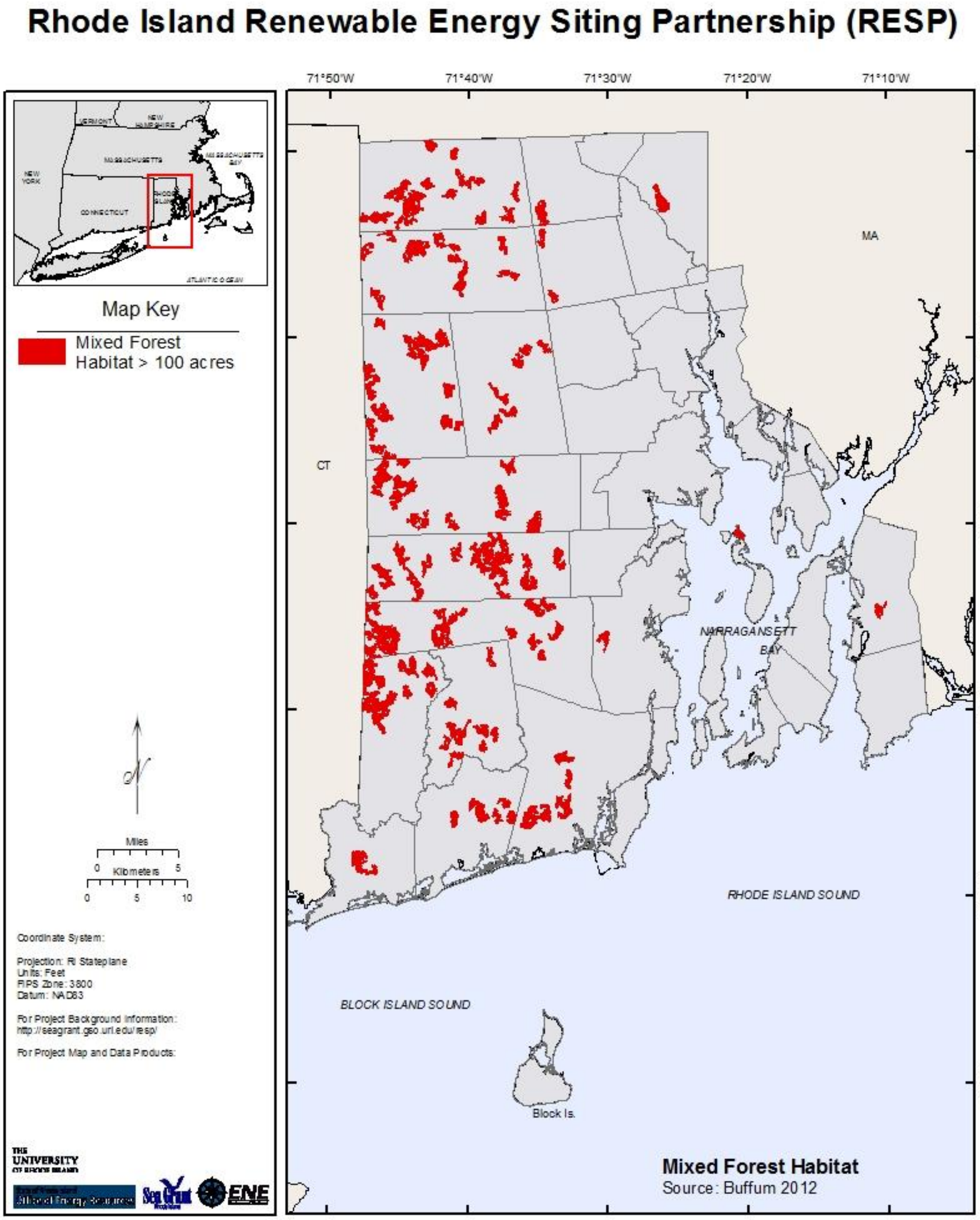


Figure 43. Distribution of potential mixed deciduous/coniferous forested habitat in Rhode Island in tracts larger than 100 acres based on Buffum (2012).

Given the distribution of forests throughout Rhode Island, it is not surprising that birds that nest in forests are widespread also, with up to 25 species confirmed as breeding in 25 km^2 cells (Fig. 44; Enser 1992). As would be expected, the western half of Rhode Island tends to have more forest specialists.

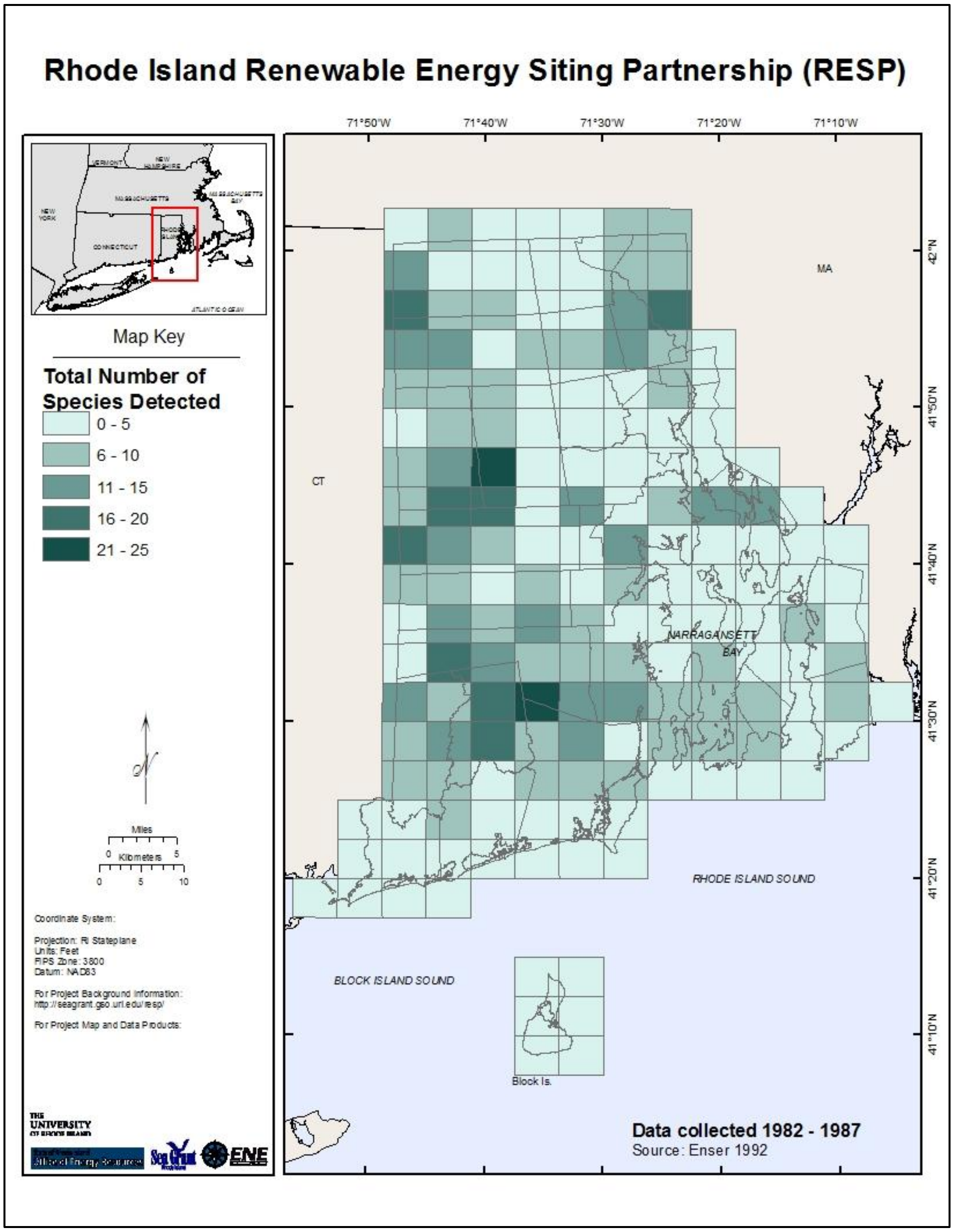


Figure 44. Distribution of breeding birds that primarily nest in forested habitats in Rhode Island based on surveys conducted from 1982-1987 (Enser 1992). Shown is the total number of species of forest specialist birds with a confirmed nest detected in each 25 km^2 grid cell. Species that nest primarily in forested habitats are given in Table 14.

6.8.3.1 Management Implications

Forests provide nesting and foraging habitat to over 75 species in Rhode Island. From a conservation perspective, the critical question is area sensitivity. Many of these species often nest only in large forest tracts, with their probability of occupancy increasing as forest patch size increases. Some species in some landscapes are only like to use the forest patch if it is >1000 acres in size, which is larger than virtually all forest patches in Rhode Island. However, a more reasonable threshold value is 100 acres, which can still affect occupancy probabilities of many area sensitive species (***http://www.npwrc.usgs.gov/resource/birds/manbook/areareq.htm***; Table 14).

First, we recommend not fragmenting forest patches that are over 100 acres in size when feasible. This will help to minimize impacts on area sensitive species and to minimize edge effects (Thompson 2005). Second, we recommend not placing wind turbines within 500 m of forest patches >100 acres in size. Again, this will help to minimize impacts on area sensitive species.

6.8.4 Shorebirds and Wading Birds

6.8.4.1 SHOREBIRDS

There are at least 78 species of shorebirds (Order: Charadriiformes) that have been documented in Rhode Island, including seven species of plovers, 37 species of sandpipers (and their allies), five species of jaegers and skuas, 15 species of gulls, and 14 species terns (Table A2.1). All species are migratory, except Herring and Great Black-backed Gulls. Ten species nest in Rhode Island (Piping Plover and Killdeer; American Oystercatcher, Willet, Spotted Sandpiper, American Woodcock; Common and Least Tern; and Great Black-backed and Herring Gull). Two species of shorebirds are listed under the Endangered Species Act, thus we have devoted specific sections of this report to these species (Piping plover, Section 6.4.1.1.; Roseate Tern, 6.4.1.2). Four species are listed by the state: American Oystercatcher (Concern), Willet (Concern), Upland Sandpiper (State Endangered) and Least Tern (State Threatened).

Based on Bird Priority plans for Bird Conservation Region 30 (New England), there four species listed as highest priority that are not federally-listed (American Oystercatcher, American Woodcock, Red Knot, Ruddy Turnstone). In addition, there are 12 species that are listed as high priority in BCR 30 (American Golden Plover, Buff-breasted Sandpiper, Dunlin, Forster's Tern, Greater Yellowlegs, Least Tern, Marbled Godwit, Sandwich Tern, Semipalmated Sandpiper, Solitary Sandpiper, White-rumped Sandpiper, and Willet). Finally, ten species of shorebirds are moderate conservation priorities in BCR 30 (Black Skimmer, Common Snipe, Common Tern, Killdeer, Least Sandpiper, Red and Red-necked Phalarope, Semipalmated Plover, and Upland Sandpiper).

American Woodcock are an uncommon upland species that is widespread throughout the state. This species has their courtship displays in old fields, and it forages in adjacent forest wetlands. The creation of openings in forested areas for wind turbine could potentially create display grounds for woodcocks. American Golden Plovers, Buff-breasted Sandpipers, Upland Sandpipers, and Killdeer are upland specialists that use large grasslands as stopover habitat. Thus our recommendation is to not locate wind turbines in large turf fields over 40 acres (see also grassland restrictions, section 6.8.1).

A number of shorebirds of conservation concern use intertidal mudflats as stopover habitat in Rhode Island (e.g. Red Knot, Ruddy Turnstone, Dunlin, Greater Yellowlegs, Marbled Godwit, Semipalmated Sandpiper, White-rumped Sandpiper, and Willet). There are some key stopover areas in coastal Rhode Island for shorebirds where we recommend no wind turbines be located with a 1 km buffer (Sandy Point, Napatree Spit, Maschaug Pond, Winnapaug Pd, Quonochontaug Pond, Ninigret Pond, Green Hill Pond, Trustom Pond, Card Pond, Potter Pond, Point Judith Pond, Narrow River Estuary, Bluff Hill Cove, Third Beach Restoration Site at Sachuest NWR, 100-Acre Pond, Nonquit, Nannaquaket, Briggs Marsh and Quicksand Pond) (Fig. 45).

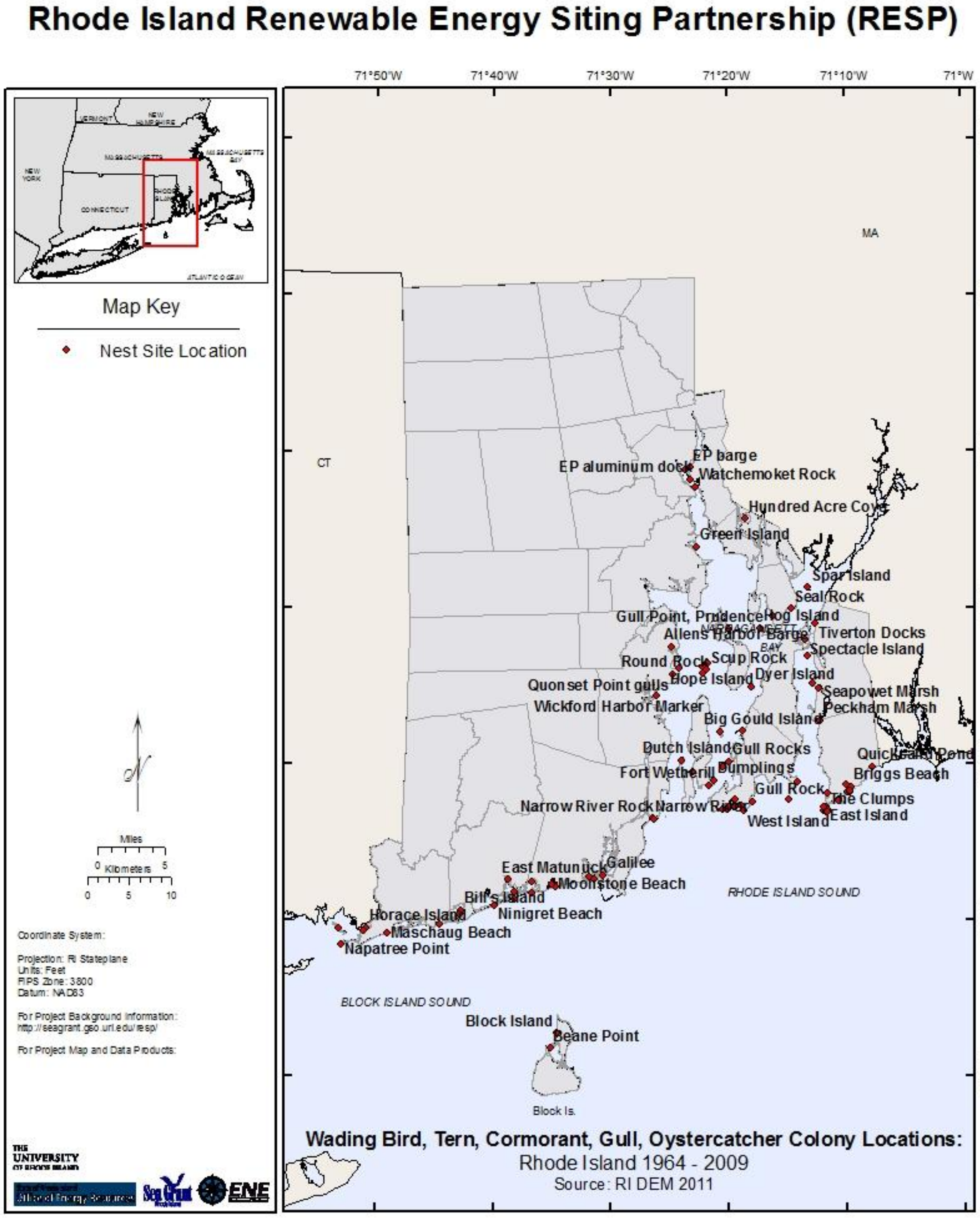


Figure 45. Distribution of tern, cormorant and oystercatcher colonies from 1964 – 2009 based on research by Ferren and Myers (1998) and August et al. (2001).

6.8.4.2 MANAGEMENT IMPLICATIONS

For federally-listed Piping Plovers, we recommend a 1-km buffer around nest sites. For American Oystercatchers, we recommend a 500-m buffer around nest sites. Finally, for key mudflats that provide critical stopover habitat, we recommend 1 km buffers for construction of wind turbines. These mudflats include Sandy Point, Napatree Spit, Maschaug Pond, Winnapaug Pd, Quonochontaug Pond, Ninigret Pond, Green Hill Pond, Trustom Pond, Card Pond, Potter Pond, Point Judith Pond, Bluff Hill Cove, Third Beach Restoration Site at Sachuest NWR, Briggs Marsh and Quicksand Pond (Fig. 45).

6.8.4.3 WADING BIRDS

There are 13 species of wading birds (Order: Ciconiformes) that nest in Rhode Island (Table 15); we also added Double-crested Cormorants as they often nest near many colonial wading birds. Wading birds are conservation concern in Rhode Island. The state of Rhode Island classifies American Bittern as State Endangered, Least Bittern as State Threatened, and seven species as Species of Concern (Great Blue Heron, Great Egret, Little Blue Heron, Snowy Egret, Cattle Egret, Black-crowned and Yellow-crowned Night Herons, Glossy Ibis; Table 6; RI Natural Heritage Program 2006). Within the Bird Conservation Region 30 (New England and Mid-Atlantic), Glossy Ibis is classified as High Priority and seven species are Moderate Priority (American and Least Bittern; Snowy Egret; Little Blue and Tricolored Heron, and Black-crowned and Yellow-crowned Night Heron; Table 15). Although the Breeding Bird survey is not designed to specifically monitoring population trends of wading birds, annual rates of change indicate only two species had significant annual population declines (Green Heron and Cattle Egret) while three species had significant population increases (Double-crested Cormorant, Great Blue Heron, and Great Egret; Table 15).

Most of these species are colonial breeders that nest in trees or on the grounds on islands throughout Narragansett Bay or on Block Island (Tables 15 and 16; Fig. 46). Great Blue Herons are also a colonial breeder, but tend to nest inland in trees near freshwater ponds or lakes (e.g., Enser 1992).

Table 15. Description of nesting and foraging habitat for wading birds that occur in Rhode Island. Also given is their conservation status for Bird Conservation Region 30 and Breeding Bird Survey (BBS) estimated annual rate of change from 1989-2009 for routes in the Northeast (NE) or survey-wide (SW). Most species (except American and Least Bittern, and Green Heron) nest in colonies in trees. Significant values are in bold.

Species	Nesting habitat	Foraging habitat	Conservation status*	BBS Annual Trend	BBS Region
Double-crested Cormorant	Colonies on island	Nearshore saltwater, lakes		**20.91**	NE
American Bittern	Marshes with tall vegetation	Freshwater marshes, saltmarshes	M, Tier V	-3.92	NE
Least Bittern	Marshes with tall vegetation	Freshwater marshes, saltmarshes	M, Tier V	2.73	NE
Great Blue Heron	Colonies in trees near wetlands	Freshwater wetlands, saltmarshes	Tier V	**3.07**	NE
Great Egret	Colonies on islands	Saltmarshes	Tier V	**3.68**	NE
Snowy Egret	Colonies on islands	Saltmarshes	M, Tier V	3.01	NE
Little Blue Heron	Colonies on islands	Saltmarshes	M	0.22	NE
Tricolored Heron (NB)	Colonies on islands	Saltmarshes	M, Tier V	5.14	NE
Cattle Egret	Colonies on islands	Upland fields with cows	Tier V	**-4.27**	NE
Green Heron	Solitary, shrubs in wetlands	Swamps, creeks, streams, wetlands		**-1.40**	NE
Black-crowned Night-Heron	Colonies on islands	Saltmarshes	M, Tier V	-1.06	NE
Yellow-crowned Night Heron	Colonies on islands	Saltmarshes	M, Tier V	-0.55	SW
Glossy Ibis	Colonies on islands	Upland fields, saltmarshes	H, Tier V	-2.12	NE

*Bird Conservation Region 30 priorities: HH = Highest priority, H = high priority, M = Moderate priority, MC = Management Concern (overabundant); Partners in Flight priorities: Tier I A: High Continental Priority - High Regional Responsibility, Tier I B: High Continental Priority - Low Regional Responsibility, Tier II A: High Regional Concern, Tier II B: High Regional Responsibility, Tier II C: High Regional Threats, Tier III: Additional Watch List, Tier IV: Additional Federally Listed, Tier V: Additional State Listed.

Table 16. Distribution of wading bird nest locations throughout Rhode Island based on RI DEM surveys from 1964-2009 (Ferren and Myers (1998), C. Raithel, pers. comm.). Given are average (Ave) number of nests counted on each island and the frequency (freq: % of years with nests).

	BCNH[a]		CAEG		DCCO		GLIB		GREG		LBHE		SNEG	
Location	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**
Big Gooseberry					4	33								
Big Gould Island	41	78	3	30	31	100	53	63	5	31	1	20	16	34
Bill's Island	0	3												
Block Island	32	100							2	67	0	11	1	44
Clumps					19	53								
Dumplings					61	50								
Dyer Island	8	52	1	11			26	43	1	17	1	14	11	45
East Island					160	71								
Gull Rock					5	42								
Hope Island	228	100	16	42	163	56	47	64	32	91	6	73	97	97
Little Gooseberry					27	41								
Little Gould Island	62	100	5	24	247	51	22	54	60	98	2	34	15	59
Price Neck West					105	100								
Rose Island	34	95	0	33			60	59	11	53	2	55	15	53
Sandy Point Island							1	15	0	4			2	10
Seekonk R. N. Pilings					0	29								
West Island					502	85								
Total RI	290	96	18	72	992	66	153	78	93	91	7	87	115	93

[a] BCNH = Black-crowned Night Heron, CAEG = Cattle Egret, DCCO = Double-crested Cormorant, GLIB = Glossy Ibis, GREG = Great Egret, LBHE= Little Blue Heron, SNEG = Snowy Egret

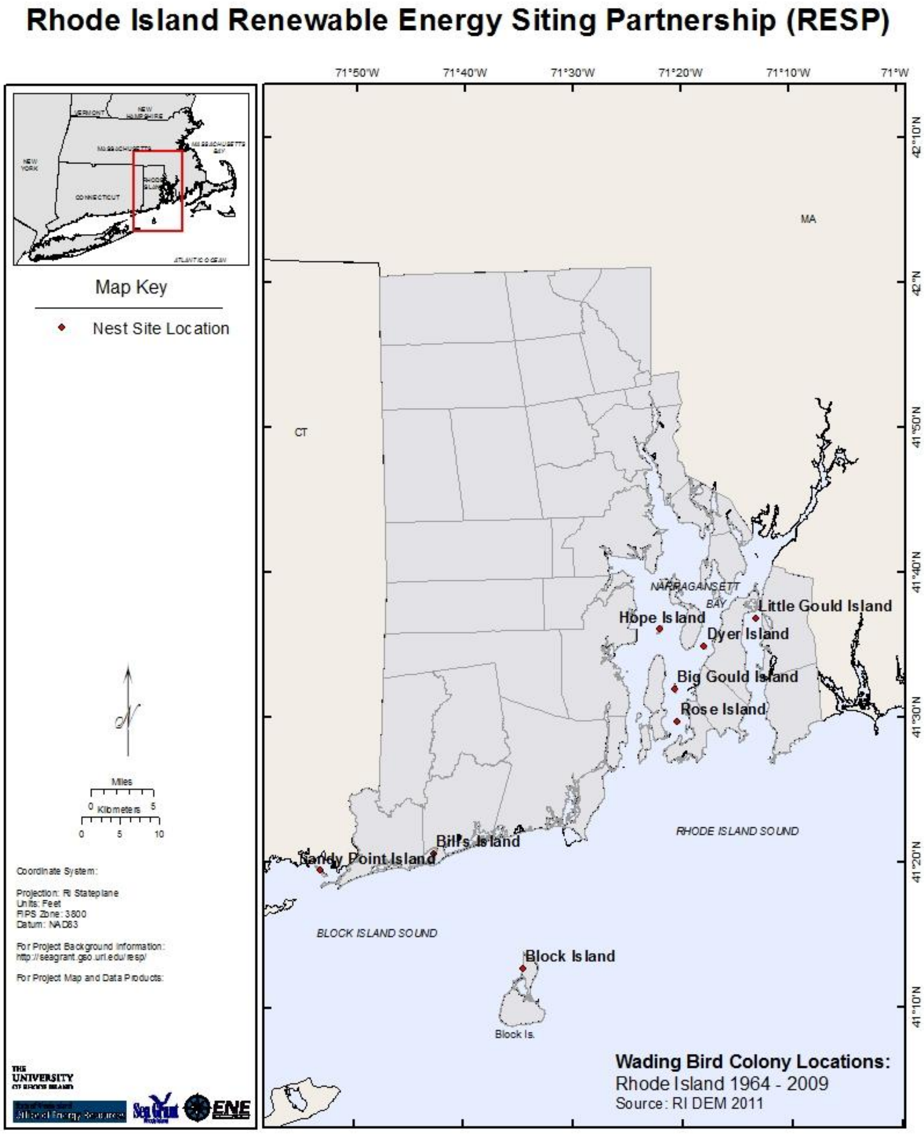


Figure 46. Distribution of wading bird (egrets, herons and ibis) colony locations in Rhode Island from 1964 – 2009 based on research by Ferren and Myers (1998) and C. Raithel (RI DEM, unpubl. data).

6.8.4.4 MANAGEMENT IMPLICATIONS

Given the conservation concern for the most of the colonial wading birds in Rhode Island, we recommend not constructing any wind turbines within 500 m of known wading bird colonies (Fig. 46). Some wading birds are solitary breeders (American and Least Bittern, Green Heron). Both American Bittern and Least Bittern occur primarily in coastal ponds where we are recommending a 1-km buffer on construction of wind turbines. Green Herons are not a conservation concern, thus we are not recommending and wind turbine design criteria for this species. Finally, Double-crested Cormorants are not a conservation concern in the region, thus we do not have wind turbine design criteria near nesting colonies of this species, when they are nesting away from other species of colonial wading birds.

6.8.5 Coastal Pond Birds

Coastal ponds in Rhode Island provide important habitat to a broad suite of species that are of conservation concern in the region (Fig. 47). Federally-listed species that use the coastal ponds include Piping Plover and Roseate Tern (Table 6). State listed species that use the coastal ponds include two State Endangered species (Pied-billed Grebe, American Bittern), one State Threatened species (Least Bittern) and several Species of Concern (Great Blue, Great and Snowy Egret, Black-crowned Night Heron, Green-winged and Blue-winged Teal, Gadwall, Hooded Merganser, Bald Eagle, Osprey, King and Clapper Rail, Sora, Willet, Roseate and Least Tern; Table 6).

Based on Partners In Flight conservation criteria, maritime marshes in southern New England (Region 9) provide critical habitat for the a large proportion of the world's population of Saltmarsh Sparrows (a Tier 1A species: High Continental Priority and High Regional responsibility), a large proportion of the eastern population of Seaside Sparrows (Tier 1A species also), and important habitat for breeding and wintering American Black Ducks (a Tier IIC species – High Regional Threats) (Table A2.2).

Priority Bird Species in Bird Conservation Region 30 that use coastal ponds occasionally for foraging, roosting, and nesting include several species of shorebirds that are highest priority (Piping Plover, Red Knot, Roseate Tern Ruddy Turnstone), of high priority (Dunlin, Forster's Tern, Greater Yellowlegs, Least Tern, Marbled Godwit, Semipalmated Sandpiper, Solitary Sandpiper, and Willet), and of moderate priority (Common Tern, Killdeers, Least Sandpiper, Semipalmated Plover, and Spotted Sandpiper) (Table A2.2).

Surveys conducted by the USFWS conducted in the winter over the past decade clearly show the importance of coastal ponds, including the Narrow River Estuary, to waterbirds in the region (Table 17; Fig. 47). There are no comparable sites for most of these species to winter in Rhode Island.

6.8.5.1 MANAGEMENT IMPLICATIONS

Given the importance of coastal ponds on estuaries to local, regional, and national avian conservation concerns, we recommend a 1 km buffer for all wind turbine development near these critical wetlands.

Table 17. Summary of birds detected during mid-winter waterbird surveys at two coastal ponds (Ninigret and Trustom) and a coastal estuary (Chafee) by US Fish and Wildlife Service biologists (unpubl. data). Given are the mean (SD) number of individuals detected per survey, frequency (Freq = % of surveys with at least one individual detected), and maximum (Max = maximum number of individuals detected). Sample sizes (n) refer to the total number of surveys conducted at each site.

	J.H. Chafee 2004-2011 (n = 70)				Ninigret 2000 - 2011 (n = 89)				Trustom 1992-2011 (n = 211)			
Species	**Mean**	**SD**	**Freq**	**Max**	**Mean**	**SD**	**Freq**	**Max**	**Mean**	**SD**	**FREQ**	**Max**
Eared Grebe									1.3	0.6	1.4	1
Pied-billed Grebe									4.0	3.5	12.3	17
Red-necked Grebe									1.8	1.0	4.3	3
Great Cormorant									17.0	12.7	0.9	26
Mute Swan	15.00	12.61	95.71	66	2.53	3.65	56.18	17	24.9	39.6	87.2	225
Tundra Swan	0.13	1.08	1.43	9					0.0	0.1	0.5	1
Snow Goose	0.09	0.72	1.43	6					5.9	28.4	12.3	200
Canada Goose*	38.94	67.50	67.14	298	15.42	25.29	43.82	120	277.0	363.0	92.4	3800
G. White-fronted Goose									3.0	0.0	0.5	3
Brant					0.72	3.37	6.74	25	0.1	0.7	2.4	7
Wood Duck					0.05	0.30	2.25	2	0.9	3.8	19.0	44
Mallard	25.46	22.68	90.00	90	3.80	8.59	44.94	50	52.1	90.4	92.4	514
American Black Duck	83.37	87.94	91.43	466	53.74	66.45	97.75	374	69.6	65.8	94.3	460
Gadwall	9.06	13.32	68.57	62	0.57	3.83	4.49	35	11.9	31.3	54.5	270
Northern Pintail	0.21	0.74	11.43	5	0.21	1.11	4.49	8	1.5	3.4	28.9	18
American Wigeon	9.07	24.83	32.86	141	1.91	11.82	10.11	100	13.7	29.9	45.0	167
Eurasian Wigeon	0.03	0.17	2.86	1					0.2	1.6	7.1	22
Northern Shoveler									0.8	3.2	13.3	34

	J.H. Chafee 2004-2011 (n = 70)				**Ninigret 2000 - 2011 (n = 89)**				**Trustom 1992-2011 (n = 211)**			
Species	**Mean**	**SD**	**Freq**	**Max**	**Mean**	**SD**	**Freq**	**Max**	**Mean**	**SD**	**FREQ**	**Max**
Blue-winged Teal	0.06	0.48	1.43	4					0.4	1.9	10.0	20
Green-winged Teal	0.06	0.38	2.86	3	0.61	4.08	7.87	38	7.3	14.9	47.9	1260
Canvasback	0.03	0.17	2.86	1	0.44	3.72	3.37	35	9.9	31.9	36.0	275
Redhead					0.02	0.15	2.25	1	0.9	2.6	18.5	18
Lesser Scaup	0.14	1.20	1.43	10					18.4	66.2	24.2	598
Ring-necked Duck					0.03	0.24	2.25	2	3.4	18.8	19.4	217
Tufted Duck									1.0	0.0	0.9	1
Greater Scaup	0.14	0.98	2.86	8	21.87	73.58	19.10	380	152.6	194.0	72.5	1260
Common Eider	0.39	1.53	8.57	10	0.01	0.11	1.12	1	30.0	227.5	17.5	2500
King Eider									0.0	0.1	0.9	1
Harlequin Duck									0.0	0.1	0.5	96
Long-tailed Duck									0.0	0.3	1.4	3
White-winged Scoter									3.2	16.9	12.8	140
Surf Scoter					0.06	0.32	3.37	2	2.0	13.2	13.7	180
Black Scoter					0.01	0.11	1.12	1	4.6	22.7	15.2	275
Common Goldeneye	3.51	5.37	45.71	24	47.93	78.30	57.30	360	26.6	42.1	65.4	236
Barrow's Goldeneye	0.01	0.12	1.43	1	0.01	0.11	1.12	1				
Bufflehead	46.50	28.66	95.71	143	108.61	140.14	84.27	595	6.3	11.3	51.2	57
Hooded Merganser	9.03	13.99	68.57	75	26.35	57.29	77.53	480	18.3	27.5	65.9	165
Red-breasted Merganser	18.69	21.02	85.71	113	70.83	100.89	82.02	418	23.7	41.3	72.5	273
Common Merganser	0.56	2.53	7.14	15	1.29	6.23	14.61	54	1.2	7.3	13.3	98

	J.H. Chafee 2004-2011 (n = 70)				Ninigret 2000 - 2011 (n = 89)				Trustom 1992-2011 (n = 211)			
Species	**Mean**	**SD**	**Freq**	**Max**	**Mean**	**SD**	**Freq**	**Max**	**Mean**	**SD**	**FREQ**	**Max**
Ruddy Duck	0.04	0.36	1.43	3	0.36	2.33	4.49	21	140.8	228.8	72.5	1244
American Coot									188.3	344.8	39.8	1500
Common Moorhen									5.0	0.0	0.5	5
Sandhill Crane									1.0	0.0	0.5	1
Grand Total	260.51	176.59		929	357.37	333.12		1514	999.7	826.9		5312

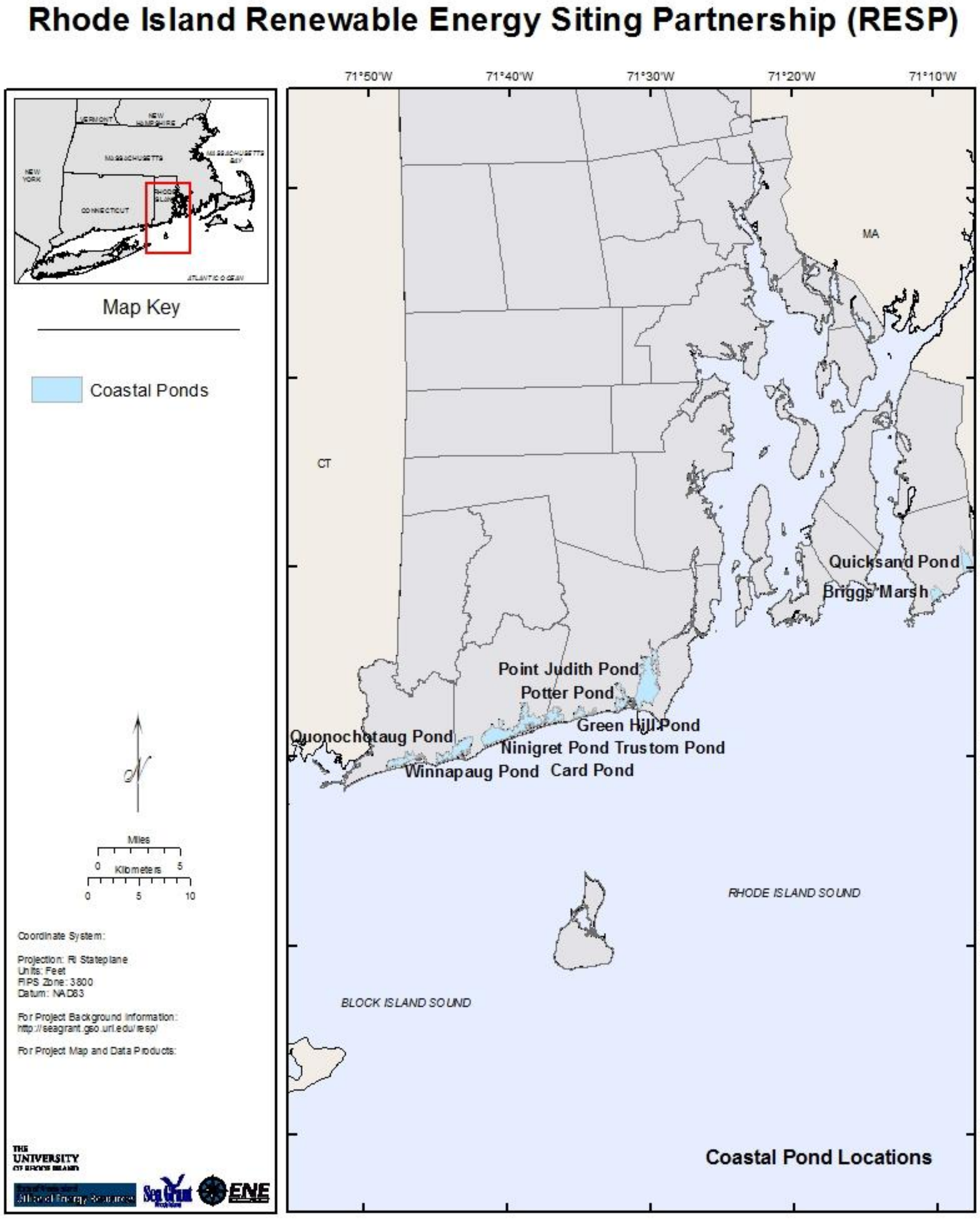


Figure 47. Key coastal ponds in Rhode Island for birds in Rhode Island. These ponds provide critical nesting habitat for some wading birds and waterfowl. In addition, shorebirds use these ponds as stopover habitat during spring and fall migration. Little Narragansett Bay and Napatree Spit are also important habitats for shorebirds. Finally, many species of waterfowl use these ponds as key wintering habitat.

7. BATS

There are nine species of bats that are either year-round residents or migrants through Rhode Island (Table 18; August et al. 2001, Smith and McWilliams 2011). There is no equivalent international legislation to protect bats as does the Migratory Bird Treaty Act for birds. The primary federal legislation to protect bats is the Endangered Species Act, as regulated by the USFWS. In New England, there is one federally-listed species, the Indiana Bat (*Myotis sodalis*), which is classified as Endangered due to documented declines in populations caused by human disturbances at roosting caves. Cave-roosting species are less affected by wind turbines than are tree-roosting, migratory species (Arnett et al. 2008a), although cave-roosting species in the northeast have been decimated by White-nosed Syndrome, which is caused by a fungus (*Geomyces destructans*) apparently introduced by cavers from Europe (see www.fws.gov/whitenosesyndrome).

In fact, when Arnett et al. (2008a) conducted an extensive review of bat mortality at wind turbines in North America, no federally-listed species had been killed by a wind turbine. However, on 27 September 2011, an Indiana Bat was killed at the North Allegheny Wind, PA facility, which led to the power company ceasing night-time operations of the turbines until the USFWS developed a mitigation plan (see www.fws.gov/northeast/pafo).

In Rhode Island, although the state has a list of threatened and endangered species, there are no state-listed bat species (RI Natural Heritage Program 2006). However, with dramatic declines in cave-roosting species in the region due to White-nosed Syndrome (see Table 18), several species are being considered for listing. This disease has led to the deaths of an estimated 5.7 to 5.7 million North American bats since 2006, with 100 percent mortality at some caves (USFWS, unpubl. data).

7.1.1 Breeding

In Rhode Island, little is known about the distribution or abundance of bats during the breeding season, in winter, or during spring or fall migration (see Davis and Hitchcock 1965, Mendelsohn et al. 2009, Smith and McWilliams 2011, 2012).

Four species of bats have been documented as having maternity roosts in Rhode Island: Little Brown Bat, Tri-colored Bat, Big Brown Bat and Eastern Red Bat (August et al. 2001). The Eastern Red Bat and Silver-haired Bat roost in tall, mature trees, while the Northern Long-eared Bat requires older forested habitats. All of the tree-roosting species, including the Tri-colored Bat and Hoary Bat, exhibit strong fidelity to the same roosts during summer, thus loss and fragmentation of the forested habitat can affect bat populations by removing vital maternity roosts. Other structures that provide roosting habitat include rocky outcrops, dams and riprap slopes, barns, attics and other outbuildings. Interestingly, summer foraging flights by Hoary Bats and Silver-haired Bats suggest bats can forage out to 20 km and 17 km (Pierson 1998), respectively from material roosts. If and when significant maternal roosts are identified in the state, these foraging flight distances should be taking into consideration when developing wind facilities in the region.

Some pilot work has been done locating maternity roost sites for Big Brown and Little Brown Bats in Rhode Island; however, this data is preliminary and little is known about other species that breed in Rhode Island (Charles Brown, RI DEM, pers. comm.).

7.1.2 Migrating

Several species of bats migrate through Rhode Island, although we are just beginning to start to understand distribution and abundance of migratory bats throughout the state (see Cryan and Brown 2007, Smith and McWilliams 2011, 2012). The most detailed work on bat migration conducted to date in Rhode Island has been research by Smith and McWilliams (2011, 2012), who used acoustic bat detectors at three coastal sites on National Wildlife Refuges (NWR) in the fall (8 Sept to 9 Nov) of 2010 (Sachuest in Middletown, and Kurz and Wash Pond on Block Island) and 6 coastal sites in the fall (8 Sept to 12 Nov) of 2011 (the three NWR sites used in 2010 plus Trustom Pond NWR in South Kingstown, Ninigret NWR in Charlestown, and Watchaug Pond in Charlestown).

In 2010, the greatest passage rates by bats were relatively high at Sachuest NWR and the Kurz property on Block Island, averaging approximately 171 passes per night (PPN) (43 PPN on 2011 scale) and 109 PPN (27 PPN on 2011 scale) , respectively, compared to 19 PPN at Wash Pond on Block Island (Smith and McWilliams 2011, 2012). In 2011, passage rates were greatest at Trustom Pond NWR (44 PPN), Kurz (25 PPN), Watchaug Pond (19 PPN) and Ninigret NWR (19 PPN), and lower at Sachuest (10 PPN) and Wash Pond (3 PPN). This suggest considerable variation among coastal sites in passage rates of migrants. It is still not clear if there are migration corridors for bats in Rhode Island, or exact habitat associations for migrants in Rhode Island. It is interesting that relatively high detection rates for bats were observed at the Kurz property on Block Island, suggesting that some bats will readily cross potential large water barriers.

During research by Smith and McWilliams (2011, 2012) at up to six coastal locations, the two most commonly detected migrant bats in Rhode Island were Eastern Red Bat and Silver-haired Bat (both tree-roosting bats), while detection rates were intermediate for Tri-colored Bat (cave-roosting species) and Hoary Bat (tree-roosting species), and relatively low for Eastern small-footed Myotis and Big Brown Bat (both cave-roosting species (Fig. 48).. In 2010, passage rates for Eastern Red Bat were high at Sachuest and at Kurz (on Block Island), while in 2011 relative detection rates were greatest at Trustom, Ninigret, and Kurz, with fewer detections at Sachuest and Wash Pond (Block Island). Overall, detection rates for Silver-haired Bats were even greater than Eastern Red Bat, with high detection rates at Kurz and Wash Pond (both on Block Island), and were less evident at Sachuest NWR in 2010, and high detection rates at

Trustom, Kurz, and Ninigret in 2011 with intermediate detection rates at the other three sites. Tri-colored Bats in 2010 were often detected at Sachuest and Kurz, while in 2011 this species was most evident at Trustom, Watchaug, and Kurz. Little Brown Myotis were not detected in 2010, and primarily detected at Trustom in 2011. Hoary Bats were most commonly detected at Sachuest in 2010 and Trustom and Watchaug in 2011, with few detections of this species on Block Island. Big Brown Bat were also often detected at these coastal refuges

To our knowledge, the only other comprehensive study of bat migration in Rhode Island that was available for our review documented a southeast migration of Little Brown Bats (*Myotis lucifugus*) from a cave in Vermont to Rhode Island, with bats migrating in a narrow band through southern Vermont into SW New Hampshire, NE Massachusetts, and NE Connecticut in the spring and migrating north back to Vermont in the fall (Davis and Hitchcock 1965).

The migration phenology of bats in Rhode Island is just beginning to being understood. Smith and McWilliams (2011, 2012) monitored bat migration from early September to early November in 2010 and 2011. However, Arnett et al. (2007) monitoring bat migration in northern Massachusetts had high detection rates of bats as early as mid-July, thus more extended surveys need to be conducted to capture the entire migration season for bats in Rhode Island. Work by Smith and McWilliams did document substantial seasonal variation in detection rates of bats at the sites they monitored (Fig. 49). They detected relatively large detection rates of bats in the middle of September and the middle of October in 2010 and 2011. Their analyses investigated the effects of wind profit (a combination of wind speed and direction), wind speed, change in nightly temperature, change in relative humidity, atmospheric pressure and change in atmospheric on bat detection rates to investigate factors that affect bat migration. Smith and McWilliams (2012) found that bat detection rates increased with wind profit and the 24-hr change in atmospheric pressure (both an indication of the passage of cold fronts) and the decrease in wind speed. However, this analysis was preliminary and other factors such as geographic location, sky conditions, moon phase, precipitation, and front passage history all need to be investigated in the future

7.1.3 Wintering

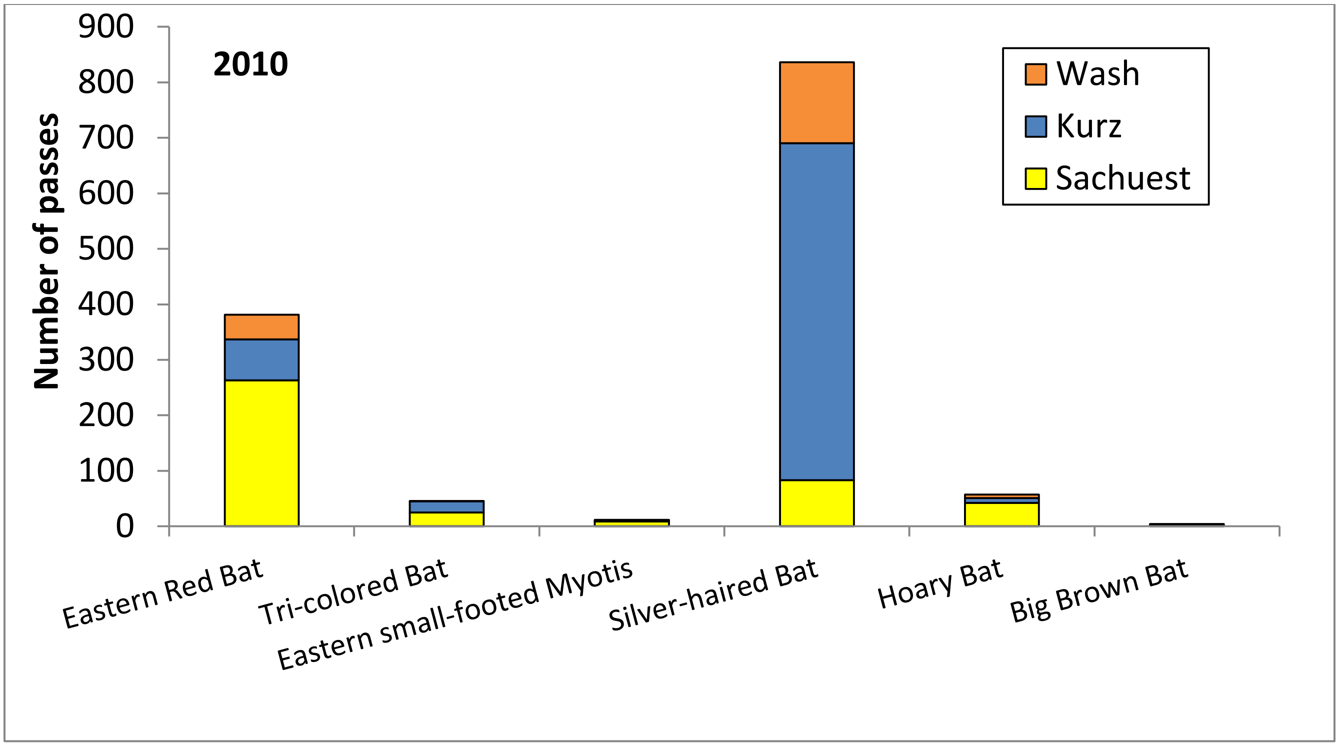
Most species of bats in Rhode Island either migrate south for the winter (although Little Brown Myotis migrant north, Davis and Hitchcock 1965) or go into a state of torpor (lowered body temperature) and hibernate in during cold months. Little is known about specific hibernation locations in Rhode Island; however, bats tend to hibernate in caves, abandoned mines and man-made structures. Unfortunately, at the time this report was compiled, little information was available to us to describe wintering distribution and trends for bats in Rhode Island (Charles Brown, RI DEM pers. comm.). However, given that all bats typically are not active during the winter months in Rhode Island, there is little potential for conflict with wind development. However, given climatic changes in the region, with relatively warm nights even in the winter, there is the possibility of bats being active throughout the winter in the future.

Table 18. **Status of nine species of bats documented in Rhode Island (August et al. 2001). Bats are separated into tree-roosting species cave-roosting bats, and the latter category are affected by White-nosed Syndrome (WNS).**

Species	Scientific name	Conservation Status[A]	Roost Behavior	Affected by WNS?	RI Life History	Abundance in New England[B]	Distribution in New England[B]
Little Brown Bat	*Myotis lucifugus*	Declining	Cave	Yes	Breeding	Common	Throughout New England
Northern Long-eared Bat	*Myotis septentrionalis*	.	Cave	Yes	Breeding and hibernate, numbers unknown[c]	Common to uncommon	Throughout New England especially in the White Mountains (NH). Common in spring and summer on Martha's Vineyard (Buresch 1999)
Indiana Bat	*Myotis sodalis*	FE	Cave	Yes	No records in RI[c]	Rare and endangered	S Vermont, W Massachusetts, NW Connecticut
Eastern Small-footed Bat	*Myotis leibii*	.	Cave	Yes	.	Uncommon	Summer distribution poorly known. Winter in mines in the White Mountains (NH) and the Adirondacks (NY)
Silver-haired Bat	*Lasionycteris noctivagans*	.	Tree	No	Migratory	Uncommon	Summer resident. Seen during migration foraging over marshes, lakes, ponds in the White Mts. Detected on Martha's Vineyard
Tri-colored Bat	*Pipistrellus subflavus*	.	Cave	Yes	Breeding	Uncommon to rare	Summer resident, breeding distribution unknown. Winter in NH. Detected on Martha's Vineyard
Big Brown Bat	*Eptesicus fuscus*	.	Cave	Yes	Breeding	Common	Throughout the region

Species	Scientific name	Conservation Status[A]	Roost Behavior	Affected by WNS?	RI Life History	Abundance in New England[B]	Distribution in New England[B]
Eastern Red Bat	*Lasiurus borealis*	.	Tree	No	Breeding	Uncommon to rare	Migratory through New England but breeds locally. Detected on Martha's Vineyard
Hoary Bat	*Lasiurus cinereus*	.	Tree	No	Migratory	Rare to unknown	Migratory throughout the region

[A]FE = federally endangered, [B]Degraaf and Yamasaki 2001, [c]C. Brown, RI DEM, pers. cmm.



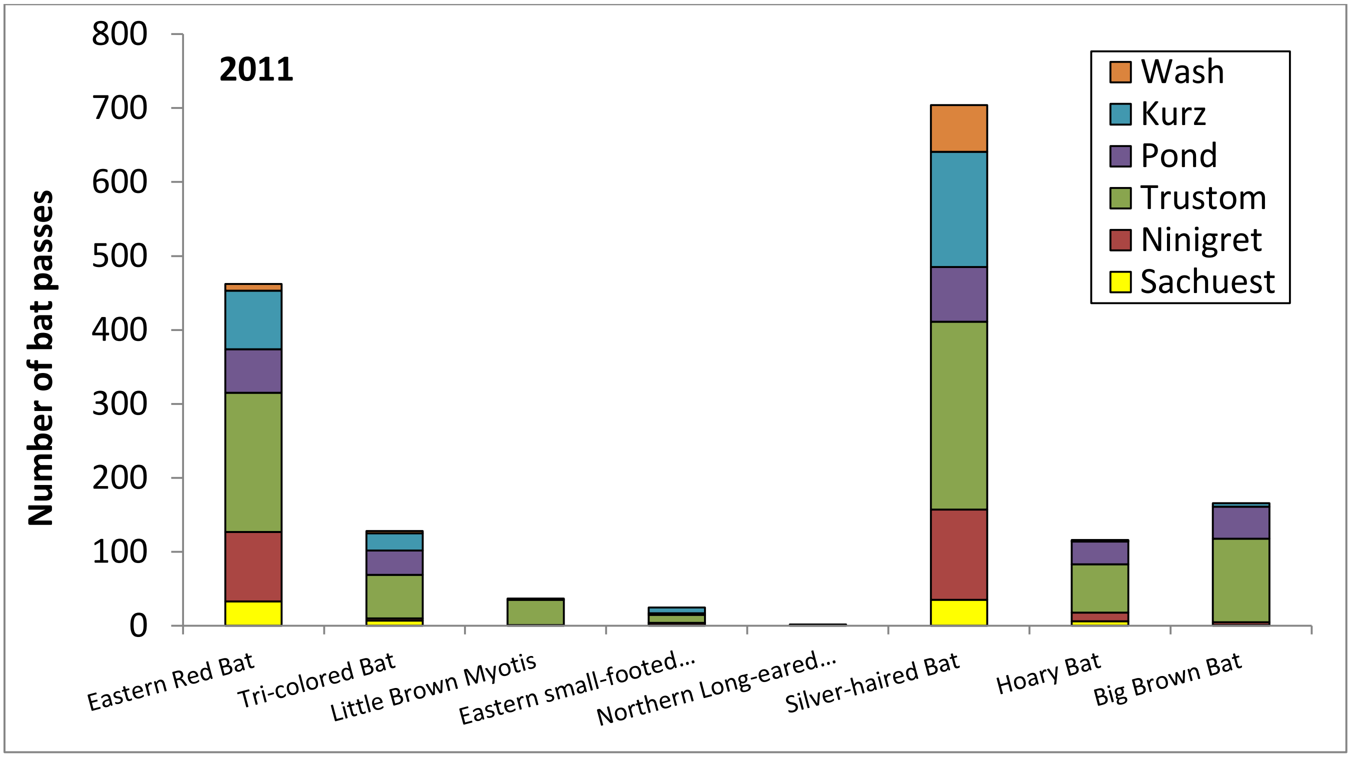
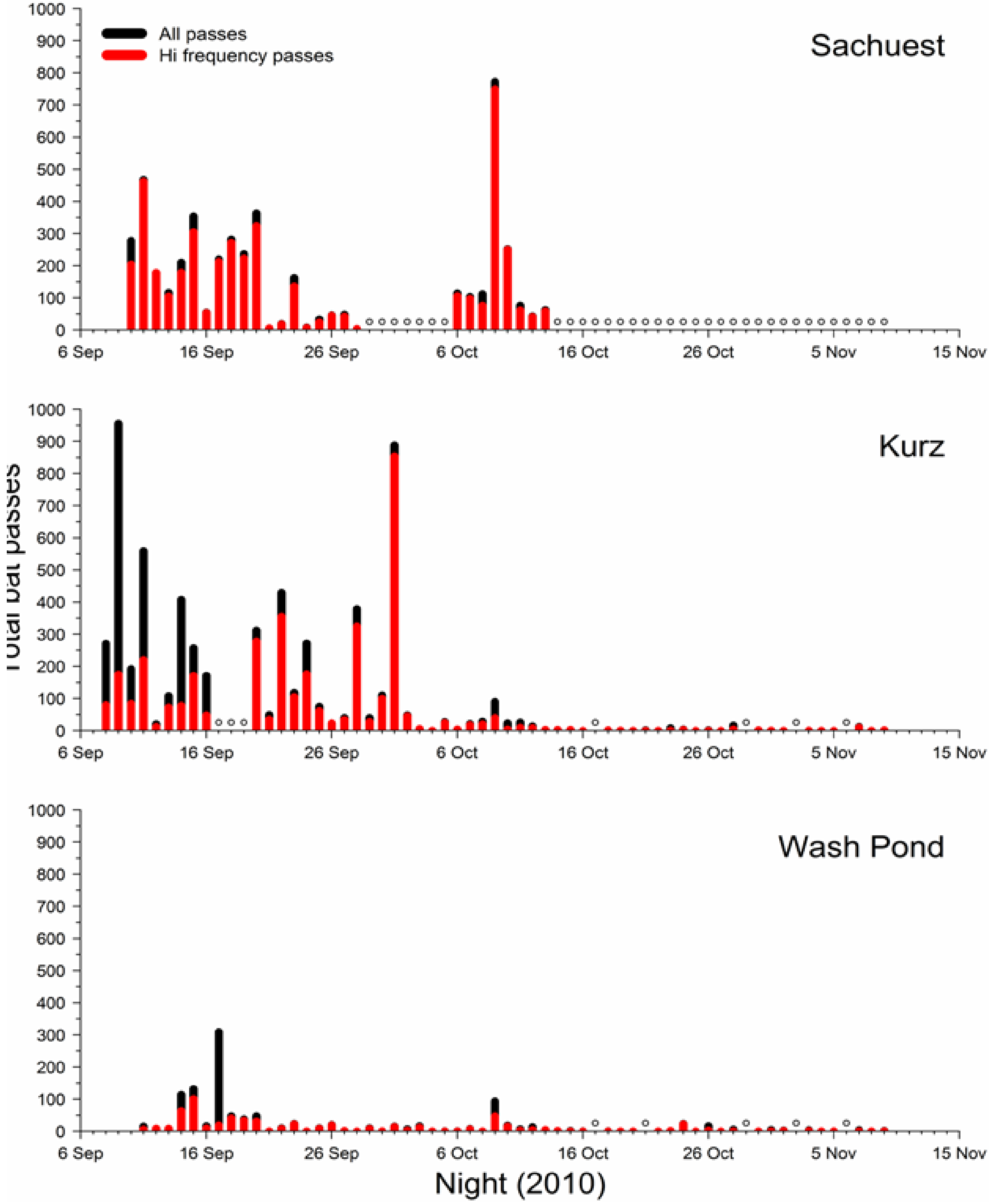
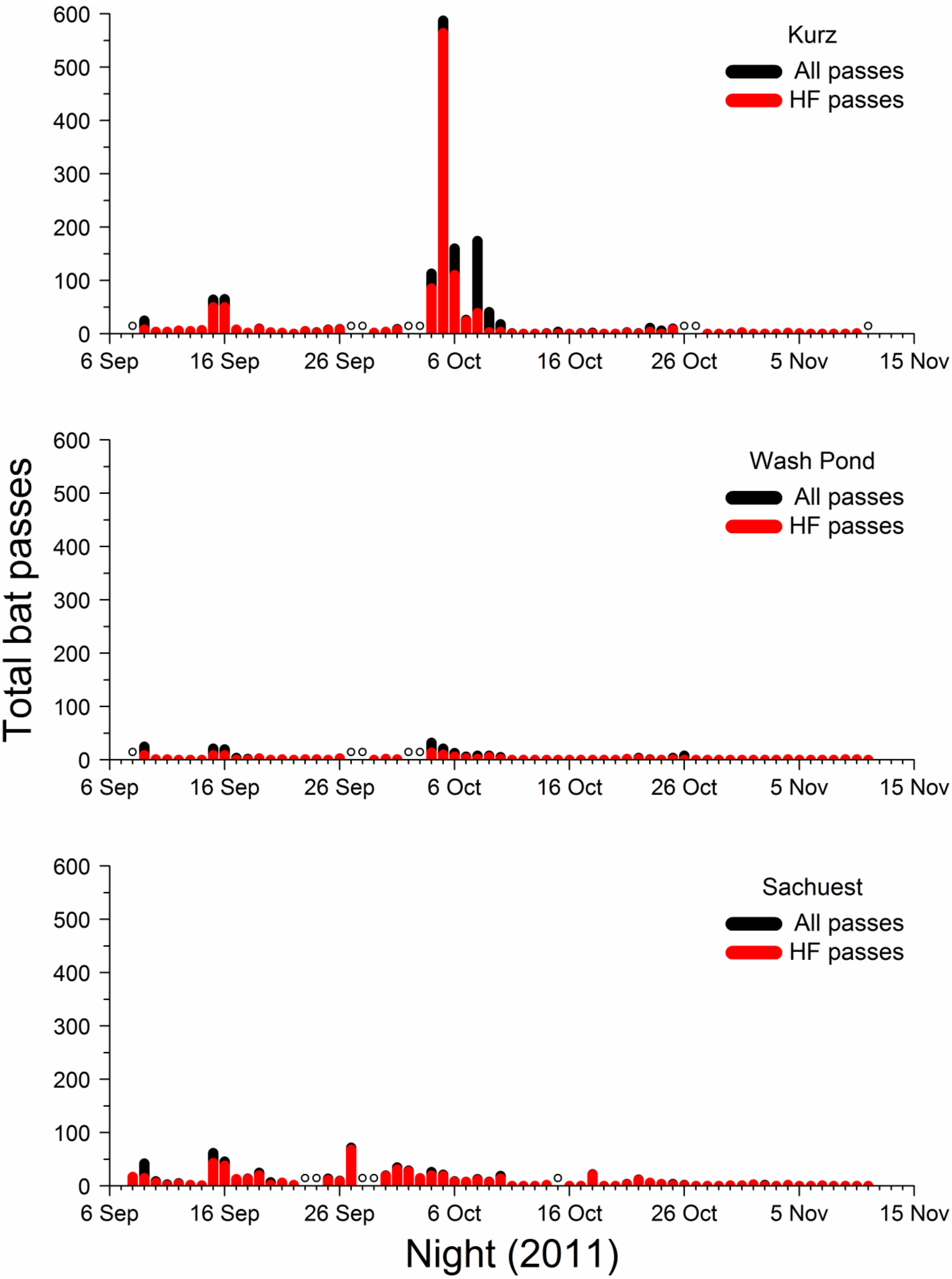


Figure 48. Summary of bats detected by Smith and McWilliams (2011, 2012) on National Wildlife Refuges in Rhode Island during the fall of 2010 and 2011. Shown are the number of passes by bats at each station. The number of nights each site was monitored differed among sites, so abundance differences among sites cannot be distinguished.


All passes
Hi frequency passes
Sachuest
Kurz
Wash Pond
Total bat passes
0
100
200
300
400
500
600
700
800
900
1000
6 Sep
16 Sep
26 Sep
6 Oct
16 Oct
26 Oct
5 Nov
15 Nov
Night (2010)


Total bat passes
600
500
400
300
200
100
0
6 Sep
16 Sep
26 Sep
6 Oct
16 Oct
26 Oct
5 Nov
15 Nov
Kurz
All passes
HF passes
Wash Pond
All passes
HF passes
Sachuest
All passes
HF passes
Night (2011)

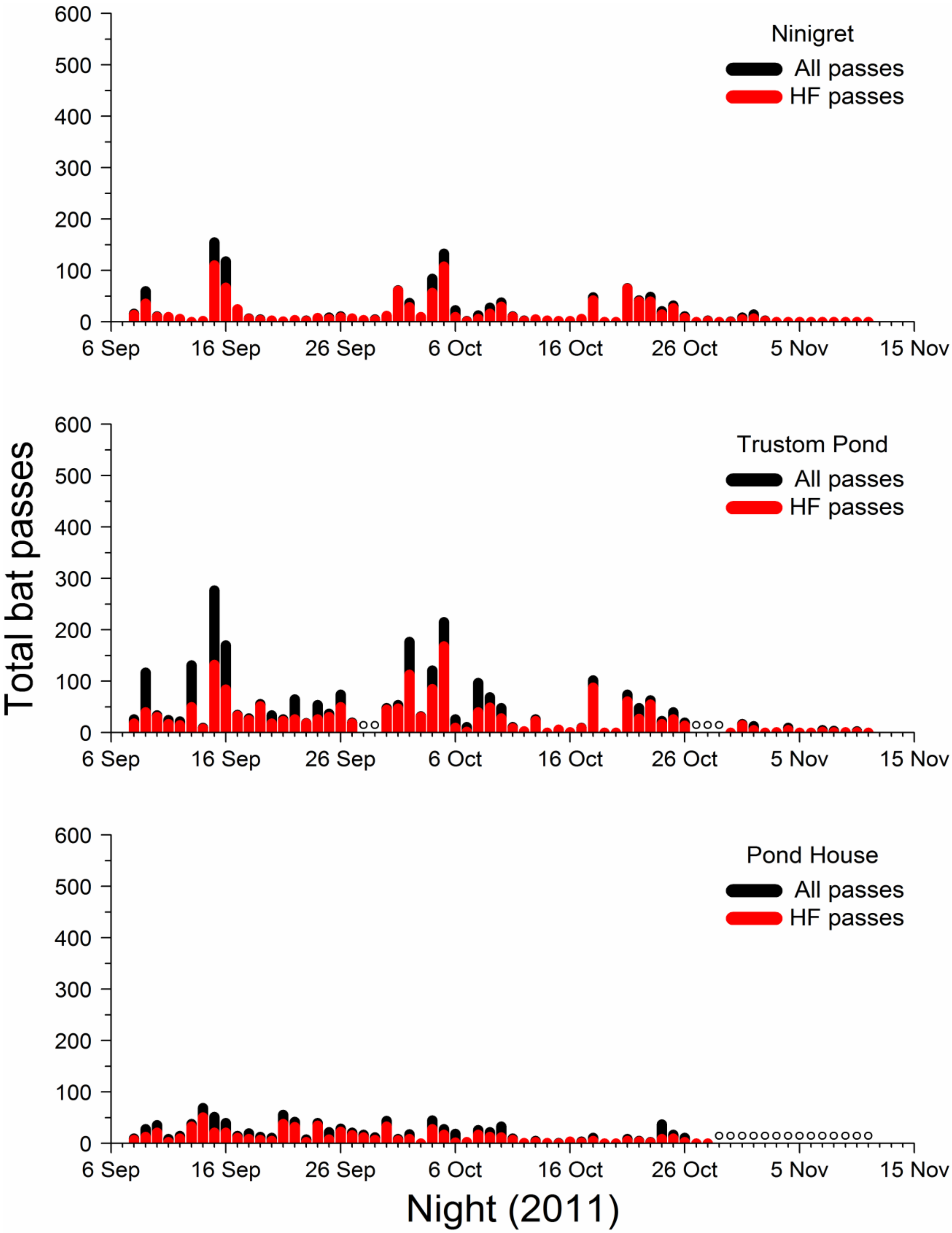


Figure 49. Daily variation in bat activity levels at National Wildlife Refuges in coastal Rhode Island during Fall 2010 and Fall 2011 from Smith and McWilliams (2011, 2012).

7.1.4 Management Implications

We are just beginning to understand bat ecology in Rhode Island. There are a number of ongoing efforts in the state and region that were not available to be included in this report. Biologists with RI DEM and the USFWS have been conducting road-based surveys with ultrasonic detectors for the past two summers (C. Brown, RI DEM and S. Paton, pers. comm.). In addition, biologists with TetraTech have used bat detectors on Block Island as part of studies for wind development off of Block Island. Unfortunately those survey data have not been analyzed yet, so were not available to be included in this summary report. These studies would be useful as they would provide additional information on the spatial distribution and abundance of bats in the state. Presently, we only have some survey data from selected coastal sites, thus it is difficult to quantitatively assess key areas in the state that provide important habitat for bats, either during migration, the summer, or winter.

7.1.5 Mitigation Options

Available evidence suggests bat mortality rates are greatest in late summer and early fall during the peak migration period for migratory bats from approximately early August to early October depending on location (Kunz et al. 2007, Arnett et al. 2008). Based on the limited bat migration data collected in Rhode Island, migratory bats are passing through the region throughout September into mid-October (Fig. 49; Smith and McWilliams 2011) – bats could be migrating in August in the region but no survey data are currently available for that time period. However, bat acoustic surveys were conducted on Block Island for an extended time period, which may provide insights into bat migration phenology once a report is produced for the Deepwater Offshore wind facility off of Block Island.

There are no known large cave-roosting populations of bats in Rhode Island (S. Paton, USFWS, pers. comm.), where current management recommendations suggest avoiding constructing wind turbines (Arnett et al. 2008). There are small roost populations scattered throughout the state, but spatial-explicit information on the distribution of bats in Rhode Island were not available for this report. In addition, there has not been a systematic survey of bats in Rhode Island, although biologists from RI DEM and USFWS have initiated road-based surveys in some parts of the state to obtain initial estimates of the distribution of bats in the region during the 2010 and 2011 field seasons (C. Brown, RI DEM, pers. Comm.) Unfortunately, results from those surveys were not available at the time this report was produced.

Available evidence suggests that nights with low winds (<6 m/sec) are when most bat mortalities take place (Arnett et al. 2008a, 2011). In addition, there appears to be a negative relationship between stormy nights and bat mortality rates (Kerns et al. 2005). Based on these observations and research by Arnett et al. (2011), we recommend that during nights with high potential for bat migration, and hence bat mortality, that the operational wind speed for wind turbines be 11 miles per hr (6 m per sec), rather than 8-9 miles per hour to start power generation. This would result in a <1% reduction in power production, yet could result in up to a 93% reduction in bat mortality (Arnett et al. 2011).

8. SUMMARY AND MANAGEMENT RECOMMENDATIONS

Based on our review of state and federal guidelines for siting wind turbines, we suggest that developers in siting renewable energy projects in Rhode Island follow USFWS guidelines (2012). Below we have modified those recommendations specifically for Rhode Island based on our understanding of the vulnerability of various birds and bats to wind turbines and local information on birds and bats in Rhode Island. However, developers should follow USFWS (2012) guidelines, which are briefly summarized below.

Tier 1: Preliminary evaluation or screening of potential sites

In Tier 1, developers work the USFWS, RI DEM, and local conservation entities (e.g., Audubon Society of Rhode Island, The Nature Conservancy, and local land trusts) to determine areas that are inappropriate for wind energy development based on the risks to wildlife and their habitats. We suggest that developers read this report and follow our voluntary buffer guidelines for vulnerable species that are of conservation concern (Table 19) or for specific habitats (grasslands, scrub-shrub, forest, or coastal ponds) depending on where the wind turbines might be located. Developers should use local resources and the voluntary guidelines in this report to address Tier 1 guidelines before moving on to the second tier guidelines. If it does not appear that species of conservation concern or vulnerable habitats are near the proposed project, the developer should move on to Tier 2 considerations. If the developers find that vulnerable species or important habitats might be compromised if a wind facility is constructed in the proposed area, they should consider finding an alternate location or implementing mitigation techniques in order to preserve the wildlife and its habitats in the area.

Tier 2: Site characterization

In Tier 2 of the process, the developer should narrow their search to specific wind turbine locations, addressing many of the same points as in Tier 1, but with a specific location chosen. In addition, the developer should do some initial field-based evaluations of the appropriateness of the specific site for wind facility development. The same points should be considered at this stage as were considered in Tier 1, following particular attention to voluntary buffer guidelines outlined in Table 19. Developers should be especially careful when siting potential wind turbine locations near the coast, given the proximity to species of conservation concern and key habitats. A wildlife biologist with expertise in habitat delineation should visit the site and surrounding habitats to insure that no species of concern (Tables 6 and 19) might be compromised in the future. If the developer is planning to build the wind facility within a grassland or scrub-shrub habitat, a trained biologist should conduct surveys at the site during the nesting season (May and June) to ensure that no species of conservation concern are breeding at the site. If species of conservation concern are at the site, then the location of the wind facility should be moved to meet voluntary buffer guidelines. If none of the above points are compromised, the developer should move on to Tier 3 considerations. If the developer finds that any of the above points will be compromised if a wind facility is constructed in the given area, they should consider finding an alternate location or implementing mitigation techniques in order to preserve the wildlife and its habitats in the area.

Tier 3: Pre-Construction monitoring and assessments

Tier 3 is where scientifically rigorous and quantitative evaluations of the wind facility site begin. At this stage, the developer evaluates the site to determine how the facility should be designed, constructed and operated to minimize the effects to wildlife; establish compensation measures if wildlife or its habitat will unavoidably be compromised due to wind facility development; and determine the duration and intensity of pre- and post-construction surveys. In Tier 3, the affected species' distribution, site use and behavior are quantified, as well as the potential risks to local and migration populations. A variety of assessment and monitoring tools are recommended at this stage including following buffer guidelines in this report, conducting an in-depth literature search of the selected site including relevant theses and dissertations, initiating baseline surveys for bird and bats, consulting with local authorities on species of concern, and developing risk models for species and habitat. If the developer determines there is low risk to species and habitat with the installation of a wind facility, the developer should move on to Tier 4 considerations. If the developer finds that the species or habitat will be compromised if a wind facility is constructed in the given area, they should consider finding an alternate location or implementing mitigation techniques in order to preserve the wildlife and its habitats in the area.

Tier 4: Post-construction monitoring of effects

After construction of the wind facility has commenced, fatality and other effects are monitored in Tier 4. Given that no fatality studies for birds or bats have been conducted at existing wind turbines in Rhode Island, this is an important recommendation, because so little is known about mortality rates of birds or bats at wind turbines in coastal New England. In fact, we know of no quantitative investigation of mortality rates at wind turbines in the region (see Table 1). If feasible, we recommend carcasses searches be conducted for a minimum of one year following construction of the turbine. This means conducting search within a minimum of a 50 m radius around the turbine at least every three days. Concurrently, controlled searcher efficacy trials should be conducted using small passerines (e.g. warblers and sparrows) to determine what percentage of carcasses are being found by searchers. In addition, carcass removal studies (also with small passerines) should be implemented to determine how often carrion eaters take prey before searchers find the carcass. This is critical to building correction factors in mortality rate estimates, particularly since no studies have been conducted in the region. In addition, fatality patterns should be examined to determine if certain aspects of the wind facility, such as location of certain towers or other features, or if other factors, such as season or weather, are contributing to higher rates of mortality than others. The developer can then assess the need for modifications to the wind facility to minimize fatalities at the site. In addition, any adverse effects to habitat or species behavior should also be identified in this step. The type, duration and intensity of monitoring will depend on the fatality rates as well as factors identified in Tiers 1-3.

Tier 5: Research

Research should be conducted when Tier 3 highlights potential high risk for species or habitats and there is some uncertainty regarding effective mitigation techniques or Tier 4 assessments resulted in higher than predicted mortality rates. Developers would design experiments and research projects to address any issues that arose in the operation of their wind facility. This is particularly important in Rhode Island when wind facilities are built near the coast where there is presumably high species richness and abundance.

There is some evidence to suggest that coastal areas are migration pathways for songbirds and bats, but much more needs to be learned about migration ecology in the region. There is no quantitative information on flight altitude of birds or bats anywhere in mainland Rhode Island. Thus we do not know how vulnerable these nocturnal migrants are to wind turbines in the region.

Table 19. Suggested Siting Considerations and Distances from the nests of sensitive species of birds and sensitive habitats in Rhode Island.

Species	Distance	Conservation status[A]	Comments	Towns where documented
Pied-billed Grebe	1 km	SE	See Coastal Pond guidelines	Westerly, Charlestown, South Kingstown, Little Compton
American Bittern	1 km	SE	See Coastal Pond guidelines	Westerly, Charlestown, South Kingstown, Little Compton
Least Bittern	1 km	ST	See Coastal Pond guidelines	Westerly, Charlestown, South Kingstown, Little Compton
Great Blue Heron	0.5 km	SC		State-wide
Osprey	0.5 km	SC	Known nesting locations	State-wide
Bald Eagle	1.6 km	C		Scituate
Northern Harrier	0.1 m	SE	See grassland guidelines	New Shoreham
Peregrine Falcon	0.5 km	SE	Avoid known nesting locations and concentration sites	New Shoreham, Westerly, Charlestown, South Kingstown, Newport, Providence

Species	Distance	Conservation status[A]	Comments	Towns where documented
Piping Plover	2 km	FT	Prevent impacts on coastal nesting beaches, foraging sites, and staging areas	South Kingstown, Narragansett, New Shoreham, Charlestown, Westerly, Middletown, Little Compton
American Oystercatcher	0.5 km	SC	Prevent impacts on coastal nesting beaches, foraging sites, and staging areas	Westerly, New Shoreham, Jamestown, Portsmouth, Tiverton, Newport, Bristol, Little Compton, Middletown, Warwick
Upland Sandpiper	0.1 km	SE	Avoid turf fields over 40 acres	Richmond, South Kingstown, North Kingstown
Least Tern	1 km	ST	Prevent impacts on coastal nesting beaches, foraging sites, and staging areas	Westerly, Charlestown, South Kingstown, Narragansett
Roseate Tern	2 km	FE	Prevent impacts roosting and staging areas	Westerly, Charlestown, South Kingstown, Middletown, Little Compton
Barn Owl	0.1 km	SE	See grassland guidelines	New Shoreham, Newport, Middletown, Portsmouth
Northern Parula	0.1 km	ST	See forest guidelines	State-wide
Black-throated Blue Warbler	0.1 km	ST	See forest guidelines	State-wide
Blackburnian Warbler	0.1 km	ST	See forest guidelines	State-wide
Cerulean Warbler	0.1 km	SE	See forest guidelines	State-wide
Yellow-breasted Chat	0.1 km	SE	See shrub guidelines	State- wide, primarily coastal
Grasshopper Sparrow	0.1 km	ST	See grassland guidelines	State-wide
Coastal ponds	1 km	Variety	See Fig. 47, key nesting, foraging, and wintering habitat for a broad suite of species	Westerly, Charlestown, South Kingstown, Narragansett, Little Compton
National Wildlife Refuges	1 km	Variety	Includes all critical Habitats and listed species	Westerly, Charlestown, South Kingstown, Middletown, New Shoreham, Narragansett

Species	**Distance**	**Conservation status**[A]	**Comments**	**Towns where documented**
State, Town and non-government Conservation Areas	0.1-1 km	Variety	Buffer distance a function of preference of owner of conservation land	State-wide
Forest birds	0.1 km	Variety	Recommend not constructing within contiguous forests >100 acres, but turbines can be at the edge of large forest patches	State-wide
Grassland birds	0.1 km	Variety	Have buffer when grassland in >5 acres	State-wide
Scrub-Shrub birds	0.1 km	Variety	Have buffer when shrubs are >3 acres	State-wide
Wading/Shore birds	1 km	Variety	Buffer for key stopover habitat during migration at coastal ponds and mudflats in southern Rhode Island and Block Island	Westerly, Charlestown, South Kingstown, Middletown, Narragansett Bay Islands, New Shoreham

REFERENCES

Anderson, R., Morrison, M., Sinclair, K., Strickland, D., Davis, H. and Kendall, W. 1999. Studying wind energy/bird interactions: a guidance document Report for the Avian Subcommittee and the National Wind Coordinating Committee 94 pp.

Anderson, R., Neumann, N., Tom, J., Erickson, W.P., Strickland, M.D., Bourassa, M., Bay, K.J., and Sernka, K.J. 2004. Avian monitoring and risk assessment at the Tehachapi Pass Wind Resource Area. Period of Performance: October 2, 1996 - May 27, 1998. Report for the National Renewable Energy Laboratory. 102 pp.

Arnett, E.B., Erickson, W.P., Kerns, J., and Horn, J. 2005. Relationship between bats and wind turbines in Pennsylvania and West Virginia: An assessment of fatality search protocols, pattern of fatality, and behavioral interactions with wind turbines. A Final Report for the Bats and Wind Energy Cooperative. 187 pp.

Arnett, E.B. 2006. A preliminary evaluation on the use of dogs to recover bat fatalities at wind energy facilities. Wildlife Society Bulletin 34: 1440-1445.

Arnett, E.B., Brown, W.K., Erickson, W.P, Fiedler, J.K, Hamilton, B.L, Henry, T.H., Jain, A., Johnson, G.D., Kerns, J., Koford, R.R., Nicholson, C.P., O'Connell, T.J., Piorkowski, M.D., Tankersley, R.D. 2008a. Patterns of bat fatalities at wind energy facilities in North America. Journal of Wildlife Management, 72: 61-78. Doi:10.2193/2007-221.

Arnett, E.B., Schirmacher, M., Huso, M.M.P. and Hayes, J.P. 2008b. Effectiveness of changing wind turbine cut-in speed to reduce bat fatalities at wind facilities. Annual Report for the Bats and Wind Energy Cooperative and the Pennsylvania Game Commission. 45 pp.

Arnett, E.B., Huso, M.P., Schirmacher, M.R., and Hayes, J.P. 2011. Altering turbine speed reduces bat mortality at wind-energy facilities. Frontiers in Ecology and the Environment 9: 209-214.

Arnett, E.B., Huso, M.P., D. S. Reynolds, and S. Schirmacher. 2007. Patterns of pre-construction bat activity at a proposed wind facility in northwestern Massachusetts. 2006 Annual Report submitted Bat and Wind Energy Cooperative. Bat Conservation International, Austin, Texas.

Askins, R. A., Lynch, J.F., and Greenberg, R.. 1990. Population declines in migratory birds in eastern North America. Current Ornithology 7:1-57.

August, P. V., R. W. Enser, and L.L. Gould. 2001. Vertebrates of Rhode Island, Volume 2 of the biota of Rhode Island. Rhode Island Natural History Survey, Kingston, RI.

Baerwald, E.F. and Barclay, R.M.R. 2009. Geographic variation in activity and fatality of migratory bats at wind energy facilities. Journal of Mammology 90: 1341-1349.

Baerwald, E.F., D'Amours, G.H., Klug, B.J. and Barclay, R.M.R. 2008. Barotrauma is a significant cause of bat fatalities at wind turbines. Current Biology 18: 695-696.

Bansal, R.C., Bhatti, T.S., and Kothari, D.P. 2002. On some of the design aspects of wind energy conversion systems. Energy Conversion and Management. 43: 2175 - 2187.

Barclay, R.M.R., Baerwald, E.F. and Gruver, J.C. 2007. Variation in bat and bird fatalities at wind energy facilities: assessing the effects of rotor size and tower height. Canadian Journal of Zoology 85: 381-387.

Barrios, L. and Rodriguez, A. 2004. Behavioral and environmental correlated of soaring-bird mortality at on-shore wind turbines. Journal of Applies Ecology 41: 72-81.

Brawn, J.D., Robinson, S.K., and Thompson, F.R. III. 2001. The role of disturbance in the ecology and conservation of birds. Annual Review of Ecology and Systematics 32: 251 – 276.

Brinkmann, R., Schauer-Weisshahn, H. and Bontadina, F. 2006. Survey of possible operational impacts on bats by wind facilities in Southern Germany. Report ordered by the Administrative District of Freiburg - Department 56 Conservation and Landscape Management. 63 pp.

Brown, K. and Hamilton, B.L. 2002. Bird and bat interactions with wind turbines: Castle river wind farm, Alberta. Report for Vision Quest Windelectric, Inc. Calgary, AB 42 pp.

Buffum, B. 2012. A new tool for mapping forest habitats in Rhode Island. Kingston, Rhode Island: Department of Natural Resources Science, University of Rhode Island. Available at: http://nrs.uri.eud/ce/Reports.html.

Buresch, K. 1999. Seasonal pattern of abundance and habitat use by bats on Martha's Vineyard, Massachusetts. M.S. Thesis, University of New Hampshire, Durham, New Hampshire. 69pp.

Carrete, M., b Sanchez-Zapata, J.A., Benitez, J.R., Lobon, M., Donazar, J.A. 2009. Large scale risk-assessment of wind-farms on population viability of a globally endangered long-lived raptor. Biological Conservation doi: 10.1016/j.biocon.2009.07.027.

Cathrine, C. and Spray, S. 2009. Bats and onshore wind farms: site-by-site assessment and post-construction monitoring protocols. In Practice 4 pp.

Cook, J., McCarthy, A., Holloway, S., Oliver, G. 2008. Survey guidance for assessing bat activity at proposed on-shore wind farms. In Practice 4 pp.

Crawford, R.L. and Engstrom, R.T. 2001. Characteristics of avian mortality at a north Florida television tower: A 29-year study. Journal of Field Ornithology 72: 380 - 388.

Cryan, P.M. 2008. Mating behavior as a possible cause of bat fatalities at wind turbines. Journal of Wildlife Management 3: 845-849.

Cryan, P.M. 2011. Wind turbines as landscape impediments to the migratory connectivity of bats. Environmental Law 41:355-370.

Cryan, P.M. and Brown, A.C. 2007. Migration of bats past a remote island offers clues toward the problem of bat fatalities at wind turbines. Biological Conservation doi: 10.1016/j.biocon.2007.05.019.

Davis, W. H. and Hitchcock, H. B. 1965. Biology and migration of the bat, *Myotis lucifugus*, in New England. Journal of Mammology 46:296-313.

Degraaf, R.M. and Yamasaki, M. 2001. New England Wildlife: Habitat, Natural History, and Distribution. University Press of New England, Hanover, NH. 482 pp.

de Lucus, M., Janss, G.F.E., Whitfield, D.P. and Ferre, M. 2008. Collision fatality of raptors in wind farms does not depend on raptor abundance. Journal of Applied Ecology 45: 1695-1703.

DeSante, D. and P. Pyle. 1986. Distributional checklist of North American birds. Volume 1: United States and Canada. Artemesia Press, Lee Vining, CA. 442 pp.

Desholm, M. 2006. Wind farm related mortality among avian migrants - a remote sensing study and model analysis. PhD thesis National Environmental Research Institute Ministry of the Environment, Denmark. 132 pp.

Devereux, C.L., Denny, M.J.H. and Whittingham, M.J. 2008. Minimal effects of wind turbines on the distribution of wintering farmland birds. Journal of Applied Ecology 45: 1689-1694.

Drewitt, A.L. and Langston R.H.W. 2006. Assessing the impacts of wind farms on birds. Ibis 148: 29-42.

Enk, T., Bay, K., Sonnenberg, M., Flaig, J., Boehrs, J.R., and Palochak, A. 2011. Year 1 post-construction avian and bat monitoring report. Biglow Canyon wind farm phase II Sherman County, Oregon September 10, 2009 - September 12, 2010. Report for Portland General Electric Company. 75 pp.

Enser, R.W. 1992. The atlas of breeding birds in Rhode Island. Rhode Island Department of Environmental Management. 206 pp.

Environment Canada 2006. Wind turbines and birds. A guidance document for environmental assessment. Report by Environmental Canada, Canadian Wildlife Service 50 pp.

Erickson, W.P., Johnson, G.D., Strickland, M.D., and Kronner, K. 2000. Avian and bat mortality associated with the Vansycle Wind Project, Umatilla County, Oregon, 1999 study year. Final report for the Umatilla County. 26 pp.

Erickson, W.P., Johnson, G.D., Strickland, M.D., Young, D.P. Jr., Sernke, K.J. and Good R.E. 2001. Avian collisions with wind turbines: a summary of existing studies and comparison to other sources of avian collision mortality in the United States. A report for the National Wind Coordinating Committee 67 pp.

Erickson, W., Johnson, G., Young, D., Strickland, D., Good, R., Michelle, B., Bay, K. and Sernka, K. 2002. Synthesis and comparison of baseline avian and bat use, raptor nesting and mortality information from proposed and existing wind developments. Report for Bonneville Power Administration 129 pp.

Erickson, W., Kronner, K., and Gritski, B. 2003. Nine Canyon Wind Power Project. Avian and bat monitoring report. September 2002 – August 2003. Final report for the Nine Canyon Technical Advisory Committee and Energy Northwest. 37 pp.

Erickson, W.P., Johnson, G.D. and Young, D.P. Jr. 2005. A summary and comparison of bird mortality from anthropogenic causes with an emphasis collisions. USDA Forest Service general technical report PSW-GTR-191. 14 pp.

Erickson, W.P., Jeffrey, J.D., and Poulton V.K. 2008. Puget sound energy wild horse wind facility post-construction avian and bat monitoring first annual report January - December 2007 Report for Puget Sound Energy and the Wild Horse Wind Facility Technical Advisory Committee. 54 pp.

Everaert, J. and Stienen, E.W.M. 2002. Wind turbines and birds in Flanders: preliminary study results and recommendations. Natuur.Oriolus 69: 145-155.

Everaert, J. and Stienen, E.W.M. 2007. Impact of wind turbines on birds in Zeebrugge (Belgium). Significant effect on breeding tern colony due to collisions. Biodiversity Conservation 16: 3345-3359.

Ferren, R. L. and J. E. Myers. 1998. Rhode Island’s maritime nesting birds. Federal Aid to Wildlife Restoration, West Kingston, RI, USA. W23R Rhode Island.

Fiedler, J.K. 2004. Assessment of bat mortality and activity at Buffalow Mountain Windfarm, eastern Tennessee. Master’s thesis, The University of Tennessee, Knoxville. 180 pp..

Fiedler, J.K., Henry, T.H., Tankersley, R.D., and Nicholson, C.P. 2007. Results of bat and bird mortality monitoring at the expanded buffalo mountain windfarm, 2005. Report for the Tennessee Valley Authority. 42 pp.

Foster, D. R. 1992. Land-use history (1730-1990) and vegetation dynamics in central New England, USA. Journal of Ecology 80:753-772.

Gehring, J., Kerlinger, P. and Manville, A.M. III. 2009. Communication towers, lights, and birds: successful methods of reducing the frequency of avian collisions. Ecological Applications 19: 505-514.

Gritski, B., Downes, S., and Kronner K. 2010. Klondike III (Phase 1) wind power project wildlife monitoring study October 2007 - October 2009. Report for Iberdrola renewables Klondike wind power III LLC. 64 pp.

Hoover, S.L. and Morrison, M.L. 2005. Behavior of red-tailed hawks in a wind turbine development. Journal of Wildlife Management 69: 150-159.

Horn, J.W., Arnett, E.B. and Kunz, T.H. 2008. Behavioral responses of bats to operating wind turbines. Journal of Wildlife Management 72: 123-132.

Howe, R.W., Evans W. and Wolf A.T. 2002. Effects of wind turbines on birds and bats in Northeastern Wisconsin. Report for Wisconsin Public Service Corporation and Madison Gas and Electric Company 112 pp.

Howell, J.A. 1997. Bird mortality at rotor swept area equivalents, Altamont Pass and Montezuma Hills, California Transactions of the Western Section of the Wildlife Society 33: 24-29.

Howell, J.A. and DiDonato, J.E. 1991. Assessment of avian use and mortality related to wind turbine operations. Altamont Pass, Alameda and Contra Costa Counties, California. Spetember 1988 through August 1989. Report prepared for U.S. Windpower, Inc. 78 pp.

Hunter, W.C., Buehler, D.A., Canterbury, R.A., Confer, J.L., Hamel, P.B. 2001. Conservation of disturbance dependent birds in eastern North America. Wildlife Society Bulletin 29: 440-455.

Insignia Environmental. 2009. 2008/2009 Annual report for the Buena Vista avian and bat monitoring project. Report prepared for the Contra Costa County California. 95 pp..

Jain, A.A. 2005. Bird and bat behavior and mortality at a northern Iowa windfarm. M.S. thesis Iowa State University 112 pp.

Jain, A., Kerlinger, P., Curry, R., Slobodnik, L., Quant, J., and Pursell, D. 2009. Annual report for the Noble Bliss Windpark, LLC Post construction bird and bat fatality study -2008. Report for Noble Environmental Power, LLC. 68 pp.

Jain, A., kerlinger, P., Curry, R., and Slobodnik, L. 2009b. Annual report for the Maple Ridge Wind power project postconstruction bird and bat fatality study - 2007. Report for PPM Energy and Horizon Energy and Technical Advisory Committee (TAC) for the Maple Ridge Project Study. 70 pp.

James, R.D. 2002. Pickering wind turbine bird monitoring program in 2002 Report to Ontario Power Generation. 16 pp.

James, R.D. and Coady, G. 2003. Exhibition Place wind turbine bird monitoring program in 2003. Report to Toronto Hydro Energy Services, Inc and WindShare. 12 pp.

Johnson, G.D., Erickson, W.P., Strickland, M.D., Shepherd, M.F. and Shepherd, D.A. 2000. Avian monitoring studies at the Buffalo Ridge, Minnesota Wind Resource Area: results of a 4-year study. Report for Northern States Power Company. 273 pp..

Johnson, G.D., Erickson, W.P., Strickland, M.D. and Shepherd, M.F. 2002. Collision mortality of local and migrant birds at a large-scale wind-power development on Buffalo Ridge, Minnesota. Wildlife Society Bulletin 30: 879-887.

Johnson, G., Erickson, W., White, J., and McKinney, R. 2003. Avian and bat mortality during the first year of operation at the Klondike Phase I Wind Project, Sherman County, Oregon. Report for Northwestern Wind Power. 17 pp..

Johnson, G.D., Perlik, M.K., Erickson, W.P., and Strickland, M.D. 2004. Bat activity, composition, and collision mortality at a large wind plant in Minnesota. Wildlife Society Bulletin 32: 1278-1288.

Jones, A. and P. Vickery. 1997. Conserving grassland birds. Massachusetts Audubon Society, 208 So. Great Rd., Lincoln, MA 01773 available at http://www.massaudubon.org/Birds_and_Birding/grassland/. Accessed 19 Jan 2012.

Kerlinger, P., Curry, R., Culp, L., Jain, A., Wilkerson, C., Fischer, B., and Hasch, A. 2006. Post-construction avian and bat fatality monitoring study for the high winds wind power project Solano County, California: Two year report. Report for High Winds, LLC FPL energy. 136 pp.

Kerlinger, P., Gerhrig, J.L., Erickson, W.P., Curry, R., Jain, A., and Guarnaccia, J. 2010. Night migrant fatalities and obstruction lighting at wind turbines in North America. The Wilson Journal of Ornithology 122: 744 – 754.

Kerns, J. and Kerlinger, P. 2004. A study of bird and bat collision fatalities at the Mountaineer Wind Energy Center, Tucker County, West Virginia: Annual Report for 2003 Report for FPL Energy and Mountaineer Wind Energy Center Technical Review Committee. 39 pp.

Kingsley, A. and Whittam, B. 2005. Wind turbines and birds. A background review for environmental assessment. Report for Environment Canada 81 pp.

Knopf, F.L. 1999. Use of cultivated fields by breeding Mountain Plovers in Colorado. Studies in avian biology 19: 81.

Kunz, T.H., Arnett, E.B., Cooper, B.M., Erickson, W.P., Larkin, R.P., Mabee, T., Morrison, M.L., Strickland, M.D. and Szewczak, J.M. 2007. Assessing impacts of wind-energy development on nocturnally active birds and bats: a guidance document. Journal of Wildlife Management 71: 2449-2486.

Kuvlesky, W.P., Leonard, A.B., Morrison, M.L., Boydston, K.K., Ballard, B.M. and Bryant, F.C. 2007. Wind energy development and wildlife conservation: challenges and opportunities. Journal of Wildlife Management 71: 2487-2498.

Langston, R.H.W. and Pullan, J.D. 2003. Windfarms and birds: an analysis of the effects of windfarms on birds, and guidance on environmental assessment criteria and site selection issues. Report written on behalf of the Bern Convention by Birdlife International 58 pp.

Leddy, K.L., Higgins, K.F. and Naugle, D.E. 1999. Effects of wind turbines on upland nesting birds in conservation reserve program grasslands. Wilson Bulletin 111: 100-104.

Mabee, T.J., Plissner, J.H., Cooper, B.A. 2005. A radar and visual study of nocturnal bird and bat migration at the proposed Flat Rock Wind Power Project, New York, Fall 2004 Report to the Atlantic Renewable Energy Corporation 38 pp.

Madsen, J. and Boertmann, D. 2008. Animal behavioral adaptation to changing landscapes: spring-staging geese habituate to wind farms. Landscape Ecology 23: 1007-1011.

Mendelsohn, D., Crowley, D., Gifford, J., Loria, D. and Gross, R. 2009. Wind power feasibility study town of Jamestown, RI. Report prepared for the Jamestown Wind Committee, Jamestown, RI 145 pp.

Mizrahi, D. R. Fogg, T. Magarian, V. Elia, P. Hodgetts, and D. LaPuma. 2010. Radar monitoring of bird and bat movement patterns on Block Island and its coastal waters. Technical report, RI Ocean SAMP, prepared by New Jersey Audubon Society, Cape May, NJ.

National Research Council 2007. Environmental Impacts of Wind-Energy Projects The National Academies Press, Washington, D.C., USA. 278 pp.

Newton, I. 1998. Population limitation in birds. Academic Press, San Diego, California.

Nicholls, B. and Racey, P.A. 2007. Bats avoid radar installations: Could electromagnetic fields deter bats from colliding with wind turbines? PLoS ONE 2: e297. doi:10.1371/journal.pone.0000297.

Nicholson, C.P., Tankersley, R.D., Fiedler, J.K., and Nicholas, N.S. 2005. Assessment and prediction of bird and bat mortality at wind energy facilities in the southeastern United States. Final Report for the Tennessee Valley Authority. 65 pp.

Orloff, S.G. and Flannery, A. 1992. Wind turbine effects on avian activity, habitat use, and mortality in Altamont Pass and Solano County Wind Resource Areas 1989 - 1991. Report to the California Energy Commission. 199 pp.

Osborn, R.G., Dieter, C.D., Higgins, K.F. and Usgaard, R.E. 1998. Bird flight characteristics near wind turbines in Minnesota. American Midland Naturalist 139: 29-38.

Osborn, R.G., Higgins, K.F., Usgaard, R.E., Dieter, C.D. and Neiger, R.D. 2000. Bird mortality associated with wind turbines at the Buffalo Ridge Wind Resource Area, Minnesota. American Midland Naturalist 143: 41-52.

Paton, P., K. Winiarski, C. Trocki, and S. McWilliams. 2010. Spatial distribution, abundance, and flight ecology of birds in nearshore and offshore waters of Rhode Island. Interim Technical Report, Rhode Island Ocean Special Area Management Plan, Kingston, RI. available at http://seagrant.gso.uri.edu/oceansamp/pdf/appendix/11a-PatonAvianRept.pdf.

Pearce-Higgings, J.W., Stephen, L., Langston, R.H.W., Bainbridge, I.P. and Bullamn R. 2009. The distribution of breeding birds around upland wind farms. Journal of Applied Ecology 46: 1323-1331.

Peterjohn, B.G.,Sauer, J.R., and Robbins, C.S. 1995. Population trends from the North American Breeding Bird Survey. Pp. 3-39 in T.E. Martin & D.M. Finch, Eds., Ecology and Management of Neotropical Migratory Birds. Oxford University Press, New York.

Pierson, E. D. 1998. Movements and behavior In Bat Biology and Conservation (T. Kunz and P. A. Racey, eds). Smithsonian Institution Press, Washington, DC.

Piorkowski, M.D. 2006. Breeding bird habitat use and turbine collisions of birds and bats located at a wind farm in Oklahoma mixed-grass prairie. Master's of Science Thesis, Oklahoma State University 112 pp.

Piorkowski, M.D. and O'Connell T.J. 2010. Spatial pattern of summer bat mortality from collisions with wind turbines in mixed-grass prairie. American Midland Naturalist 164: 260-269.

Raithel, C. 2008. Patterns and timing of bird migration as it related to the placement of wind turbines. Report for the RI DEM Division of Fish and Wildlife. 16 pp.

Reynolds, D.S. 2006. Monitoring the potential impact of a wind development site on bats in the Northeast. Journal of Wildlife Management 70: 1219-1227.

Rhode Island Natural Heritage Program. 2006. Rare native animals of Rhode Island. Rhode Island Department of Environmental Management, Providence , Rhode Island. http://www.rinhs.org/wp-content/uploads/ri_rare_animals_2006.pdf.

Rich, T.D., Beardmore, C.J., Berlanga, H., Blancher, P.J., Bradstreet, M.S.W, Butcher, G.S., Demarest, D.W., Dunn, E.H., Hunter, W.C., Inigo-Elias, E.E., Kennedy, J.A., Martell, A.M., Panjabi, A.O., Pashley, D.N., Rosenberg, K.V., Rustay, C.M., Wendt, J.S., Will, T.C. 2004. Partners in Flight North American landbird conservation plan. Cornell Lab of Ornithology. Ithaca, NY. 84 pp.

Rodrigues, L., Back, L., Dubourg-Savage, M.-J., Goodwin, J., and Harbusch, C. 2008. Guidelines for consideration of bats in wind farm projects. EUROBATS Publication Series No. 3 (English version). UNEP/EUROBATS Secretariat, Bonn, Germany. 27 pp.

Rothbart, P., and S. Capel. 2006. Maintaining and restoring grasslands. In Managing grasslands, shrublands, and young forests for wildlife: a guide for the Northeast. J. D. Oehler, D. R. Covell, S. Capel, and B. Long (eds.). Northeast Upland Habitat Technical Committee, Mass. Div. of Fisheries and Wildlife. http://www.dem.ri.gov/programs/bnatres/fishwild/grasspdf/4.pdf; accessed 19 Jan 2012.

Saidur, R., Rahim, N.A., Islam, M.R. and Solangi, K.H. 2011. Environmental inpact of wind energy. Renewable and sustainable energy reviews 15: 2423-2430.

Schlossberg, S. and D. I. King. 2007. Ecology and management of scrub-shrub birds in New England: a comprehensive review. USDA Natural Resources Conservation Service, Amherst, MA. Accessed at ftp://ftp-fc.sc.egov.usda.gov/NHQ/nri/ceap/schlossbergkingreport.pdf.

Schmidt, E., Piaggio, A.J., Bock, C.E. and Armstrong, D.M. 2003. National wind technology center site environmental assessment: bird and bat use and fatalities - final report. National Renewable Energy Laboratory subcontractor report. 29 pp.

Scottish Natural Heritage. 2005. Methods to assess the impacts of proposed onshore wind farms on bird communities. S.N.H., Edinburgh. www.snh.org.uk/pdfs/strategy/renewable/bird_survey.pdf.

Sibley, D. A. 2003. The Sibley field guide to birds of eastern North America. A. Knopf Press, New York.

Sillett, T. S. and R. T. Holmes. 2002. Variation in survivorship of a migratory songbird throughout its annual cycle. Journal of Animal Ecology 71:296-308.

Smallwood, K.S. 2007. Estimating wind turbine-caused bird mortality. Journal of Wildlife Management 71: 2781-2791.

Smallwood, K.S. and Karas, B. 2009. Avian and bat fatality rates at old-generation and repowered wind turbines in California. Journal of Wildlife Management 73: 1062-1071.

Smallwood, K.S. and Thelander, C.G. 2005. Bird mortality at the Altamont Pass Wind Resource Area March 1998-September 2001. Report for the National Renewable Energy Laboratory. 411 pp.

Smallwood, K.S. and Thelander, C. 2008. Bird mortality in the Altamont Pass Wind Resource Area, California. Journal of Wildlife Management 72: 215-223.

Smith, S.B., K.H. McPherson, J. Backer, B.J. Pierce, D. Podlesak, S.R. McWilliams. 2007. Fruit quality and consumption by songbirds during autumn migration. Wilson Journal of Ornithology 119:419-428.

Smith, S. B. and S. R. McWilliams. 2011. Recommended plantings for migratory songbird habitat management. Kingston, Rhode Island: Department of Natural Resources Science, University of Rhode Island. 2 p.

Smith, A.D. and S. R. McWilliams. 2011. Acoustic monitoring of migrating bats on Rhode Island National Wildlife Refuges. Interim Report. Dept. of Natural Resources Science, Univ. of Rhode Island, Kingston RI.02881.

Smith, A.D. and S. R. McWilliams. 2012. Acoustic monitoring of migrating bats on Rhode Island National Wildlife Refuges. Final Report. Dept. of Natural Resources Science, Univ. of Rhode Island, Kingston RI.02881.

Sovacool, B.K. 2009. Contextualizing avian mortality: A preliminary appraisal of bird and bat fatalities from wind, fossil-fuel and nuclear. Energy Policy 37: 2241-2248.

Stantec Consulting, formerly Woodlot Alternatives, Inc. 2008. 2007 Spring, summer, and fall post-construction bird and bat mortality study at the Mars Hill Wind Warm, Maine. Report for the UPC Wind Management, LLC. 51 pp.

Strickland, D., Arnett, E., Erickson, W., Johnson D., Johnson, G., Morrison, M., Shaffer, J., and Warren-Hicks, W. 2011. Comprehensive guide to studying wind energy/wildlife interactions. Report prepared for the National Wind Coordinating Collaborative. 289 pp.

Thelander, C.G., Smallwood, K.S. and Rugge, L. 2003. Bird risk behaviors and fatalities at the Altamont Pass Wind Resource Area. National Renewable Energy Laboratory subcontractor report. 92 pp.

Thompson, F. R. III. 2005. Landscape level effects on forest bird populations in eastern broadleaf forests: principles of conservation. USDA Forest Service General Technical Report PSW-GTR-191.

US Fish and Wildlife Service (USFWS). 2003. Interim guidelines to avoid and minimize wildlife impacts from wind turbines. USFWS Report. 55 pp.

US Fish and Wildlife Service. 2012. U.S. Fish and Wildlife Service Land-Based Wind Energy Guidelines. USFWS Report. 71 pp.

US Fish and Wildlife Service (USFWS). 2012. List of threatened and endangered species. http://www.fws.gov/endangered/species/.

Vickery, P. D. and P. W. Dunwiddie. 1997. Grasslands in eastern North America: ecology and conservation of native and agricultural landscapes. Massachusetts Audubon Society, Lincoln, MA.

Vickery, P.D., M. L Hunter, Jr., and S. M. Melvin. 1997. Effects of habitat area on the distribution of grassland birds in Maine. Pages 137-152 in Vickery, P. D. and P. W. Dunwiddie. 1997. Grasslands in eastern North America: ecology and conservation of native and agricultural landscapes. Massachusetts Audubon Society, Lincoln, MA.

Western Ecosystems Technology, Inc. 2006. Diablo winds wildlife monitoring progress report. 31 pp.

Western Ecosystems Technology, Inc. and Northwest Wildlife Consultants, Inc. 2004. Stateline wind project wildlife monitoring final report. Report for FPL Energy Stateline Technical Advisory Committee Oregon Department of Energy 105 pp.

Young, D.P., Erickson, W.P., Strickland, M.D., Good, R.E. and Sernka, K.J. 2003. Comparison of avian responses to UV-light-reflective paint on wind turbines. National Renewable Energy Laboratory subcontractor report. 67 pp. Young, D.P., Jeffrey, J.D., Erickson W.P., Bay, K.J., Poulton, V.K., Kronner, K., Gritski, B., and Baker, J. 2006. Eurus Combine Hills Turbine Ranch Phase 1 post construction wildlife monitoring first annual report February 2004 - February 2005 Report for the Eurus Energy America Corporation and Combine Hills Technical Advisory Committee. 49 pp.

Young, D.P., Erickson, W.P., Jeffrey, J.D., and Poulton, V.K. 2007. Puget Sound Energy Hopkins Ridge Wind Project Phase 1 post-construction avian and bat monitoring first annual report. January – December 2006. Report for Puget Sound Energy and the Hopkins Ridge Wind Project Technical Advisory Committee. 32 pp.

APPENDIX 1. LITERATURE REVIEW TABLES

Table A1. 1 Total number of fatalities by bird species in the 34 studies across the United States, 26 studies across the United States excluding California, and 6 studies in the Eastern United States.

Species	U.S. (N=34)	U.S. excluding CA (N=26)	Eastern U.S. (N=6)
Red-tailed Hawk	278	23	8
Horned Lark	244	208	0
Rock Dove	159	11	1
American Kestrel	142	22	0
Western Meadowlark	112	21	0
Bird Unidentified	105	59	37
Passerine Unidentified	91	29	7
Dark-eyed Junco	80	78	0
European Starling	78	35	8
Burrowing Owl	64	0	0
Golden-crowned Kinglet	54	54	13
Ring-necked Pheasant	50	48	0
Barn Owl	44	0	0
Golden Eagle	39	1	0
Mallard	37	8	2
Great Horned Owl	32	2	0
Red-winged Blackbird	25	3	0
Red-eyed Vireo	24	24	23
Common Raven	23	0	0
Yellow-rumped Warbler	23	20	3
Mourning Dove	22	9	0
Hawk (buteo)	19	0	0
White-crowned Sparrow	18	16	0
Partridge	17	15	0
House Finch	17	2	0
Ruby-crowned Kinglet	17	15	2
Townsend's Warbler	16	13	0
Northern Flicker	12	8	0
Turkey Vulture	12	2	0
Raptor Unidentified	12	0	0
Brewer's Blackbird	11	1	0
Warbler Unidentified	11	8	6
American Robin	10	10	2
Northern Bobwhite	10	10	0
Savanna Sparrow	10	10	2

Species	U.S. (N=34)	U.S. excluding CA (N=26)	Eastern U.S. (N=6)
Common Yellowthroat	9	8	0
Grey Partridge	9	9	0
Hungarian Partridge	9	9	0
Brewer's Sparrow	8	8	0
Cedar Waxwing	8	8	7
Magnolia Warbler	8	8	5
Rock Wren	8	7	0
Buteo Unidentified	8	1	0
Owl Unidentified	8	0	0
Vesper Sparrow	8	8	0
Winter Wren	8	8	1
American Coot	7	5	0
Black-and-white Warbler	7	7	4
House Wren	7	7	0
Loggerhead Shrike	7	1	0
Tree Swallow	7	6	2
Bay-breasted Warbler	6	6	6
Mountain Bluebird	6	2	0
Prairie Falcon	6	2	0
Gull Unidentified	6	0	0
Virginia Rail	6	3	1
Barn Swallow	5	5	0
Black-billed Magpie	5	5	0
California Gull	5	0	0
Canada Goose	5	5	1
Chipping Sparrow	5	4	0
Ferruginous Hawk	5	1	0
Grasshopper Sparrow	5	5	0
Orange-crowned Warbler	5	4	0
Ring-billed Gull	5	0	0
Swainson's Hawk	5	4	0
Wilson's Warbler	5	4	0
Wood Thrush	5	5	4
American Goldfinch	4	4	1
Blackburnian Warbler	4	4	4
Black-crowned Night Heron	4	1	0
Brown Creeper	4	4	2
Cliff Swallow	4	1	1
Golden-crowned Sparrow	4	4	0

Species	U.S. (N=34)	U.S. excluding CA (N=26)	Eastern U.S. (N=6)
Hermit Thrush	4	3	2
Lincoln's Sparrow	4	3	1
MacGillivray's Warbler	4	4	0
Northern Harrier	4	2	0
Tennessee Warbler	4	4	4
Unidenitfied Sparrow	4	3	0
Warbling Vireo	4	2	0
White-tailed Kite	4	0	0
White-throated Swift	4	2	0
Yellow-billed Cuckoo	4	4	4
American Pipit	3	1	0
Blackpoll Warbler	3	3	2
Chestnut-sided Warbler	3	3	3
Common Nighthawk	3	3	0
Eastern Kingbird	3	3	2
Empidonax Flycatcher	3	2	0
Great Blue Heron	3	3	0
Green-tailed Towhee	3	3	0
Hooded Warbler	3	3	3
Ovenbird	3	3	2
Red-breasted Nuthatch	3	3	0
Red-shafted Flicker	3	0	0
Sedge Wren	3	3	0
Short-eared Owl	3	3	0
Sora	3	0	0
Western Tanager	3	3	0
Yellow Warbler	3	3	1
Yellow-bellied Sapsucker	3	3	1
Black-throated Green Warbler	2	2	2
Blue-headed Vireo	2	2	2
Blue-winged Teal	2	2	0
Bobolink	2	2	2
Brown-headed Cowbird	2	1	0
California Quail	2	0	0
Chestnut-collared Longspur	2	2	0
Eastern Meadowlark	2	2	0
Eastern Towhee	2	2	2
Greater Roadrunner	2	0	0

Species	U.S. (N=34)	U.S. excluding CA (N=26)	Eastern U.S. (N=6)
Grey Catbird	2	2	0
Hairy Woodpecker	2	2	1
Herring Gull	2	2	0
Lark Sparrow	2	2	0
Pied-billed Grebe	2	2	0
Purple Finch	2	2	1
Rose-breasted Grossbeak	2	2	2
Ruffed Grouse	2	2	2
Scrub Jay	2	0	0
Sharp-shinned Hawk	2	2	2
Veery	2	2	2
Western Grebe	2	2	0
White-throated Sparrow	2	2	2
Wild Turkey	2	1	1
Acadian Flycatcher	1	1	1
Alder Flycatcher	1	1	1
American Crow	1	1	1
American Redstart	1	1	1
American Woodcock	1	1	1
Black-billed Cuckoo	1	1	1
Unidentified Blackbird	1	0	0
Black-throated Grey Warbler	1	1	0
Brown Pelican	1	0	0
Cerulean Warbler	1	1	1
Chimney Swift	1	1	0
Common Grackle	1	1	0
Common Moorhen	1	0	0
Common Poorwill	1	1	0
Common Redpoll	1	1	0
Cooper's Hawk	1	1	0
Dickcissel	1	1	0
Double-crested Cormorant	1	0	0
Field Sparrow	1	1	1
Flammulated Owl	1	0	0
Franklin's Gull	1	1	0
House Sparrow	1	1	0
Indigo Bunting	1	1	1
Kentucky Warbler	1	1	1
Killdeer	1	1	0

Species	**U.S.** **(N=34)**	**U.S. excluding CA** **(N=26)**	**Eastern U.S.** **(N=6)**
Least Flycatcher	1	1	0
Lewis' Woodpecker	1	1	0
Long-eared Owl	1	0	0
Pacific-slope Flycatcher	1	0	0
Palm Warbler	1	1	1
Philadelphia Vireo	1	1	0
Prairie Warbler	1	1	1
Purple Martin	1	1	0
Red Crossbill	1	1	1
Rough-legged Hawk	1	0	0
Ruby-throated Hummingbird	1	1	1
Ruddy Duck	1	1	0
Sage Grouse	1	1	0
Sage Sparrow	1	1	0
Scarlet Tanager	1	1	1
Snow Bunting	1	1	0
Song Sparrow	1	1	1
Spotted Towhee	1	1	0
Swainson's Thrush	1	1	0
Swamp Sparrow	1	1	0
Tri-coloroed Blackbird	1	0	0
Tufted Titmouse	1	1	1
Blackbird Unidentified	1	0	0
Chickadee Unidentified	1	1	0
Flycatcher Unidentified	1	1	0
Partridge Unidentified	1	1	0
Shorebird Unidentified	1	1	0
Swallow Unidentified	1	1	0
Vaux's Swift	1	1	0
Violet-green Swallow	1	0	0
Western Bluebird	1	0	0
Western Wood Pewee	1	0	0
White-eyed Vireo	1	1	1
Williamson's Sapsucker	1	1	0
Yellow-throated Vireo	1	1	0
Total bird fatalities	**2361**	**1098**	**217**

Table A1. 2 Fatalities to bat species in the 34 studies across the United States, 26 studies across the United States excluding California, and 6 studies in the Eastern United States.

Species	U.S. (N=34)	U.S. excluding CA (N=26)	Eastern U.S. (N=6)
Hoary	712	643	230
Eastern Red	432	431	336
Silver-haired	278	276	92
Brazilian free-tailed	189	189	0
Little Brown	112	112	79
Tri-colored	109	109	100
Mexican Free-tailed	50	0	0
Big Brown	42	42	24
Bat Unidentified	40	40	8
Little Brown	12	12	0
Myotis Spp.	12	12	1
Western Red	7	3	0
Seminole	4	4	4
Cave Myotis	1	1	0
Long-eared	1	0	0
Total bat fatalities	**2001**	**1874**	**874**

Table A1. 3 State-based siting guidelines related to potential bird/bat impacts for wind facilities in the United States (as of December 2010).

State	Guidelines established	Installed capacity (MW)	Voluntary	Pre-Construction guidelines	Operation/Construction phase	Post-construction guidelines	Mitigation
Alabama	no	0	NA	NA	NA	NA	NA
Alaska	yes	9	yes	Initial site screening, bird surveys to determine bird use and flight patterns following USFWS protocols and guidelines.	Follow USFWS guidelines.	Potentially monitor for mortality, depending on the project size. Follow USFWS guidelines and protocols.	Minimize or mitigate if problems arise following USFWS guidelines and protocols.
Arizona	yes	128	yes	preliminary site screening, nocturnal bat surveys, acoustic detection for bats, mist-netting for bats, roost surveys for bats, visual monitoring for bats, diurnal bird surveys, large bird use surveys, raptor nest searches, bird migration counts, small bird counts, winter bird counts, nocturnal migrating bird counts	Minimize habitat fragmentation, establish buffer zones, avoid lighting that attracts birds and bats, reduce impacts with appropriate turbine layout, minimize ground disturbance near turbines, avoid lighting that attracts birds and bats, minimize power line impacts, avoid guy wires.	Estimate presence and activity of birds and bats, carcass searches, acoustic detection, mist-netting, roost surveys, visual monitoring, bird use counts, raptor nest searches.	Compensate for lost habitat.
Arkansas	no	0	NA	NA	NA	NA	NA
California	yes	3253	yes	Site screening, bird use counts, raptor nest searches, bat monitoring	Minimize habitat fragmentation, establish buffer zones, avoid lighting that attracts birds and bats, minimize power line impacts, avoid guy wires, decommission non-operational turbines.	Carcass searches, searcher efficiency trials, carcass removal trials, bird use counts, bat acoustic monitoring.	Compensate for lost habitat.
Colorado	no	1299	NA	NA	NA	NA	NA
Connecticut	no	0	NA	NA	NA	NA	NA
Delaware	no	2	NA	NA	NA	NA	NA
Florida	no	0	NA	NA	NA	NA	NA
Georgia	no	0	NA	NA	NA	NA	NA
Hawaii	no	63	NA	NA	NA	NA	NA
Idaho	no	353	NA	NA	NA	NA	NA

State	Guidelines established	Installed capacity (MW)	Voluntary	Pre-Construction guidelines	Operation/Construction phase	Post-construction guidelines	Mitigation
Illinois	no	2045	NA	NA	NA	NA	NA
Indiana	no	1339	NA	NA	NA	NA	NA
Iowa	no	3675	NA	NA	NA	NA	NA
Kansas	yes	1074	yes	Preliminary site screening	Bury power lines, avoid lattice-type towers, minimize lighting, avoid placing turbines along wildlife corridors	NA	When avoiding ecological impact is impossible, mitigate.
Kentucky	no	0	NA	NA	NA	NA	NA
Louisiana	no	0	NA	NA	NA	NA	NA
Maine	yes	266	yes	Initial site screening, bird and bat nocturnal radar studies, diurnal survey for migratory birds and raptors, and acoustic studies for bats. Surveys should follow Maine Audubon methods.	Limited lighting.	Mortality studies for birds and bats following the Maine Audubon's methodologies.	NA
Maryland	no	70	NA	NA	NA	NA	NA
Massachusetts	yes	18	yes	NA	Minimize lighting and amount of ground cleared for construction.	NA	NA
Mighigan	yes	164	yes	Thorough review on existing species and habitats in project areas, survey for bats, raptors and general avian use.	Bury power lines.	Not mandatory	NA
Minnesota	no	2205	NA	NA	NA	NA	NA
Mississippi	no	0	NA	NA	NA	NA	NA
Missouri	no	457	NA	NA	NA	NA	NA
Montana	yes	386	yes	USFWS guidelines	USFWS guidelines	USFWS guidelines	USFWS guidelines
Nebraska	yes	213	yes	Nesting raptor surveys, whooping crane assessment, breeding bird survey, prairie grouse survey, bat surveys, threatened and endangered species surveys,	Site turbines on previously altered landscapes, avoid areas with protected plants and animals, avoid migration routes, avoid prairie grouse habitat, increase cut in speed to minimize bat fatalities, use existing roads and avoid new construction, avoid state and federally owned management areas, avoid whopping crane migration pathways, bury electrical	Survey and monitor birds and bats using USFWS protocols.	When habitat is displaced for turbine construction, habitat mitigation should occur at a 1:1 ratio unless the area was rare habitat, in which case the ratio would be

State	Guidelines established	Installed capacity (MW)	Voluntary	Pre-Construction guidelines	Operation/Construction phase	Post-construction guidelines	Mitigation
					power lines, space turbines widely, use tubular towers, avoid using guy wires, use minimal lights, lower tower heights if they are a risk.		higher.
Nevada	yes	0		USFWS guidelines	USFWS guidelines	USFWS guidelines	USFWS guidelines
New Hampshire	yes	25	NA	NA	NA	NA	NA
New Jersey	yes	8	yes	For turbines > 250 ft tall, visual bird and migratory bat surveys.	NA	For turbines >250 ft. tall, carcass searches, carcass removal and searcher efficiency trials, visual bird surveys and migratory bat surveys.	NA
New Mexico	yes	700	yes	NA	Avoid critical habitat, avoid placing turbines in migratory pathway, high bird use area, or bat hibernation, breeding colony, maternity colony, or flight path. Avoid habitat fragmentation. Avoid placing turbines in arrays that will attract raptors or impact Lesser Prairie Chickens. use tubular towers, avoid guy wires, minimize lighting, adjust tower height to reduce risk to birds and bats, and bury power wires.	Monitor for bird and bat mortality using protocols from the USFWS guidelines.	Shut down turbines when there are high concentrations of birds at the site.
New York	yes	1274	yes	Site review, habitat surveys, raptor migration surveys, breeding and migratory bird surveys, bat acoustical monitoring, radar studies, waterfowl surveys, breeding bird surveys, wintering bird surveys, focused study	NA	Ground searches, searcher efficiency and carcass removal trials, bird habituation and avoidance studies, bat acoustical sampling, radar studies, raptor migration surveys.	NA

State	Guidelines established	Installed capacity (MW)	Voluntary	Pre-Construction guidelines	Operation/Construction phase	Post-construction guidelines	Mitigation
				of Indiana bats, expanded studies for migratory bats			
North Carolina	no	0	NA	NA	NA	NA	NA
North Dakota	yes	1424	yes	USFWS guidelines	USFWS guidelines	USFWS guidelines	USFWS guidelines
Ohio	yes	10		Breeding bird surveys, raptor nest surveys and monitoring, bat acoustic monitoring, passerine and diurnal raptor migration surveys, owl playback surveys, bat mist-netting, nocturnal marsh bird surveys, barn owl surveys, sandhill crane migration surveys, waterfowl surveys, shorebird migration surveys, and radar monitoring.	Minimize lighting, perches, guyed structures, and tree removal, avoid raptor nests	Wildlife monitoring, mortality searches, searcher efficiency and scavenging rates	Mitigate for habitat loss or when mortality rates are higher than average
Oklahoma	yes	1482	yes	USFWS guidelines	USFWS guidelines	USFWS guidelines	USFWS guidelines
Oregon	yes	2104	yes	Habitat mapping, raptor nest surveys, general avian use surveys, surveys for threatened, endangered and sensitive species, bat surveys	Encourage siting on agricultural lands, protect key habitats, use tubular towers, avoid guy wires, discourage overhear lines, use red lights when necessary, avoid construction during nesting season, minimize construction around raptor nests, avoid sensitive habitat	Monitor bird and bat fatalities	Mitigate for habitat loss.
Pennsylvania	yes	748	yes	Diurnal raptor surveys, breeding bird surveys in May and June, acoustic bat surveys	NA	Mortality monitoring, searcher efficiency trials, carcass removal trials, acoustic bat surveys	NA

State	Guidelines established	Installed capacity (MW)	Voluntary	Pre-Construction guidelines	Operation/Construction phase	Post-construction guidelines	Mitigation
Rhode Island	no	2	NA	NA	NA	NA	NA
South Carolina	no	0	NA	NA	NA	NA	NA
South Dakota	yes	709	yes	Contact wildlife agencies to ensure facility siting is in an appropriate area and avoid protected or important areas.	Bury power lines, avoid lattice towers, consider turbine design, consider timing of construction and maintenance activities.	NA	Mitigate for habitat loss.
Tennessee	no	29	NA	NA	NA	NA	NA
Texas	yes	10089	yes	Bird and bat surveys following NWCC and Kunz et al. 2007 for protocols	Site facility on disturbed land, minimize habitat destruction, limit access roads, place wires underground, avoid guy wires, minimize lighting, avoid barrier placement of turbines, use tubular towers.	Bird and bat surveys following NWCC and Kunz et al. 2007 for protocols	Avoid or minimize impacts to habitat. Compensate for unavoidable impacts by providing replacement resources.
Utah	no	223	NA	NA	NA	NA	NA
Vermont	yes	6		Preliminary site assessment, radar and acoustic surveys, evaluation or rare, threatened or endangered species and habitats, resident bird and bat surveys, diurnal raptor survey		If the wind facility has an undue adverse impact on the environment, mitigation procedures such as modified operations, modified lighting, on-site habitat management, and habitat protection should occur.	
Virginia	no	0	NA	NA	NA	NA	NA
Washington	yes	2104	yes	Pre-project assessment, information review, habitat mapping, raptor nest surveys, general avian use surveys, bat surveys, surveys for threatened, endangered and sensitive species	Avoid developing on priority habitat, avoid overhead and guy wires, use tubular towers, avoid rodenticides, minimize light usage, minimize roads	Use current protocols to monitor bird and bat fatalities.	Wind development should occur on previously disturbed habitats, and previously undisturbed habitat that is used should be replaced.
West Virginia	no	431	NA	NA	NA	NA	NA

State	Guidelines established	Installed capacity (MW)	Voluntary	Pre-Construction guidelines	Operation/Construction phase	Post-construction guidelines	Mitigation
Wisconsin	yes	469	yes	Use accepted protocols to conduct pre-construction bird and bat surveys, following the USFWS guidelines. Do not site wind facility in protected habitats such as state parks, protected wetlands, etc.	NA	Monitor collisions and evaluations for 2 years to determine what, if any, mitigation methods are necessary.	Lists potential mitigation measures to minimize collisions.
Wyoming	yes	1412	yes	Select sites on already developed or degraded land, conduct habitat evaluation, passive and active acoustic monitoring, live capture, point count surveys,	NA	Habitat evaluations, passive acoustic surveys, carcass searches.	NA

Appendix 2. Rhode Island Tables

Table A2. 1 Status of birds documented in Rhode Island. Nesting status is based on Enser (1992). Conservation status is based on Partners in Flight (PIF; Rich et al. 2001) and priority bird list for Bird Conservation Region (BCR) 30 (New England/mid-Atlantic; http://www.acjv.or). Summer, migration and winter status based on Desante and Pyle (1986) [A].

Species	Nest in RI?	Conservation Status[B]	Summer	Migration	Winter
Red-throated Loon	No	BCR	Rare	Common	Common
Pacific Loon	No	.	.	Rare	Rare
Common Loon	No	.	Uncommon	Common	Common
Pied-billed Grebe	Yes	BCR	Rare	Uncommon	Uncommon
Horned Grebe	No	BCR	Rare	Fairly Common	Fairly Common
Red-necked Grebe	No	.	.	.	Uncommon
Eared Grebe	No	.	.	Accidental	Accidental
Western Grebe	No	.	.	Accidental	Accidental
Northern Fulmar	No	.	.	.	Uncommon
Yellow-nosed Albatross	No	.	.	Accidental	.
Cory's Shearwater	No	.	Common	.	.
Greater Shearwater	No	BCR	Common	Common	.
Sooty Shearwater	No	.	Uncommon	Fairly common	.
Manx Shearwater	No	.	Uncommon	.	.
Audubon's Shearwater	No	BCR	Accidental	.	.
Wilson's Storm Petrel	No	.	Common	.	.
White-faced Storm-Petrel	No	.	.	Accidental	.
Leach's Storm-Petrel	No	.	Accidental	Rare	.
Red-billed Tropicbird	No	.	.	Accidental	.
Northern Gannet	No	.	Uncommon	Common	Uncommon
American White Pelican	No	.	.	Accidental	.
Brown Pelican	No	.	.	Accidental	.
Double-crested Cormorant	Yes	.	Common	Common	Uncommon
Great Cormorant	No	.	.	Uncommon	Common
Magnificent Frigatebird	No	.	.	Accidental	.
American Bittern	Yes	BCR	Rare	Rare	Rare
Least Bittern	Yes	BCR	Rare	Rare	.
Great Blue Heron	Yes	.	Uncommon	Uncommon	Uncommon
Great Egret	Yes	.	Fairly Common	Fairly Common	Rare

Species	Nest in RI?	Conservation Status[B]	Summer	Migration	Winter
Snowy Egret	Yes	BCR	Fairly Common	Fairly Common	Accidental
Little Blue Heron	Yes	.	Rare	Rare	.
Tricolored Heron	Yes	.	Rare	Rare	.
Cattle Egret	Yes	.	Fairly Common	Fairly Common	.
Green Heron	Yes	.	Fairly Common	Fairly Common	Accidental
Black-crowned Night-Heron	Yes	.	Fairly Common	Fairly Common	Uncommon
Yellow-crowned Night-Heron	Yes	.	Rare	Rare	.
White Ibis	No	.	.	Accidental	.
Glossy Ibis	Yes	.	Uncommon	Uncommon	.
Wood Stork	No	.	.	Accidental	.
Fulvous Whistling -Duck	No	.	Accidental	Accidental	.
Tundra Swan	No	.	.	Rare	Rare
Mute Swan	Yes	.	Common	Common	Common
Greater White-fronted Goose	No	.	.	Uncommon	Rare
Snow Goose	No	.	.	Uncommon	Rare
Canada Goose	Yes	.	Common	Common	Common
Brant	No	.	.	Fairly common	Common
Wood Duck	Yes	.	Uncommon	Fairly common	Rare
Green-winged Teal	Yes	.	Rare	Common	Uncommon
American Black Duck	Yes	.	Uncommon	Common	Common
Mallard	Yes	.	Common	Common	Common
Northern Pintail	No	.	.	Fairly common	Uncommon
Blue-winged Teal	Yes	.	Rare	Uncommon	Rare
Northern Shoveler	No	.	.	Uncommon	Rare
Gadwall	Yes	.	Rare	Fairly common	Uncommon
Eurasian Wigeon	No	.	.	Rare	Rare
American Wigeon	No	.	Rare	Common	Uncommon
Canvasback	No	.	Accidental	Fairly common	Uncommon
Redhead	No	.	.	Uncommon	Rare
Ring-necked Duck	No	.	Rare	Fairly common	Uncommon
Greater Scaup	No	.	Rare	Uncommon	Common

Species	**Nest in RI?**	**Conservation Status**[B]	**Summer**	**Migration**	**Winter**
Lesser Scaup	No	.	Rare	Fairly common	Uncommon
Common Eider	No	.	Rare	Common	Common
King Eider	No	.	Rare	Rare	Rare
Harlequin Duck	No	.	Rare	Uncommon	Uncommon
Long-tailed Duck	No	.	Accidental	Uncommon	Uncommon
Black Scoter	No	.	Rare	Common	Common
Surf Scoter	No	.	Rare	Common	Common
White-winged Scoter	No	.	Rare	Common	Common
Common Goldeneye	No	.	Accidental	Common	Common
Barrow's Goldeneye	No	.	.	Rare	Rare
Bufflehead	No	.	Rare	Common	Common
Smew	No	.	.	.	Accidental
Hooded Merganser	Yes	.	Rare	Fairly common	Uncommon
Common Merganser	No	.	.	Uncommon	Uncommon
Red-breasted Merganser	No	.	Rare	Common	Common
Ruddy Duck	No	.	Rare	Fairly common	Common
Black Vulture	No	.	.	Uncommon	Rare
Turkey Vulture	Yes	.	Common	Common	Uncommon
Osprey	Yes	.	Common	Common	Rare
Swallow-tailed Kite	No	.	.	Accidental	.
Bald Eagle	Yes	BCR	Rare	Uncommon	Uncommon
Northern Harrier	Yes	.	Rare	Uncommon	Uncommon
Sharp-shinned Hawk	Yes	.	Rare	Common	Uncommon
Cooper's Hawk	Yes	.	Uncommon	Common	Uncommon
Northern Goshawk	Yes	.	Rare	Uncommon	Rare
Red-shouldered Hawk	Yes	PIF	Uncommon	Uncommon	Rare
Broad-winged Hawk	Yes	.	Common	Common	.
Swainson's Hawk	No	.	.	Accidental	.
Red-tailed Hawk	Yes	.	Common	.	Common
Rough-legged Hawk	No	.	.	.	Uncommon
Golden Eagle	No	.	.	.	Rare
American Kestrel	Yes	.	Rare	Uncommon	Fairly Common
Merlin	No	.	.	Uncommon	Rare
Peregrine Falcon	Yes	.	Uncommon	Uncommon	Rare
Gyrfalcon	No	.	.	.	Rare

Species	Nest in RI?	Conservation Status[B]	Summer	Migration	Winter
Ring-necked Pheasant	Yes	.	Uncommon	.	Uncommon
Ruffed Grouse	Yes	.	Uncommon	.	Uncommon
Wild Turkey	Yes	.	Common	.	Common
Northern Bobwhite	Yes	.	Uncommon	.	Uncommon
Yellow Rail	No	.	.	.	Accidental
Black Rail	No	BCR	Accidental	Accidental	.
Corn Rail	No	.	.	Accidental	.
Clapper Rail	Yes	.	Rare	Rare	Rare
King Rail	Yes	.	Rare	Rare	Accidental
Virginia Rail	Yes	.	Rare	Rare	Rare
Sora	Yes	.	Rare	Uncommon	Rare
Purple Gallinule	No	.	.	Accidental	.
Common Moorhen	No	.	Rare	Uncommon	Accidental
American Coot	No	.	Uncommon	Common	Uncommon
Sandhill Crane	No	.	.	Rare	.
Northern Lapwing	No	.	.	Accidental	.
Black-bellied Plover	No	.	Rare	Fairly common	Rare
American Golden-Plover	No	.	.	Uncommon	.
Wilson's Plover	No	BCR	.	Accidental	.
Semipalmated Plover	No	.	.	Common	.
Piping Plover	Yes	.	Uncommon	Uncommon	.
Killdeer	Yes	.	Uncommon	Common	Rare
American Oystercatcher	Yes	BCR	Uncommon	Uncommon	.
Black-necked Stilt	No	.	Rare	Rare	.
American Avocet	No	BCR	.	Uncommon	.
Greater Yellowlegs	No	.	.	Common	Rare
Lesser Yellowlegs	No	BCR	.	Uncommon	Rare
Spotted Redshank	No	.	.	Accidental	.
Solitary Sandpiper	No	BCR	.	Uncommon	.
Willet	Yes	.	Uncommon	Uncommon	.
Spotted Sandpiper	Yes	.	Uncommon	Uncommon	.
Upland Sandpiper	No	BCR	.	Rare	.
Eskimo Curlew	No	.	.	Extinct	.

Species	**Nest in RI?**	**Conservation Status^{B}**	**Summer**	**Migration**	**Winter**
Whimbrel	No	BCR	.	Uncommon	.
Long-billed Curlew	No	.	.	Accidental	.
Hudsonian Godwit	No	BCR	.	Rare	.
Marbled Godwit	No	BCR	.	Rare	.
Ruddy Turnstone	No	.	.	Common	Rare
Red Knot	No	BCR	.	Uncommon	Rare
Sanderling	No	.	Rare	Common	Uncommon
Semipalmated Sandpiper	No	BCR	.	Common	.
Western Sandpiper	No	.	.	Uncommon	Accidental
Least Sandpiper	No	.	.	Common	Rare
White-rumped Sandpiper	No	.	.	Uncommon	.
Baird's Sandpiper	No	.	.	Uncommon	.
Pectoral Sandpiper	No	.	.	Uncommon	.
Purple Sandpiper	No	BCR	.	.	Uncommon
Dunlin	No	.	.	Common	Uncommon
Curlew Sandpiper	No	.	.	Accidental	.
Stilt Sandpiper	No	.	.	Uncommon	.
Buff-breasted Sandpiper	No	BCR	.	Uncommon	.
Ruff	No	.	.	Rare	.
Short-billed Dowitcher	No	BCR	.	Common	.
Long-billed Dowitcher	No	.	.	Uncommon	Rare
Common Snipe	No	.	.	Fairly common	Rare
American Woodcock	Yes	.	Uncommon	.	Uncommon
Wilson's Phalarope	No	.	.	Rare	.
Red-necked Phalarope	No	.	.	Fairly common	.
Red Phalarope	No	.	.	Fairly common	.
Pomarine Jaegar	No	.	.	Uncommon	.
Parasitic Jaegar	No	.	.	Uncommon	.
Long-tailed Jaeger	No	.	.	Rare	.
Greater Skua	No	.	.	.	Accidental
South Polar Skua	No	.	Rare	Rare	.
Laughing Gull	No	.	Common	Common	Accidental
Franklin's Gull	No	.	.	Accidental	.
Little Gull	No	.	.	Rare	Rare
Common Black-head Gull	No	.	.	Rare	Rare
Bonaparte's Gull	No	.	Rare	Uncommon	Uncommon
Mew Gull	No	.	.	Accidental	.

Species	Nest in RI?	Conservation Status^B	Summer	Migration	Winter
Ring-billed Gull	No	.	Common	Common	Fairly Common
Herring Gull	Yes	.	Common	Common	Common
Thayer's Gull	No	.	.	.	Accidental
Iceland Gull	No	.	.	.	Uncommon
Lesser Black-backed Gull	No	.	.	.	Rare
Glaucous Gull	No	.	.	.	Uncommon
Great Black-backed Gull	Yes	.	Common	Common	Common
Black-legged Kittewake	No	.	Rare	Uncommon	Common
Sabine's Gull	No	.	.	Accidental	.
Gull-billed Tern	No	BCR	Rare	Rare	.
Caspian Tern	No	.	.	Uncommon	.
Royal Tern	No	.	Rare	Rare	.
Sandwich Tern	No	.	.	Accidental	.
RoseateTern	No	.	Uncommon	Fairly common	.
Common Tern	Yes	.	Common	Common	.
Arctic Tern	No	.	.	Rare	.
Forster's Tern	No	.	.	Uncommon	.
Least Tern	Yes	BCR	Common	Uncommon	.
Bridled Tern	No	.	.	Accidental	Accidental
Sooty Tern	No	.	.	Accidental	.
Black Tern	No	.	.	Uncommon	.
Brown Noddy	No	.	.	Accidental	.
Black Skimmer	No	BCR	Rare	Uncommon	.
Dovekie	No	.	.	.	Common
Common Murre	No	.	.	.	Uncommon
Thick-billed Murre	No	.	.	.	Rare
Razorbill	No	.	.	.	Uncommon
Black Guillemot	No	.	.	.	Uncommon
Atlantic Puffin	No	.	.	.	Rare
Mourning Dove	Yes	.	Common	Common	Common
Rock Dove	Yes	.	Common	Common	Common
Black-billed Cuckoo	Yes	.	Uncommon	Uncommon	.
Yellow-billed Cuckoo	Yes	.	Uncommon	Uncommon	.
Barn Owl	Yes	.	Rare	.	.
Eastern Screech-Owl	Yes	.	Uncommon	Uncommon	Uncommon
Great Horned Owl	Yes	.	Uncommon	Uncommon	Uncommon

Species	**Nest in RI?**	**Conservation Status^{B}**	**Summer**	**Migration**	**Winter**
Snowy Owl	No	.	.	.	Uncommon
Northern Hawk Owl	No	.	.	Accidental	.
Burrowing Owl	No	.	.	Accidental	.
Barred Owl	Yes	.	Uncommon	Uncommon	Uncommon
Great Gray Owl	No	.	.	Accidental	Accidental
Long-eared Owl	Yes	.	Rare	Rare	Uncommon
Short-eared Owl	No	BCR	.	Uncommon	Uncommon
Boreal Owl	No	.	.	Accidental	Accidental
Northern Saw-whet Owl	Yes	.	Rare	Common	Uncommon
Common Nighthawk	Yes	.	Uncommon	Uncommon	.
Chuck-will's-widow	No	PIF	.	Rare	.
Whip-poor-will	Yes	BCR	Uncommon	Uncommon	.
Chimney Swift	Yes	.	Common	Uncommon	.
Ruby-throated Hummingbird	Yes	.	Common	Common	.
Belted Kingfisher	Yes	.	Uncommon	Uncommon	Uncommon
Lewis' Woodpecker	No	.	.	Accidental	.
Red-headed Woodpecker	Yes	BCR/PIF	Rare	Uncommon	Rare
Red-bellied Woodpecker	Yes	PIF	Common	Common	Common
Yellow-bellied Sapsucker	No	.	.	Fairly common	Rare
Downy Woodpecker	Yes	.	Common	Common	Common
Hairy Woodpecker	Yes	.	Uncommon	Uncommon	Uncommon
Black-backed Woodpecker	No	.	.	Accidental	Accidental
Northern Flicker	Yes	.	Common	Common	Uncommon
Pileated Woodpecker	Yes	.	Rare	Rare	Rare
Olive-sided Flycatcher	No	.	.	Uncommon	.
Eastern Wood-Pewee	Yes	.	Fairly Common	Common	.
Yellow-bellied Flycatcher	No	.	.	Uncommon	.
Acadian Flycatcher	Yes	PIF	Rare	Rare	.
Alder Flycatcher	No	.	.	Uncommon	.
Willow Flycatcher	Yes	PIF	Uncommon	.	.
Least Flycatcher	Yes	.	Rare	Uncommon	.
Eastern Phoebe	Yes	.	Common	.	Uncommon
Say's Phoebe	No	.	.	Accidental	Accidental

Species	Nest in RI?	Conservation Status[B]	Summer	Migration	Winter
Ash-throated Flycatcher	No	.	.	Accidental	.
Great-crested Flycatcher	Yes	.	Uncommon	Uncommon	.
Western Kingbird	No	.	.	Rare	.
Eastern Kingbird	Yes	.	Common	Common	.
Scissor-tailed Flycatcher	No	.	.	Accidental	.
Horned Lark	Yes	.	Rare	Uncommon	Uncommon
Purple Martin	Yes	.	Uncommon	Uncommon	.
Tree Swallow	Yes	.	Common	Common	Rare
N. Rough-winged Swallow	Yes	.	Rare	Uncommon	.
Bank Swallow	Yes	.	Rare	Uncommon	.
Cliff Swallow	Yes	.	Rare	Rare	.
Cave Swallow	No	.	.	Rare	.
Barn Swallow	Yes	.	Common	Common	.
Blue Jay	Yes	.	Common	Common	Common
Jackdaw	No	.	.	Accidental	.
American Crow	Yes	.	Common	Common	Common
Fish Crow	Yes	.	Common	Common	Uncommon
Common Raven	Yes	.	Rare	Rare	Uncommon
Black-capped Chickadee	Yes	.	Common	Common	Common
Boreal Chickadee	No	.	.	.	Rare
Tufted titmouse	Yes	.	Common	Common	Common
Red-breasted Nuthatch	Yes	.	Rare	Common	Common
White-breasted Nuthatch	Yes	.	Common	Common	Common
Brown Creeper	Yes	.	Uncommon	Common	Uncommon
Carolina Wren	Yes	PIF	Common	Common	Common
Bewick's Wren	No	.	.	Accidental	.
House Wren	Yes	.	Common	Common	Rare
Winter Wren	No	.	Rare	Uncommon	Uncommon
Sedge Wren	No	BBC	.	Rare	.
Marsh Wren	Yes	.	Uncommon	Uncommon	Rare
Golden-crowned Kinglet	Yes	.	Rare	Common	Fairly Common
Ruby-crowned Kinglet	No	.	.	Common	Uncommon
Blue-gray Gnatcatcher	Yes	.	Rare	Uncommon	.
Northern Wheateater	No	.	.	Accidental	.
Eastern Bluebird	Yes	.	Uncommon	Uncommon	Uncommon

Species	Nest in RI?	Conservation Status[B]	Summer	Migration	Winter
Townsend's Solitaire	No	.	.	.	Accidental
Veery	Yes	.	Common	Fairly common	.
Gray-cheeked Thrush	No	.	.	Uncommon	.
Bicknell's Thrush	No	.	.	Uncommon	.
Swainson's Thrush	No	.	.	Fairly common	.
Hermit Thrush	Yes	.	Fairly Common	Fairly common	Uncommon
Wood Thrush	Yes	BCR/PIF	Common	Fairly common	.
American Robin	Yes	.	Common	Common	Common
Varied Thrush	No	.	.	.	Accidental
Gray Catbird	Yes	.	Common	Common	Uncommon
Northern Mockingbird	Yes	.	Common	Common	Uncommon
Brown Thrasher	Yes	PIF	Uncommon	Uncommon	Rare
American Pipit	No	.	.	Fairly common	Uncommon
Bohemian Waxwing	No	.	.	Accidental	Rare
Cedar Waxwing	Yes	.	Uncommon	Common	Fairly Common
European Starling	Yes	.	Common	Common	Common
Phainopepla	No	.	.	Accidental	.
Northern Shrike	No	.	.	.	Uncommon
Loggerhead Shrike	No	BCR	.	.	Rare
White-eyed Vireo	Yes	PIF	Uncommon	Uncommon	.
Blue-headed Vireo	Yes	.	Uncommon	Uncommon	.
Yellow-throated Vireo	Yes	PIF	Uncommon	Uncommon	.
Warbling Vireo	Yes	.	Uncommon	Uncommon	.
Philadelphia Vireo	No	.	.	Rare	.
Red-eyed Vireo	Yes	.	Common	Common	.
Blue-winged Warbler	Yes	BCR/PIF	Uncommon	Uncommon	.
Golden-winged Warbler	No	BCR/PIF	Rare	Rare	.
Tennessee Warbler	No	.	.	Uncommon	.
Orange-crowned Warbler	No	.	.	Uncommon	Rare
Nashville Warbler	Yes	.	Rare	Uncommon	.
Northern Parula	Yes	.	Rare	Fairly common	.

Species	Nest in RI?	Conservation Status[B]	Summer	Migration	Winter
Yellow Warbler	Yes	.	Uncommon	Uncommon	.
Chestnut-sided Warbler	Yes	.	Uncommon	Uncommon	.
Magnolia Warbler	No	.	.	Fairly common	.
Cape May Warbler	No	.	.	Fairly common	.
Black-throated Blue Warbler	Yes	.	Rare	Fairly common	.
Yellow-rumped Warbler	Yes	.	Rare	Common	Fairly Common
Black-throated Gray Warbler	No	.	Accidental	Accidental	.
Black-throated Green Warbler	Yes	.	Common	Common	.
Blackburnian Warbler	No	.	.	Uncommon	Accidental
Yellow-throated Warbler	No	.	Rare	Rare	.
Pine Warbler	Yes	PIF	Fairly Common	Fairly common	Rare
Prairie Warbler	Yes	BCR/PIF	Uncommon	Uncommon	.
Palm Warbler	No	.	.	Fairly common	Rare
Bay-breasted Warbler	No	.	.	Uncommon	.
Blackpoll Warbler	No	.	.	Common	.
Cerulean Warbler	No	BCR/PIF	Rare	Rare	.
Black-and-white Warbler	Yes	.	Fairly Common	Common	.
American Redstart	Yes	.	Fairly Common	Common	.
Prothonotary Warbler	Yes	PIF	Rare	Uncommon	.
Worm-eating Warbler	Yes	BCR/PIF	Uncommon	Uncommon	.
Ovenbird	Yes	.	Common	Common	.
Northern Waterthrush	Yes	.	Uncommon	Fairly common	.
Louisiana Waterthrush	Yes	PIF	Uncommon	Uncommon	.
Kentucky Warbler	No	BCR/PIF	Rare	Rare	.
Connecticut Warbler	No	.	.	Uncommon	.
Mourning Warbler	No	.	.	Uncommon	.
Common Yellowthroat	Yes	.	Common	Common	Uncommon
Hooded Warbler	Yes	PIF	Uncommon	Uncommon	.
Wilson's Warbler	No	.	.	Uncommon	.

Species	Nest in RI?	Conservation Status^B	Summer	Migration	Winter
Canada Warbler	Yes	.	Uncommon	Uncommon	.
Yellow-breasted Chat	Yes	.	Rare	Rare	Rare
Summer Tanager	No	.	Rare	Rare	.
Scarlet Tanager	Yes	.	Uncommon	Uncommon	.
Western Tanager	No	.	.	Accidental	.
Northern Cardinal	Yes	.	Common	Common	Common
Rose-breasted Grosbeak	Yes	.	Uncommon	Uncommon	.
Black-headed Grosbeak	No	.	.	Accidental	Accidental
Blue Grosbeak	No	.	.	Uncommon	Accidental
Indigo Bunting	Yes	PIF	Uncommon	Uncommon	.
Painted Bunting	No	.	.	Accidental	.
Dickcissel	No	PIF	.	Rare	Rare
Eastern Towhee	Yes	PIF	Common	Uncommon	Uncommon
American Tree Sparrow	No	.	.	Uncommon	Uncommon
Chipping Sparrow	Yes	.	Common	Common	Rare
Clay-colored Sparrow	No	.	.	Rare	.
Field Sparrow	Yes	.	Uncommon	Uncommon	Uncommon
Vesper Sparrow	Yes	.	Rare	.	.
Lark Sparrow	No	.	.	Rare	Accidental
Lark Bunting	No	.	.	Accidental	.
Savannah Sparrow	Yes	.	Uncommon	Common	Uncommon
Grasshopper Sparrow	Yes	.	Rare	Rare	.
Henslow's Sparrow	No	BCR/PIF	Rare	Accidental	Accidental
Nelson's Sparrow	No	BCR/PIF	.	Uncommon	Rare
Saltmarsh Sparrow	Yes	PIF	Uncommon	Uncommon	.
Seaside Sparrow	Yes	BCR/PIF	Rare	Rare	Rare
Fox Sparrow	No	.	.	Fairly common	Uncommon
Song Sparrow	Yes	.	Common	Common	Common
Lincoln's Sparrow	No	.	.	Uncommon	.
Swamp Sparrow	Yes	.	Uncommon	Uncommon	Uncommon
White-throated Sparrow	Yes	.	Rare	Common	Common
White-crowned Sparrow	No	.	.	Uncommon	Rare
Harris Sparrow	No	.	.	Accidental	Accidental
Dark-eyed Junco	Yes	.	Rare	Common	Common

Species	**Nest in RI?**	**Conservation Status**^{B}	**Summer**	**Migration**	**Winter**
Lapland Longspur	No	.	.	.	Uncommon
Smith's Longspur	No	.	.	Accidental	.
Snow Bunting	No	.	.	.	Uncommon
Bobolink	Yes	.	Uncommon	Uncommon	.
Red-winged Blackbird	Yes	.	Common	Common	Uncommon
Eastern Meadowlark	Yes	.	Rare	Rare	Uncommon
Western Meadowlark	No	.	.	Accidental	.
Yellow-headed Blackbird	No	.	.	Rare	Accidental
Rusty Blackbird	No	BCR/PIF	.	Uncommon	Rare
Brewer's Blackbird	No	.	.	Accidental	Accidental
Common Grackle	Yes	.	Common	Common	Uncommon
Brown-headed Cowbird	Yes	.	Common	Common	Uncommon
Orchard Oriole	Yes	.	Uncommon	Uncommon	.
Baltimore Oriole	Yes	.	Common	Uncommon	Rare
Pine Grosbeak	No	.	.	.	Rare
Purple Finch	Yes	.	Uncommon	Uncommon	Fairly Common
House Finch	Yes	.	Common	Common	Common
Red Crossbill	No	.	.	.	Uncommon
White-winged Crossbill	No	.	.	.	Uncommon
Common Redpoll	No	.	.	.	Fairly Common
Hoary Redpoll	No	.	.	.	Rare
Pine Siskin	No	.	.	.	Fairly Common
American Goldfinch	Yes	.	Common	Common	Fairly Common
Evening Grosbeak	Yes	.	Rare	Uncommon	Uncommon
House Sparrow	Yes	.	Common	Common	Common

[A] Desante and Pyle (1986) definitions: few individuals encountered on >90% of days (common); 50-90% (fairly common); 10-50% of days (uncommon); <10% of days (rare); Occuring outside of its range (accidental); unrecorded in last 50 years (extinct); or many individuals encountered on >50% of days (common); 10-50% of days (fairly common); >10% of days (uncommon).

[B] Bird Conservation Region priorities = BCR; Partners in Flight priorities = PIF.

Table A2. 2 Conservation status of birds in Rhode Island base classification in Bird Conservation Region 30 (http://www.acjv.org/bird_conservation_regions.htm) and Partners in Flight for Eastern US.

Species	BCR 30 Status	PIF Status
Red-throated Loon	HH	
Pied-billed Grebe		Tier V
Horned Grebe	H	
Audubon's Shearwater	H	
Manx Shearwater	M	
Cory's Shearwater	M	
Greater Shearwater	H	
Northern Gannet	H	
Least Bittern	M	Tier V
American Bittern	M	Tier V
Black-crowned Night Heron	M	Tier V
Yellow-crowned Night Heron	M	Tier V
Little Blue Heron	M	Tier V
Tricolored Heron	M	Tier V
Cattle Egret		Tier V
Snowy Egret	M	Tier V
Great Egret		Tier V
Great Blue Heron		Tier V
Glossy Ibis	H	Tier V
Tundra Swan	H	
Canada Goose, Atlantic Population	HH	
Canada Goose, North Atlantic Population	H	
Atlantic Brant	HH	
Mallard	H	
American Black Duck	HH	Tier IIC
Gadwall	M	
Green-winged Teal	M	
American Wigeon	M	
Northern Pintail	M	
Ruddy Duck	M	
Wood Duck	M	
Canvasback	H	
Lesser Scaup	H	
Common Eider	H	
White-winged Scoter	H	
Black Scoter	H	
Greater Scaup	H	
Harlequin Duck	M	

Species	BCR 30 Status	PIF Status
Surf Scoter	H	
Long-tailed Duck	H	
Broad-winged Hawk	H	
Common Goldeneye	M	
Bufflehead	H	
Red-breasted Merganser	M	
Hooded Merganser	M	
King Rail	M	Tier V
Clapper Rail	H	
Black Rail	HH	Tier IB
Sora	M	
Common Moorhen		Tier V
American Oystercatcher	HH	Tier IA
American Avocet	M	
Piping Plover	HH	Tier IA
Semipalmated Plover	M	
Wilson’s Plover	H	
Killdeer	M	
Black-bellied Plover	H	
American Golden Plover	H	
Hudsonian Godwit	H	
Marbled Godwit	H	
Whimbrel	HH	
Willet	H	
Lesser Yellowlegs	M	
Greater Yellowlegs	H	
Wilson’s Phalarope	H	
Red Phalarope	M	
Red-necked Phalarope	M	
Short-billed Dowitcher	H	
Semipalmated Sandpiper	H	
Solitary Sandpiper	H	
Spotted Sandpiper	M	
American Woodcock	HH	Tier IA
Common Snipe	M	
Ruddy Turnstone	HH	
Purple Sandpiper	H	
Red Knot	HH	
Sanderling	HH	
White-rumped Sandpiper	H	

Species	BCR 30 Status	PIF Status
Western Sandpiper	M	
Least Sandpiper	M	
Dunlin	H	
Buff-breasted Sandpiper	H	
Upland Sandpiper	M	Tier IB
Common Tern	M	Tier V
Roseate Tern	HH	Tier IV
Forster's Tern	H	
Gull-billed Tern	HH	
Bridled Tern	H	
Sandwich Tern	H	
Least Tern	H	Tier V
Royal Tern	M	
Arctic Tern		Tier V
Black Skimmer	M	
Razorbill	M	
Bald Eagle	M	
Northern Harrier		Tier V
Osprey		Tier V
Sharp-shinned Hawk		Tier V
Cooper's Hawk		Tier V
Northern Goshawk		Tier V
Red-shouldered Hawk		Tier V
Peregrine Falcon		Tier IIC
Northern Bobwhite	H	
Black-billed Cuckoo		Tier IA
Barn Owl		Tier V
Long-eared Owl		Tier V
Barred Owl		Tier V
Short-eared Owl		Tier IIC
Chuck-will's-widow		Tier III
Whip-poor-will	H	Tier V
Common Nighthawk		Tier V
Chimney Swift	H	Tier IIA
Hairy Woodpecker		Tier IIA
Red-cockaded Woodpecker	M	
Red-headed Woodpecker	M	Tier IIC
Northern Flicker	H	
Eastern Kingbird	H	
Great Crested Flycatcher	H	

Species	BCR 30 Status	PIF Status
Eastern Wood-Pewee		Tier IIA
Willow Flycatcher	H	
Horned Lark		Tier V
Purple Martin		Tier V
Brown-headed Nuthatch	M	
Marsh Wren	H	
Sedge Wren	M	Tier IIC
Bicknell’s Thrush	H	
Wood Thrush	HH	Tier IA
Gray Catbird	M	
Brown Thrasher	H	
Loggerhead Shrike	M	
Yellow-throated Vireo	H	
Prothonotary Warbler	H	
Blue-winged Warbler	HH	Tier IA
Northern Parula		Tier V
Golden-winged Warbler	M	Tier IB
Black-and-white Warbler	H	Tier IIA
Black-throated Blue Warbler		Tier IB
Cerulean Warbler	M	Tier IB
Blackburnian Warbler	M	Tier IIC
Prairie Warbler	HH	Tier IA
Bay-breasted Warbler	H	
Canada Warbler	M	Tier IIC
Kentucky Warbler	H	Tier IB
Worm-eating Warbler	H	Tier IA
Swainson’s Warbler	M	
Louisiana Waterthrush	H	Tier IA
Yellow-breasted Chat		Tier V
Rose-breasted Grosbeak		Tier IIA
Eastern Towhee	H	Tier IIA
Grasshopper Sparrow	M	Tier V
Henslow’s Sparrow	M	Tier IB
Saltmarsh Sparrow	HH	Tier IA
Nelson’s Sparrow	M	
Seaside Sparrow	HH	Tier IA
Vesper Sparrow		Tier V
Savannah Sparrow		Tier V
Ipswich Savannah Sparrow	M	
Coastal Plain Swamp Sparrow	M	

Species	BCR 30 Status	PIF Status
Field Sparrow	H	
Bachman's Sparrow	M	
Bobolink		Tier III
Rusty Blackbird	H	
Baltimore Oriole	H	Tier IA
Scarlet Tanager		Tier IA
Purple Finch		Tier IIA

[a] BCR30 categories: HH – highest priority, H – High priority, M = Moderate priority.

[b] Partners in Flight categories: Tier I A: High Continental Priority - High Regional Responsibility, Tier I B: High Continental Priority - Low Regional Responsibility, Tier II A: High Regional Concern, Tier II B: High Regional Responsibility, Tier II C: High Regional Threats, Tier III: Additional Watch List, Tier IV: Additional Federally Listed, Tier V: Additional State Listed.

Table A2. 3 Conservation status and habitat selection by birds breeding in Rhode Island. Conservation status is based on federal and state lists (see text). Breeding Bird Survey (BBS) population trends were based on surveys conducted from 1989 to 2009, with the trend region of either New England (NE) or survey-wide (SW). Species with significant population trends are shown with an asterisk (*).

Breeding Species	State/federal Conservation Status*	Primary nesting habitat	BBS population trend	BBS Trend Region
Pied-billed Grebe	SE	wetland	decline	SW
Double-crested Cormorant		coastal	increase*	NE
American Bittern	SE	wetland	decline	NE
Least Bittern	ST	wetland	increase	NE
Great Blue Heron	C	forest	increase*	NE
Great Egret	C	bay Islands	increase*	NE
Snowy Egret	C	bay Islands	increase*	NE
Little Blue Heron	C	bay Islands	increase	NE
Tricolored Heron		coastal	increase	NE
Cattle Egret	C	grassland	decline	NE
Green Heron		wetland	decline	NE
Black-crowned Night-Heron	C	bay Islands	decline	NE
Yellow-crowned Night - Heron	C	bay Islands	decline	SW
Glossy Ibis	C	bay Islands	increase	NE
Mute Swan		wetland	increase	NE
Canada Goose		wetland	increase*	NE
Wood Duck		wetland	increase	NE
Green-winged Teal	C	wetland	increase	SW
American Black Duck		wetland	decline	NE
Mallard		wetland	decline	NE
Blue-winged Teal	C	wetland	increase	SW
Gadwall	C	wetland	increase*	SW
Hooded Merganser	C	wetland	increase*	SW
Turkey Vulture		forest	increase*	NE
Osprey	C	mixed	increase*	NE
Bald Eagle	FT	forest	increase*	NE
Northern Harrier	SE	grassland	increase	NE

Breeding Species	State/federal Conservation Status*	Primary nesting habitat	BBS population trend	BBS Trend Region
Sharp-shinned Hawk	SH	forest	increase	SW
Cooper's Hawk	C	forest	increase*	NE
Northern Goshawk	C	forest	increase	SW
Red-shouldered Hawk		forest	increase	NE
Broad-winged Hawk		forest	decline*	NE
Red-tailed Hawk		forest	increase*	NE
American Kestrel		various	decline	NE
Peregrine Falcon	SE	mixed	increase	SW
Ring-necked Pheasant		grassland	decline*	NE
Ruffed Grouse		forest	decline	NE
Wild Turkey		various		
Northern Bobwhite		successional	decline*	NE
Clapper Rail	C	wetland	increase	NE
King Rail	C	wetland	increase	NE
Virginia Rail		wetland	increase	NE
Sora	C	wetland	no data	
Piping Plover	FT	coastal	increase	RI
Killdeer		grassland	decline	NE
American Oystercatcher	C	coastal	no data	na
Willet	C	wetland	decline	NE
Spotted Sandpiper		wetland	increase	NE
American Woodcock		grassland	decline	NE
Herring Gull		coastal	decline	NE
Great Black-backed Gull		coastal	decline	SW
Common Tern		coastal	decline	NE
Least Tern	ST	coastal	decline	NE
Mourning Dove		mixed	increase	NE
Rock Dove		Urban	decline	NE
Black-billed Cuckoo		forest	decline*	NE
Yellow-billed Cuckoo		forest	increase	NE

Breeding Species	State/federal Conservation Status*	Primary nesting habitat	BBS population trend	BBS Trend Region
Barn Owl	SE	forest	increase	NE
Eastern Screech-Owl		forest	increase	NE
Great Horned Owl		forest	decline	NE
Barred Owl		forest	increase	NE
Long-eared Owl	C	forest	no data	
Northern Saw-whet Owl	C	forest	no data	
Common Nighthawk	C	grassland	decline	NE
Whip-poor-will		forest	decline	NE
Chimney Swift		open	decline*	NE
Ruby-throated Hummingbird		forest	increase*	NE
Belted Kingfisher		wetland	decline	NE
Red-headed Woodpecker		forest	increase	SW
Red-bellied Woodpecker		forest	increase*	NE
Downy Woodpecker		forest	increase	NE
Hairy Woodpecker		forest	decline	NE
Northern Flicker		forest	decline	NE
Pileated Woodpecker	C	forest	increase*	NE
Eastern Wood-Pewee		forest	decline	NE
Acadian Flycatcher	C	forest	increase	NE
Willow Flycatcher		Successional	increase*	NE
Least Flycatcher		forest	decline*	NE
Eastern Phoebe		successional	decline	NE
Great-crested Flycatcher		forest	increase*	NE
Eastern Kingbird		wetland	decline*	NE
Horned Lark	C	grassland	increase	NE
Purple Martin		wetland	increase	NE
Tree Swallow		successional	decline	NE
N. Rough-winged Swallow		open	increase	NE
Bank Swallow		open	decline	NE

Breeding Species	State/federal Conservation Status*	Primary nesting habitat	BBS population trend	BBS Trend Region
Cliff Swallow	SH	open	increase	NE
Barn Swallow		open	decline	NE
Blue Jay		forest	decline*	NE
American Crow		open	decline	NE
Fish Crow		forest	increase*	NE
Common Raven		forest	increase	NE
Black-capped Chickadee		forest	increase	NE
Tufted Titmouse		forest	increase*	NE
Red-breasted Nuthatch		forest	increase	NE
White-breasted Nuthatch		forest	increase*	NE
Brown Creeper		forest	increase	NE
Carolina Wren		forest	increase*	NE
House Wren		successional	decline	NE
Marsh Wren	C	wetland	decline	NE
Golden-crowned Kinglet		forest	decline	SW
Blue-gray Gnatcatcher		forest	increase*	NE
Eastern Bluebird		grassland	increase*	NE
Veery		forest	decline	NE
Hermit Thrush		forest	decline	NE
Wood Thrush		forest	decline*	NE
American Robin		Urban	decline	NE
Gray Catbird		forest	increase	NE
Northern Mockingbird		successional	decline*	NE
Brown Thrasher		successional	decline	NE
Cedar Waxwing		successional	increase*	NE
European Starling		Urban	decline*	NE
White-eyed Vireo		successional	increase	NE
Blue-headed Vireo		forest	decline	NE
Yellow-throated Vireo		forest	increase	NE
Warbling Vireo		forest	increase*	NE

Breeding Species	State/federal Conservation Status*	Primary nesting habitat	BBS population trend	BBS Trend Region
Red-eyed Vireo		forest	decline*	NE
Blue-winged Warbler		successional	decline	NE
Nashville Warbler		successional	decline	NE
Northern Parula	ST	forest	increase*	SW
Yellow Warbler		Successional	increase	NE
Chestnut-sided Warbler		successional	decline*	NE
Black-throated Blue Warbler	ST	forest	increase	SW
Yellow-rumped Warbler		forest	increase	NE
Black-throated Green Warbler		forest	increase	SW
Pine Warbler		forest	increase*	NE
Prairie Warbler		successional	decline*	NE
Black-and-white Warbler		forest	decline*	NE
American Redstart		forest	increase	NE
Prothonotary Warbler	C	wetland	increase	NE
Worm-eating Warbler	C	forest	increase*	NE
Ovenbird		forest	decline	NE
Northern Waterthrush		forest	decline	NE
Louisiana Waterthrush		forest	increase	NE
Common Yellowthroat		forest	decline*	NE
Hooded Warbler		forest	increase	NE
Canada Warbler		wetland	decline	NE
Yellow-breasted Chat		Successional	decline	NE
Scarlet Tanager		forest	decline*	NE
Northern Cardinal		successional	increase*	NE
Rose-breasted Grosbeak		forest	decline*	NE
Indigo Bunting		successional	increase	NE
Eastern Towhee		successional	decline*	SW
Chipping Sparrow		grassland	increase*	NE

Breeding Species	State/federal Conservation Status*	Primary nesting habitat	BBS population trend	BBS Trend Region
Field Sparrow		successional	decline*	NE
Vesper Sparrow	SH	forest	decline	NE
Savannah Sparrow		grassland	decline	NE
Grasshopper Sparrow	ST	grassland	decline	NE
Saltmarsh Sparrow		wetland	increase*	SW
Seaside Sparrow	C	wetland	increase	NE
Song Sparrow		successional	decline	NE
Swamp Sparrow		wetland	decline	NE
White-throated Sparrow	C	successional	decline*	NE
Dark-eyed Junco	C	forest	decline*	NE
Bobolink		grassland	decline*	NE
Red-winged Blackbird		wetland	decline*	NE
Eastern Meadowlark		grassland	decline*	NE
Common Grackle		forest	decline*	NE
Brown-headed Cowbird		successional	increase*	NE
Orchard Oriole		successional	increase	NE
Baltimore Oriole		forest	decline*	NE
Purple Finch		forest	decline*	NE
House Finch		Urban	decline	NE
American Goldfinch		successional	increase	NE
Evening Grosbeak		forest	increase*	NE
House Sparrow		urban	decline*	NE

*FT = Federally Threatened; FE = Federally Endangered, ST = State Threatened, SE = State Endangered, C = State species of Concern

Table A2. 4 Status of migratory birds in Rhode Island, including primary habitat each species is usually detected based on Desante and Pyle (1986) and August et al. (2001).

Migratory Species	Status	Primary habitat[B]
Red-throated Loon	Common	Offshore
Pacific Loon	Rare	Offshore
Common Loon	Common	Offshore
Pied-billed Grebe	Uncommon	Wetland
Horned Grebe	Fairly Common	Wetland
Eared Grebe	Accidental	Wetland
Western Grebe	Accidental	Offshore
Yellow-nosed Albatross	Accidental	Off shore
Great Shearwater	Common	Offshore
Sooty Shearwater	Fairly common	Offshore
White-faced Storm-Petrel	Accidental	Offshore
Leach's Storm-Petrel	Rare	Offshore
Red-billed Tropicbird	Accidental	Offshore
Northern Gannet	Common	Offshore
American White Pelican	Accidental	Offshore
Brown Pelican	Accidental	Offshore
Double-crested Cormorant	Common	Coastal
Great Cormorant	Uncommon	Coastal
Magnificent Frigatebird	Accidental	Offshore
American Bittern	Rare	Wetland
Least Bittern	Rare	Wetland
Great Blue Heron	Uncommon	Forest
Great Egret	Fairly Common	Wetland
Snowy Egret	Fairly Common	Wetland
Little Blue Heron	Rare	Wetland
Tricolored Heron	Rare	Wetland
Cattle Egret	Fairly Common	Grassland
Green Heron	Fairly Common	Wetland
Black-crowned Night-Heron	Fairly Common	Wetland
Yellow-crowned Night	Rare	Wetland s

Migratory Species	**Status**	**Primary habitat[B]**
Heron		
White Ibis	Accidental	Wetland
Glossy Ibis	Uncommon	Wetland
Wood Stork	Accidental	Wetland
Fulvous Whistling -Duck	Accidental	Wetland
Tundra Swan	Rare	Wetland
Mute Swan	Common	Wetland
Greater White-fronted Goose	Uncommon	Wetland/upland
Snow Goose	Uncommon	Wetland/upland
Canada Goose	Common	Wetland/upland
Brant	Fairly common	Wetland/upland
Wood Duck	Fairly common	Wetland
Green-winged Teal	Common	Wetland
American Black Duck	Common	Wetland
Mallard	Common	Wetland
Northern Pintail	Fairly common	Wetland
Blue-winged Teal	Uncommon	Wetland
Northern Shoveler	Uncommon	Wetland
Gadwall	Fairly common	Wetland
Eurasian Wigeon	Rare	Wetland
American Wigeon	Common	Wetland
Canvasback	Fairly common	Wetland
Redhead	Uncommon	Wetland
Ring-necked Duck	Fairly common	Wetland
Greater Scaup	Uncommon	Wetland
Lesser Scaup	Fairly common	Wetland
Common Eider	Common	Wetland
King Eider	Rare	Wetland
Harlequin Duck	Uncommon	Nearshore
Long-tailed Duck	Uncommon	Offshore
Black Scoter	Common	Off shore

Migratory Species	**Status**	**Primary habitat[B]**
Surf Scoter	Common	Off shore
White-winged Scoter	Common	Off shore
Common Goldeneye	Common	Nearshore
Barrow's Goldeneye	Rare	Wetland
Bufflehead	Common	Wetland
Hooded Merganser	Fairly common	Wetland
Common Merganser	Uncommon	Wetland
Red-breasted Merganser	Common	Nearshore
Ruddy Duck	Fairly common	Wetland
Black Vulture	Uncommon	Mixed
Turkey Vulture	Common	Mixed
Osprey	Common	Nearshore/wetland
Swallow-tailed Kite	Accidental	Mixed
Bald Eagle	Uncommon	Wetland
Northern Harrier	Uncommon	Grassland
Sharp-shinned Hawk	Common	Forest
Cooper's Hawk	Common	Forest
Northern Goshawk	Uncommon	Forest
Red-shouldered Hawk	Uncommon	Forest
Broad-winged Hawk	Common	Forest
Swainson's Hawk	Accidental	Mixed
American Kestrel	Uncommon	Grassland
Merlin	Uncommon	Mixed
Peregrine Falcon	Uncommon	Mixed
Black Rail	Accidental	Wetland
Corn Rail	Accidental	Wetland
Clapper Rail	Rare	Wetland
King Rail	Rare	Wetland
Virginia Rail	Rare	Wetland
Sora	Uncommon	Wetland
Purple Gallinule	Accidental	Wetland
Common Moorhen	Uncommon	Wetland

Migratory Species	**Status**	**Primary habitat[B]**
American Coot	Common	Wetland
Sandhill Crane	Rare	Wetland/upland
Northern Lapwing	Accidental	Wetland
Black-bellied Plover	Fairly common	Wetland/intertidal
American Golden-Plover	Uncommon	Grassland
Wilson's Plover	Accidental	Wetland/intertidal
Semipalmated Plover	Common	Wetland/intertidal
Piping Plover	Uncommon	Wetland/intertidal
Killdeer	Common	Grassland
American Oystercatcher	Uncommon	Intertidal
Black-necked Stilt	Rare	Wetland/intertidal
American Avocet	Uncommon	Wetland/intertidal
Greater Yellowlegs	Common	Wetland/intertidal
Lesser Yellowlegs	Uncommon	Wetland/intertidal
Spotted Redshank	Accidental	Wetland/intertidal
Solitary Sandpiper	Uncommon	Wetland/intertidal
Willet	Uncommon	Wetland/intertidal
Spotted Sandpiper	Uncommon	Wetland/intertidal
Upland Sandpiper	Rare	Grassland
Eskimo Curlew	Extinct	Wetland/intertidal
Whimbrel	Uncommon	Wetland/intertidal
Long-billed Curlew	Accidental	Wetland/intertidal
Hudsonian Godwit	Rare	Wetland/intertidal
Marbled Godwit	Rare	Wetland/intertidal
Ruddy Turnstone	Common	Wetland/intertidal
Red Knot	Uncommon	Wetland/intertidal
Sanderling	Common	Wetland/intertidal
Semipalmated Sandpiper	Common	Wetland/intertidal
Western Sandpiper	Uncommon	Wetland/intertidal
Least Sandpiper	Common	Wetland/intertidal
White-rumped Sandpiper	Uncommon	Wetland/intertidal
Baird's Sandpiper	Uncommon	Wetland/intertidal

Migratory Species	**Status**	**Primary habitat**[B]
Pectoral Sandpiper	Uncommon	Wetland/intertidal
Dunlin	Common	Wetland/intertidal
Curlew Sandpiper	Accidental	Wetland/intertidal
Stilt Sandpiper	Uncommon	Wetland/intertidal
Buff-breasted Sandpiper	Uncommon	Grassland
Ruff	Rare	Wetland/intertidal
Short-billed Dowitcher	Common	Wetland/intertidal
Long-billed Dowitcher	Uncommon	Wetland/intertidal
Common Snipe	Fairly common	Wetland/intertidal
Wilson's Phalarope	Rare	Wetland/intertidal
Red-necked Phalarope	Fairly common	Offshore
Red Phalarope	Fairly common	Offshore
Pomarine Jaegar	Uncommon	Offshore
Parasitic Jaegar	Uncommon	Offshore
Long-tailed Jaeger	Rare	Offshore
South Polar Skua	Rare	Offshore
Laughing Gull	Common	Nearshore
Franklin's Gull	Accidental	Nearshore
Little Gull	Rare	Nearshore
Common Black-head Gull	Rare	Wetland/nearshore
Bonaparte's Gull	Uncommon	Nearshore
Mew Gull	Accidental	Nearshore
Ring-billed Gull	Common	Wetland/nearshore
Herring Gull	Common	Wetland/nearshore
Great Black-backed Gull	Common	Wetland/nearshore
Black-legged Kittewake	Uncommon	Offshore
Sabine's Gull	Accidental	Offshore
Gull-billed Tern	Rare	Nearshore
Caspian Tern	Uncommon	Nearshore
Royal Tern	Rare	Nearshore
Sandwich Tern	Accidental	Nearshore
Roseate Tern	Fairly common	Nearshore

Migratory Species	Status	Primary habitat[B]
Common Tern	Common	Nearshore
Arctic Tern	Rare	Nearshore
Forster's Tern	Uncommon	Nearshore
Least Tern	Uncommon	Nearshore
Bridled Tern	Accidental	Nearshore
Sooty Tern	Accidental	Nearshore
Black Tern	Uncommon	Nearshore
Brown Noddy	Accidental	Nearshore
Black Skimmer	Uncommon	Nearshore
Mourning Dove	Common	Mixed
Rock Dove	Common	Urban
Black-billed Cuckoo	Uncommon	Forest
Yellow-billed Cuckoo	Uncommon	Forest
Eastern Screech-Owl	Uncommon	Forest
Great Horned Owl	Uncommon	Forest
Northern Hawk Owl	Accidental	Forest
Burrowing Owl	Accidental	Forest
Barred Owl	Uncommon	Forest
Great Gray Owl	Accidental	Forest
Long-eared Owl	Rare	Forest
Short-eared Owl	Uncommon	Grassland
Boreal Owl	Accidental	Forest
Northern Saw-whet Owl	Common	Forest
Common Nighthawk	Uncommon	Grassland/mixed
Chuck-will's-widow	Rare	Forest/mixed
Whip-poor-will	Uncommon	Forest/mixed
Chimney Swift	Uncommon	Mixed
Ruby-throated Hummingbird	Common	Mixed
Belted Kingfisher	Uncommon	Wetland
Lewis' Woodpecker	Accidental	Forest
Red-headed Woodpecker	Uncommon	Forest

Migratory Species	Status	Primary habitat[B]
Red-bellied Woodpecker	Common	Forest
Yellow-bellied Sapsucker	Fairly common	Forest
Downy Woodpecker	Common	Forest
Hairy Woodpecker	Uncommon	Forest
Black-backed Woodpecker	Accidental	Forest
Northern Flicker	Common	Mixed
Pileated Woodpecker	Rare	Forest
Olive-sided Flycatcher	Uncommon	Forest
Eastern Wood-Pewee	Common	Forest
Yellow-bellied Flycatcher	Uncommon	Forest
Acadian Flycatcher	Rare	Forest
Alder Flycatcher	Uncommon	Forest
Least Flycatcher	Uncommon	Forest
Say's Phoebe	Accidental	Mixed
Ash-throated Flycatcher	Accidental	Forest
Great-crested Flycatcher	Uncommon	Forest
Western Kingbird	Rare	Mixed
Eastern Kingbird	Common	Wetland
Scissor-tailed Flycatcher	Accidental	Grassland
Horned Lark	Uncommon	Grassland
Purple Martin	Uncommon	Mixed
Tree Swallow	Common	Mixed
N. Rough-winged Swallow	Uncommon	Mixed
Bank Swallow	Uncommon	Mixed
Cliff Swallow	Rare	Mixed
Cave Swallow	Rare	Coastal
Barn Swallow	Common	Mixed
Blue Jay	Common	Mixed
Jackdaw	Accidental	
American Crow	Common	Mixed
Fish Crow	Common	Mixed
Common Raven	Rare	Forest

Migratory Species	Status	Primary habitat[B]
Black-capped Chickadee	Common	Forest
Tufted Titmouse	Common	Forest
Red-breasted Nuthatch	Common	Forest
White-breasted Nuthatch	Common	Forest
Brown Creeper	Common	Forest
Carolina Wren	Common	Mixed
Bewick's Wren	Accidental	Forest
House Wren	Common	Mixed
Winter Wren	Uncommon	Forest
Sedge Wren	Rare	Wetland
Marsh Wren	Uncommon	Wetland
Golden-crowned Kinglet	Common	Forest
Ruby-crowned Kinglet	Common	Forest
Blue-gray Gnatcatcher	Uncommon	Forest
Northern Wheateater	Accidental	Coastal
Eastern Bluebird	Uncommon	Grassland
Veery	Fairly common	Forest
Gray-cheeked Thrush	Uncommon	Forest
Bicknell's Thrush	Uncommon	Forest
Swainson's Thrush	Fairly common	Forest
Hermit Thrush	Fairly common	Forest
Wood Thrush	Fairly common	Forest
American Robin	Common	Mixed
Gray Catbird	Common	Forest
Northern Mockingbird	Common	Mixed
Brown Thrasher	Uncommon	Mixed
American Pipit	Fairly common	Grassland
Bohemian Waxwing	Accidental	Forest
Cedar Waxwing	Common	Mixed
European Starling	Common	Mixed
Phainopepla	Accidental	Mixed
White-eyed Vireo	Uncommon	Forest

Migratory Species	Status	Primary habitat[B]
Blue-headed Vireo	Uncommon	Forest
Yellow-throated Vireo	Uncommon	Forest
Warbling Vireo	Uncommon	Forest
Philadelphia Vireo	Rare	Forest
Red-eyed Vireo	Common	Forest
Blue-winged Warbler	Uncommon	Mixed
Golden-winged Warbler	Rare	Mixed
Tennessee Warbler	Uncommon	Forest
Orange-crowned Warbler	Uncommon	Forest
Nashville Warbler	Uncommon	Mixed
Northern Parula	Fairly common	Forest
Yellow Warbler	Uncommon	Mixed
Chestnut-sided Warbler	Uncommon	Mixed
Magnolia Warbler	Fairly common	Forest
Cape May Warbler	Fairly common	Forest
Black-throated Blue Warbler	Fairly common	Forest
Yellow-rumped Warbler	Common	Mixed
Black-throated Gray Warbler	Accidental	Forest
Black-throated Green Warbler	Common	Forest
Blackburnian Warbler	Uncommon	Forest
Yellow-throated Warbler	Rare	Forest
Pine Warbler	Fairly common	Forest
Prairie Warbler	Uncommon	Mixed
Palm Warbler	Fairly common	Forest
Bay-breasted Warbler	Uncommon	Forest
Blackpoll Warbler	Common	Forest
Cerulean Warbler	Rare	Forest
Black-and-white Warbler	Common	Forest
American Redstart	Common	Forest

Migratory Species	**Status**	**Primary habitat**^{B}
Prothonotary Warbler	Uncommon	wetland
Worm-eating Warbler	Uncommon	Forest
Ovenbird	Common	Forest
Northern Waterthrush	Fairly common	Forest
Louisiana Waterthrush	Uncommon	Forest
Kentucky Warbler	Rare	Forest
Connecticut Warbler	Uncommon	Forest
Mourning Warbler	Uncommon	Forest
Common Yellowthroat	Common	Mixed
Hooded Warbler	Uncommon	Forest
Wilson's Warbler	Uncommon	Forest
Canada Warbler	Uncommon	Wetland
Yellow-breasted Chat	Rare	Mixed
Summer Tanager	Rare	Forest
Scarlet Tanager	Uncommon	Forest
Western Tanager	Accidental	Forest
Northern Cardinal	Common	Mixed
Rose-breasted Grosbeak	Uncommon	Forest
Black-headed Grosbeak	Accidental	Forest
Blue Grosbeak	Uncommon	Forest
Indigo Bunting	Uncommon	Mixed
Painted Bunting	Accidental	Mixed
Dickcissel	Rare	Grassland
Eastern Towhee	Uncommon	Mixed
American Tree Sparrow	Uncommon	Forest
Chipping Sparrow	Common	Mixed
Clay-colored Sparrow	Rare	Mixed
Field Sparrow	Uncommon	Mixed
Lark Sparrow	Rare	Grassland
Lark Bunting	Accidental	Grassland
Savannah Sparrow	Common	Grassland
Grasshopper Sparrow	Rare	Grassland

Migratory Species	Status	Primary habitat[B]
Henslow's Sparrow	Accidental	Grassland
Nelson's Sparrow	Uncommon	Saltmarsh
Saltmarsh Sparrow	Uncommon	Saltmarsh
Seaside Sparrow	Rare	Saltmarsh
Fox Sparrow	Fairly common	Forest
Song Sparrow	Common	Mixed/forest
Lincoln's Sparrow	Uncommon	Mixed
Swamp Sparrow	Uncommon	Mixed
White-throated Sparrow	Common	Mixed/forest
White-crowned Sparrow	Uncommon	Mixed
Harris Sparrow	Accidental	Mixed
Dark-eyed Junco	Common	Forest
Smith's Longspur	Accidental	Grassland
Bobolink	Uncommon	Grassland
Red-winged Blackbird	Common	Mixed
Eastern Meadowlark	Rare	Grassland
Western Meadowlark	Accidental	Grassland
Yellow-headed Blackbird	Rare	Marsh
Rusty Blackbird	Uncommon	Forest
Brewer's Blackbird	Accidental	Mixed
Common Grackle	Common	Mixed/forest
Brown-headed Cowbird	Common	Mixed/forest
Orchard Oriole	Uncommon	Mixed
Baltimore Oriole	Uncommon	Forest
Purple Finch	Uncommon	Forest
House Finch	Common	Mixed
American Goldfinch	Common	Mixed
Evening Grosbeak	Uncommon	Forest
House Sparrow	Common	Urban

[A] Desante and Pyle (1986) definitions: few individuals encountered on >90% of days (common); 50-90% (fairly common); 10-50% of days (uncommon); <10% of days (rare); Occuring outside of its range (accidental); unrecorded in last 50 years (extinct); or many individuals encountered on >50% of days (common); 10-50% of days (fairly common); >10% of days (uncommon).

[B] Mixed includes old field, scrub-shrub, early successional

Table A2. 5 Summary of the total number of individuals captured at three constant-effort bird banding stations in Rhode Island.

	Kingston Wildlife Research Station			**Block Island Banding Station**			**Ninigret NWR**			
Species	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Overall rank**
Northern Harrier			109	8	0.01	112			72	293
Sharp-shinned Hawk	2	0.01	94	79	0.08	74	4	0.07	41	209
Cooper's Hawk			109	3	0.00	126			72	307
American Kestrel			109	3	0.00	126			72	307
Merlin			109	7	0.01	115			72	296
American Woodcock	11	0.03	84	78	0.08	75			72	231
Mourning Dove	8	0.02	85	34	0.03	93			72	250
Black-billed Cuckoo	15	0.04	79	71	0.07	79			72	230
Yellow-billed Cuckoo	5	0.01	91	47	0.05	83	2	0.03	52	226
Northern Saw-whet Owl			109	83	0.08	73			72	254
Whip-poor-will			109	7	0.01	115	2	0.03	52	276
Yellow-bellied Sapsucker	17	0.05	74	284	0.29	45			72	191
Red-bellied Woodpecker	16	0.05	75	8	0.01	112			72	259
Downy Woodpecker	224	0.67	33	197	0.20	57	9	0.15	32	122
Hairy Woodpecker	7	0.02	87	10	0.01	108			72	267
Northern Flicker	69	0.21	52	558	0.57	33	1	0.02	60	145
Olive-sided Flycatcher			109	5	0.01	120			72	301
Eastern Wood-Pewee	38	0.11	63	75	0.08	76	1	0.02	60	199
Willow Flycatcher	2	0.01	94	50	0.05	82			72	248

	Kingston Wildlife Research Station			Block Island Banding Station			Ninigret NWR			
Species	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Overall rank**
Traill's Flycatcher	119	0.35	42	100	0.10	70	56	0.92	9	121
Least Flycatcher	75	0.22	51	169	0.17	62	1	0.02	60	173
Yellow-bellied Flycatcher	96	0.29	46	149	0.15	65			72	183
Empidonax spp.			109	17	0.02	101			72	282
Acadian Flycatcher	1	0.00	101	39	0.04	90			72	263
Eastern Phoebe	185	0.55	35	659	0.67	29	37	0.61	12	76
Say's Phoebe			109	1	0.00	134			72	315
Great-crested Flycatcher	21	0.06	70	43	0.04	87			72	229
Eastern Kingbird	4	0.01	92	41	0.04	88			72	252
Loggerhead Shrike			109	1	0.00	134			72	315
Northern Shrike			109	2	0.00	130			72	311
Philadelphia Vireo	20	0.06	72	187	0.19	59	3	0.05	47	178
White-eyed Vireo	162	0.48	38	283	0.29	46	32	0.53	14	98
Red-eyed Vireo	434	1.29	23	3986	4.06	6	52	0.86	10	39
Warbling Vireo			109	187	0.19	60			72	241
Yellow-throated Vireo	7	0.02	87	12	0.01	103			72	262
Blue-headed Vireo	138	0.41	39	588	0.60	31	5	0.08	38	108
Blue Jay	166	0.49	37	860	0.88	24	17	0.28	19	80
American Crow			109	9	0.01	109			72	290
Purple Martin			109	1	0.00	134			72	315

Species	Kingston Wildlife Research Station			Block Island Banding Station			Ninigret NWR			Overall rank
	Total number of individuals	% of all birds captured	Rank	Total number of individuals	% of all birds captured	Rank	Total number of individuals	% of all birds captured	Rank	
Barn Swallow	2	0.01	94	9	0.01	109			72	275
Tree Swallow	21	0.06	70	87	0.09	72	119	1.96	5	147
Northern Rough-winged Swallow			109	8	0.01	112			72	293
Bank Swallow			109	28	0.03	95			72	276
Black-capped Chickadee	1217	3.63	6	447	0.46	36	312	5.13	3	45
Tufted Titmouse	445	1.33	21	1	0.00	134	24	0.39	17	172
Brown Creeper	60	0.18	54	1570	1.60	15	3	0.05	47	116
White-breasted Nuthatch	112	0.33	44	38	0.04	91	1	0.02	60	195
Red-breasted Nuthatch	8	0.02	85	685	0.70	27	1	0.02	60	172
Marsh Wren	1	0.00	101	25	0.03	98	4	0.07	41	240
Carolina Wren	225	0.67	32	348	0.35	39	6	0.10	36	107
Bewick's Wren			109	1	0.00	134			72	315
House Wren	482	1.44	18	621	0.63	30	16	0.26	24	72
Winter Wren	54	0.16	56	551	0.56	34	2	0.03	52	142
Golden-crowned Kinglet	399	1.19	24	4023	4.10	5	30	0.49	15	44
Ruby-crowned Kinglet	713	2.12	12	2136	2.17	9	17	0.28	19	40
Blue-gray Gnatcatcher	2	0.01	94	38	0.04	91			72	257
Eastern Bluebird			109	3	0.00	126		0.00	72	307
Swainson's Thrush	273	0.81	29	1725	1.76	12	9	0.15	32	73
Veery	556	1.66	16	1088	1.11	21	10	0.16	31	68

	Kingston Wildlife Research Station			Block Island Banding Station			Ninigret NWR			
Species	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Overall rank**
Gray-cheeked Thrush	110	0.33	45	780	0.79	26			72	143
Hermit Thrush	789	2.35	8	2158	2.20	8	25	0.41	16	32
Wood Thrush	460	1.37	20	252	0.26	50			72	142
American Robin	329	0.98	25	1531	1.56	16	8	0.13	34	75
Gray Catbird	5221	15.55	1	14858	15.13	2	698	11.48	2	5
Northern Mockingbird	16	0.05	75	23	0.02	99			72	246
Brown Thrasher	180	0.54	36	323	0.33	43	4	0.07	41	120
European Starling			109	47	0.05	83			72	264
Cedar Waxwing	32	0.10	66	840	0.86	25	4	0.07	41	132
Phainopepla			109	1	0.00	134			72	315
Snow Bunting			109	7	0.01	115			72	296
Tennessee Warbler	30	0.09	67	191	0.19	58			72	197
Nashville Warbler	96	0.29	47	262	0.27	48	4	0.07	41	136
Orange-crowned Warbler	12	0.04	81	22	0.02	100	1	0.02	60	241
Blue-winged Warbler	874	2.61	7	66	0.07	80	6	0.10	36	123
Golden-winged Warbler	16	0.05	75	11	0.01	106	1	0.02	60	241
Brewster's Warbler	2	0.01	94	1	0.00	134			72	300
Lawrence's Warbler	1	0.00	101			147			72	320
Northern Parula	52	0.15	58	685	0.70	27	3	0.05	47	132
Yellow Warbler	13	0.04	80			147	12	0.20	27	254

	Kingston Wildlife Research Station			**Block Island Banding Station**			**Ninigret NWR**			
Species	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Overall rank**
Chestnut-sided Warbler	305	0.91	27	159	0.16	63			72	162
Magnolia Warbler	230	0.69	31	1582	1.61	14	12	0.20	27	72
Cape May Warbler	33	0.10	65	336	0.34	40			72	177
Blackburnian Warbler	12	0.04	81	72	0.07	77			72	230
Black-throated Blue Warbler	293	0.87	28	1235	1.26	20	1	0.02	60	108
Cerulean Warbler	2	0.01	94	1	0.00	134			72	300
Black-throated Green Warbler	82	0.24	50	257	0.26	49	5	0.08	38	137
Yellow-rumped Warbler	3824	11.39	2	20058	20.42	1	3930	64.63	1	4
Palm Warbler	51	0.15	59	418	0.43	38	17	0.28	19	116
Pine Warbler			109	17	0.02	101			72	282
Prairie Warbler	26	0.08	69	72	0.07	77	13	0.21	25	171
Blackpoll Warbler	479	1.43	19	1643	1.67	13	36	0.59	13	45
Bay-breasted Warbler	20	0.06	72	199	0.20	55			72	199
Black-and-white Warbler	715	2.13	11	1243	1.27	19	11	0.18	31	61
Yellow-throated Warbler			109	2	0.00	130			72	311
American Redstart	1675	4.99	5	1858	1.89	11	60	0.99	7	23
Prothonotary Warbler	1	0.00	101	7	0.01	115			72	288
Worm-eating Warbler	62	0.18	53	44	0.04	86			72	211

	Kingston Wildlife Research Station			Block Island Banding Station			Ninigret NWR			
Species	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Overall rank**
Common Yellowthroat	2108	6.28	4	5882	5.99	3	157	2.58	4	11
Mourning Warbler	56	0.17	55	145	0.15	66	2	0.03	52	173
Connecticut Warbler	49	0.15	61	46	0.05	85	5	0.08	38	184
Kentucky Warbler	1	0.00	101	26	0.03	97			72	270
Northern Waterthrush	272	0.81	30	986	1.00	23	12	0.20	27	80
Louisiana Waterthrush			109	4	0.00	123			72	304
Ovenbird	603	1.80	14	1025	1.04	22	3	0.05	47	83
Canada Warbler	309	0.92	26	443	0.45	37	1	0.02	60	123
Hooded Warbler	129	0.38	40	33	0.03	94	1	0.02	60	194
Wilson's Warbler	50	0.15	60	242	0.25	52	4	0.07	41	153
Yellow-breasted Chat	83	0.25	49	135	0.14	67	12	0.20	27	143
Scarlet Tanager	88	0.26	48	12	0.01	103			72	223
Summer Tanager			109	331	0.34	42			72	223
Western Tanager			109	2	0.00	130			72	311
Dickcissel	2	0.01	94			147			72	313
Rose-breasted Grosbeak	62	0.18	53	309	0.31	44	1	0.02	60	157
Blue Grosbeak			109	4	0.00	123			72	304
Indigo Bunting	36	0.11	64	173	0.18	61	1	0.02	60	185
Northern Cardinal	497	1.48	17	502	0.51	35	21	0.35	18	70
Eastern Towhee	753	2.24	10	1344	1.37	18	44	0.72	11	39

	Kingston Wildlife Research Station			Block Island Banding Station			Ninigret NWR			
Species	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Total number of individuals**	**% of all birds captured**	**Rank**	**Overall rank**
Chipping Sparrow	45	0.13	62	128	0.13	68	2	0.03	52	182
Field Sparrow	123	0.37	41	159	0.16	63	17	0.28	19	123
American Tree Sparrow	1	0.00	101	25	0.03	98			72	271
Clay-colored Sparrow			109	4	0.00	123			72	304
Grasshopper Sparrow	1	0.00	101	3	0.00	126			72	299
Savannah Sparrow	4	0.01	92			147	8	0.13	34	273
Song Sparrow	636	1.89	13	2483	2.53	7	63	1.04	6	26
Lincoln's Sparrow	28	0.08	68	243	0.25	51	2	0.03	52	171
Henslow's Sparrow			109	1	0.00	134			72	315
Saltmarsh Sparrow			109	11	0.01	106			72	287
Swamp Sparrow	562	1.67	15	1378	1.40	17	58	0.95	8	40
Fox Sparrow	16	0.05	75	27	0.03	96			72	243
White-crowned Sparrow	12	0.04	81	199	0.20	55	3	0.05	47	183
White-throated Sparrow	2934	8.74	3	4425	4.51	4	13	0.21	25	32
Dark-eyed Junco	767	2.28	9	1911	1.95	10	17	0.28	19	38
Baltimore Oriole	115	0.34	43	334	0.34	41	3	0.05	47	131
Orchard Oriole			109	6	0.01	119			72	300
Bullock's Oriole			109	1	0.00	134			72	315
Bobolink	1	0.00	101	40	0.04	89			72	262
Red-winged Blackbird	6	0.02	89	265	0.27	47			72	208

Species	Kingston Wildlife Research Station			Block Island Banding Station			Ninigret NWR			Overall rank
	Total number of individuals	% of all birds captured	Rank	Total number of individuals	% of all birds captured	Rank	Total number of individuals	% of all birds captured	Rank	
Yellow-headed Blackbird			109	1	0.00	134			72	315
Eastern Meadowlark			109	1	0.00	134			72	315
Brewer's Blackbird			109	1	0.00	134			72	315
Rusty Blackbird			109	12	0.01	103			72	284
Brown-headed Cowbird	6	0.02	89	91	0.09	71			72	232
Common Grackle	19	0.06	73	113	0.12	69	2	0.03	52	194
American Goldfinch	216	0.64	34	567	0.58	32			72	138
Pine Siskin			109	54	0.05	81			72	262
Evening Grosbeak			109	9	0.01	109			72	290
House Finch	54	0.16	56	205	0.21	54			72	182
Purple Finch	440	1.31	22	235	0.24	53	2	0.03	52	127
Red Crossbill			109	2	0.00	130			72	311
House Sparrow			109	5	0.01	120			72	301
Total number of captures	**33571**			**98217**			**6081**			
Total number of species	**110**			**146**			**73**			

Table A2. 6 Summary of migratory and resident bird species that occur in winter in Rhode Island based on Desante and Pyle (1986).

Wintering Species	Winter Status	Habitat
Red-throated Loon	Common	Offshore
Pacific Loon	Rare	Offshore
Common Loon	Common	Offshore
Pied-billed Grebe	Uncommon	Wetland
Horned Grebe	Fairly Common	Wetland
Red-necked Grebe	Uncommon	Wetland
Eared Grebe	Accidental	Wetland
Western Grebe	Accidental	Wetland
Northern Fulmar	Uncommon	Offshore
Northern Gannet	Uncommon	Offshore
Double-crested Cormorant	Uncommon	Coastal
Great Cormorant	Common	Coastal
American Bittern	Rare	Wetland
Great Blue Heron	Uncommon	Wetland
Great Egret	Rare	Wetland
Snowy Egret	Accidental	Wetland
Green Heron	Accidental	Wetland
Black-crowned Night-Heron	Uncommon	Wetland
Tundra Swan	Rare	Wetland
Mute Swan	Common	Wetland
Greater White-fronted Goose	Rare	Wetland
Snow Goose	Rare	Wetland
Canada Goose	Common	Wetland/grassland
Brant	Common	Nearshore
Wood Duck	Rare	Wetland
Green-winged Teal	Uncommon	Wetland
American Black Duck	Common	Wetland
Mallard	Common	Wetland
Northern Pintail	Uncommon	Wetland
Blue-winged Teal	Rare	Wetland
Northern Shoveler	Rare	Wetland

Wintering Species	Winter Status	Habitat
Gadwall	Uncommon	Wetland
Eurasian Wigeon	Rare	Wetland
American Wigeon	Uncommon	Wetland
Canvasback	Uncommon	Wetland
Redhead	Rare	Wetland
Ring-necked Duck	Uncommon	Wetland
Greater Scaup	Common	Nearshore
Lesser Scaup	Uncommon	Nearshore
Common Eider	Common	Offshore
King Eider	Rare	Offshore
Harlequin Duck	Uncommon	Offshore
Long-tailed Duck	Uncommon	Offshore
Black Scoter	Common	Offshore
Surf Scoter	Common	Offshore
White-winged Scoter	Common	Offshore
Common Goldeneye	Common	Nearshore
Barrow's Goldeneye	Rare	Nearshore
Bufflehead	Common	Nearshore
Smew	Accidental	Nearshore
Hooded Merganser	Uncommon	Wetland
Common Merganser	Uncommon	Wetland
Red-breasted Merganser	Common	Nearshore
Ruddy Duck	Common	Wetland
Black Vulture	Rare	Mixed
Turkey Vulture	Uncommon	Mixed
Osprey	Rare	Nearshore
Bald Eagle	Uncommon	Nearshore/wetland
Northern Harrier	Uncommon	Grassland
Sharp-shinned Hawk	Uncommon	Forest
Cooper's Hawk	Uncommon	Forest
Northern Goshawk	Rare	Forest
Red-shouldered Hawk	Rare	Forest

Wintering Species	**Winter Status**	**Habitat**
Red-tailed Hawk	Common	Mixed
Rough-legged Hawk	Uncommon	Grassland
Golden Eagle	Rare	Mixed
American Kestrel	Fairly Common	Grassland
Merlin	Rare	Mixed
Peregrine Falcon	Rare	Mixed
Gyrfalcon	Rare	Mixed
Ring-necked Pheasant	Uncommon	Grassland
Ruffed Grouse	Uncommon	Forest
Wild Turkey	Common	Mixed
Northern Bobwhite	Uncommon	Successional
Yellow Rail	Accidental	Marsh
Clapper Rail	Rare	Marsh
King Rail	Accidental	Wetland/ saltmarsh
Virginia Rail	Rare	Wetland/ saltmarsh
Sora	Rare	Wetland/ saltmarsh
Common Moorhen	Accidental	Wetland
American Coot	Uncommon	Wetland
Black-bellied Plover	Rare	Intertidal
Killdeer	Rare	Grassland
Greater Yellowlegs	Rare	Intertidal
Lesser Yellowlegs	Rare	Intertidal
Upland Sandpiper		Grassland
Ruddy Turnstone	Rare	Intertidal
Red Knot	Rare	Intertidal
Sanderling	Uncommon	Intertidal
Western Sandpiper	Accidental	Intertidal
Least Sandpiper	Rare	Intertidal
Purple Sandpiper	Uncommon	Intertidal
Dunlin	Uncommon	Intertidal
Long-billed Dowitcher	Rare	Intertidal
Common Snipe	Rare	Wetland

Wintering Species	Winter Status	Habitat
American Woodcock	Uncommon	Mixed
Greater Skua	Accidental	Offshore
Laughing Gull	Accidental	Offshore
Little Gull	Rare	Offshore
Common Black-head Gull	Rare	Nearshore
Bonaparte's Gull	Uncommon	Nearshore
Ring-billed Gull	Fairly Common	Nearshore
Herring Gull	Common	Nearshore/Offshore
Thayer's Gull	Accidental	Offshore
Iceland Gull	Uncommon	Offshore
Lesser Black-backed Gull	Rare	Offshore
Glaucous Gull	Uncommon	Offshore
Great Black-backed Gull	Common	Nearshore/Offshore
Black-legged Kittiwake	Common	Offshore
Caspian Tern		Nearshore
Roseate Tern		Nearshore
Bridled Tern	Accidental	Offshore
Dovekie	Common	Offshore
Common Murre	Uncommon	Offshore
Thick-billed Murre	Rare	Offshore
Razorbill	Uncommon	Offshore
Black Guillemot	Uncommon	Offshore
Atlantic Puffin	Rare	Offshore
Mourning Dove	Common	Mixed
Rock Dove	Common	Urban
Eastern Screech-Owl	Uncommon	Forest
Great Horned Owl	Uncommon	Forest
Snowy Owl	Uncommon	Forest
Barred Owl	Uncommon	Forest
Great Gray Owl	Accidental	Forest
Long-eared Owl	Uncommon	Forest
Short-eared Owl	Uncommon	Grassland

Wintering Species	Winter Status	Habitat
Boreal Owl	Accidental	Forest
Northern Saw-whet Owl	Uncommon	Forest
Belted Kingfisher	Uncommon	Wetland
Red-headed Woodpecker	Rare	Forest
Red-bellied Woodpecker	Common	Forest
Yellow-bellied Sapsucker	Rare	Forest
Downy Woodpecker	Common	Forest
Hairy Woodpecker	Uncommon	Forest
Black-backed Woodpecker	Accidental	Forest
Northern Flicker	Uncommon	Forest
Pileated Woodpecker	Rare	Forest
Eastern Phoebe	Uncommon	Forest
Say's Phoebe	Accidental	Mixed
Horned Lark	Uncommon	Grassland
Tree Swallow	Rare	Successional
Blue Jay	Common	Forest
American Crow	Common	Mixed
Fish Crow	Uncommon	Forest
Common Raven	Uncommon	Forest
Black-capped Chickadee	Common	Forest
Boreal Chickadee	Rare	Forest
Tufted Titmouse	Common	Forest
Red-breasted Nuthatch	Common	Forest
White-breasted Nuthatch	Common	Forest
Brown Creeper	Uncommon	Forest
Carolina Wren	Common	Forest
House Wren	Rare	Mixed
Winter Wren	Uncommon	Forest
Sedge Wren		Wetland
Marsh Wren	Rare	Wetland
Golden-crowned Kinglet	Fairly Common	Forest
Ruby-crowned Kinglet	Uncommon	Forest

Wintering Species	Winter Status	Habitat
Eastern Bluebird	Uncommon	Grassland
Townsend's Solitaire	Accidental	Forest
Hermit Thrush	Uncommon	Forest
American Robin	Common	Mixed
Varied Thrush	Accidental	Forest
Gray Catbird	Uncommon	Forest
Northern Mockingbird	Uncommon	Mixed
Brown Thrasher	Rare	Mixed
American Pipit	Uncommon	Grassland
Bohemian Waxwing	Rare	Forest
Cedar Waxwing	Fairly Common	Mixed
European Starling	Common	Urban/Mixed
Northern Shrike	Uncommon	Mixed
Loggerhead Shrike	Rare	Mixed
Golden-winged Warbler		Mixed
Orange-crowned Warbler	Rare	Forest
Yellow-rumped Warbler	Fairly Common	Mixed
Blackburnian Warbler	Accidental	Forest
Yellow-throated Warbler		Forest
Pine Warbler	Rare	Forest
Palm Warbler	Rare	Forest
Cerulean Warbler		Forest
Common Yellowthroat	Uncommon	Mixed
Yellow-breasted Chat	Rare	Shrubs
Northern Cardinal	Common	Mixed
Black-headed Grosbeak	Accidental	Forest
Blue Grosbeak	Accidental	Forest
Dickcissel	Rare	Grassland
Eastern Towhee	Uncommon	Mixed
American Tree Sparrow	Uncommon	Grassland
Chipping Sparrow	Rare	Grassland
Field Sparrow	Uncommon	Grassland

Wintering Species	Winter Status	Habitat
Lark Sparrow	Accidental	Grassland
Savannah Sparrow	Uncommon	Grassland
Henslow's Sparrow	Accidental	Grassland
Nelson's Sparrow	Rare	Marsh
Seaside Sparrow	Rare	Marsh
Fox Sparrow	Uncommon	Forest
Song Sparrow	Common	Mixed
Swamp Sparrow	Uncommon	Wetland/Mixed
White-throated Sparrow	Common	Forest/Mixed
White-crowned Sparrow	Rare	Mixed
Harris Sparrow	Accidental	Forest
Dark-eyed Junco	Common	Forest
Lapland Longspur	Uncommon	Grassland
Snow Bunting	Uncommon	Grassland
Red-winged Blackbird	Uncommon	Mixed
Eastern Meadowlark	Uncommon	Grassland
Yellow-headed Blackbird	Accidental	Marsh
Rusty Blackbird	Rare	Forest
Brewer's Blackbird	Accidental	Mixed
Common Grackle	Uncommon	Mixed
Brown-headed Cowbird	Uncommon	Mixed
Baltimore Oriole	Rare	Forest
Pine Grosbeak	Rare	Forest
Purple Finch	Fairly Common	Forest
House Finch	Common	Mixed
Red Crossbill	Uncommon	Forest
White-winged Crossbill	Uncommon	Forest
Common Redpoll	Fairly Common	Forest
Hoary Redpoll	Rare	Scrub
Pine Siskin	Fairly Common	Forest
American Goldfinch	Fairly Common	Mixed
Evening Grosbeak	Uncommon	Forest

Wintering Species	**Winter Status**	**Habitat**
House Sparrow	Common	Urban

[A] Desante and Pyle (1986) definitions: few individuals encountered on >90% of days (common); 50-90% (fairly common); 10-50% of days (uncommon); <10% of days (rare); Occuring outside of its range (accidental); unrecorded in last 50 years (extinct); or many individuals encountered on >50% of days (common); 10-50% of days (fairly common); >10% of days (uncommon).

Table A2.7. Average (Mean ± Standard deviation [SD]) number of individuals detected annually on four Christmas Bird Counts in Rhode Island for 233 species. Frequency (Freq) is the percent of counts with at least one detection. Data are available at http://birds.audubon.org/historical-results.

	Newport 1981-2010			Block Island 1981-2010			South Kingstown 1981-2010			Providence 1902-1950		
Species	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**FREQ**
Red-throated Loon	46.7	46.4	100.0	47.1	92.8	96.6	85.8	95.7	100.0	0.0	0.0	0.0
Pacific Loon	0.0	0.2	3.3	0.0	0.2	3.4	0.0	0.0	0.0	0.0	0.0	0.0
Common Loon	85.1	43.8	100.0	98.3	99.7	100.0	141.8	100.4	100.0	0.0	0.0	0.0
Pied-billed Grebe	4.8	7.6	83.3	1.1	1.6	55.2	4.3	7.2	73.3	0.0	0.2	2.9
Horned Grebe	126.7	72.7	100.0	16.9	30.7	96.6	50.2	39.3	100.0	1.0	2.0	29.4
Red-necked Grebe	7.2	7.7	86.7	3.8	6.2	65.5	4.8	5.6	83.3	0.0	0.0	0.0
Western Grebe	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sooty Shearwater	0.0	0.0	0.0	0.0	0.2	3.4	0.0	0.2	3.3	0.0	0.0	0.0
Northern Gannet	27.1	47.8	73.3	306.0	392.8	96.6	406.8	533.9	96.7	0.0	0.0	0.0
Brown Pelican	0.0	0.0	0.0	0.0	0.2	3.4	0.0	0.0	0.0	0.0	0.0	0.0
Double-crested Cormorant	6.8	6.7	93.3	6.8	9.5	89.7	32.0	21.1	96.7	0.0	0.0	0.0
Great Cormorant	714.4	915.4	100.0	66.4	58.9	96.6	182.1	191.5	100.0	0.2	0.7	8.8
American Bittern	0.3	0.4	26.7	0.3	0.6	27.6	0.7	0.9	50.0	0.0	0.0	0.0
Least Bittern	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Great Blue Heron	32.7	13.8	100.0	5.6	3.4	100.0	49.9	19.2	100.0	0.1	0.3	11.8
Great Egret	0.3	0.7	16.7	0.0	0.2	3.4	0.1	0.3	13.3	0.0	0.0	0.0
Snowy Egret	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Little Blue Heron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
Green Heron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0

	Newport 1981-2010			Block Island 1981-2010			South Kingstown 1981-2010			Providence 1902-1950		
Species	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**FREQ**
Black-crowned Night-Heron	0.8	2.4	20.0	0.9	1.8	34.5	1.0	2.4	36.7	3.9	5.8	41.2
Tundra Swan	0.6	2.6	13.3	0.2	0.7	10.3	0.2	0.7	10.0	0.0	0.0	0.0
Mute Swan	185.2	106.5	100.0	5.7	4.3	82.8	172.6	70.4	100.0	0.0	0.0	0.0
Greater White-fronted Goose	0.2	0.5	13.3	0.0	0.0	0.0	0.1	0.6	6.7	0.0	0.0	0.0
Snow Goose	2.4	5.2	36.7	0.6	1.0	31.0	1.8	7.6	26.7	0.0	0.0	0.0
Canada Goose	6352.9	2469.6	100.0	120.4	116.3	93.1	3028.9	1414.1	100.0	0.0	0.0	0.0
Brant	125.3	129.6	86.7	1.2	3.2	27.5	19.6	24.4	76.7	0.0	0.0	0.0
Wood Duck	1.2	2.0	53.3	0.4	0.8	24.1	1.1	1.7	43.3	0.1	0.4	5.9
Green-winged Teal	31.6	41.9	80.0	4.2	5.7	69.0	26.2	24.5	100.0	0.1	0.3	8.8
American Black Duck	1354.5	526.0	100.0	133.0	72.1	100.0	934.5	500.7	100.0	315.4	406.6	61.8
Mallard	726.0	304.8	100.0	79.4	82.1	100.0	748.7	310.2	100.0	4.1	7.2	38.2
Northern Pintail	53.9	57.3	100.0	0.8	1.8	27.6	47.7	26.1	100.0	0.6	2.6	11.8
Blue-winged Teal	0.3	0.8	20.0	0.1	0.3	10.3	0.3	0.8	20.0	0.0	0.0	0.0
Northern Shoveler	3.1	6.1	40.0	0.1	0.4	6.9	2.4	2.5	63.3	0.0	0.2	2.9
Gadwall	47.4	45.5	96.7	3.0	3.7	62.1	89.5	46.2	100.0	0.0	0.0	0.0
Eurasian Wigeon	0.3	0.5	26.7	0.1	0.3	6.9	0.3	0.6	26.7	0.0	0.2	2.9
American Wigeon	40.0	48.9	96.7	4.0	5.5	55.2	83.9	43.0	100.0	30.7	108.1	14.7
Canvasback	140.6	196.2	93.3	1.4	4.8	27.6	62.7	86.5	93.3	0.1	0.7	5.9
Redhead	1.9	5.5	43.3	1.2	4.5	13.8	3.4	9.4	36.7	0.0	0.0	0.0
Ring-necked Duck	15.9	38.6	70.0	12.5	16.2	72.4	34.5	40.4	93.3	0.1	0.9	2.9
Greater Scaup	1333.4	1054.9	100.0	4.8	13.7	48.3	143.8	175.3	96.7	2160.6	4305.0	35.3

	Newport 1981-2010			Block Island 1981-2010			South Kingstown 1981-2010			Providence 1902-1950		
Species	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**FREQ**
Lesser Scaup	71.0	66.4	96.7	1.3	3.8	34.5	29.8	48.1	76.7	0.0	0.0	0.0
Common Eider	1232.9	1828.4	100.0	630.5	1444.2	79.3	763.5	1578.1	96.7	0.0	0.0	0.0
King Eider	0.8	1.6	33.3	0.4	1.5	13.8	0.6	1.1	26.7	0.0	0.0	0.0
Harlequin Duck	64.8	41.2	100.0	0.8	1.4	27.6	0.9	1.6	36.7	0.0	0.0	0.0
Long-tailed Duck	4.4	4.7	83.3	3.7	4.5	69.0	11.0	14.3	63.3	0.8	3.5	11.8
Black Scoter	189.5	191.7	100.0	261.0	954.8	93.1	142.5	249.9	100.0	1.1	6.3	2.9
Surf Scoter	127.3	109.3	100.0	161.2	560.6	86.2	143.9	334.9	100.0	7.9	42.9	5.9
White-winged Scoter	200.5	211.9	100.0	200.5	399.0	96.6	75.2	47.5	100.0	28.9	120.9	23.5
Common Goldeneye	814.2	287.7	100.0	127.3	70.4	100.0	290.3	148.6	100.0	117.0	273.4	47.1
Barrow's Goldeneye	0.6	1.0	36.7	0.1	0.3	10.3	0.1	0.3	6.7	0.0	0.2	2.9
Bufflehead	558.7	179.7	100.0	62.0	33.7	100.0	189.5	99.8	96.7	23.1	31.8	52.9
Hooded Merganser	44.8	39.3	100.0	14.2	20.7	79.3	114.8	99.9	93.3	0.1	0.6	5.9
Common Merganser	215.1	135.3	100.0	2.2	2.9	62.1	64.4	70.5	96.7	41.5	89.3	41.2
Red-breasted Merganser	644.4	446.4	100.0	1400.0	2713.1	100.0	1275.5	1155.5	100.0	14.4	21.6	47.1
Ruddy Duck	298.6	435.1	100.0	70.1	132.0	75.9	152.9	288.1	80.0	2.2	12.9	2.9
Black Vulture	0.1	0.3	6.7	0.0	0.0	0.0	0.1	0.6	6.7	0.0	0.0	0.0
Turkey Vulture	22.3	28.6	60.0	0.0	0.2	3.4	5.7	8.6	56.7	0.0	0.0	0.0
Osprey	0.0	0.2	3.3	0.0	0.0	0.0	0.1	0.3	10.0	0.0	0.0	0.0
Bald Eagle	0.4	0.9	23.3	0.0	0.0	0.0	0.5	0.8	36.7	0.0	0.2	2.9
Northern Harrier	17.5	8.8	100.0	11.8	3.2	100.0	9.3	3.7	100.0	0.0	0.2	2.9
Sharp-shinned Hawk	10.0	5.3	100.0	3.7	2.4	96.6	8.1	4.8	100.0	0.2	0.5	14.7
Cooper's Hawk	5.0	5.2	76.7	2.0	2.4	62.1	4.3	4.4	83.3	0.1	0.2	5.9

	Newport 1981-2010			Block Island 1981-2010			South Kingstown 1981-2010			Providence 1902-1950		
Species	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**FREQ**
Northern Goshawk	0.4	0.6	30.0	0.1	0.3	6.9	0.4	0.8	26.7	0.0	0.0	0.0
Red-shouldered Hawk	2.3	3.6	56.7	0.0	0.0	0.0	2.2	1.9	70.0	0.3	0.5	26.5
Red-tailed Hawk	29.8	14.1	100.0	0.2	0.4	20.7	15.0	9.0	100.0	0.1	0.3	8.8
Rough-legged Hawk	0.9	1.3	40.0	0.0	0.2	3.4	0.8	1.8	36.7	0.1	0.7	2.9
Golden Eagle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
American Kestrel	15.6	11.9	100.0	2.1	2.4	58.6	5.1	5.2	96.7	0.9	1.0	55.9
Merlin	2.0	2.3	70.0	1.2	1.0	65.5	0.9	1.1	53.3	0.0	0.0	0.0
Peregrine Falcon	0.9	0.9	60.0	0.2	0.5	20.7	0.4	0.7	30.0	0.1	0.3	8.8
Gyrfalcon	0.1	0.3	6.7	0.0	0.0	0.0	0.0	0.0	0.0	1.6	3.4	32.4
Ring-necked Pheasant	5.4	7.7	70.0	25.0	16.0	100.0	0.4	0.6	36.7	0.1	0.5	5.9
Ruffed Grouse	0.3	0.7	20.0	0.0	0.0	0.0	0.8	1.0	50.0	0.0	0.0	0.0
Wild Turkey	3.2	8.3	20.0	0.2	0.8	10.3	17.3	28.3	46.7	0.0	0.0	0.0
Northern Bobwhite	0.3	1.0	10.0	0.0	0.0	0.0	4.6	9.6	46.7	0.0	0.0	0.0
Clapper Rail	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	6.7	0.0	0.0	0.0
Virginia Rail	2.8	3.1	83.3	2.8	2.4	82.8	1.1	1.7	50.0	0.0	0.0	0.0
Sora	0.1	0.4	3.3	0.0	0.0	0.0	0.1	0.4	6.7	0.0	0.0	0.0
Common Moorhen	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
American Coot	167.7	431.1	86.7	7.1	12.1	55.2	86.7	147.4	80.0	0.1	0.2	5.9
Sandhill Crane	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
Black-bellied Plover	2.4	5.8	46.7	6.4	8.2	72.4	2.3	2.8	56.7	0.0	0.0	0.0
American Golden-Plover	0.0	0.0	0.0	0.0	0.2	3.4	0.0	0.0	0.0	0.0	0.0	0.0
Semipalmated Plover	0.2	0.9	6.7	0.0	0.2	3.4	0.1	0.3	6.7	0.0	0.0	0.0

	Newport 1981-2010			Block Island 1981-2010			South Kingstown 1981-2010			Providence 1902-1950		
Species	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**FREQ**
Killdeer	5.1	7.5	80.0	0.1	0.4	13.8	4.3	4.6	83.3	0.1	0.6	5.9
Greater Yellowlegs	0.8	2.0	20.0	0.1	0.3	6.9	0.5	1.0	30.0	0.0	0.0	0.0
Lesser Yellowlegs	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Willet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
Spotted Sandpiper	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
Ruddy Turnstone	11.8	15.7	76.7	0.0	0.2	3.4	0.5	1.9	16.7	0.0	0.0	0.0
Red Knot	0.1	0.3	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sanderling	123.9	67.1	100.0	20.3	17.2	79.3	47.7	47.4	100.0	0.0	0.0	0.0
Least Sandpiper	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
White-rumped Sandpiper	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Purple Sandpiper	130.0	80.3	100.0	3.9	5.6	51.7	56.6	54.2	96.7	0.0	0.0	0.0
Dunlin	315.7	296.7	96.7	2.8	3.2	65.5	170.7	98.1	100.0	0.0	0.0	0.0
Long-billed Dowitcher	0.1	0.4	3.3	0.0	0.2	3.4	0.0	0.2	3.3	0.0	0.0	0.0
Common Snipe	0.0	0.0	0.0	0.1	0.5	20.7	0.9	1.4	66.7	0.0	0.0	0.0
American Woodcock	1.3	1.6	70.0	0.2	0.4	17.2	1.5	1.9	63.3	0.0	0.0	0.0
Great Skua	0.0	0.0	0.0	0.0	0.2	3.4	0.0	0.0	0.0	0.0	0.0	0.0
Laughing Gull	0.2	0.5	16.7	0.2	0.8	10.3	0.3	0.7	23.3	0.0	0.2	2.9
Little Gull	0.0	0.2	3.3	0.0	0.0	0.0	0.1	0.3	6.7	0.0	0.0	0.0
Common Black-headed Gull	0.3	0.5	26.7	0.1	0.4	6.9	0.4	0.6	33.3	0.0	0.2	2.9
Bonaparte's Gull	193.8	203.1	96.7	60.5	136.0	96.6	330.9	261.7	100.0	3.6	13.7	11.8
Ring-billed Gull	1242.0	793.2	100.0	39.9	108.2	100.0	563.4	342.3	100.0	0.5	2.1	5.9
Herring Gull	2272.9	1062.0	100.0	1653.9	1012.1	100.0	2720.5	1507.4	100.0	441.4	443.6	76.5

	Newport 1981-2010			Block Island 1981-2010			South Kingstown 1981-2010			Providence 1902-1950		
Species	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**FREQ**
Thayer's Gull	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	6.7	0.0	0.0	0.0
Iceland Gull	0.2	0.4	20.0	0.8	1.2	41.4	0.8	1.2	43.3	0.0	0.0	0.0
Lesser Black-backed Gull	0.1	0.3	10.0	0.1	0.3	10.3	0.5	0.7	36.7	0.0	0.0	0.0
Glaucous Gull	0.0	0.2	3.3	0.2	0.6	17.2	0.0	0.0	0.0	0.0	0.0	0.0
Great Black-backed Gull	290.8	188.6	100.0	1061.0	636.2	100.0	1057.7	670.6	100.0	3.8	7.6	38.2
Black-legged Kittiwake	1.5	5.3	30.0	108.6	305.5	93.1	232.1	877.6	96.7	0.0	0.0	0.0
Common Tern	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forster's Tern	0.1	0.3	10.0	0.0	0.0	0.0	0.1	0.4	10.0	0.0	0.0	0.0
Dovekie	0.3	0.7	13.3	0.2	0.7	6.9	1.3	5.1	16.7	0.0	0.0	0.0
Common Murre	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
Thick-billed Murre	0.2	0.9	6.7	0.2	1.0	10.3	0.0	0.0	0.0	0.0	0.0	0.0
Razorbill	3.6	6.3	60.0	27.0	52.7	79.3	50.9	82.7	86.7	0.0	0.0	0.0
Black Guillemot	0.1	0.4	3.3	0.7	1.4	31.0	0.2	0.5	16.7	0.0	0.0	0.0
Rock Dove	544.6	264.8	100.0	2.0	4.0	41.4	250.0	204.4	80.0	2.8	8.2	11.8
Barn Owl	1.1	1.3	56.7	1.7	1.6	79.3	0.1	0.3	13.3	0.0	0.0	0.0
Eastern Screech-Owl	8.4	6.9	93.3	0.0	0.0	0.0	1.4	1.3	66.7	0.1	0.3	8.8
Great Horned Owl	9.2	5.5	96.7	0.0	0.0	0.0	7.3	4.8	100.0	0.0	0.0	0.0
Snowy Owl	0.2	0.5	16.7	0.3	0.9	13.8	0.1	0.3	13.3	0.0	0.0	0.0
Barred Owl	0.2	0.5	13.3	0.0	0.0	0.0	1.9	1.5	86.7	0.0	0.0	0.0
Long-eared Owl	0.3	0.7	16.7	0.2	1.1	6.9	0.4	0.6	36.7	0.0	0.0	0.0
Short-eared Owl	0.7	1.1	36.7	0.1	0.4	13.8	1.0	1.7	43.3	0.0	0.0	0.0
Northern Saw-whet Owl	0.2	0.6	16.7	0.3	1.0	17.2	0.7	1.2	30.0	0.0	0.0	0.0

	Newport 1981-2010			Block Island 1981-2010			South Kingstown 1981-2010			Providence 1902-1950		
Species	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**FREQ**
Rufous Hummingbird	0.1	0.4	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ruby-throated Hummingbird	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Belted Kingfisher	10.7	19.7	100.0	2.2	1.9	86.2	12.2	4.0	100.0	0.4	0.8	26.5
Red-headed Woodpecker	0.0	0.2	3.3	0.0	0.0	0.0	0.4	1.0	16.7	0.0	0.0	0.0
Red-bellied Woodpecker	10.6	12.0	80.0	0.7	1.3	41.4	14.0	14.4	80.0	0.0	0.0	0.0
Yellow-bellied Sapsucker	1.6	2.0	60.0	0.1	0.3	10.3	1.5	2.0	66.7	0.0	0.0	0.0
Downy Woodpecker	53.3	16.3	100.0	9.8	8.6	96.6	57.5	21.4	100.0	6.1	7.6	79.4
Hairy Woodpecker	3.8	2.1	93.3	0.5	1.0	27.6	7.6	4.8	100.0	0.8	1.1	38.2
Northern Flicker	66.7	22.7	96.7	71.1	47.7	100.0	3.0	9.6	100.0	2.4	4.7	44.1
Pileated Woodpecker	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	6.7	0.0	0.0	0.0
Eastern Phoebe	0.5	1.1	26.7	0.0	0.2	3.4	0.7	0.9	50.0	0.0	0.0	0.0
Horned Lark	150.0	73.2	100.0	2.0	3.8	27.6	169.1	142.6	100.0	4.8	8.9	38.2
Tree Swallow	1.0	5.3	10.0	1.9	6.0	20.7	0.5	1.7	13.3	0.0	0.0	0.0
Blue Jay	224.9	70.4	100.0	21.3	12.5	100.0	263.7	134.7	100.0	20.3	21.5	94.1
American Crow	606.0	310.4	100.0	238.1	110.4	100.0	255.6	132.0	100.0	47.6	200.3	23.5
Fish Crow	1.5	5.4	13.3	5.9	9.1	51.7	0.6	1.8	23.3	0.9	5.1	5.9
Common Raven	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	10.0	0.0	0.0	0.0
Black-capped Chickadee	405.8	83.9	100.0	90.4	62.6	100.0	676.2	658.6	100.0	21.4	30.7	55.9
Tufted Titmouse	84.8	52.0	100.0	0.1	0.4	3.4	172.8	91.2	100.0	0.0	0.0	0.0
Red-breasted Nuthatch	3.3	5.3	60.0	24.0	37.0	93.1	11.5	11.8	96.7	0.8	2.2	14.7
White-breasted Nuthatch	32.6	12.1	100.0	0.9	1.4	41.4	72.5	33.6	100.0	4.6	4.8	79.4

	Newport 1981-2010			Block Island 1981-2010			South Kingstown 1981-2010			Providence 1902-1950		
Species	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**FREQ**
Brown Creeper	3.7	2.9	100.0	0.4	1.2	17.2	8.9	6.4	100.0	3.3	3.7	76.5
Carolina Wren	115.5	57.3	100.0	83.6	55.3	100.0	51.3	36.1	100.0	0.0	0.0	0.0
House Wren	0.7	1.0	46.7	0.4	0.8	31.0	0.3	0.4	26.7	0.0	0.0	0.0
Winter Wren	3.6	1.8	100.0	3.3	4.7	69.0	4.7	5.5	83.3	0.1	0.3	11.8
Marsh Wren	3.0	2.3	86.7	1.0	1.5	37.9	1.2	1.4	56.7	6.2	8.6	67.6
Golden-crowned Kinglet	29.2	16.3	100.0	4.3	6.4	65.5	71.9	49.2	100.0	0.3	1.1	8.8
Ruby-crowned Kinglet	5.4	6.7	80.0	1.7	1.6	65.5	2.5	1.9	93.3	0.0	0.0	0.0
Blue-gray Gnatcatcher	0.1	0.3	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eastern Bluebird	9.0	11.8	63.3	0.2	0.8	10.3	23.7	22.5	86.7	0.0	0.0	0.0
Hermit Thrush	16.5	11.7	100.0	11.6	15.9	86.2	15.7	14.9	93.3	0.1	0.4	5.9
American Robin	2011.0	3562.6	100.0	183.0	209.1	96.6	4569.1	5676.4	100.0	1.6	3.2	38.2
Varied Thrush	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gray Catbird	37.0	18.7	100.0	22.7	19.9	100.0	14.1	12.2	96.7	0.0	0.0	0.0
Northern Mockingbird	139.1	39.0	100.0	26.0	13.6	100.0	81.6	27.5	100.0	0.1	0.2	5.9
Brown Thrasher	1.2	1.3	66.7	1.2	1.6	55.2	1.5	1.6	66.7	0.0	0.0	0.0
American Pipit	7.1	10.2	70.0	1.6	3.5	37.9	12.3	37.2	66.7	0.0	0.0	0.0
Bohemian Waxwing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
Cedar Waxwing	134.6	147.2	96.7	25.6	41.9	62.1	57.0	61.6	93.3	1.0	3.1	14.7
European Starling	11593.6	10447.4	100.0	790.3	664.2	100.0	2950.3	3685.3	100.0	248.2	344.0	70.6
Northern Shrike	0.3	0.8	16.7	0.8	2.8	24.1	0.4	1.7	13.3	0.1	0.2	5.9
Loggerhead Shrike	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
White-eyed Vireo	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	Newport 1981-2010			Block Island 1981-2010			South Kingstown 1981-2010			Providence 1902-1950		
Species	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**FREQ**
Orange-crowned Warbler	0.3	0.8	20.0	0.3	0.7	20.7	0.3	0.6	20.0	0.0	0.0	0.0
Nashville Warbler	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
Cape May Warbler	0.0	0.0	0.0	0.0	0.2	3.4	0.0	0.0		0.0	0.0	0.0
Yellow-rumped Warbler	232.6	184.7	96.7	721.9	413.3	100.0	28.4	88.9	100.0	29.5	45.7	70.6
Pine Warbler	0.1	0.3	13.3	0.1	0.3	6.9	0.5	0.9	33.3	0.0	0.0	0.0
Prairie Warbler	0.0	0.2	3.3	0.1	0.3	6.9	0.0	0.0	0.0	0.0	0.0	0.0
Palm Warbler	5.9	8.3	80.0	1.0	2.0	37.9	2.3	2.4	73.3	0.0	0.0	0.0
Blackpolled Warbler	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
American Redstart	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Northern Waterthrush	0.0	0.2	3.3	0.0	0.0	0.0	0.1	0.3	6.7	0.0	0.0	0.0
Mourning Dove	617.9	237.5	100.0	65.4	51.8	96.6	445.0	188.0	100.0	0.6	3.4	2.9
Common Yellowthroat	1.7	2.1	60.0	0.6	1.0	27.6	0.3	0.5	26.7	0.0	0.2	2.9
Wilson's Warbler	0.1	0.3	6.7	0.0	0.2	3.4	0.0	0.0	0.0	0.0	0.0	0.0
Yellow-breasted Chat	1.2	1.5	60.0	0.2	0.5	20.7	0.5	0.8	36.7	0.0	0.0	0.0
Northern Cardinal	223.2	58.5	100.0	62.4	40.7	100.0	169.9	72.0	100.0	0.0	0.2	2.9
Black-headed Grosbeak	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.3	0.0	0.0	0.0
Dickcissel	0.1	0.3	10.0	0.0	0.2	3.4	0.1	0.4	10.0	0.0	0.0	0.0
Eastern Towhee	16.1	8.5	100.0	5.9	7.2	93.1	5.8	8.2	100.0	0.0	0.0	0.0
American Tree Sparrow	126.6	50.1	100.0	7.9	12.1	86.2	121.1	78.3	100.0	30.7	35.9	88.2
Chipping Sparrow	0.7	1.1	36.7	0.2	0.5	20.7	2.1	2.4	63.3	0.0	0.0	0.0
Clay-colored Sparrow	0.1	0.3	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Field Sparrow	22.9	17.3	100.0	3.8	4.4	69.0	59.1	32.7	100.0	0.9	2.0	26.5

Species	Newport 1981-2010			Block Island 1981-2010			South Kingstown 1981-2010			Providence 1902-1950		
	Mean	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**FREQ**
Vesper Sparrow	0.6	0.9	40.0	0.0	0.0	0.0	1.0	1.8	40.0	0.0	0.0	0.0
Lark Sparrow	0.1	0.4	6.7	0.0	0.2	3.4	0.0	0.0	0.0	0.0	0.0	0.0
Lark Bunting	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.9
Savannah Sparrow	62.2	47.6	100.0	2.7	2.5	75.9	29.4	23.8	100.0	0.5	2.9	2.9
Grasshopper Sparrow	0.1	0.3	6.7	0.0	0.2	3.4	0.0	0.2	3.3	0.0	0.0	0.0
Le Conte's Sparrow	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Neslon's Sparrow	0.0	0.0	0.0	0.0	0.2	3.4	0.1	0.4	10.0	0.0	0.0	0.0
Saltmarsh Sparrow	0.3	0.6	23.3	0.0	0.0	0.0	0.3	0.7	20.0	0.0	0.0	0.0
Seaside Sparrow	0.1	0.3	6.7	0.0	0.2	3.4	0.0	0.2	3.3	0.0	0.0	0.0
Fox Sparrow	4.0	3.6	93.3	3.2	4.6	62.1	8.3	7.6	96.7	0.4	0.9	23.5
Song Sparrow	401.3	171.6	100.0	191.1	115.2	100.0	214.6	98.2	100.0	11.6	15.4	85.3
Lincoln's Sparrow	0.1	0.4	6.7	0.1	0.3	6.9	0.1	0.3	6.7	0.0	0.0	0.0
Swamp Sparrow	68.8	35.6	100.0	11.3	7.9	96.6	17.9	13.6	100.0	0.3	1.1	8.8
White-throated Sparrow	535.4	175.4	100.0	205.6	135.1	100.0	572.3	226.9	100.0	5.1	12.8	50.0
White-crowned Sparrow	14.3	9.4	100.0	0.4	0.9	24.1	4.1	6.0	66.7	0.0	0.0	0.0
Dark-eyed Junco	216.8	127.8	100.0	30.2	37.9	100.0	430.6	241.7	100.0	30.9	42.6	76.5
Lapland Longspur	0.5	1.4	13.3	0.0	0.2	3.4	0.3	0.8	20.0	0.3	1.5	2.9
Snow Bunting	39.0	60.0	83.3	2.3	5.7	37.9	18.5	46.9	66.7	1.2	4.6	11.8
Red-winged Blackbird	295.5	460.6	100.0	12.4	10.9	89.7	107.3	162.7	96.7	0.0	0.2	2.9
Eastern Meadowlark	26.0	16.7	100.0	8.4	10.3	75.9	15.5	20.8	83.3	2.6	4.7	44.1
Yellow-headed Blackbird	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rusty Blackbird	0.6	1.0	30.0	0.3	1.2	10.3	0.0	0.0	0.0	0.0	0.0	0.0

	Newport 1981-2010			Block Island 1981-2010			South Kingstown 1981-2010			Providence 1902-1950		
Species	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**Freq**	**Mean**	**SD**	**FREQ**
Rusty Blackbird	0.0	0.0	0.0	0.0	0.0	0.0	12.0	34.4	73.3			
Brewer's Blackbird	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Common Grackle	291.1	645.1	93.3	1.3	3.0	31.0	162.4	520.7	80.0	0.0	0.0	0.0
Brown-headed Cowbird	325.8	373.5	100.0	4.8	8.3	55.2	123.1	165.1	100.0	4.4	25.7	2.9
Baltimore Oriole	0.6	1.1	36.7	0.0	0.0	0.0	0.2	0.5	20.0	0.0	0.0	0.0
Pine Grosbeak	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	3.7	11.8
Purple Finch	7.1	9.4	76.7	0.9	1.6	31.0	8.5	9.4	93.3	1.9	3.1	38.2
House Finch	476.4	182.0	100.0	76.4	54.3	100.0	402.5	214.6	100.0	0.0	0.0	0.0
Red Crossbill	0.0	0.0	0.0	1.3	4.7	13.8	0.3	1.1	10.0	2.9	17.1	2.9
White-winged Crossbill	5.7	26.0	6.7	6.9	36.9	6.9	0.7	4.0	3.3	0.0	0.0	0.0
Common Redpoll	6.4	22.1	30.0	2.2	9.7	20.7	2.3	7.5	26.7	0.0	0.0	0.0
Hoary Redpoll	0.0	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pine Siskin	0.7	1.8	26.7	3.3	9.3	24.1	8.5	15.6	53.3	2.4	8.1	14.7
American Goldfinch	129.9	73.3	96.7	15.3	12.6	89.7	152.4	98.7	100.0	6.2	16.6	41.2
Evening Grosbeak	11.6	36.0	20.0	0.2	0.9	6.9	28.0	51.5	43.3	0.1	0.3	2.9
House Sparrow	467.3	195.0	96.7	93.2	70.8	100.0	456.4	142.3	100.0	26.3	41.4	44.1

Table A2.8. Summary of The Great Backyard Bird count data from 1998 - 2011. These species are birds that winter in Rhode Island and have a significantly declining trend based on Breeding Bird Surveys.

Town	American Kestrel	American Wigeon	Blue Jay	Common Grackle	Dark-eyed Junco	Eastern Towhee	Field Sparrow	Killdeer	Pine Siskin	Purple Finch	Red-winged Blackbird	White-throated Sparrow
Adamsville	.	.	.	18	.	.	12	.	.	.	.	.
Ashaway	.	.	5	5	16	.	9	.	.	.	.	13
Barrington	2	.	8	10	27	2	12	.	13	5	43	9
Block Island	.	4	9	2	12	.	8	.	4	.	58	13
Bristol	1	.	6	5	7	.	3	.	2	3	3	17
Carolina	.	.	16	.	14	.	.	.	.	.	2	19
Charlestown	.	.	11	3	26	2	.	.	33	5	13	19
Chepachet	.	.	7	.	39	.	.	.	.	5	.	4
Coventry	.	.	8	23	27	.	.	.	16	7	10	6
Cranston	.	19	6	2	26	.	6	1	.	2	1	8
Cumberland	.	.	23	5	37	.	4	.	1	4	8	6
East Greenwich	.	.	7	27	16	2	.	.	1	8	.	8
East Providence	1	41	3	8	32	.	1	.	.	10	10	26
Exeter	.	.	13	21	32	.	.	.	34	5	.	21
Foster	.	.	14	3	46	.	2	.	2	.	2	11
Glendale	.	.	10	.	14	2	.	.	.	3	.	2
Greene	.	.	6	.	10	.	.	.	.	.	3	8
Greenville	.	.	10	5	34	.	.	.	2	.	3	11
Harmony	.	.	.	.	4	.	.	.	.	.	.	.
Harrisville	.	.	24	.	44	.	5	.	.	4	3	3

Town	American Kestrel	American Wigeon	Blue Jay	Common Grackle	Dark-eyed Junco	Eastern Towhee	Field Sparrow	Killdeer	Pine Siskin	Purple Finch	Red-winged Blackbird	White-throated Sparrow
Hope Valley	.	2	14	.	46	.	5	.	93	4	2	9
Hopkinton	.	.	.	.	34	2	.	.	.	.	.	7
Jamestown	.	.	5	.	8	1	.	.	4	2	.	11
Johnston	.	.	6	1	27	1	.	.	4	2	7	6
Kingston	.	.	4	.	22	.	1	.	.	2	.	11
Lincoln	.	.	4	10	11	.	4	.	.	.	2	8
Little Compton	.	.	5	2	7	2	.	.	.	7	5	21
Manville	.	.	7	.	6	.	1	.	.	.	7	1
Mapleville	.	.	19	.	69	.	2	.	.	.	1	.
Matunuck	.	.	1	.	4	.	.	.	.	1	.	3
Middletown	.	4	5	.	12	.	.	.	1	4	13	48
Narragansett	.	1	9	6	11	2	2	.	.	3	2	18
New Shoreham	.	10	4	.	.	.	.	.	.	.	7	2
Newport	.	2	7	24	6	.	1	.	.	4	27	3
North Kingstown	1	.	13	28	41	1	4	1	2	9	15	8
North Providence	.	.	15	4	15	.	2	.	.	2	.	.
North Scituate	.	.	8	.	14	.	.	.	1	3	6	3
North Smithfield	.	.	28	31	67	.	2	.	3	6	22	4
Pascoag	.	.	12	19	18	.	6	.	38	15	11	5
Pawtucket	.	.	4	.	10	.	.	.	.	.	.	3

Town	American Kestrel	American Wigeon	Blue Jay	Common Grackle	Dark-eyed Junco	Eastern Towhee	Field Sparrow	Killdeer	Pine Siskin	Purple Finch	Red-winged Blackbird	White-throated Sparrow
Peace Dale	.	.	3	2	3	.	.	.	.	.	3	6
Portsmouth	.	.	7	10	18	.	3	.	.	4	4	4
Providence	2	29	11	7	32	.	2	.	1	2	1	8
Prudence Island	.	.	9	1	4	.	.	.	.	2	10	4
Riverside	1	23	8	14	19	.	2	.	2	9	21	7
Rockville	.	.	14	.	18	.	.	.	.	2	.	10
Rumford	.	.	3	125	16	.	.	.	.	6	14	12
Saunderstown	.	.	4	8	7	1	5	.	.	4	3	9
Shannock	.	.	4	.	69	.	.	.	.	.	1	4
Smithfield	.	.	5	.	13	.	1	.	.	8	.	3
Tiverton	1	.	10	3	32	2	11	.	.	2	10	11
Trustom Pond	.	4	.	.	.	.	.	.	.	.	.	.
Wakefield	1	.	21	35	48	4	7	.	13	7	9	27
Warren	.	26	10	5	29	1	.	.	3	2	12	7
Warwick	.	26	29	27	72	1	3	.	6	4	79	15
West Greenwich	.	.	8	1	32	2	.	.	23	1	.	5
West Kingston	1	.	22	7	54	9	8	.	43	5	15	86
West Warwick	.	.	5	4	16	.	11	.	.	.	2	5
Westerly	.	.	18	27	41	3	1	.	15	5	48	23
Wood River Junction	.	.	2	.	7	.	.	.	.	3	.	4

Town	**American Kestrel**	**American Wigeon**	**Blue Jay**	**Common Grackle**	**Dark-eyed Junco**	**Eastern Towhee**	**Field Sparrow**	**Killdeer**	**Pine Siskin**	**Purple Finch**	**Red-winged Blackbird**	**White-throated Sparrow**
Woonsocket	.	.	4	2	17	.	.	.	.	.	2	.
Wyoming	.	.	4	.	11	.	.	.	.	.	.	.

Table A2.9. Specific grassland characteristics for grassland birds (Jones and Vickery 2001).

Grassland Species[A]	Grassland Type	Grassland Size (acres)	Grassland Age	Vegetation Height	Vegetation Composition
Upland Sandpiper	Upland meadow, old field, sandplain grassland	150	.	1-24 inches	Mixture of short and tall grasses and bare ground
Vesper Sparrow	Upland meadow, old field, sandplain grassland	30	.	1-8 inches	Open, sparse, short grass
Savannah Sparrow	Upland meadow, old field, sandplain grassland, salt meadow	20-40 acres	All ages	grasses: 1-25 inches; forbs: 1-10 inches	Hayfields, pastures, coastal grasslands, blueberry barrens (saplings, shrubs, forbes), thick layer of dead grass
Grasshopper Sparrow	Upland meadow, old field, sandplain grassland	30	.	Grasses: 4-12 inches; forbes: 8-25 inches; short shrubs: 1-4 inches	Short bunch grasses with minimal litter and grass cover, patches of bare ground, scattered tall forbes and short shrubs
Bobolink	Upland meadow, wet meadow, old field	10-May	Older than 8 years	8-12 inches	Hayfields with mixed grasses, wildflowers, small shrubs
Eastern Meadowlark	Upland meadow, old field	15-20	.	Grass: 10-20 inches; shrubs : 1-8 inches; forbs: 1-15 inches	Grass-dominated fields with a thick layer of dead grass, scattered shrubs and forbs

Table A2.10. Specific nesting habitat requirements for scrub-shrub associated birds that nest in Rhode Island based on Appendix B in Schlossberg and King (2007).

Species	Shrub habitat	Forest canopy	Habitat features
Ruffed Grouse	Dense shrub/saplings at least 1.5 m tall	Moderate canopy cover	Deciduous and mesic habitats
Northern Bobwhite	Dry, open areas, dense shrubs up to 2 m high	Little to no canopy	Large areas of bare ground or litter cover
American Woodcock	Roost and display in open fields and thickets of dense shrubs	No canopy in display areas	Feed in low areas with moist, fertile soil
Wilson's Snipe	Variable shrub cover		Wet, open area, bogs and shrub swamps
Whip-poor-will	Dry, open areas with sparse understory	Avoids dense stands of trees, uses clearings for foraging	
Ruby-throated Hummingbird	Vary levels of shrubs	Open to completely closed	Deciduous habitats with nectar-producing flowers
Alder Flycather	Dense, wet stands of shrubs and saplings	Little to no canopy	Bogs, swamps, margins of streams/lakes
Willow Flycatcher	Dense, patchy thickets	Open canopy	Common along coast
White-eyed Vireo	Dense. Low shrub cover	Variable	Deciduous vegetation
House Wren	Open to closed deciduous habitats	.	Needs nest box or cavity tree >25 cm dbh
Carolina Wren	Dense shrub cover	Open or closed canopy	.
Gray Catbird	Dense, tall shrubs/saplings	Low, open canopy	Deciduous habitats
Brown Thrasher	Open areas with dense clusters of shrubs > 1m tall	.	Dry habitats with deep litter cover for feeding
Northern Mockingbird	Open areas with dense shrub cover	.	Some elevated perches for singing
Cedar Waxwing	Many berry producing shrubs	Few tall tree, open canopy	Fruit availability important for habitat selection
Blue-winged Warbler	Open areas with dense herbaceous vegetation, patchy shrub/sapling cover	Will use areas with some tall trees	.
Yellow Warbler	Wet habitat with dense shrubs < 2 m tall	Few to no trees	Deciduous vegetation, particularly willows
Chestnut-sided Warbler	Dense shrub cover	Moderate canopy cover	Deciduous habitats

Species	Shrub habitat	Forest canopy	Habitat features
Prairie Warbler	Open areas with some shrub cover	Few or small trees	Little herbaceous cover
Black-and-white Warbler	Dense sapling to pole-sized trees	Deciduous forests preferred, will use mature forests	.
Common Yellowthroat	Some shrub cover	Open canopy	Dense cover of herbaceous vegetation, moist deciduous areas.
Canada Warbler	Moderate to high density of shrubs/saplings	Some canopy cover	Groundcover of moss and coarse woody debris
Yellow-breasted Chat	Dense shrub or saplings	Areas with few trees or scattered openings	Deciduous habitats near water
Indigo Bunting	Open area, moderate to dense shrub cover	Use forest edges, some tall trees	Dense herbaceous vegetation
Northern Cardinal	Any habitat with dense shrub cover	Open to completely closed	.
Eastern Towhee	Patchy to dense shrub cover	Few trees	Dry open, habitats
Field Sparrow	Low to moderate shrub cover	Small trees	Open, grassy areas
Song Sparrow	Tall, dense shrub/sapling cover	.	Significant herbaceous vegetation, moist situations
White-throated Sparrow	Dense shrub cover	Can use areas with significant tree cover	Prefers coniferous stands with significant herbaceous vegetation
Dark-eyed Junco	Moderate to dense shrub cover	Use taller trees if canopy open	Dry areas, slash and coarse woody debris important
American Goldfinch	Weedy areas, with thistles and dandelions composite flowers	Scattered trees	.

Table A2.11. Distribution of nesting American Oystercatcher, terns, and gulls in Rhode Island based on surveys conducted by RI DEM staff form 1976 – 2009 (C. Raithel, pers. comm.). Given are the average (Ave) number of nests or active territories at each location and the frequency (Freq, % of years) that nests or adults were detected at each location.

	Am. Oystercatcher		**Common Tern**		**Least Tern***		**Great Blk-bd. Gull**		**Herring Gull**	
Location	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**
100 Acre cove			21.2	93.3						
Allen's Harbor Barge			1.8	65.6						
Bailey's Beach Rock			21.1	96.8						
Big Gooseberry Is., East Annex							0.1	2.9	0.1	3.0
Big Gooseberry Island							27.3	100.0	226.0	100.0
Big Gould Island	1.8	89.3	3.4	18.8			119.4	93.9	436.7	100.0
Block Is. Sandy Point							332.9	100.0		
Block Island	2.3	100.0			0.0	0.0			493.9	100.0
Briggs Beach					11.4	65.4				
Brigg's Beach Rk, East			9.3	87.9						
Brigg's Beach Rk, Middle			1.8	24.2						
Brigg's Beach Rk, West			10.1	90.6						
Briggs Beach Rock, East							0.0	0.0	0.1	11.8
Briggs Beach Rock, West							0.1	6.1		
Coddington Cove Docks			2.5	100.0						
Coggeshall Ledge									0.5	9.7
Comorant Rock							0.0	0.0	0.2	18.8
Cormorant Rock			0.4	3.1						
Despair Island			17.5	72.7			0.4	25.0	0.2	6.5
Dumpling- Clingstone							1.8	84.4	1.0	46.9
Dumpling- Middle							40.9	100.0	12.8	100.0
Dumpling- NE							14.6	100.0	25.3	100.0

	Am. Oystercatcher		Common Tern		Least Tern*		Great Blk-bd. Gull		Herring Gull	
Location	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**
Dumpling- NE-SE Annex									0.2	20.6
Dumpling- NE-SW Annex									0.1	10.0
Dumpling- NW							18.6	100.0	8.7	100.0
Dumpling- NW Annex									0.4	25.0
Dumpling- NW of Clingstone									0.2	21.9
Dumpling- SE							6.8	84.4	1.3	43.8
Dumpling- SW							2.2	93.8	3.3	93.8
Dumpling- SW of Clingstone							0.0	0.0	0.2	16.1
Dumpling- W of Clingstone							0.0	3.2	0.2	22.6
Dumpling- W of Clingstone #2									0.2	20.0
Dumpling, NE	0.1	6.5								
Dumpling-SW of Clingstone			0.1	5.0						
Dumpling-W of Clingstone			0.1	5.0						
Dutch Island							0.2	13.6	0.0	4.5
Dyer Island	2.4	96.7	11.3	58.1			86.4	100.0	588.8	100.0
East Island							85.1	100.0	85.3	100.0
East Matunuck					14.0	76.9				
EP alum dock			27.8	58.3			1.5	100.0		
EP Oil Rig (nr. Shore)			0.0	0.0						
Fort Hill Pond, NW Island							0.8	83.3		
Fort Hill Pond, SW Island							0.2	19.0		
Fort Neck Pond Is., NE			1.4	37.5						
Fort Neck Pond Is., NW			0.3	25.0						
Fort Wetherill Mainland									0.0	3.3

	Am. Oystercatcher		Common Tern		Least Tern*		Great Blk-bd. Gull		Herring Gull	
Location	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**
Fort Wetherill Rock			14.9	70.6			0.9	73.3	0.1	6.7
Galilee							3.3	83.3	88.8	100.0
Green Bridge Pond			7.5	82.4						
Green Hill Pond Island			14.4	75.0						
Green Island	0.7	66.7	27.9	70.0						
Gull Island (under bridge)	0.1	14.3								
Gull Point, Prudence	0.2	17.2	0.0	0.0					0.0	0.0
Gull Rock, Sheep Point							3.9	100.0	40.9	100.0
Gull Rocks under Bridge			5.6	26.5						
Gull Rocks, Under bridge							1.2	90.6	0.6	15.2
Hog Island	0.9	67.9	24.4	60.6	20.8	61.5			0.1	9.7
Hope Island	1.2	81.5					46.1	100.0	472.8	100.0
Horace Island	0.1	12.5	28.3	71.9			0.1	7.1		
Island Rocks			19.5	80.6						
Lily Pond Rock			4.6	47.1			0.2	20.0		
Little Gooseberry Island							13.1	100.0	3.9	69.0
Little Gould Island	0.6	66.7					14.4	91.2	120.3	100.0
Long Pond Rock			1.3	30.4						
Maschaug Beach					91.4	88.5				
Napatree Point	0.7	65.5			34.3	82.8			0.1	11.5
Narrow River					30.1	85.7				
Narrow River Rock			0.0	0.0						
NE Rock							1.6	82.4	18.9	97.1
NE Rock Annex									0.1	11.8

	Am. Oystercatcher		Common Tern		Least Tern*		Great Blk-bd. Gull		Herring Gull	
Location	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**
Ninigret Beach					28.7	56.0				
Ninigret Pond Marsh Is.			6.8	15.2						
Ninigret Pond Marsh Island									0.1	9.5
NW Rock							1.4	91.2	11.8	97.1
NW Rock Annex									0.3	24.2
Pawcatuck Osprey Pole							0.6	60.0		
Peckham's Marsh			0.0	0.0						
Potters pond Island			27.4	96.7						
Price's Neck, East Island			16.6	32.4			0.2	20.6	0.2	15.2
Price's Neck, Western Rocks							8.6	100.0	63.8	96.9
Providence River Barge			14.7	75.8						
Prudence Island					3.9	29.2				
Quicksand Pond					51.7	96.2				
Quonochontaug Rocks			0.6	20.6						
Quonset Point			0.9	15.2	36.1	73.1				
Quonset Pt							0.3	33.3	46.5	100.0
Rose Island	1.4	75.0					40.3	100.0	351.0	100.0
Round Rock									0.0	3.0
Sakonnet Harbor Rock			0.0	0.0						
Sandy Point Is.					16.5	7.7				
Sandy Point Island	3.8	96.6					261.1	100.0	1066.0	100.0
Scup Island			0.1	5.0						
Scup Island (Rock)	0.1	11.1								
Scup Rock							1.0	63.6	0.8	42.4

	Am. Oystercatcher		**Common Tern**		**Least Tern***		**Great Blk-bd. Gull**		**Herring Gull**	
Location	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**	**Ave**	**Freq**
Seal Rock	0.3	32.1	19.5	93.9			0.0	3.2	0.0	0.0
Seapowet					4.8	42.1				
Seapowet Marsh			0.3	10.3						
Seekonk River Platform							0.9	86.7		
Sheffield Cove Island			1.2	24.1						
South Clumps							0.5	41.2	4.8	94.1
Spar Island	0.8	79.3	53.1	90.6	0.7	15.4				
Spectacle Island			3.1	32.1						
The Clumps							32.3	100.0	73.0	100.0
Tiverton Docks			5.0	100.0						
Trustom					78.1	100.0				
Trustom Pond Rock			8.8	32.3						
Walker Island	0.1	10.0								
War College									22.5	100.0
Watchemoket Rock							1.0	100.0		
Weekapaug Beach					33.6	57.1				
West Island	0.2	21.9					120.6	100.0	171.1	100.0
Wickford Harbor Marker			76.3	90.9						
Grand Total	3.8	100.0	431.9	100.0	415.2	100.0	1078.9	100.0	3185.5	100.0

*Average = number of adults, not number of nests for Least Terns only

APPENDIX 3. RHODE ISLAND FIGURES

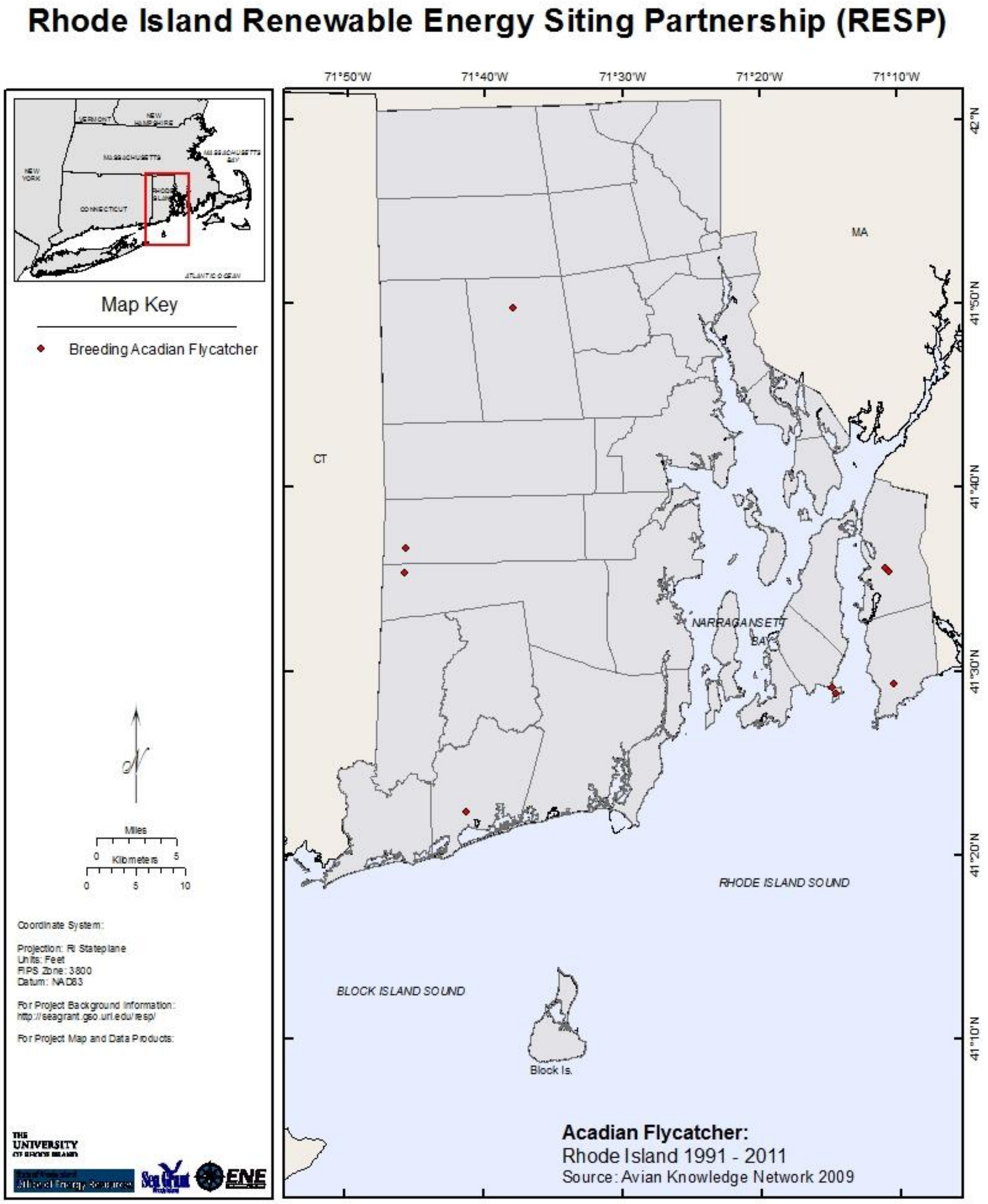


Figure A3.1. Distribution and abundance of **Acadian Flycatcher (*Empidonax virescens*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is an uncommon migrant during spring and fall in Rhode Island and is a state species of concern.

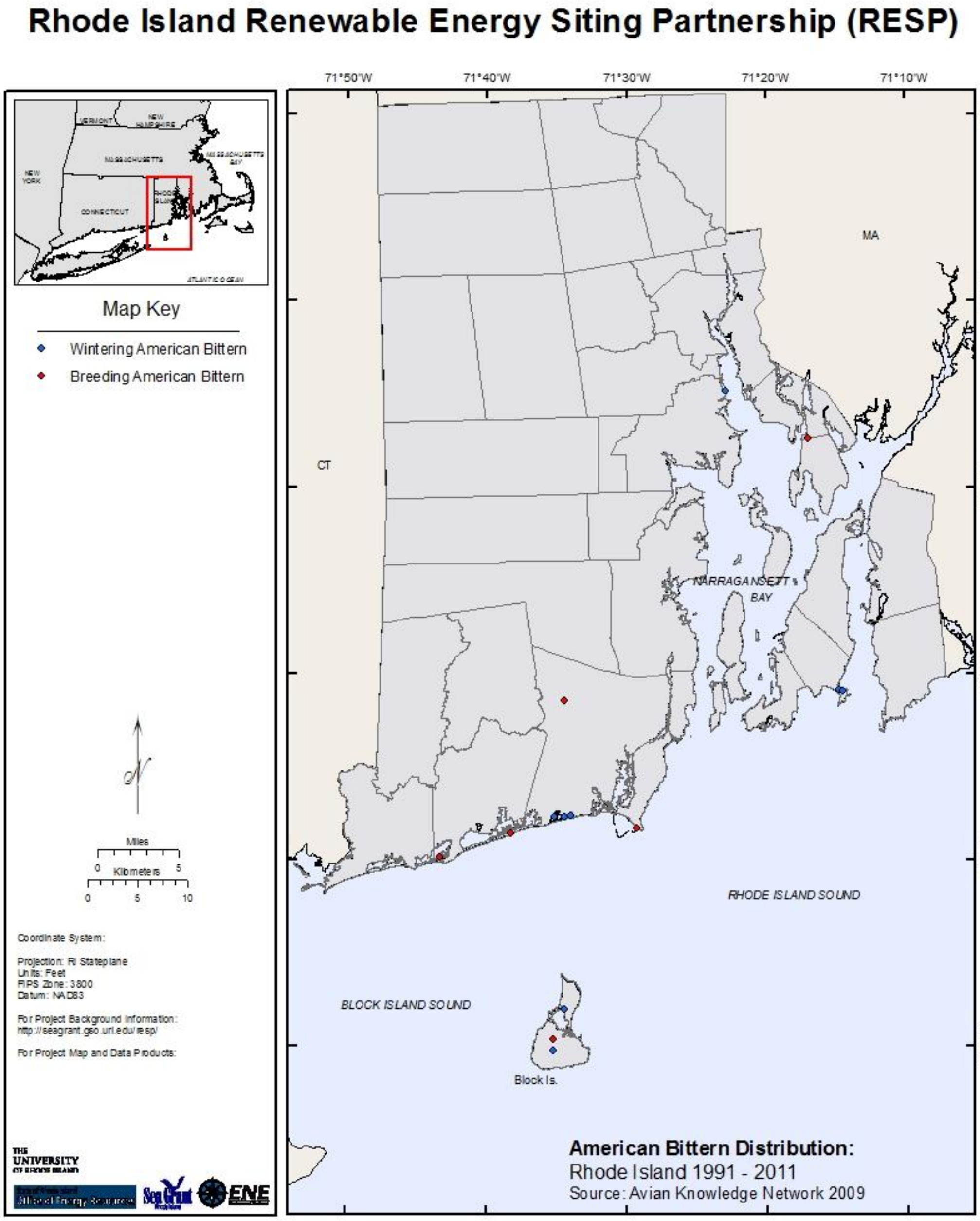


Figure A3.2. Distribution and abundance of **American Bittern (*Botaurus lentiginosus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state endangered in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

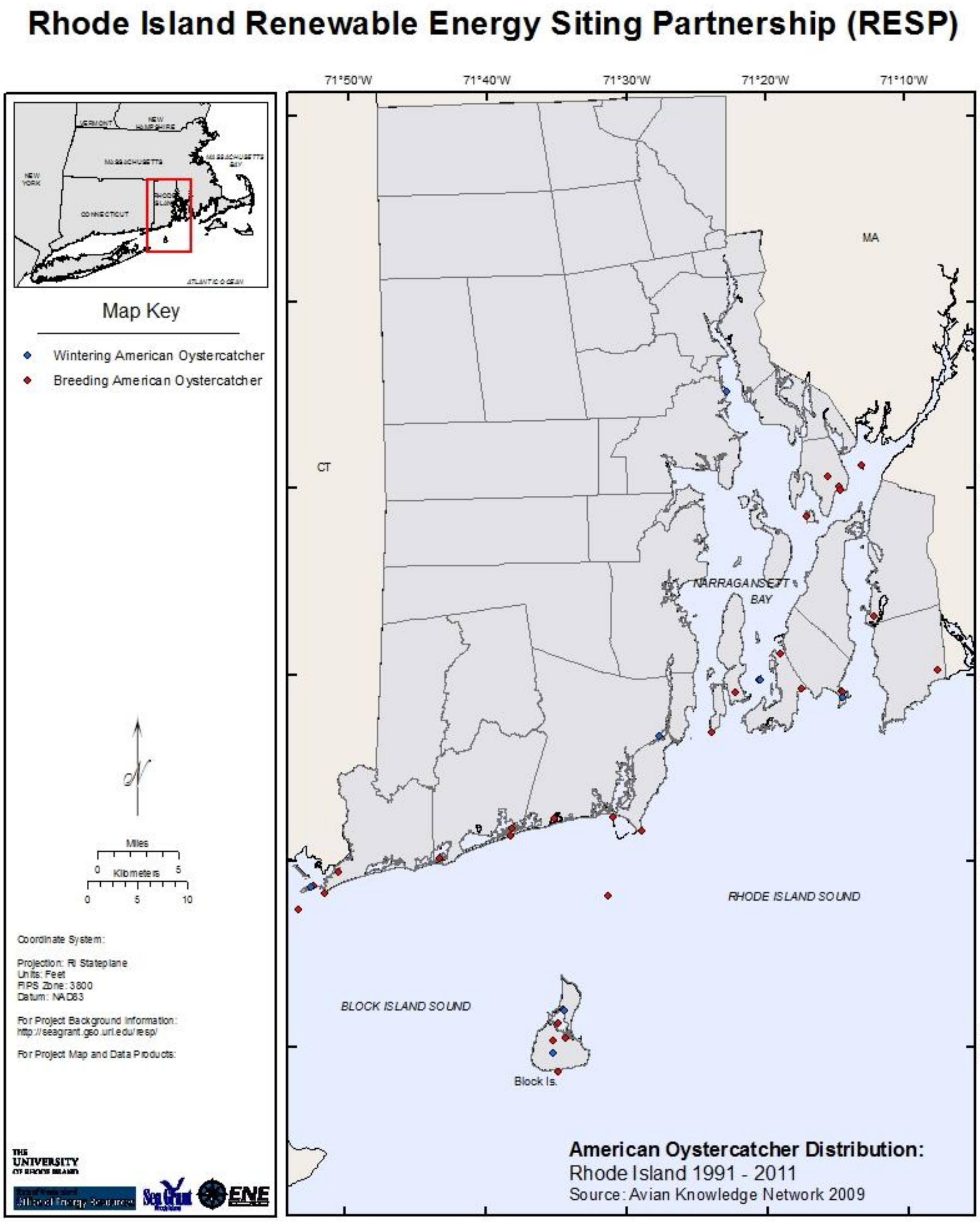


Figure A3.3. Distribution and abundance of **American Oystercatcher (*Haematopus bachmani*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as the highest conservation priority based on the BCR 30 Status, and it is listed as a Tier 1A conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

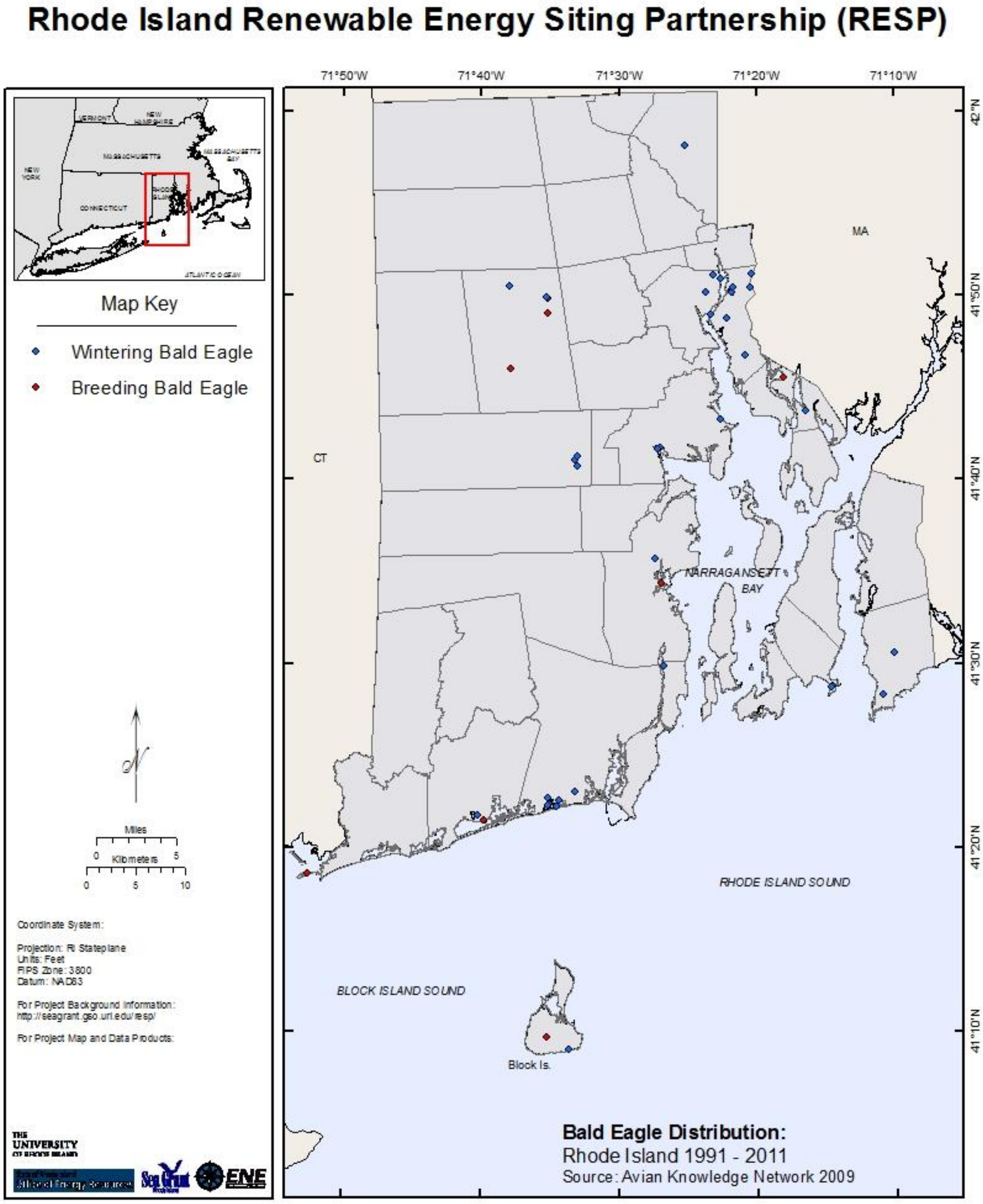


Figure A3.4. Distribution and abundance of **Bald Eagle (*Haliaeetus leucocephalus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

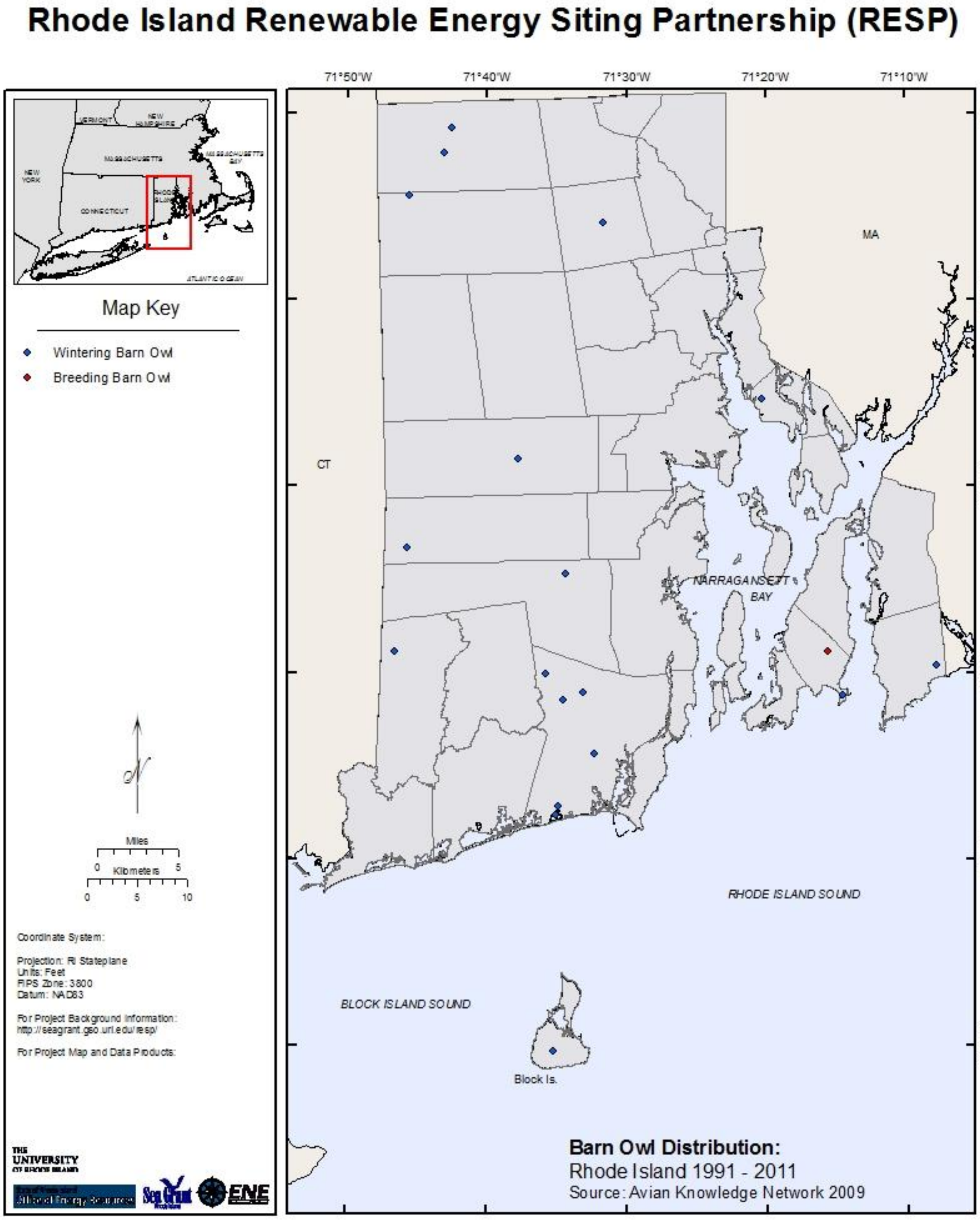


Figure A3.5. Distribution and abundance of Barn Owl (*Tyto alba*) in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

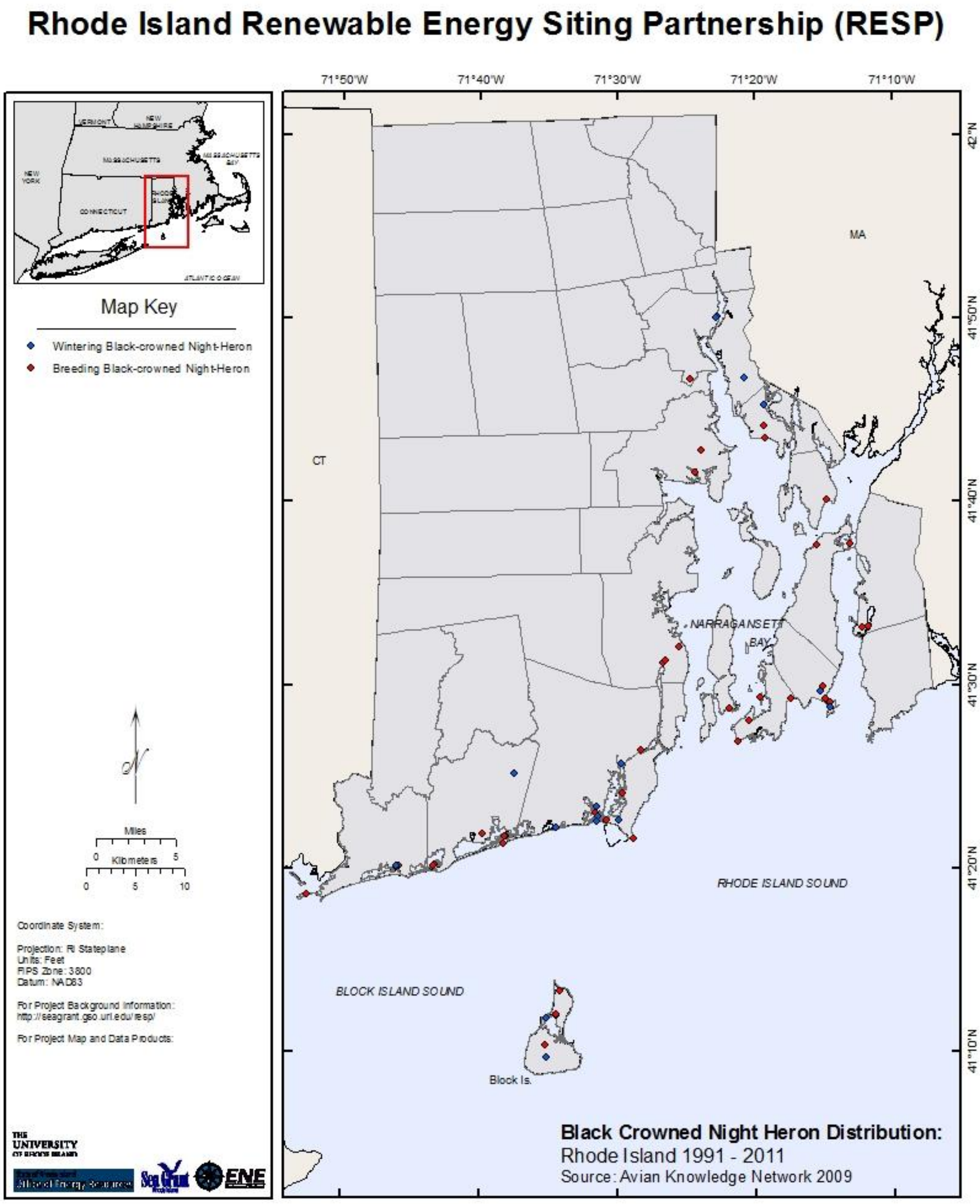


Figure A3.6. Distribution and abundance of **Black-crowned Night-Heron (*Nycticorax nycticorax*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

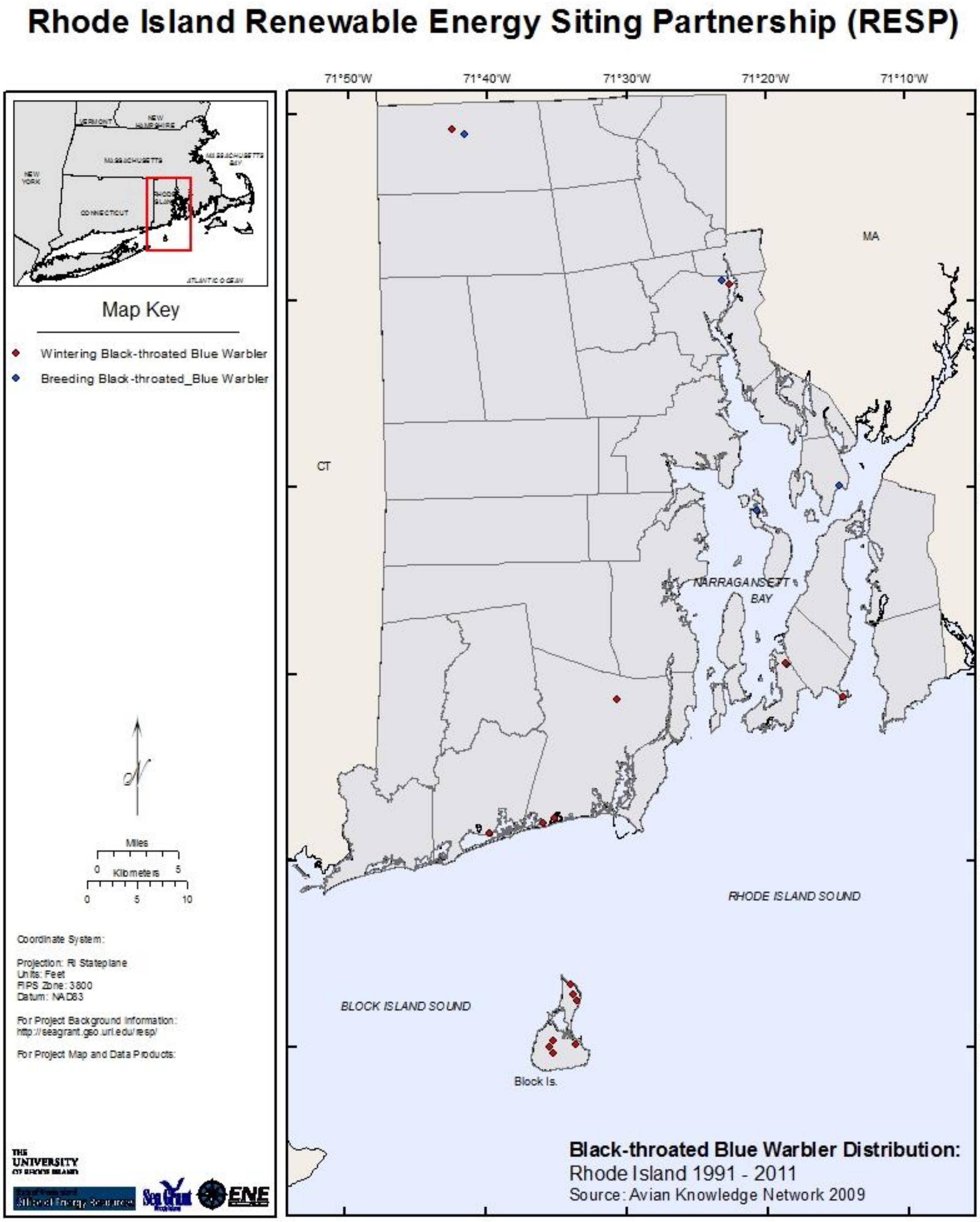


Figure A3.7. Distribution and abundance of **Black-throated Blue Warbler (*Dendroica caerulescens*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state threatened in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed a Tier 1B conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

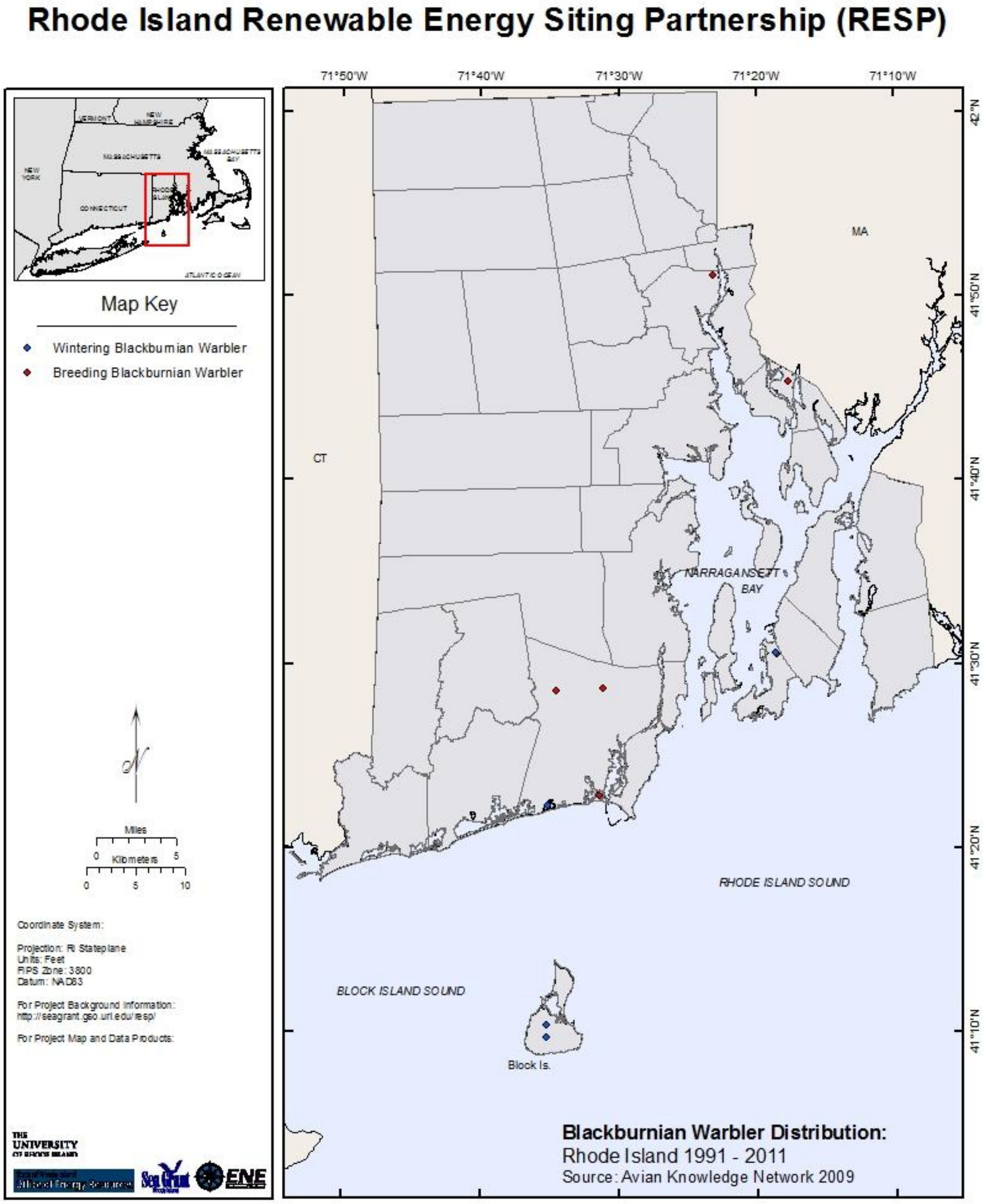


Figure A3.8. Distribution and abundance of **Blackburnian Warbler (*Dendroica fusca*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state threatened in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier IIC conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

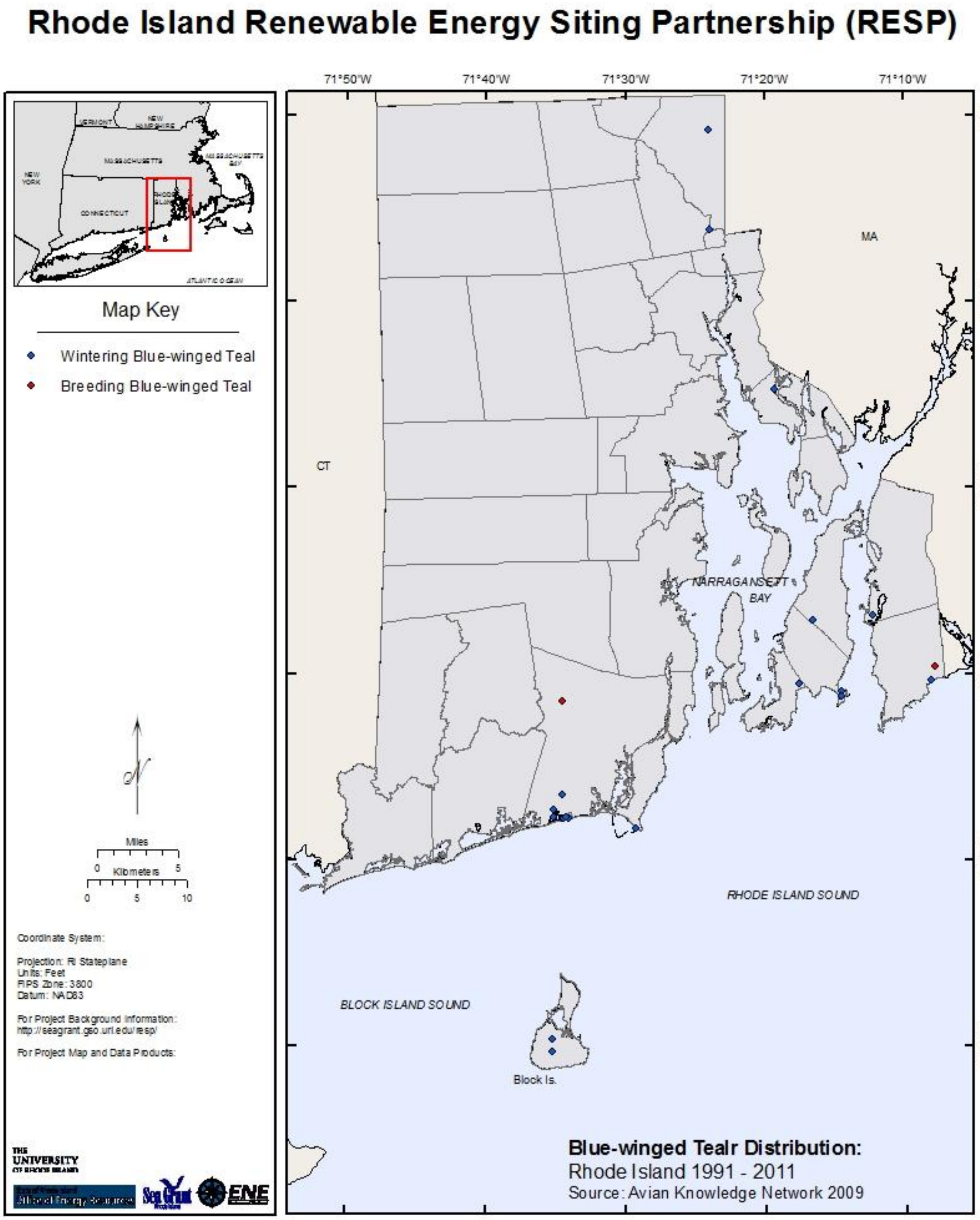


Figure A3.9. Distribution and abundance of **Blue-winged Teal (*Anas discors*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

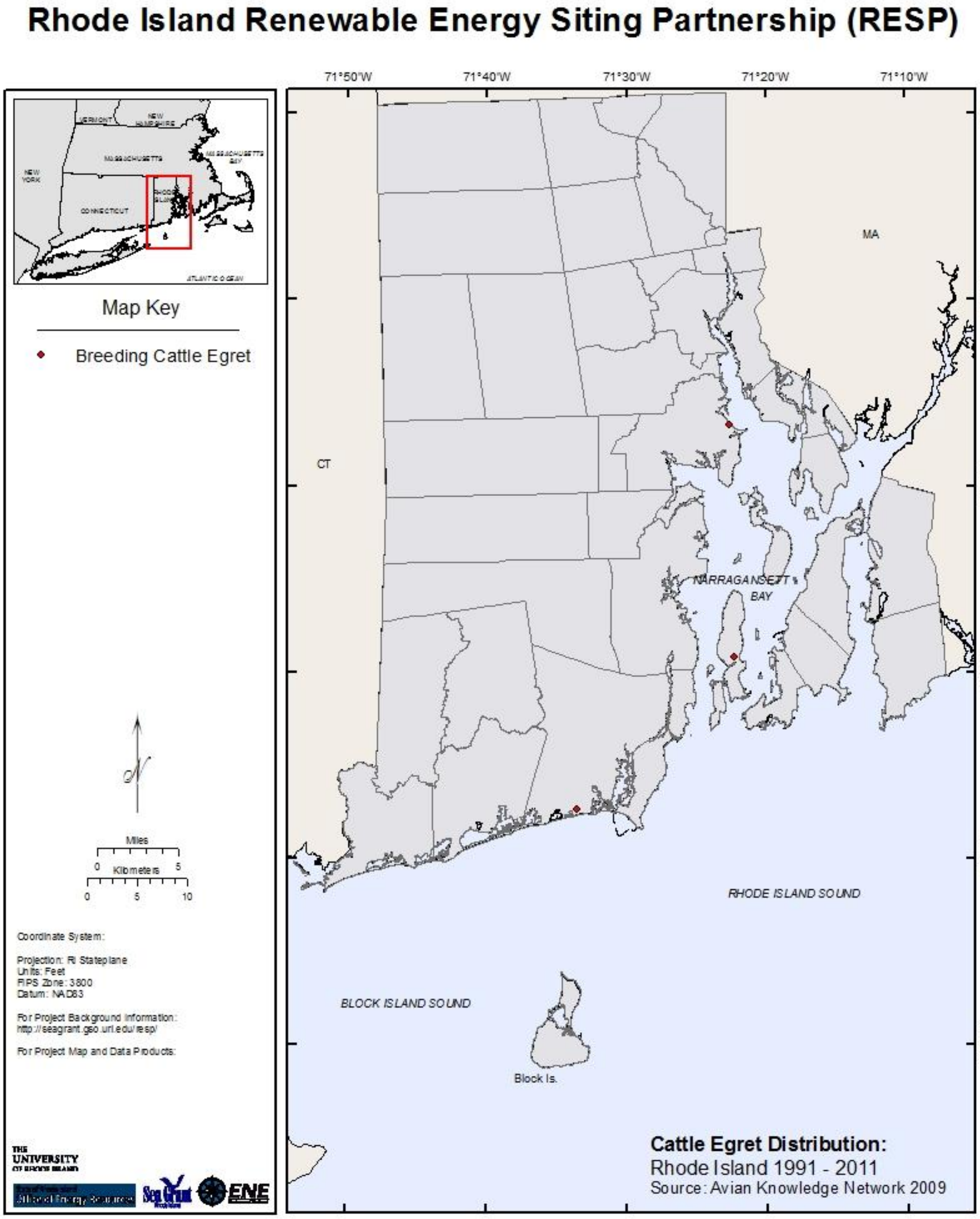


Figure A3.10. Distribution and abundance of **Cattle Egret (*Bubulcus ibis*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

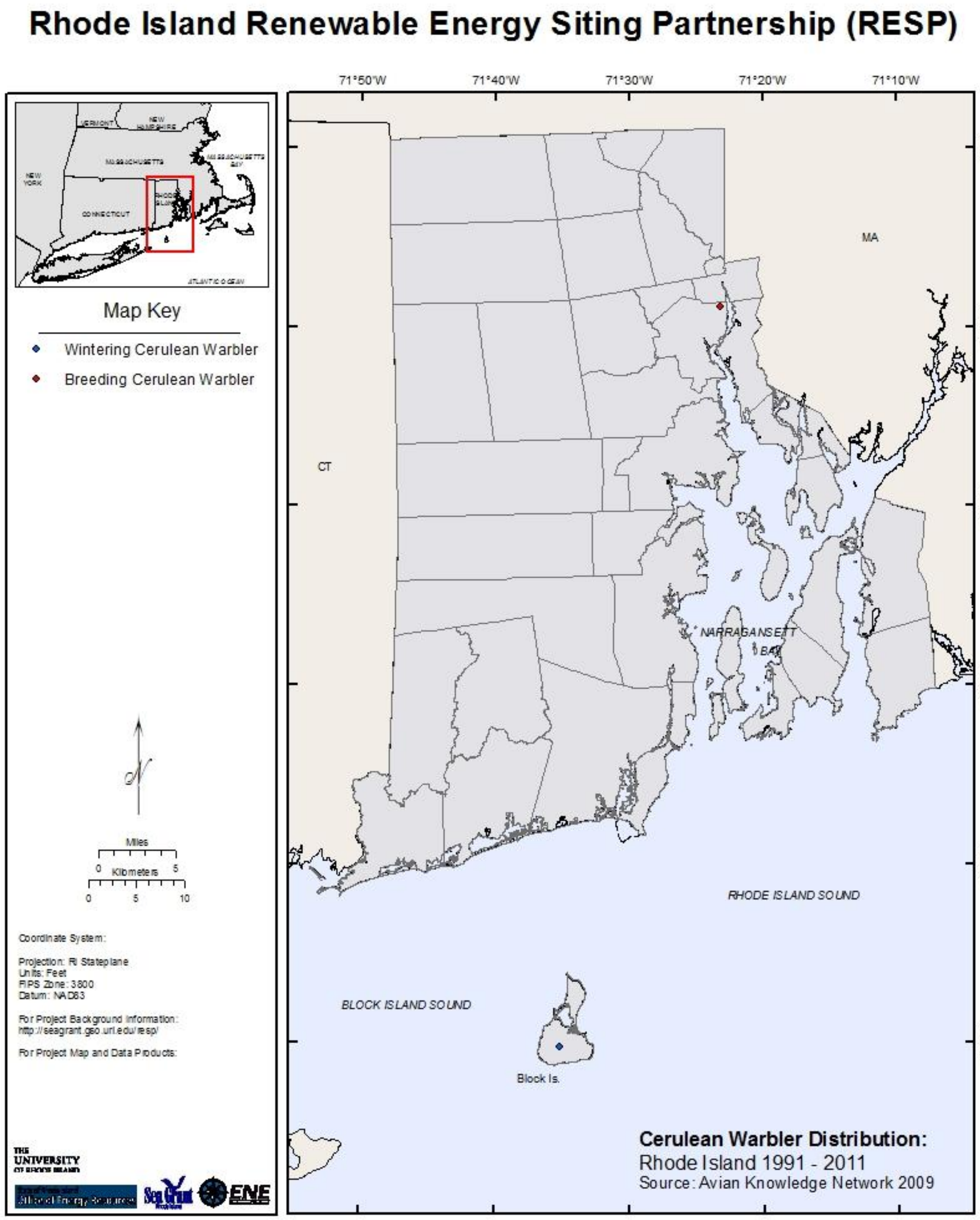


Figure A3.11. Distribution and abundance of **Cerulean Warbler (*Dendroica cerulea*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state endangered in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier IB conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

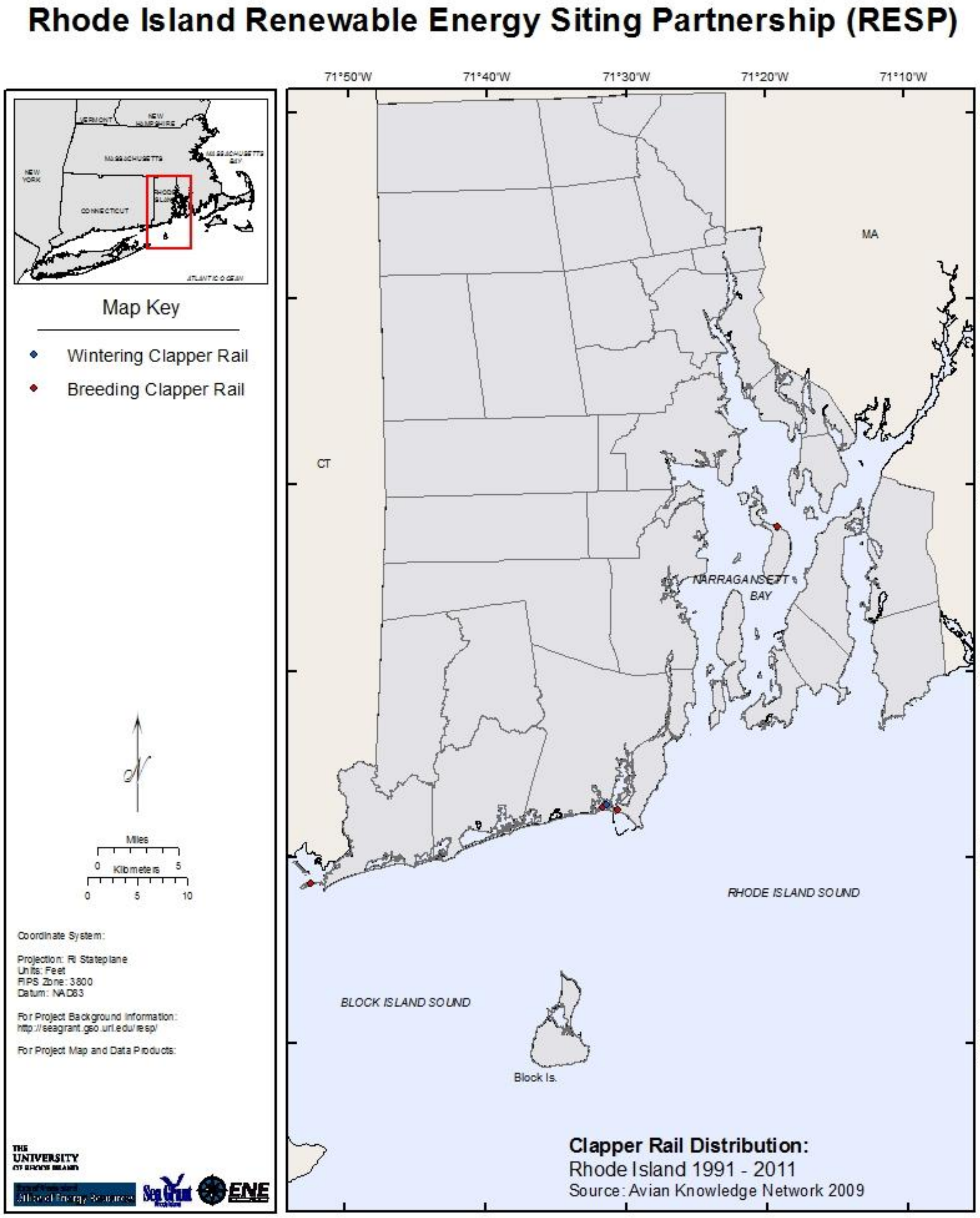


Figure A3.12. Distribution and abundance of **Clapper Rail (*Rallus longirostris*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as high conservation priority based on the BCR 30 Status (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

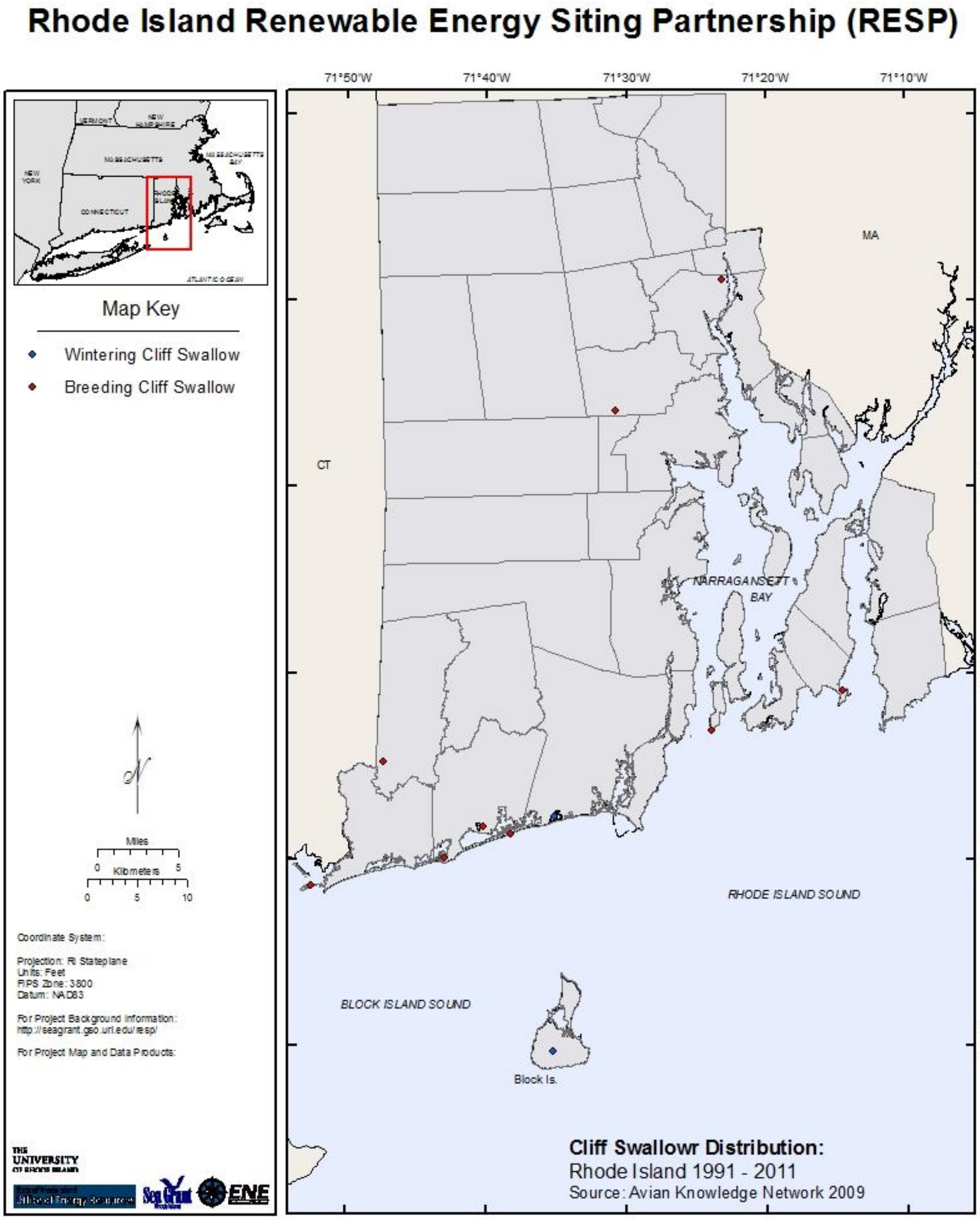


Figure A3.13. Distribution and abundance of **Cliff Swallow (*Petrochelidon pyrrhonota*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state historic bird in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

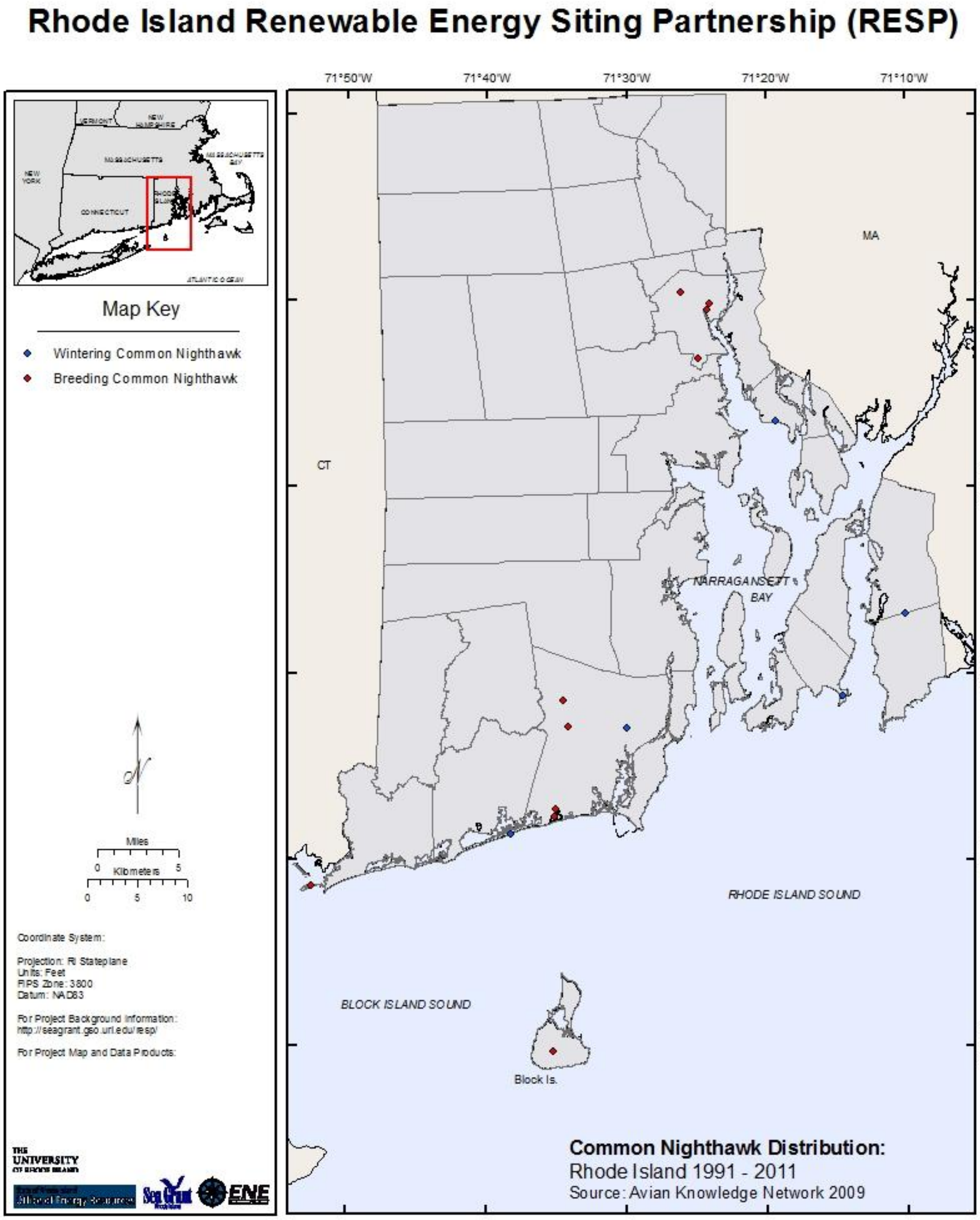


Figure A3.14. Distribution and abundance of **Common Nighthawk (*Chordeiles minor*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

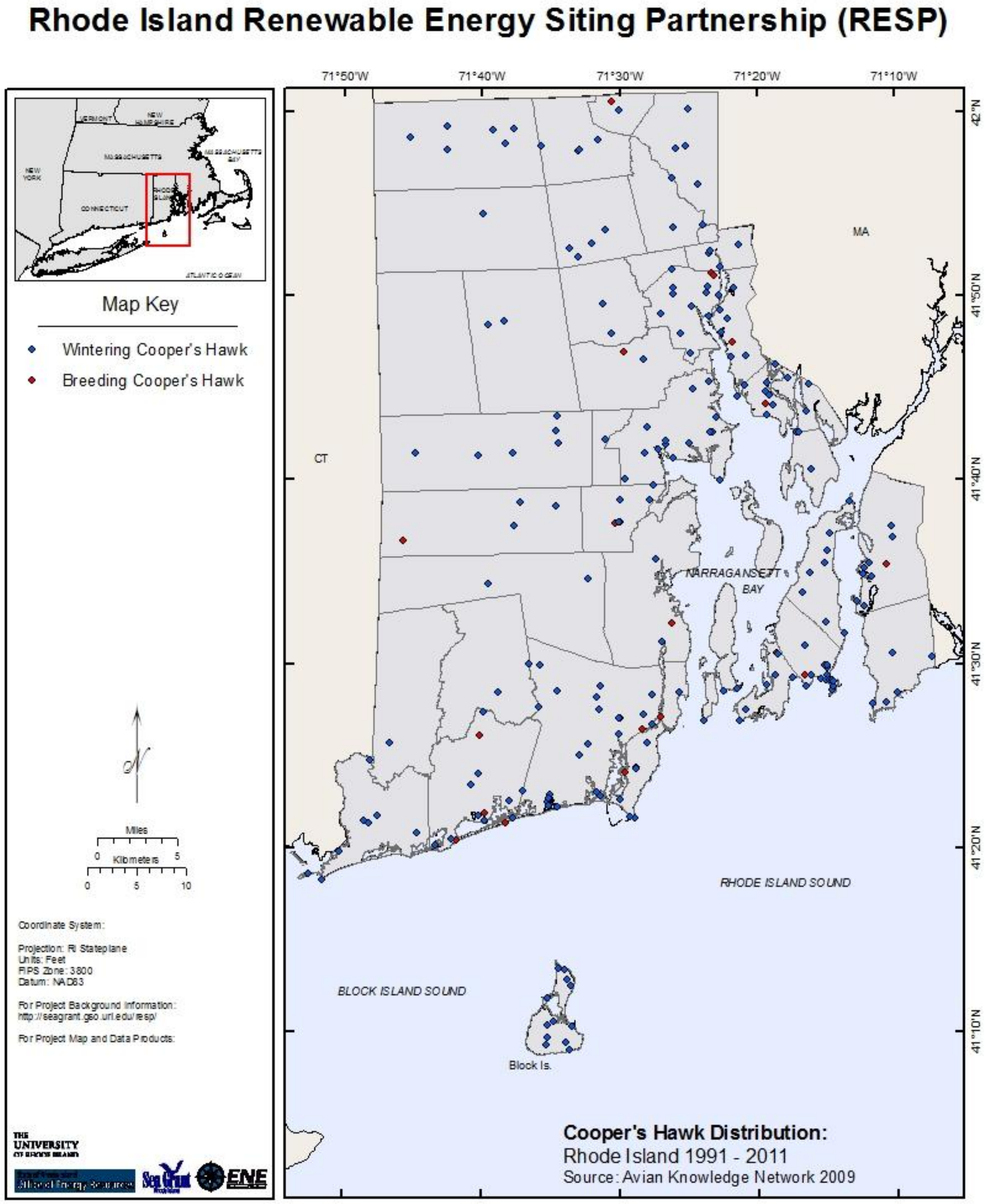


Figure A3.15. Distribution and abundance of **Cooper's Hawk (*Accipiter cooperii*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

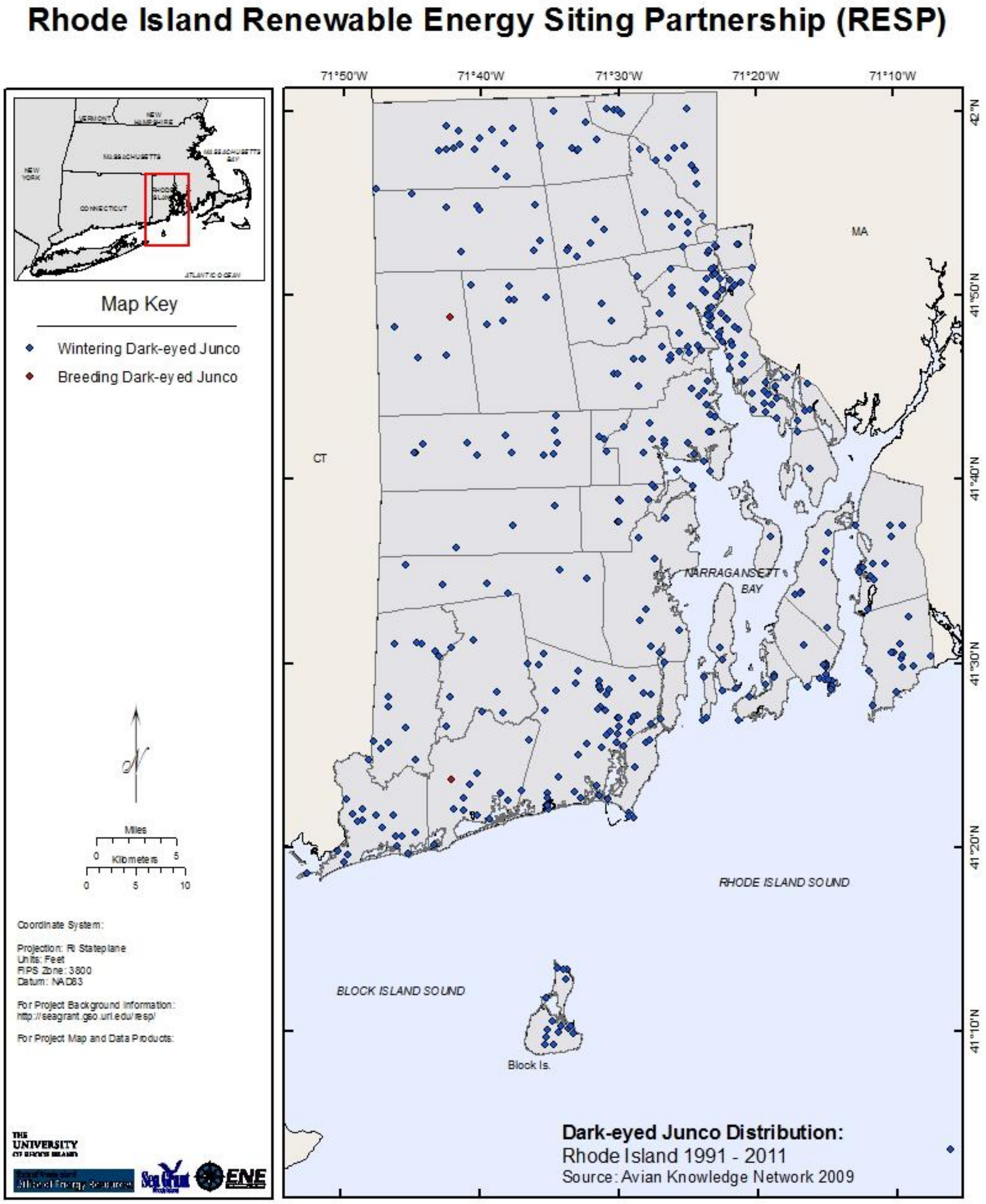


Figure A3.16. Distribution and abundance of **Dark-eyed Junco (*Junco hyemalis*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

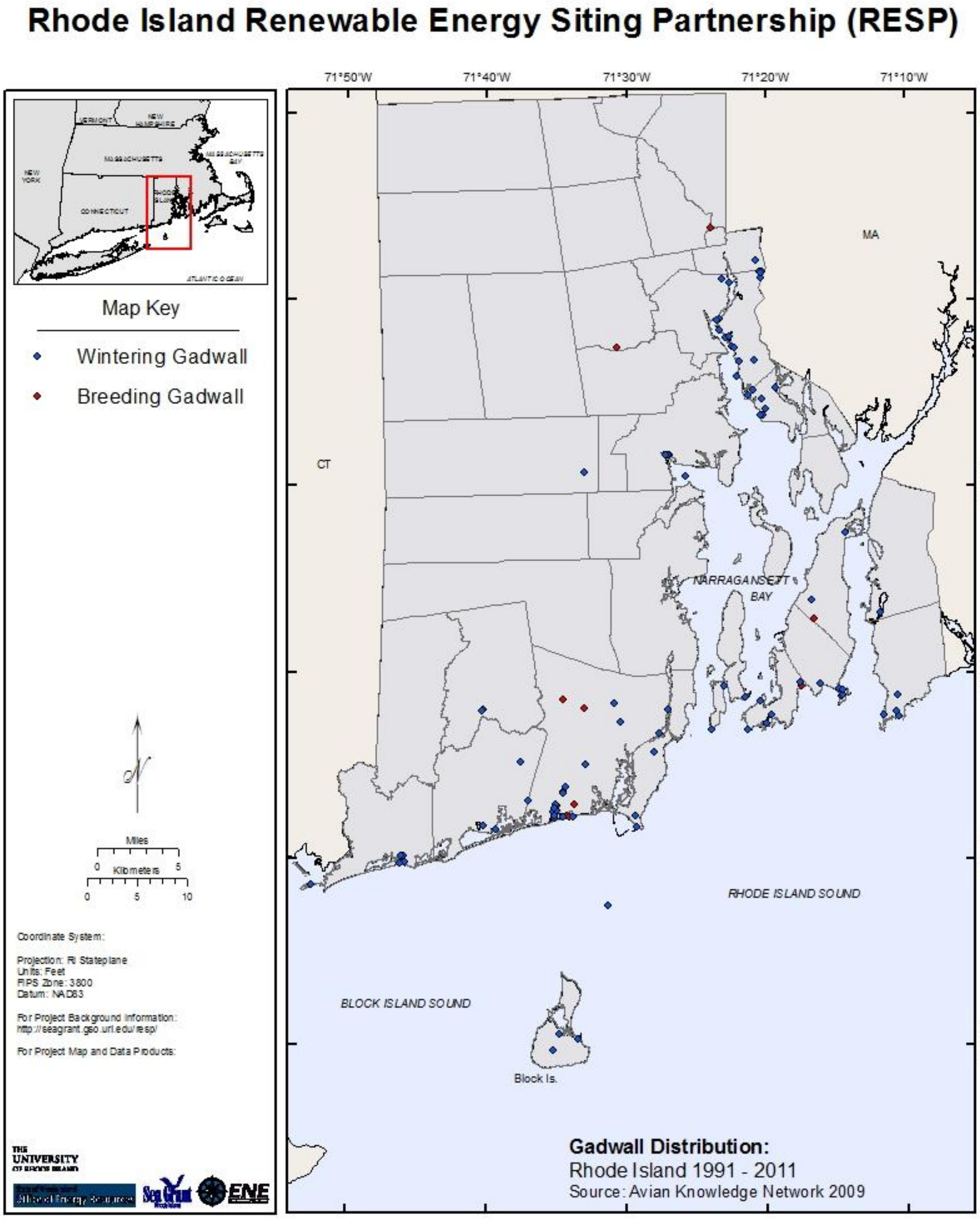


Figure A3.17. Distribution and abundance of **Gadwall (*Anas strepera*) i**n Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

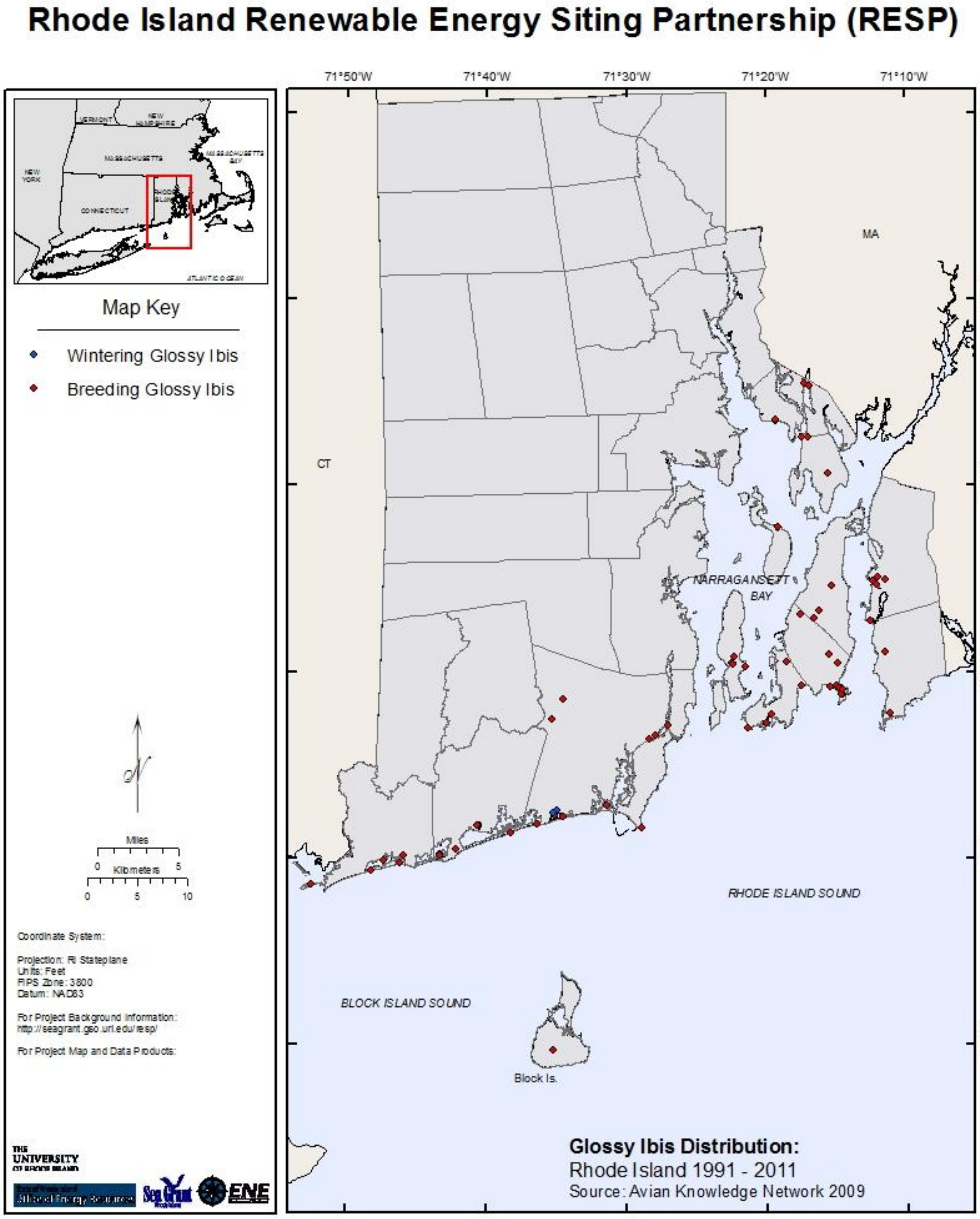


Figure A3.18. Distribution and abundance of **Glossy Ibis (*Plegadis falcinellus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a high conservation priority based on the BCR 30 Status, and it is listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

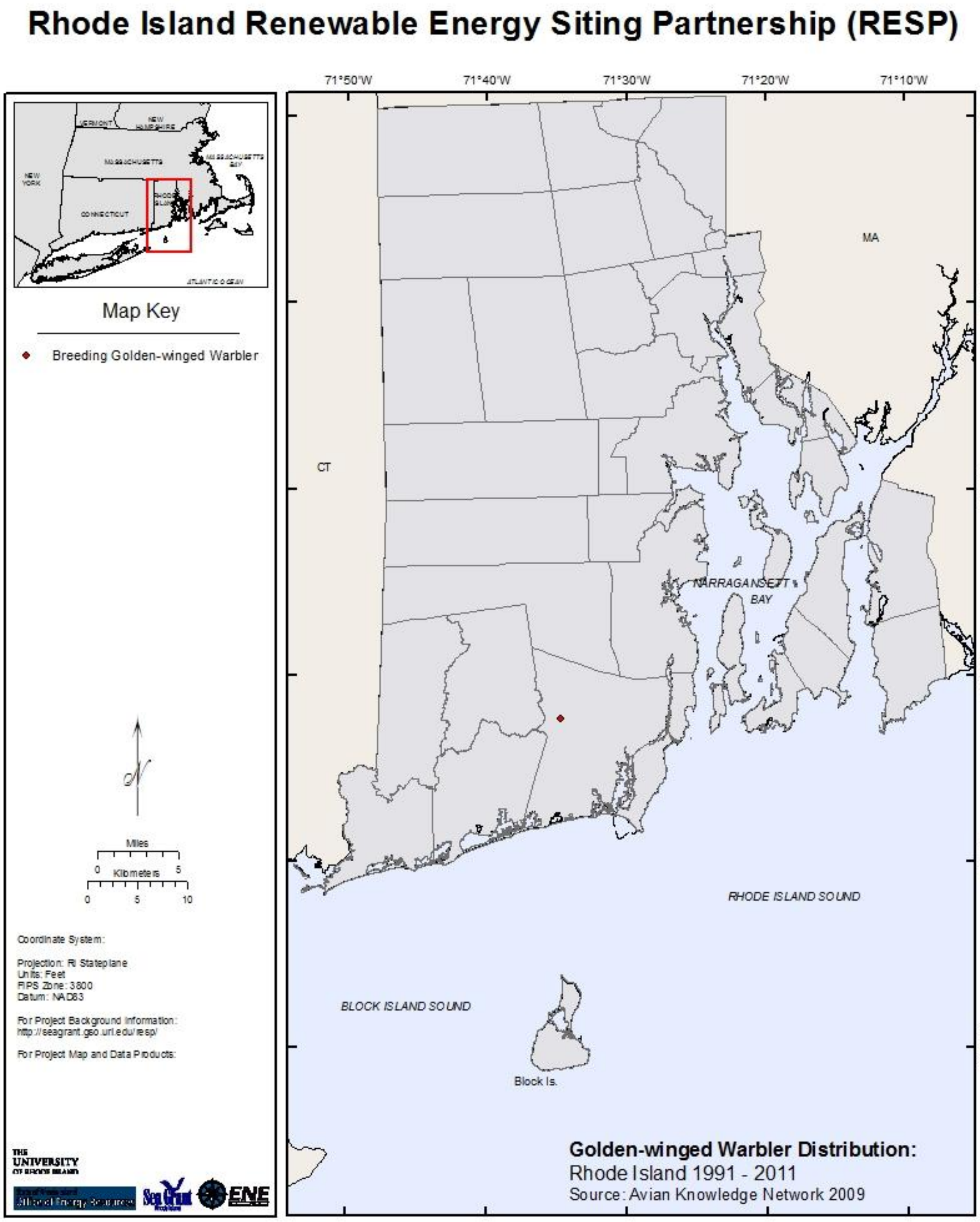


Figure A3.19. Distribution and abundance of **Golden-winged Warbler (*Vermivora chrysoptera*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state historic in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier IB conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

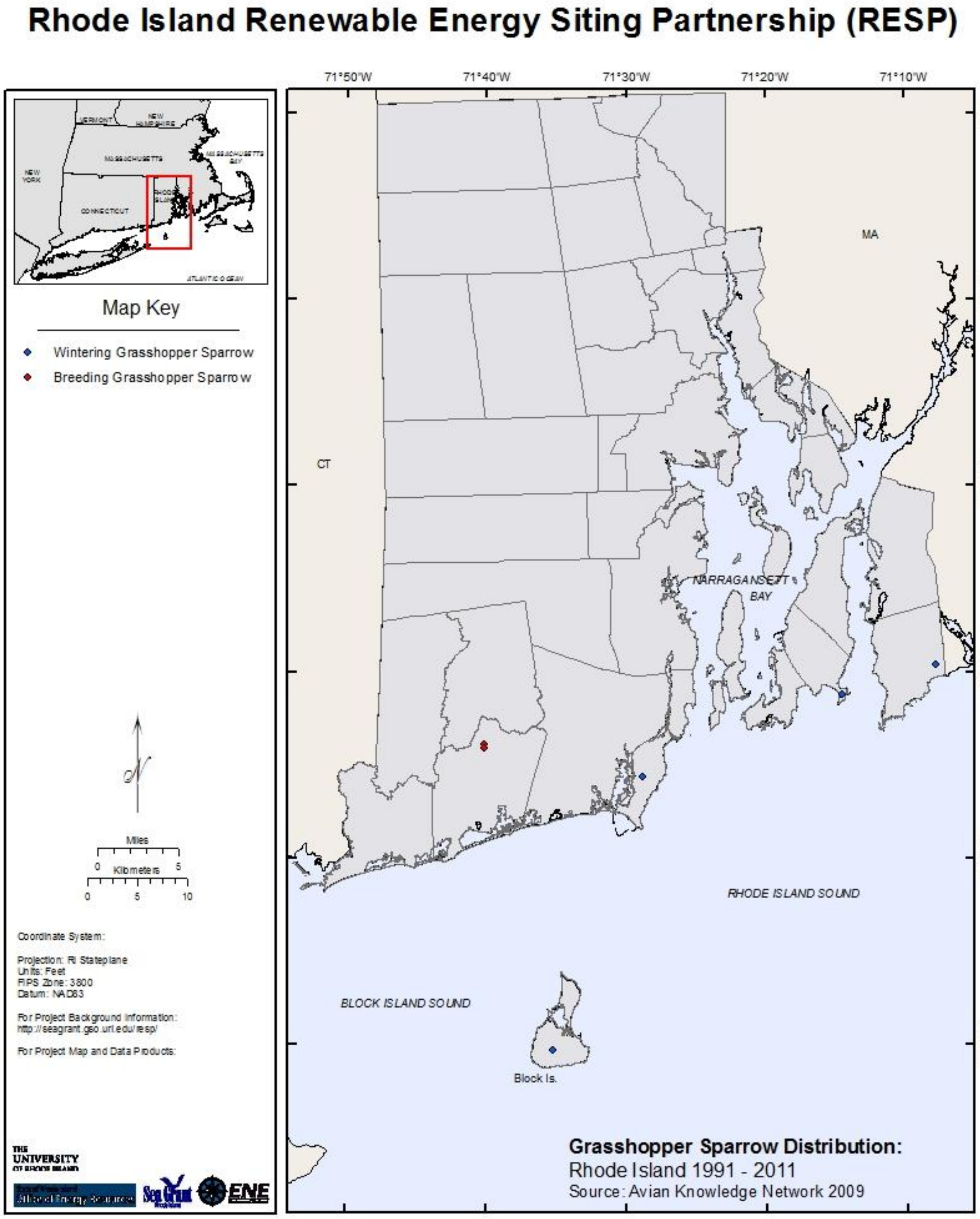


Figure A3.20. Distribution and abundance of **Grasshopper Sparrow (*Ammodramus savannarum*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state threatened in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

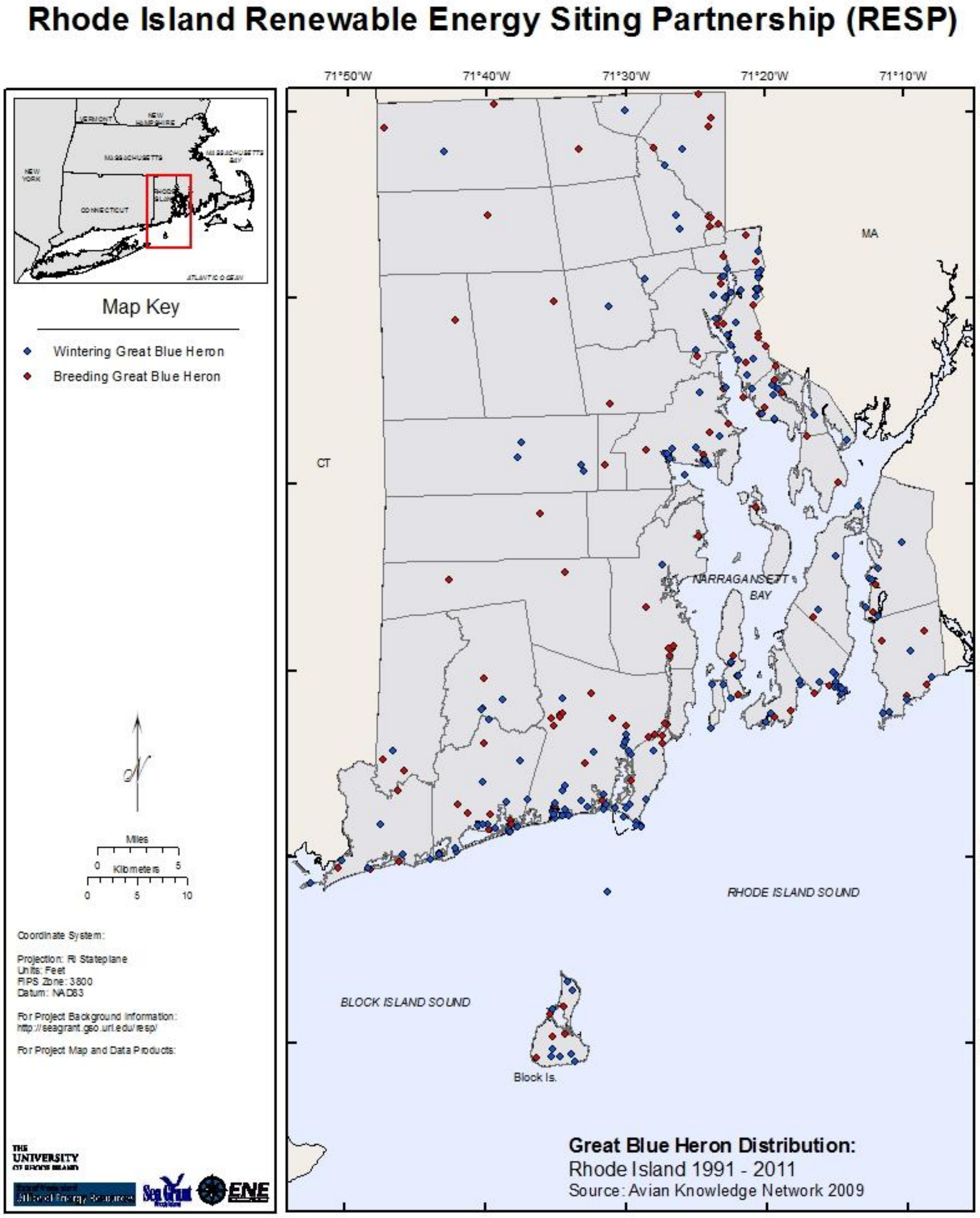


Figure A3.21. Distribution and abundance of **Great Blue Heron (*Ardea herodias*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

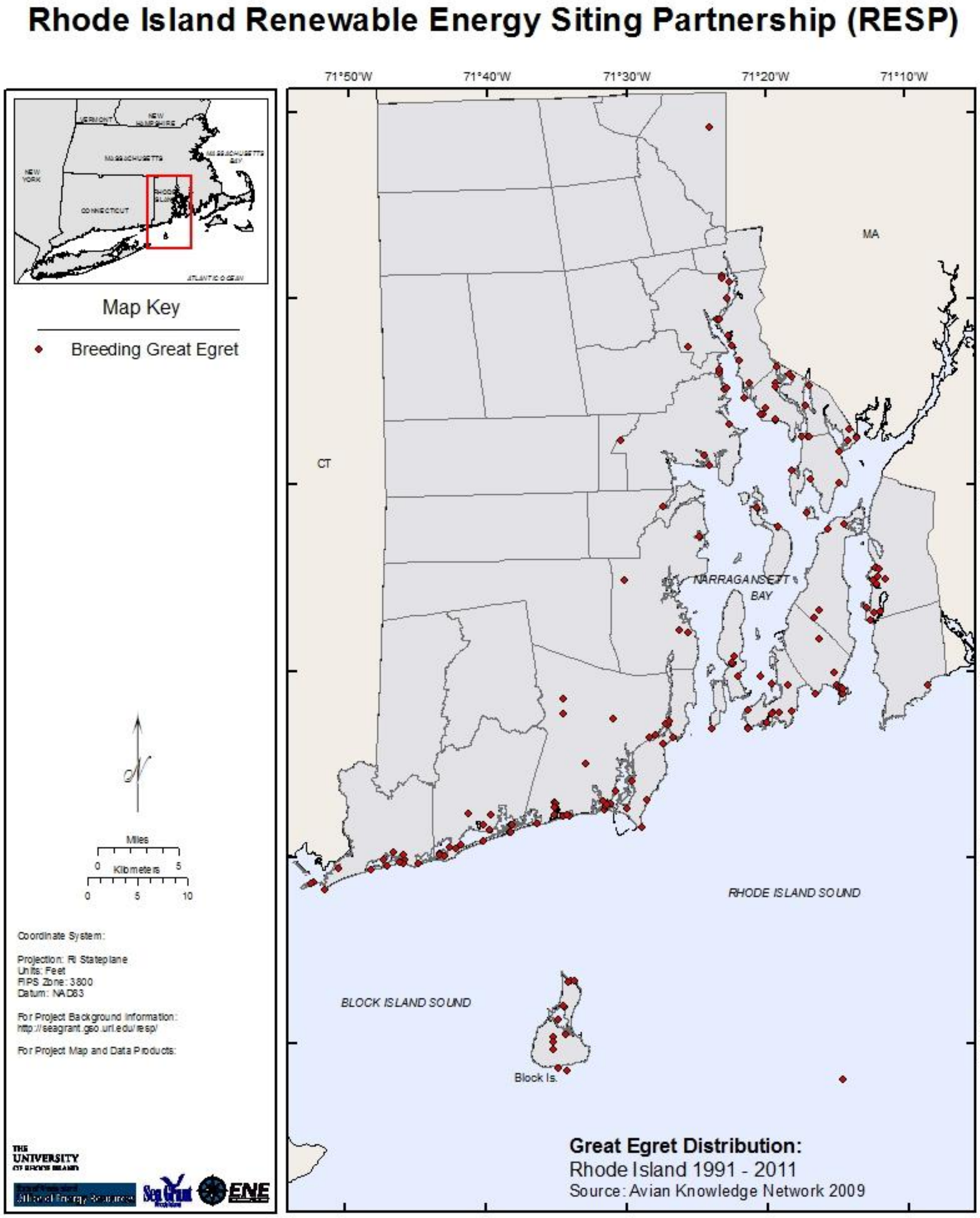


Figure A3.22. Distribution and abundance of **Great Egret (*Casmerodius albus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

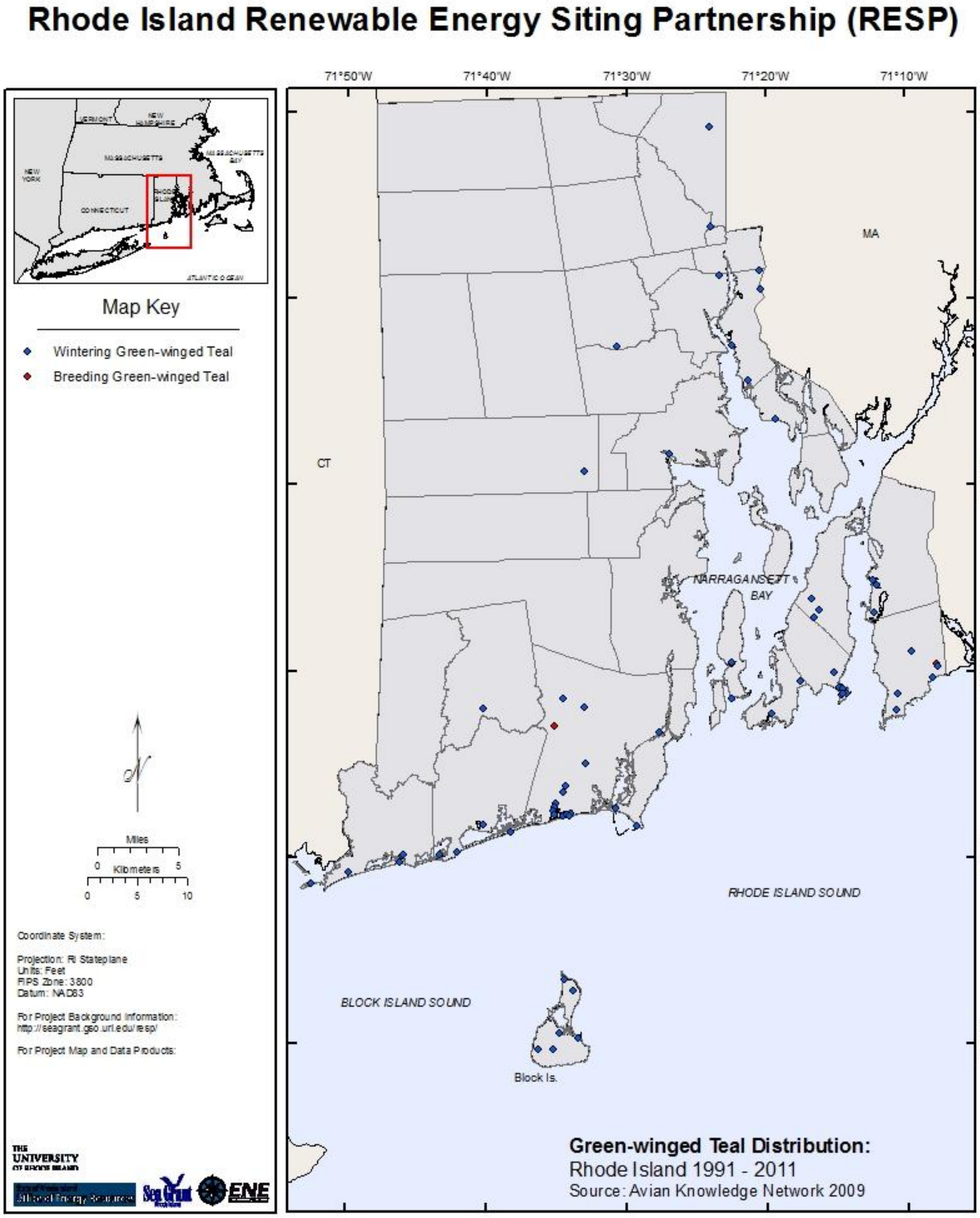


Figure A3.23. Distribution and abundance of **Green-winged Teal (*Anas crecca*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

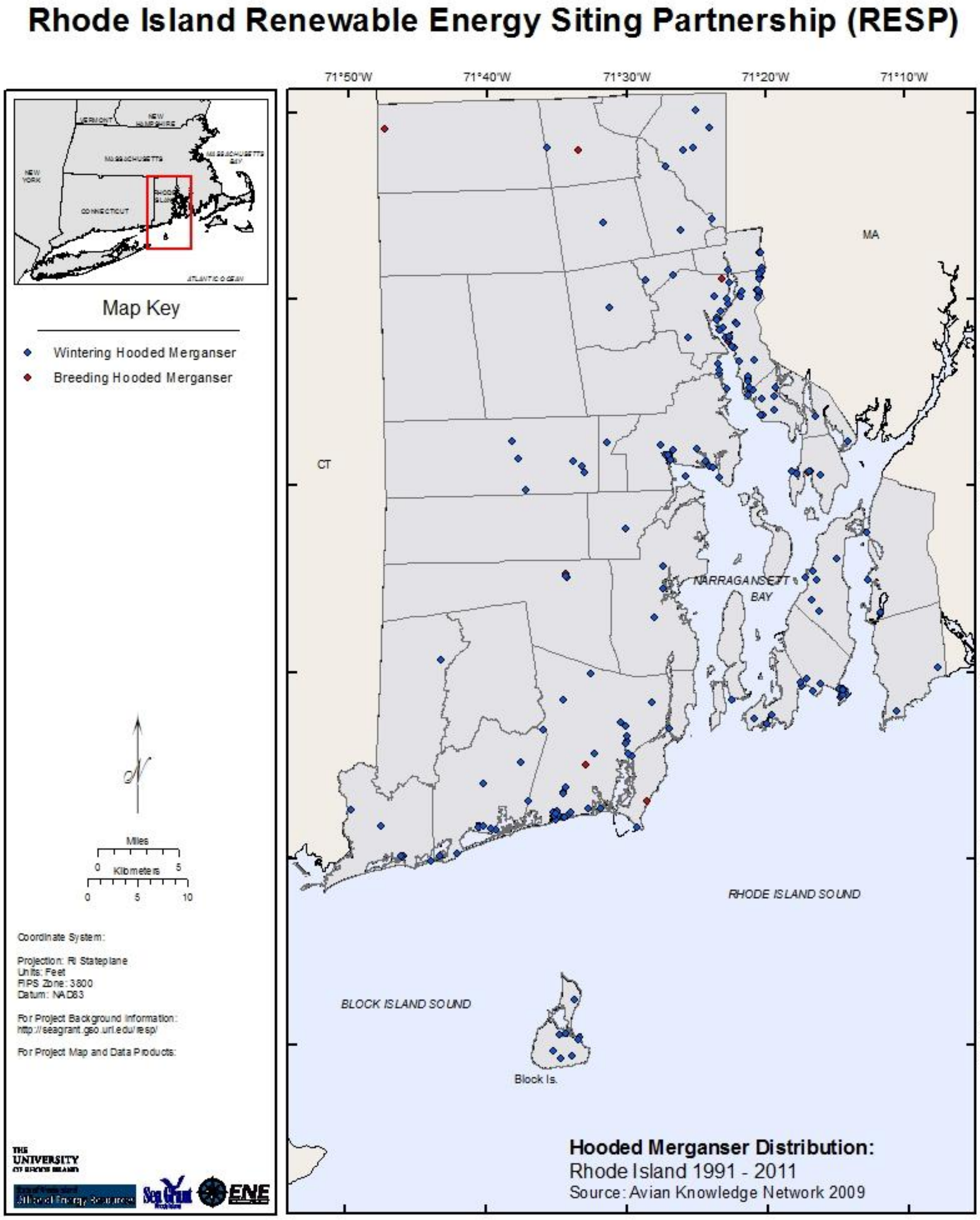


Figure A3.24. Distribution and abundance of **Hooded Merganser (*Lophodytes cucullatus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

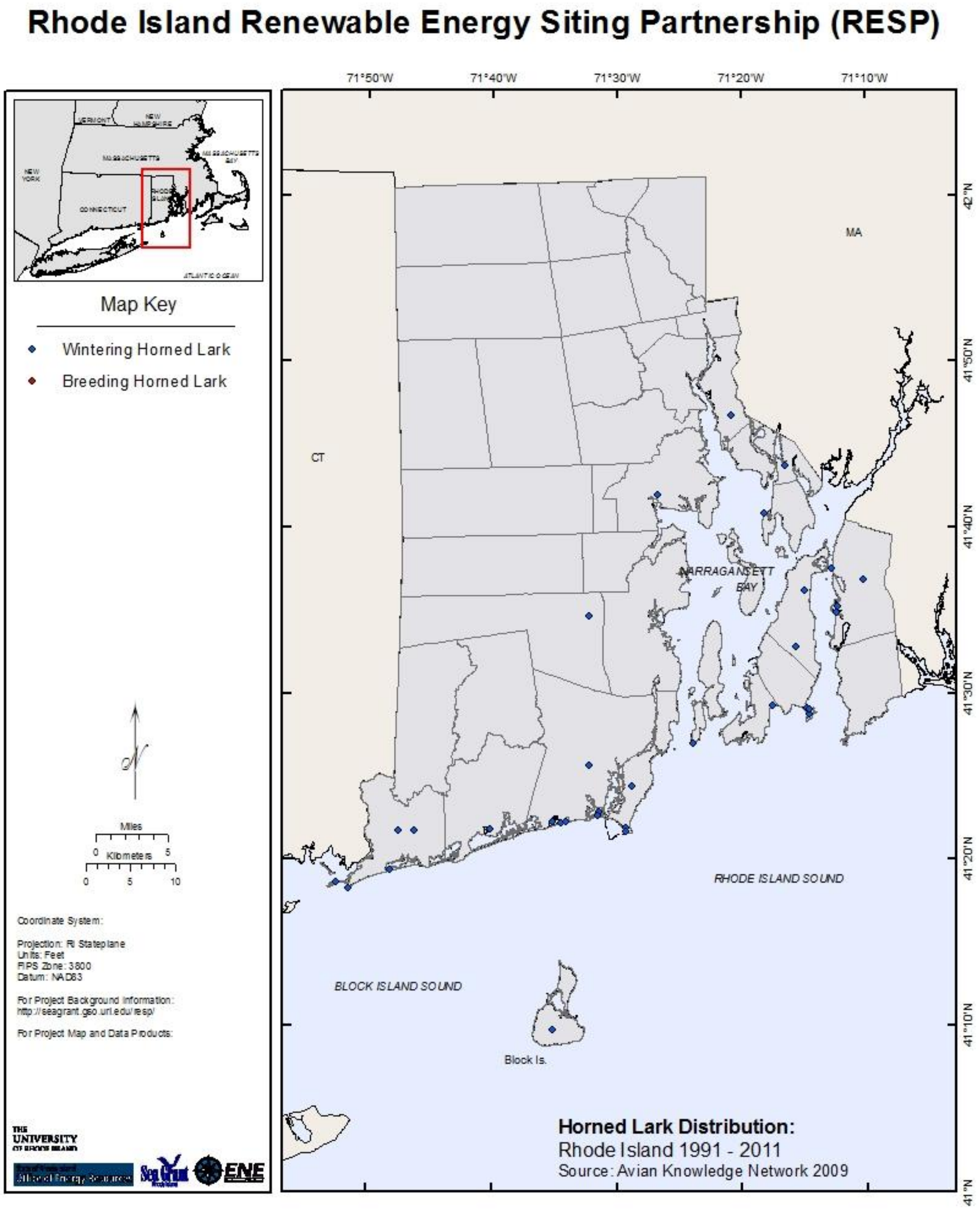


Figure A3.25. Distribution and abundance of **Horned Lark (*Eremophila alpestris*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

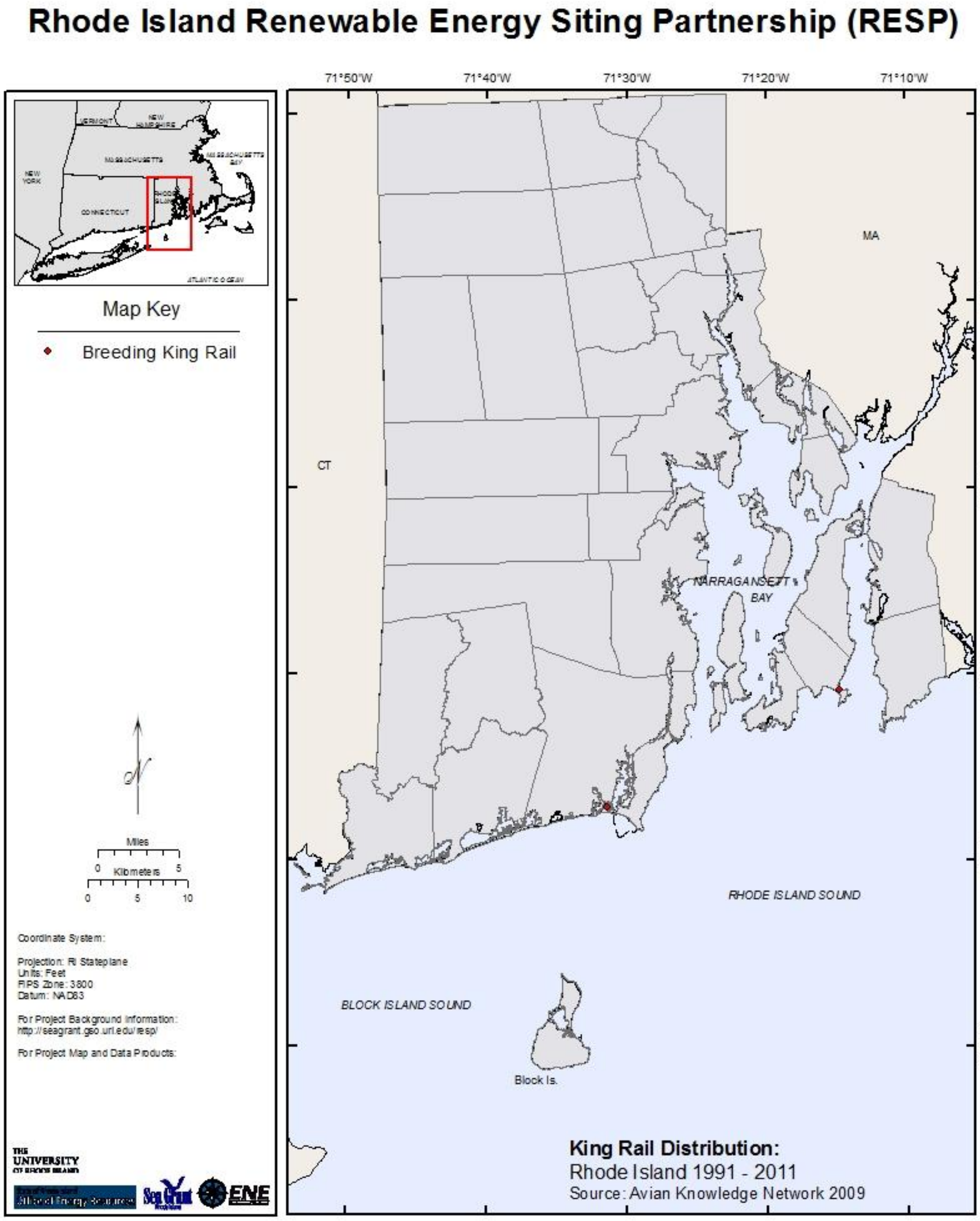


Figure A3.26. Distribution and abundance of **King Rail (*Rallus elegans*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

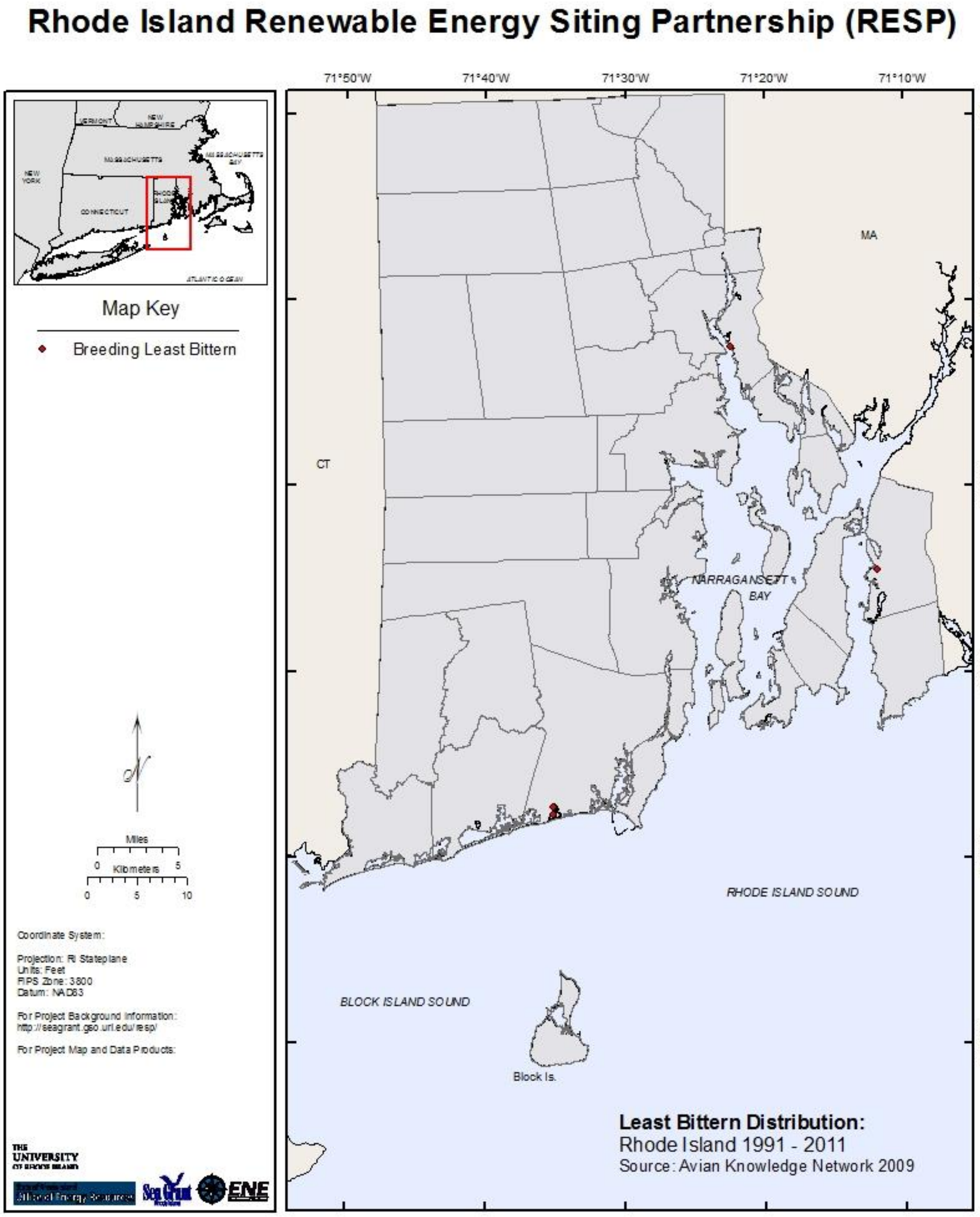


Figure A3.27. Distribution and abundance of **Least Bittern (*Ixobrychus exilis*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

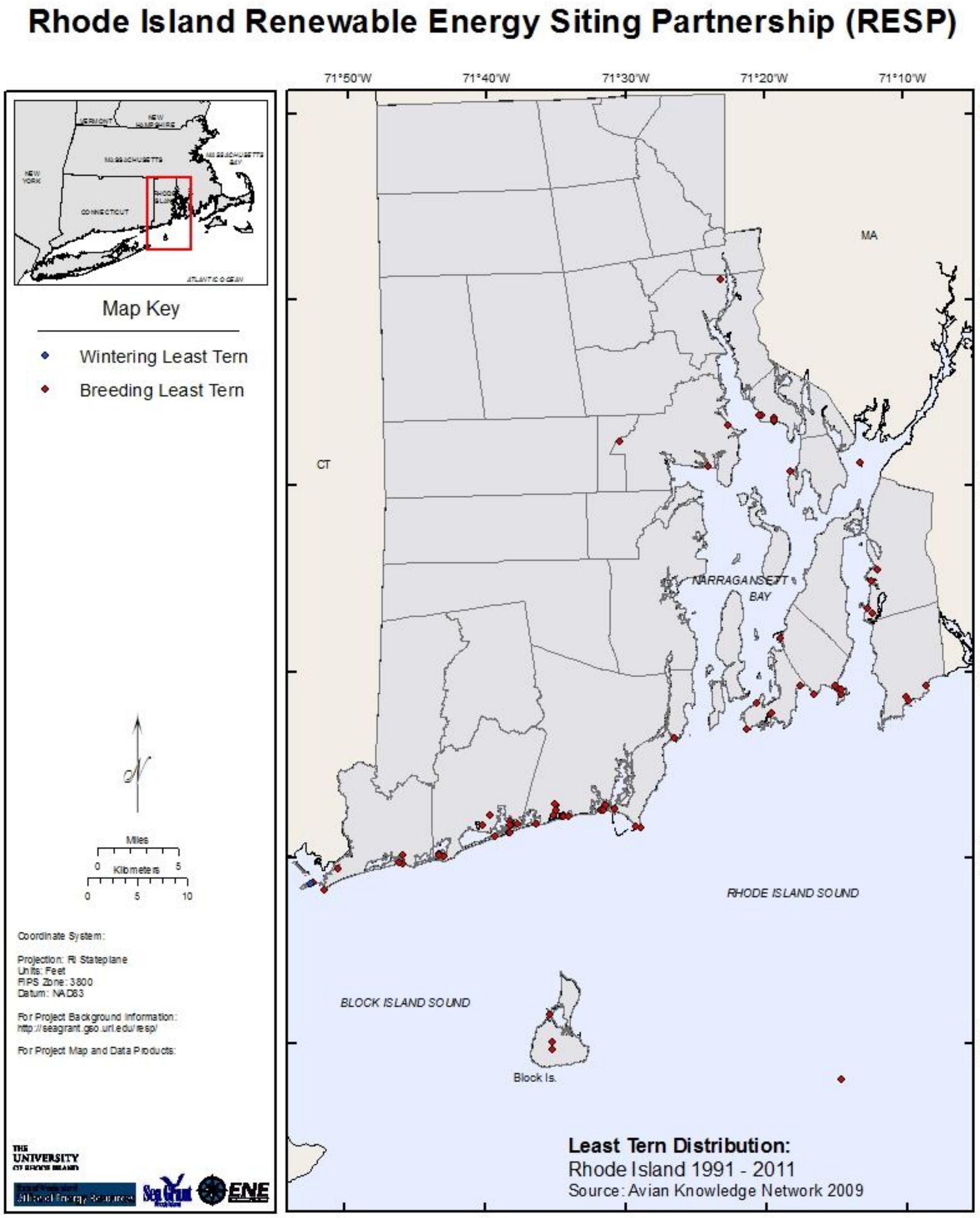


Figure A3. 28. Distribution and abundance of **Least Tern (*Sterna antillarum*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a threatened species in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as high conservation priority based on the BCR 30 Status, and it is listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

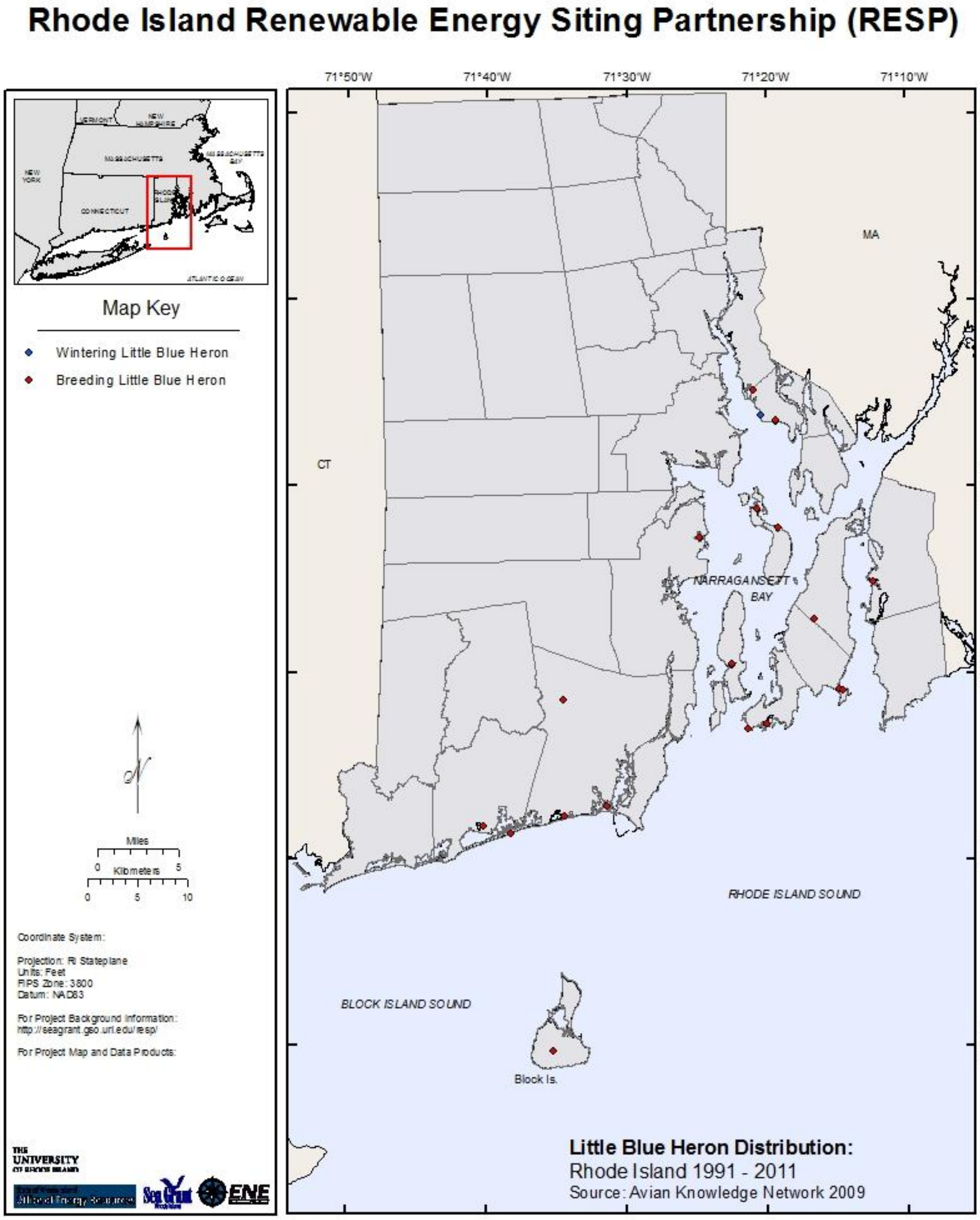


Figure A3.29. Distribution and abundance of **Little Blue Heron (*Egretta caerulea*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

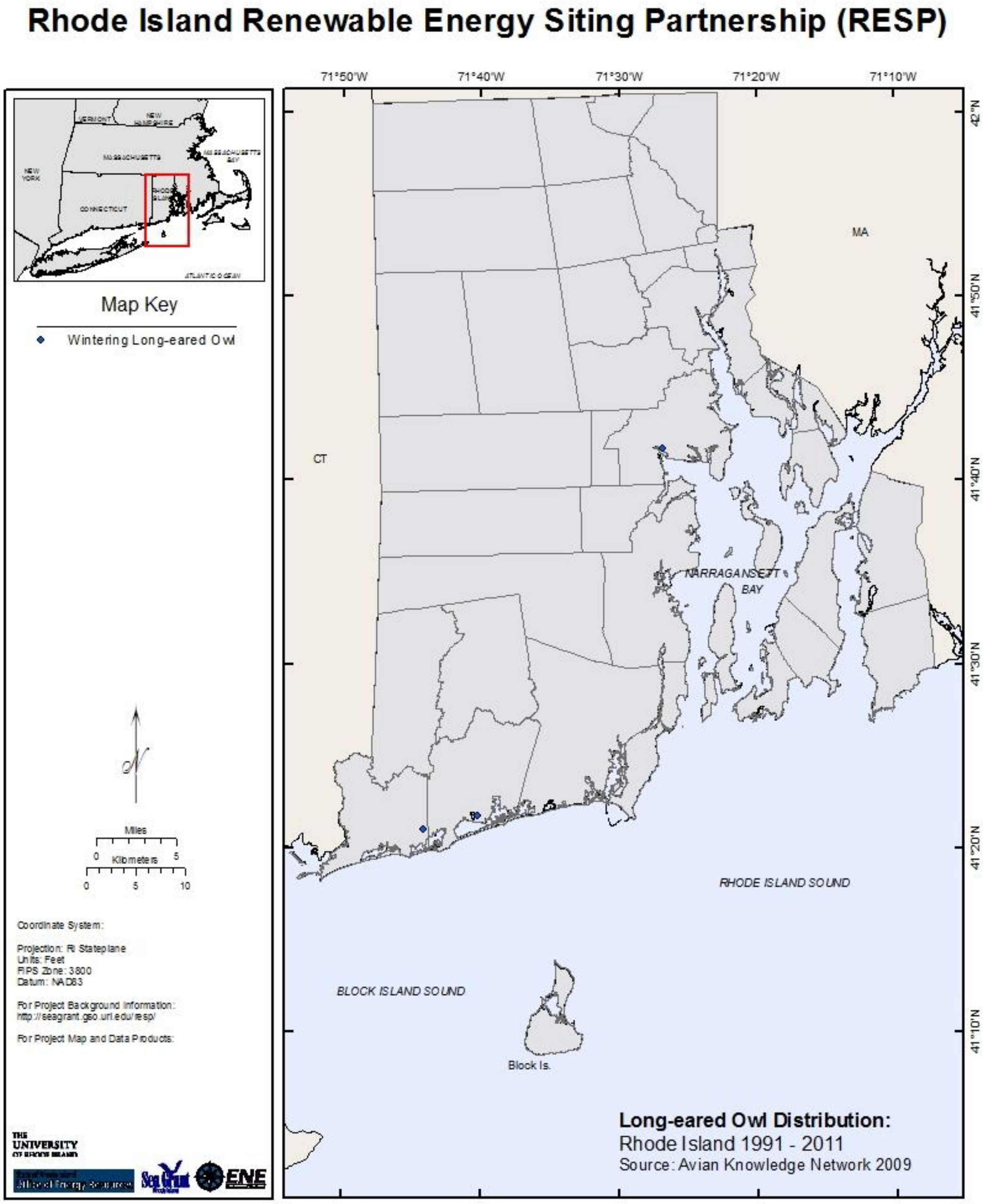


Figure A3.30. Distribution and abundance of **Long-eared Owl (*Asio otus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

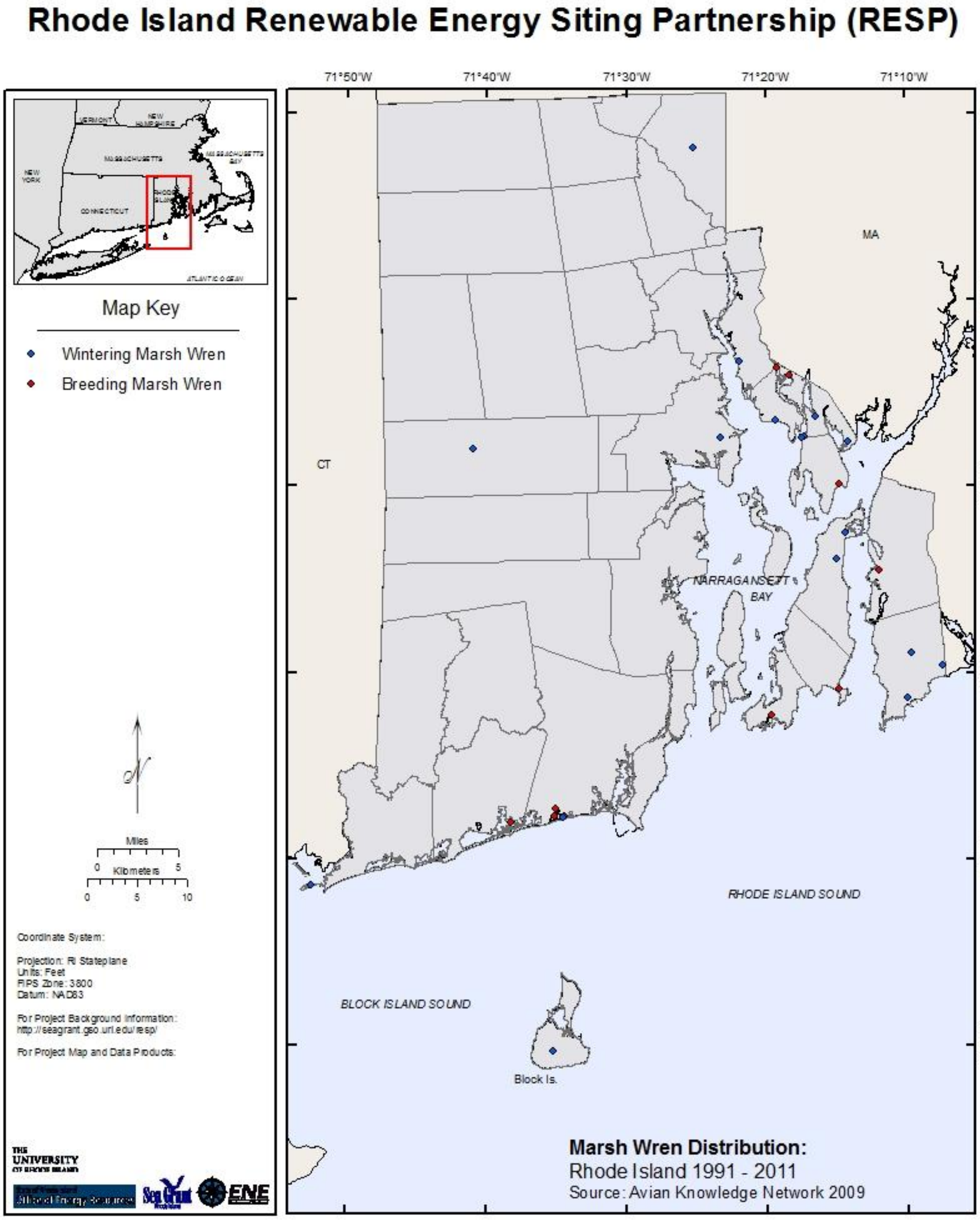


Figure A3.31. Distribution and abundance of **Marsh Wren (*Cistothorus palustris*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as high conservation priority based on the BCR 30 Status (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

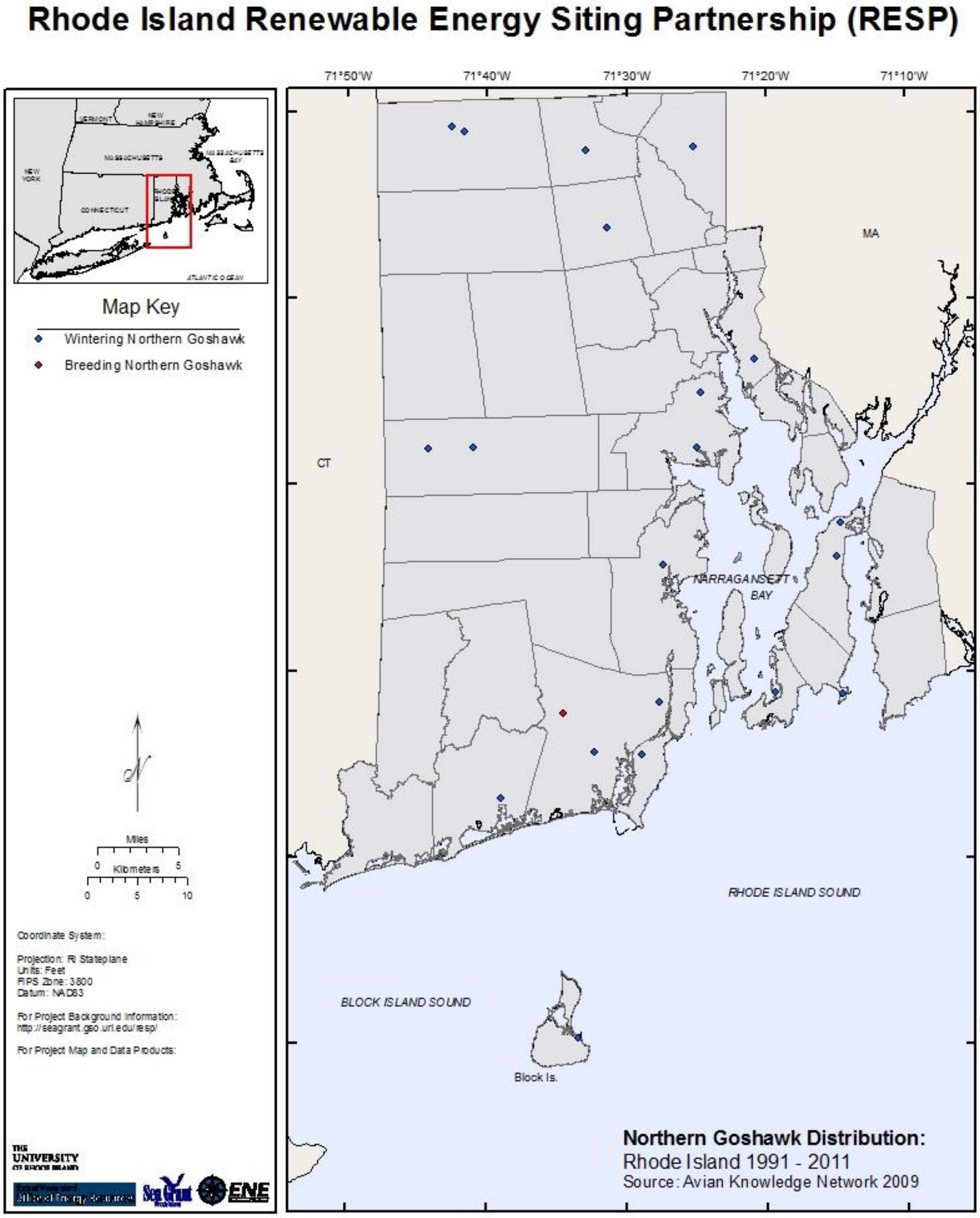


Figure A3.32. Distribution and abundance of **Northern Goshawk (*Accipiter gentilis*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

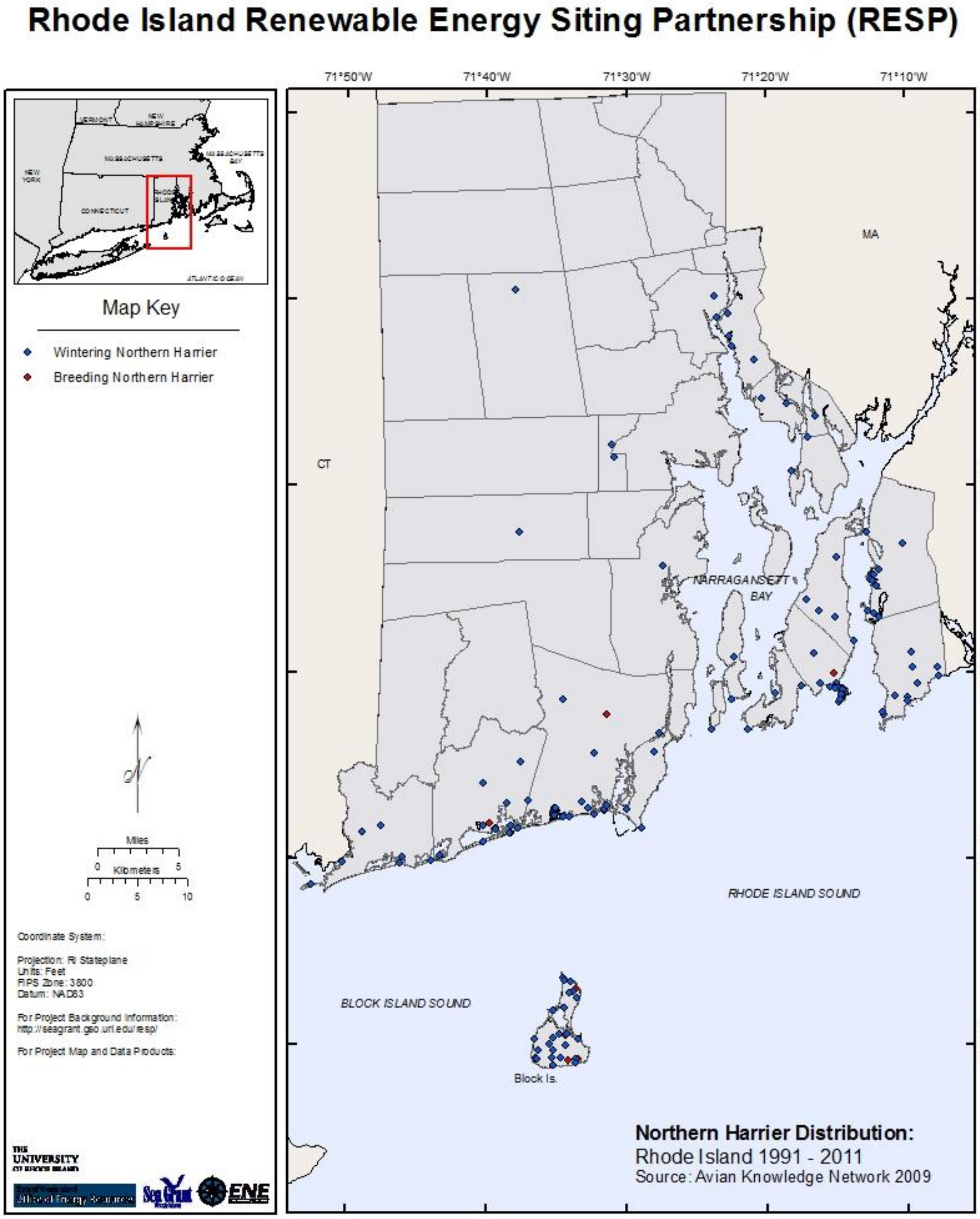


Figure A3.33. Distribution and abundance of **Northern Harrier (*Circus cyaneus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state endangered in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

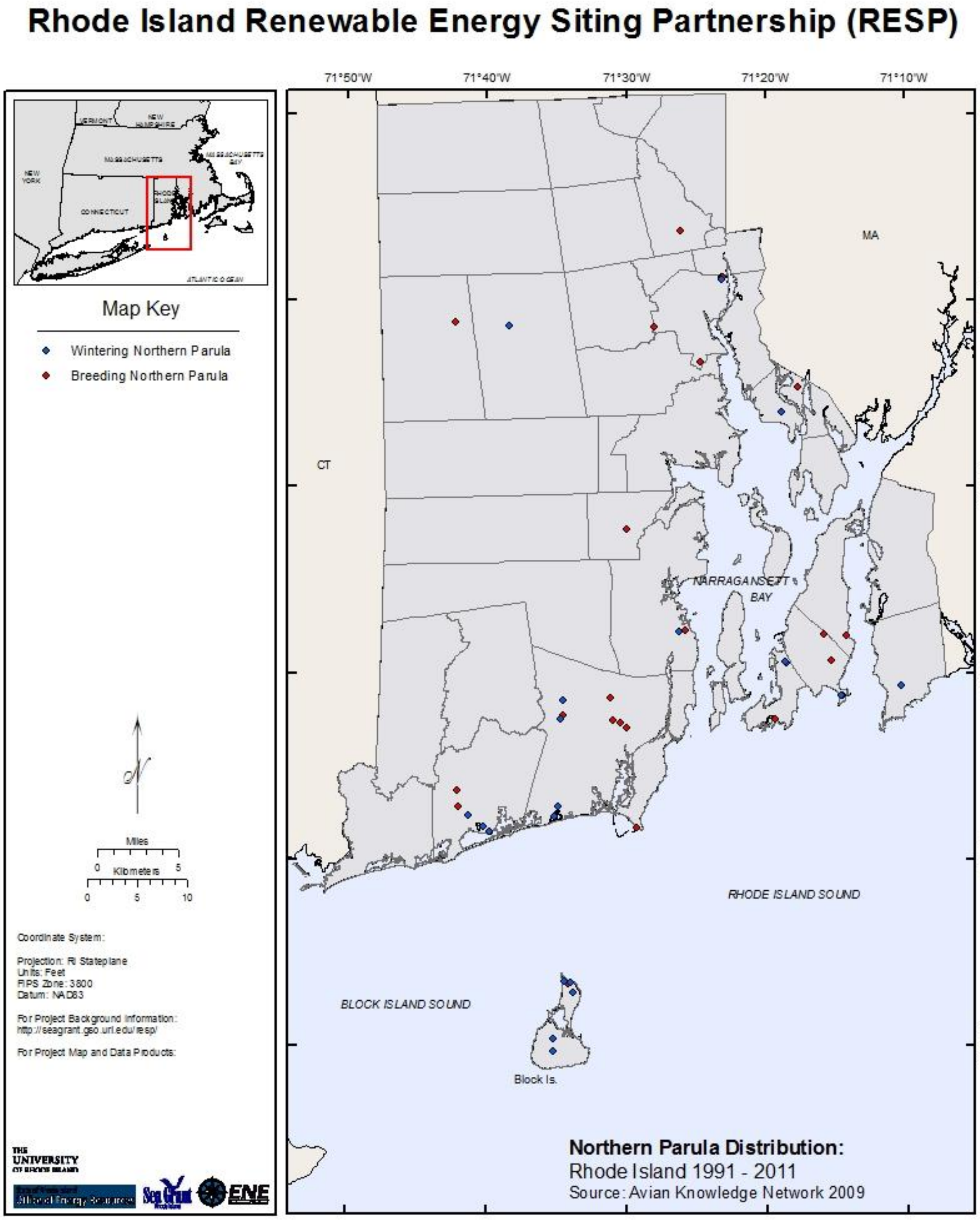


Figure A3.34. Distribution and abundance of **Northern Parula (*Parula americanna*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state threatened in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

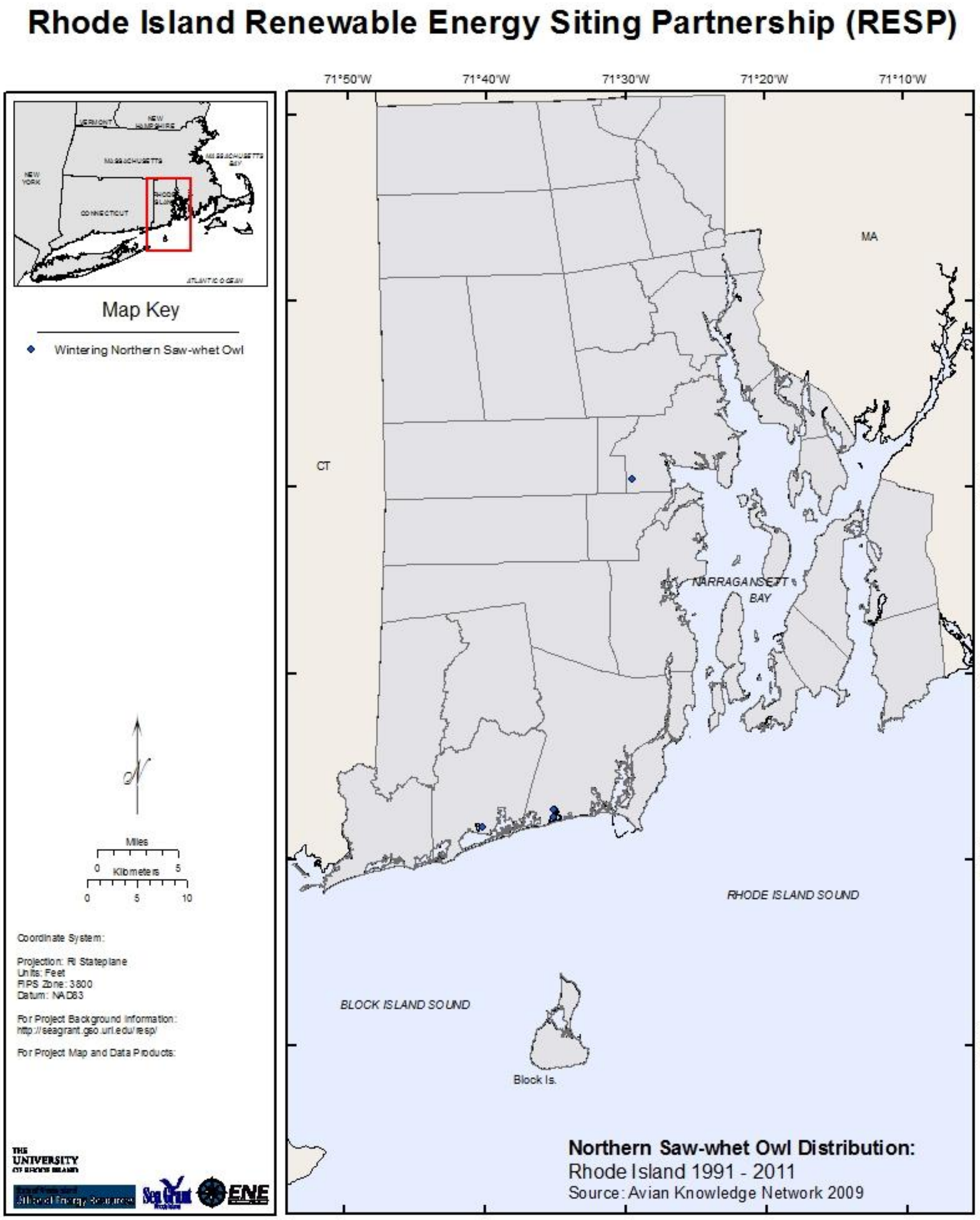


Figure A3.35. Distribution and abundance of **Northern Saw-whet Owl (*Aegolius acadicus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

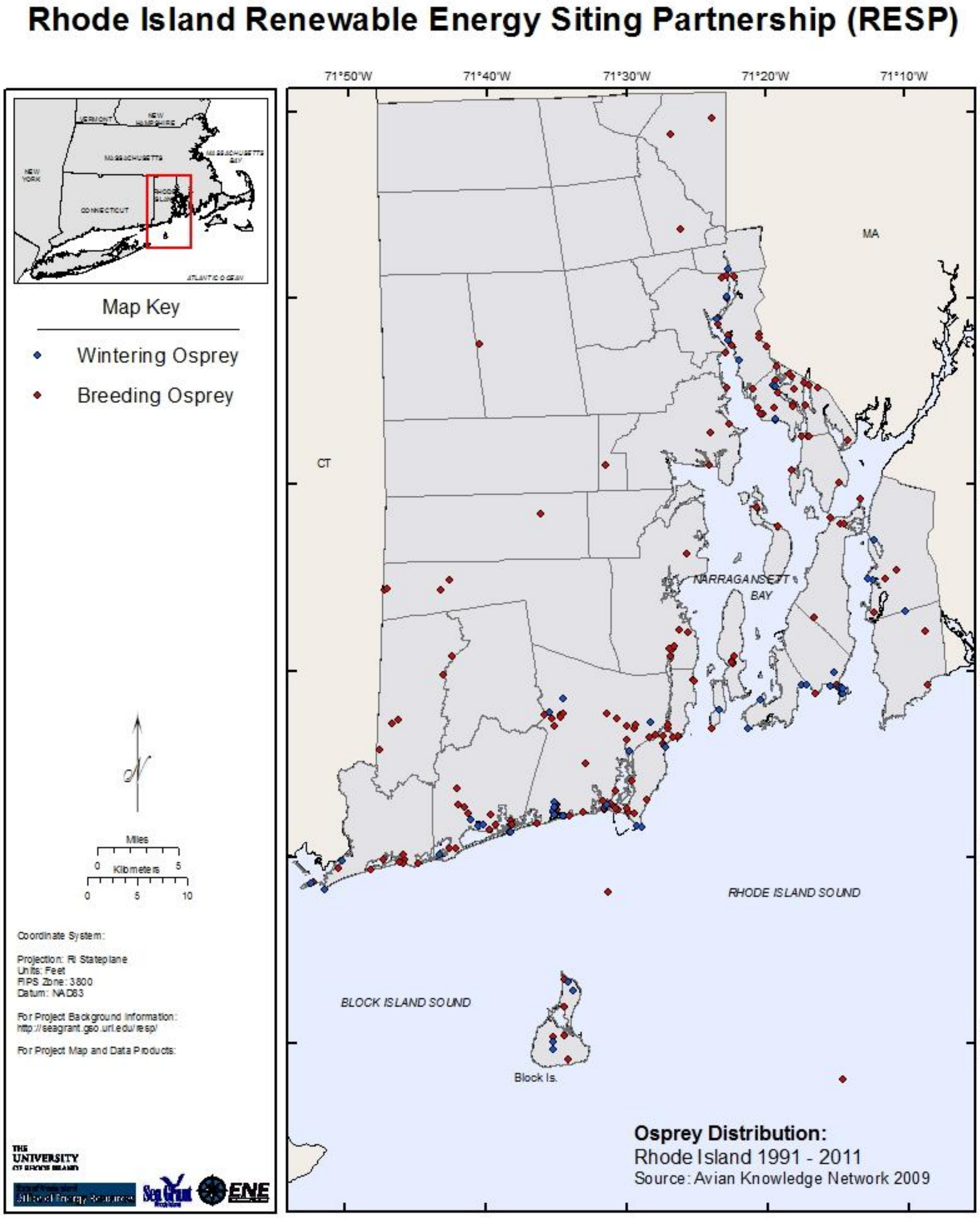


Figure A3.36. Distribution and abundance of **Osprey (*Pandion haliaetus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

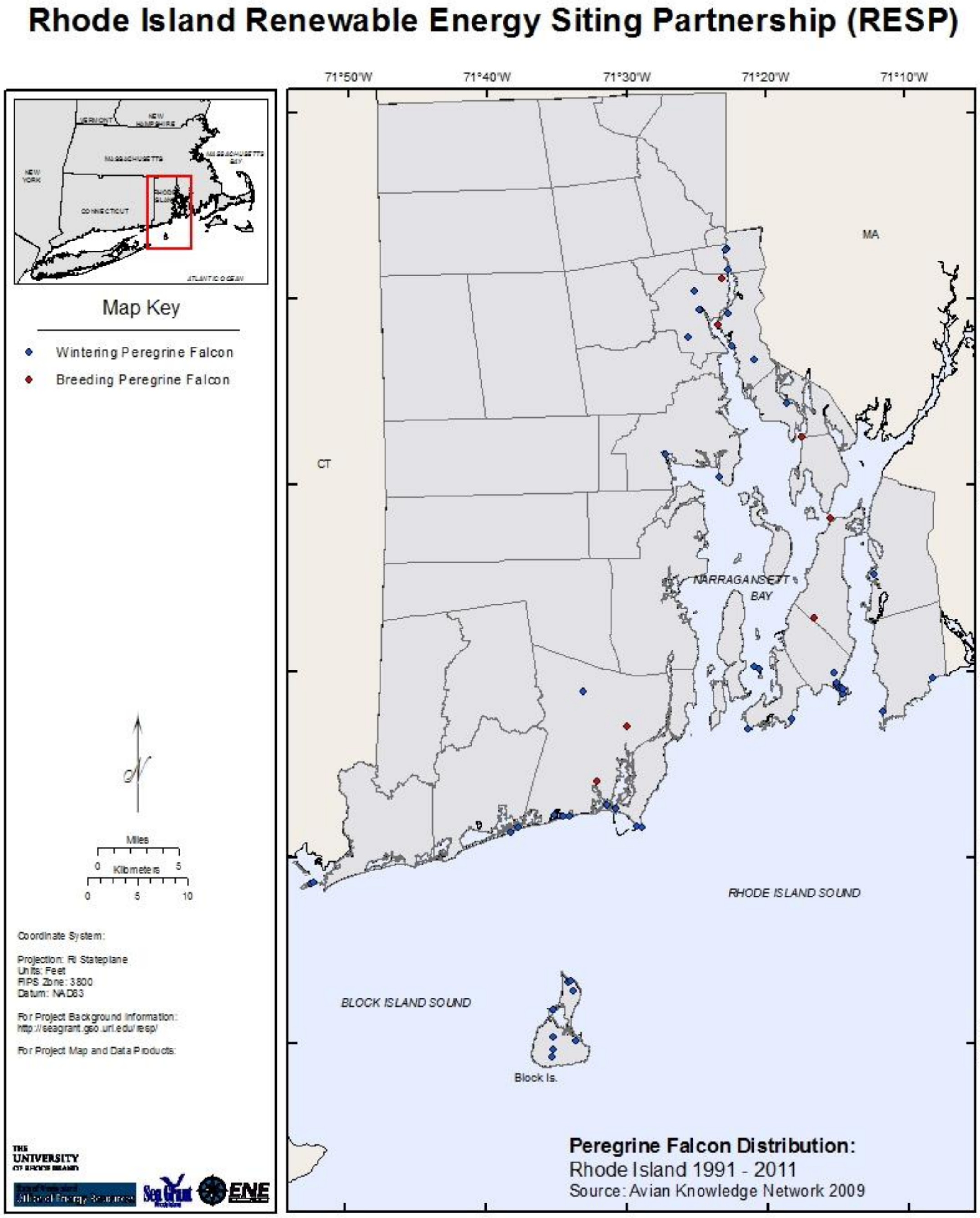


Figure A3.37. Distribution and abundance of **Peregrine Falcon (*Falco peregrinus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state endangered in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a Tier IIC conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

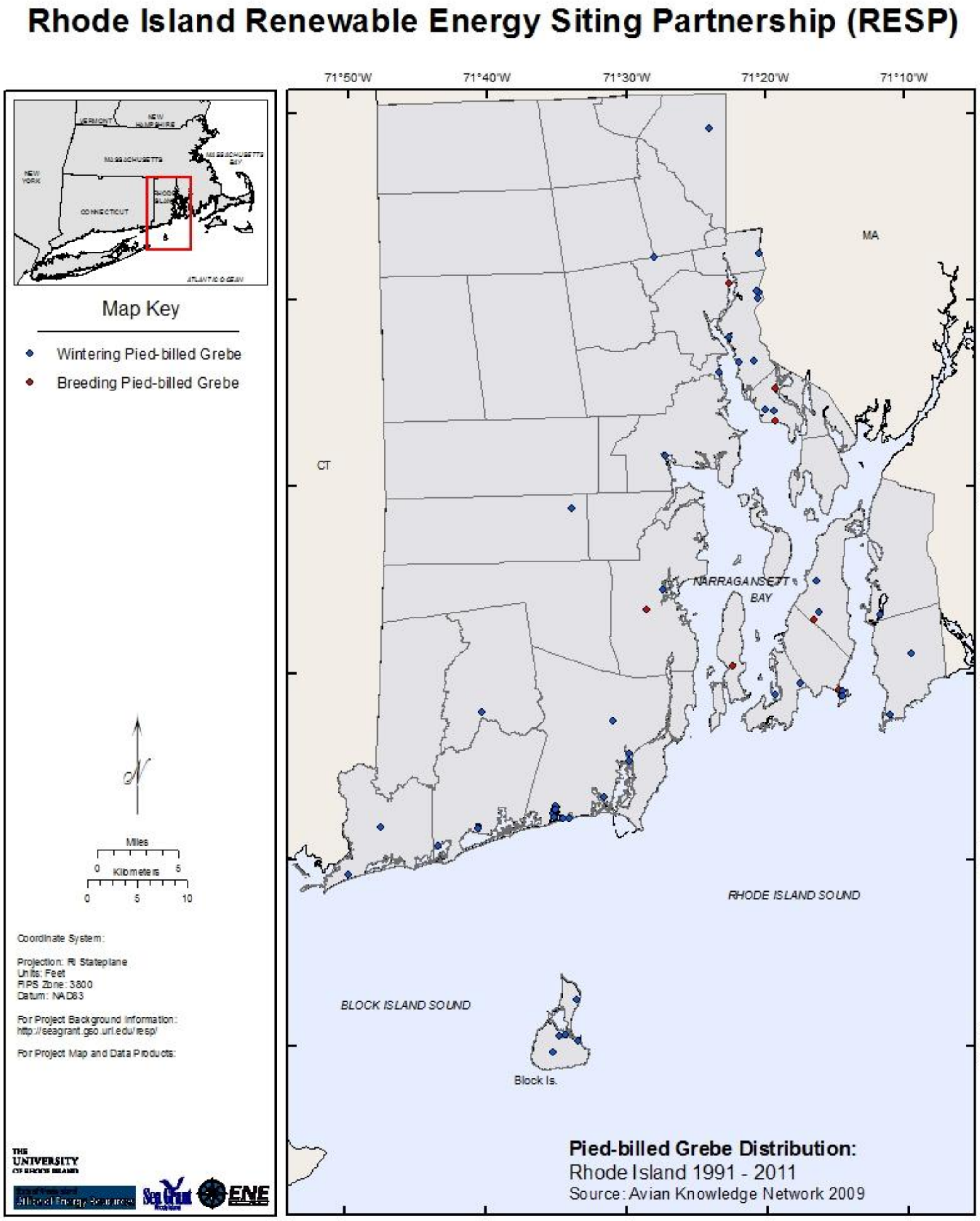


Figure A3.38. Distribution and abundance of **Pied-billed Grebe (*Podilymbus podiceps*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state endangered in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

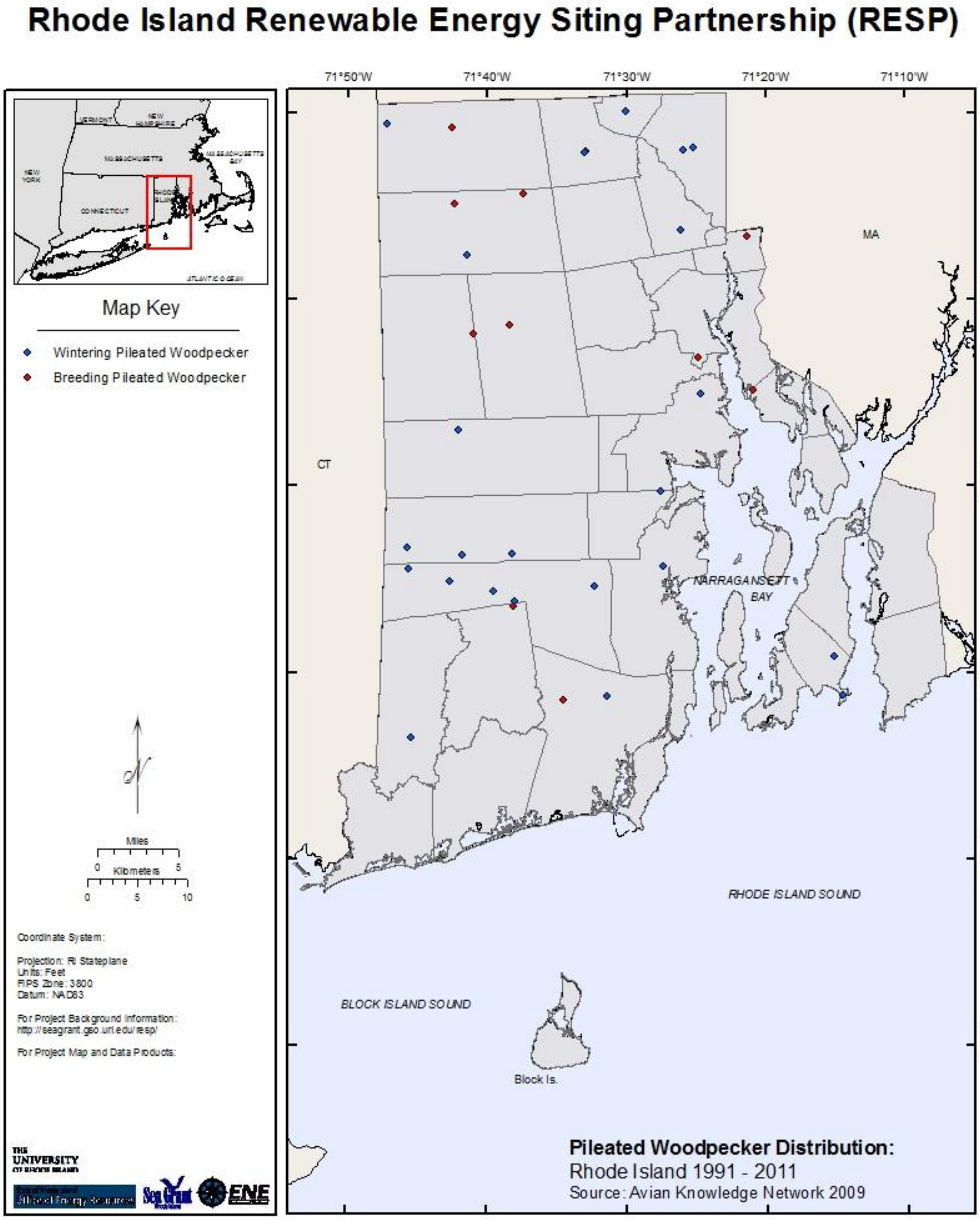


Figure A3.39. Distribution and abundance of **Pileated Woodpecker (*Dryocopus pileatus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

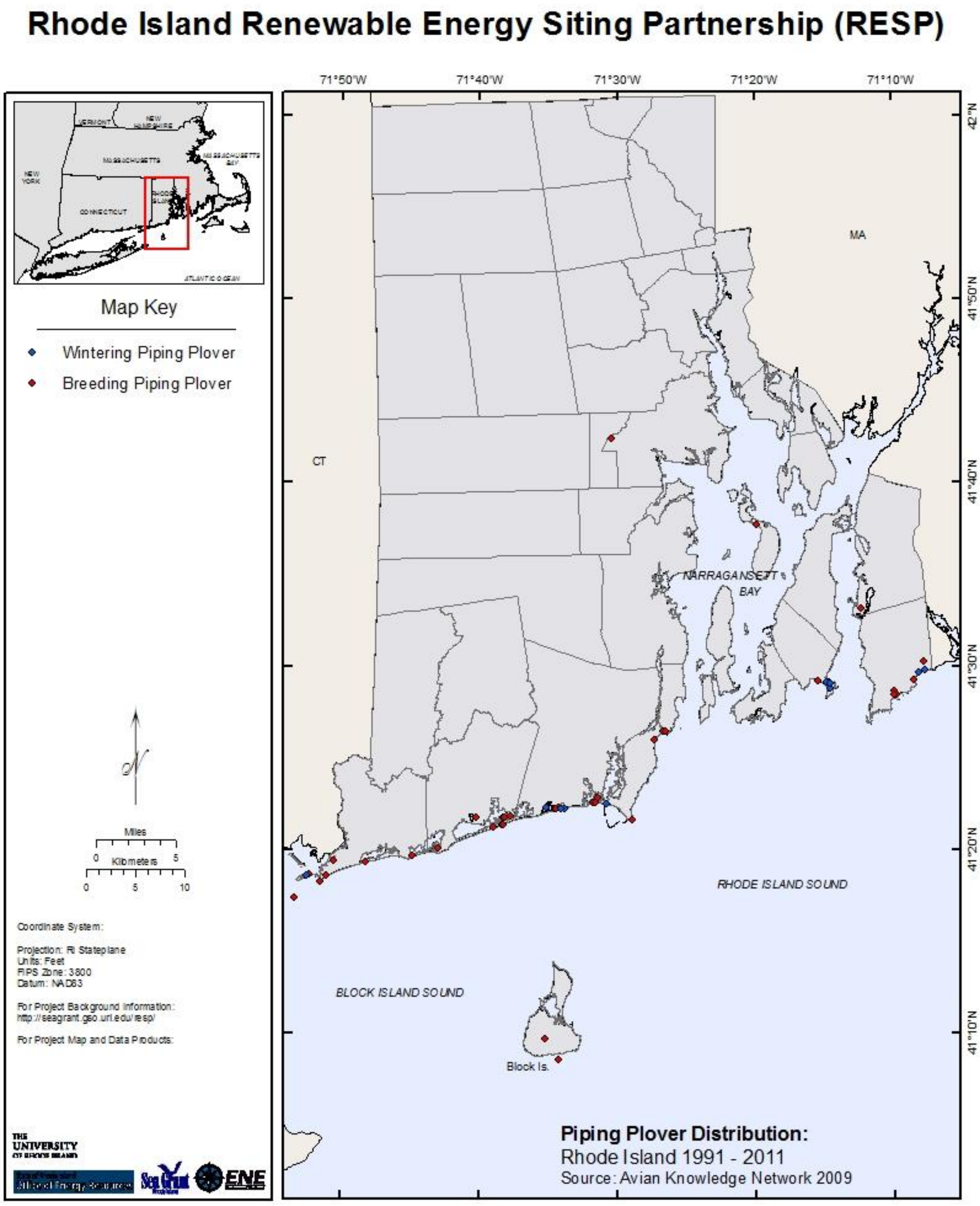


Figure A3.40. Distribution and abundance of **Piping Plover (*Charadrius melodus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as federally threatened (Table 5). It is also listed as the highest conservation priority based on the BCR 30 Status, and it is listed as a Tier 1A conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

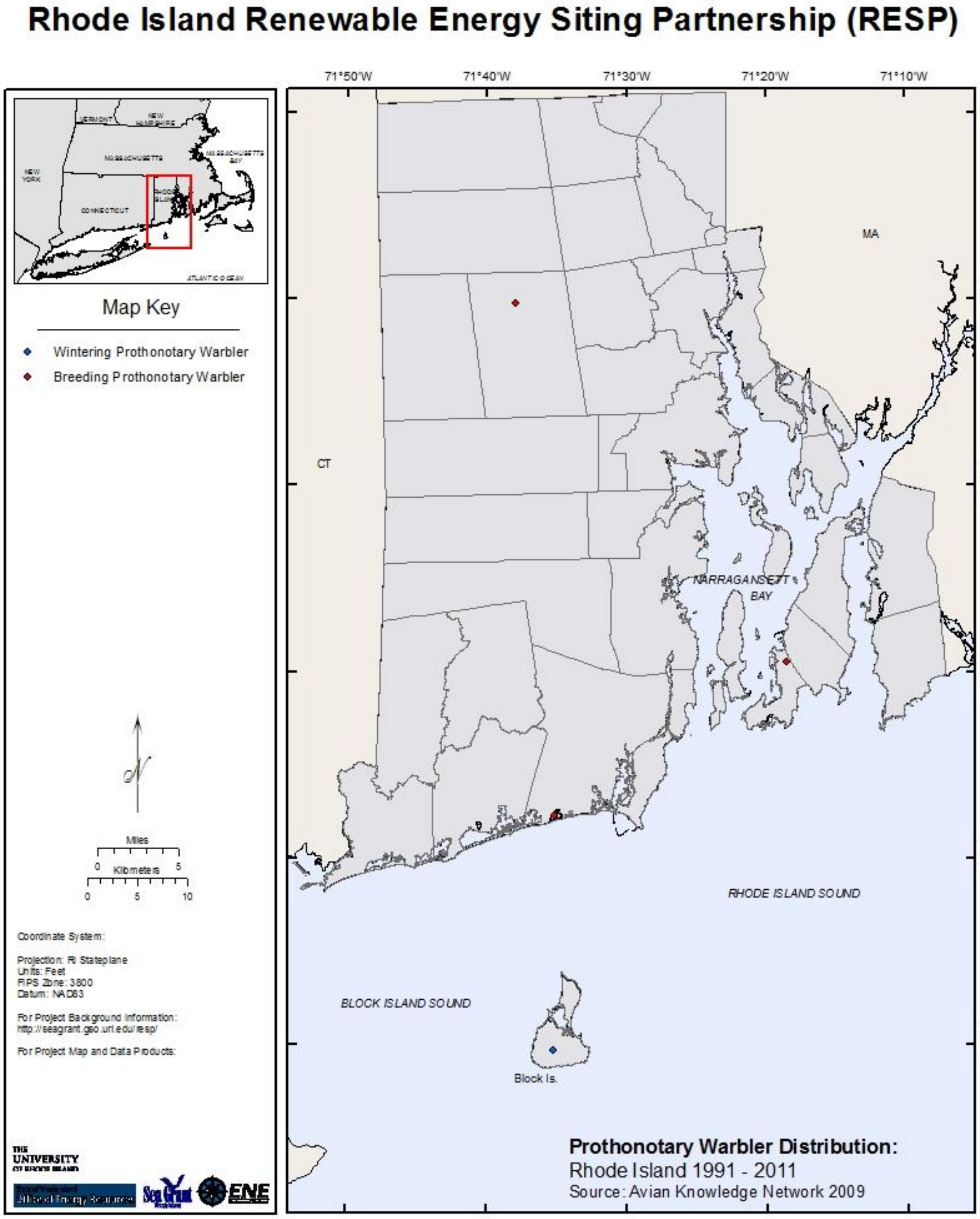


Figure A3.41. Distribution and abundance of **Prothonotary Warbler (*Prothonotaria citrea*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as high conservation priority based on the BCR 30 Status (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

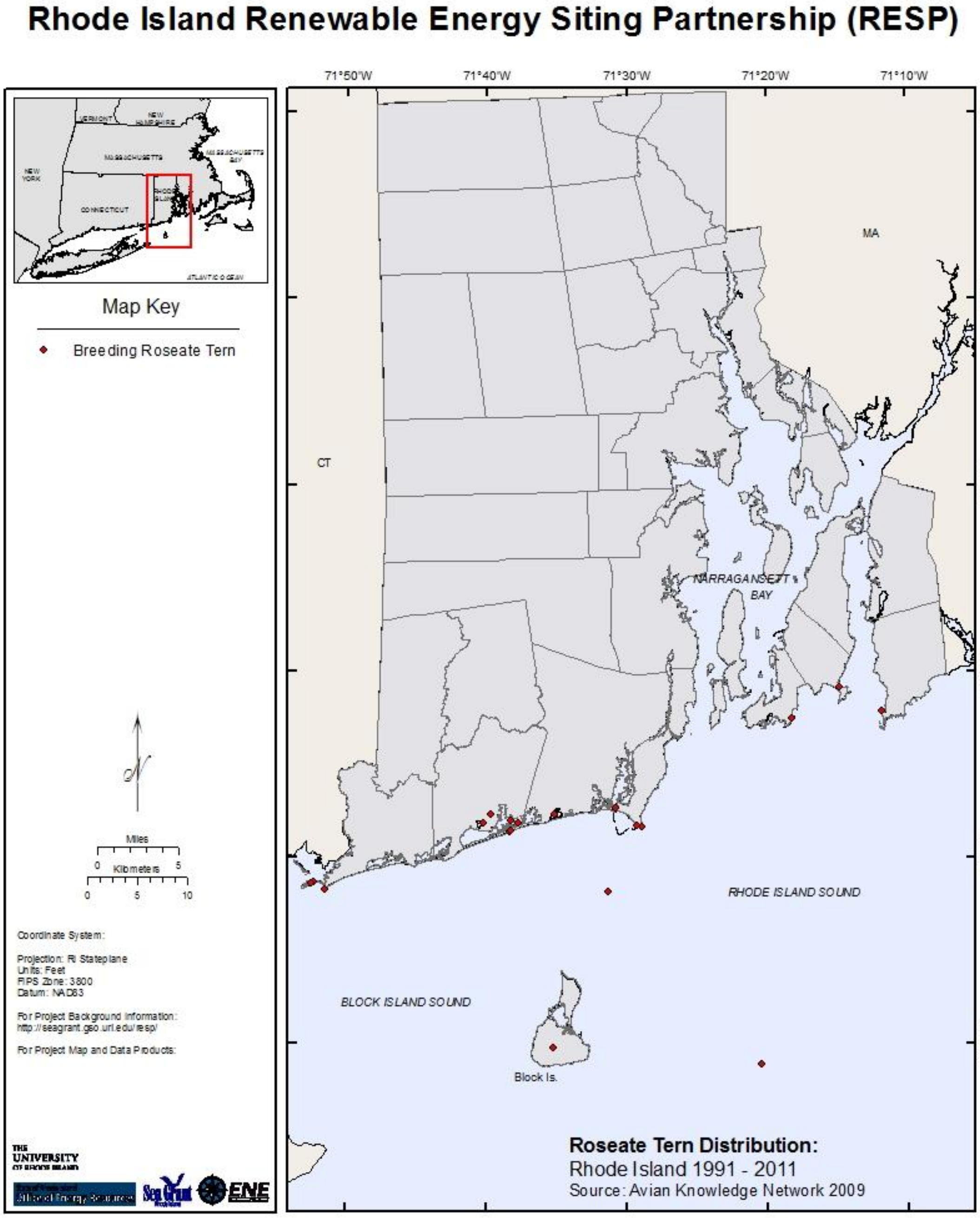


Figure A3. 42. Distribution and abundance of **Roseate Tern (*Sterna dougallii*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as federally threatened and state historic in Rhode Island (Table 5). It is also listed as the highest conservation priority based on the BCR 30 Status, and it is listed as a Tier IV conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

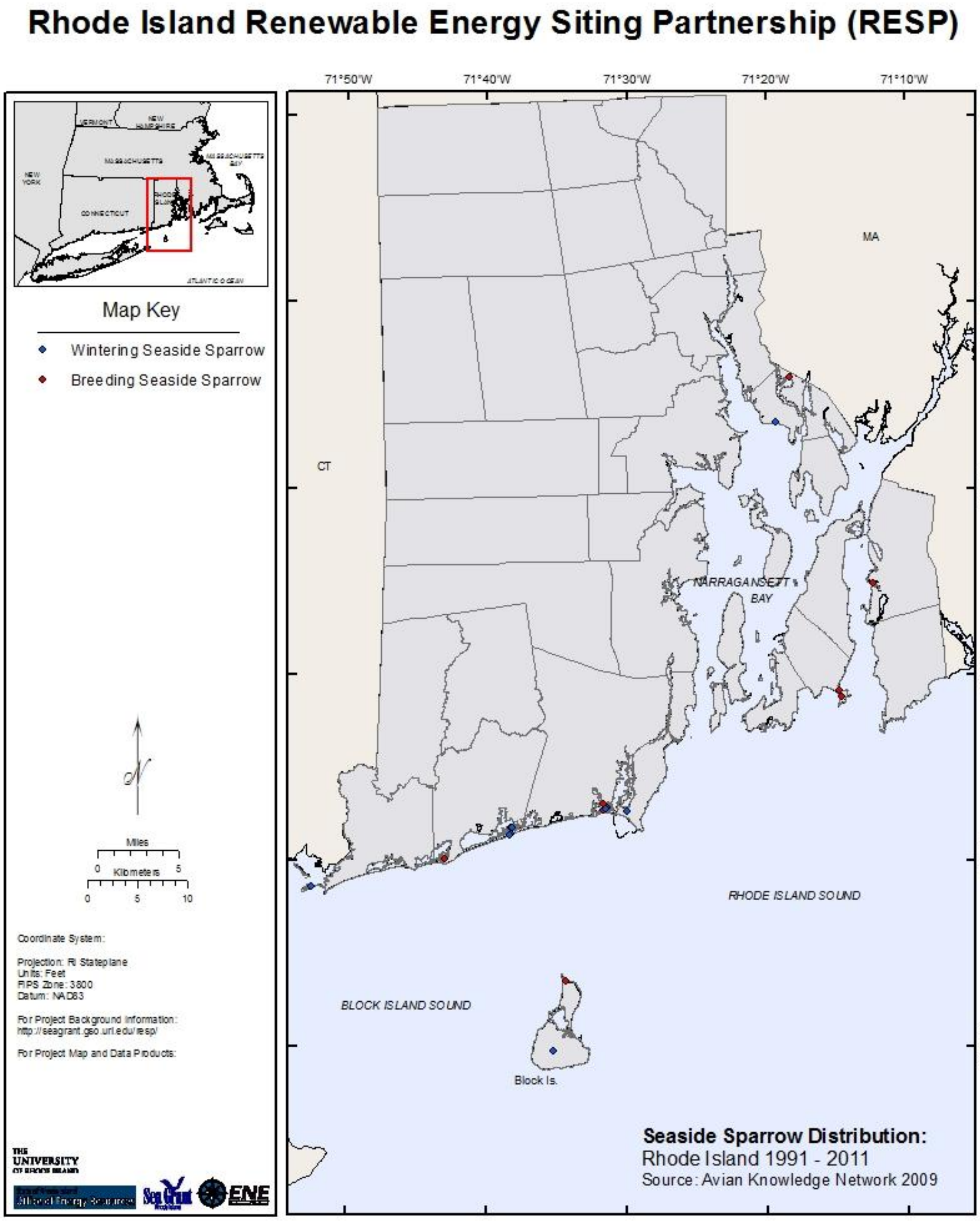


Figure A3. 43. Distribution and abundance of **Seaside Sparrow (*Ammodramus maritimus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as the highest conservation priority based on the BCR 30 Status, and it is listed as a Tier IA conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

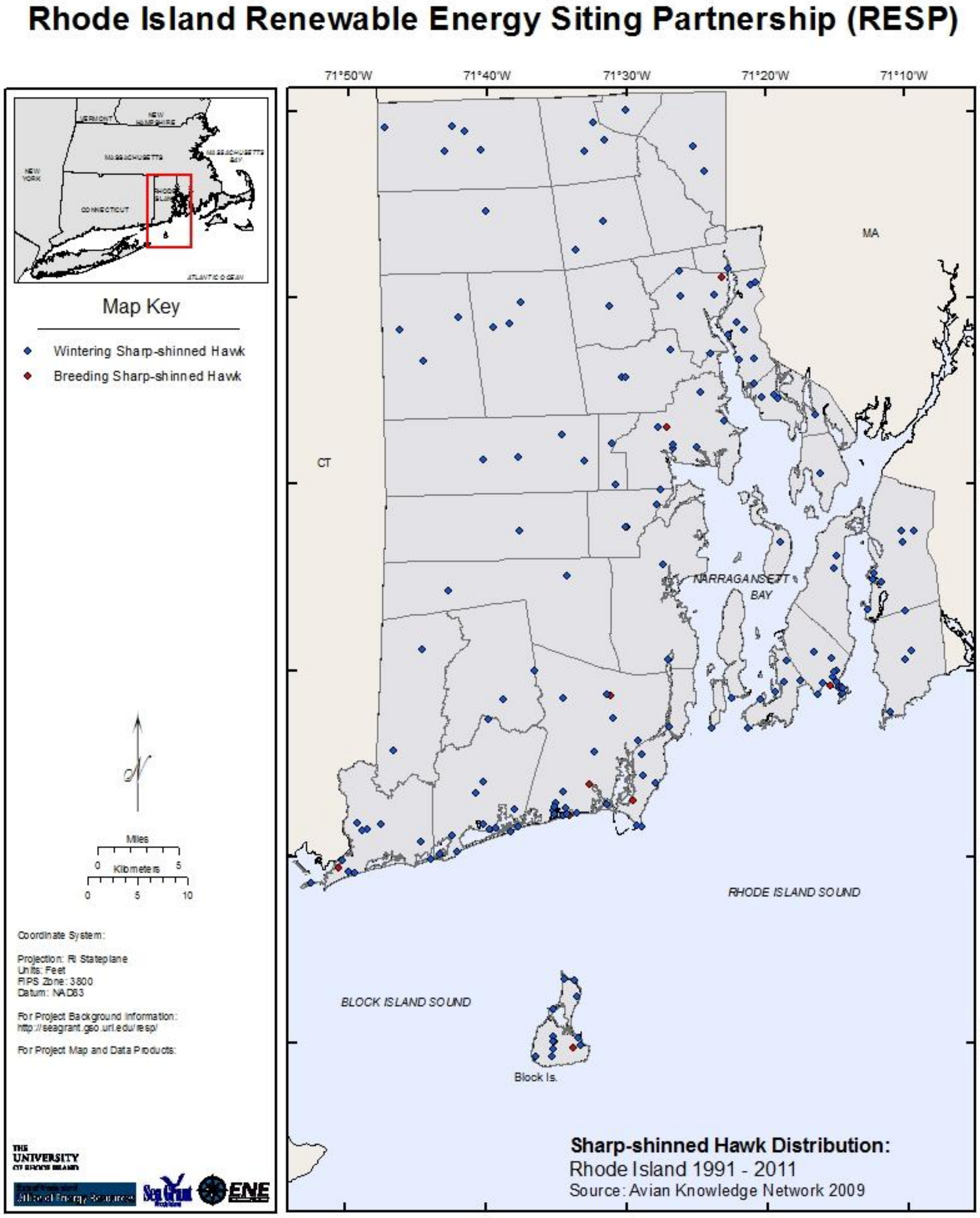


Figure A3.44. Distribution and abundance of **Sharp-shinned Hawk (*Accipiter striatus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state historic species in Rhode Island (Table 5), primarily due to the few birds that now breed in the state a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

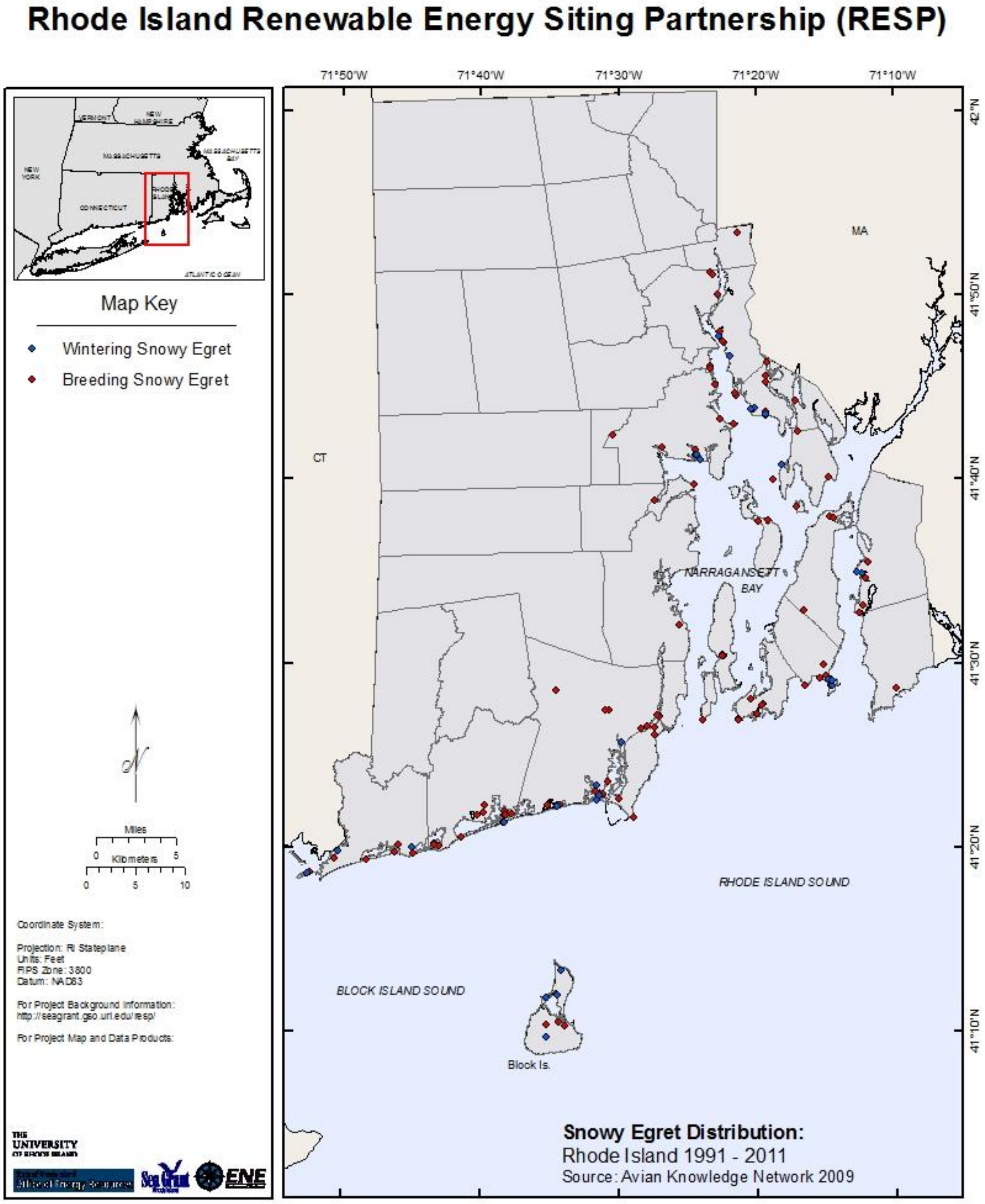


Figure A3.45. Distribution and abundance of **Snowy Egret (*Egretta thula*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

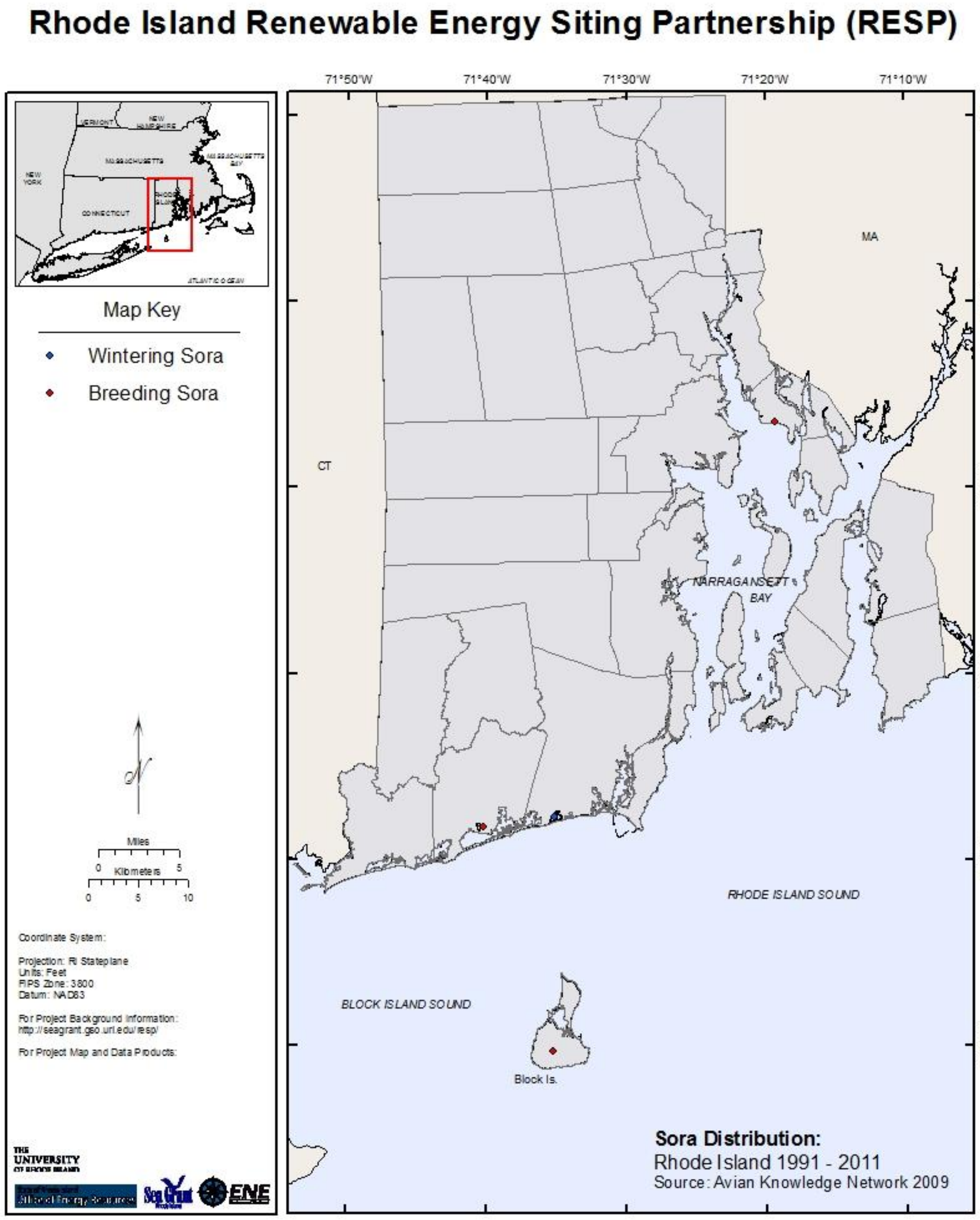


Figure A3.46. Distribution and abundance of **Sora (*Porzana carolina*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

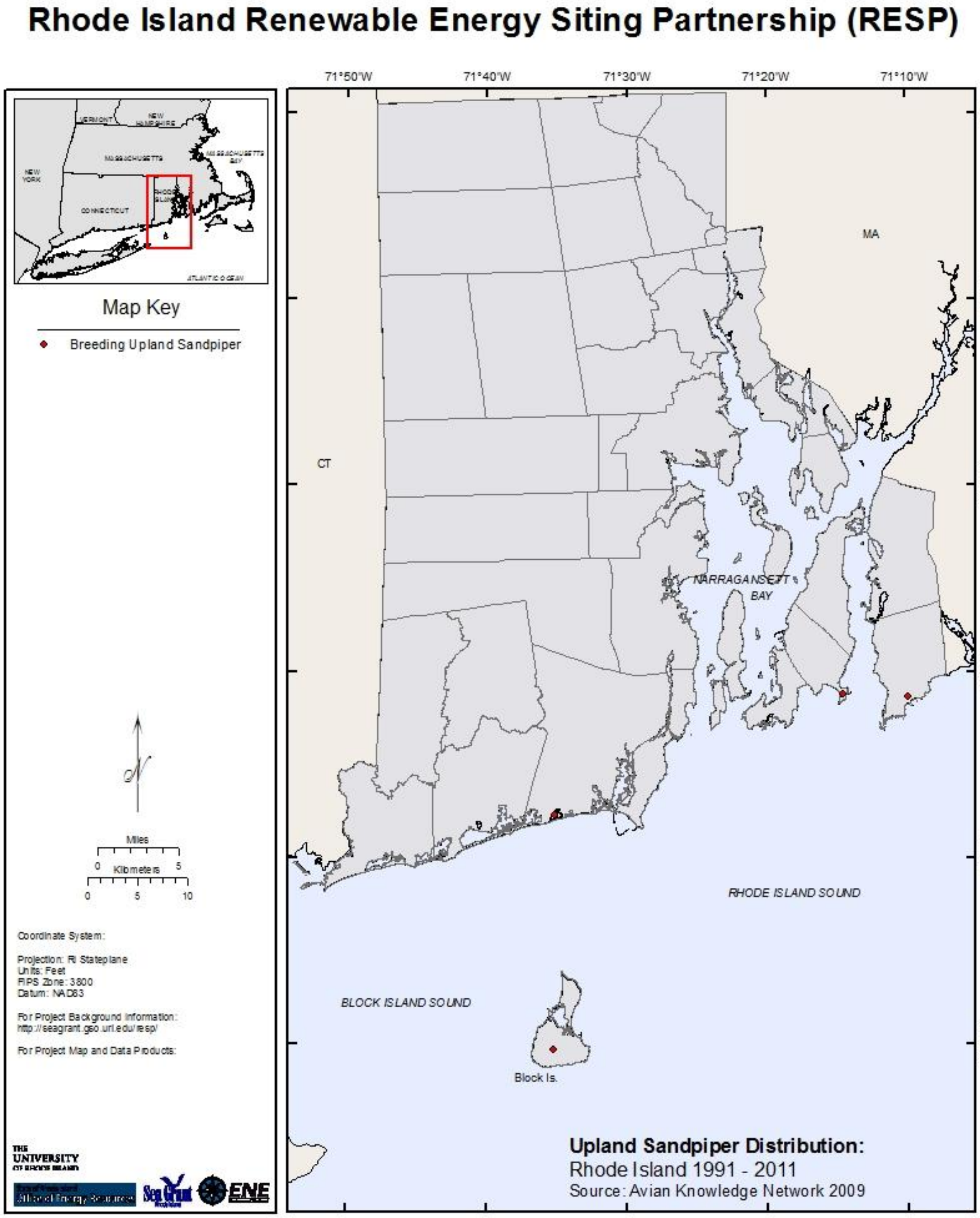


Figure A3.47. Distribution and abundance of **Upland Sandpiper (*Bartramia longicauda*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state endangered in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier IB conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

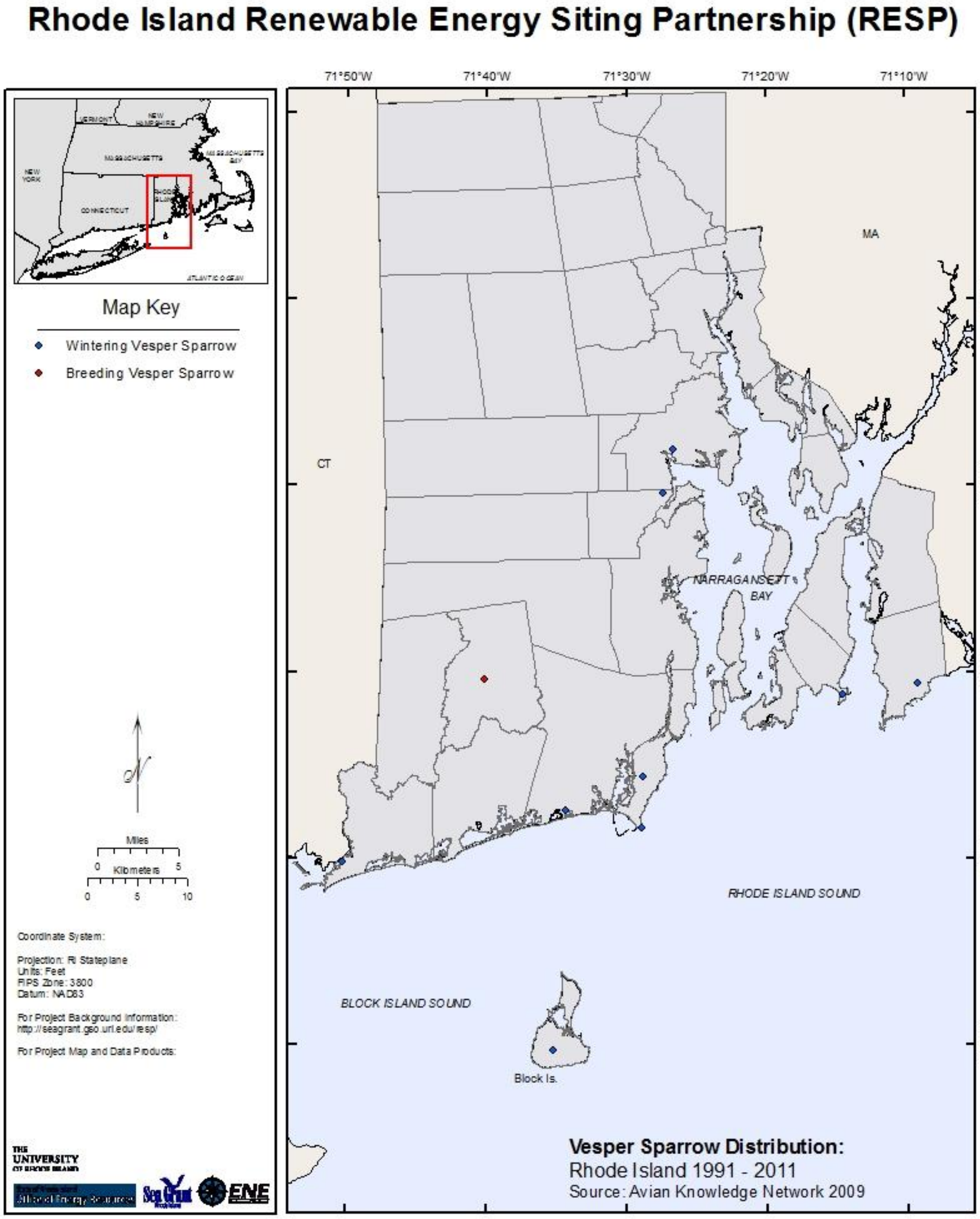


Figure A3.46. Distribution and abundance of **Vesper Sparrow (*Pooecetes gramineus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state historic in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

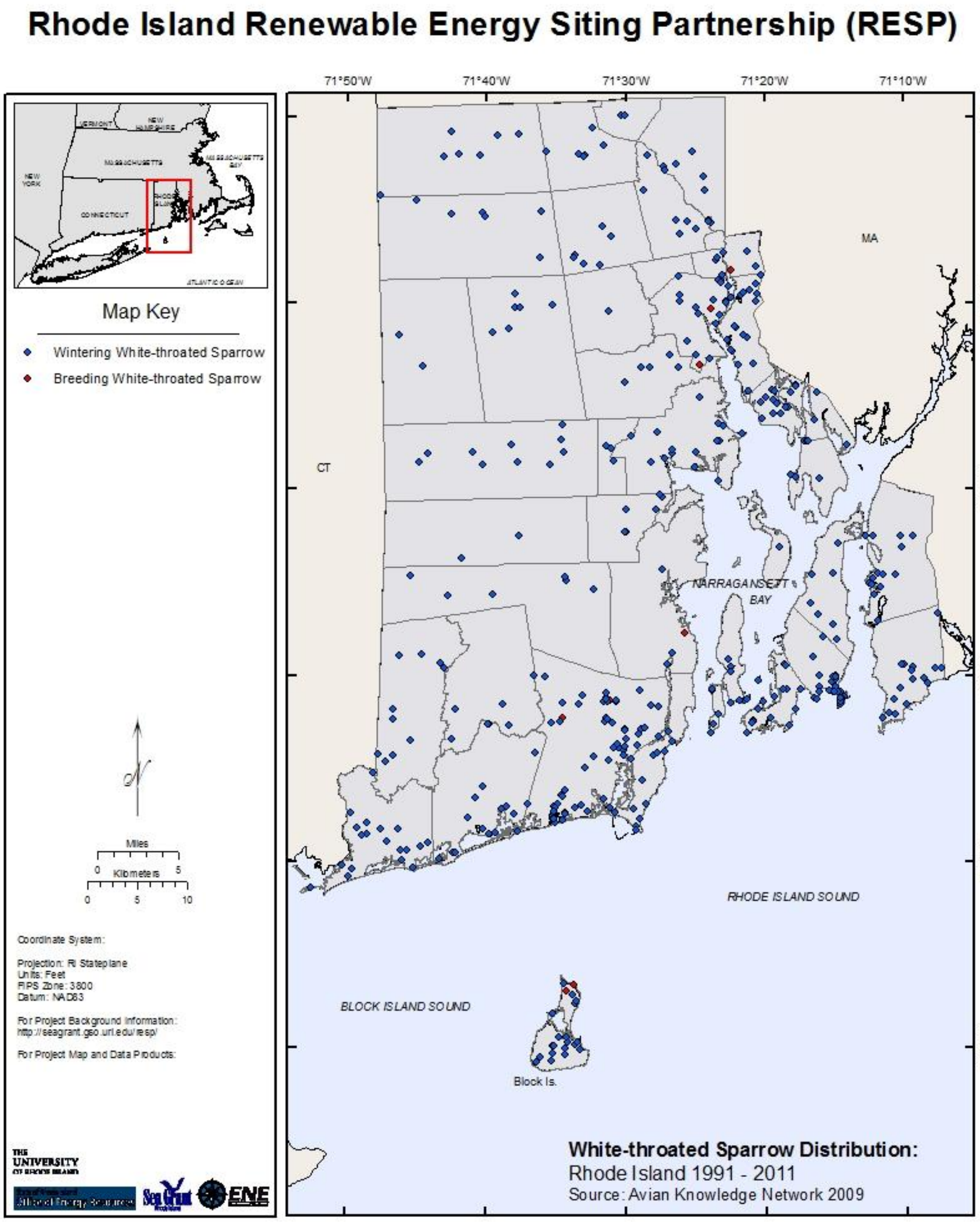


Figure A3.47. Distribution and abundance of **White-throated Sparrow (*Zonotrichia albicollis*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

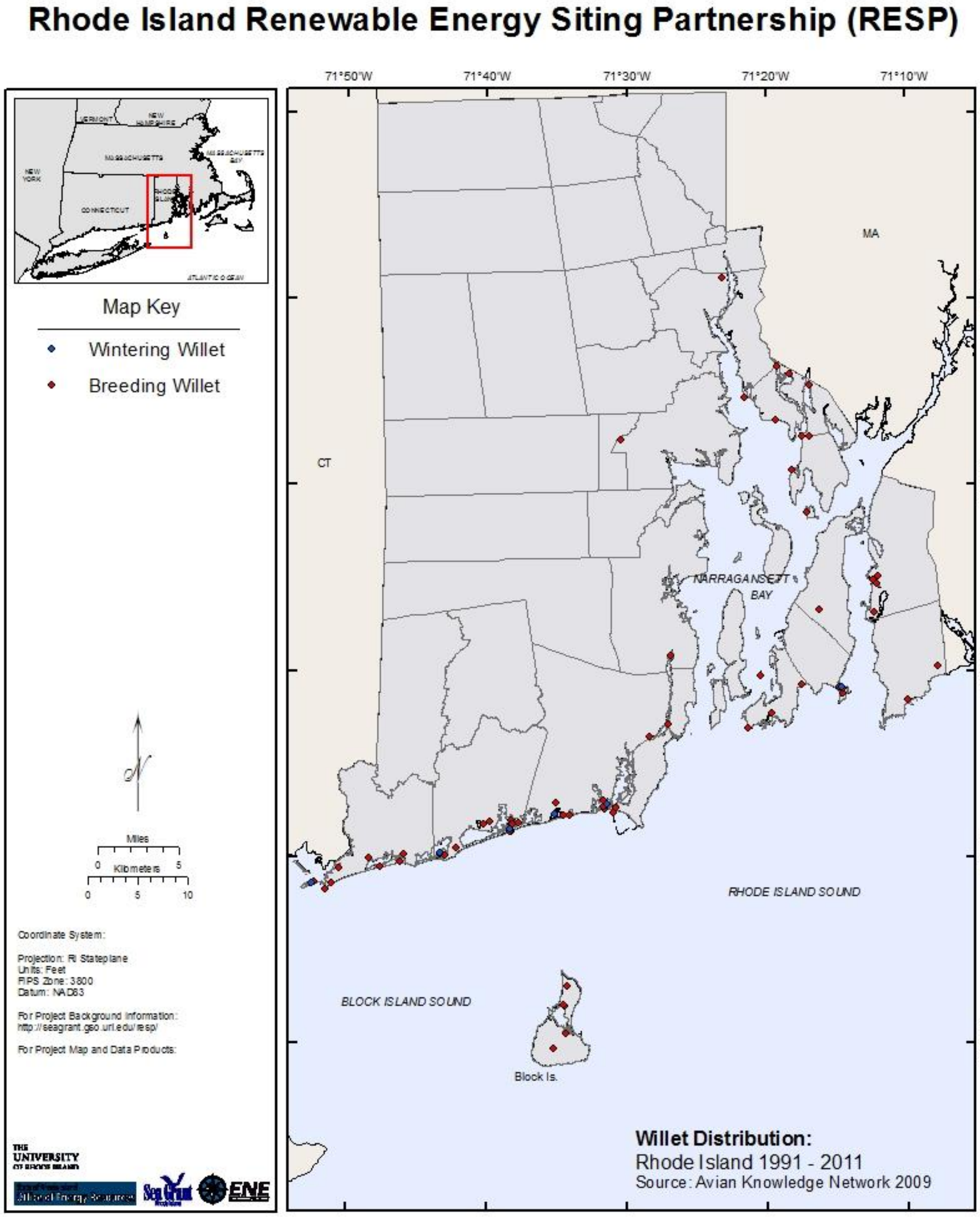


Figure A3.48. Distribution and abundance of **Willet (*Catoptrophorus semipalmatus*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as high conservation priority based on the BCR 30 Status (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

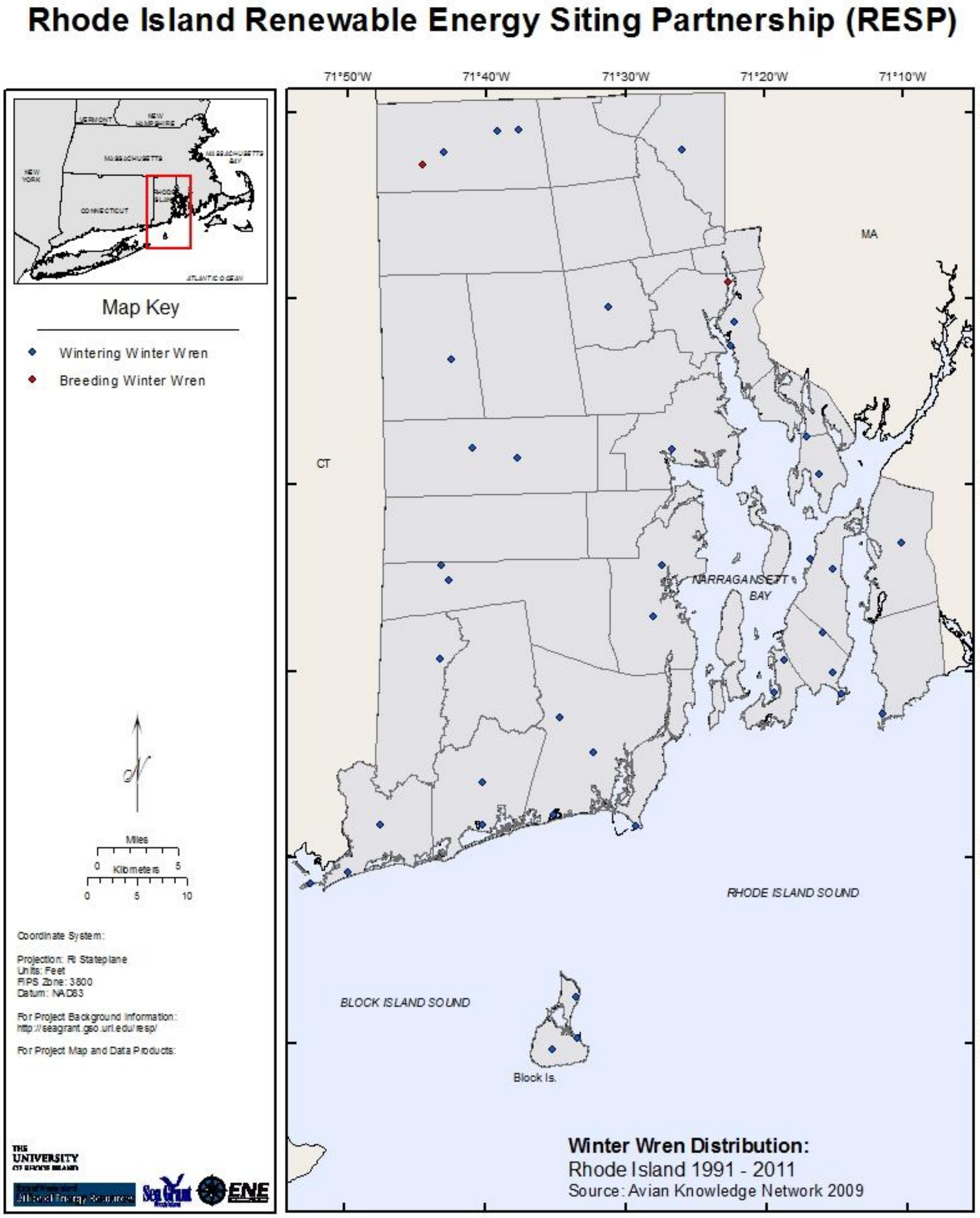


Figure A3.49. Distribution and abundance of **Winter Wren (*Troglodytes hiemalis*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

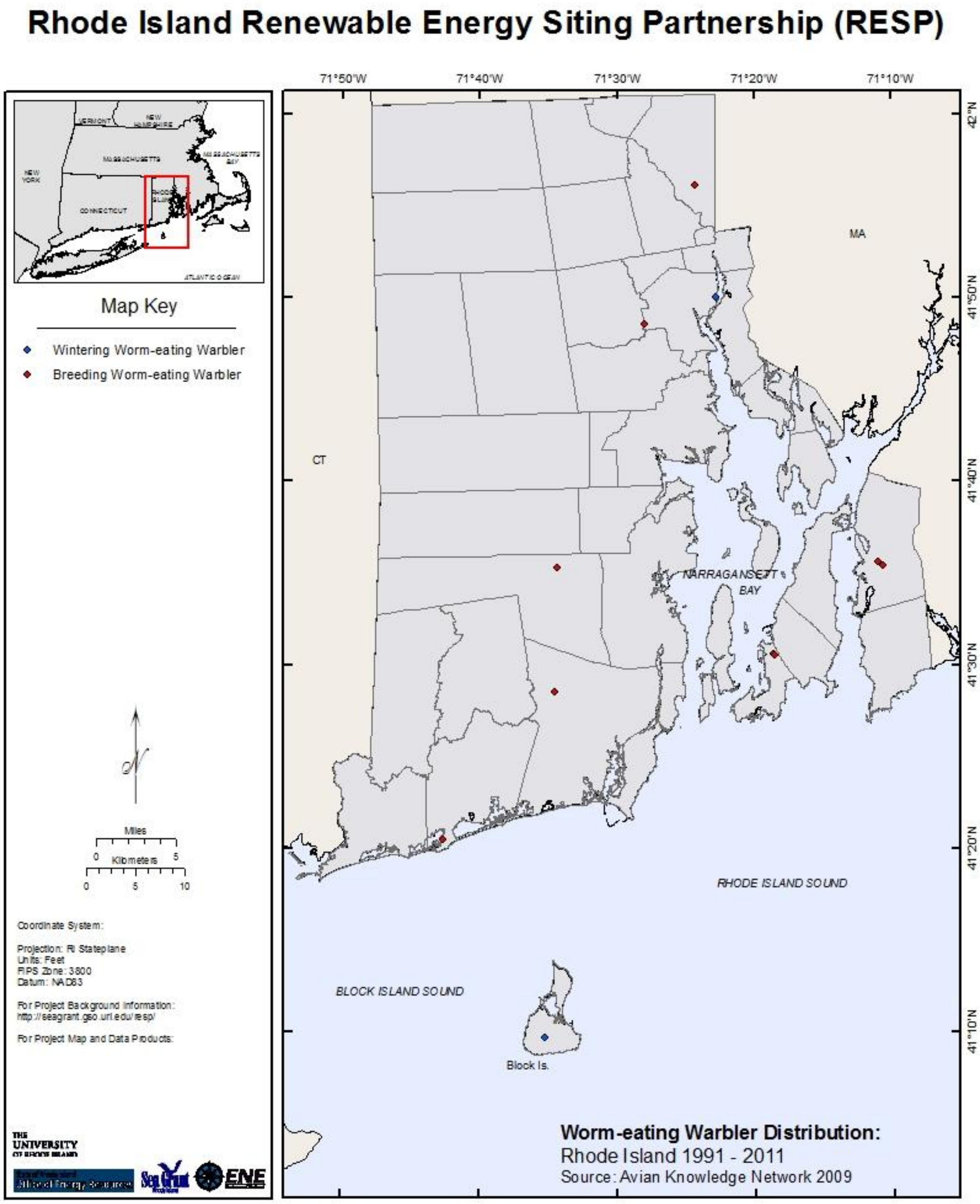


Figure A3.50. Distribution and abundance of **Worm-eating Warbler (*Helmitheros vermivora*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as high conservation priority based on the BCR 30 Status, and it is listed as a Tier IA conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

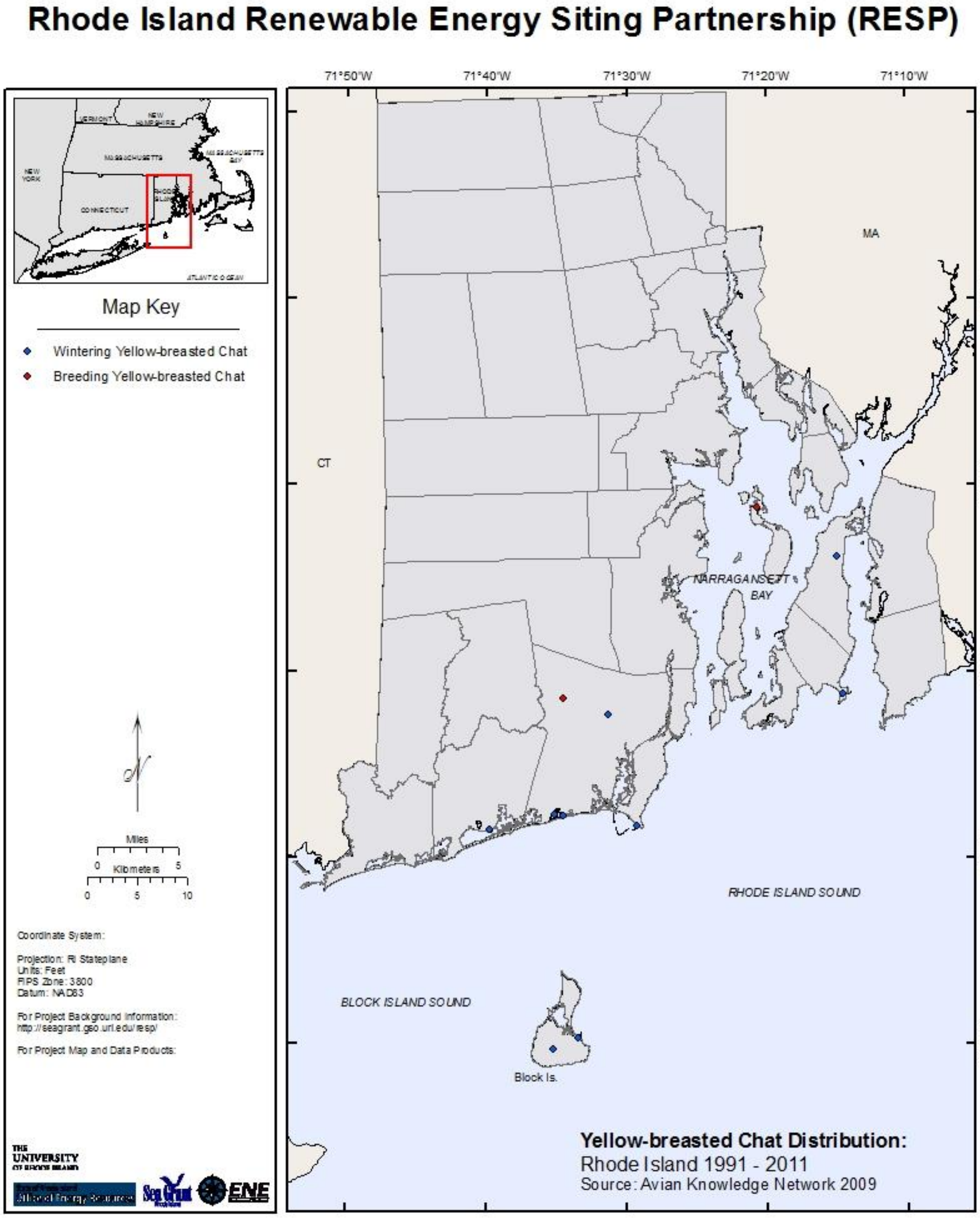


Figure A3.51. Distribution and abundance of **Yellow-breasted Chat (*Icteria virens*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as state endangered in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).

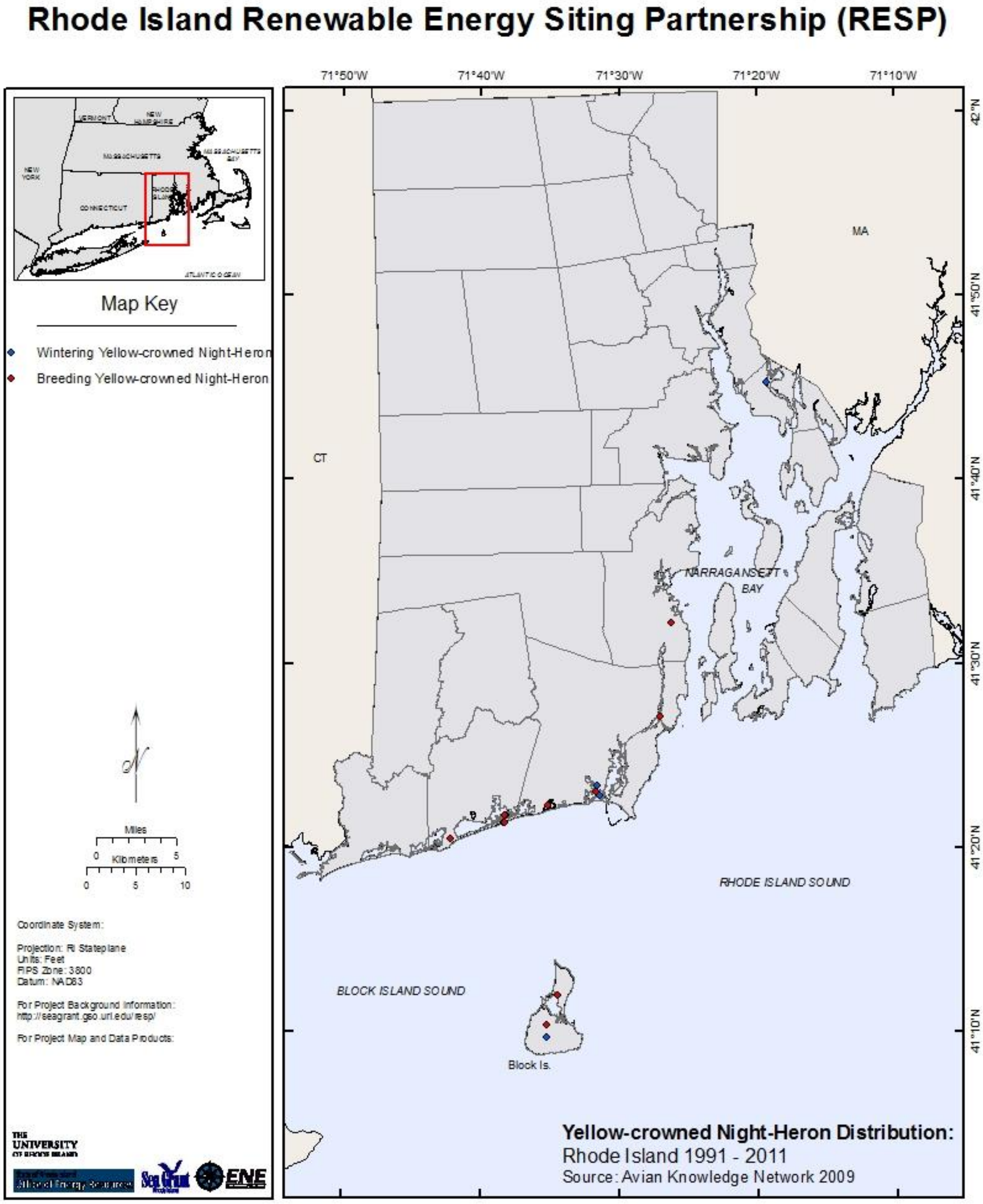
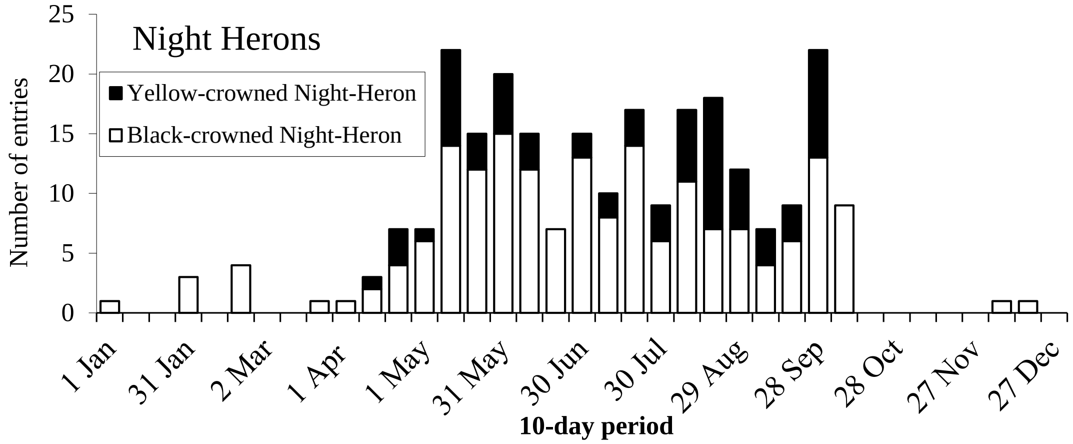
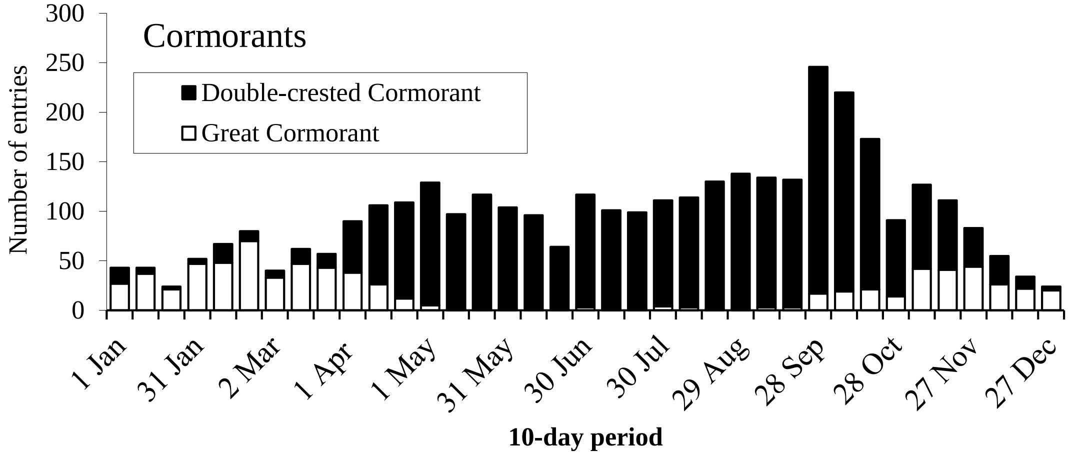
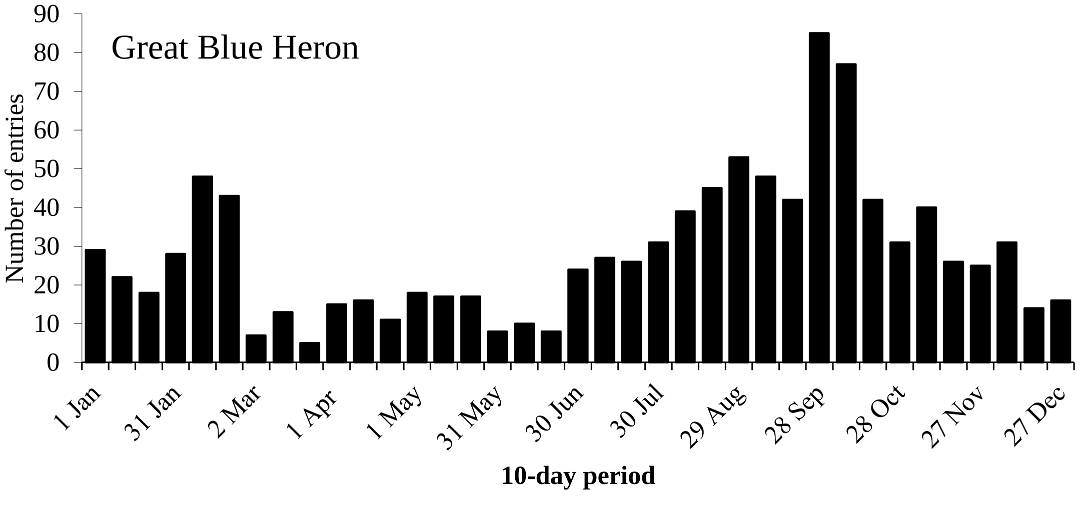


Figure A3.52. Distribution and abundance of **Yellow-crowned Night-Heron (*Nyctanassa violacea*)** in Rhode Island from 1991 - 2011 based year-round reports of citizens of bird sightings to the Avian Knowledge Network (2011). This species is listed as a state concern in Rhode Island (Table 5), primarily due to the few birds that now breed in the state. It is also listed as a moderate conservation priority based on the BCR 30 Status, and it is listed as a Tier V conservation concern based on the PIF assessment (Table A2.2). This species is migratory and more likely to be detected in winter in Rhode Island than during the breeding season (see Enser 1992).


Night Herons
■ Yellow-crowned Night-Heron
□ Black-crowned Night-Heron
Number of entries
0
5
10
15
20
25
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period


Cormorants
■ Double-crested Cormorant
□ Great Cormorant
Number of entries
0
50
100
150
200
250
300
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period


Great Blue Heron
Number of entries
0
10
20
30
40
50
60
70
80
90
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period

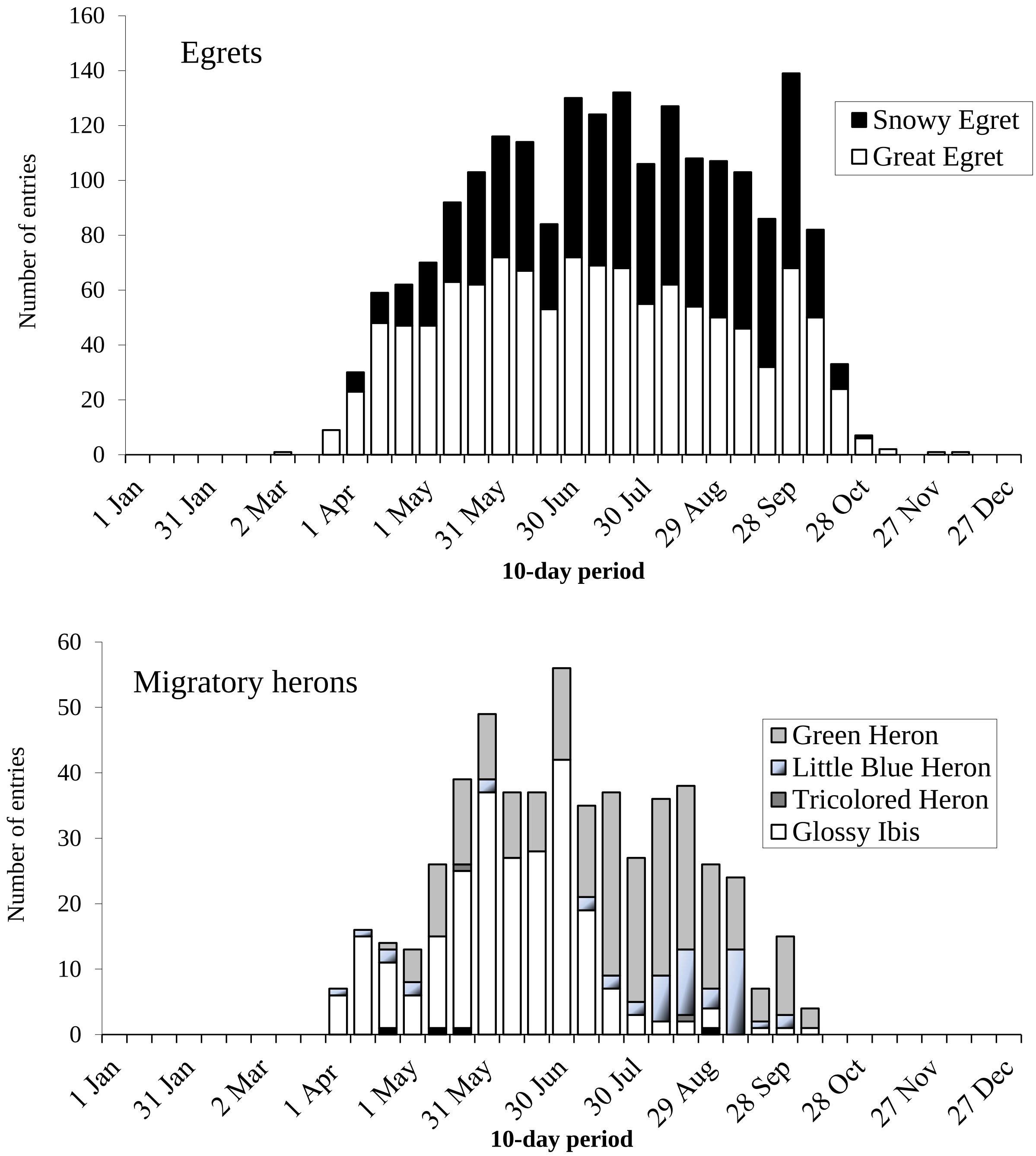
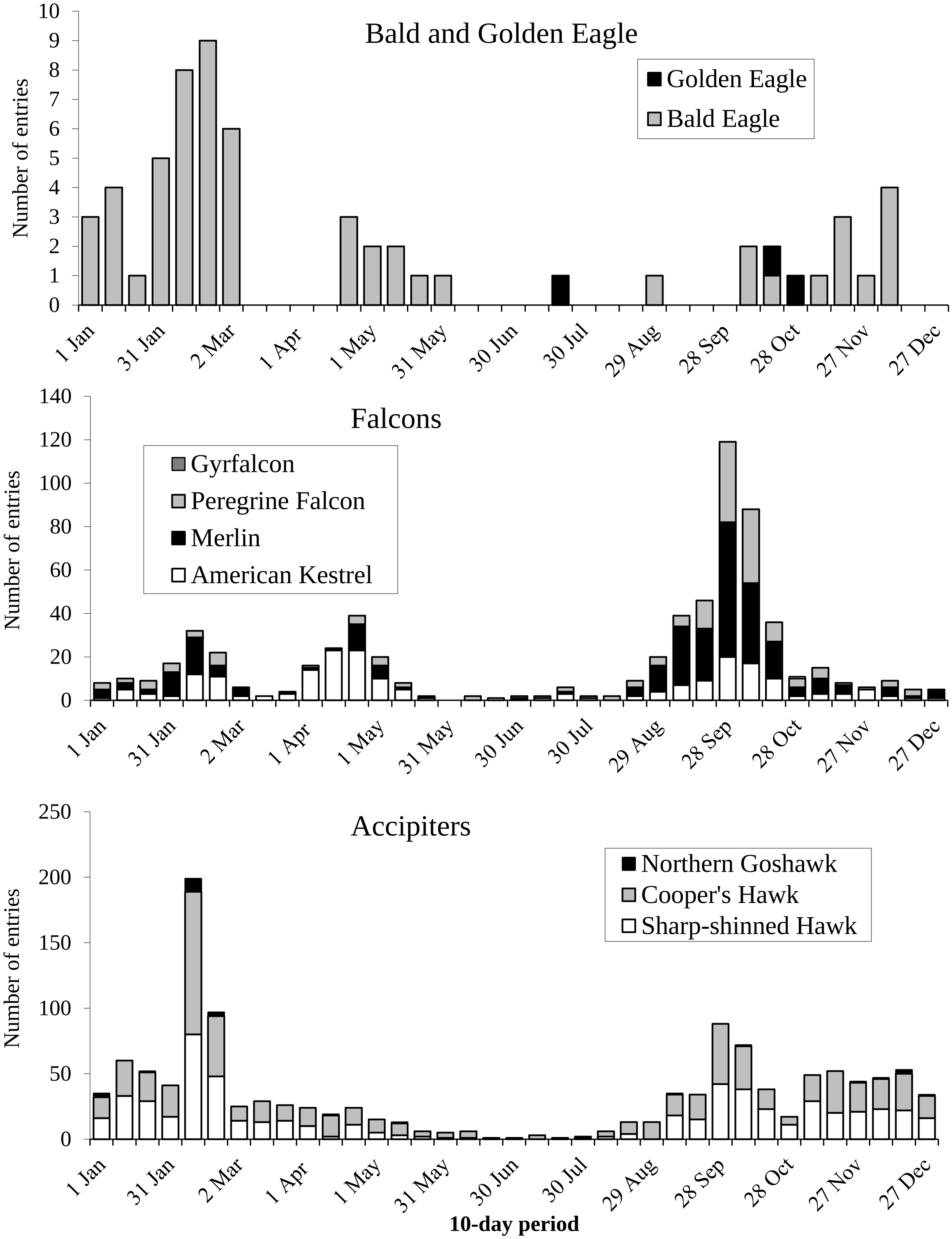
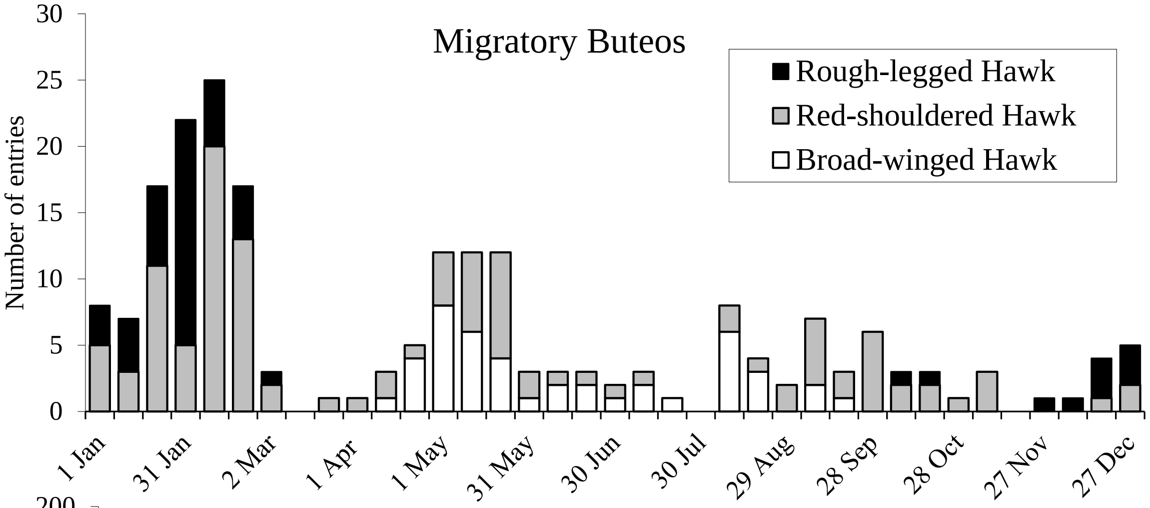
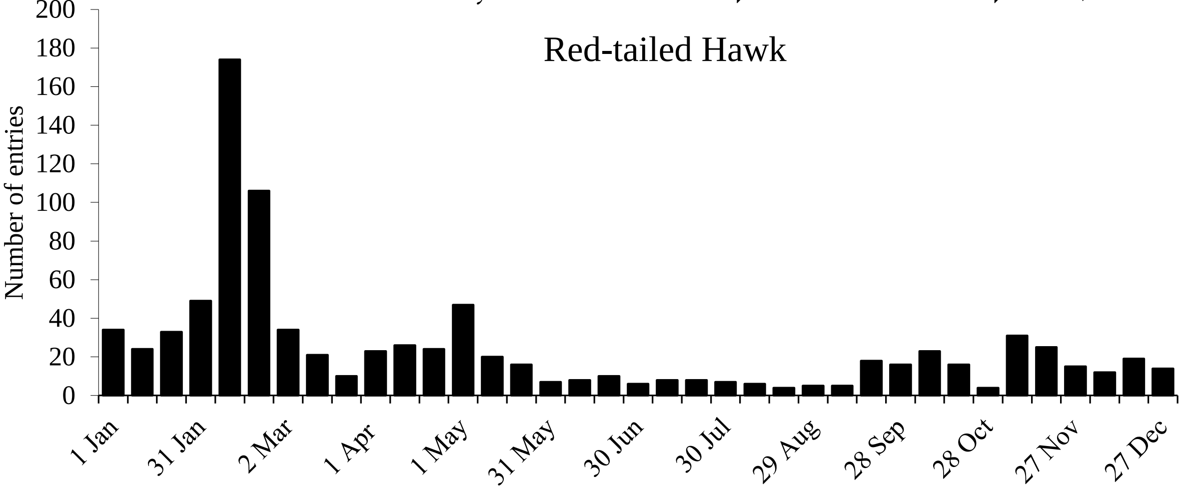
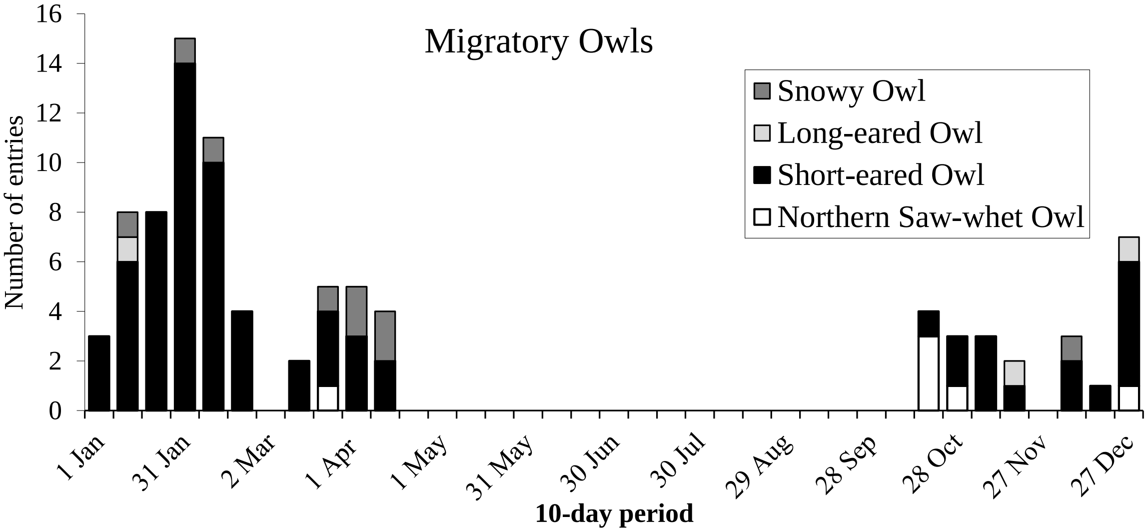


Figure A3.53. Wading bird migration phenology based on Avian Knowledge Network.


Bald and Golden Eagle
■ Golden Eagle
▨ Bald Eagle
Number of entries
0
1
2
3
4
5
6
7
8
9
10
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
Falcons
▨ Gyrfalcon
▨ Peregrine Falcon
■ Merlin
☐ American Kestrel
Number of entries
0
20
40
60
80
100
120
140
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
Accipiters
■ Northern Goshawk
▨ Cooper's Hawk
☐ Sharp-shinned Hawk
Number of entries
0
50
100
150
200
250
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period


Migratory Buteos
■ Rough-legged Hawk
▨ Red-shouldered Hawk
☐ Broad-winged Hawk
Number of entries
0
5
10
15
20
25
30
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec


Red-tailed Hawk
Number of entries
0
20
40
60
80
100
120
140
160
180
200
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec


Migratory Owls
▨ Snowy Owl
▨ Long-eared Owl
■ Short-eared Owl
☐ Northern Saw-whet Owl
Number of entries
0
2
4
6
8
10
12
14
16
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period

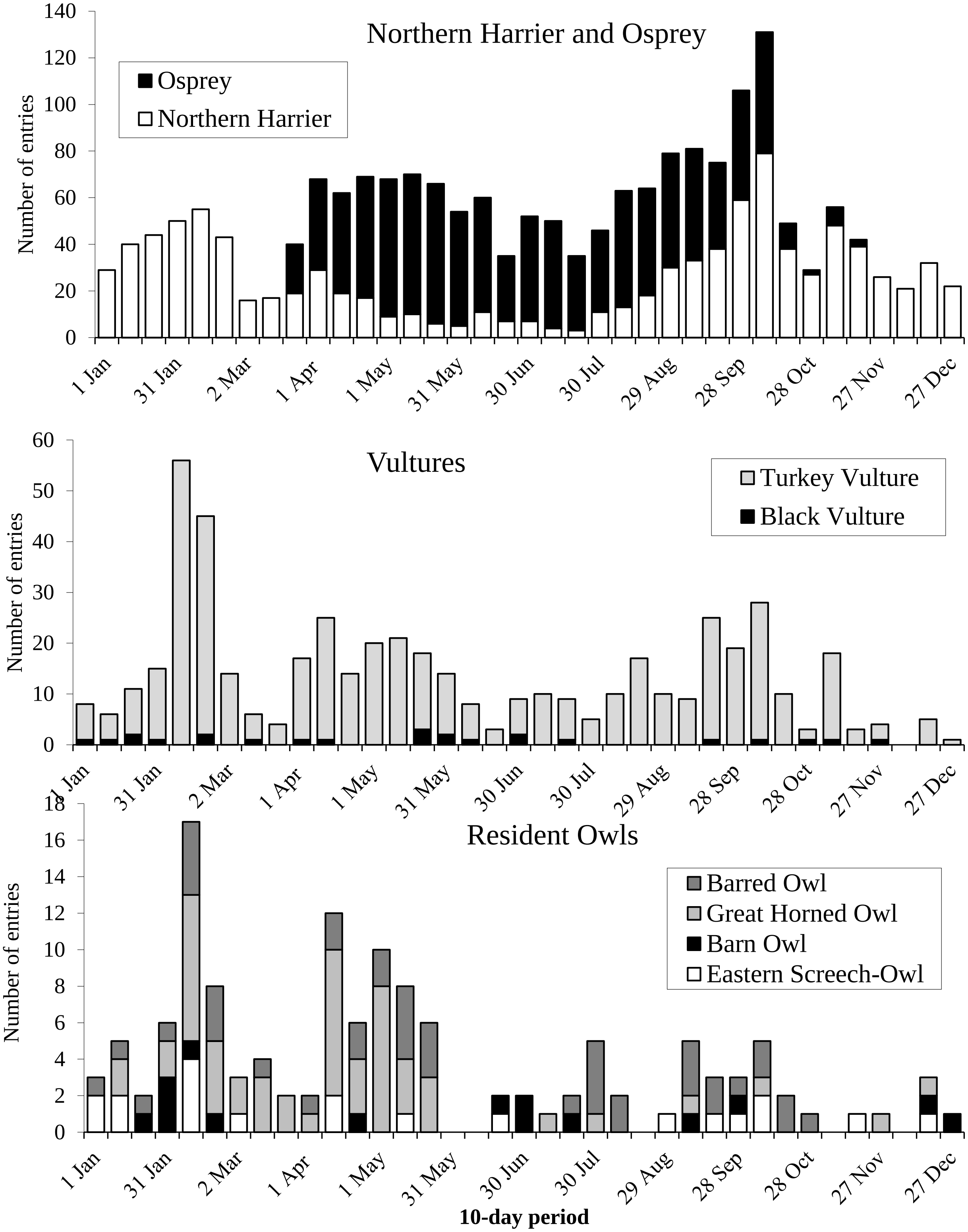
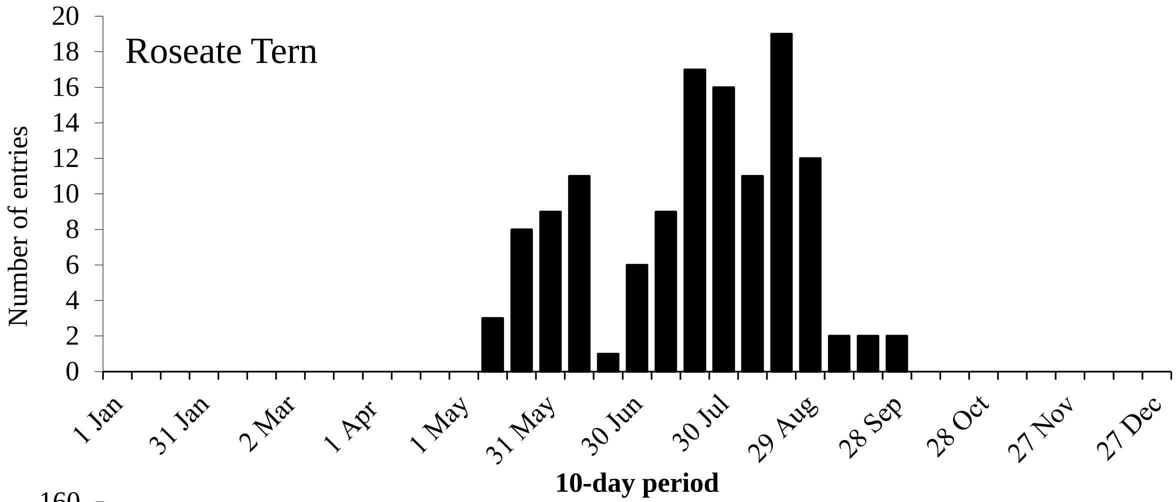
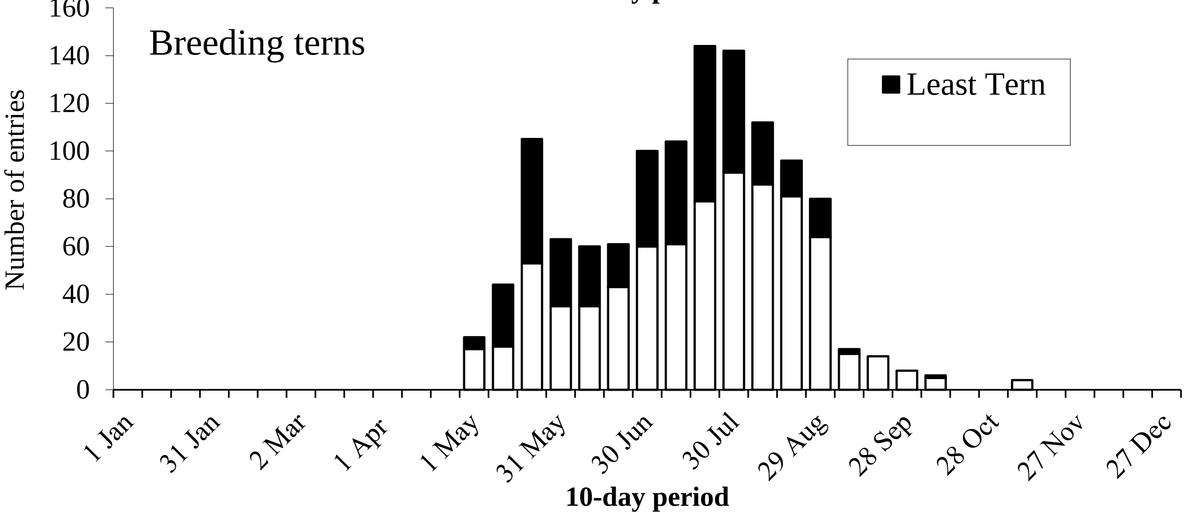
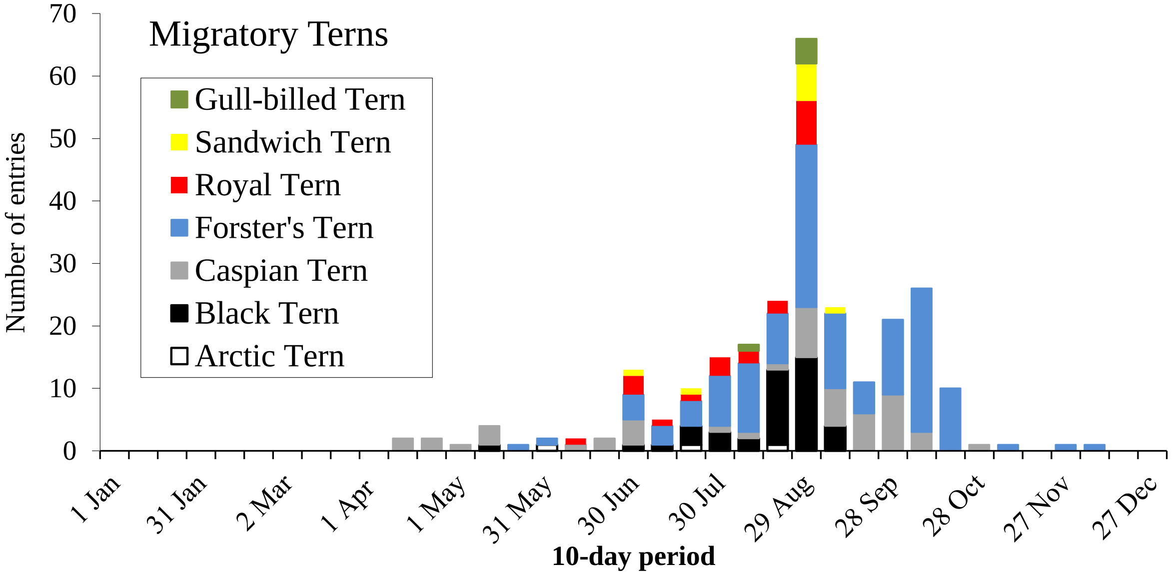
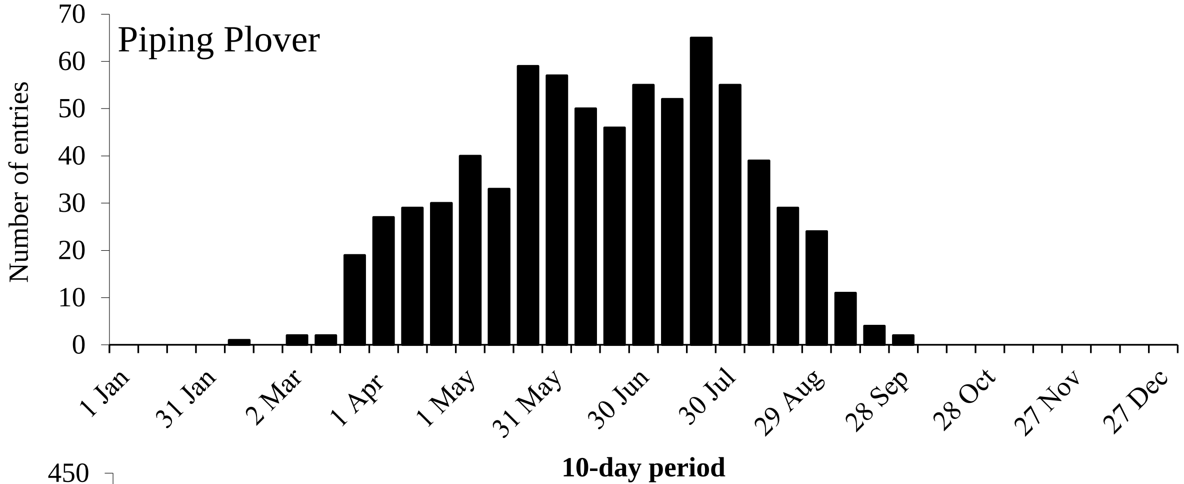


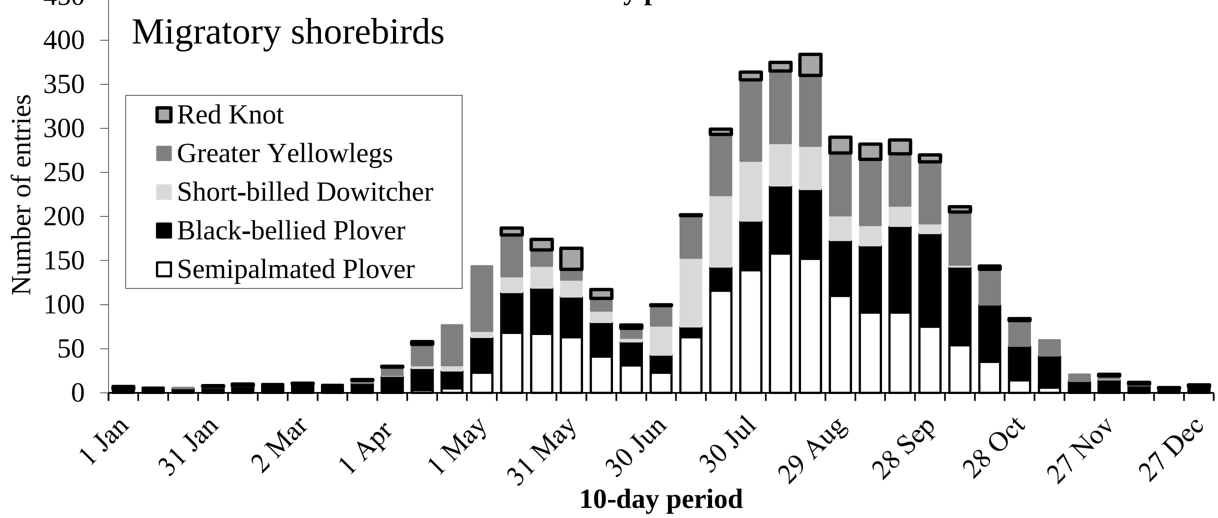
Figure A3.54. Migration phenology of raptors based on ebird records in Avian Knowledge Network.

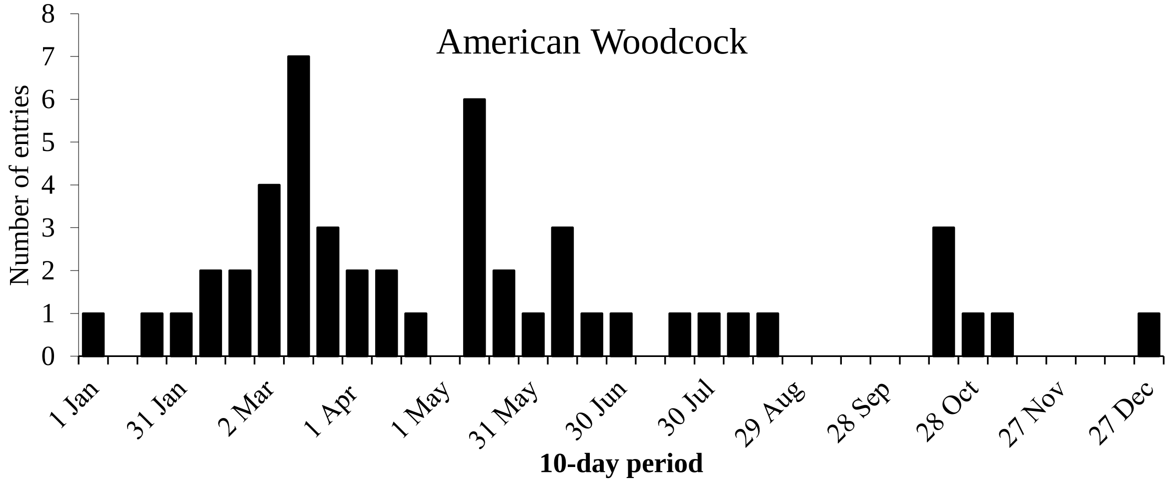

Roseate Tern
Number of entries
0
2
4
6
8
10
12
14
16
18
20
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period

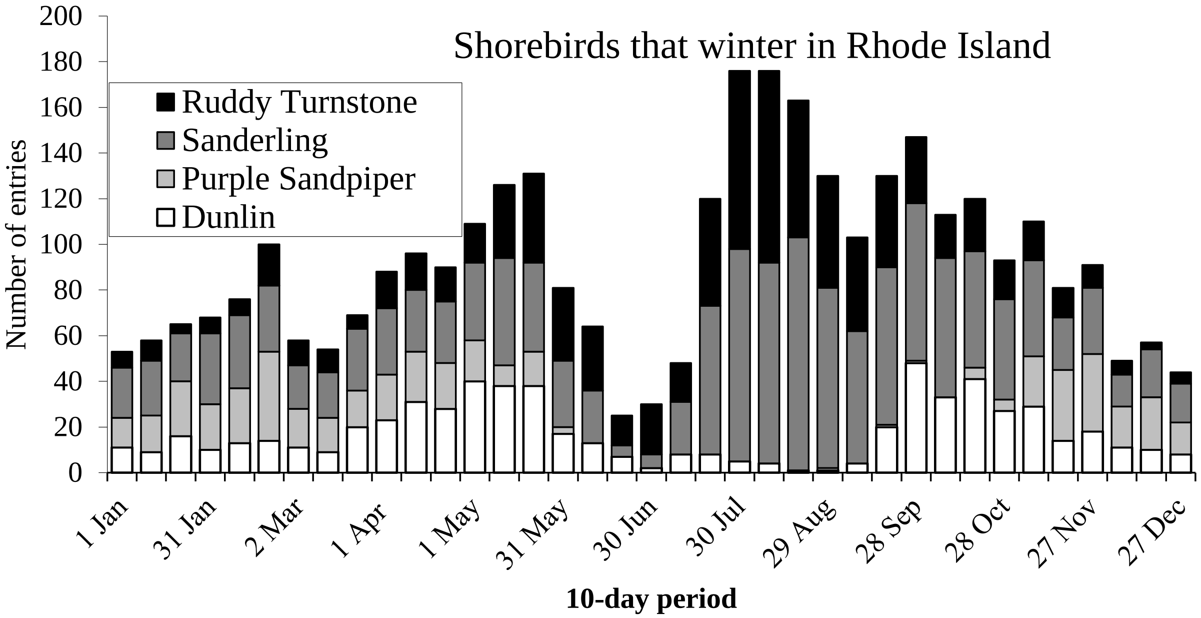

Breeding terns
Least Tern
Number of entries
0
20
40
60
80
100
120
140
160
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period

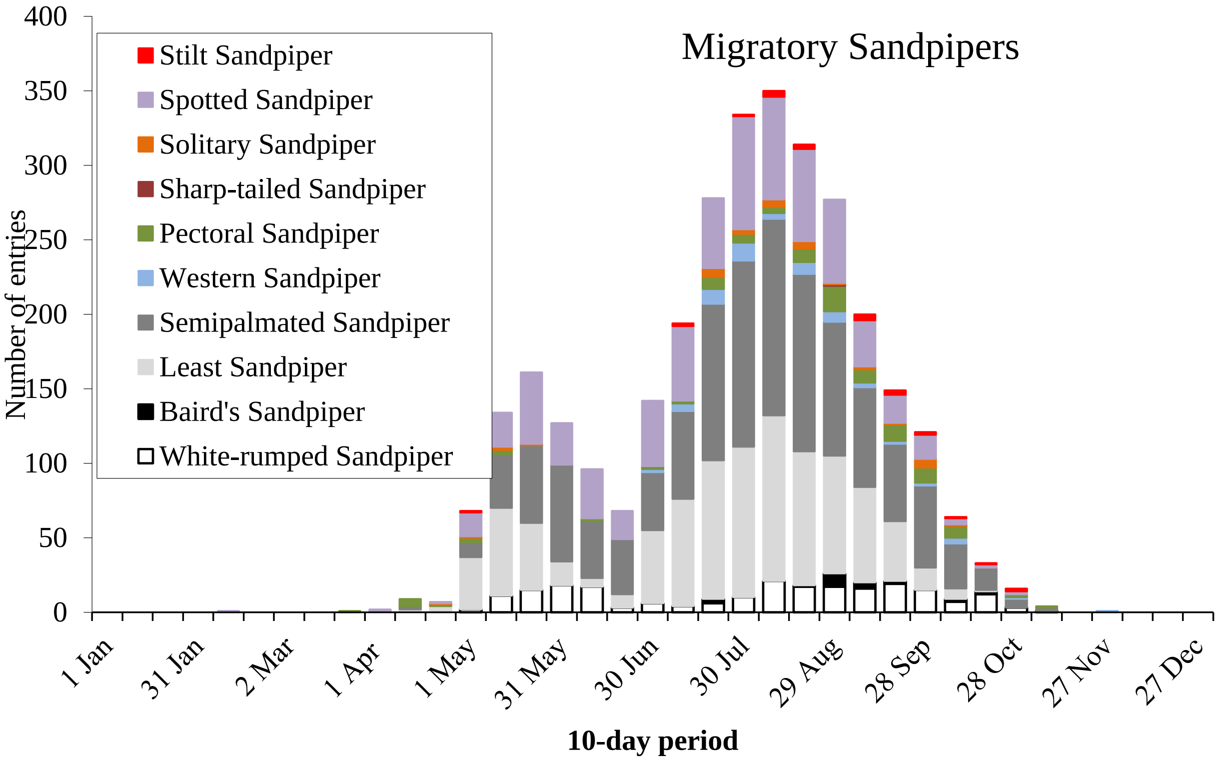

Migratory Terns
Gull-billed Tern
Sandwich Tern
Royal Tern
Forster's Tern
Caspian Tern
Black Tern
Arctic Tern
Number of entries
0
10
20
30
40
50
60
70
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period

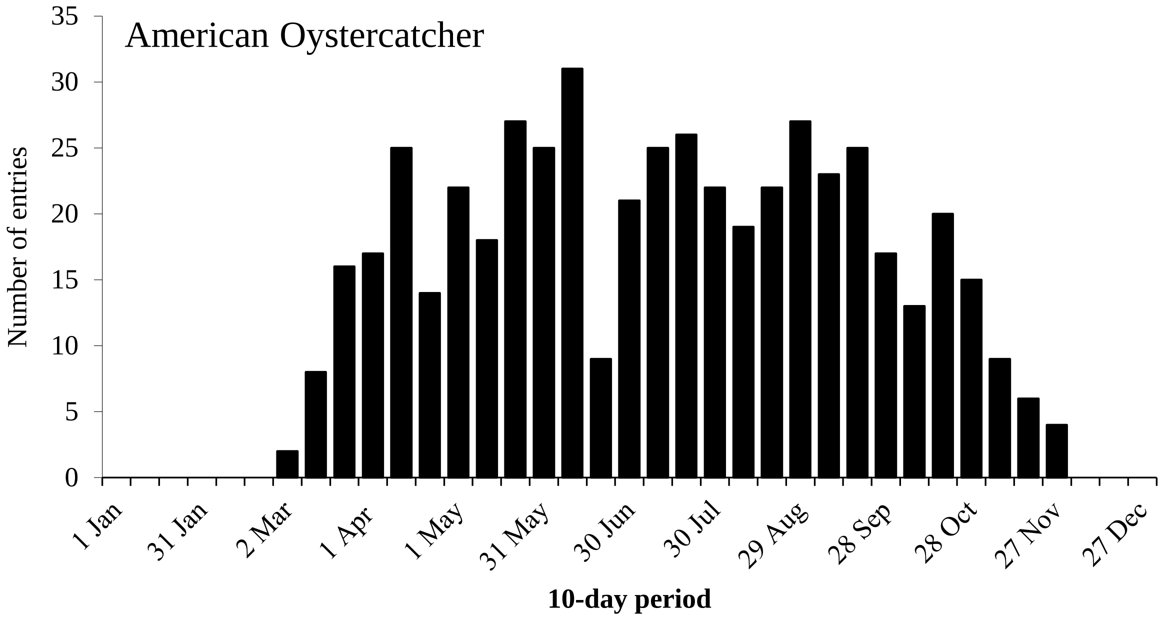

Piping Plover
Number of entries
0
10
20
30
40
50
60
70
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period


Migratory shorebirds
Red Knot
Greater Yellowlegs
Short-billed Dowitcher
Black-bellied Plover
Semipalmated Plover
Number of entries
0
50
100
150
200
250
300
350
400
450
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period


American Woodcock
Number of entries
0
1
2
3
4
5
6
7
8
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period


Shorebirds that winter in Rhode Island
Ruddy Turnstone
Sanderling
Purple Sandpiper
Dunlin
Number of entries
0
20
40
60
80
100
120
140
160
180
200
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period


Migratory Sandpipers
Stilt Sandpiper
Spotted Sandpiper
Solitary Sandpiper
Sharp-tailed Sandpiper
Pectoral Sandpiper
Western Sandpiper
Semipalmated Sandpiper
Least Sandpiper
Baird's Sandpiper
White-rumped Sandpiper
Number of entries
0
50
100
150
200
250
300
350
400
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period



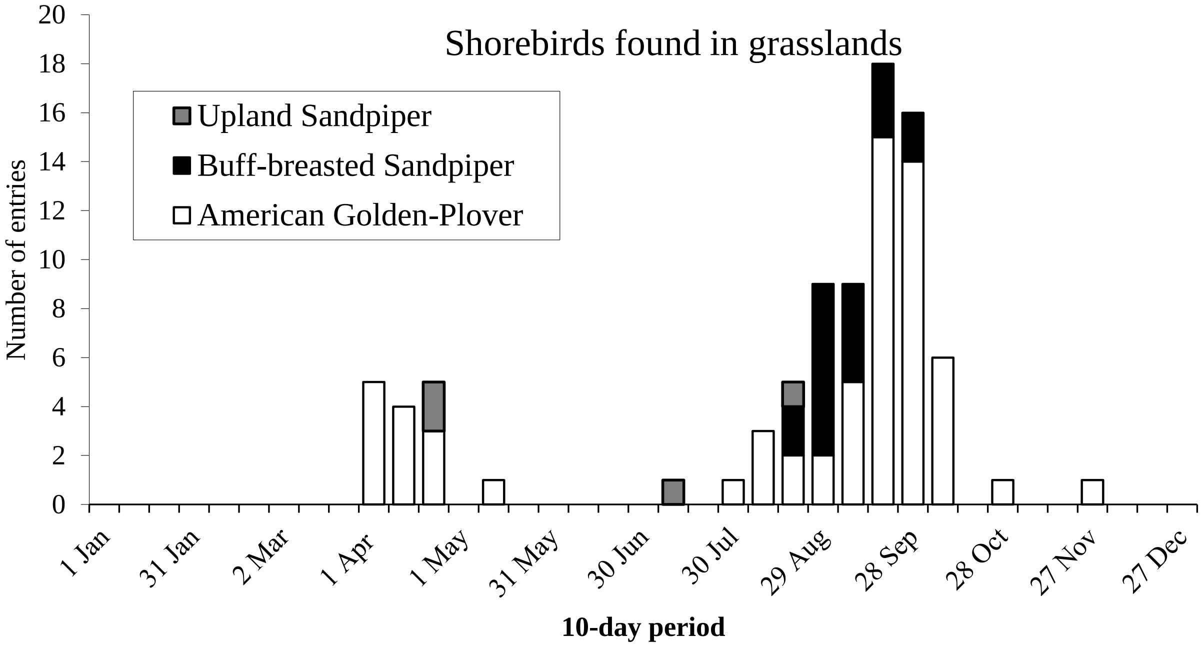
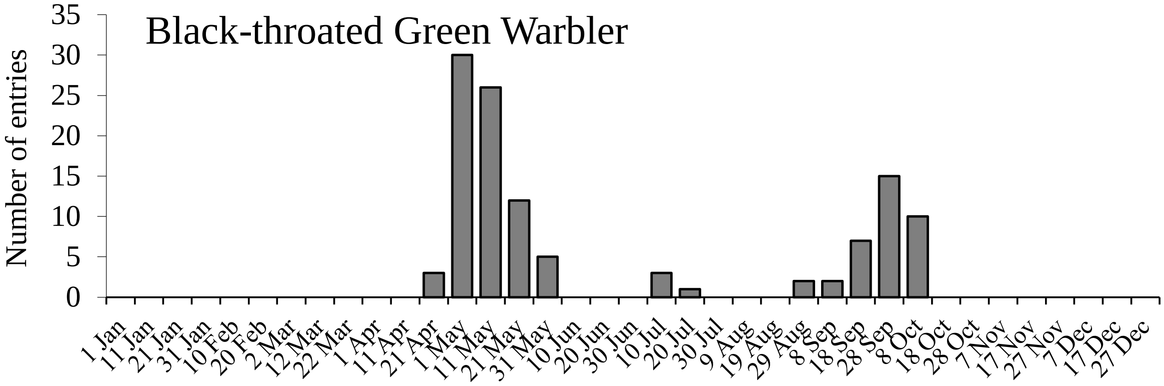
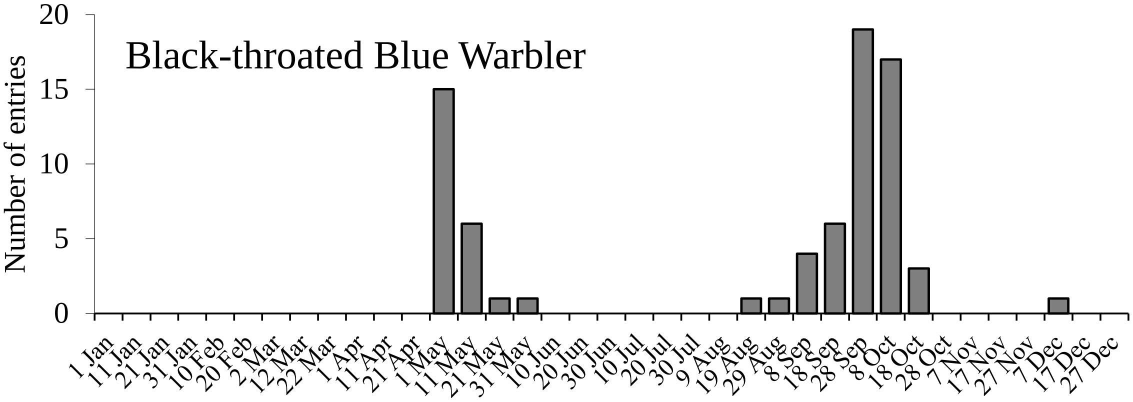
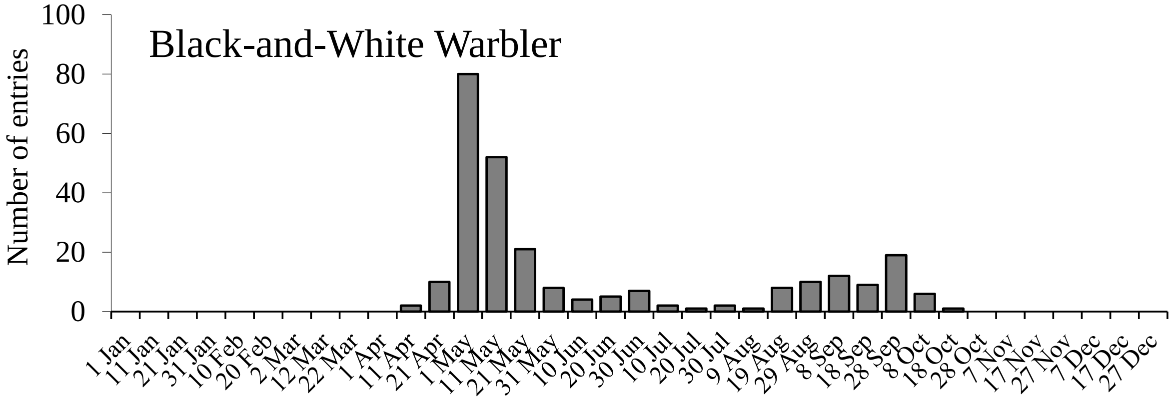
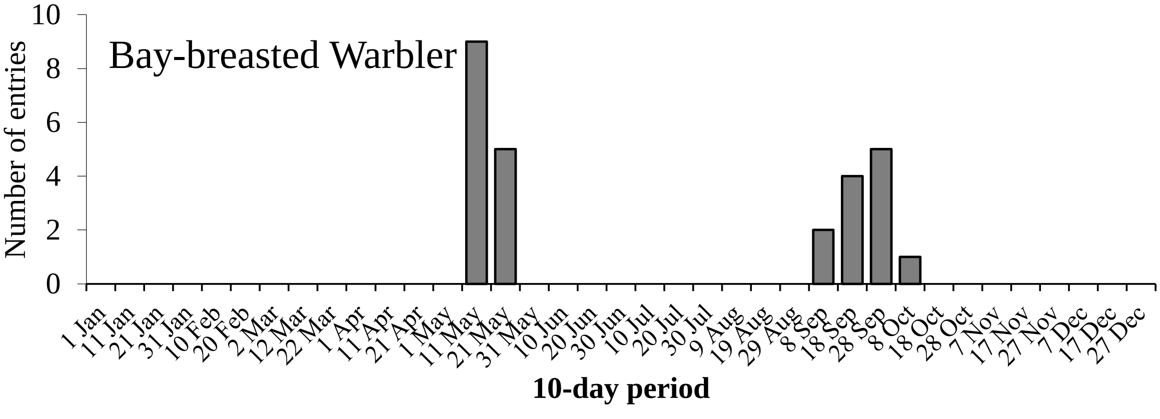


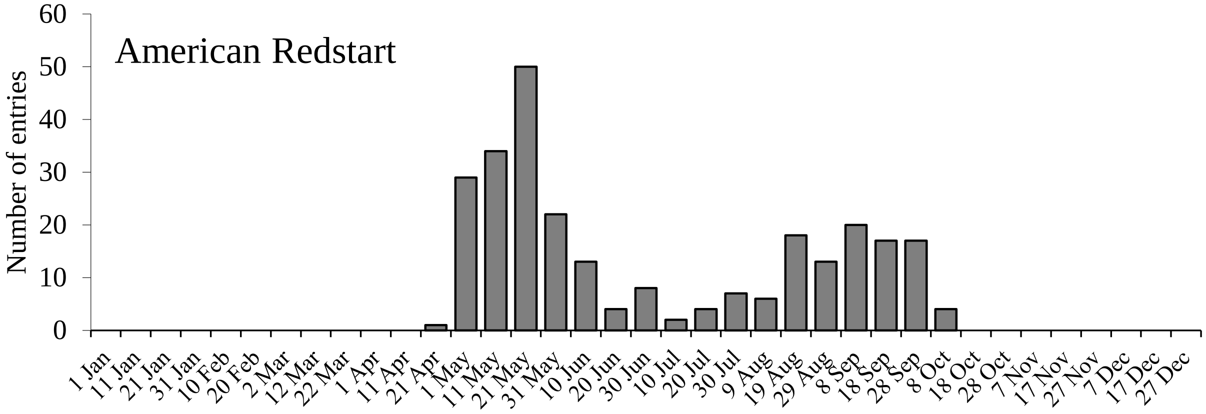
Figure A3.55. Migration phenology of shorebirds based on eBird records in Avian Knowledge Network.

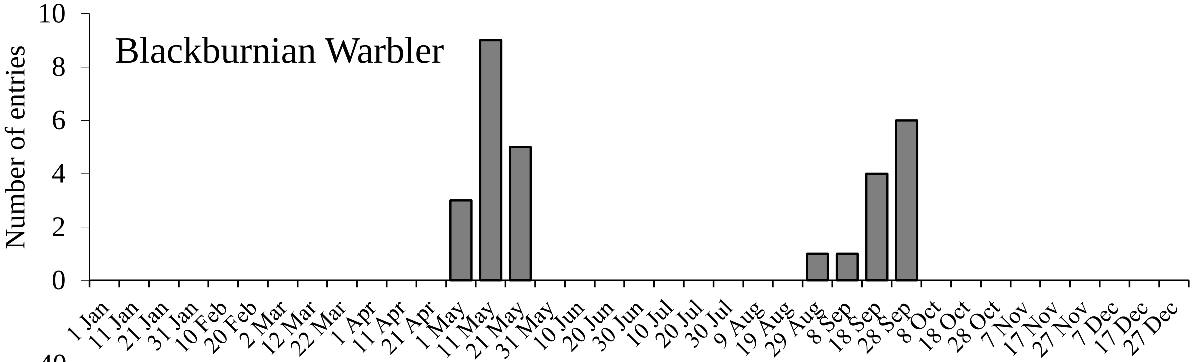

Black-throated Green Warbler
Number of entries
0 5 10 15 20 25 30 35
1 Jan 11 Jan 21 Jan 31 Jan 10 Feb 20 Feb 2 Mar 12 Mar 22 Mar 1 Apr 11 Apr 21 Apr 1 May 11 May 21 May 31 May 10 Jun 20 Jun 30 Jun 10 Jul 20 Jul 30 Jul 9 Aug 19 Aug 29 Aug 8 Sep 18 Sep 28 Sep 8 Oct 18 Oct 28 Oct 7 Nov 17 Nov 27 Nov 7 Dec 17 Dec 27 Dec

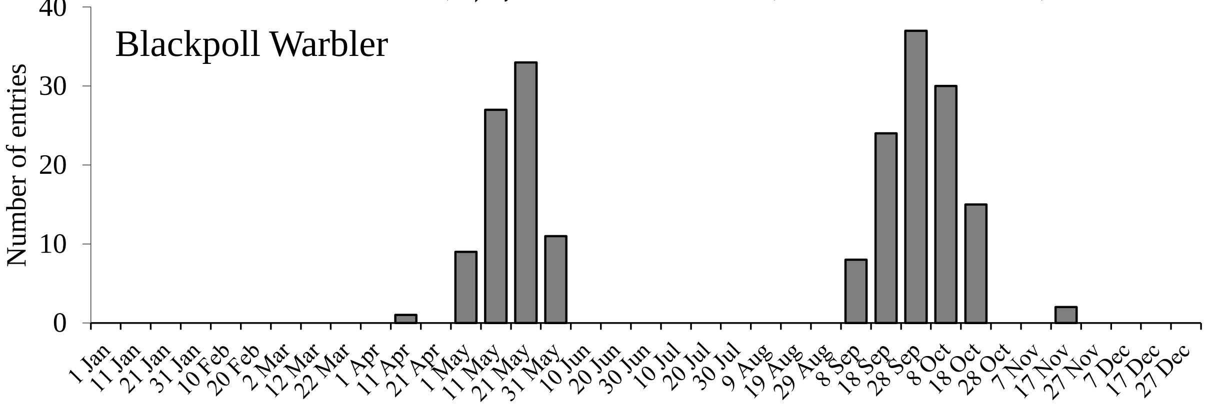

Black-throated Blue Warbler
Number of entries
0 5 10 15 20
1 Jan 11 Jan 21 Jan 31 Jan 10 Feb 20 Feb 2 Mar 12 Mar 22 Mar 1 Apr 11 Apr 21 Apr 1 May 11 May 21 May 31 May 10 Jun 20 Jun 30 Jun 10 Jul 20 Jul 30 Jul 9 Aug 19 Aug 29 Aug 8 Sep 18 Sep 28 Sep 8 Oct 18 Oct 28 Oct 7 Nov 17 Nov 27 Nov 7 Dec 17 Dec 27 Dec

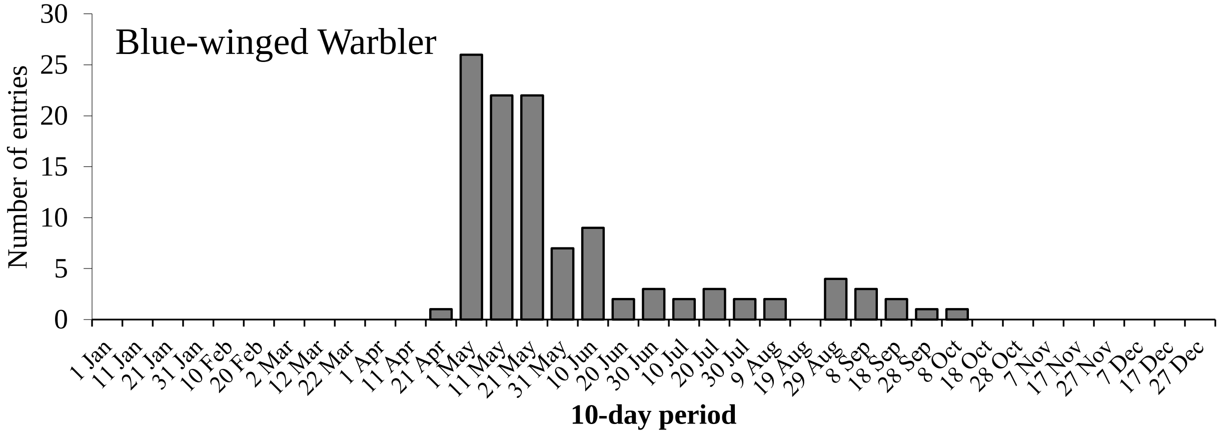

Black-and-White Warbler
Number of entries
0 20 40 60 80 100
1 Jan 11 Jan 21 Jan 31 Jan 10 Feb 20 Feb 2 Mar 12 Mar 22 Mar 1 Apr 11 Apr 21 Apr 1 May 11 May 21 May 31 May 10 Jun 20 Jun 30 Jun 10 Jul 20 Jul 30 Jul 9 Aug 19 Aug 29 Aug 8 Sep 18 Sep 28 Sep 8 Oct 18 Oct 28 Oct 7 Nov 17 Nov 27 Nov 7 Dec 17 Dec 27 Dec

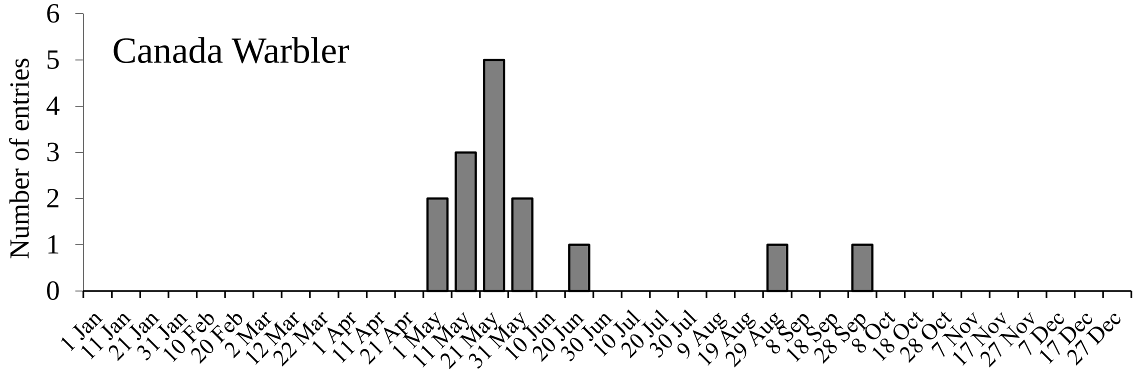

Bay-breasted Warbler
Number of entries
0 2 4 6 8 10
1 Jan 11 Jan 21 Jan 31 Jan 10 Feb 20 Feb 2 Mar 12 Mar 22 Mar 1 Apr 11 Apr 21 Apr 1 May 11 May 21 May 31 May 10 Jun 20 Jun 30 Jun 10 Jul 20 Jul 30 Jul 9 Aug 19 Aug 29 Aug 8 Sep 18 Sep 28 Sep 8 Oct 18 Oct 28 Oct 7 Nov 17 Nov 27 Nov 7 Dec 17 Dec 27 Dec
10-day period

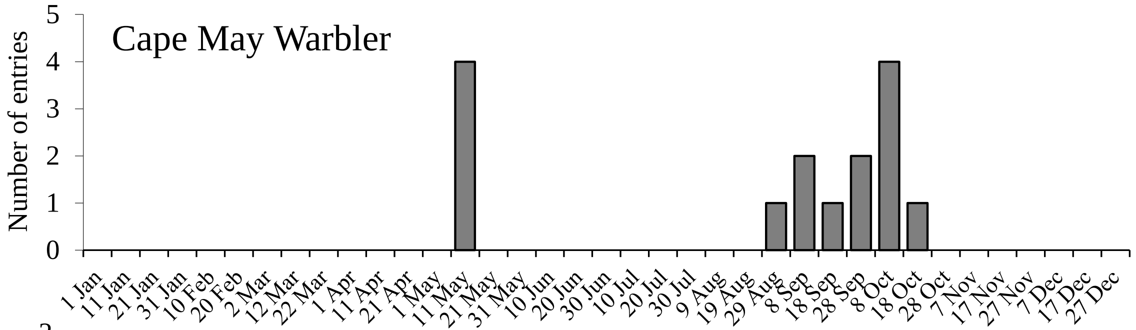

American Redstart
Number of entries
0
10
20
30
40
50
60
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

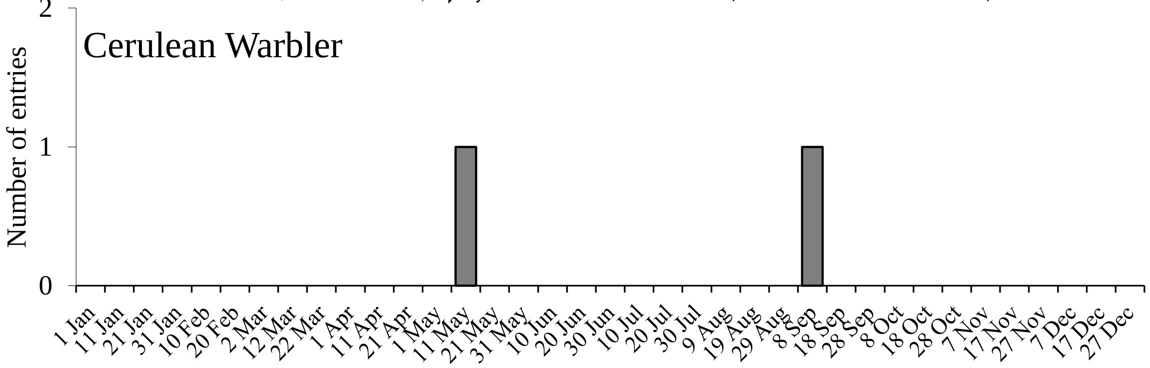

Blackburnian Warbler
Number of entries
0
2
4
6
8
10
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

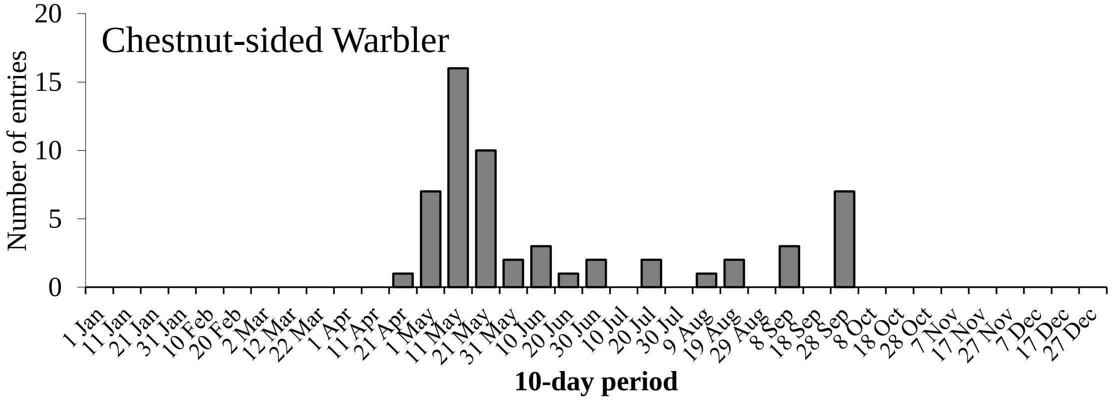

Blackpoll Warbler
Number of entries
0
10
20
30
40
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

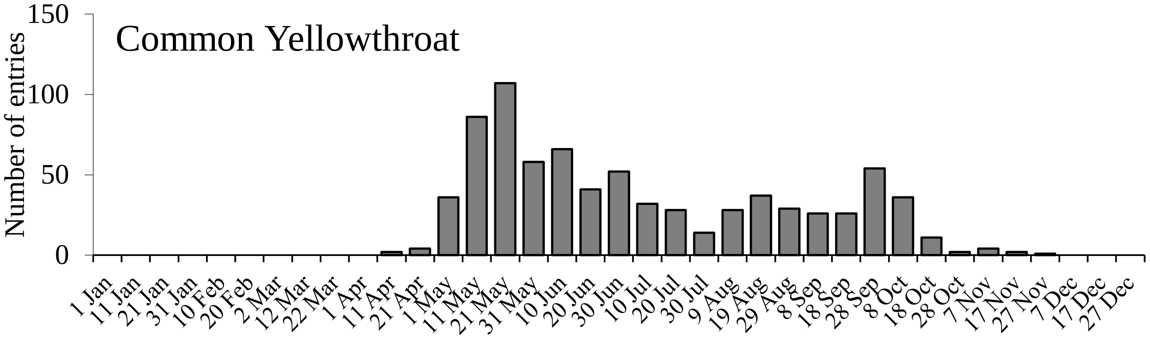

Blue-winged Warbler
Number of entries
0
5
10
15
20
25
30
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec
10-day period

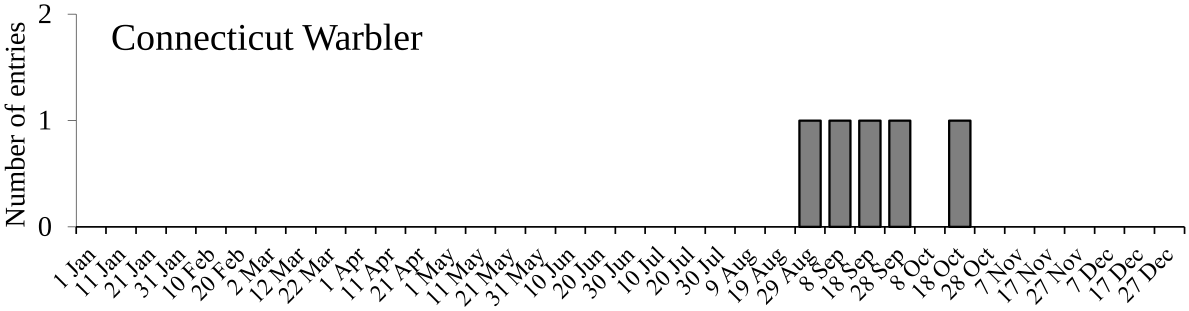

Canada Warbler
Number of entries
0
1
2
3
4
5
6
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

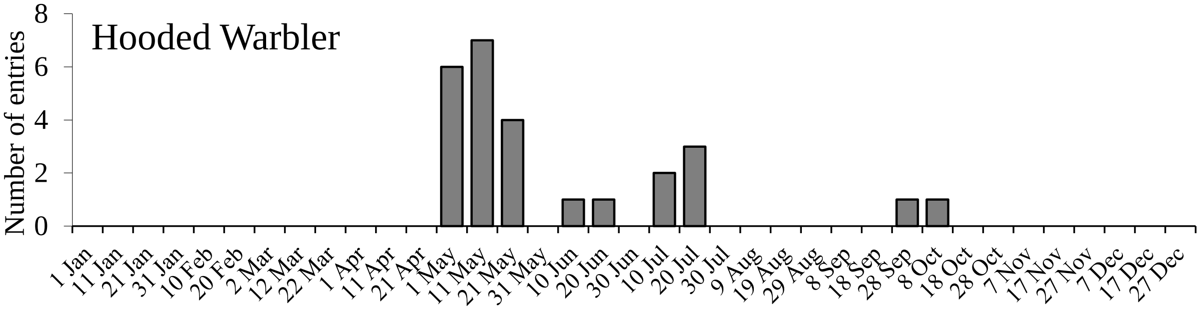

Cape May Warbler
Number of entries
0
1
2
3
4
5
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

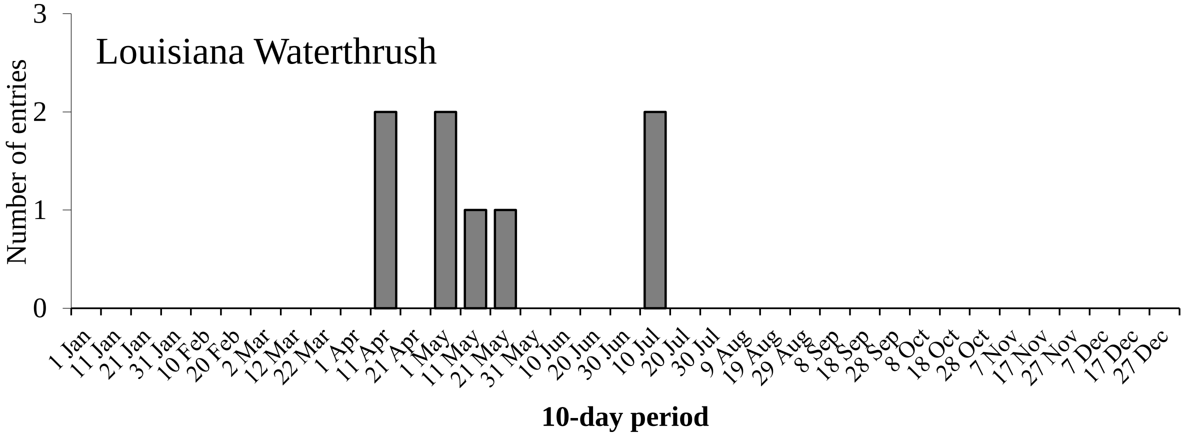

Cerulean Warbler
Number of entries
0
1
2
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

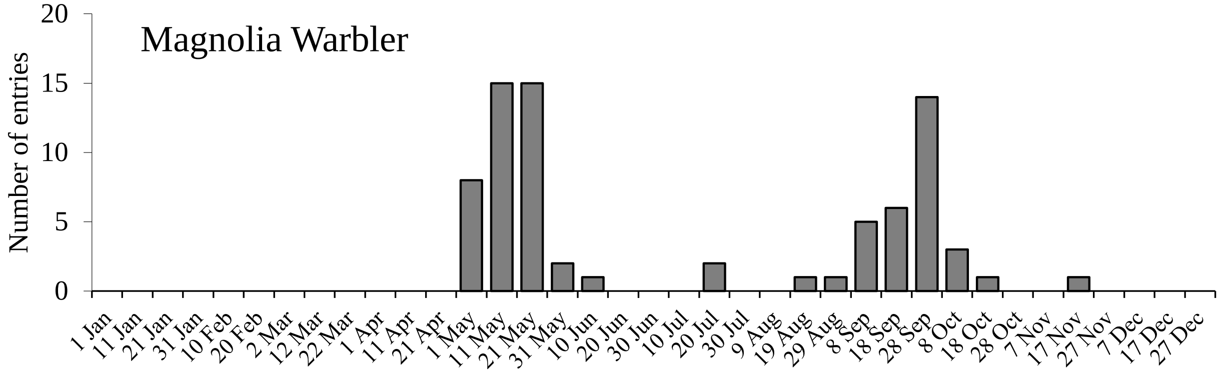

Chestnut-sided Warbler
Number of entries
0
5
10
15
20
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec
10-day period

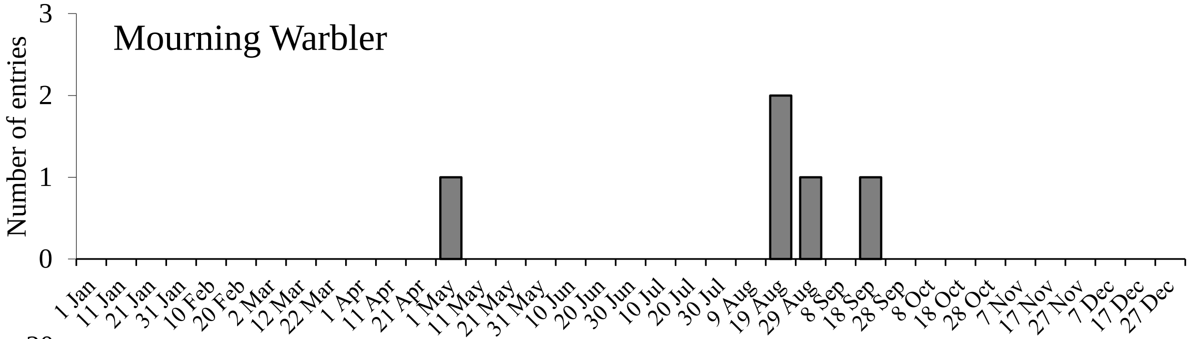

Common Yellowthroat
Number of entries
150
100
50
0
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

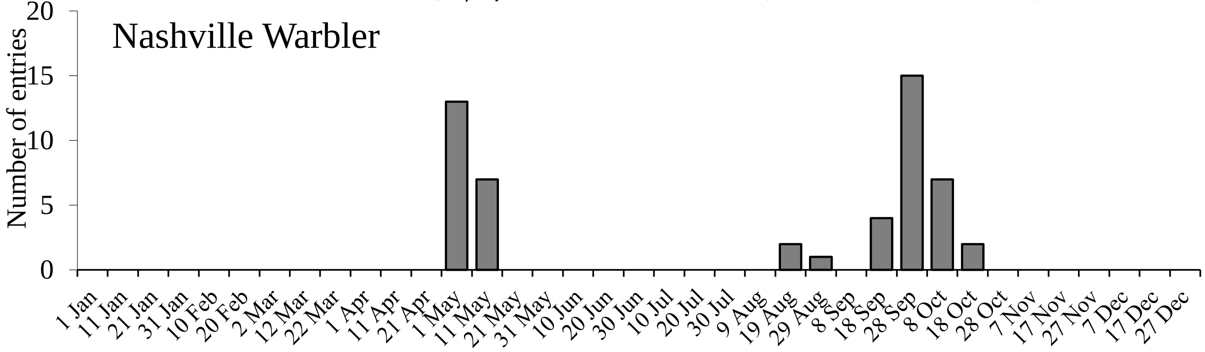

Connecticut Warbler
Number of entries
2
1
0
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

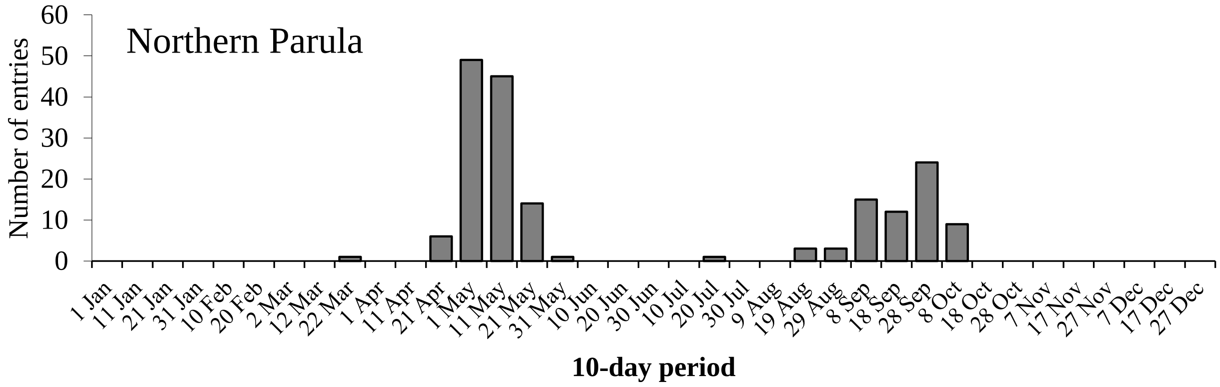

Hooded Warbler
Number of entries
8
6
4
2
0
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

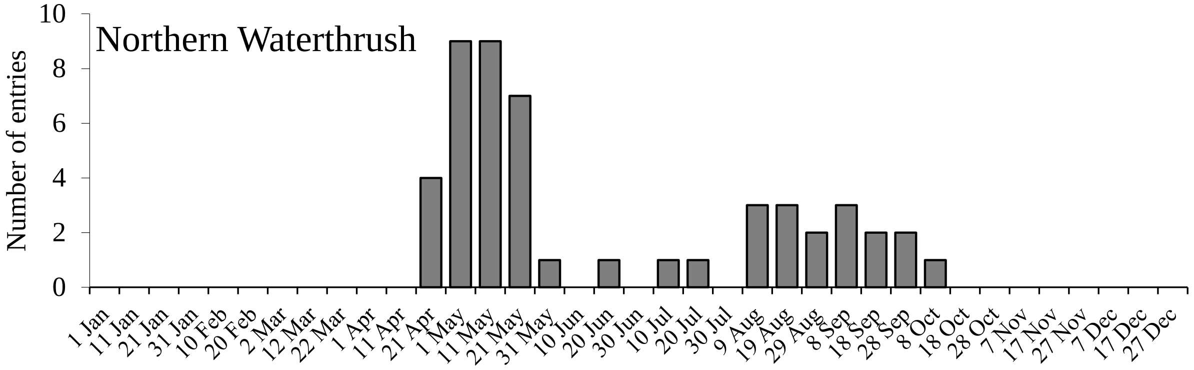

Louisiana Waterthrush
Number of entries
3
2
1
0
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec
10-day period

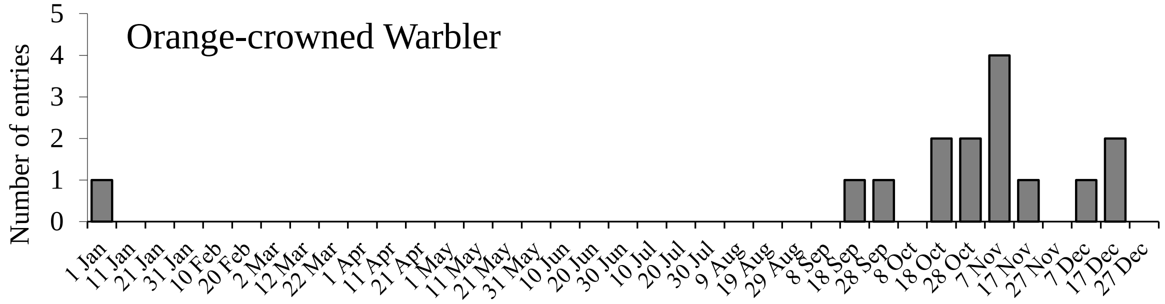

Magnolia Warbler
Number of entries
20
15
10
5
0
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

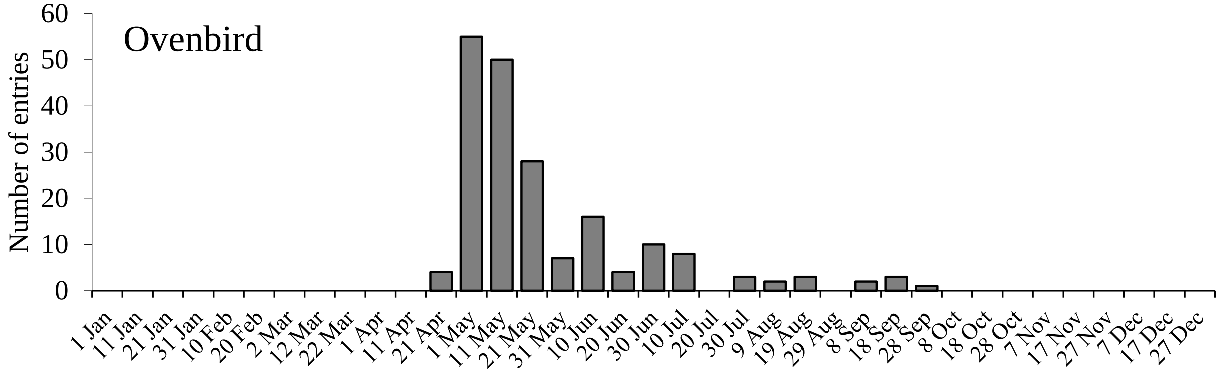

Mourning Warbler
Number of entries
3
2
1
0
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

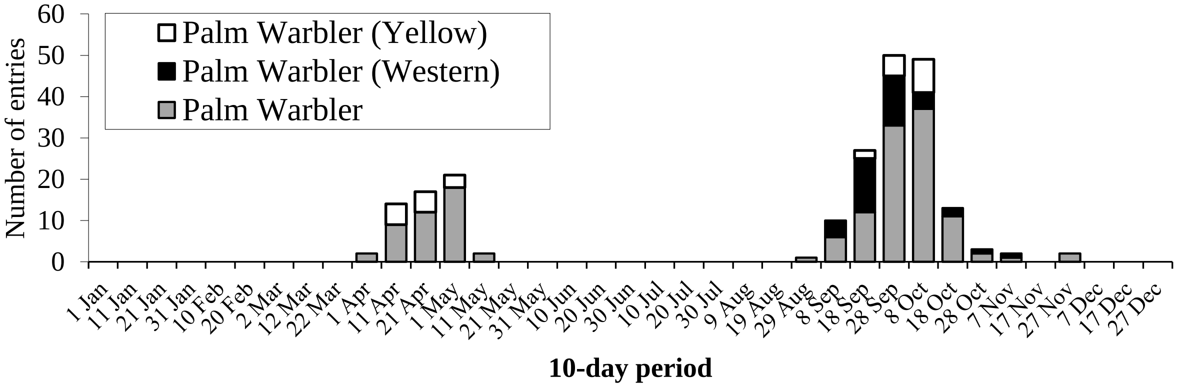

Nashville Warbler
Number of entries
20
15
10
5
0
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

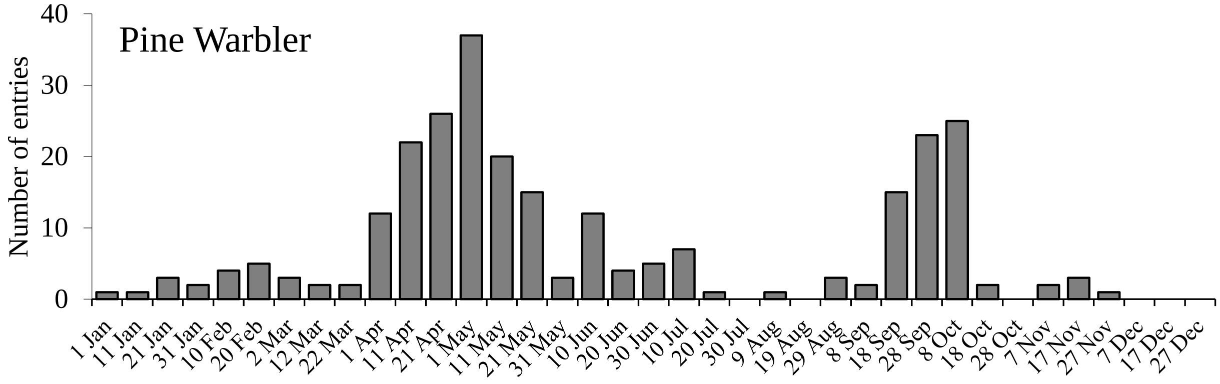

Northern Parula
Number of entries
60
50
40
30
20
10
0
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec
10-day period

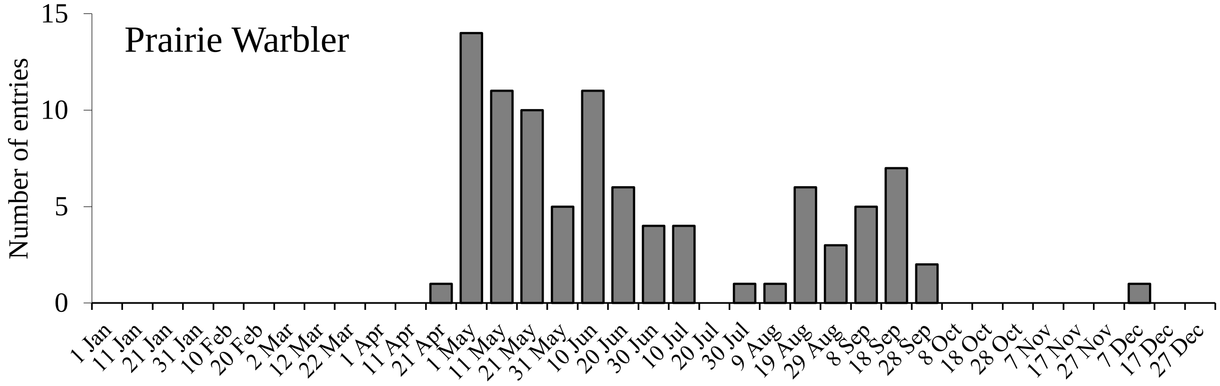

Northern Waterthrush
Number of entries
0
2
4
6
8
10
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

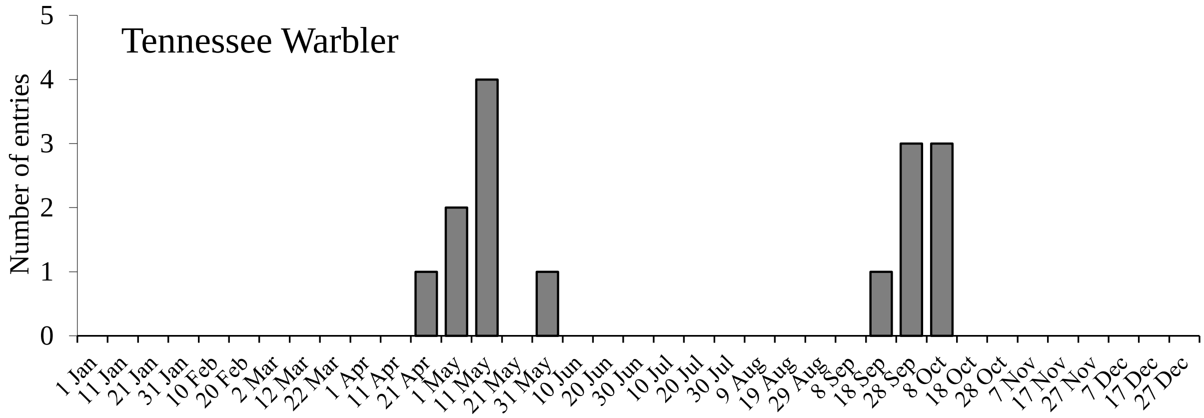

Orange-crowned Warbler
Number of entries
0
1
2
3
4
5
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec

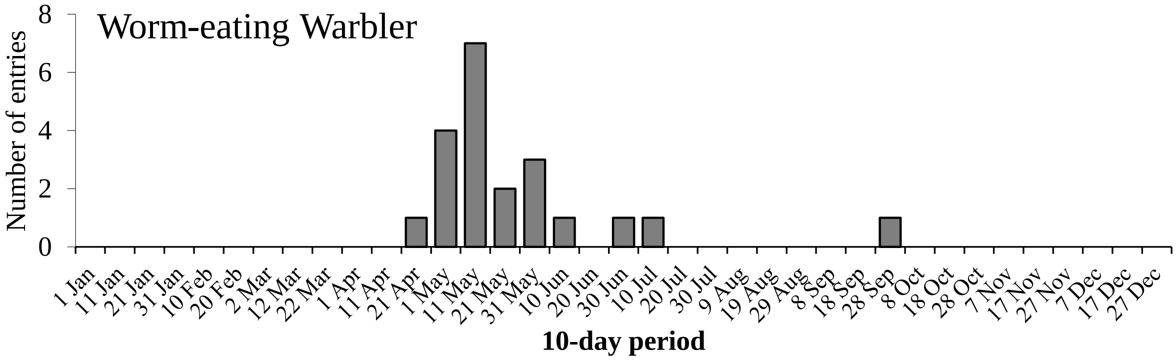

Ovenbird
Number of entries
0
10
20
30
40
50
60
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec


☐ Palm Warbler (Yellow)
■ Palm Warbler (Western)
▨ Palm Warbler
Number of entries
0
10
20
30
40
50
60
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec
10-day period


Pine Warbler
Number of entries
0
10
20
30
40
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec


Prairie Warbler
Number of entries
0
5
10
15
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec


Tennessee Warbler
Number of entries
0
1
2
3
4
5
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec


Worm-eating Warbler
Number of entries
0
2
4
6
8
1 Jan
11 Jan
21 Jan
31 Jan
10 Feb
20 Feb
2 Mar
12 Mar
22 Mar
1 Apr
11 Apr
21 Apr
1 May
11 May
21 May
31 May
10 Jun
20 Jun
30 Jun
10 Jul
20 Jul
30 Jul
9 Aug
19 Aug
29 Aug
8 Sep
18 Sep
28 Sep
8 Oct
18 Oct
28 Oct
7 Nov
17 Nov
27 Nov
7 Dec
17 Dec
27 Dec
10-day period

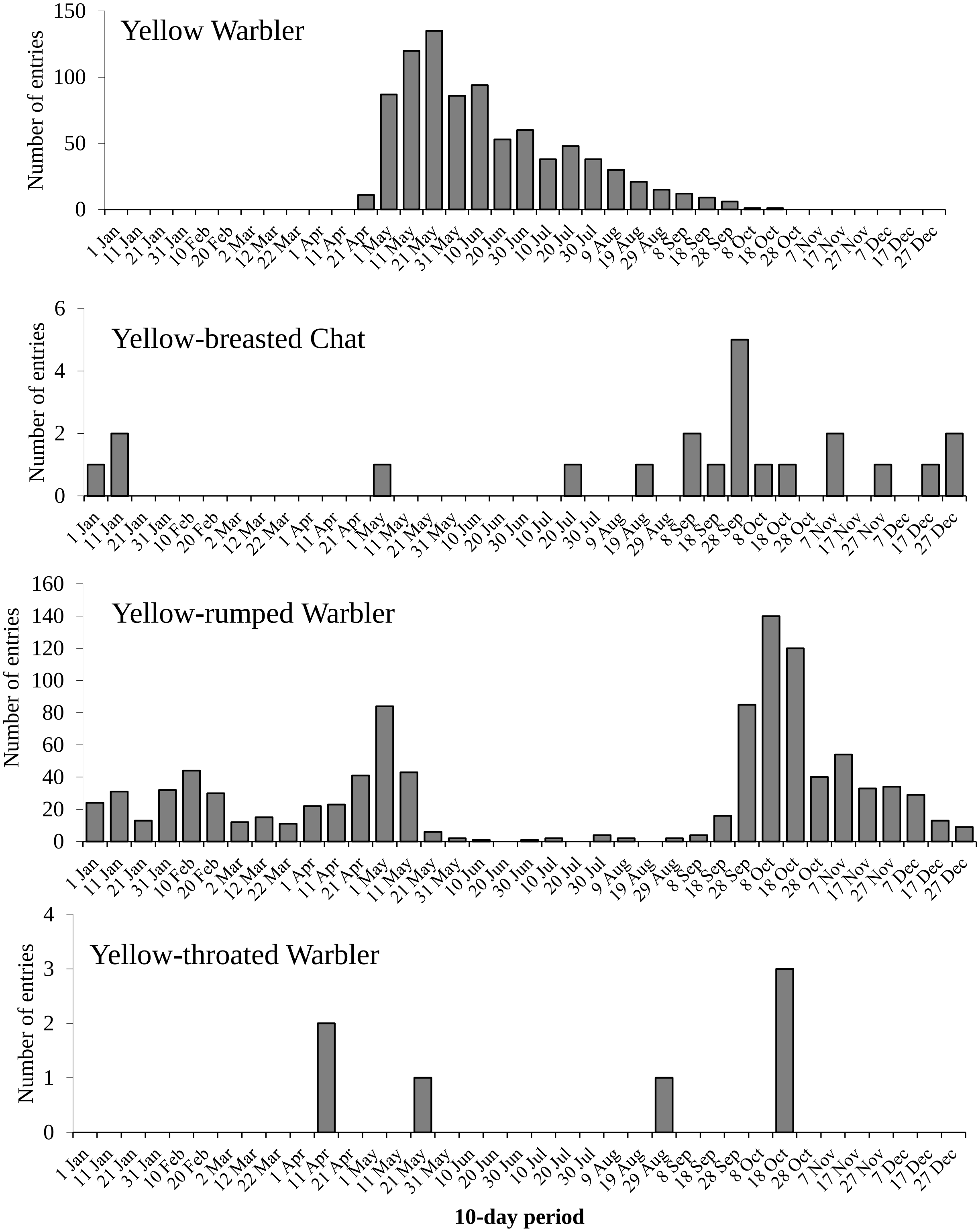
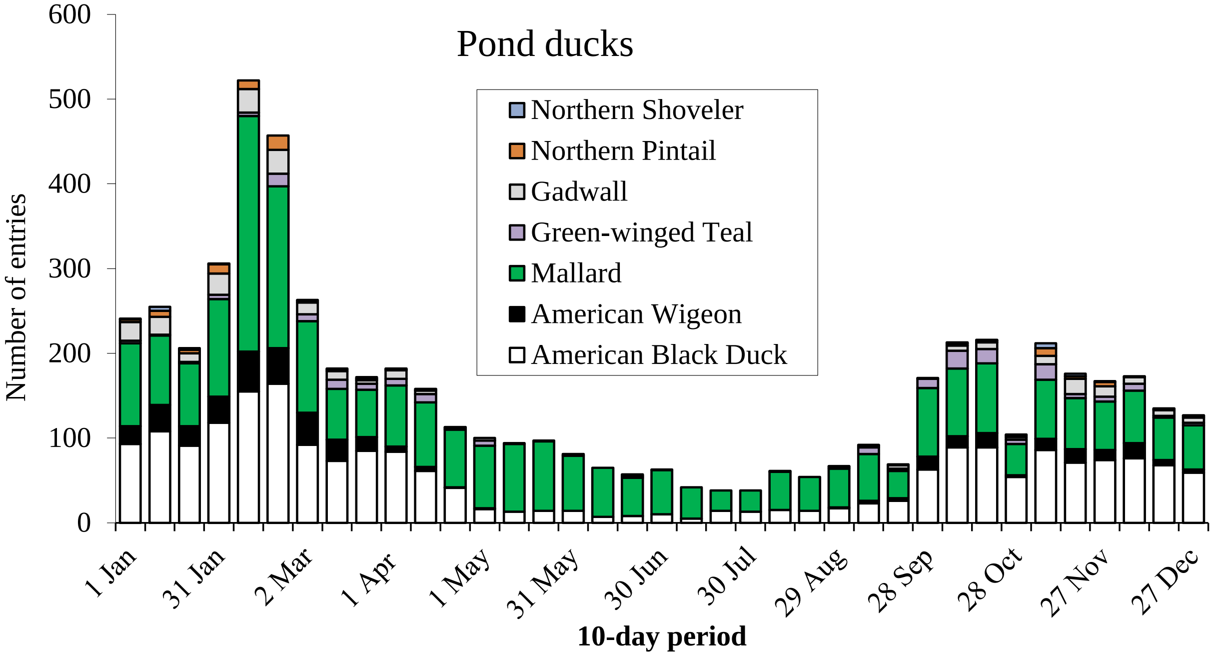
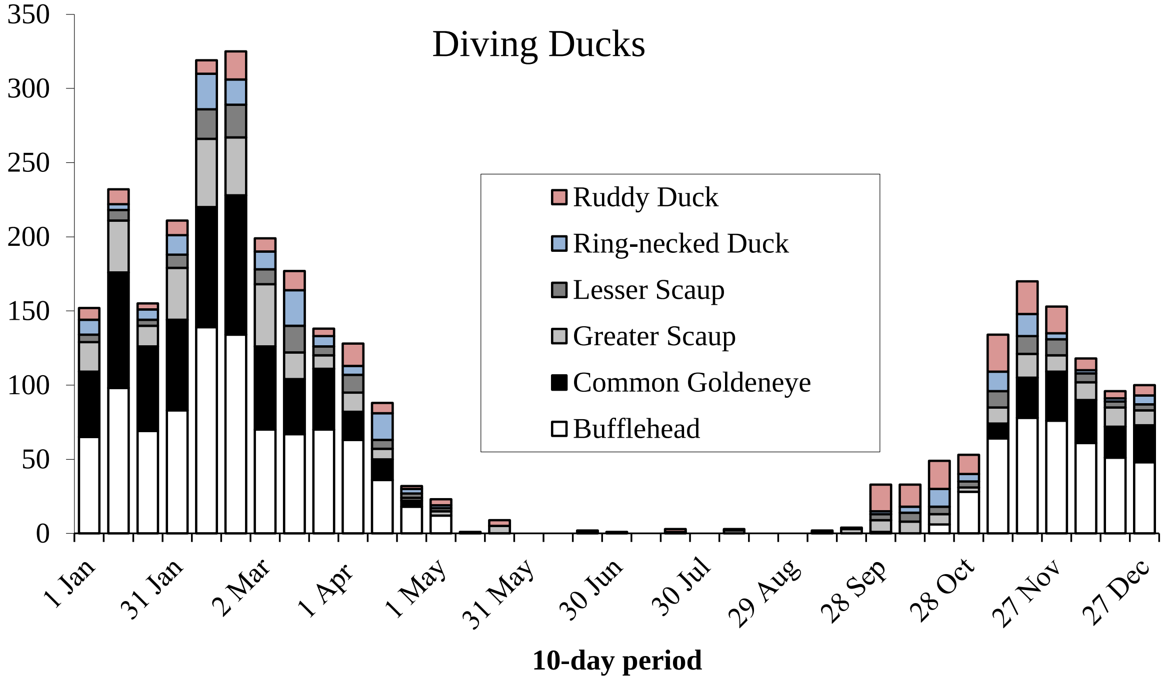
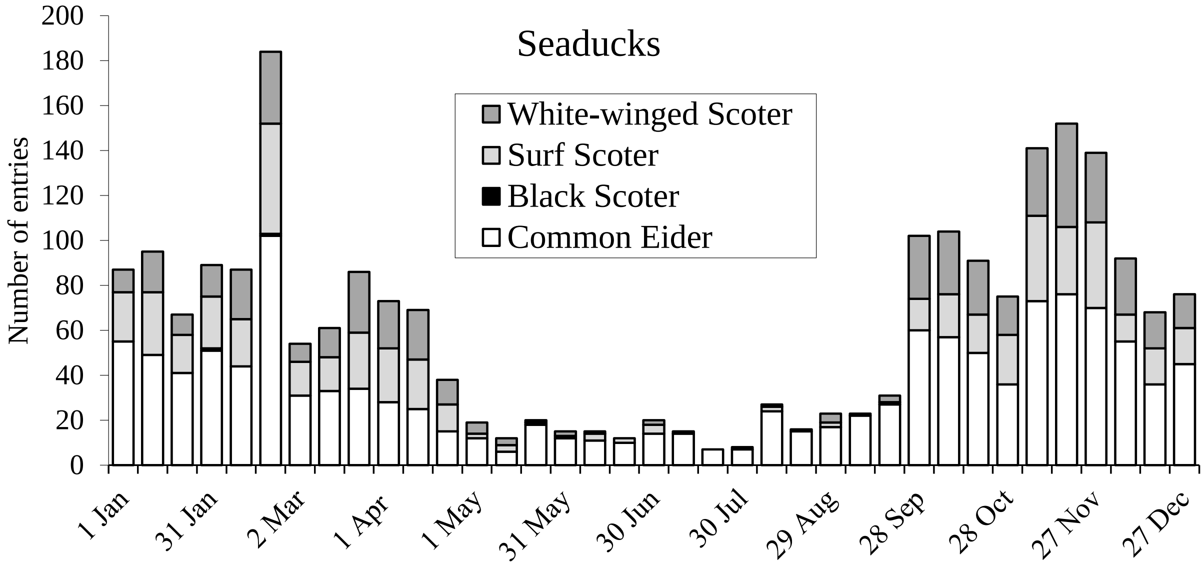
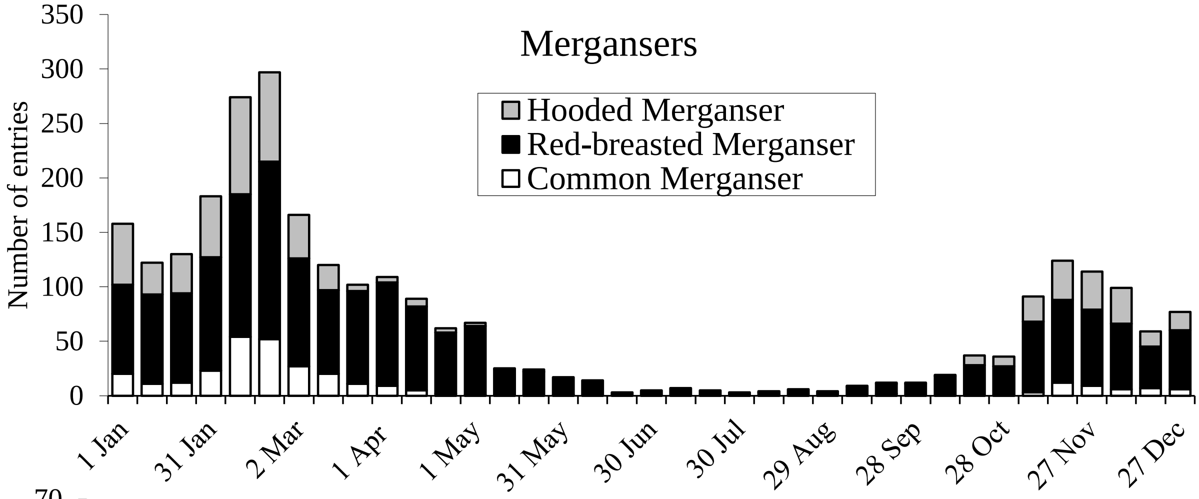


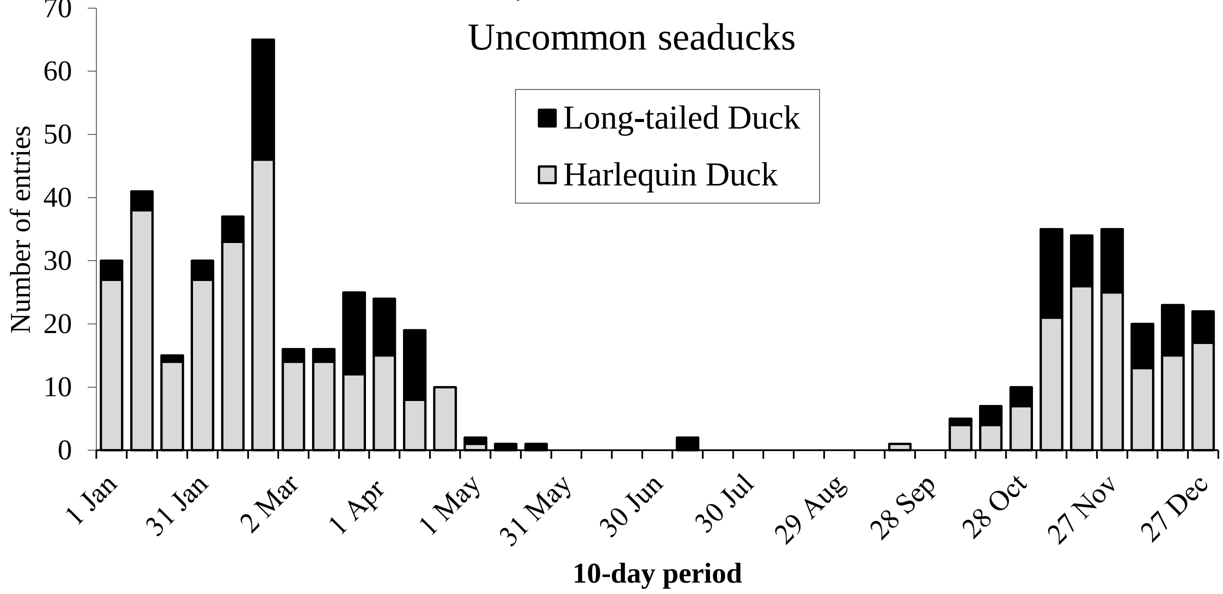
Figure A3.56. Migration phenology of warblers based on eBird records in Avian Knowledge Network.

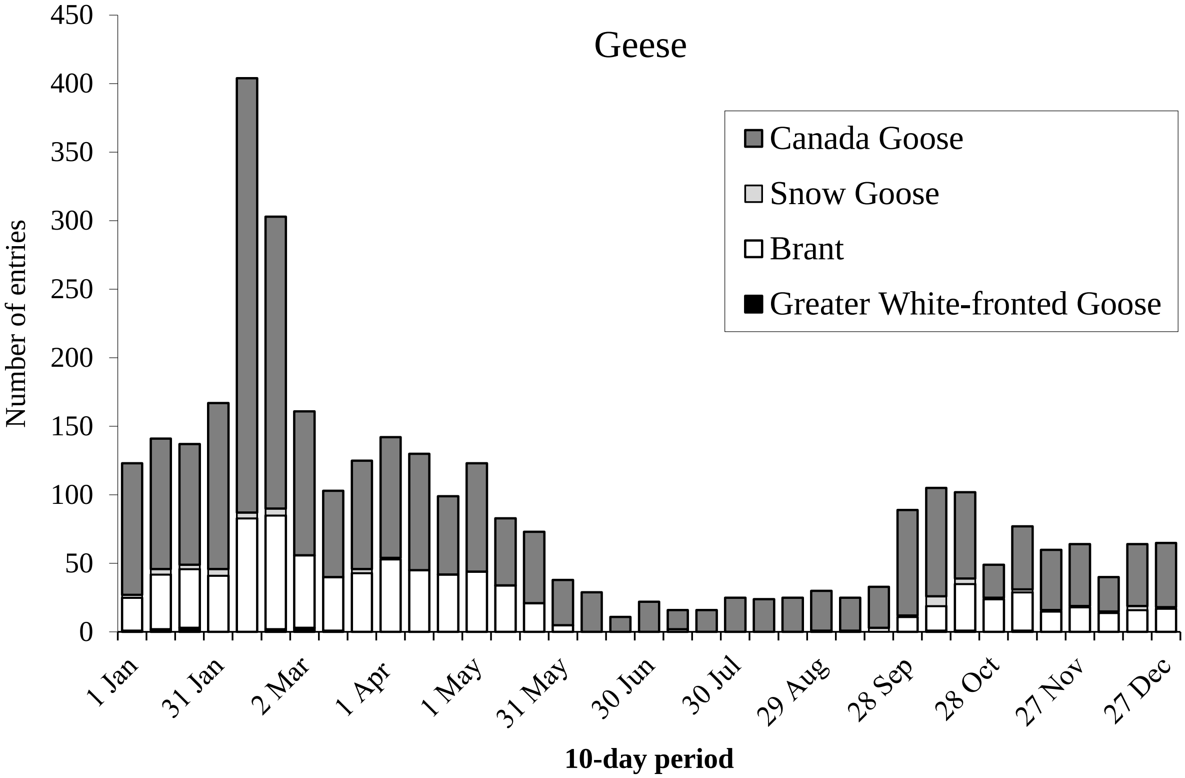

Pond ducks
Northern Shoveler
Northern Pintail
Gadwall
Green-winged Teal
Mallard
American Wigeon
American Black Duck
Number of entries
600
500
400
300
200
100
0
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period


Diving Ducks
Ruddy Duck
Ring-necked Duck
Lesser Scaup
Greater Scaup
Common Goldeneye
Bufflehead
350
300
250
200
150
100
50
0
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period


Seaducks
White-winged Scoter
Surf Scoter
Black Scoter
Common Eider
Number of entries
0
20
40
60
80
100
120
140
160
180
200
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec


Mergansers
Hooded Merganser
Red-breasted Merganser
Common Merganser
Number of entries
0
50
100
150
200
250
300
350
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec


Uncommon seaducks
Long-tailed Duck
Harlequin Duck
Number of entries
0
10
20
30
40
50
60
70
1 Jan
31 Jan
2 Mar
1 Apr
1 May
31 May
30 Jun
30 Jul
29 Aug
28 Sep
28 Oct
27 Nov
27 Dec
10-day period



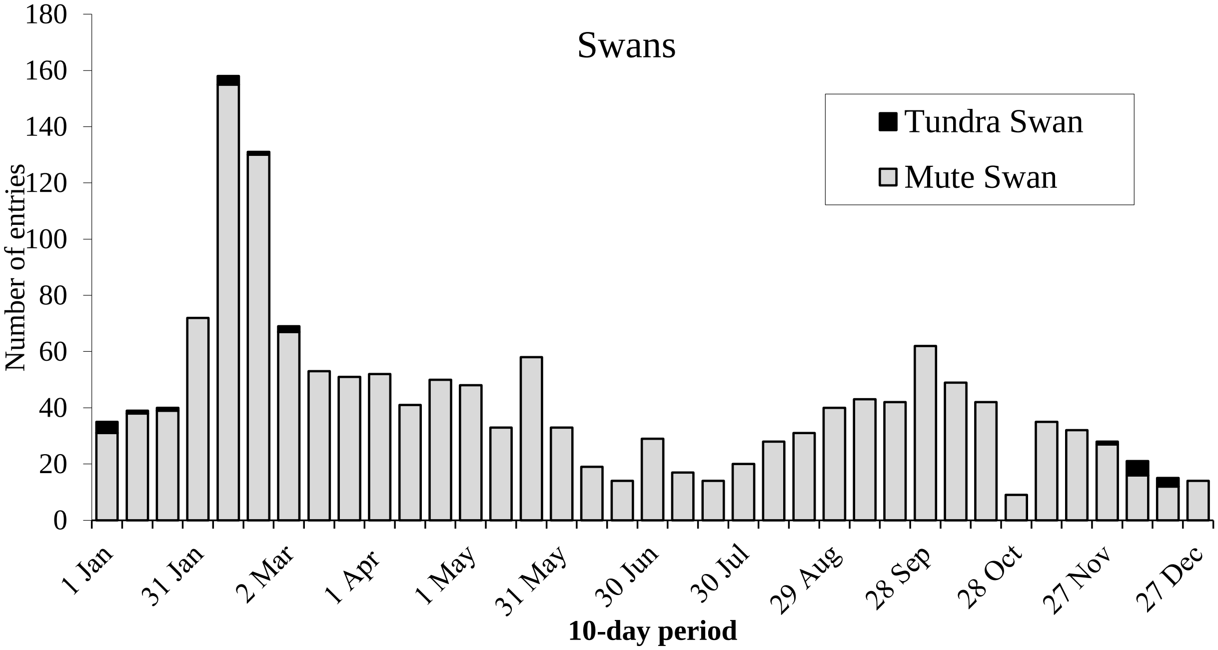


Figure A3.57. Migration phenology of waterfowl in Rhode Island based on observations in the Avian Knowledge Network.

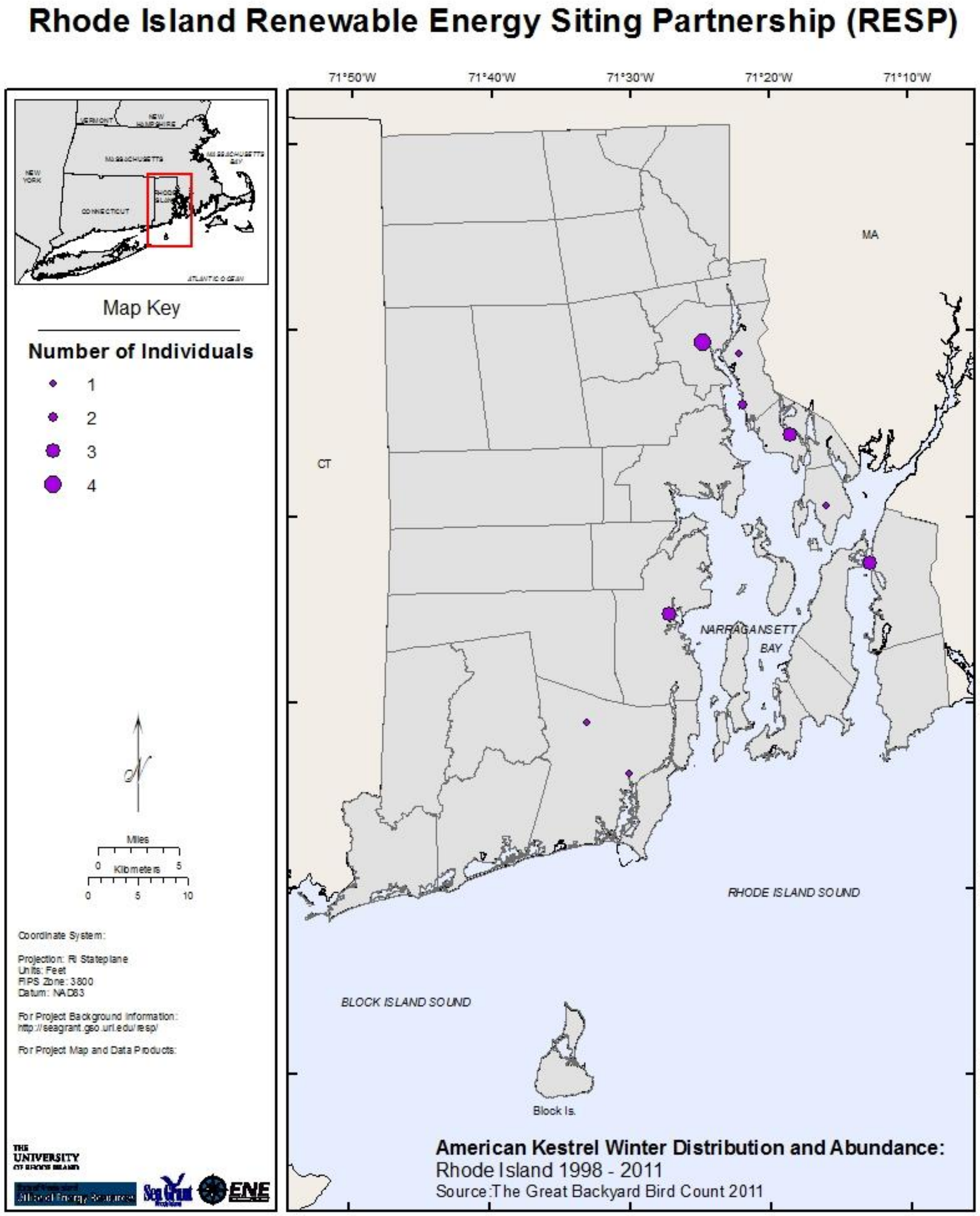


Figure A3.58. Distribution and abundance of **American Kestrel (*Falco sparverius*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species winters in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

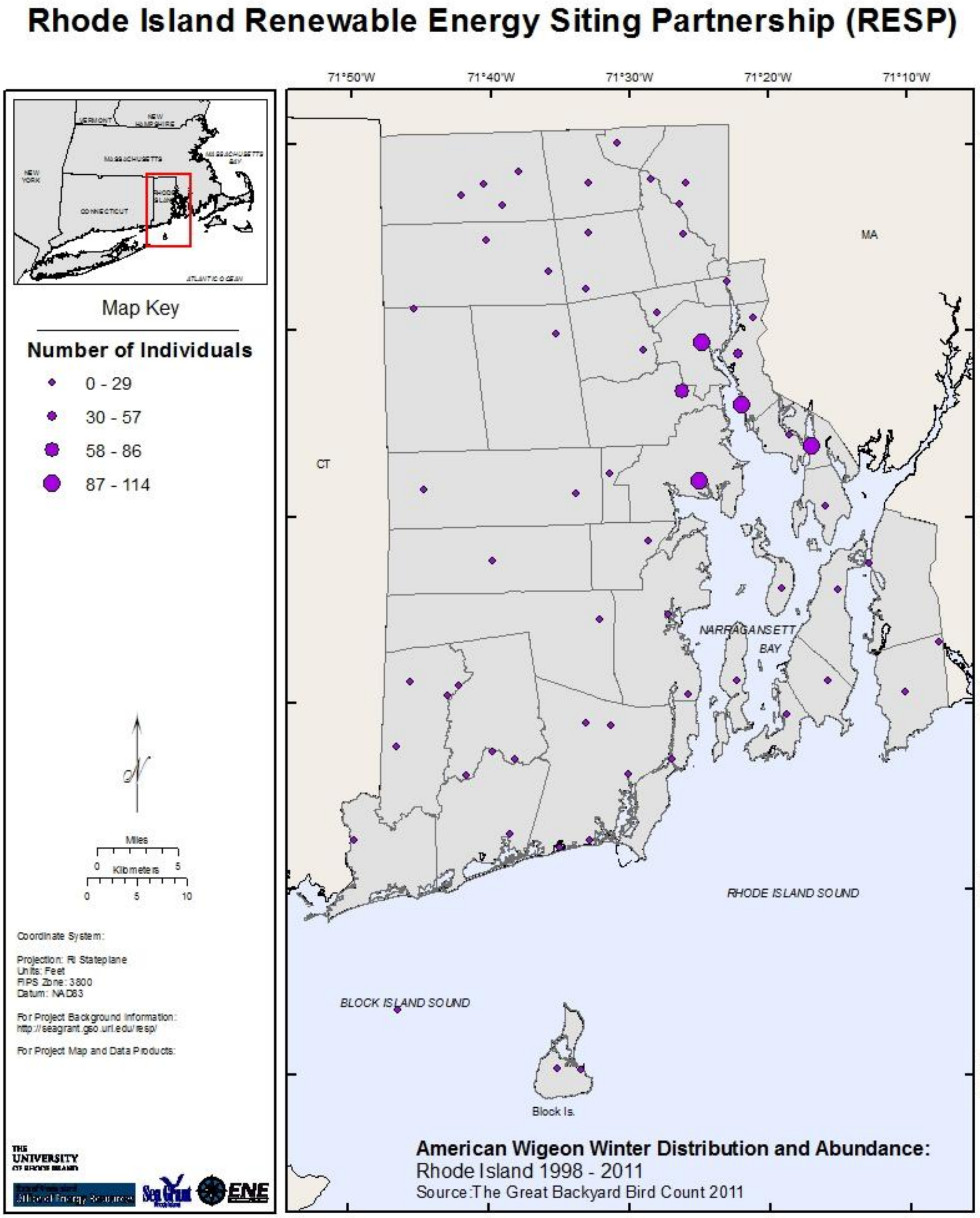


Figure A3.59. Distribution and abundance of **American Wigeon (*Anas americana*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species winters in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

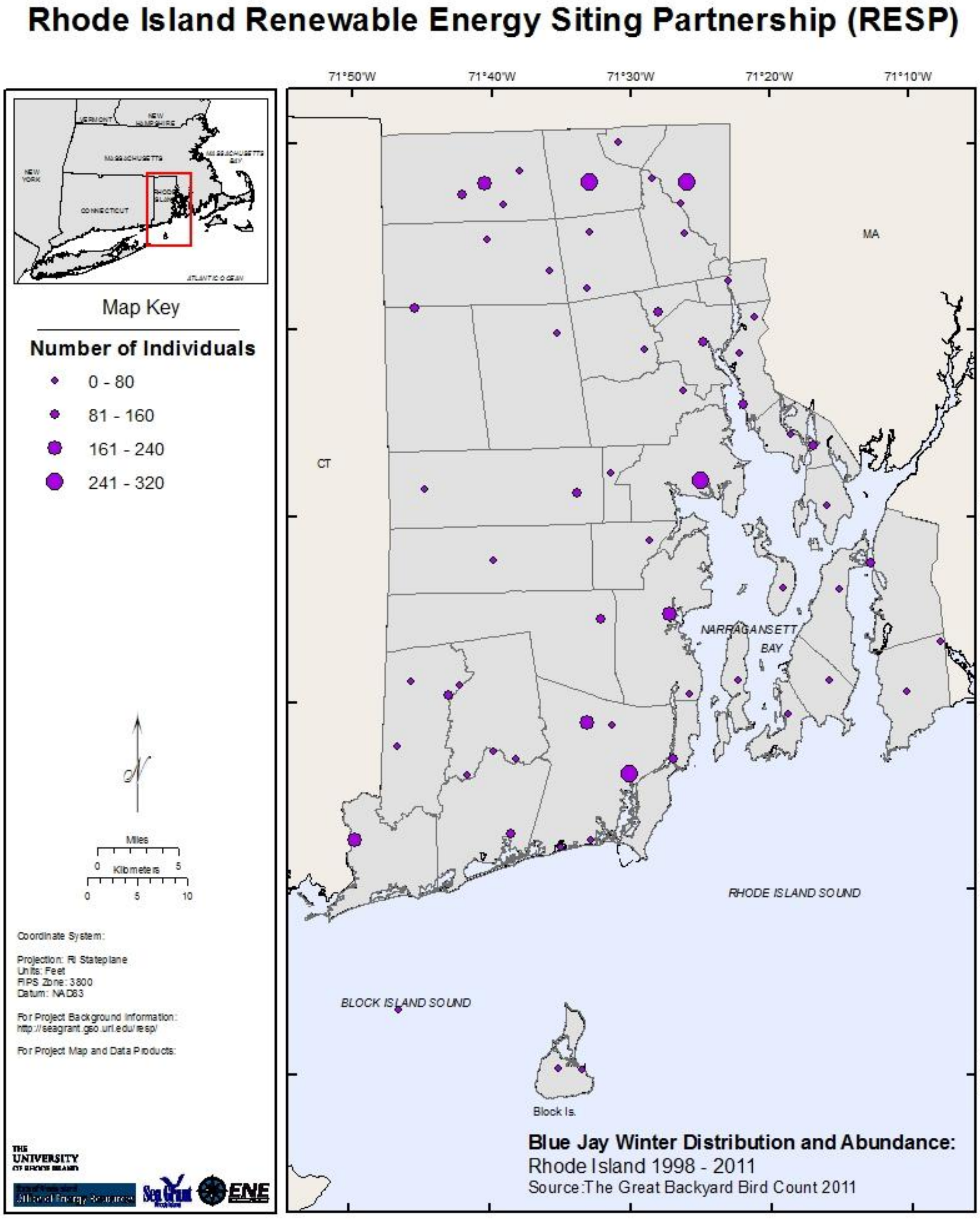


Figure A3. 60. Distribution and abundance of **Blue Jay (*Cyanocitta cristata*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species is resident in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

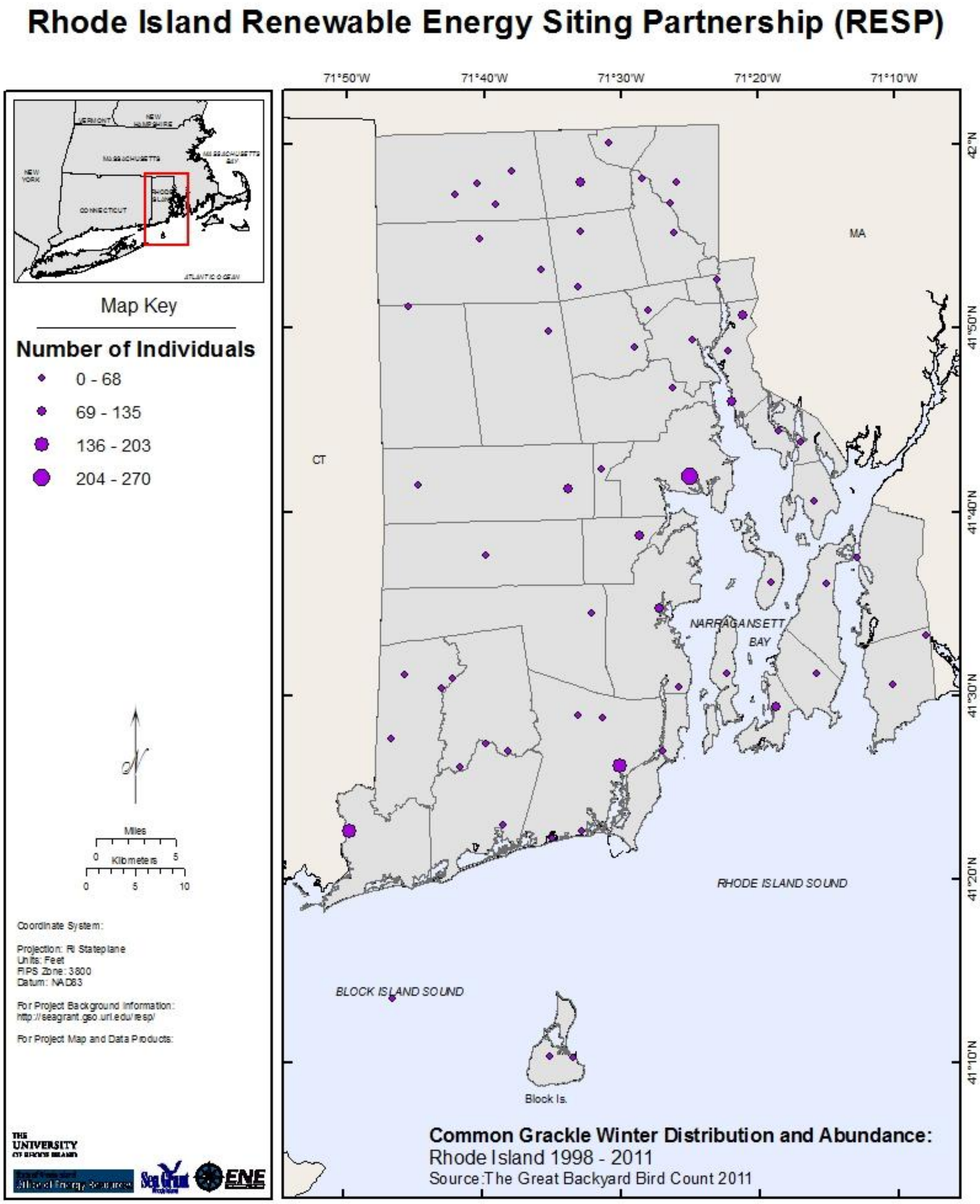


Figure A3.61. Distribution and abundance of **Common Grackle (*Quiscalus quiscula*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species is much more common in summer than winter in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

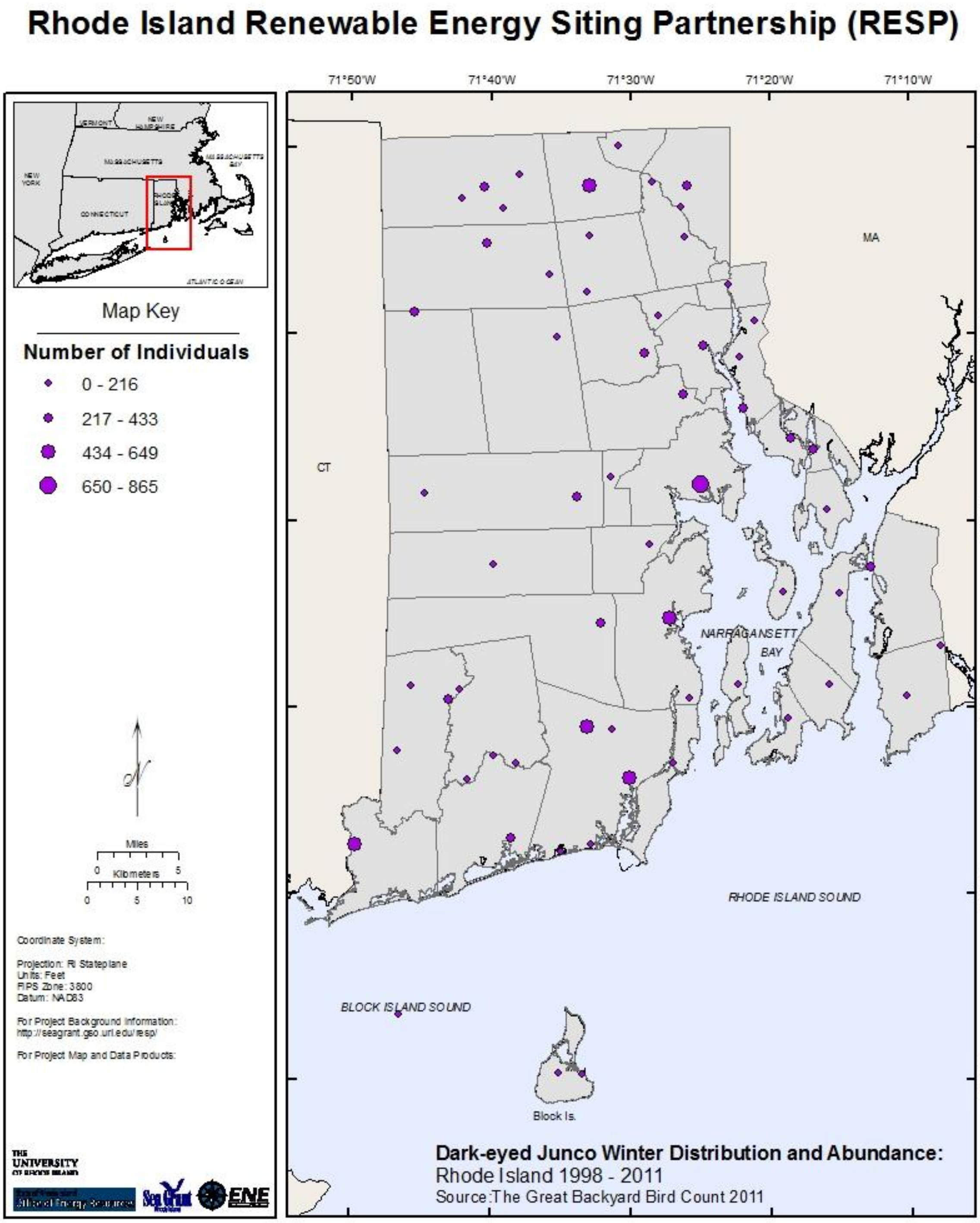


Figure A3.62. Distribution and abundance of **Dark-eyed Junco (*Junco hyemalis*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species winters in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

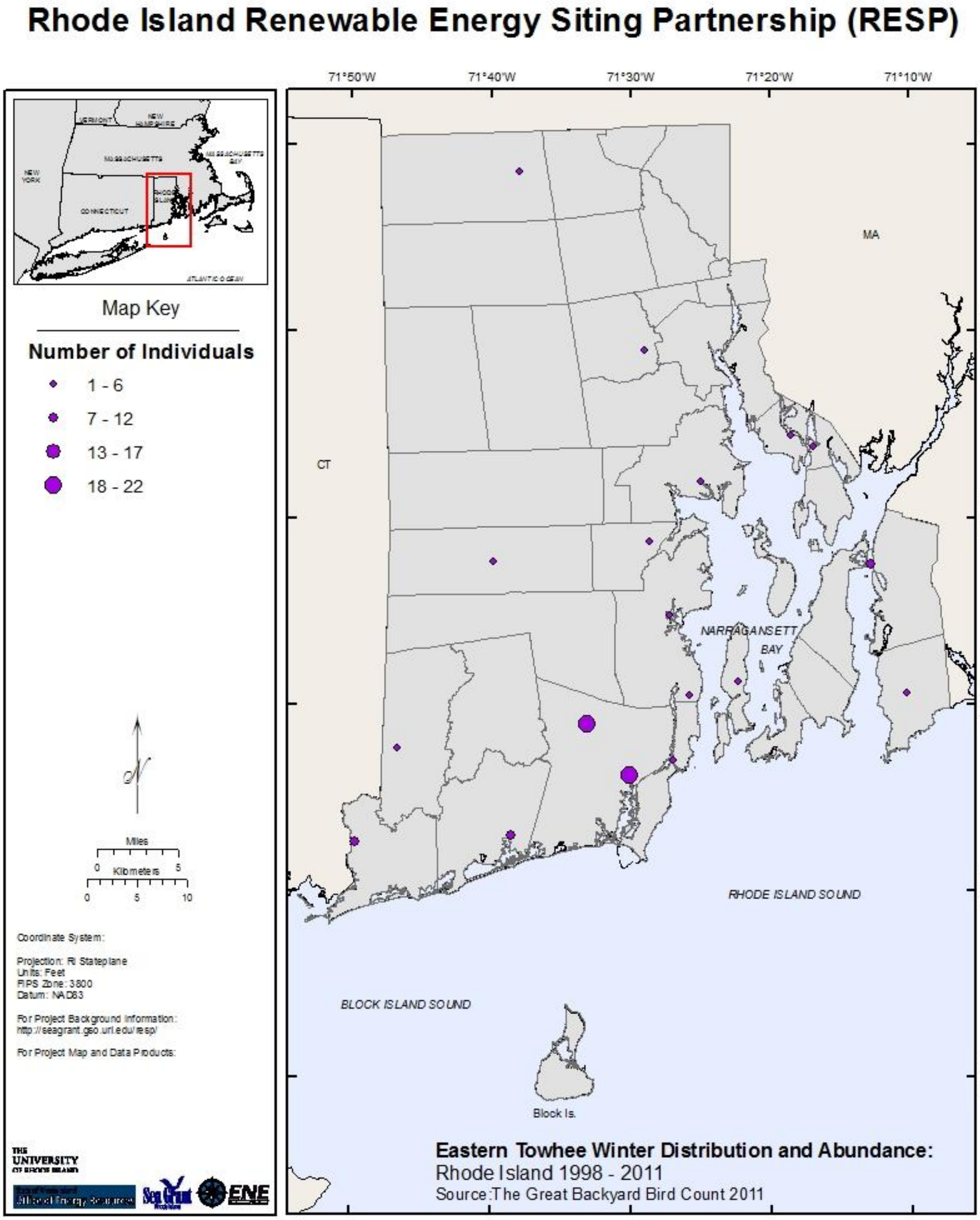


Figure A3.63. Distribution and abundance of **Eastern Towhee (*Pipilo erythrophthalmus*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species winters in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

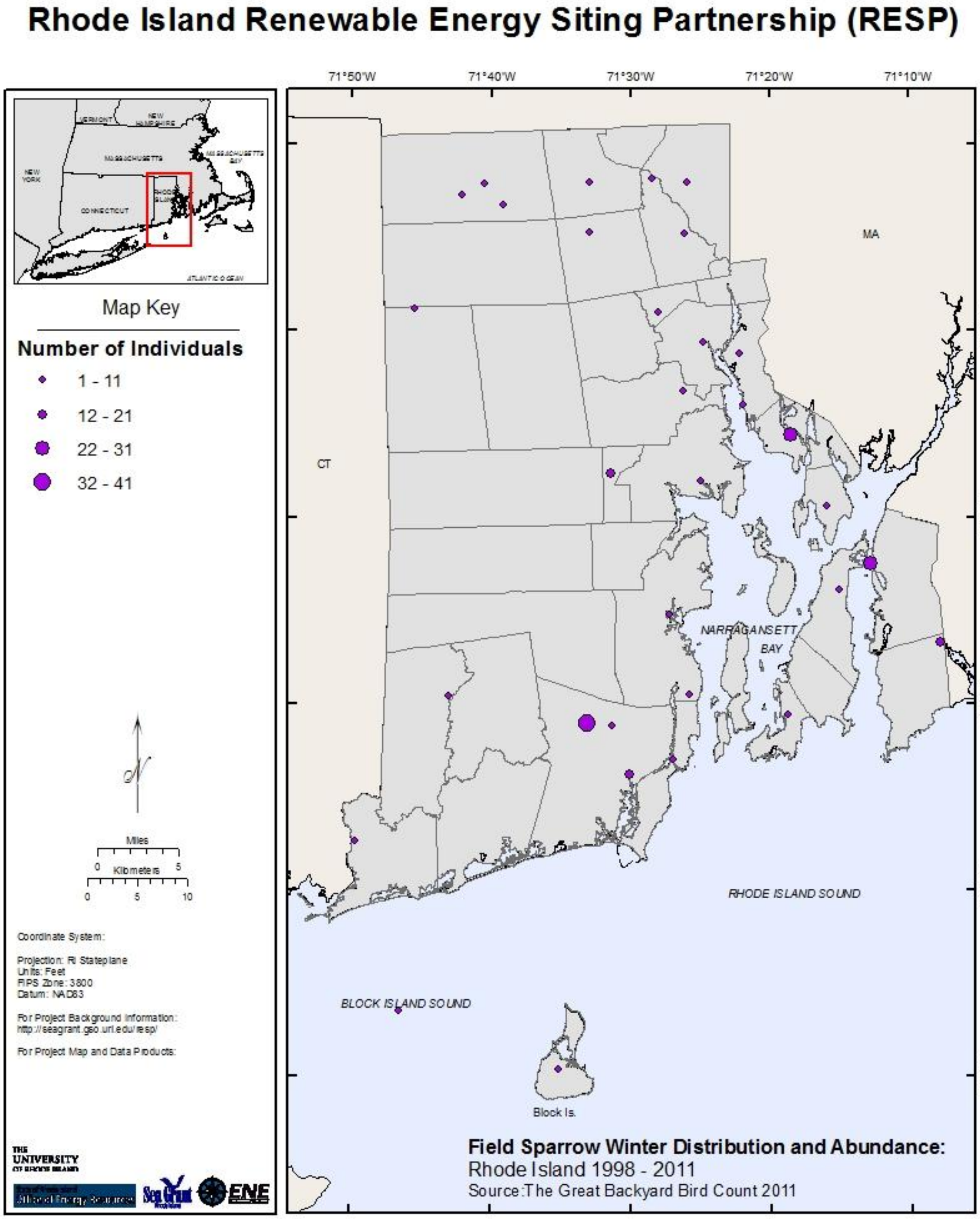


Figure A3.64. Distribution and abundance of **Field Sparrow (*Spizella pusilla*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species winters in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

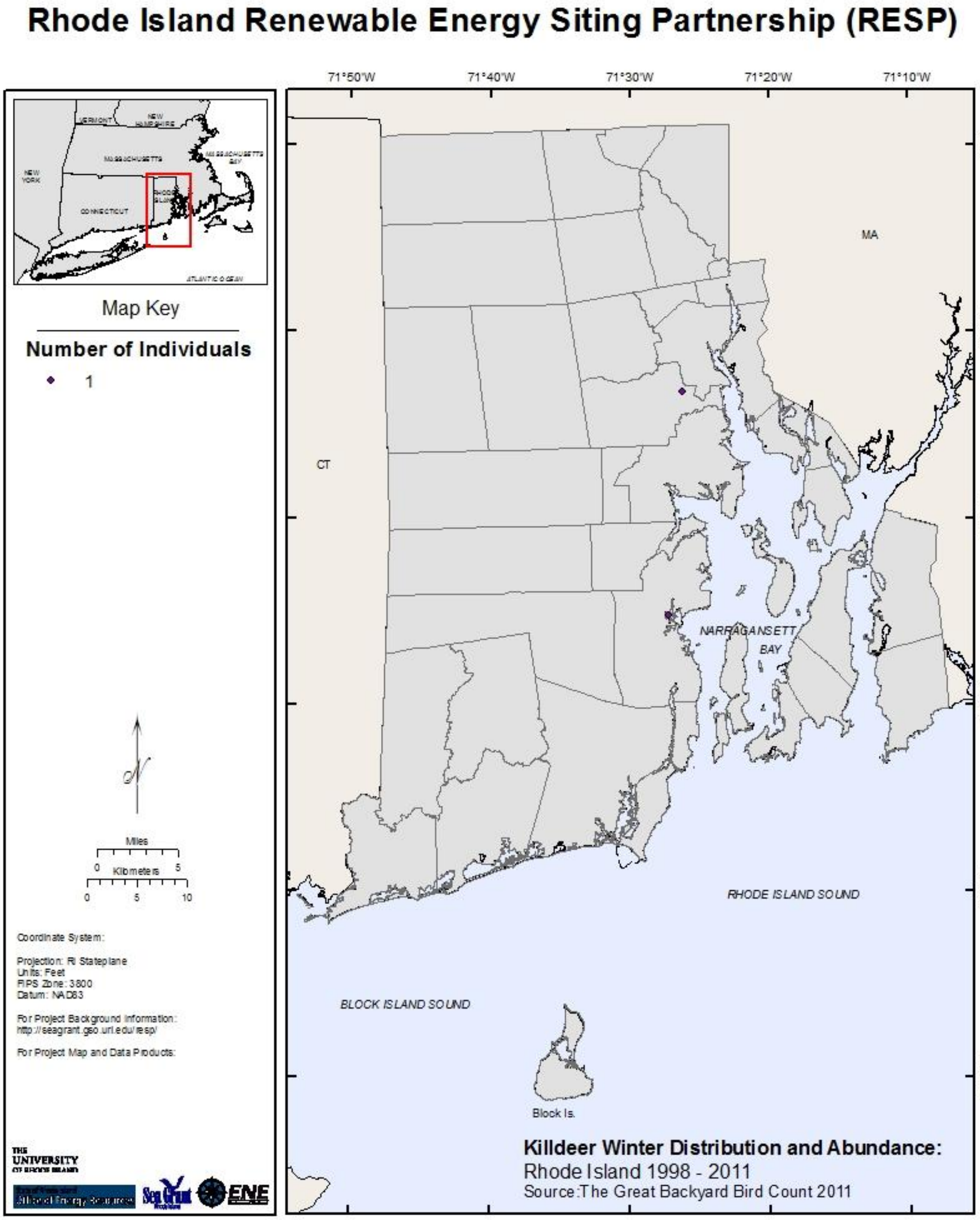


Figure A3.65. Distribution and abundance of **Killdeer (*Charadrius vociferus*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species breeds in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

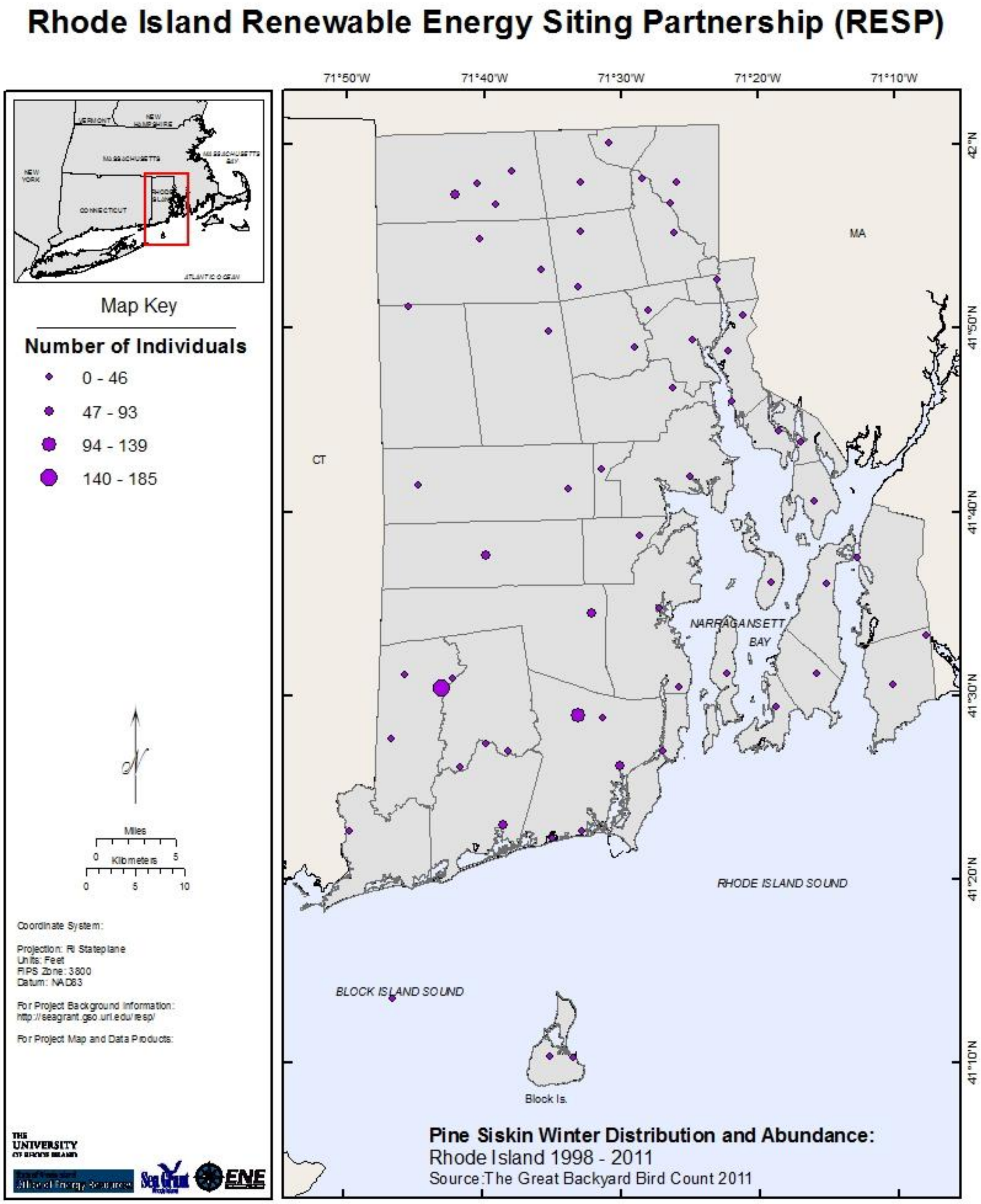


Figure A3.66. Distribution and abundance of **Pine Siskin (*Carduelis pinus*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species winters in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

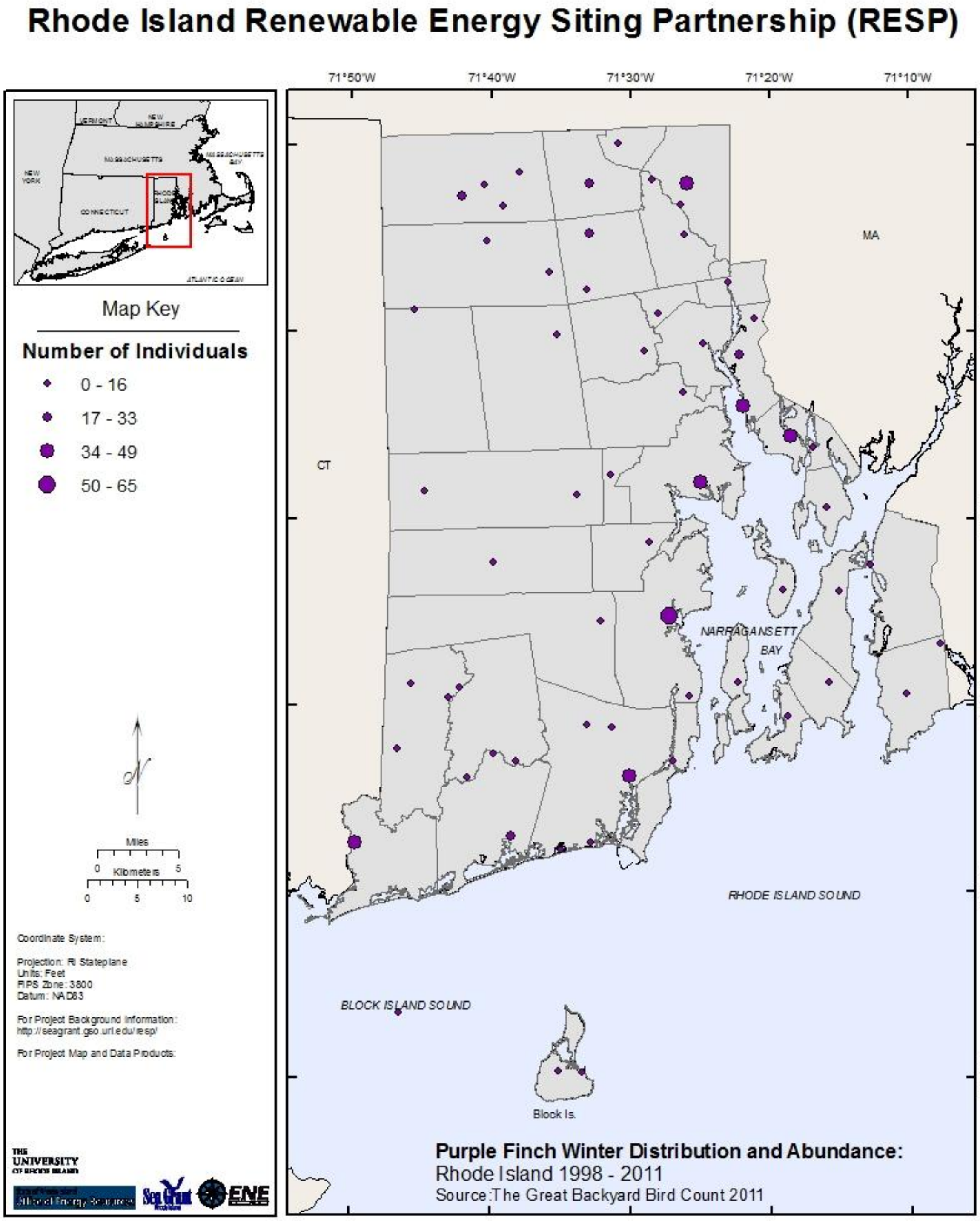


Figure A3.67. Distribution and abundance of **Purple Finch (*Carpodacus purpureus*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species winters in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

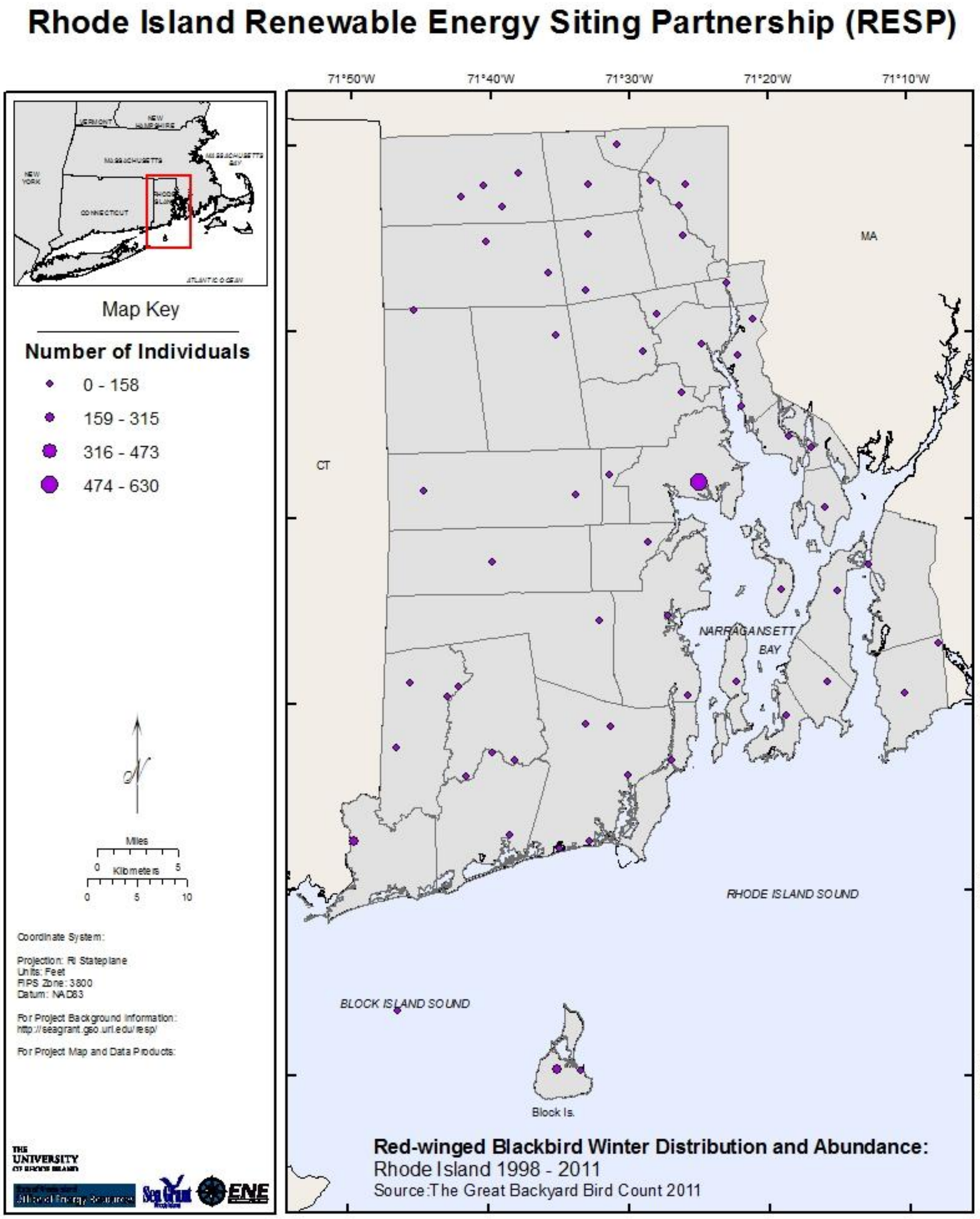


Figure A3.68. Distribution and abundance of **Red-winged Blackbird (*Agelaius phoeniceus*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species nests and winters in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

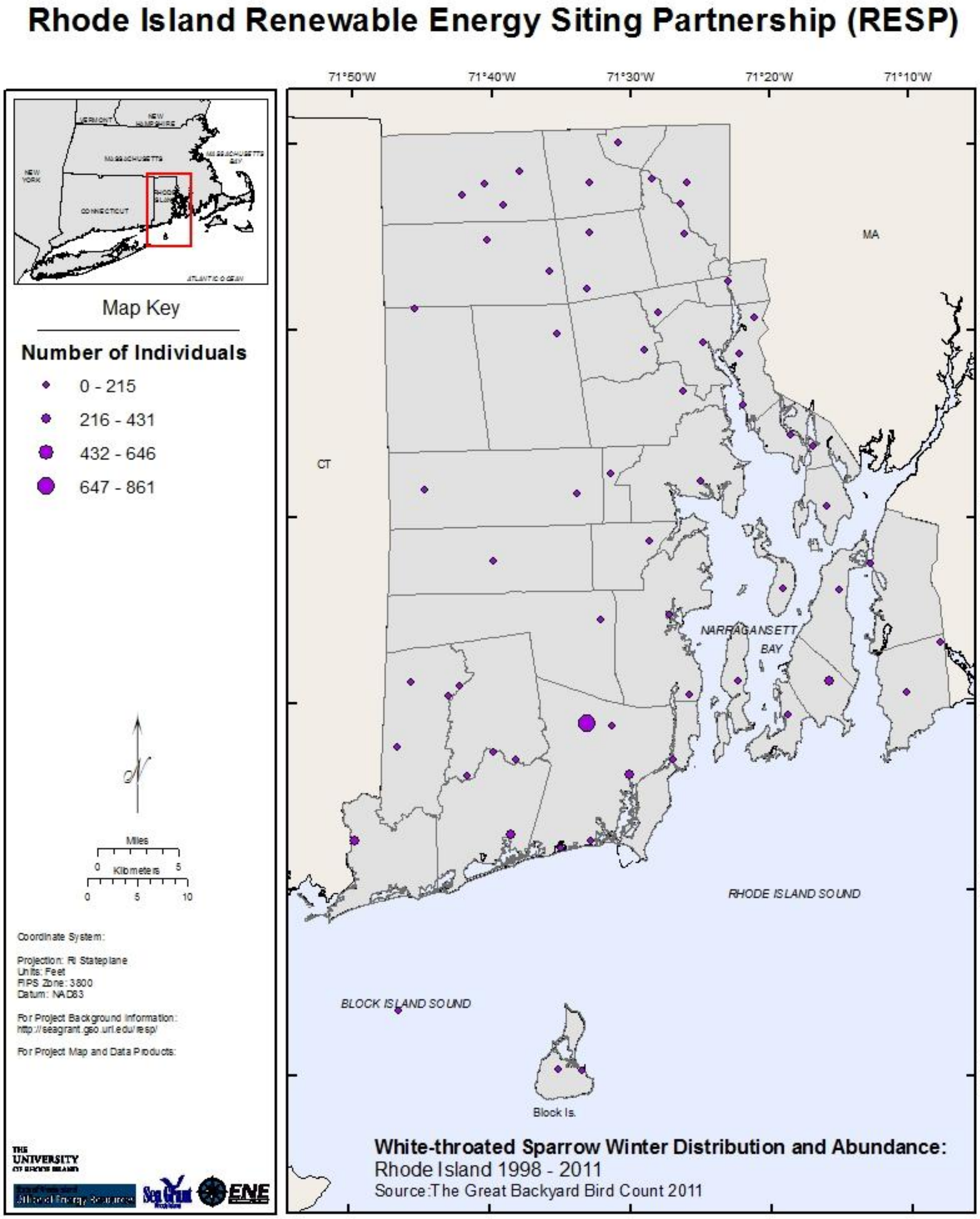


Figure A3.69. Distribution and abundance of **White-throated Sparrow (*Zonotrichia albicollis*)** in Rhode Island from 1998 - 2011 based on surveys conducted annually in February for The Great Backyard Bird Count (2011). This species winters in Rhode Island and is significantly declining based on the USGS Breeding Bird Survey.

APPENDIX 4. PRE- AND POST-CONSTRUCTION BIRD AND BAT MONITORING GUIDE

4.1 Pre-construction studies

Pre-construction site assessments are important in understanding the current bird and bat populations and behaviors at the potential site of the wind facility. Establishing the presence of critical habitat and species of concern will allow appropriate mitigation and avoidance when constructing a wind facility. Table A4.1 summarizes the recommended search parameters. Developers should work with the USFWS, RI DEM and other agencies to develop a rigorous study design following USFWS (2012) guidelines.

4.1.1 Species searches

Determining the abundance and distribution of birds and bats at a potential wind facility site can be done in many ways, including point count surveys, transects, hawk watch surveys, spot mapping, raptor nest surveys, lek surveys, radio telemetry, and radar studies. Methods vary in each survey technique, and the most appropriate method will vary based on site specifications and species present.

4.1.2 Habitat Assessments

In addition to species searches, habitat mapping will give researchers an idea of potentially suitable habitat for species of concern. Irreplaceable and essential habitats should be identified and avoided. When avoidance is not possible, habitat mitigation is a possible alternative.

4.2 Post-construction studies

Post-construction monitoring studies are important in understanding the effect of turbines on bird and bat fatalities and behavior changes in response to turbine installation. The monitoring effort may vary based on site sensitivity, risk level, amount of data available on post-construction surveys of similar wind facilities nearby, and the level of risk estimated for the species in question (Strickland et al. 2011). In general, two years of surveys are suggested for post-construction studies; however, if the risk level is especially high, three or more years might be needed, and if the risk level is relatively low, only one year of surveys might be adequate. Searches should examine the number of bird and bat fatalities at the wind facility, how this fatality rate compares to predicted rates as well as average bird and bat fatalities at similar sites, and how the fatality rates for individual species may affect overall populations and species viability. Table A4.1 summarizes the recommended search parameters.

4.2.1 Fatality searches

Estimates of fatalities at a wind facility can be expressed in a variety of ways. In the literature, fatality rates are expressed as fatalities per turbine, megawatt, or rotor-swept area per year. Calculating fatality rates using all of these metrics would be helpful when comparing with other studies.

4.2.2 Search specifications

Based on carcass studies, 80% of bats fall within half of the maximum distance of turbine height to ground (Strickland et al. 2011, Erickson et al. 2003). To ensure the appropriate area is searched for bird carcasses, it is recommended that the radius of the search plot equal the distance from the ground to the highest point on the rotor swept area (Strickland et al. 2003). If the entire area cannot be searched, a subsection of the searchable area can be delineated and surveyed, and the fatality estimates can be adjusted to reflect the entire searchable area. In addition, the vegetation within the searchable area may vary from easy to search (bare ground and sparse vegetation) to very difficult (little or no bare ground and more than 25% of vegetation over 12 inches in height) (Strickland et al. 2011). Surveying in all vegetation types is important when determining fatality estimates.

The amount of time spent searching each plot depends on plot size, search method, number of searchers, and ground cover. When the vegetation is thicker, more time is generally needed to search for carcasses (Strickland et al. 2011), and biases associated with the variation in ground cover should be taken into account when calculating fatality rates.

It is recommended that 30% of turbines be searched. If fewer than 30 turbines occur in the wind facility, at least 10 turbines should be searched (Strickland et al. 2011).

In the literature, search intervals have ranged from every 1 to 90 days (Strickland et al. 2011). The recommended search interval is once every seven days; however, searches conducted every 30 days would result in fatality estimates that would likely be comparable to shorter search intervals.

4.2.3 Time of year

Ideally, surveys should be conducted year-round to determine the effect of turbines on the breeding, migrating, and wintering populations of birds and bats at the wind facility. However, many of the fatalities reported at wind facilities in the literature occur during migration season. Fall migration occurs from August – October in Rhode Island, and spring migration is April – June. These windows of time are especially important when considering when to conduct carcass searches.

4.2.4 Search Protocol

A common carcass survey method is conducting searches along transects delineated in the search area. Typically, date, time, weather and observer are recorded at the start of each survey. Observers walk transects, marking carcasses with a flag. At the end of the survey, observers return to the carcasses and record specific details about each carcass (i.e. species, sex, age, distance from turbine, turbine number, habitat, condition of carcass, and estimated date of death (if determinable). Following carcass searches, biases should be accounted for by conducting carcass removal, searcher efficiency, and field bias studies.

4.2.5 Carcass removal rate and searcher efficiency estimates

Estimating fatalities based just on carcasses found around each turbine often results in an underestimation of the actual number of collisions, due to both searcher inefficiency, variation in vegetation, and predators. It is recommended that, in addition to fatality searches, carcass removal and searcher efficiency studies be conducted and fatality rates be adjusted to decrease any biases. Searcher efficiency trials are done by placing carcasses in known, random locations, and having other observers conduct transect surveys to determine the percentage of known carcasses found. Similarly, for carcass removal studies, carcasses are placed in known locations, and these locations are visited at an established time interval to determine if the carcass is still onsite or if it has been scavenged. These rates should be determined for small, medium and large birds as well as bats. Strickland et al. (2011) recommend using a minimum of 50 specimens for each size class of birds as well as bats and habitat type to determine these bias correction factors. Variation around these searches can help determine confidence intervals for fatality estimates.

4.2.6 Other survey methods

In addition to carcass surveys, radar, acoustic surveys and thermal imaging surveys can be conducted to get a clearer picture of the diurnal and annual distribution and abundances of birds and bats. Various approaches have been used, and interested parties should consult recent literature to obtain the most up-to-date methods.

Table A4.1 Survey recommendations for pre-and post-construction monitoring in Rhode Island.

Search Parameter	Recommendation
Length of surveys	1-3 years
Area searched	Plot radius = height of turbine
No turbines	30% of turbines (or all if fewer than 10 turbines)
Search interval	Every 7 days
Time of year	Year round
Search method	Transect
Carcass removal	50 carcasses per size class and vegetation type
Searcher efficiency	50 carcasses per size class and vegetation type

APPENDIX 5. SUMMARY OF MANAGEMENT RECOMMENDATIONS

Based on our review of state and federal guidelines for siting wind turbines, we suggest that developers in siting renewable energy projects in Rhode Island follow USFWS guidelines (2011). Below is a shortened list of Tiered recommendations for Rhode Island. In each Tier, if species of concern or habitats are deemed vulnerable or at risk to the proposed or installed wind facility, alternate locations or mitigation techniques should be considered at the site.

Tier 1: Preliminary evaluation or screening of potential sites

- Determine areas that are inappropriate for wind energy development based on the risks to wildlife and their habitats, working with the USFWS, RI DEM, and local conservation entities.

Tier 2: Site characterization

- Narrow site search and conduct initial field-based evaluations of site suitability for species and critical habitats (coastal ponds, grasslands and scrub-shrub habitats).

Tier 3: Pre-Construction monitoring and assessments

- Scientifically rigorous and quantitative evaluations of species' distribution, site use and behavior, and potential risks to local and migration populations at the facility location.

Tier 4: Post-construction monitoring of effects

- Carcasses searches, searcher efficiency and carcass removal studies should conducted for a minimum of one year following construction of the turbine.
- Fatality patterns should be examined to determine if certain factors (wind facility specifications, season or weather), are contributing to higher rates of mortality than others.

Tier 5: Research

- Design experiments and research projects to address any issues that arise related to bird and bat fatalities and the operation of the wind facility.

Table A5.1. Summary of voluntary buffer distances that wind turbines should be located from the nests of sensitive species of birds and sensitive habitats in Rhode Island.

Species	Buffer
Bald Eagle	1 mile
Pied-billed Grebe, American Bittern, Least Bittern, Piping Plover, Least Tern, Roseate Tern, Coastal ponds, Wading/shore birds	1000m
Great Blue Heron, Osprey, Peregrine Falcon, American Oystercatcher	500m
Northern Harrier, Upland Sandpiper, Barn Owl, Yellow-breasted Chat, Grasshopper Sparrow, Conservation Areas, Grassland birds, Scrub-shrub birds	100m

RESP TECHNICAL REPORT #6

ACOUSTIC EFFECTS OF WIND FARMS

By

Gopu R Potty and James H. Miller

Department of Ocean Engineering

University of Rhode Island,

Narragansett Bay Campus

June 19, 2012

Table of Contents

List of Figures

List of Tables

Executive Summary

Land based wind turbines are a relatively new source of community noise and characterization and regulation of this new noise source is an ongoing research issue. Developing the correct metric to quantify the effect of noise on communities is a difficult task. The response of this noise source at any particular site will also depend on the ambient noise levels. Another factor that has to be considered is the type of land use around the turbine. The effect of the noise produced by the wind turbine will differ depending on whether the neighborhood consists of residential, commercial, industrial or public (school, hospital etc.) areas. The propagation of sound is also affected by other factors such as wind and temperature profile. Some of these aspects of community response to land based wind turbine noise and development of simple and effective guidelines to regulate the noise are discussed in this report.

The basic terminology and definitions associated with sound and noise such as decibel levels, weighted levels (A, C and G weighting) and time averaged levels such as equivalent sound levels are introduced in the report. Different averaging times may be appropriate for different situations. For example, if one is interested in characterizing the noise in a school or a factory environment a daytime averaging (L_d) will be appropriate. If sleep disturbance in a residential location is the main concern, a night time averaging (L_n) may be used as the metric. To characterize the ambient noise quantities a metric such as L_{90} may be appropriate.

Modeling of acoustic propagation around a wind turbine is discussed in some detail in the report. The reduction in level as sound from wind turbine propagates in range is mainly due to geometrical divergence and attenuation effects. Different mechanisms contribute toward the attenuation such as atmospheric absorption, ground effects, presence of foliage, buildings and barriers. A model to estimate these losses and thereby predict the sound levels around a wind turbine is implemented as part of this study based on the guidelines provided by ISO 9613-2 (1996). One of the inputs to this model is the characterization of the sound produced by the wind turbine (sound power level). Usually the sound power level for a given wind turbine is estimated based on careful measurements at different wind conditions. The standard procedure for the measurement of the sound power level is provided in IEC 61400-11, 2nd edition and some of the key measurement procedures from that report are also discussed. The model output for a turbine similar to an existing one is also compared to some field measurements.

An extensive review of existing wind noise guidelines was conducted as part of the study which is also summarized in this report. Based on that review and considering the fact that most of the wind resources in our state are in close proximity to our shore line (densely populated) we have developed some guidelines for wind turbine noise based on the ambient noise levels.

1. INTRODUCTION

Wind turbines, when they are operating, produce various types of sounds which propagate into the neighboring region. If the level of sound is high, that may result in environmental noise issues. Depending on the type of the neighborhood, frequency and level of sound, time of the day and the sound propagation conditions (favorable vs unfavorable) the actual sound perceived at any location and the resulting reaction to it can vary. A brief review of the noise related issues associated with wind turbines are provided in this document. A summary of the acoustic terminology and basic definitions are provided in Section 2. This is followed in Section 3 by a discussion of community noise, its effects and various regulations associated with it. Various mechanisms which produce sound in wind turbines and some of the noise reduction strategies are introduced next. A review of the various regulations are summarized in section 5 followed by our recommendations which can be used by communities to develop their own guidelines in Section 6. Some special scenarios which can be favorable or unfavorable to acoustic propagation are discussed in Section 7. Section 8 presents the data collected near an operating wind turbine. The details of the noise model developed as part of this study are described in Section 9 followed by the conclusions of the study in Section 10.

2. SOUND AND NOISE

Sound is associated with small scale perturbations in ambient pressure which produces sensations in the human ear. Acoustic waves are characterized by a magnitude and a frequency. Sound waves travel in air with a speed of 340 m/s at standard pressure. Unwanted sound is perceived as noise. The perception of sound as a noise depends on many factors including the amplitude and duration of the sound. There are numerous physical quantities that have been defined which enable sounds to be compared and classified, and which also give indications for the human perception of sound. Various metrics associated with sound are reviewed in this section. Intensity of the acoustic wave is the average amount of sound power transmitted through a unit area in a specified direction. The unit of intensity is watts per square meter (W/m^2). The decibel (dB) measure of sound (sound Intensity Level or IL) is expressed as a logarithmic comparison of intensities.

$$\text{Sound Intensity Level (IL)} = 10\log_{10}\left\{\frac{\text{Acoustic Intensity}}{\text{Reference Intensity}}\right\} \qquad (1)$$

The reference intensity in air is 1x10^{-12} W/m^2 which corresponds to the threshold of hearing. In terms of acoustic pressure, the Sound Pressure Levels (SPL) can be defined as;

$$\text{Sound Pressure Level (SPL or } L_p) = 20\log_{10}\left\{\frac{\text{Acoustic Pressure}}{\text{Reference Pressure}}\right\} \qquad (2)$$

The reference pressure in air is 20 μPa which corresponds to an intensity of 1x10^{-12} W/m^2.

Equivalent continuous sound level (Leq): The equivalent continuous sound level (Leq), over some time interval T, is the level of the steady continuous noise that contains the same sound energy as the noise under consideration whose level varies with time. The Leq is used when it is important to consider variations in sound pressure levels over time. It can be calculated using the formula (Equation 3) given below:

$$L_{eq} = 10\log\left[\frac{1}{T}\int_0^T \frac{p^2}{p_{ref}^2}\,dt\right] \qquad (3)$$

$$\text{where}$$
$$\text{T} = \text{time interval}$$
$$\text{p} = \text{Sound Pressure (Pa)}$$
$$\text{p}_{ref} = \text{Reference sound pressure} (20\ \mu\text{Pa})$$

For example, consider hourly averaged sound level for community noise as given below:

1. 60 dBA from 7 A.M to 7 P.M.
2. 55 dBA from 7 P.M to 10 P.M.
3. 50 dBA from 10 P.M to 7 A.M

The L_{eq} for the 24 hour duration can be calculated using the Equation 3 or the equivalent expression given below:

$$L_{eq} = 10\log_{10}\left\{\frac{1}{T}\sum_{i=1}^{n} t_i\, 10^{\left(L_i/10\right)}\right\} \qquad (4)$$

Where:
T = Time duration (=24 hours in the example)
t_i = duration of individual measurements (=12, 3 and 9 hours for the three measurements)
L_i = Sound Pressure Level (dBA) corresponding to the t_i durations (= 60, 55 and 50 dBA)
Using equation 4, the Leq can then be calculated as:

$$L_{eq} = 10\log\left[\frac{1}{T}\left(t_1\,10^{0.1L_1} + t_2\,10^{0.1L_2} + t_3\,10^{0.1L_3}\right)\right] \qquad (5)$$

Substituting the values of Sound Pressure Levels and durations the value of Leq can be evaluated using Equation 5 as 57.6 dBA.

Adding decibel levels:

When finding the combined effect of multiple sound sources, we need to convert the decibel levels to corresponding intensities before adding them. An easier option will be to use the nomogram shown in Figure 1. For example, if we have two turbines producing sound levels 50 dB and 55 dB respectively (difference in levels equal to 5 dB), the combined effect of the two turbines will produce 56.2 dB at a particular location. Two turbines of equal levels (difference equal to 0) produce 3 dB more than one turbine assuming the listener is equidistant to each turbine.

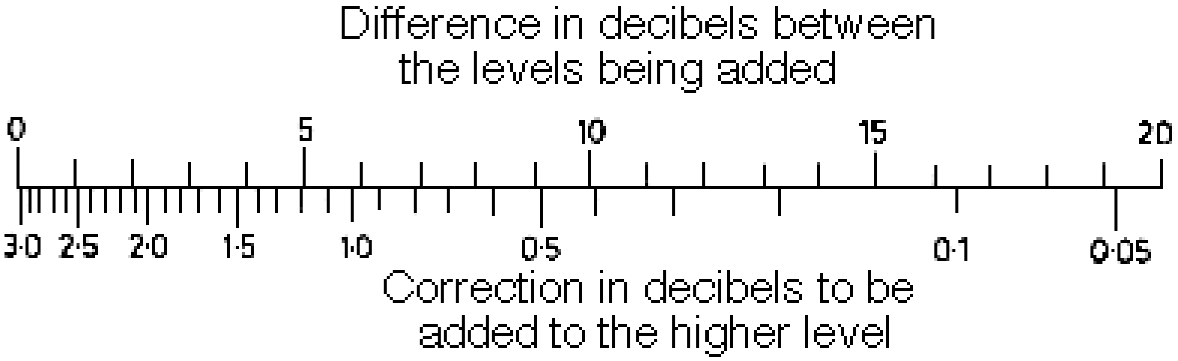


Figure 1. Nomogram for adding decibels

Source Level (SL) and Transmission Loss (TL)

The strength of an acoustic source is specified through its source level in dB re: 20 µPa at 1m which is defined as;

$$\text{Source Level (SL)} = 20\log\left[\frac{p_e}{p_{ref}}\right] \qquad (6)$$

Where p_e is the effective (root mean square) pressure measured at 1 m and p_{ref} is the reference pressure in air is 20 µPa.

Source Level is rarely used to define the power radiated by a wind turbine. Instead Sound Power Level (PWL or L_w) is the metric which is used to characterize the acoustic radiation from a wind turbine. The L_w is usually measured based on sound pressure measurements at a reference distance from the wind turbine. These measurements must be made as described in IEC 61400-11, 2nd edition. The details of the sound power level measurements are discussed in more detail in Section 4c.

The sound pressure at any distance away from the source will depend on the losses encountered during propagation from source to the receiver. Transmission Loss (TL), also known as propagation loss, describes the weakening of sound between a point 1 meter from the source and a point at a distance r meters. It is defined as the ratio of intensity at any range 'r' to intensity at 1 m.

$$\mathrm{TL} = -10\log_{10}\frac{\text{Intensity at r m}}{\text{Intensity at 1 m}} \qquad (7)$$

When the transmission loss can be calculated, the sound pressure level at any location can be expressed as follows;

$$\mathrm{SPL}\ (\text{or } L_p) = \mathrm{SL} - \mathrm{TL} \qquad (8)$$

Where SPL is the Sound Pressure Level at the receiver location, SL is the Source Level and TL is the Transmission Loss.

The total TL consists of the following components:

- Geometrical spreading
- Absorption
- Scattering: volumetric scattering, turbulence, ground cover, trees, structures
- Atmospheric effects and refraction, diffraction, and reflection
- Shielding by natural and manmade features, noise barriers.

Geometrical spreading is due to weakening of the acoustic intensity due to spreading, either spherically or cylindrically. Sound from a **small localized source** (approximating a "point" source) radiates uniformly outward, as it travels away from the source, in a spherical pattern. The sound level attenuates or drops-off at a rate of 6 dBA for each doubling of the distance (Alberts, 2006). For estimation purposes, a simple model based on the more conservative assumption of hemi-spherical sound propagation will give the spreading loss at a distance R from the source as

$$TL_{geom} = -10\log_{10}\left(2\pi R^2\right) \qquad (9)$$

Where $2\pi R^2$ is the curved surface area of a hemisphere, assuming the acoustic waves propagate in a hemispherical manner (with radius R). Sound pressure level (Lp) at a distance R meters from the source with power Lw can be calculated using a simple model assuming hemispherical propagation as follows,

$$L_p = L_w - 10\log_{10}\left(\frac{2\pi R^2}{R_0^2}\right) - \alpha R \qquad (10)$$

Where α is the frequency dependent absorption coefficient and $R_0 = 1$ m. Atmospheric absorption (α) is a function of temperature, humidity, and frequency. R is the slant distance from the hub of the turbine to the receiver. This assumes that most of the energy is emitted close to the hub which is not entirely realistic as blade noise is produced at the outer part of the blades.

Makarewicz (2011) showed that the error introduced by the point source assumption for wind turbine will be less than 1 dB provided the horizontal distance between the wind turbine and the receiver is greater than twice the blade length.

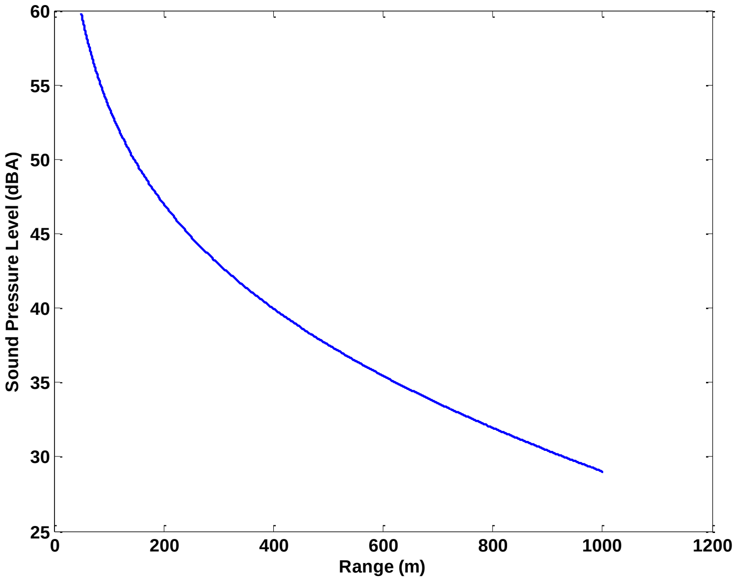


Figure 2. Sound Pressure Level vs range calculated for a 50 m hub height wind turbine with a source level of 102 dBA.

Figure 2 shows the SPL calculated using the above equation for a wind turbine with a 50 m hub height and a source level of 102 dBA. The atmospheric absorption was assumed as 0.005 dBA/m. The receiver in this case was assumed at ground level. It should be noted that this is a very simplified calculation the actual scenario required more detailed modeling of acoustic propagation.

3. ENVIRONMENTAL ACOUSTICS

The effect of noise on human emotions range from negligible, annoyance, and anger to psychologically disruptive (Kinsler et al., 2000). Physiologically, the effect of noise can range from harmless to painful and physically damaging. Noise can also have an economic impact by affecting worker efficiency, decreasing property values, etc. The development of noise rating procedures and criteria is complicated by the variety of spectra and time histories associated with noise and the variability of psychological and physiological responses not only among people but for the same person at different times (Kinsler et al., 2000). Because of the variability associated with environmental noise, developing a criterion acceptable to a community is very difficult. Often no single number measure will satisfy all situations and conditions. However there seems to be a general consensus that A-weighted sound level is an acceptable measure of the impact of many commonly occurring noise environments (Kinsler et al., 2000). The various rating systems based on A-weighting differ mainly in how the time variation of the level is taken into account.

Examples of rating procedures that use the statistical behavior of the A-weighted sound level are the day-night averaged sound level (L_{dn}), and the community noise equivalent level (CNEL).

Weighted sound levels

Humans can hear sounds at frequencies from about 20 Hz to 20,000 Hz, though we hear sounds best at around 3,000 to 4,000 Hz where human speech is centered (http://www.dosits.org/). Loudness describes how people perceive sound. The softest sounds that people can hear at a frequency of 1000 Hertz have a measured sound intensity of approximately 0 decibels relative to the intensity of a sound wave with a pressure of 20 micro Pascals (dB re 20 µPa). Figure 3 is an equal loudness curve. It shows the relative intensity in decibels referenced to 20 µPa as a function of frequency. The contour lines are lines of equal perceived loudness for sounds at different frequencies. For example, a sound at a frequency of 30 Hz and a measured relative intensity of 80 dB re 20µPa -- the purple dot -- has the same perceived loudness as a sound at a frequency of 1000 Hz and a measured relative intensity of about 30 dB re 20µPa -- the red dot. If people could hear equally well at all frequencies, the contour lines would be flat because the same measured sound intensity would be perceived to be equally loud regardless of the sound frequency. In fact, people do not hear as well at low frequencies. Therefore, the relative sound intensity has to be much greater for a low frequency sound to be perceived to be as loud as a sound at a frequency that we hear well, such as 1000 Hertz. The bottom red line is the human hearing threshold. We would not hear sounds that are below the threshold of hearing level at each frequency.

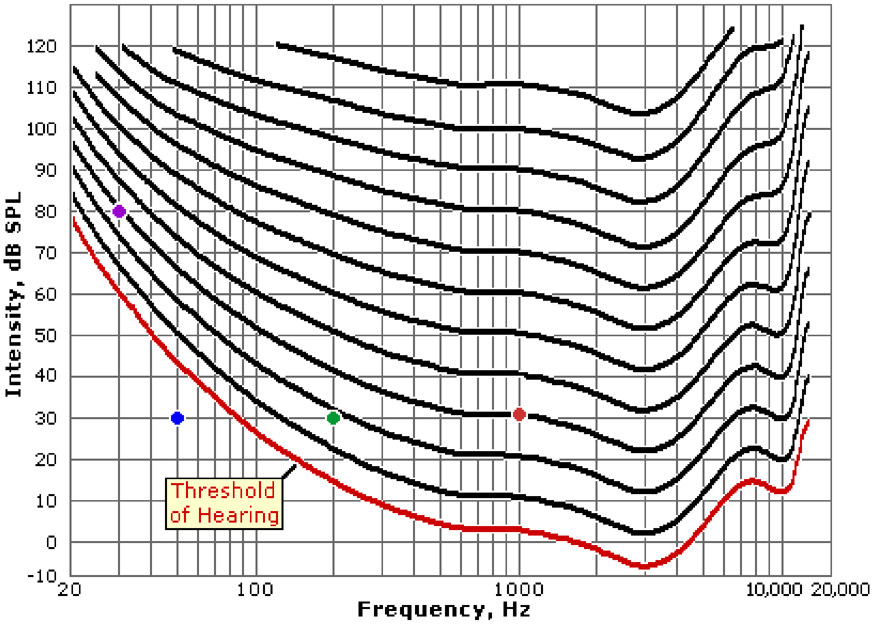


Figure 3. Equal loudness curve (from http://www.dosits.org/science/soundmeasurement/soundshear/).

One of the most widely used measure of environmental noise is the **A**-weighted sound level (L_A) expressed in dBA. The **A** weighting assigns a weight to each frequency, which is related to the hearing sensitivity of the ear at that frequency. So low frequencies will have a lower weight since the hearing sensitivity is lower at those frequencies whereas the best hearing frequencies will be weighted more. Thus the A-weighting scale replicates this filtering process of the human ear. The C-weighting scale, on the other hand, is quite flat, and therefore includes much more of the low-frequency range of sounds than the A weighting scale. It is good predictor of the ear's sensitivity to sound at high levels. C weighting, together with A weighted measurements, can be used to assess the presence of low frequencies in an acoustic signal. The G weighing is particularly designed for infrasound (frequencies less than audible range). It has a gain of 0 dB at 10 Hz, falls of quickly above 20 Hz with a rate of 24 dB per octave. Between 1 Hz and 20 Hz the G weighting curve can be approximated as a straight line with a slope of 12 dB per octave. Figure 3 shows the filter characteristics of **A**, C and **G** weighted sound levels.

A and **C** weighted levels can be obtained from the octave band levels by adding the corrections shown in Table 1 to each band level and then combining the band levels. Table 2 shows A weighted levels of some of the commonly encountered noises.

Measurement of both **A** and **C** weighted levels will yield some information about the relative strengths of various frequency components. **G** weighting is the appropriate measure if low frequency content is significant. **G**-weighting emphasizes the higher infrasound frequencies (10-20 Hz) and cut out frequency components lower and higher than this.

Table 1. Corrections to be added to octave-band levels to convert to A and C weighted band levels.

Center Frequency (Hz)	Correction (dB) A weighting	Correction (dB) C weighting
31.5	-39.4	-3.0
63	-26.2	-0.8
125	-16.1	-0.2
250	-8.6	0
500	-3.2	0
1000	0	0
2000	+1.2	-0.2
4000	+1.0	-0.8
8000	-1.1	-3.0

Table 2. A weighted sound levels of some commonly encountered noises (Kinsler et al, 2000 and Stankovic et al., 2009, Gipe, 1995).

A weighted sound level (dBA)	Source of Noise
140	Threshold of pain
110-120	Night club, rock-n-roll band
100-110	Jet flyby at 300 m
90-100	Power mower, cockpit of light aircraft
80-90	Heavy truck at 64 km/h at 15 m, food blender, motorcycle at 15 m
70-80	Car at 100 km/h at 7.6 m, clothes washer, TV audio,
60-70	Vacuum cleaner, air conditioner at 6m
70	30 m from Freeway
50-60	Light traffic at 30 m
60	Busy office
40-50	Quiet residential – daytime
30-50	Quiet residential – nighttime
50	Normal speech at 5 m
20-40	Rural night time background
20-30	Wilderness area

In summary,

- A-weighting is approximates the human frequency response to commonly encountered sounds.
- C-weighted allows more low frequency sound compared to A-weighting and used when high intensity sound such as blast and gunshot.
- G- weighting gives a measure of the infrasound (less than 20 Hz) components.

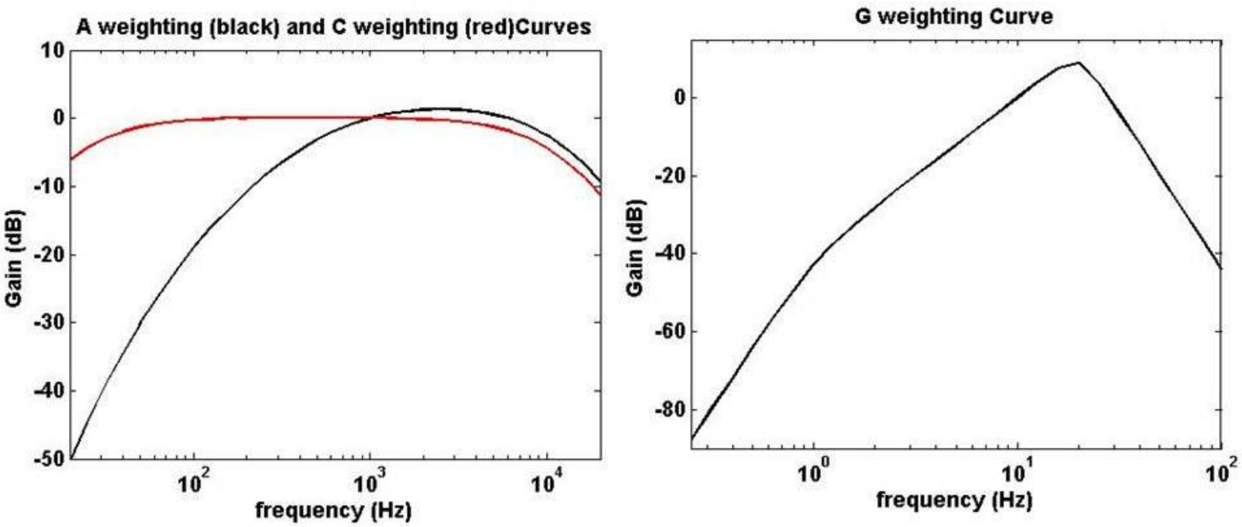


Figure 4. A, C and G weighting curves.

The measure of the environmental impact of noise should depend on the total energy received, the rate of occurrence of noise events, and the magnitudes of noisier single events (Kinsler et al., 2000). Following are some of the **A** weighted quantities used in measuring the effects of environmental noise (Kinsler et al., 2000):

1. Equivalent continuous sound level (L_{eq}): The steady state sound that has the same A weighted level as that of the time-varying sound averaged in energy over the specified time interval. Leq was discussed in more detail earlier in Section 2.
2. Daytime average sound level (L_d): The Leq calculated from 7 A.M to 7 P.M.
3. Evening average sound level (L_e): The Leq calculated from 7 P.M to 10 P.M.
4. Night average sound level (L_n): The Leq calculated from 10 P.M to 7 A.M.
5. Hourly average sound level (L_h): The Leq calculated for any one hour period.
6. Day – night averages sound level (L_{dn}): The 24 hour Leq obtained by adding 10 dBA to the sound levels from 10 PM to 7 AM.
7. x-percentile exceeded sound level (Lx): A weighted sound level equaled or exceeded x% of the sample time. Most commonly used measures of this type are L_{10}, L_{50} and L_{90} (the levels exceeded 10%, 50% and 90% of the time respectively).
8. Community noise equivalent level (CNEL): The 24 hour Leq obtained after the addition of 5dBA to the sound levels from 7 P.M to 10 P.M and 10 dBA to the levels from 10 P.M to 7 A.M.

Let us consider the example that we considered in Section 2. The community noise levels considered (L_1, L_2, and L_3) in that example were 60 dBA (7 A.M to 7 P. M), 55 dBA (7 P.M to 10 P. M) and 50 dBA (10 P.M to 7 A. M). The day – night averages sound level (L_{dn}) can be calculated as:

$$L_{dn} = 10\log\left[\frac{1}{T}\left(t_1\,10^{0.1L_1} + t_2\,10^{0.1L_2} + t_3\,10^{0.1(L_3+10)}\right)\right] = 59.6\,\text{dBA}$$

The Community noise equivalent level (CNEL) can also be calculated as:

$$L_{dn} = 10\log\left[\frac{1}{T}\left(t_1\,10^{0.1L_1} + t_2\,10^{0.1(L_2+5)} + t_3\,10^{0.1(L_3+10)}\right)\right] = 60\,\text{dBA}$$

Community Noise Standards (EPA and Municipalities)

US Environmental Protection Agency (EPA) recommends L_{dn} less than or equal to 55 dBA outdoors and 45 dBA indoors. Different communities have their own noise ordinances and an example for Gainesville, Florida is shown in Table 3 (Kinsler et al., 2000).

Table 3. Maximum Allowable Noise Levels for Gainesville, FL (from Kinsler et al., 2000).

	Noise Level limits (dBA)	
Location	Day	Night
Residential	61	55
Commercial	66	60
Manufacturing	71	65

The community noise standard for some of the European countries are shown in Table 4 (from Gipe, 1995).

Table 4. European community noise standards: Numbers are equivalent sound pressure levels in dBA.

Country	Commercial	Mixed	Residential	Rural
Denmark			40	45
Germany				
Day	65	60	55	50
Night	50	45	40	35
Netherlands				
Day		50	45	40
Night		40	35	30

Community Response to Noise

Predicting the community response to noise is a very difficult task since response to noise varies from person to person. Any attempt to quantify the response will depend on the subjective judgment of the investigator. One approach to quantifying community response to noise is to add corrections to the A-weighted sound level based on the characteristics of the noise sources and then compare the corrected dBA to a scale of expected reaction (Kinsler, 2000). Table 5 shows the corrections which need to be added to the **A** weighted sound level to produce a measure of community reaction. If the corrected level is less than 45 dBA, no community reaction is to be expected; if it is between 45 and 55 dBA, sporadic complaints are to be expected. When the corrected dBA is between 55 dBA and 65 dBA we can expect widespread complaints and threats of community action. Above 65 dBA vigorous community action is certain (Kinsler et al., 2000). It can be seen that presence of pure tone is a trigger for negative community reaction and it is penalized by 5 dBA in Table 5. So if the corrected pure tone level exceeds 45 dBA some kind of community reaction has to be expected. It can be noted that a similar pure tone penalty is imposed in many wind noise regulations.

Fidell et. al., (1991) has developed a model, based on surveys of community response to transportation related noise, relating the outdoor L_{dn} within a community to the percent of the people highly annoyed.

$$\text{Percent highly annoyed} = 0.036L_{dn}^2 - 3.27\mathrm{L}_{\mathrm{dn}} + 79 \qquad (11)$$

This relationship has an uncertainty of about 5 dBA for L_{dn} between 45 and 85 dBA. This relationship was developed based on community response surveys to transportation noise. It is speculated that this may be applicable to other kinds of community noise as well. This relationship is plotted in Figure 5 showing the percentage of people annoyed at various sound levels (L_{dn}).

Table 5. Corrections to be added to the A weighted sound level to produce a measure of community reaction.

Noise Characteristics	**Correction in dBA**
Pure tone present	+5
Intermittent or impulsive	+5
Noise only during work hours	-5
Total duration of noise each day	
Continuous	0
Less than 30 minutes	-5
Less than 10 minutes	-10
Less than 5 nimutes	-15
Less than 1 minute	-20
Less than 15 seconds	-25
Neighborhood	
Quiet suburban	+5
Suburban	0
Residential Urban	-5
Urban near some industry	-10
Heavy industry	-15

There have been some studies, based on surveys around wind farm developments, done in Europe in the past and two such studies undertaken in the Netherlands and Sweden are summarized here. A study done in Netherlands (Pedersen et. al., 2009) reported that wind turbine noise was more annoying than other types of noise at comparable levels. They also reported that one of the factors which enhance the annoyance is the visibility of the turbines. This study produced dose-response relationship for wind turbine noise and compared with other types of noise sources. The dominant quality of wind turbine noise most annoying to people was the 'swishing' nature of the sound (Pedersen et. al., 2009, Pedersen and Waye, 2004). The proportion of annoyed respondents found by the Dutch study (Pedersen et. al., 2009) was similar to that found by a previous Swedish study (Pedersen and Waye, 2004). The values predicted by the Schultz equation (Equation 11 or Figure 5) are comparable to the "percentage of very annoyed" in the Swedish and Dutch studies. It should be noted that the "percentage of people annoyed" in the Swedish and Dutch studies is much higher than the Schultz predictions.

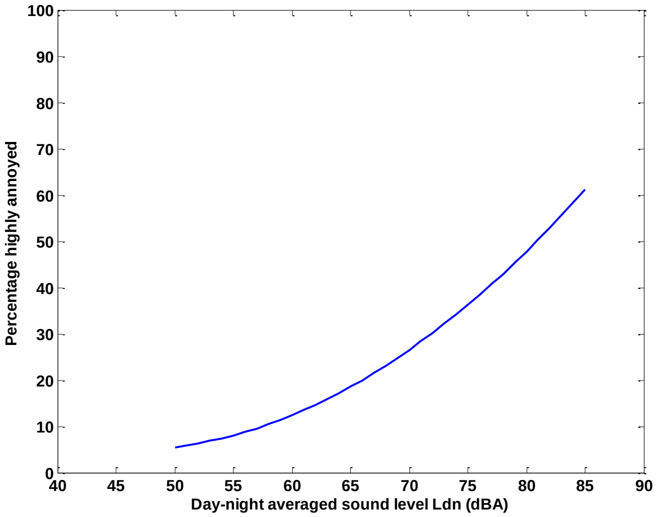


Figure 5. Estimate of the extent of the public annoyance caused by transportation noise based on day-night average sound pressure level.

4. WIND TURBINE SOURCE CHARACTERISTICS

There are four types of sound that can be generated by wind turbine operation: tonal, broadband, low frequency, and impulsive (Rogers, 2006):

- ***Tonal***: Sound defined at discrete frequencies. It is caused by components such as meshing gears, non-aerodynamic instabilities interacting with a rotor blade surface, or unstable flows over holes or slits or a blunt trailing edge.
- ***Broadband:*** Sound characterized by a continuous distribution of sound pressure with frequencies greater than 100 Hz. It is often caused by the interaction of wind turbine blades with atmospheric turbulence, and also described as a characteristic "swishing" or "whooshing" sound.
- ***Low frequency***: Sound with frequencies in the range of 20 to 200 Hz. It is mostly associated with downwind rotors (turbines with the rotor on the downwind side of the tower). It is caused when the turbine blade encounters localized flow deficiencies due to the flow around a tower.
- ***Impulsive***: Sound described by short acoustic impulses or thumping sounds that vary in amplitude with time. It is caused by the interaction of wind turbine blades with disturbed air flow around the tower of a downwind machine.

The sources of sounds emitted from operating wind turbines can be divided into two major categories:

i. ***Mechanical Sounds***, from the interaction of turbine components: Sources of such sounds include (Rogers, 2006):

  - Gearbox
  - Generator
  - Yaw Drives
  - Cooling Fans
  - Auxiliary Equipment (e.g., hydraulics)

Since the emitted sound is associated with the rotation of mechanical and electrical equipment, it tends to be tonal (of a common frequency), although it may have a broadband component as well. For example, pure tones can be emitted at the rotational frequencies of shafts and generators, and the meshing frequencies of the gears.

ii. ***Aerodynamic sounds***, produced by the flow of air over the blades: Aerodynamic noise can be divided into airfoil self-noise and turbulence inflow noise. The former is a result of the interaction of the boundary layer of the airfoil with the trailing edge and the latter results from the interaction of the existing turbulence in the wind with the airfoil. Aerodynamic noise radiated from horizontal axis wind turbines consists of either broadband noise components or a superposition of broadband and discrete frequency rotational harmonic components. The rotational harmonic (impulsive) components arise mainly from tower-wake blade interactions and from inflow velocity gradients. The broadband components are related to inflow turbulence ingestion, turbulent boundary layer-trailing edge interactions and blade trailing edge wakes (Rogers, 2006).

Low frequency Sound

As wind turbines get larger and larger, concerns have emerged that the noise emitted by the turbines would consequently move down in frequency and that the content of low-frequency and infrasonic noise would increase and reach a level, where it may be annoying for the neighbors occurs (Møller and Pedersen, 2011, Kamperman and James, 2008). However, the scientific literature on infrasonic and low-frequency noise from large wind turbines is very limited. The lower frequency limit of human hearing is around 20 Hz, and the terms infrasound and infrasonic refer to frequencies below this level. The frequency range 20–200 Hz denotes the low frequency range. Below 20 Hz, the tonal sensation disappears, the sound becomes discontinuous in character, and a sensation of pressure at the eardrums occurs (Møller and Pedersen, 2011). There is no reliable evidence of physiological or psychological effects from infrasound or low-frequency sound below the hearing threshold. Infrasound is measured with the **G**-weighting curve, which covers the frequency range 1–20 Hz. At the normal hearing threshold for pure tones, the **G**-weighted level is in the order of 95–100 dB. **G**-weighted sound pressure levels below 90 dB or 85 dB are normally not considered to be detectable by humans (Turnbull and Turner, 2011).

Due to the difference in height above ground, atmospheric turbulence, and the presence of the turbine tower the turbine blades may experience differences in wind speed and density as it rotate. The passage of the blades through areas of varying wind speed and density modulates the sound at higher frequencies with the blade-passage frequency. Because of this and due to contributions from turbine mechanics, infrasonic and low-frequency sound may be produced. For upwind turbines, the level of infrasound is much below the normal hearing threshold, even close to the turbines (Moller and Pedersen, 2011). On downwind turbines, the passage of the blades through the wake of the tower generates infrasound that may exceed the normal hearing threshold close to the turbine and possibly cause rattling of windows in the neighboring areas. Most modern turbines, but not all, are upwind turbines and hence avoid this problem.

The low-frequency noise from several of the investigated large turbines comprises tones, presumably from the gearbox, which result in peaks in the corresponding one-third-octave bands (Moller and Pedersen, 2011). ISO 1996–2 specifies a tone penalty to be used, when the tonal audibility exceeds 4 dB. National criteria for tone penalty may vary, e.g., Danish regulation requires that the tonal audibility exceed 6.5 dB, before a penalty is assessed.

Low frequency noise may be more perceptible indoors than outside. Noise reduction provided by typical houses is smaller at low frequencies compared to high frequencies (Hubbard and Shepherd, 1991). Hubbard and Shepherd (1991) also point out that depending on the measurement locations, configuration of the interior, whether the windows are open or closed, it is possible to observe higher noise levels inside the house compared to outside.

One of the ways in which we can detect the presence of low frequency noise is by making measurements in dBA and dBC units. The World Health Organization and others have determined a sound emitter's noise that results in a difference between the dBC and dBA value greater than 20 dB will be annoying low frequency issue (Kamperman and James, 2008).

The amplitude modulation of the sound from the wind turbines create a repetitive rise and fall in sound levels synchronized to the blade rotation speed of the turbine. This characteristic of wind turbine noise is suggested to increase the sleep disturbance potential compared to other long-term noise sources (Kamperman and James, 2008). Kamperman and James (2008) have reported measurements in United Kingdom showing variations of the order of 9 dBA with a repetition rate of one second. In another study, Ambrose and Rand (2011) reported similar effects at 1.4 seconds interval in Falmouth, MA. Many common weather conditions increase the magnitude of amplitude modulation. Most of these occur at night.

Noise reduction strategies

Szasz and Fuchs (2010) list some of the approaches to minimize acoustic emission from wind turbines. A summary of their suggestions are presented in this section.

i. For downwind turbines noise emission is comparatively higher since the rotor blades pass through the wake of the tower. Use of upwind turbines thus will reduce noise emission.
ii. Acoustic emission from wind turbine is proportional to the fifth power of blade speed. Reducing the turbine rotor speed with reduce the noise emission. On the flip side this will cause a reduction in power generation also.
iii. Smoother blade surface and lower blade thickness produces less noise compared to rougher and thicker blades.
iv. One of the causes for the amplification of the turbulent vortex which causes pressure fluctuations on an airfoil surface is the trailing edge noise. By carefully choosing the shape and material of the trailing edge, the noise can be minimized.

Wind turbine source level characterization using IEC standards

IEC 61400-11, 2nd edition is the standard for turbine noise measurement techniques. It is the most widely accepted measurement standard capable of producing high quality reproducible results. This standard is typically used by manufacturers to define sound power levels of turbines. The source levels specified according to this standard can be used to predict the sound levels at any receiver locations using appropriate propagation models. The relevant specifications from the IEC standard are reproduced below, which clearly highlights the type of information that will be available from the turbine manufacturer describing the acoustic characteristics of the turbine.

The acoustic measurements shall permit the following information to be determined about the noise emission from the wind turbine at the integer wind speeds ranging from 6 to 10 m/s (wind speed at 10 m height):

- apparent sound power level;
- one-third octave band levels;
- tonality.

In addition to these, other measurements such as directivity, infrasound, low-frequency noise, and impulsivity may also be reported.

A-WEIGHTED SOUND PRESSURE LEVEL

The equivalent, continuous, **A**-weighted sound pressure level of the noise from the wind turbine shall be measured at the reference position by a series of at least 30 measurements concurrent with measurements of the wind speed. Each measurement shall be integrated over a period of not less than 1 min. At least three measurements shall be within ±0.5 m/s at each integer wind speed. For the background noise at least 30 measurements in total shall be made, covering corresponding ranges of wind speed as above.

ONE-THIRD OCTAVE BAND MEASUREMENTS

The one-third octave band spectrum of the noise from the wind turbine in the reference position shall be determined as the energy average of at least three measured spectra, each measured over at least 1 min at each integer wind speed. As a minimum, one-third octave bands with center frequencies from 50 Hz to 10 kHz, inclusive, shall be measured.

CORRECTION FOR BACKGROUND NOISE

Using the methods specified in the standard, all measured sound pressure levels shall be corrected for the influence of background noise. The corrected equivalent continuous sound pressure in dB can be obtained by subtracting the equivalent continuous sound pressure of background noise (in dB) from equivalent continuous sound pressure level of the wind turbine plus background noise (in dB).

$$L_{eq}\{corrected\}dB = L_{eq}\{wind\ turbine + background\ noise\}dB - L_{eq}\{background\ noise\}dB \tag{12}$$

APPARENT SOUND POWER LEVELS

The apparent sound power level, $L_{WA,k,}$ is calculated from the background corrected sound pressure level, $L_{Aeq,c,k}$ at the integer wind speeds at the reference position using spherical spreading instead of hemi-spherical spreading in Equation 10 as follows:

$$L_{WA,k} = L_{Aeq,c,k} + 10\log\left[\frac{4\pi R_1^2}{S_0}\right] - (\text{measurement correction on the ground board})$$

where

(13) $L_{Aeq,c,k}$ is the background corrected A weighted sound pressure level at the integer wind speeds and under reference conditions

R_1 is the slant distance in meters from the rotor center to the microphone

S_0 is a reference area $(=1\,\text{m}^2)$

The additional term (measurement correction) is explained in IEC 61400-11 (2006). Based on these measurements the following acoustic data shall be reported:

• $L_{WA,k}$ at each integer wind speed from 6 to 10 m/s and a graph of background corrected normalized values.

• Table and plot of sound pressure spectrum in third octaves for each integer wind speed from 6 to 10 m/s;

5. WIND NOISE REGULATIONS

A review of some of the wind turbine noise regulations is provided in this section. Summary of representative regulations – both international and for various states in USA- are presented and discussed to highlight the similarity and differences among them.

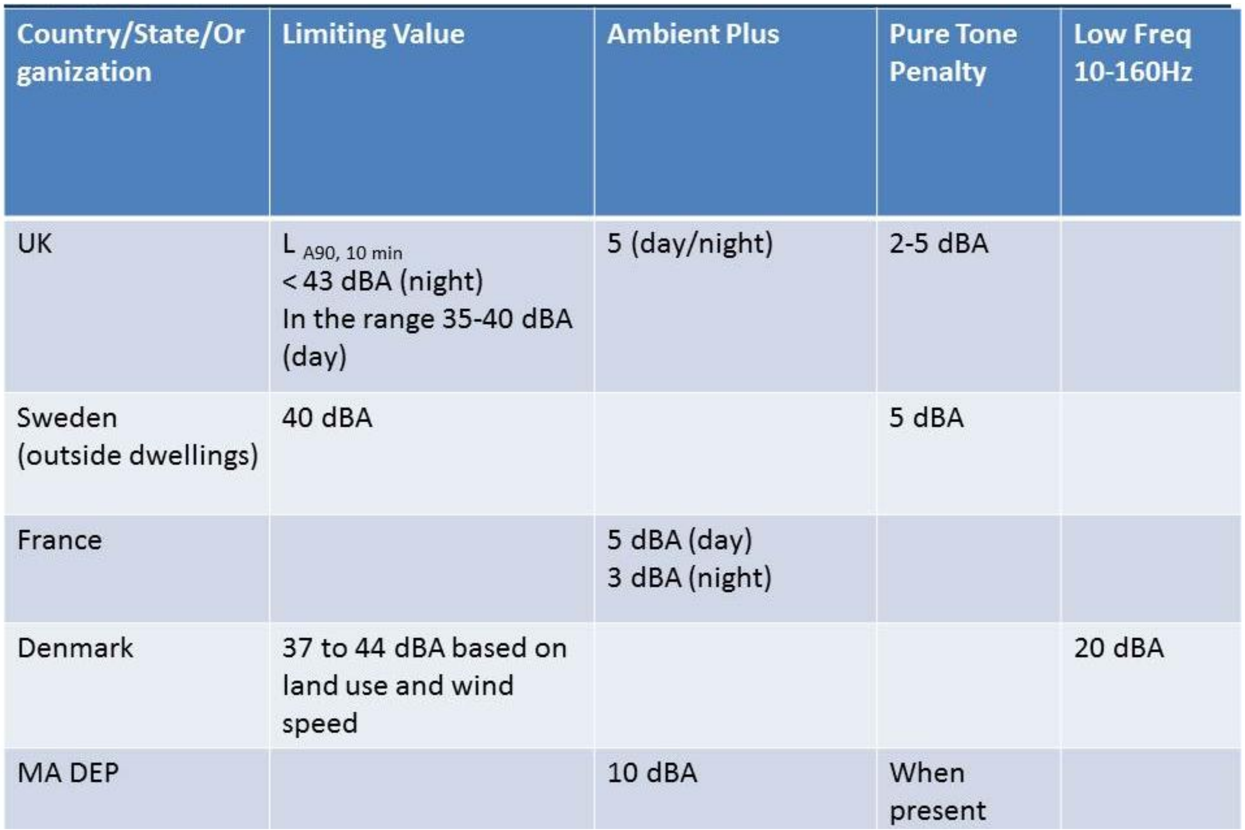
When we review the wind noise regulations (international and USA) we can classify them into three categories (Szasz. R. Z., and Fuchs, 2010):

- Fixed limit: Many communities and countries specify that the wind turbine noise should not exceed a limiting value. For example in Sweden the highest recommended sound level from wind turbines is limited to 40 dB with a 5 dBA penalty if pure tone is present (see Table 6). This approach is a straightforward method to implement but is least flexible. To add flexibility, some communities and countries specify different limits for different types of land use (urban/ rural/ mixed use, industrial /commercial / residential etc.) and time of the day (day/ evening/ night).
- Relative limits: In this case the noise limit is specified as a fixed value above the background noise levels. For example France limits the wind turbine noise to 5 dB (3 dB at night) above the background noise level (see Table 6). This method is more flexible than the fixed limit option but is more difficult to implement (Szasz. R. Z., and Fuchs, 2010).

- Variable limits: In this case the noise limit is specified as a function of wind speed. Canada (Table 9) and the Netherlands have regulations of this type. This method is more flexible than the fixed limit approach and easier to implement than the relative limit method (Szasz. R. Z., and Fuchs, 2010). Accurate estimation of wind speeds is an issue that needs to be addressed to effectively implement this approach.

A concise summary of some of the noise regulations are provided in Table 6.

Table 6. Summary of wind noise regulations (extracted from Pedersen and Halmstad, 2003; Danish Ministry of the Environment Statutory Order on Noise from Wind Turbines, 2011).



Country/State/Organization	Limiting Value	Ambient Plus	Pure Tone Penalty	Low Freq 10-160Hz
UK	$L_{A90, 10 min}$ < 43 dBA (night) In the range 35-40 dBA (day)	5 (day/night)	2-5 dBA	
Sweden (outside dwellings)	40 dBA		5 dBA	
France		5 dBA (day) 3 dBA (night)		
Denmark	37 to 44 dBA based on land use and wind speed			20 dBA
MA DEP		10 dBA	When present	

Typical Guidelines for Pure Tones

A pure tone is defined to exist if the 1/3rd octave band sound pressure level in the band, including the tone, exceeds the arithmetic average of the two contiguous 1/3 octave bands by

- 5 dBA for center frequencies of 500 Hz and above
- 8 dBA for center frequencies between 160 Hz and 400 Hz
- 15 dBA for center frequencies less than or equal to 125 Hz

Most of the codes penalize tonals (Gipe, 1995). For example, Huron County, MI, specifies that when steady pure tone is present, the standard for audible noise shall be reduced by 5 dBA (Table 11).

International wind noise regulations and WHO guidelines

Some of the regulations summarized in Table 6 are shown in more detail in Tables 7 through 10. The U.K noise limit is specified based on L $_{\text{A90, 10 min}}$ which is the A weighted sound level equaled or exceeded 90% of the sample time (10 minutes). The recommendations for wind noise in Sweden and United Kingdom are listed in Table 7. In Sweden the highest sound pressure level produced by wind turbines is limited to 40 dB and the pure tone penalty is 5 dB (Szasz and Fuchs, 2010). Great Britain specifies the noise limit relative to the background noise. The noise level produced is limited to 5 dB above the background level (Szasz and Fuchs, 2010).

Table 7. Wind Turbine Noise Regulations: Sweden and UK.

Country	Limit	Pure Tone Penalty
Sweden	40 dB	5 dB
United Kingdom	5 dBA above background (both day and night)	2-5 dB

The World Health Organization (WHO) has issued guidelines for community noise which is reproduced in Table 8 (World Health Organization (WHO), 1999). The limits are specified for different types of environments, such as outdoor and indoor living areas, bedrooms, classrooms, industrial, and commercial areas. The levels vary from 30 dBA (bedrooms) to 70 dBA for industrial and commercial areas. The last column in Table 8 specifies the measurement duration in each of these environment.

Table 8. WHO guidelines for community noise.

Environment	Critical Health Effect	Sound Level (dBA)	Time (hours)
Outdoor living areas	Annoyance	50-55	16
Indoor dwellings	Speech intelligibility	35	16
Bedrooms	Sleep disturbance	30	8
School classrooms	Disturbance of communication	35	During class
Industrial, commercial and traffic areas	Hearing impairment	70	24
Music through ear phones	Hearing impairment	85	1
Ceremonies and entertainment	Hearing impairment	100	4

Canadian, Danish, German and French regulations

The regulations in Canada specify the noise limits as a function of wind speed as shown in Table 9. The noise limits increase from 40 dBA at low wind speeds (4 to 6 m/s) to 51 dBA at 10 m/s.

Table 9. Wind turbine noise criteria: Canada (Noise Guidelines for Wind farms, Ministry of the Environment, Ontario, Canada, 2008).

10 m height wind speed (m/s)	4	5	6	7	8	9	10
Noise limit (dBA) - Rural	40	40	40	43	45	49	51
Noise limit (dBA) - Urban	45	45	45	45	45	49	51

Table 10. German noise regulations.

Area	Day (in dBA)	Night (in dBA)
Industrial	70/ 65	70/ 50
Mixed (residential with industry)	60	45
Residential	55/ 50	40/ 35
Hospital, health resort areas	45	35

New Danish regulations (Danish Ministry of the Environment, 2011*)* , which took effect in 2012, stipulate that the total noise impact from wind turbines may not exceed the following limit values:

1) At the most noise-exposed point in outdoor living area no more than 15 meters from dwellings in open countryside:
   a) 44 dBA at a wind speed of 8 m/s.
   b) 42 dBA at a wind speed of 6 m/s.
2) At the most noise-exposed point in areas with noise-sensitive land use:
   a) 39 dBA at a wind speed of 8 m/s.
   b) 37 dBA at a wind speed of 6 m/s.

Table 11. Summary of noise regulations in various communities in the USA (extracted from Oteri, 2008).

Location	Limit	Ambient Noise Adjustment*	Pure Tone Penalty	Measurement Location
Lodi, Michigan	55 dBA			At property line
Antis Township, PA	45 dBC			At property line
Brookings County, SD	50 dBA			
Buffalo County, WI	50 dBA	Yes	5 dBA	Inhabited Structure
Lehi City, UT	55 dBA			At property line
Mitchell WI	50 dBA	Yes	5 dBA	At any residence, school, hospital, church, or public library
Town of Rockland, WI	50 dBA**	Yes	None permitted	At any residence, school, hospital, church, or public library
Morrison, WI	50 dBA**	Yes	None permitted	At any inhabited structure
Door County, WI	50 dBA 45 dBA	Yes	5 dBA	At property line of any residence, school, hospital, church, or public library Inside any occupied structure
Banks County, MI	60 dBA			At property line
Huron County, MI	45 dBA or ambient plus 5 dBA whichever is greater**		5 dBA	At any residence, school, hospital, church, or public library
Manitowoc, WI	Ambient plus 5 dB			At any point on property
Shawano County, WI****	Ambient plus 5 dB***			
Long Lake Township, MI	Ambient plus 10 dBA			Beyond the property line
Hamlin, NY	Ambient plus 6 dBA		5 dBA	Closest exterior wall of a residence

** In the event the ambient noise level (exclusive of the development in question) exceeds the applicable standard given above, the applicable standard shall be adjusted so as to equal the ambient noise level.*

*** limited to 10% of the time over a continuous 24-hour period*

**** for more than 5 minutes out of any 1-hour time period*

***** Separate limits are specified for low frequency and infrasound*

Areas used for residential, institutional, holiday home, camping or areas used for noise-sensitive recreational activities are examples for noise sensitive land use.

Low-frequency noise: The total low-frequency noise from wind turbines may not exceed 20 dB at a wind speed of 8 and 6 m/s indoors in dwellings in open countryside or indoors in areas with noise sensitive land use respectively. The Danish code also specifies a method to calculate the low frequency noise from wind turbines.

German noise regulations are summarized in Table 10 (Pedersen and Halmstad, 2003). France limits the wind turbine noise to 5 dBA during the day and 3 dB during night above the background level. They do not specify a limiting value as the absolute threshold (Pedersen and Halmstad, 2003).

Summary of noise regulations in various local towns in USA

Table 11 shows a compilation of existing wind energy ordinances in various communities in different states in the USA. The regulations either specify a hard limit for the allowable noise level or specify the excess noise allowable beyond the ambient noise. Ambient noise level shall be expressed in terms of the highest whole number sound pressure level in dBA, which is exceeded for more than 5 minutes per hour. Most of the regulations penalize pure tones typically by 5 dBA. Oteri [2008] provides more detailed description of these noise ordinances and other setback requirements in each of these communities.

6. RECOMMENDATIONS FOR NOISE LIMITS

After extensive review of literature we recommend the following guidelines which can be used by each community to set their own regulations based on the site specific conditions such as land use (residential, commercial, industrial), density of population (urban or rural) and community acceptance. The guidelines are specified as least conservative, average, or most conservative. Thus we have tried to establish the upper and lower limits within which the communities can find acceptable criteria as their noise limit. These guidelines could be used by the communities as a framework to develop their own regulations to match the site conditions.

Table 12. Suggested RESP Noise Guidelines.

Least Conservative	**Average**	**Most Conservative**
Not more than 5 dB above ambient noise	Not more than 3 dB above ambient noise	Not more than 1 dB above ambient noise
Based on daytime equivalent ambient noise in vicinity of turbine	Based on day-night average ambient noise in vicinity of turbine	Based on night time equivalent ambient noise in vicinity of turbine

"Vicinity of turbine" implies the closest point of interest such as a residential building, school, or commercial/industrial building. Thus these guidelines specify the location of the wind turbine which will introduce a noise level according to one of the above suggested levels at the nearest receive location.

There are different ways to measure the background noise levels. One common background noise descriptor, recommended by ISO 1996/1, is LAeq,T, the equivalent continuous dB(A) level which has the same energy as the original fluctuating noise for the same given period of time T (Bruel and Kjaer, *Environmental Noise Measurement)*. LAeq,T is an excellent criterion for studying long-term trends in ambient noise. However, it does not convey any measure of environmental noise variations, which is also an important factor when considering human response. To overcome this ISO 1996/1 recommends measuring percentile levels, LAN,T, i.e. that dB(A) level which is exceeded for N% of a stated time period T. Percentile levels reveal maximum and minimum noise levels (Bruel and Kjaer, *Environmental Noise Measurement)*. They are used in baseline studies and in environmental impact statements to protect against new highways and new industrial plants degrading the acoustic quality of the environment. We suggest that The **A**-weighted sound pressure level of the residual noise at the assessment position that is exceeded for 90 per cent of a given time interval, T. (LA90, T) as a measure of the ambient noise level.

We have not specified any recommendations regarding low frequency and infrasound noise or tonals. Research in this area is still ongoing and yet to result in any adoptable criteria. But we suggest that in the event of any complaints of low frequency or infrasound noise or tonals a detailed investigation be conducted and appropriate remedial steps be taken.

7. EFFECT OF ATMOSPHERIC CONDITION ON SOUND PROPAGATION

The effect of wind speed and temperature variations in the atmosphere on acoustic propagation is discussed in this section. If the conditions are favorable, the received level can then be higher than a simple model prediction.

Wind

The effects of wind on noise are mostly confined to noise paths relatively close to the ground. The reason for this is the wind shear phenomenon. Wind shear is caused by the slowing down of wind in the vicinity of a ground plane due to friction. As the surface roughness of the ground increases, the friction between the ground and the air moving over it increases slowing down the wind. As the wind slows down with decreasing heights it creates a sound velocity gradient (due to differential speed of the medium) with respect to the ground. This velocity gradient tends to bend sound waves downward in the same direction of the wind and upward in the opposite direction (Gabrielson, 2006). The process, called refraction, creates a noise "shadow" (reduction) upwind from the source and a noise "focusing" (increase) downwind from the source. Figure 6 shows the effects of wind on noise.

Hubbard and Shepherd (1991) have discussed the behavior of high and low frequencies in a refractive environment. They conclude that in the downwind direction rays are bent toward the ground, are reflected upwards and then bend back towards the ground again. On the other hand, in the upwind direction, rays are bent away from the ground as mentioned in the previous paragraph. For high frequency sound, refraction causes increased attenuation in a shadow zone upwind of the source but very little effect in the downwind side of the source. The attenuation of low frequencies is reduced in the downwind direction due to refraction effects, and there is little effect in the upwind side.

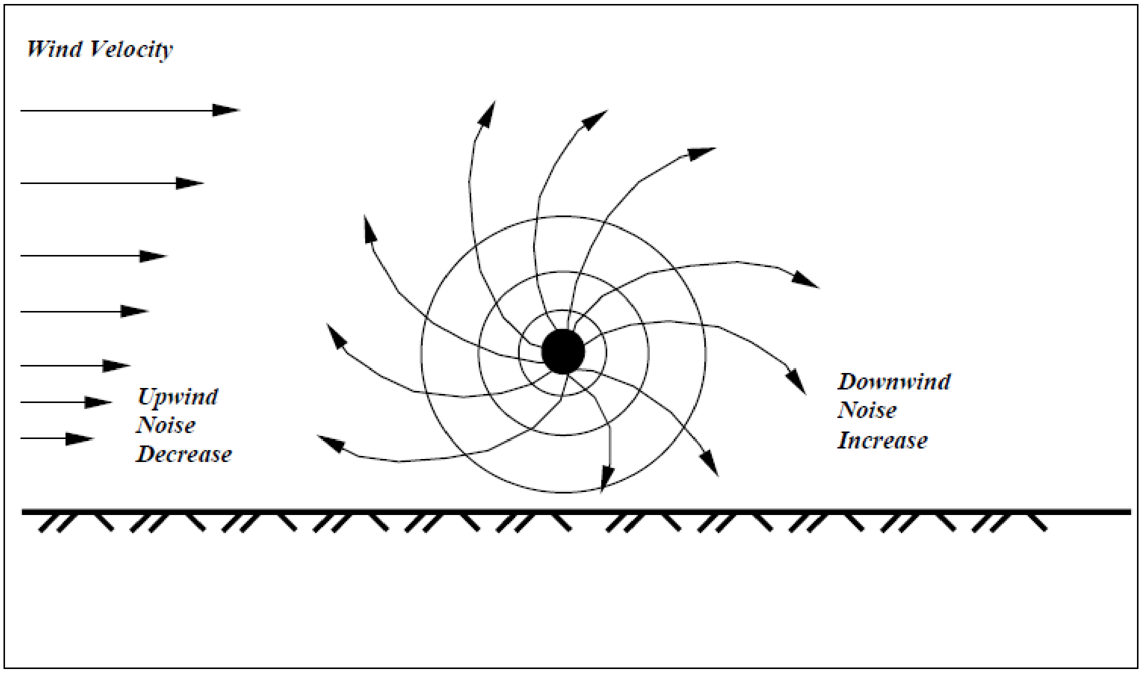


Figure 6. Effect of wind on acoustic noise propagation.

Effects of gradients in temperature on acoustic propagation

Gabrielson (2006) has provided an overview of the effect of temperature gradients on atmospheric acoustic propagation. A brief discussion of the temperature effects are provided in this section. Figure 6 shows the effects of temperature gradients on noise levels. Normally, air temperature decreases with height above the ground. This is called the normal lapse rate, which for dry air is about - 1o C per 100 m. Since the speed of sound decreases as air temperature decreases, the resulting temperature gradient creates a sound velocity gradient with height. Slower speeds of sound higher above the ground tend to refract sound waves upward in the same manner as wind shear does upwind from the source. The result is a decrease in noise. Under certain stable atmospheric conditions, however, temperature profiles are inverted, or temperatures increase with height either from the ground up, or at some altitude above the ground. This inversion results in sound speeds that temporarily increase with altitude, causing noise refraction similar to that caused by wind shear downwind from a noise source. Once trapped within an elevated inversion layer, noise may be carried over long distances in a channelized fashion. Both ground and elevated temperature inversions have the effect of propagating noise with less than the usual attenuation rates, and therefore increased noise at distance. The effects of vertical temperature gradients are more important over longer distances.

In the daytime, the temperature normally decreases with altitude. This causes sound to be refracted upward, which reduces the sound level for an observer on the ground. A temperature increase (an "inversion") with altitude often occurs at night and this causes sound to be refracted downward, which enhances the sounds for an observer on the ground. This is one of the reasons why many codes stipulate a reduced allowable sound level at night which is typically lower than the day-time level by 5 dB.

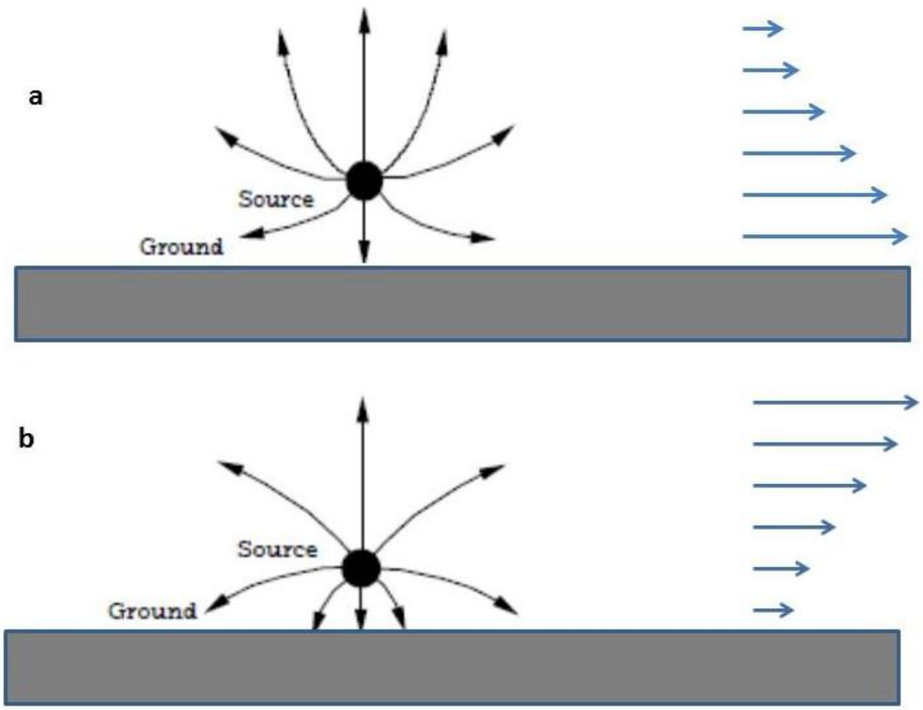


Figure 7. Effect of temperature gradient on acoustic propagation. Top panel (a) shows the scenario in which the temperature (and hence sound speed) decreases with altitude resulting in sound refraction way from the ground. In the reverse scenario, shown in the bottom panel, (b) sound gets refracted downward potentially causing an increase in noise level.

8. ACOUSTIC DATA COLLECTION USING CALIBRATED SYSTEMS IN AIR

Acoustic data were collected (Miller et. al., 2010) near the Portsmouth High School Wind Turbine (1.5 MW). Acoustic data were collected in 2009 using a Bruel and Kjaer Hand-Held Analyzer Type 2250L with a Type 4189, pre-polarized free-field ½" microphone calibrated by the factory. Spectrograms were computed by the 2250L in 1/3-octave bands with 1 second averages. The duration of the measurements was 15 minutes. The noise spectrogram for the Portsmouth High School Wind Turbine measured at a distance of 65 meters is shown in Figure 8. Units are dB re 20 μPa^2 in a 1/3-octave band. Measurements of the noise from this wind turbine were done on three days in July and August, 2009.

Other measurements were also taken near the Portsmouth High School Wind Turbine in 2011. Measurements were taken close to the base of the turbine and also at a residence half a km away from the turbine. They are shown below.

Table 13. Measure noise (dBA) near the base of the Portsmouth (RI) Wind Turbine.

Trial 1	**Trial 2:**	**Trial 3:**	**Trial 4:**	**Trial 5:**	**Trial 6:**
59.27	59.30	59.40	59.12	59.36	59.41

Table 14. Sound level measurements (dBA) at 0.5 km from the Portsmouth (RI) turbine.

11/30/2011 6:50 AM	**11/30/2011 10:31 AM**	**11/30/2011 3:30 PM**	**11/30/2011 8:30 PM**	**12/01/2011 5:30 AM**
56.7	54.4	54.7	51.3	49.2

The wind turbine and residence were close to a major highway and it is possible that highway noise dominates the readings, especially during day and evening times. The early morning and late evening readings are comparatively lower and possibly less affected by highway noise.

The measurements shown in Tables 13 and 14 will be compared to the acoustic model predictions in Section 9. The spectrogram (Figure 8) shows the frequency content of the noise measured very close to the turbine. At frequencies (up to 500 Hz) there seems to be indications of noise fading in and out with time. It should be noted that the measurements presented in Table 14 and 15 were preliminary in nature since they were not made strictly according to standards. More measurements will have to be made according to the appropriate standards to conclusively determine the noise characteristics. This will be one of the topics for future work.

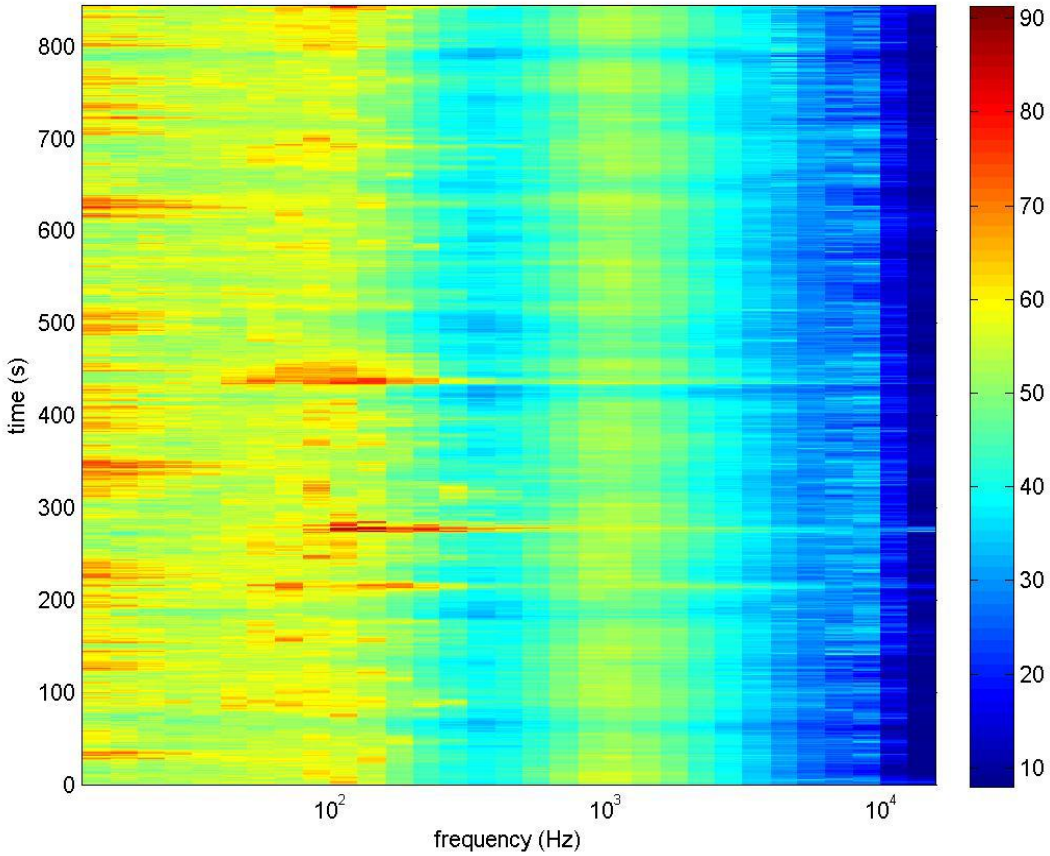


Figure 8. Noise spectrogram for the Portsmouth High School Wind Turbine measured at a distance of 65 meters. Units are dB re 20 µPa2 in a 1/3-octave band.

9. ACOUSTIC MODEL

An acoustic propagation model based on the provisions of ISO 9613-2 (1996) was implemented as part of this study to calculate the noise levels as a function of distance away from the turbine. This model will be made publically available as part of an online wind energy siting tool. The model takes into account the transmission loss due to geometric divergence and attenuation. A simple analysis considering only the geometrical spreading and few attenuation effects (absorption and ground effects) is one of the options. This option does not perform an octave band analysis and requires minimum number of input parameters. The second option performs a more detailed octave band calculation taking into consideration additional attenuation effects such as foliage and housing. Both the options are described briefly in this section and an example calculation for a hypothetical turbine is also presented.

Simple Noise Model

The acoustic propagation model described in this section is based on the provisions of ISO 9613-2 (1996). The simple noise model is a frequency independent calculation which is useful when information regarding the frequency dependent sound power levels of the wind turbine is not available. This simple model assumes a reference frequency of 500 Hz. The sound pressure level in dBA produced by a single turbine at a location (L_{fT}) is given by:

$$L_{fT} = L_w - A + (\text{Directivity Correction}) \qquad (14)$$

where

L_w sound power level in dB(A) produced by the turbine

Directivity correction is in dB (Equal to zero when the turbine is assumed as a point source).

A attenuation of sound as it propagates from source to receiver

The attenuation consists of contributions from different sources such as geometrical divergence (A_{div}), atmospheric absorption (A_{atm}), attenuation due to ground effects (A_{gr}), attenuation due to barriers (A_{bar}), attenuation due to meteorological effects (A_{met}) and attenuation due to other effects, such as foliage and areas with buildings (A_{misc}). The total attenuation is the sum of all these contributions:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} + A_{met} \qquad (15)$$

The simple acoustic model only considers the geometrical divergence (A_{div}), atmospheric absorption (A_{atm}), and attenuation due to ground effects (A_{gr}). Estimation of these parameters is discussed in the following sections.

Geometrical divergence (A_{div})

This takes into account the geometrical spreading of the acoustic waves as it propagates away from the source towards the receiver. The spherical model for geometrical divergence leads to:

$$A_{div} = 10\log_{10}\left(4\pi d^2\right) \quad \text{dB} \qquad (16)$$

Where d is the slant range from the source to the receiver in meters. The slant range is calculated in the model based on the x and y co-ordinates of the receiver location and the heights of the source and receiver.

Atmospheric absorption (A_{atm})

The attenuation due to atmospheric absorption is calculated using the atmospheric attenuation coefficient (α) using the following formula:

$$A_{atm} = \left(\frac{\alpha d}{1000}\right) \quad \text{dB} \qquad (17)$$

where α is in dB/km and d is the slant range in meters.

The atmospheric absorption is a function of frequency, temperature and humidity. The coefficients are calculated for a frequency of 500 Hz and for the input temperature and humidity as per ISO-9613-1.

Attenuation due to ground effects (A_{gr})

In the simple acoustic model, the ground attenuation is calculated based on a ground factor of zero (hard ground) and for the reference frequency of 500 Hz. The total ground attenuation is the sum of the ground attenuation in the source region (A_s), in the receiver region (A_r) and the region in between (middle region) (A_m). In the source and receiver region, the ground attenuation is -1.5 dB. The ground attenuation in the middle region can be calculated based on the approach explained in ISO 9613-2 (1996) using the hub height of the wind turbine (m), height of the receiver above the ground level (m) and the distance from turbine base to the receiver position projected on to the ground plane (m).

List of inputs to the simple acoustic model:

1.	**SL**	Wind turbine source power level (to be obtained from the manufacturer) in dB (A)
2.	**dirCorr**	Directivity correction in dB (equal to zero for omni directional source)
3.	**hSource**	Height of the source (hub height of the turbine) in meters
4.	**hReceiver**	Height of the receiver in meters
5.	**temp**	Temperature (degree centigrade); used for calculating the atmospheric absorption
6.	**humidity**	Humidity (percentage); used for calculating the atmospheric absorption
7.	**latitude**	Location of the source – latitude in decimal degrees
8.	**longitude**	Location of the source – longitude in decimal degrees

Complex Noise Model

When the wind turbine noise is available in octave bands a more refined model can be employed to calculate the noise level at the receiver. Frequency dependent attenuation coefficient is calculated to estimate the noise level at the receiver. The total noise level at the receiver is then calculated as the sum of the octave band level contributions as follows:

$$L_{total} = 10\log 10\left[\sum_{i=1}^{n} 10^{0.1L_{f_T}}\right] \qquad (18)$$

where

i indicates the eight standard octave band freqiencies (63, 125, 250, 500, 1000, 2000, 4000, 8000 Hz)

L_{fT} Octave band sound pressure level (dBA)

The various components of the attenuation are calculated as follows:

Atmospheric absorption (A_{atm})

The attenuation due to atmospheric absorption is calculated in each octave band in a manner similar to the simple noise model. The inputs are the octave band frequencies, temperature, and humidity.

Attenuation due to ground effects (A_{gr})

The calculation of the attenuation due to ground effects are more detailed compared to the simple model. Ground attenuation considers the effect of sound reflection and absorption from the ground. One important input parameter to this calculation is the ground factor (GF) which characterizes the acoustic properties of the region. The values of GF for different types of ground are shown in Table 15. Three distinct regions of ground attenuation are specified as follows:

1. Source region: Distance from the source towards the receiver of $30h_s$ with a maximum distance of d_p. h_s is the height of the source and d_p is the projection of the slant distance from source to receiver onto the horizontal plane.
2. Receiver region: Distance from the receiver towards the source of $30h_r$ with a maximum distance of d_p. h_r is the height of the receiver.
3. Middle region, between the source and receiver regions. If $d_p < 30(h_s+h_r)$, the source and receiver regions will overlap and there is no middle region. The parameters dp, hs and hr are the same as described in (1) and (2).

Table 15. Ground factors for different ground types.

Type of Ground	Example	GF
Hard	Low porosity ground (paving, water, ice, concrete etc.)	0
Porous	Ground suitable for growth of vegetation (ground covered with grass, trees, vegetation)	1
Mixed	Mix of hard and soft ground	Between 0 and 1

According to this calculation method, the ground attenuation is mostly dependent on the regions close to the source and receiver. The total ground attenuation is calculated separately for the source, receiver, and middle regions and summed up using equations provided in Table 3 of ISO 9613-2, 1996.

Attenuation of sound during propagation through foliage (A_{fol})

If there is dense foliage along the acoustic path from the source to the receiver, attenuation of sound can occur.

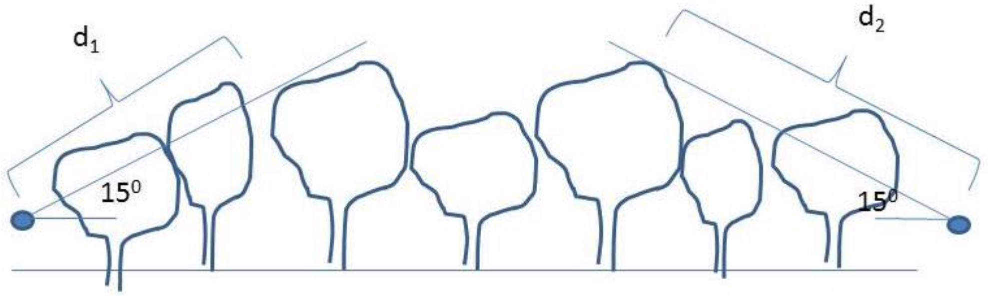


Figure 9. Calculation of distances d1 and d2 for foliage.

The total path length associated with foliage (d_f) is calculated as the sum of distances near the source (d_1) and near the receiver (d_2) as shown in Figure 9. The attenuation in dB associated with foliage can then be calculated using Table A.1 from ISO 9613-2, 1996. The inputs needed to calculate the foliage distance are the heights of the foliage, source, and receiver.

Attenuation during propagation through a built-up region of houses (A_{hous})

When the source and/or receiver are situated in a built up region attenuation can result due to screening by the houses. An approximate value for the A-weighted attenuation (A_{hous}) can be calculated based on the density of the buildings along the acoustic path and the length of the sound path through the built up region. The inputs needed for this calculation are the density of buildings and the heights of the buildings, source, and receiver.

List of inputs for the complex acoustic model:

1.	**SL**	Wind turbine source power level (to be obtained from the manufacturer) in dB (A) at the octave band frequencies.
2.	**dirCorr**	Directivity correction in dB (equal to zero for omni directional source)
3.	**hSource**	Height of the source (hub height of the turbine) in meters
4.	**hReceiver**	Height of the receiver in meters
5.	**temp**	temperature (degree centigrade); used for calculating the atmospheric absorption
6.	**humidity**	Humidity (percentage); used for calculating the atmospheric absorption
7.	**latitude**	Location of the source – latitude in decimal degrees
8.	**longitude**	Location of the source – longitude in decimal degrees
9.	**Gs**	Ground factor near the source
10.	**Gr**	Ground factor near the receiver
11.	**Gm**	Ground factor in the middle
12.	**hFoliage**	Height of the foliage (m)
13.	**densityHousing**	Density of housing (total plan area of housing/total area)

Example Results

The output of the model for a simple example is shown in Figure 10. The figure shows the A-weighted sound levels based on the *simple model calculations*. The turbine is located at (0,0). The source level was estimated based on the relationship between turbine blade diameter and noise level produced (Rogers, 2006). The input source level (110 dB) corresponds to a turbine with a blade diameter of 75 m. These parameters mimic the dimensions of the Portsmouth High School Wind Turbine. The measurements taken near this turbine has been previously discussed in Section 8. The inputs corresponding to this model run are as follows:

1. **SL** 110 dB (A)
2. **dirCorr** zero
3. **hSource** 65 m
4. **hReceiver** 1.5 m
5. **temp** 20 ºC
6. **humidity** 80 %
7. **latitude** 41.6169 degrees
8. **longitude** -71.2542 degrees

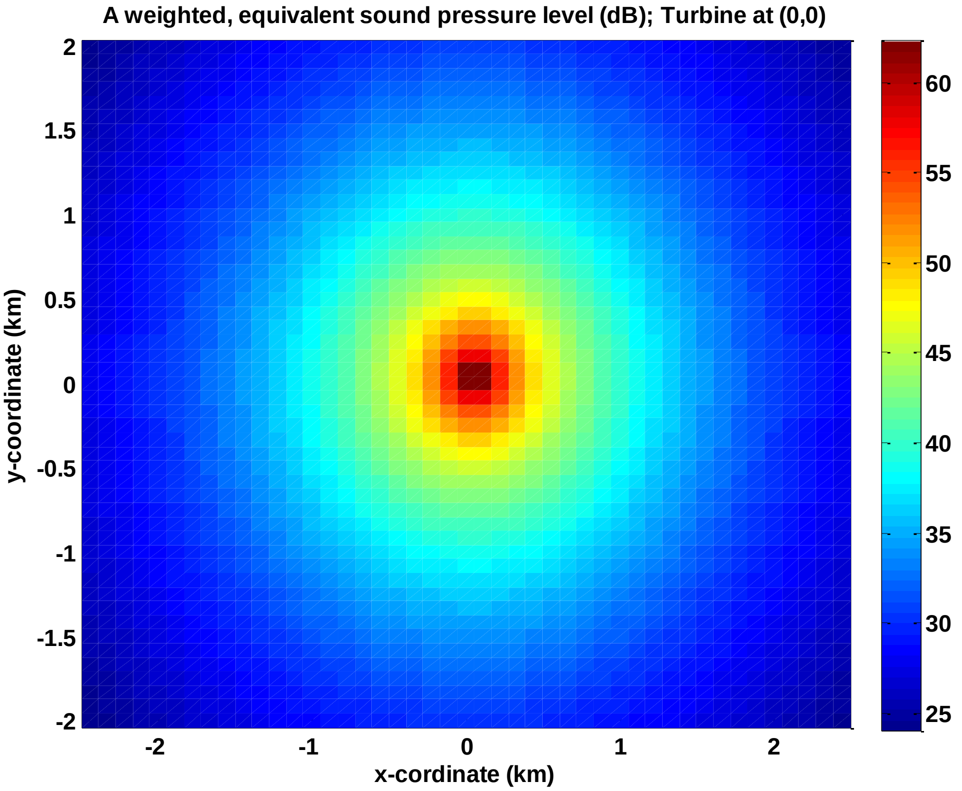


Figure 10. Acoustic noise prediction using simple model calculations for a hypothetical wind turbine assuming flat terrain.

The noise level produced by a wind turbine shown in Figure 10 is perfectly symmetric since we have assumed flat topography and uniform attenuation in all directions. We have also not considered other mechanisms which can influence the propagation (wind or temperature gradients). The model results predict 48 to 50 dBA levels at 0.5 km. This compares reasonably well with the measured values shown in Table 14. The levels close to the turbine (~100 m) is approximately 60 dBA which also compares well with the measurements shown in Table 13. It should be noted that the modeling results discussed here are very preliminary in nature and many of the input parameters were assumed based on values found in literature. The measurements presented in Table 14 also were preliminary in nature since they were not made strictly according to standards.

10. CONCLUSION

A brief overview of acoustic terminology and basic definitions are provided in this report. Characteristics of sound propagation and loss mechanisms are reviewed. An extensive review of existing wind noise guidelines was conducted as part of the study which is also summarized in this report. Based on that review and considering the fact that most of the wind resources in our state are in close proximity to our shore line (with higher density of population) we have developed some guidelines based on the ambient noise levels for wind turbine noise. These guidelines could be used by the communities as a framework to develop their own regulations to match the site conditions. A model to estimate these losses and thereby predict the sound levels around a wind turbine is implemented as part of this study based on the guidelines provided by ISO 9613-2 (1996). The model output for a turbine similar to an existing one is also compared to some field measurements.

Acknowledgements

We thank Dr. Malcolm Spaulding for providing valuable suggestions throughout the project and meticulously reviewing the manuscript. We also would like to thank Dr. Annette Grilli for her thoughtful comments. The inputs from Daniel Mendelsohn and Alex Crosby from Applied Science Associates (ASA) are thankfully acknowledged. The valuable suggestions provided by the three reviewers have been instrumental in improving the quality of this report.

11. REFERENCES

Alberts, D. J., Primer for Addressing Wind Turbine Noise, Lawrence Technological University, 2006.

Ambrose, S. E., and Rand, R. W., *The Bruce McPherson infrasound and low frequency noise study*, 2011.

Bruel and Kjaer, *Environmental Noise Measurement*, Booklet prepared in Denmark.

Danish Ministry of the Environment, *Statutory Order on Noise from Wind Turbines*, No. 1284, 2011.

Fidell, S., Barber, D. S., and Schultz, T. J., "Updating a dosage-effect relationship for the prevalence of annoyance due to general transportation noise," J. Acoust. Soc. Am., 89(1), 221-233, 1991.

Gabrielson, T. B,. "Refraction of Sound in the Atmosphere, " Acoustics Today, 2(2), April 2006.

Gipe. P., *Wind Energy Comes of Age*, John Wiley & Sons, Inc., New York, 1995.

Hubbard, H. H., and Shepherd, K. P., "Aeroacoustics of large wind turbines," J. Acoust. Soc. Am., 89(6), 2495-2508, 1991.

International Standard ISO 9613-2 *Attenuation of sound during propagation outdoors -- Part 2: General method of calculation,* 1996

INTERNATIONAL STANDARD IEC Edition 2.1 2006-11, Wind turbine generator systems Part 11: Acoustic noise measurement techniques

Kamperman, G. W. and James, R. R., "Simple guidelines for siting wind turbines to prevent health risks," Proceedings of NOISE-CON 2008.

Kinsler, L. E., Frey, A. R., Coppens , A. B., Sanders, J. V., Fundamentals of Acoustics, John Wiley & Sons Inc. , 2000.

Miller, J. H., Potty, G. R., Vigness-Raposa, K., Casagrande, D., Miller, L. A., Nystuen, J., and Scheifele, P. M., Acoustic Noise and Electromagnetic Study in Support of the Rhode Island Ocean SAMP, Technical Report #12, University of Rhode Island, November 12, 2010.

Ministry of the Environment, Ontario, Canada, *Noise Guidelines for Wind Farms,* October, 2008.

Møller, H and Pedersen, C. S., "Low-frequency noise from large wind turbines," J. Acoust. Soc. Am. 129 (6), June 2011

Oteri, F., *An Overview of Existing Wind Energy Ordinances, Technical Report NREL/TP-500-44439, December 2008*

Pedersen, E., and Halmstad, H., "Noise annoyance from wind turbines - a review," Swedish Environmental Protection Agency, Report 5 308, 2 0 0 3.

Pedersen, E., Berg, F. V. D., Bakker, R., and Bouma, J., "Response to noise from modern wind farms in The Netherlands," J. Acoust. Soc. Am. 126(2), 2009, Pedersen, E., and Waye, P. K., "Perception and annoyance due to wind turbine noise: A dose–response relationship," J. Acoust. Soc. Am., 116, 3460–3470, 2004.

Rogers, A. L., Wind Turbine Acoustic Noise, A white paper Prepared by the Renewable Energy Research Laboratory, Department of Mechanical and Industrial Engineering, University of Massachusetts at Amherst, 2006.

Stankovic. S., Campbell. N., and Harries. A., *Urban Wind Energy*, Earthscan Publishers, London, UK, 2009.

Szasz. R. Z., and Fuchs, L., "Wind Turbine Acoustics," in *Wind Power Generation and Wind Turbine Design*, ed. Tong. W, WITPRESS Publishers, Southampton, UK, 2010.

Turnbull, C. P., and Turner, J. P., "Measurement of Infrasound from Wind Farms and Other Sources," Proceedings of the Fourth International Meeting on Wind Turbine Noise (WTN2011), Rome, 2011.

World Health Organization (WHO), *Guidelines for community noise*, Ed. Berglund et al., Geneva, 1999.

Appendix – I
Sound Pressure Level Calculation Due to Multiple Turbines

The Sound Pressure Levels at any receiver location due to multiple sources can be calculated by summing, on an energy basis, the contributions from the turbines. Shepherd and Hubbard [1] have developed techniques to address this problem. The calculation of the total sound pressure level described here assumes that the sound sources are incoherent i.e., random phase. Let the Sound Pressure Levels at any location due to multiple sources (turbines) were calculated as S_i. The total Sound Pressure Level at that location can then be calculated as:

$$\text{Total Sound Pressure Level} = 10\log_{10}\int_{i=1}^{n} 10^{S_i/10} \qquad \text{(A1)}$$

where n is the number of sources (turbines). If the sound pressure levels due to the individual are calculated or measured at different frequencies, equation A1 can be repeatedly applied at all these frequencies. This will yield a sound level spectrum at the receiver. Other noise measures such as A-weighted sound pressure level can subsequently calculated for each receiver location.

Shepherd and Hubbard [1] have calculated the total sound pressure levels due to multiple turbines at different atmospheric absorption. They found that the decay rate for the multiple turbine configurations is less than that for a single source. At intermediate distances the array of sources acts like a line source. Even though the individual machines are typically treated as omni directional, an array of turbines may not have uniform directivity characteristics. Hence directivity needs to be considered especially at close ranges.

References:

Shepherd K. P and Hubbard H. H., Prediction of far field noise from wind energy farms, NASA Contractor Report, NAS1-16978, 1986.

RESP TECHNICAL REPORT #7

WIND TURBINE SHADOW FLICKER AND SIGNAL INTERFERENCE EFFECTS

By

Gopu R Potty and James Miller

Department of Ocean Engineering

University of Rhode Island,

Narragansett Bay Campus

June, 2012

Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

This report is organized in two parts. The first part of the report discusses the shadow flicker effect caused by a wind turbine. Various signal interference effects produced when a new wind turbine structure is introduced in a location is listed in the second part of the report.

Land based wind turbines create visual impacts caused by flickering shadows. Characterization and regulation of this impact is an ongoing research issue. The shadow flicker effect produced by rotating blades of the wind turbine is one of the major concerns in any new wind turbine development. Depending upon the repetition rate of this flickering effect, various community responses such as annoyance, irritation etc. have been observed. The basic terminology and definitions associated with modeling the shadow flicker is reviewed in this report. The astronomical and trigonometric calculations required to locate the position of the shadow of the wind turbine as a function of time of day over the whole year are discussed in detail. A simple shadow flicker prediction model is developed based on these calculations and the inputs into the model and outputs produced by it are presented. Some results for a turbine which is very similar to the Portsmouth Wind Turbine are also discussed. The model is capable of producing a flicker map (total accumulated flicker in hours over a period of one year around a wind turbine) and also the amount of flicker at any location of interest. The calculations are based on the " theoretical worst case" scenario, i.e. a situation where there is always sunshine, when the wind is blowing all the time, and when the wind and the turbine rotor keep tracking the sun by yawing the turbine exactly as the sun moves. The impact of realistic scenario on shadow flicker incidence is also discussed in detail in the report.

An extensive review of existing shadow flicker guidelines was conducted as part of the study which is also summarized in this report. Based on that review we have developed some guidelines. Most of the codes specify a limit of 30 hours per year as the maximum limit for the shadow flicker incidence. We have recommended 30 hours as the least conservative limit per year. On the other hand, the most conservative criterion suggests no impacts on any residence or business in the area of interest. A site specific regulation can be developed within these upper and lower bounds taking into consideration various factors such as land use (residential, commercial, industrial), density of population (urban or rural) and community acceptance.

A summary of possible signal interference effects is also provided in this report. No setback distances are generally provided to counter signal interferences. Many regulations require interference to be considered and minimized. We suggest that the wind turbine not interfere with signal transmission or reception of existing fixed broadcast, retransmission, or reception antennas for radio, television, or wireless phone or other personal communication system.

PART 1: WIND TURBINE SHADOW FLICKER

1. INTRODUCTION

Wind turbines, like other tall structures will cast a shadow on the neighboring area when the sun is shining and when the turbine blades are in the line of sight connecting an observer and the sun (Figure 1). When the blades are turning, this can produce a flickering (blinking) effect resulting in annoyance in the shadow zone. The effect of the shadow flicker will be maximum when the rotor blades are perpendicular to the line between the sun and the viewer (depends on wind direction). The likelihood and duration of the effect depends upon:

- Direction of the property relative to the turbine
- Distance from turbine
- Turbine height and rotor diameter
- Time of year and day
- Weather conditions (i.e. cloudy days reduce the likelihood of effects occurring)

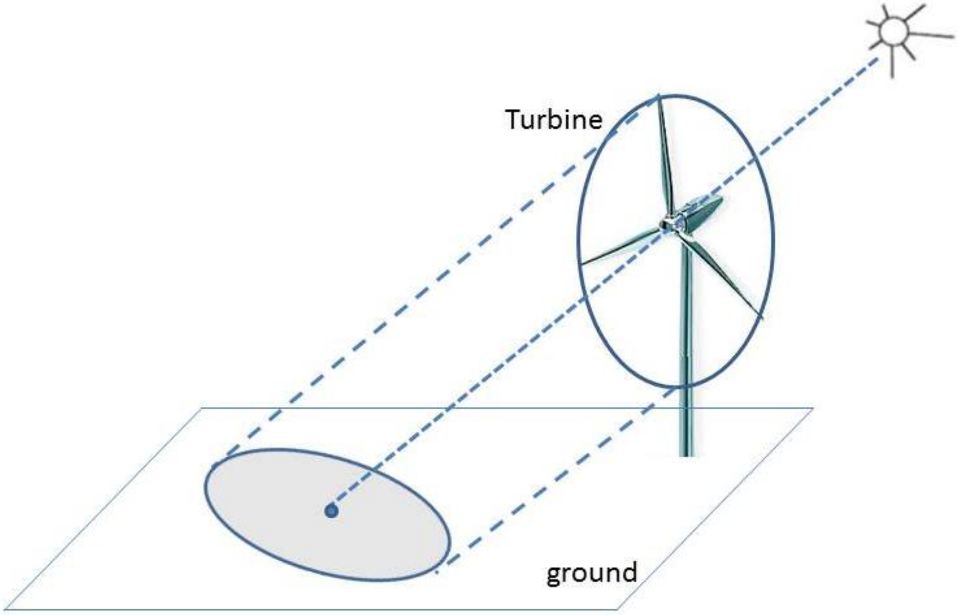


Figure 1. Cartoon showing the location of the shadow relative to the turbine and sun.

Shadow flicker is most pronounced (occurs at greater distances for a greater portion of the day) in northern latitudes during winter months because of the lower angle of the sun in the winter sky. However, it is possible to encounter shadow flicker anywhere for brief periods after sunrise and before sunset. Shadows cast close to a turbine will be more intense, distinct and focused and as one moves away from the turbine the intensity fades. Many consider shadow distances over ten rotor diameters away from the turbine insignificant (UK Shadow Flicker Evidence Base, Department of Energy and Climate Change, UK; Stankovic et al., 2009). For shadow receptor sites within a turbine's shadow's reach, not all will receive shadow due to existing obstructions that block the shadows path such as other buildings, hills or trees. While evergreen trees will fairly consistently block shadows year-round, deciduous trees will have a lesser impact in the winter months when they have no leaves. Unobstructed shadows in our latitudes will typically have a bow tie or flatten cross shape.

It has been reported (*Refining Shadow Calculations for Wind Turbines, Danish Wind Industry Association, www.windpower.org*) that the hub height of a wind turbine is of minor importance for the shadow from the rotor. The same shadow will be spread over a larger area, so in the vicinity of the turbine, say, up to 1,000 m, the number of minutes per year with shadows will actually decrease. If you are farther away from a wind turbine rotor than about 500-1000 meters, the rotor of a wind turbine will not appear to be intermittently blocking the light, but the turbine will be regarded as an object with the sun behind it. Therefore, it is generally not necessary to consider shadow casting at such distances. At the same time, the size of the rotor shadow and the number of shadow minutes per year in the vicinity of the turbine varies in proportion to the rotor area.

While the flickering effect may be considered annoying and intrusive, there is also concern that the variations in light frequencies may trigger epileptic seizures in the susceptible population (Burton et al. 2001). However, the rate at which modern three-bladed wind turbines rotate generates blade-passing frequencies of less than 1.75 Hz, below the threshold frequency of 2.5 Hz, indicating that seizures should not be an issue (Burton et al. 2001; Stankovic et al., 2009). There is anecdotal evidence suggesting that shadow flicker can also sometimes cause eye strain, headaches, nausea and disorientation.

Careful site selection and the use of good software to plan your wind turbine location is one of the ways to minimize this problem. If you know where the potential flicker effect is of a certain size, you may be able to place the turbines to avoid any major inconvenience for the neighbors. A simple model is developed as part of this study to predict the shadow locations and the accumulated shadow incidence around a turbine. Details of the model are presented in Section 2. Results from the model for a typical turbine are given in Section 2.4. Section 3 lists the factors which affect the actual shadow flicker occurrence. Various guidelines which regulate the amount of shadow flicker are summarized in Section 4. Our recommendations for regulating the shadow flicker are included in Section 5.

2. SHADOW FLICKER MODEL

We can predict quite accurately the probability of when and for how long there may be a flicker effect. We may not know in advance whether there is wind, or what the wind direction is, but using astronomy and trigonometry we can compute either a likely, or a " theoretical worst case " scenario, i.e. a situation where there is always sunshine, when the wind is blowing all the time, and when the wind and the turbine rotor keep tracking the sun by yawing the turbine exactly as the sun moves. The theoretical worst case scenario assumes the following:

- Sun is always shining during the day
- Wind is always blowing (blades are continuously spinning)
- Wind direction is always favorable for generating shadow at the receiver

In addition to these assumptions, we also assume a flat terrain for computational simplicity.

The problem of prediction of shadow location involves the following:

- Calculating the location (azimuth and altitude angles) of the sun given the location (latitude and longitude), day and time of shadow occurrence. This involves astronomical calculations which will be described in Section 2.1.
- Calculation of the location of the shadow (x, y co-ordinates) based on the position of the sun, location, size and height of the turbine and height of the observer. This involves trigonometrical calculations which are described in Section 2.2.

2.1 Location of the sun

The equation for calculating the solar azimuth *(A)*, is given by the following equations (Stine and Harrigan, 1986). The solar azimuth angle is measured from due north in a clockwise direction, as with compass directions.

$$A' = \cos^{-1}\left(\frac{\sin\delta\cos\phi - \cos\delta\cos\omega\sin\phi}{\cos\alpha}\right) \quad \text{(degrees)} \qquad (1)$$

where if :

$$\sin\omega > 0 \qquad \text{then} \qquad A = 360^\circ - A'$$

$$\sin\omega \le 0 \qquad \text{then} \qquad A = A'$$

δ - declination angle

ϕ - latitude angle

ω - hour angle

α - solar altitude angle

The solar azimuth angle and altitude angles are shown in Figure 2. All the angles defined above are in degrees and they can be calculated as described in the following sections.

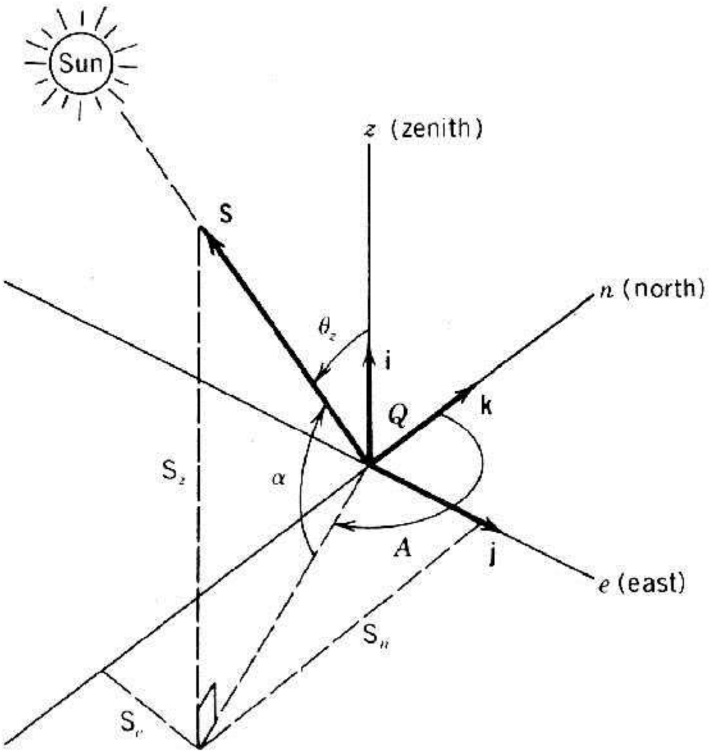


Figure 2. Earth surface co-ordinate system for observer at Q showing the solar azimuth angle (A) and altitude angle.

2.1.1 Declination Angle (δ)

The plane that includes the earth's equator is called the equatorial plane. If a line is drawn between the center of the earth and the sun, the angle between this line and the earth's equatorial plane is called the declination angle (δ). The declination angle can be calculated using Equation 2:

$$\sin\delta = 0.39795\cos[0.98563(N-173)] \qquad (2)$$

where the day number, N being the number of days since January 1.

2.1.2 Latitude Angle (ϕ)

The latitude angle is the angle between a line drawn from a point on the earth’s surface to the center of the earth, and the earth’s equatorial plane. The intersection of the equatorial plane with the surface of the earth forms the equator and is designated as 0 degrees latitude.

2.1.3 Hour Angle (ω)

To describe the earth's rotation about its polar axis, we use the concept of the hour angle. The hour angle is the angular distance between the meridian of the observer and the meridian whose plane contains the sun. The hour angle is zero at solar noon (when the sun reaches its highest point in the sky). At this time the sun is said to be ‘due south’ (or ‘due north’, in the

Southern Hemisphere) since the meridian plane of the observer contains the sun. The hour angle increases by 15 degrees every hour. An expression to calculate the hour angle from solar time (t_s) in hours is,

$$\omega = 15(t_s - 12) \qquad (3)$$

Solar time is based on the 24-hour clock, with 12:00 as the time that the sun is exactly due south. The concept of solar time is used in predicting the direction of sunrays relative to a point on the earth. Solar time is location (longitude) dependent and is generally different from local clock time, which is defined by politically defined time zones and other approximations.

2.1.4 Sun's Altitude Angle (α)

The solar altitude angle is defined as the angle between the central ray from the sun, and a horizontal plane containing the observer. It can be calculated knowing the latitude angle, declination angle and hour angle using the following equation:

$$\alpha = \sin^{-1}(\sin\delta\sin\phi + \cos\delta\cos\omega\cos\phi) \quad \text{(degrees)} \qquad (4)$$

2.2 Location of the shadow

An important use of your understanding of the sun's position is in predicting the location of a shadow. Since sunlight travels in straight lines, the projection of an obscuring point onto the ground (or any other surface) can be described in terms of simple geometry. Figure 3 shows a vertical pole on a horizontal surface. The problem here is to define the length and direction of the shadow cast by the pole. This can be done in Cartesian coordinates with the base of the pole as the origin, north as the positive y-direction and east the positive x-direction as follows.

The equations for the coordinates of the tip of the shadow from the vertical pole OP are:

$$x = OP\left[\frac{\sin(A - 180^o)}{\tan\alpha}\right] \quad \text{(m)} \qquad 5(a)$$

$$y = OP\left[\frac{\cos(A - 180^o)}{\tan\alpha}\right] \quad \text{(m)} \qquad 5(b)$$

2.3 Shadow flicker model

A simple model which implements the trigonometric and astronomical calculations described in Sections 2.1 to 2.2 was developed as part of the study. This model will be a freely accessible online tool and hence can be used by anyone for a quick assessment of shadow flicker impact caused by a wind turbine. The model predicts the amount of shadow incidence (in hours) accumulated over a period of time. A shadow incidence map can be created to visualize the areas affected by the turbine shadow which will be very useful for turbine location planning. It should be noted that the shadow accumulation predicted by this model is based on 'theoretical worst case' conditions and the actual values may be much less than the prediction. But knowing the affected locations a priori is very valuable during the planning process. Some example results from the model are discussed in Section 2.4.

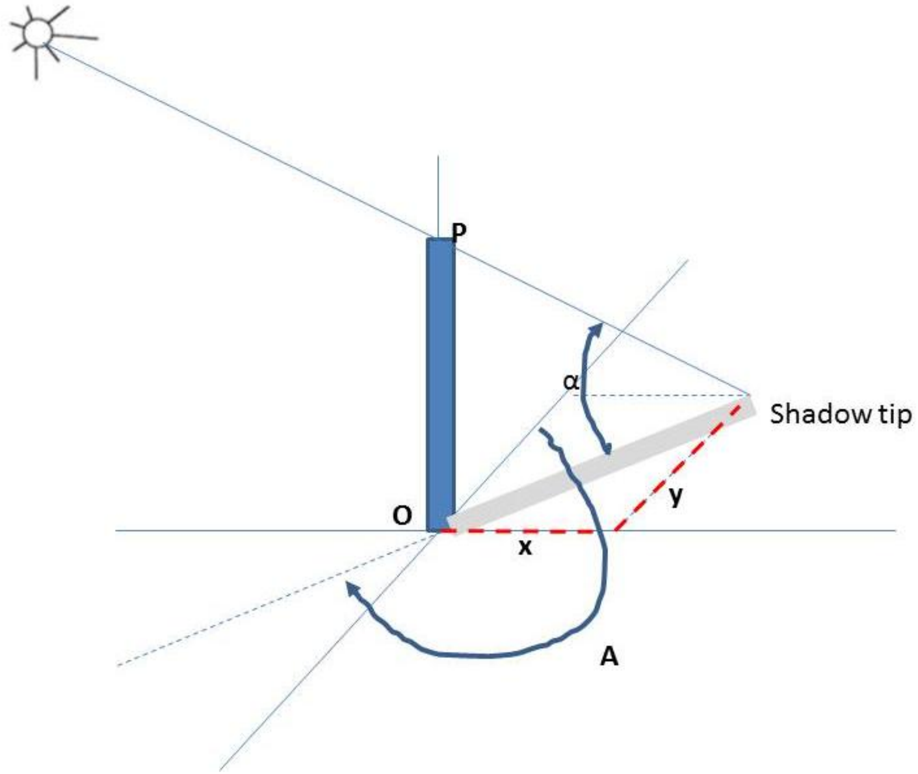


Figure 3. Shadow cast by a pole OP showing x and y co-ordinates of the shadow tip.

2.4 Model Results

The accumulated shadow flicker amount in hours over a period of one year around a hypothetical wind turbine is shown in Figure 4. The calculations are done based on the 'theoretical worst case scenario' assumption discussed in Section 2. Some of the input parameters corresponding to this model prediction are listed below (these dimensions mimic the wind turbine at the Portsmouth High School):

Location of the turbine: 41.6169 (Latitude); 71.2542 (Longitude)

Blade length =37.5 m

Height of the rotor hub=65 m

Height of the receiver =1.5 m

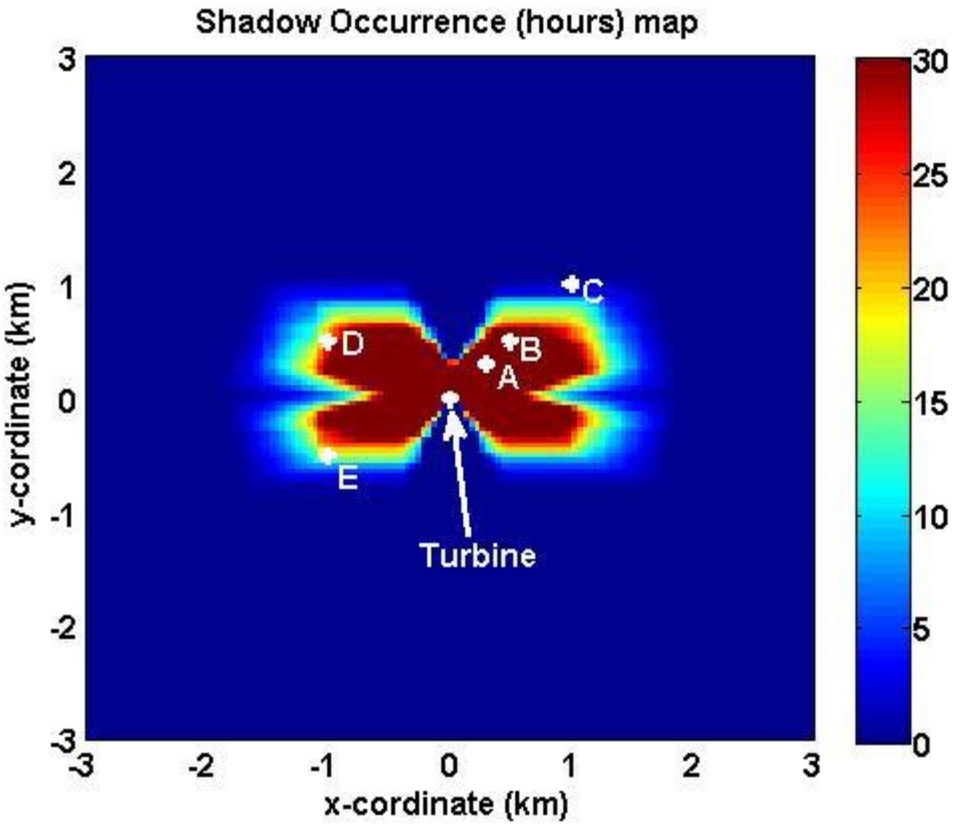


Figure 4. Shadow duration (cumulative) around a hypothetical turbine. The color scale indicates the total shadow duration in hours.

Shadow calculations were done every 15 minutes for one year and the accumulated amount shadow duration is plotted as a function of x and y co-ordinates with the location of the turbine as the origin. Since the solar altitude angle is defined as the angle between the central ray from the sun, and a horizontal plane containing the observer, the x-y co-ordinates are also defined in the same plane. The area around turbine is gridded in x and y directions and the x-y location of the shadow is then assigned to the appropriate bin for each 15 minute interval. So the map shown in Figure 4 has a spatial resolution equal to the grid spacing (which for the result shown in Figure 4 is equal to approximately 40 m in x and y) and a temporal resolution of 15 minutes.

Figure 4 clearly shows the areas around the turbine where shadow flicker could pose problems. This provides planners and developers vital information as to position the turbine in relation to existing residential or other dwellings. In Figure 5, the hourly variation of the total (over a year) shadow occurrences at five locations (marked A,B, C, D and E in Figure 4) is shown. Figure 5 clearly shows that the major shadow accumulation occurs either in the morning (for location to the southwest and northwest of the turbine) or in the evenings (for location to the southeast and northeast of the turbine). At location A, which is at (300m, 300m), the time of the day with the highest amount of shadow flicker is around 3 PM. The information provided by Figure 5 will be useful if any remedial measures are planned based on shutting down the turbine at peak shadow occurrence times. Figure 6 shows the daily variation of flicker over one year at two locations which is shown as X (300m, 300m) and Y (30 m, 30 m) in the left panel. The comparison of the shadow flicker at X and Y clearly shows that close to the turbine the shadow flicker is dominant during summer months where at locations away from the turbine the low sun angles (winter months) dominate. Some codes restrict the maximum allowable flicker amount per day in addition to the total allowable amount per year. This result will help the planners to isolate the areas where the daily ‘dose’ of flicker exceeds the allowable limit (typically set as 30 minutes per day- Table 2).

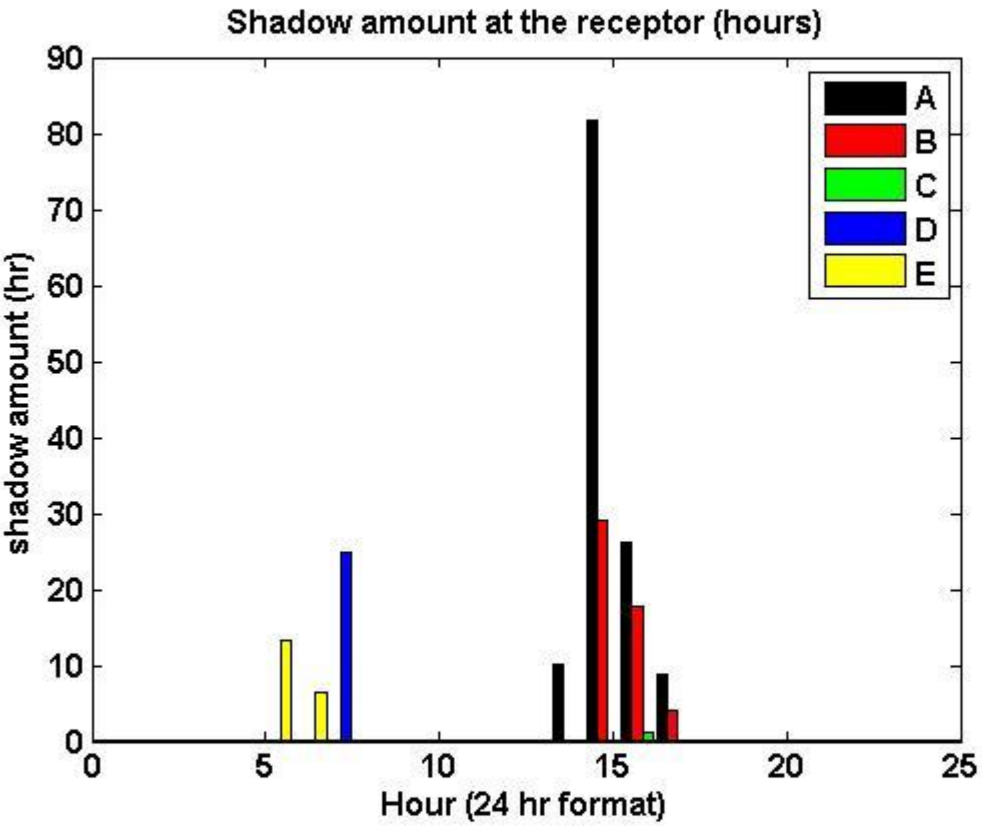


Figure 5. Hourly distribution of shadow occurrences (accumulated over a year). X-axis shows the hour of the day using a 24 hour format.

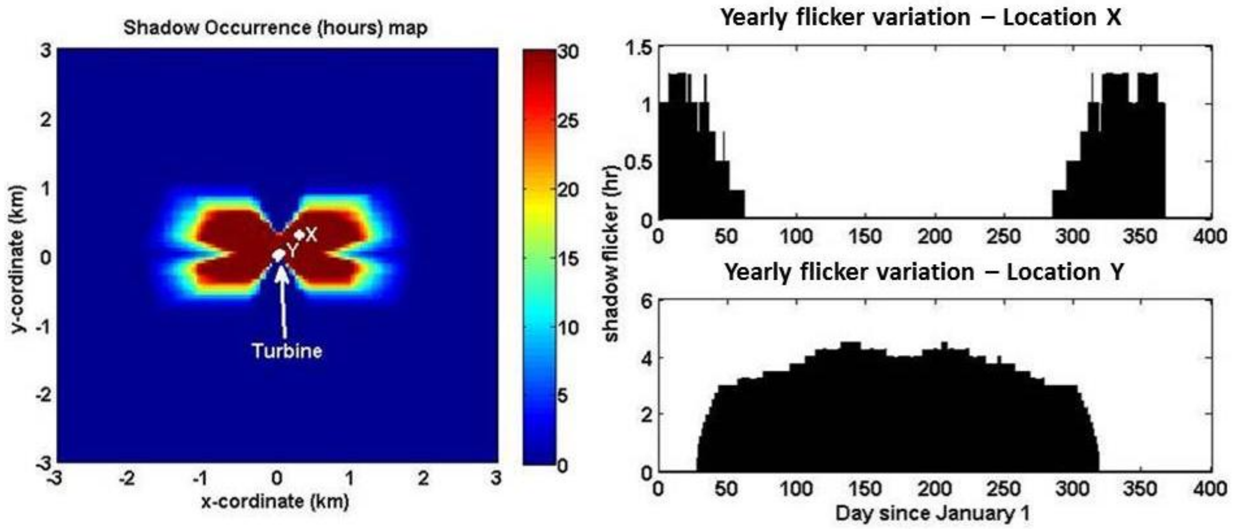


Figure 6. Variation of shadow flicker at two locations (A and B in the left panel).

3. REFINING SHADOW CALCULATIONS FOR WIND TURBINES BASED ON ACTUAL CONDITIONS

As previously mentioned, the flicker model calculations shown in Figures 4, 5 and 5 are based on theoretical worst case conditions. This should provide the upper bound for the flicker estimates. The actual shadow flicker occurrence is influenced by a number of parameters some of which are listed below.

3.1 Actual Rotor Direction

In practice the wind turbine rotor will follow the wind direction (if the wind speed is above the cut in speed). Usually the developer will have access to a wind rose with a frequency distribution of the wind in the different directions of the compass when they are planning a wind turbine site. Using that information, the developer may calculate a more exact shadow picture. In has been shown one example (*Refining Shadow Calculations for Wind Turbines, Danish Wind Industry Association, www. windpower.org*) , that shadow occurrences are reduced to some 64 per cent of the comparable worst case value when actual wind directions were used in the calculation.

3.2 Turbine Operating Hours

The rotor will not be running all the time, depending on the wind speed, so we may multiply the number of minutes of shadow flicker by a factor of typically 0.75 (*Refining Shadow Calculations for Wind Turbines, Danish Wind Industry Association, www. windpower.org*), depending on the local wind climate, (a more precise calculation should ideally use the correct factor for daytime during each month).

3.3 Actual Sunshine Hours

When studying shadows, we should only count the fraction of the time when the sun is actually shining brightly, ideally using the correct fraction for each hour of the day during the year. If meteorological data showing accurate long term statistics on the number of hours of bright sunshine during the year is available at the location, which can be factored into the shadow flicker calculation.

The number of bright sunshine hours varies with the geographical location and the season (summer or winter). The days with sunshine for two locations in Rhode Island (Providence and Block Island) are shown in Table 1. Sunny days have cloud cover up to 30 % of the sky during daylight hours. Partly sunny days have cloud covering from 40 % to 70% of the sky during day time. Based on this data we can see that sunlight is available (and hence a shadow is produced) only for approximately 55 to 60 % of the time. The actual time of the day when sunshine is available will also play very important role in determining the shadow distribution (as can be inferred from Figure 5).

Table 1. Days with sunshine in Rhode Island (http://www.currentresults.com/Weather/Rhode-Island/annual-weather-averages.php).

Location	Sunny	Partly Sunny	Sunny and Partly sunny days
Providence	98	103	201 (55%)
Block Island	98	113	2118%)

3.4 Combining Turbine operating hours, Actual Rotor Direction, and Actual Sunshine Hours

If we use the actual turbine operating hours, the actual rotor direction, and the actual bright sunshine hours for a test case, we get a result which is approximately 18 per cent of the worst case assumption. (The percentages given above are the results of simulations for Copenhagen on a 720 by 720 meter square with a turbine in the center with 43 m rotor diameter and 50 m hub height; (*Refining Shadow Calculations for Wind Turbines, Danish Wind Industry Association, www. windpower.org*). It should be noted that this percentage reduction value (18%) reported for Copenhagen may not be the same for Rhode Island conditions.

The important conclusion of their simulation is that actual sunshine hours play a very important role in diminishing the amount of shadows north of the turbine (in the Northern hemisphere). Since sunshine likelihood is lower during winter, there is a larger reduction in the calculation of actual shadow flicker during the winter months.

4. SHADOW FLICKER REGULATIONS

Many shadow flicker regulations requires "avoid unreasonable adverse shadow flicker effects at any occupied building located on a non-participating land owner's property (Maine)" or "a wind turbine shall be sited in a manner that does not result in significant shadow flicker impacts (NH)", or "turbine shall be sited in a manner that minimizes shadowing or flicker impacts (MA)". Internationally, in Germany, there has been a court case in which the judge set a limit of 30 hours of shadow flicker per year (theoretical worst case) at a certain neighbor's property. Many of the regulations follow the 30 hour yearly limit (based on theoretical worst case scenario) as a general rule. Table 2 summarizes various regulations existing internationally and in various states in USA.

Table 2. Summary of Shadow Flicker Regulations.

	Guideline or Regulation
Germany	30 hr/year or 30 min/day
Denmark	10 hr/year
Netherlands	17 days/year or 20 min/day
Massachusetts	No Limit "minimize flicker"
Maine	No Limit "avoid unreasonable shadow flicker"
New Hampshire	30 hr/year
Ohio	30 hr/year
Wisconsin	30 hr/year (mitigation required if greater than 20 hrs/year)

5. SHADOW FLICKER RECOMMENDATION

After extensive review of literature we recommend the following guidelines which can be used by each community to set their own regulations based on the site specific conditions such as land use (residential, commercial, industrial), density of population (urban or rural) and community acceptance. The guidelines are specified as least conservative, average or most conservative. Thus we have tried to establish the hard and soft limits within which the communities can find acceptable criteria as their flicker limit. As we can see from Table 2, most of the codes specify a limit of 30 hours per year as the maximum limit for the shadow flicker incidence. The numbers shown in Table 2 are shadow flicker calculations based on theoretical worst case conditions. We have recommended 30 hours as the least conservative limit per year.

On the other hand, the most conservative criterion suggests no impacts on any residence or business in the area of interest. Considering the fact that the calculations (which assumes most favorable conditions for shadow occurrence such as no cloudy days, turbine always facing the receiver, turbine always turning, and no barriers) will always estimate at least some amount of shadow flicker occurrence (since dilution of the shadow with distance is not taken into account) we suggest a limit of 3 hours of shadow incidence per year.

Table 3. Suggested RESP shadow flicker recommendations.

Least conservative	Average	Most conservative
Duration of flicker- 30 hrs per yr	Duration of flicker - 20 hrs per yr	Duration of flicker 3 hrs per yr
		No impacts on any residence or business in area

PART II: WIND TURBINE SIGNAL INTERFERENCE

1. COMMON EFFECTS

One of the concerns associated with wind turbine development is whether they will interfere with electromagnetic transmissions such as radio, television, or cell-phone signals. This is generally not a problem for modern small (residential) wind turbines. The materials used to make such machines are non-metallic (composites, plastic, wood) and small turbines are too small to create electromagnetic interference (EMI) by "chopping up" a signal.

Large wind turbines, such as those typically installed at wind farms, can interfere with radio or TV signals if a turbine is in the "line of sight" between a receiver and the signal source, but this problem can usually be easily dealt with improving the receiver's antenna or installing relays to transmit the signal around the wind farm (http://archive.awea.org/faq/wwt_environment.html).

Following are the common effects with respect to signal interference associated with a wind turbine development which should be investigated prior to installing a wind turbine at any location.

1. Signal blocking: Signal blockage behind the turbine for a limited distance results in creating a shadow zone. This shadow zone depends on the material and geometry (height and width) of wind turbine.
2. Television (ghosting): Television signals can get distorted when turbine is in the line of site between transmitter and receiver. Generally TV interference problems are predictable and normally there are a range of solutions available. The most cost effective remedial measure if television signals are affected is to provide direct broadcast satellite (DBS) television reception systems to the residents who have degraded off-air television reception. Another method of mitigating the effects of interference is to install wireless or cable television distribution systems that can rebroadcast the television channels to the communities whose off-air television reception is affected by the wind turbine facility. This is a not a serious problem for digital signals (*British Office of Communications*). In the case of satellite television interference is a problem when turbine is in the line of site between satellite and receiver. This is not a likely issue since signals are received from very high and the wind turbines will not be in the line of sight unless the receiver is very close to the turbine.
3. EM Noise: Wind turbines are not significant emitters of EM noise. The electric motors and generators used in the nacelle of a wind turbine emit a small amount of low frequency electromagnetic noise. Because this noise is outside of the high frequency band used by cellular telephones, it should not cause system interference. Transmitting and receiving antennas have a “near-field” zone, which requires freedom from any object that can conduct or absorb radio waves. The “near-field” zone for Ultra High Frequency (UHF) signals, such as cellular telephones (800MHz to 1900MHz) is approximately 20 meters.
4. Diffraction: Diffraction occurs when the wind turbine partially or totally blocks a radio wave. Diffraction effects from wind turbines can be avoided by placing them outside the first Fresnel Zone, which determines the distance of obstruction signal loss. The Fresnel

Zone is the defined volume between two microwave stations wherein an obstacle can substantially degrade the performance of the communication links. The following formula defines the dimensions of the zone.

$$R_n = 17.3\sqrt{\frac{n}{F_{GHz}}\frac{d_1 d_2}{d_1 + d_2}}$$

where

R_n Fresnel zone radius at a specific point in the microwave path (m)

n Fresnel zone number (1)

F_{GHz} Frequency of microwave system (GHz)

d_1 Distance from antenna 1 to a specific point in the microwave path (km)

d_2 Distance from antenna 2 to a specific point in the microwave path (km)

5. Reflection: Scattering is the reflection of waves off of an object that has reflective properties. Reflection can occur when structure is line of sight to a transmitter. Reflection depends on material, rotational speed of turbine, geometry and orientation of blades relative to transmitter. Because the tower and blades are relatively slim and curved they tend to disperse rather than obstruct the waves. Furthermore, typical “blades are made from glass reinforced plastic (GRP), which is essentially transparent to electromagnetic waves. The minimum signal to noise ratio (SNR) for overall impact is 12dB and 18dB for cellular (voice only) and cellular (all services) respectively. This means the signal power level must be 12 or 18 times higher than the power level of the noise, which is common for the sensitivity levels of the Code Division Multiple Access (CDMA) technology. These ratios correspond to an estimated minimum separation (between the tower and turbines) of 100 m.

   Other interference effects are summarized as follows:

- FM and DBA radio: Interference possible only within few 10’s of meters of the turbine (because of the low frequency nature of the signals)
- Scanning telemetry systems (used by water and power industries to monitor substations/ pipelines/ supply networks): Work in the UHF band and hence susceptible to multi-path effects from reflecting blades.
- Fixed radio links: Public safety radio systems work using microwave wavelengths can be affected when the wind turbine is placed within the line of sight between the transponder and a receiver
- A wind turbine in the line of sight of a radar station can create a radar echo which can mask potential target echoes (Stankovic et. al., 2009).

2. SIGNAL INTERFERENCE: RECOMMENDATIONS

No setback distances are generally provided to counter signal interferences. Many regulations require interference to considered and minimized (Oteri, 2008). For example, regulations in Henry County, Illinois specifies that *the owner of a wind energy system must take such reasonable steps as are necessary to prevent, eliminate, or mitigate any interference with cellular, radio, or television signals caused by the wind energy system.* Huron County, Michigan requires that *no large-scale WECS shall be installed in any location where its proximity with existing fixed broadcast, retransmission, or reception antennas for radio, television, or wireless phone or other personal communication system would produce electromagnetic interference with signal transmission or reception. No large-scale WECS shall be installed in any location along the major axis of an existing microwave communications link where its operation is likely to produce electromagnetic interference in the links operation.* Fillmore County, Minnesota stipulates that t*he applicant shall minimize or mitigate interference with electromagnetic communications, such as radio, telephone, microwaves, or television signals caused by WECS. The applicant shall notify all communication tower operators within 2 miles of the proposed WECS location upon application to the county for permits. No WECS shall be constructed as to interfere with County or Minnesota Department of Transportation microwave transmissions.*

We also do not recommend any specific back distances with regards to signal interference. But we suggest that the wind turbine not interfere with signal transmission or reception of existing fixed broadcast, retransmission, or reception antennas for radio, television, or wireless phone or other personal communication system. Also care should be taken not to place a turbine along the major axis of an existing microwave communications link where its operation is likely to produce electromagnetic interference in the links operation. We suggest that check for all communication towers within 3.25 km of the wind turbine for any interference with their operation. We recommend that appropriate mitigation measured be taken if signal interference is present.

3. CONCLUSIONS

The basic terminology and definitions associated with modeling the shadow flicker is reviewed in this report. The astronomical and trigonometric calculations required to locate the position of the shadow of the wind turbine as a function of time of day over the whole year are discussed in detail. A simple shadow flicker prediction model is developed based on these calculations and the inputs into the model and outputs produced by it are presented. Some results for a turbine which mimics the Portsmouth Wind Turbine are also discussed. The model is capable of producing a flicker map (total accumulated flicker in hours over a period of one year around a wind turbine) and also the amount of flicker at any location of interest. The calculations are based on the "theoretical worst case" scenario, i.e. a situation where there is always sunshine, when the wind is blowing all the time, and when the wind and the turbine rotor keep tracking the sun by yawing the turbine exactly as the sun moves. The impact of realistic scenario on shadow flicker incidence is also discussed in detail in the report.

An extensive review of existing shadow flicker guidelines was conducted as part of the study which is also summarized in this report. Based on that review we have developed some guidelines. Most of the codes specify a limit of 30 hours per year as the maximum limit for the shadow flicker incidence. We have recommended 30 hours as the least conservative limit per year. On the other hand, the most conservative criterion suggests no impacts on any residence or business in the area of interest. A site specific regulation can be developed within these upper and lower bounds taking into consideration various factors such as land use (residential, commercial, industrial), density of population (urban or rural) and community acceptance.

A summary of possible signal interference effects is also provided in this report. No setback distances are generally provided to counter signal interferences. Many regulations require interference to considered and minimized. But we suggest that the wind turbine not interfere with signal transmission or reception of existing fixed broadcast, retransmission, or reception antennas for radio, television, or wireless phone or other personal communication system.

Acknowledgements

We thank Dr. Malcolm Spaulding for providing valuable suggestions throughout this study. We also would like to thank Dr. Annette Grilli for her thoughtful comments. The inputs from Daniel Mendelsohn and Alex Crosby from Applied Science Associates (ASA) are also thankfully acknowledged. The valuable suggestions provided by the three reviewers have been instrumental in improving the quality of this report.

REFERENCES

Burton (2001), Wind Energy Handbook

Danish Wind Industry Association, *Refining Shadow Calculations for Wind Turbines*, www.windpower.org

Lester E. Polisky, Identifying and Avoiding Radio Frequency Interference for Wind Turbine Facilities, White Paper, Andrew Corporation, 2005.

Oteri, F., *An Overview of Existing Wind Energy Ordinances*, Technical Report NREL/TP-500-44439, December 2008

Stankovic. S., Campbell. N., and Harries. A., *Urban Wind Energy*, Earthscan Publishers, London, UK, 2009.

Stine, W. B., and Harrigan, R. W., *Power From The Sun*, John Wiley and Sons, Inc. 1986.

RESP TECHNICAL REPORT #8

RHODE ISLAND LANDFILL SOLAR RESOURCE ASSESSMENT AND SCREENING ANALYSIS

By

Tom Boving, Pamela Cady, Danny Musher,

Tiffany Davis, and Christopher Damon

University of Rhode Island,

Kingston Campus

June, 2012

Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

The following screening analysis quantifies estimates of landfill solar potential at 58 sites in Rhode Island. Opportunities and constraints were characterized at all locations based on a host of site suitability criteria. The principal goals of this study were to develop a set of site screening tools, calculate total estimated landfill solar resources in Rhode Island, and to identify landfill sites with the potential to support PV arrays of one megawatt (MW) nameplate capacity or greater. The following steps were taken to complete the analysis:

- Potential natural solar resource availability in Rhode Island was evaluated,
- Subsequently, a spreadsheet tool was developed to quantify a blanket value for PV capacity per area (in MW/acre) in Rhode Island in order to produce an estimate of energy potential for each landfill in Rhode Island, and
- Finally, landfill site suitability was summarized for all sites.

This analysis applied data and information from a variety of sources, including published meteorological datasets, landfill site investigation and site assessment reports, communication with the Rhode Island Department of Environmental Management (RIDEM), Rhode Island Geographic Information System (RIGIS) land use data, and original EXCEL-based spreadsheet tools.

2. SOLAR RESOURCE ASSESSMENT

The available solar resource at a location is measured in terms of irradiance, or power per area (watts/m2). Solar radiation absorbed at the earth’s surface varies both geographically and over time due to a diversity of factors including topography, weather, time of day, season, latitude, and the changing distance and orientation between the earth and sun.

Analysis of solar resources in Rhode Island shows that average annual daily solar insolation is between 3.5 and 4.0 kWh/m2/day, when measured at a south-facing fixed tilt equal to latitude. The US EPA and NREL consider sites with > 3.5 kWh/m2/day to be good candidates for solar energy generation (EPA and NREL no date). The EPA observes, however, that utility scale photovoltaic generation optimally requires ≥ 5 kWh/m2/day (EPA 2011(b)). Even so, “with the right mix of targeted policies, utility-scale solar generation is possible anywhere the sun shines” (EPA 2011(c)). Although modest compared to other regions of the country, Rhode Island’s solar resource represents viable potential, particularly when accounting for state incentives.

To conduct the solar resource assessment, solar radiation data was accessed through the National Renewable Energy Laboratory (NREL), the principal research laboratory for the U.S. Department of Energy’s (DOE) Office of Efficiency and Renewable Energy (EERE). NREL’s National Solar Radiation Data Base contains ‘Typical Meteorological Year’ (TMY) datasets, which describe typical weather conditions at stations located throughout the United States. The most recent TMY dataset spans the period between 1991 and 2005 (TMY3) (NREL no date(b)).

TMY data consists of meteorological data and metrics taken hourly over the course of an average year. To create these files NREL combines in-depth measurements over a 30 year period. The cumulative data is broken into monthly datasets and processed. For each month, the dataset which is closest to the statistical average is selected as the representative in the typical meteorological year (NREL no date(c)). This is based on five criteria: global horizontal radiation, direct normal radiation, dry bulb temperature, dew point temperature, and wind speed. These were chosen based on their importance in simulating renewable energy systems (Wilcox, S. and Marion, W. 2008). The datasets are a serially complete and normalized collection of meteorological information. However, they do not provide information about extremes.

TMY3 data for Rhode Island is collected daily at meteorological stations in four state locations: Block Island, Newport, TF Green Airport in Warwick, and Pawtucket, RI. Average annual daily insolation (kWh/m^2) values are: 3.63 (Pawtucket), 3.49 (Block Island), 3.74 (Providence), and 3.75 (Newport) for global insolation (**Error! Reference source not found.**). The difference in total annual insolation measured at the four stations is marginal (range = 0.26 kWh/ m^2), suggesting that solar resources are relatively homogenously distributed throughout the state. The solar resource does vary significantly, however, throughout the year, as would be expected with the changing seasons. At T.F. Green Airport, for example, insolation values range from a low of 1.61 kWh/m^2 per day during winter months to a high of 5.89 kWh/m^2 during the summer (range = 4.28 kWh/ m^2).

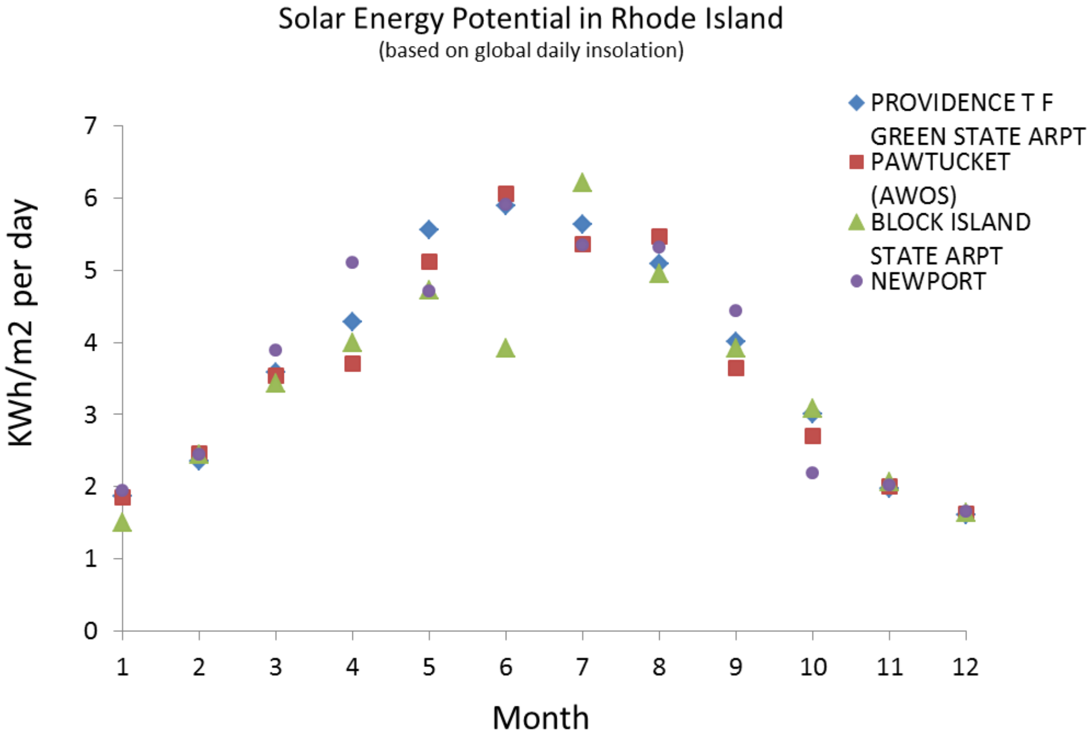


Figure 1. Solar Energy Potential in Rhode Island.

Table 1. Rhode Island Solar Insolation (Derived from NREL).

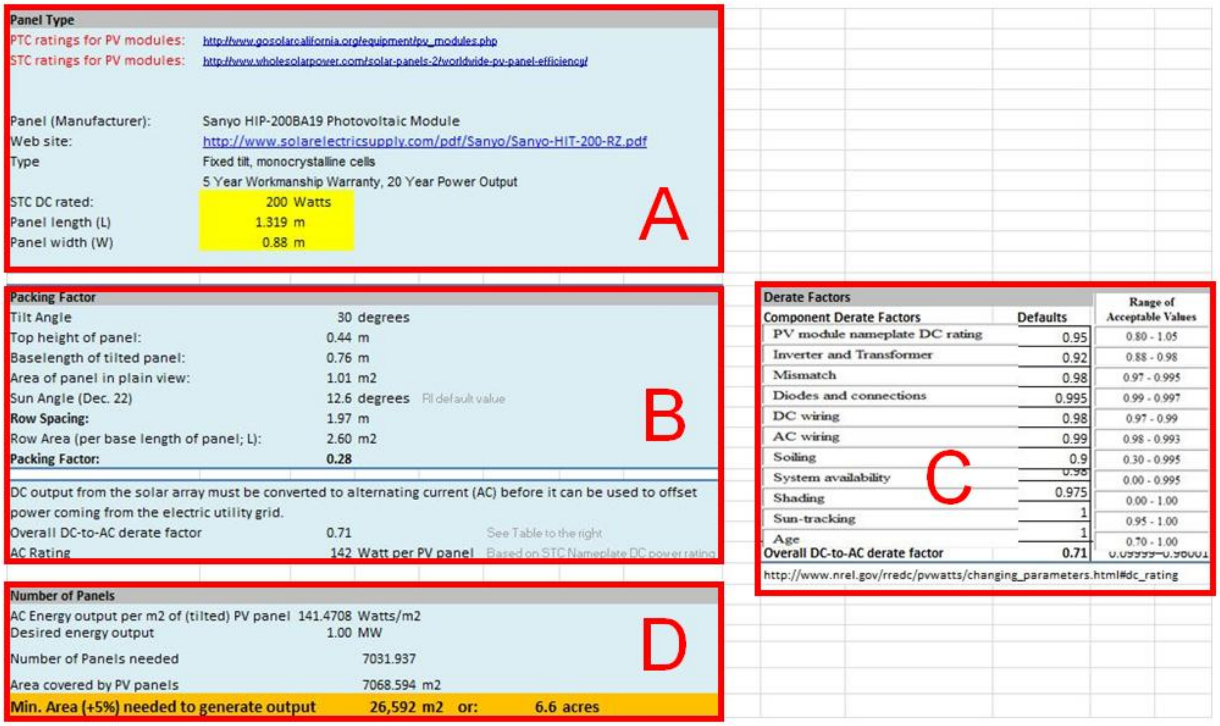
Typical Meteorological Year (TMY3) Values													
Total Global Horizontal Insolation (GHI) Watt-hours per square meter (kWh/m^2)													
TMY3 Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Pawtucket (AWOS)	57.48	76.24	109.52	115.05	158.77	187.87	166.00	169.62	113.04	83.96	62.25	50.43	1350.22
Block Island State Airport	46.59	75.84	106.44	123.65	146.40	121.34	192.62	153.27	121.57	95.62	63.86	51.01	1298.20
Providence T.F. Green State Airport	57.76	73.10	111.01	132.73	172.13	182.56	174.46	157.75	124.11	93.37	61.19	49.81	1389.98
Newport	60.45	75.99	120.28	158.31	145.75	183.22	165.71	164.79	137.31	67.63	62.66	51.50	1393.60
Average	55.57	75.29	111.81	132.44	155.76	168.75	174.70	161.36	124.01	85.15	62.49	50.69	1358.00
Average Daily Global Horizontal Insolation (GHI) kilo Watt-hours per square meter (kWh/m^2)													
TMY3 Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Pawtucket (AWOS)	1.85	2.46	3.53	3.71	5.12	6.06	5.35	5.47	3.65	2.71	2.01	1.63	3.63
Block Island State Airport	1.50	2.45	3.43	3.99	4.72	3.91	6.21	4.94	3.92	3.08	2.06	1.65	3.49
Providence T.F. Green State Airport	1.86	2.36	3.58	4.28	5.55	5.89	5.63	5.09	4.00	3.01	1.97	1.61	3.74
Newport	1.95	2.45	3.88	5.11	4.70	5.91	5.35	5.32	4.43	2.18	2.02	1.66	3.75
Average	1.79	2.43	3.61	4.27	5.02	5.44	5.64	5.21	4.00	2.75	2.02	1.64	3.65

3. "ESITIMATION OF PHOTOVOLTAIC ENERGY POTENTIAL OF RHODE ISLAND LANDFILL SITES" SPREADSHEET TOOL

To calculate the acreage required to support one megawatt (MW) of solar generating capacity on Rhode Island landfills, an EXCEL spreadsheet tool was developed, entitled "Estimation of Photovoltaic Energy Potential of Rhode Island Landfill Sites". The spreadsheet produces an estimate of acreage needed to produce one MW of photovoltaic solar power using information on panel type, packing factor, derate factors, and number of panels. A screenshot of the spreadsheet tool can be seen in Figure 2, and the complete spreadsheet can be found in Appendix B.

The section below describes how values for these inputs were determined. This study only assessed fixed rigid and flexible panels; spreadsheet tools were developed to account for the difference between rigid and flexible panel technology. Concentrating PV panels or sun tracking systems were not considered because of their cost, space, and weight incompatibility with landfill applications (Sampson, G. 2009).

The results of this analysis determined that approximately 6.6 acres are required to generate one MW of nameplate power (using approximately 7,032 panels) in Rhode Island. Using less conservative values for the inputs in the spreadsheet tool, such as higher efficiency PV models or less stringent margins of error, would reduce the required acreage accordingly. The results of this analysis are in line with the data from existing solar facilities sited on landfills. A review of data from 9 currently operating landfill solar sites in the northeastern United States found a range of 4 – 12 acres per MW, with an average of 7 acres per MW (Appendix C). More recent anecdotal information from solar energy companies suggests requirements of 4 to 5 acres per MW in the New England area. A survey of four PV systems in the northeast region showed that those facilities required the installation of 3,231 to 5,135 rigid panels per megawatt (average: 4,047 panels/MW) (Appendix C).



Panel Type		
PTC ratings for PV modules:	http://www.gosolarcalifornia.org/equipment/pv_modules.php	
STC ratings for PV modules:	http://www.wholesolarpower.com/solar-panels-2/worldwide-pv-panel-efficiency/	
Panel (Manufacturer):	Sanyo HIP-200BA19 Photovoltaic Module	
Web site:	http://www.solarelectricsupply.com/pdf/Sanyo/Sanyo-HIT-200-RZ.pdf	
Type	Fixed tilt, monocrystalline cells	
	5 Year Workmanship Warranty, 20 Year Power Output	
STC DC rated:	200	Watts
Panel length (L)	1.319	m
Panel width (W)	0.88	m

Packing Factor			
Tilt Angle	30	degrees	
Top height of panel:	0.44	m	
Baselength of tilted panel:	0.76	m	
Area of panel in plain view:	1.01	m2	
Sun Angle (Dec. 22)	12.6	degrees	RI default value
Row Spacing:	1.97	m	
Row Area (per base length of panel; L):	2.60	m2	
Packing Factor:	**0.28**		

DC output from the solar array must be converted to alternating current (AC) before it can be used to offset power coming from the electric utility grid.

Overall DC-to-AC derate factor	0.71		See Table to the right
AC Rating	142	Watt per PV panel	Based on STC Nameplate DC power rating

Derate Factors		
Component Derate Factors	**Defaults**	**Range of Acceptable Values**
PV module nameplate DC rating	0.95	0.80 - 1.05
Inverter and Transformer	0.92	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.9	0.30 - 0.995
System availability	0.98	0.00 - 0.995
Shading	0.975	0.00 - 1.00
Sun-tracking	1	0.95 - 1.00
Age	1	0.70 - 1.00
Overall DC-to-AC derate factor	0.71	0.09999–0.96001

http://www.nrel.gov/rredc/pvwatts/changing_parameters.html#dc_rating

Number of Panels				
AC Energy output per m2 of (tilted) PV panel	141.4708	Watts/m2		
Desired energy output	1.00	MW		
Number of Panels needed	7031.937			
Area covered by PV panels	7068.594	m2		
Min. Area (+5%) needed to generate output	**26,592**	**m2**	**or:**	**6.6 acres**

Figure 2. Spreadsheet Tool for the Estimation of Photovoltaic Energy Potential of RI Landfill Sites

3.1 Panel Type

Power capacity calculations require information about the type of PV panel, including dimension and efficiency ratings. In Section A (seen in Figure 2), "Panel Type", the user can choose a specific PV model brand and input model specifications. There are several links to websites that aid the user in selecting currently available PV models by efficiency and manufacturer. The user may need to visit the manufacturer's website to obtain the technical PV product details. For this analysis, the Sanyo HIP-200BA19 (200W) brand module was chosen as the rigid panel model. This PV module has a 19% efficiency rating, which is higher than most other panels on the market today (Sanyo Corp 2008). For an example for the analysis of flexible PV laminates on south-facing side slopes, a Solyndra SL-200-220 (220W) solar panels with efficiency ratings of 8.85% was used (SolarDesignTool.com 2012).

3.2 Packing Factor

The capacity of a PV array is directly proportional to the number of panels in that array. The number of panels depends in turn on assumptions about "packing factor", a value describing the ratio of land area covered by PV modules to the total amount of land area used for the solar array (see section B in Figure 2). The packing factor value represents space not covered by PV panels to account for shading effects and space requirements for maintenance and equipment. For example, the "ideal" packing factor is 1.0, meaning that the entire area is covered by solar panels. Such a high packing factor, however, cannot be realized in Rhode Island and similarly high latitude areas. This is because of the lower azimuth of the sun relative to the equator, where a packing factor of 1.0 is theoretical possible. A lower sun angle results in shading of adjacent panels, which needs to be avoided by spacing them farther apart. For Rhode Island, packing factors around 0.3 are typical (e.g. Stafford et al. 2011). In this analysis a packing factor of 0.28 was used, which means that 28% of the area is covered by PV modules while 72% is open space, i.e. the space between the PV modules. The packing factor value can be used to determine the maximum number of PV panels that can be placed on the landfill top deck (Stafford et al. 2011). This, in turn, is used to calculate the amount of power that can be generated on any given landfill acreage.

Section B, "Packing Factor" in the spreadsheet tool allows the user to determine a value for packing factor. For this analysis, packing factor is calculated by dividing row spacing of panels by row-to-row spacing of panels. Row-to-row spacing designates the distance from the upper edge of the front panel to the upper edge of the next row of panels (Figure 8) (Stafford et al. 2011). Row spacing designates the distance from the top edge of the front panel to the bottom edge of the next row of panels. Spacing between panel rows permits access for maintenance and repair of the PV array and for mowing vegetation (Stafford et al. 2011). Row-to-row spacing and row spacing are determined by variables such as the tilt angle of the panels, panel size, and sun angle.

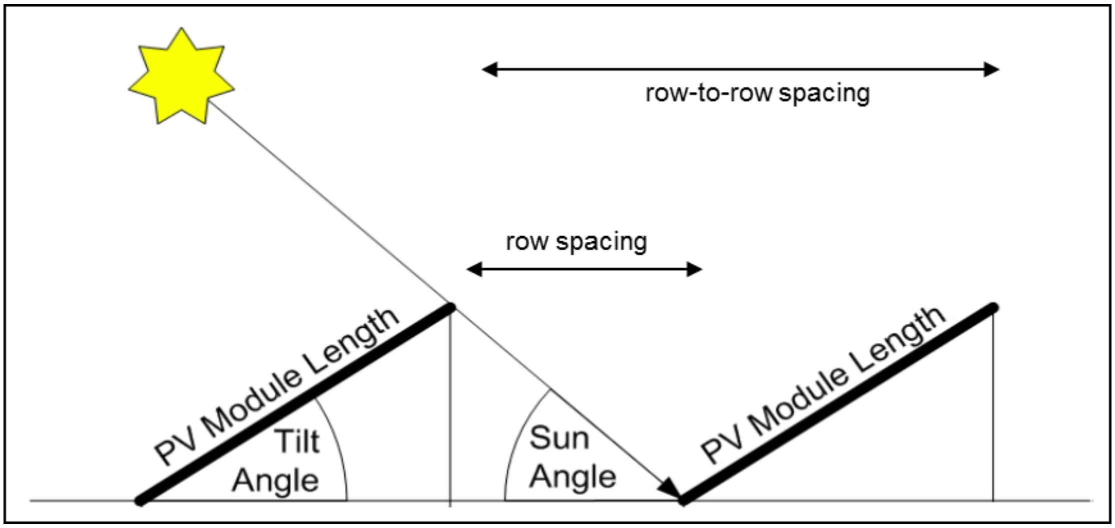
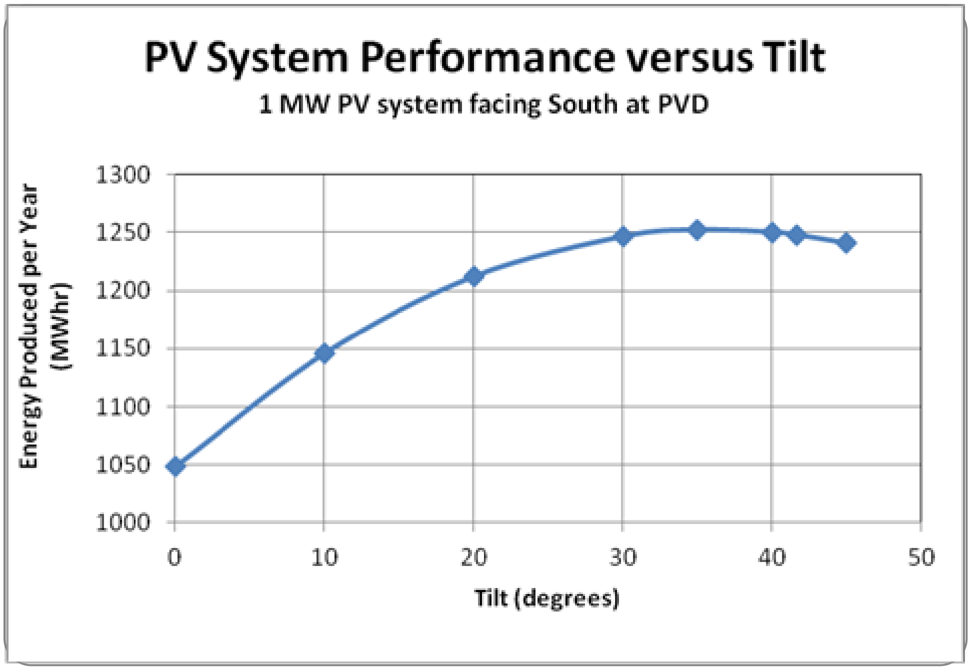


Figure 3. Calculating Packing Factor (Adapted from Stafford et al., 2011)

3.2.1 Tilt

Results from a study on Cape Cod at the Otis Air National Guard Base demonstrated that a 30° tilt angle for rigid panels maximizes energy yield while minimizing wind loading issues (Stafford et al. 2011). TF Green Airport in Warwick, RI (latitude 41.4°) is approximately due west of Otis Air National Guard Base (latitude: 41.7°), making tilt calculations essentially equal for these two study locations. Therefore, a 30° tilt angle was used for calculations in this report (Figure 4).



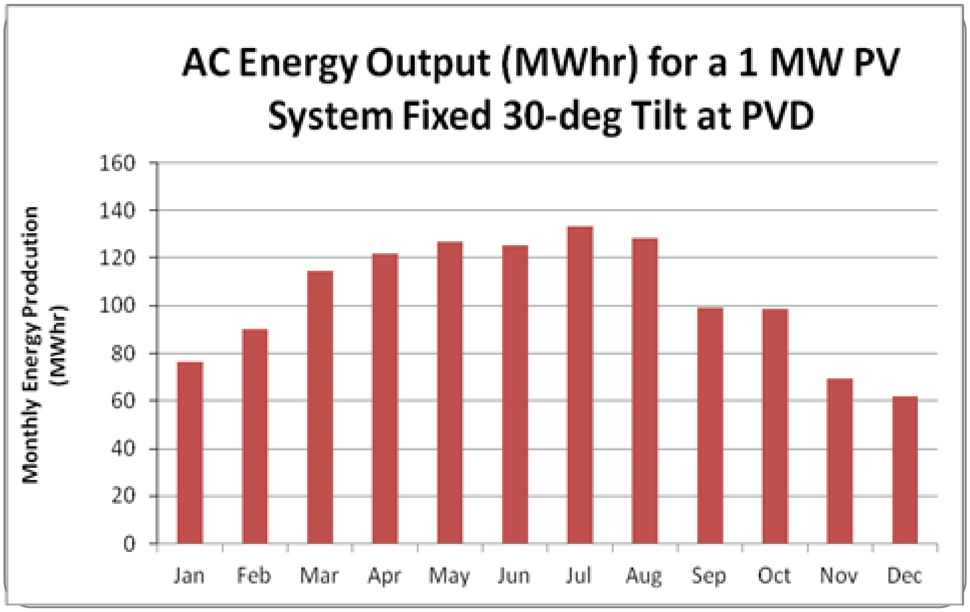


Figure 4. A) Solar Panel Tilt of 30° to 40° Maximizes Annual Solar Energy Production (Data from PVWATTS 2.0) (NREL. 2011(b); Stafford et al. 2011); B) Peak Solar Energy Production in Providence occurs in July.

3.2.2 Panel Size

Dimension specifications of the panel are determined by information input in the first section of the spreadsheet tool “Panel Type”.

3.2.3 Sun Angle

In this study, the packing factor was set to maximize winter solar gain, meaning panels do not shade the row of panels behind them even when the sun is lowest in the sky, on December 22nd each year (for the northern hemisphere). Arguments could be made for sacrificing winter solar gain by allowing some winter shading (Stafford et al. 2011; MassDOER 2012). This would reduce the amount of acreage needed for the rigid panel system or, in other words, result in greater energy output per area. There are economic reasons for sacrificing winter production for greater energy output during summer. For instance, electricity pricing is higher during peak load times such as summer afternoons (Newsham, G.R. and Bowker, B.G. 2010). These are times when air conditioning (a particularly sizeable energy load) demand is highest. Winter peaking, on the other hand, tends to happen during early mornings and evenings, which is less advantageous for solar power generation (Newsham, G.R. and Bowker, B.G. 2010). Optimizing the summer packing factor for a given site may therefore result in quicker financial break-even point on the PV investment.

3.3 Derate Factors

Section C, “Derate Factors”, specifies energy losses due to factors such as module age, shading, soiling from dirt and snow cover, power losses in wires, etc. Together, these derate factors determine expected system power losses and the actual power output per panel (NREL. 2011(a)). Default derate factors were defined for this study, which closely resemble those used by NREL. A link to the NREL site where these factors are explained in greater detail is provided.

3.4 Number of Panels

In Section D, “Number of Panels”, the number of PV panels and acres needed to produce one megawatt of power are calculated. One MW was set as the default for this study, however, users can alter desired energy output. For instance, setting this parameter to 0.5 MW would decrease the acreage requirements, allowing smaller landfills to meet minimum power specifications.

4. LANDFILL SOLAR SITE SUITABILITY SCREENING ANALYSIS

The following screening analysis provides an estimate of landfill solar resources in Rhode Island and an assessment of the feasibility of developing those resources. A screening methodology was developed to evaluate site suitability characteristics that could determine the degree of compatibility of a landfill with solar development.

4.1 Methodology

In order to quantify what portion of Rhode Island landfill acreage represents areas likely suitable for landfill solar development, a discrete unit of analysis was required. The most practical way to delineate the border of each landfill site for quantitative analysis was to use parcel information associated with each landfill site. In many instances, the landfill parcel may be larger than the area designated specifically for waste disposal. Therefore, although this study focuses on siting opportunities and constraints for PV arrays on closed landfills, an assumption was made that the siting of a landfill solar project could conceivably occur anywhere within the limits of the landfill parcel.

The raw acreage information defined by the parcel boundary, however, does not provide information on whether that area is suitable for solar development. For example, the center of waste disposal at a landfill site may only occupy a small portion of that landfill parcel. The rest of the parcel may contain a heterogeneous assortment of land uses, such as forested area or agricultural land. Although projects might not necessarily have to be necessarily confined to the location of waste disposal, they do need to be sited on suitable locations within the parcel. Therefore, a strategy was developed to determine what areas within the parcel might best be suitable for developing landfill solar power.

Two primary site suitability criteria were selected to provide an initial screening of the sites: topography and land use class (Table 2). The primary site suitability criteria were used to narrow down total and site-specific landfill area to likely suitable spots for landfill solar development. The remaining acreage—with appropriate slopes and land uses—represents an estimate of potential area for solar development. Using the assumptions of packing factor described in the previous section, this acreage value could be converted to a MW potential value. Finally, a host of secondary site suitability criteria were used to classify the landfill sites according to expert knowledge at the RIDEM Landfill Closure Program.

Table 2. Landfill Solar Site Suitability Screening Criteria

Screening Criteria	Description	Source
Slope gradient	Acreage with less than 3% slope (conservative)	GIS analysis (URI Environmental Data Center)
Slope gradient	Acreage with less than 6% slope (less conservative)	GIS analysis (URI Environmental Data Center)
Land use class	"Appropriate" land uses: • Waste Disposal • Agricultural • Brush • Vacant	RIGIS
Average Energy Output per Unit Landfill Area	1 MW photovoltaic power per 6.6 acres	See Section 0 "Esitimation of Photovoltaic Energy Potential of Rhode Island Landfill Sites" Spreadsheet Tool
Site Suitability	"Secondary" Site Suitability Criteria • Location • Site Control • Remediation Requirements • Presence of Cap • Reuse	RIDEM Landfill Closure Program

4.2 Study Sites

A total of 87 landfill sites in Rhode Island were identified in cooperation with the Rhode Island Department of Environmental Management (RIDEM) Landfill Closure Program (LCP). In order to quantitatively screen sites according to resource availability and site suitability criteria, site parcel information was required. Only sites for which GIS parcel data was available were included in this screening analysis. A total of 58 sites (comprising 2,787.6 acres) for which sufficient parcel data existed were analyzed. These landfill sites are displayed on the map in Figure 5.

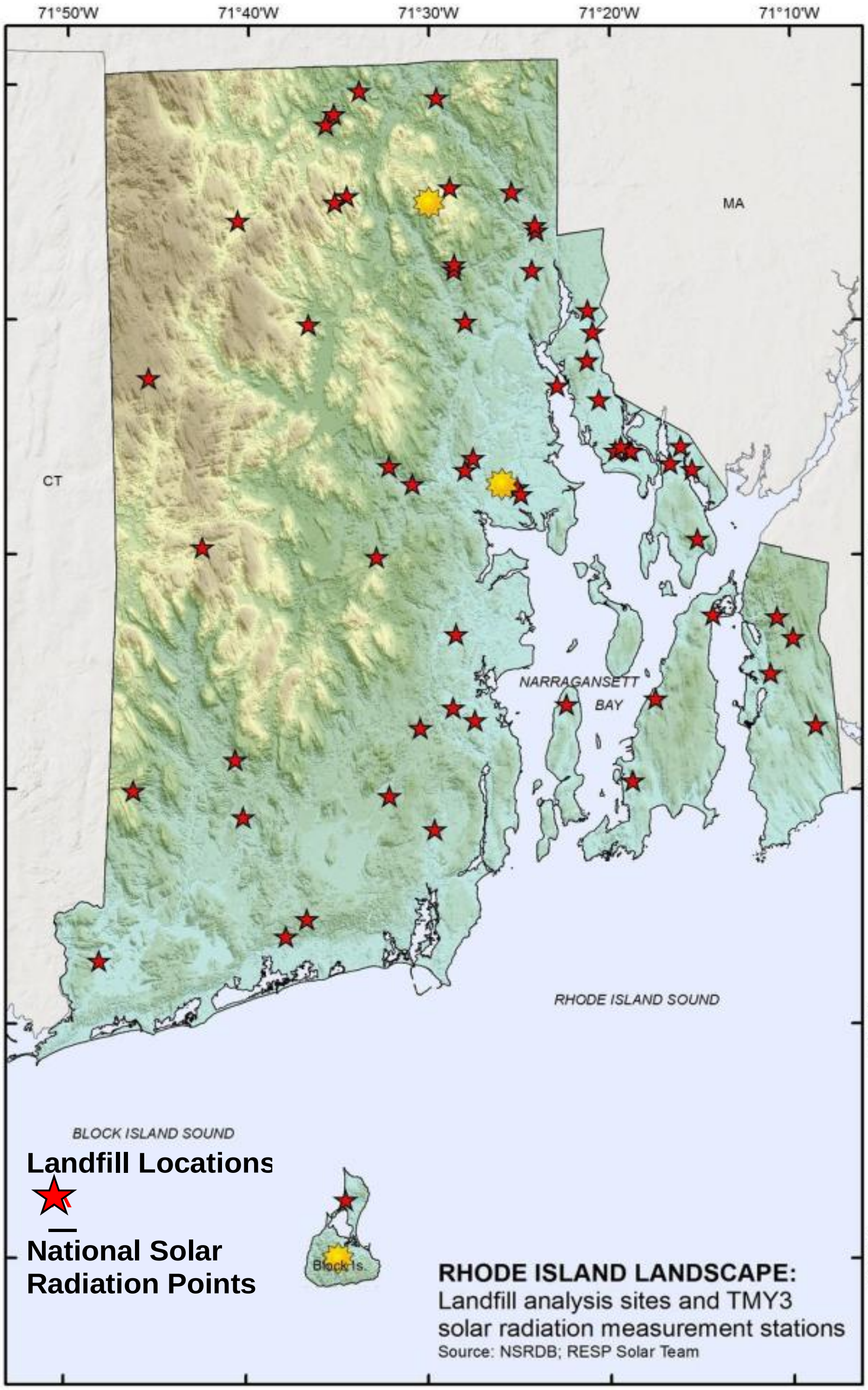


Figure 5. Rhode Island Landfill Sites and Solar Measurement Stations

Of the 87 landfills in Rhode Island, the vast majority are landfills that no longer accept waste. According to the 2006 Rhode Island Resource Recovery Corporation (RIRRC) Statewide Comprehensive Plan, the Central Landfill accepted accepts nearly 100% of the municipal solid waste stream, with a small fraction disposed at the Tiverton Landfill (RIRRC 2006). Although it is possible to build solar arrays on closed and capped portions of currently operating landfills, that option was not included in this assessment. As of the writing of this report, RIRRC was investigating solar development options for closed sections of the Central Landfill (Card, B. 2011. Personal communication). Therefore, the Central Landfill was omitted from the screening analysis. This analysis focuses on the much smaller municipal dump and landfill sites found throughout the state, as well as some sites listed on the National Priorities List. Many of these landfill sites have been out of operation for decades (RIDEM 2007).

4.3 Site Suitability: Topography

Optimizing PV system design, performance and cost is dependent on site-specific topographical parameters. Unobstructed south-facing exposure is required for the panels and level topography helps ensure structural integrity of the system.

Based on topographical data, areas most suitable for locating PV systems were identified within each landfill parcel. Suitable "flat" acreage was quantified using slope gradient analysis performed with GIS software. Areas with appropriately gentle slopes and areas with south-facing slopes were identified. These areas are likely the most valuable for solar PV generation.

4.3.1 Cap Top Deck Area & Slope

Two slope gradient scenarios were considered: A) excluding all areas with a slope greater than 3%; B) excluding all areas with a slope greater than 6%. Scenario A represents a more conservative approach to screening the available area suitable for solar development. Scenario B explores the effect of opening up more potential area to solar development.

Figure 6A shows the results of excluding all areas with slopes greater than 3%. Land shaded black represents area not suitable for siting PV systems. Figure 6B summarizes the results of excluding all areas with slopes greater than 6%. This alternative scenario opens up more land for siting PV systems.

Figure 6. A) Slopes Greater than 3%; B) Slopes Greater than 6% (Forbes St. Landfill, East Providence)

It should be noted that the "flat" areas identified within each parcel are not necessarily contiguous. For example, in Figure 7, it can be seen that the topography of the parcel is quite heterogeneous and no evident smooth gradients exist. Therefore, discrepancies may exist between the estimated values for total "flat" area available and the actual suitable area for constructing a PV system. The analysis did not consider any potential grading or in-fill that might be judged economical by a developer to increase the amount of suitable area at a site.

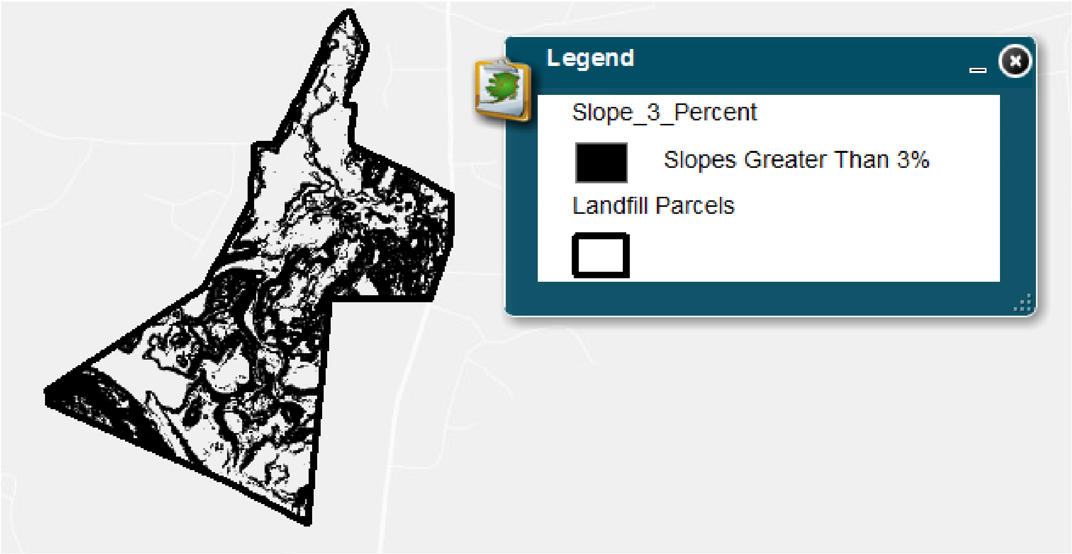


Figure 7. Non-contiguous Slopes Greater than 3% (Pine Road Hill Dump, Richmond)

4.3.2 Landfill Side Slopes

In addition to areas with slopes less than 6%, the south-facing aspects (up to 150 - 210 degrees) of landfills were examined as potential locations for installing flexible PV panels. Because flexible panels cannot track the sun, their efficiency drops on slopes that face less than 150° south or more than 210° south. Figure 8A shows areas facing ±15 degrees of due south. Figure 8B shows areas facing ± 30 degrees of due south.

Figure 8. A) Slope Aspect 15 Degrees; B) Slope Aspect 30 Degrees (Forbes St. Landfill, East Providence)

As in the slope gradient analysis, south-facing slopes identified within each parcel are not necessarily contiguous. For example, in Figure 9, it can be seen that the topography of the parcel is quite heterogeneous and no evident contiguous slopes exist. Therefore, discrepancies may exist between the calculated values for total south-facing slope area available and the actual suitable area for applying flexible PV laminates.

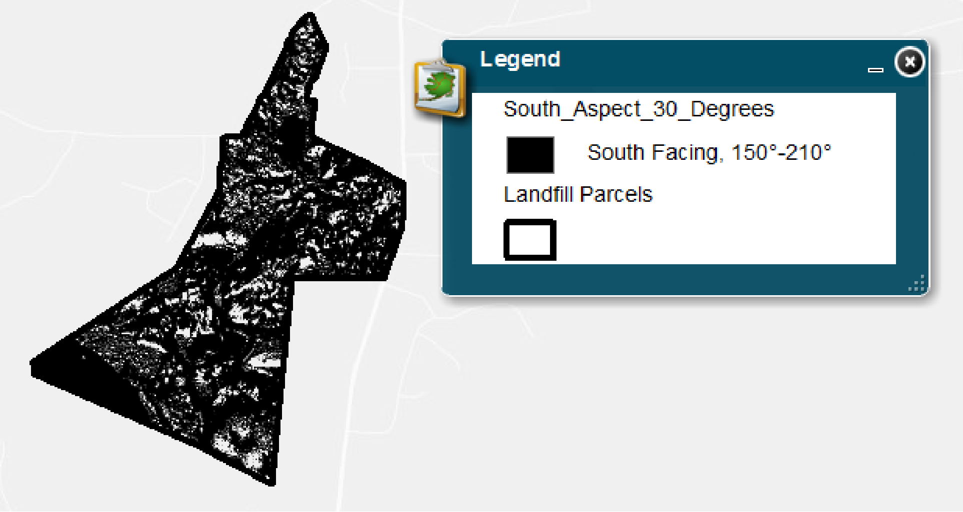


Figure 9. Non-contiguous South Aspect 30 Degrees (Pine Road Hill Dump, Richmond)

4.4 Site Suitability: Land Use Class

Many landfill sites in Rhode Island have been repurposed for one or more new uses, rendering the area unsuitable for solar development. In order to characterize the current use(s) of each landfill parcel, information was harvested from a land use classification system employed by the Rhode Island Geographic Information System (RIGIS). Aerial data from RIGIS was used to quantify the relative area occupied by each constituent land use class within the landfill parcels. This strategy helped zero in on areas most suitable for landfill solar by enabling a segregation of land use classes deemed incompatible with solar development from those deemed compatible.

Land use classes at Rhode Island landfills vary from site to site and include uses such as forested land, brushland, wetlands and open water, commercial and residential uses, and currently active waste disposal areas. For the purposes of the screening, land use classes within the landfill parcels that were considered appropriate for solar PV development included: waste disposal, vacant/barren, brushland, and agricultural land use classes. These “appropriate” land use classes are shaded in Table 2. Land use classes that were excluded from final analysis were forest, commercial/industrial/institutional, infrastructure, recreation, residential, wetland, and water.

Not all assumptions related to land use class information employed in this study may pass muster on the ground. For example, the land use class “waste disposal” includes both inactive waste disposal sites as well as active transfer stations (Figure 10). The former is ideal for PV development; the latter not. Even at inactive waste disposal sites, adequate documentation delineating the actual extent of area containing disposed waste is lacking (Grady, T. 2011. Personal communication; Grady, T. 2012. Personal communication). Finally, although this study chose to include and exclude certain land use classes, there may be an interest on the part of a community, developer, or agency to develop PV on one of the land use classes excluded in this study. For example, it is possible that cutting trees might be deemed economical or desirable in some instances. In this case the “forest” land use class would be appropriate for solar development.

Table 3. Land Use Classes ("Appropriate" classes are shaded)

Group Name	Land Uses that Fall within the Group
Agriculture	Confined Feeding Operations, Cropland (tillable), Orchards, Groves, Nurseries, Pasture (agricultural not suitable for tillage)
Brush land	Shrub and brush areas, Reforestation, Abandoned fields and orchards
Commercial, Industrial, Institutional	Cemeteries, Commercial, Commercial/Residential Mixed, Industrial (manufacturing, design, assembly, etc.), Institutional (schools, hospitals, churches, etc.)
Forest	Hardwood → Mixed → Softwood Forest
Infrastructure	Airports (and associated facilities), Other Transportation (terminals, docks, etc.), Power Lines (100' or more width), Railroads (and associated facilities), Roads (divided highways >200' plus related facilities)
Recreation	Beaches, Developed Recreation (all recreation)
Residential	anywhere from <1/8 acre to 2 acre lots (High Density to Medium Low Density Residential)
Vacant, Barren	Mines, Quarries and Gravel Pits, Mixed Barren Areas, Rock Outcrops, Sandy Areas (not beaches), Transitional Areas (urban open), Vacant Land
Waste Disposal	Waste Disposal (landfills, junkyards, etc.), Water and Sewage Treatment. Note: some areas may be capped (Figure 10A) while others may be currently active (Figure 10B).

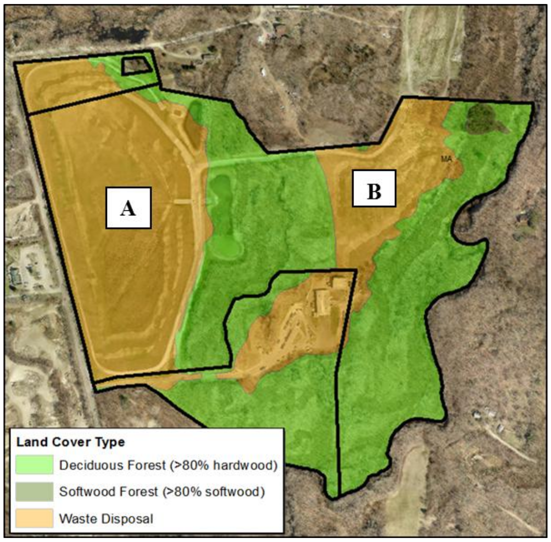


Figure 10. Waste Disposal Land Use Class A) Capped Landfill; B) Active Transfer Station (Rose Hill Regional Landfill, South Kingstown)

4.5 Results

Figure 11 displays the landfill solar power potential estimates after screening by 3% and 6% slope and "appropriate" land uses. Available acreage was directly converted to MW potential via the relationship described in the previous section (1 MW of photovoltaic solar capacity = ~6.6 acres). Expanding land coverage from less than 3% slope to less than 6% slope increased megawatt potential, but only enough to marginally alter the distribution of landfills within capacity range categories (Figure 11). Therefore, final results are reported for the <6% slope category.

The screening indicates that 37 landfills in Rhode Island could support the generation of at least 1 MW of solar power each (Table 4). Additionally, 4 landfills could generate between 0.5 MW and 1 MW of power each (Table 5), 5 landfills could generate between up to 0.5 MW of power each (Table 6), and 16 landfills had no potential to generate solar power based on the slope and land use criteria used (Table 7). Twenty-five landfills lacked sufficient data for inclusion in the screening (Table 8).

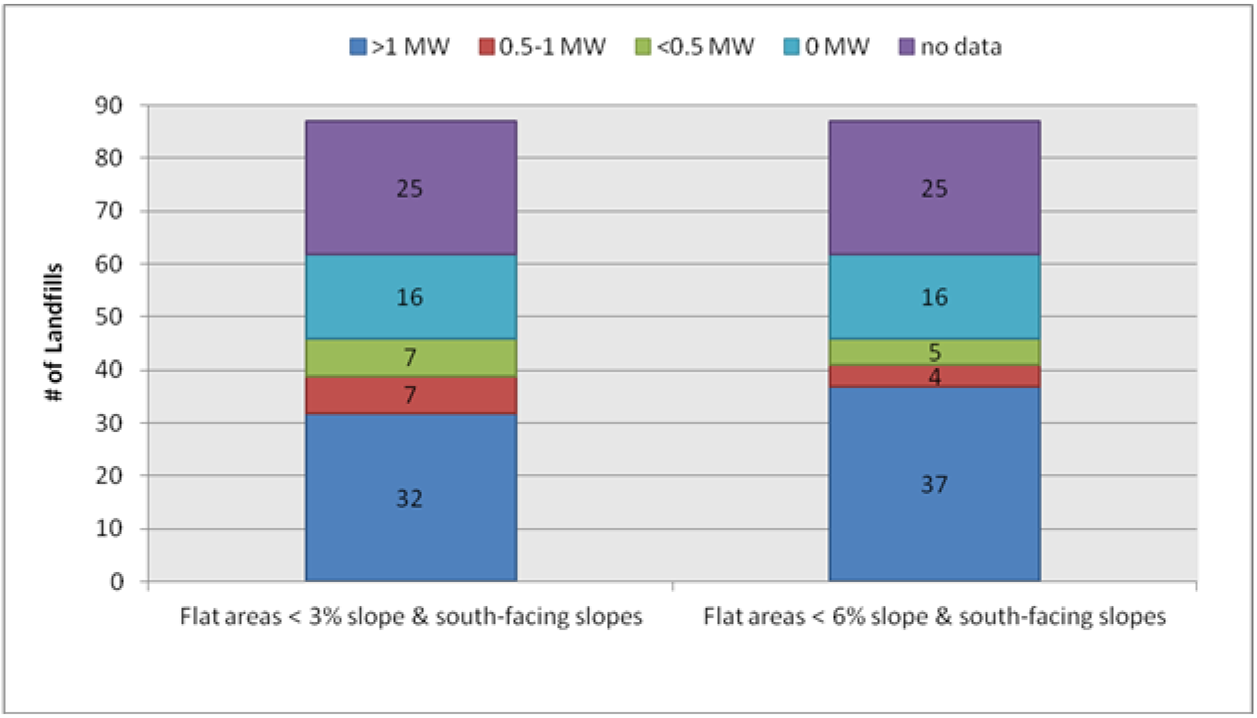


Figure 11. Rhode Island Solar Landfill Power Potential by Capacity

Table 4. Landfills with Potential for > 1 MW Solar Power Generation

Allen Harbor Landfill
Barrington Landfill #3
Bristol Landfill
Burrillville Landfill #1
Burrillville Landfill #2
Charlestown Sanitary Landfill
Coventry Municipal Landfill
Cranston Sanitary Landfill
DAVIS LIQUID WASTE
Fields Point City Dump
Forbes Street Landfill
Foster Landfill
GSR LANDFILL
Hometown Properties Landfill
Hopkinton Landfill
Jamestown Landfill
LANDFILL AND RESOURCE RECOVERY (L&RR)
North Kingstown Landfill #1
North Providence Landfill
Pawtucket Incinerator Residue Landfill
PETERSON-PURITAN
PICILLO FARM
Pine Hill Road Dump
Portsmouth Town Dump
Richmond Town Landfill
ROSE HILL REGIONAL LANDFILL
Tiverton Town Dump
Tiverton Town Landfill #2
Truk Away Landfill
WEST KINGSTON/URI LANDFILL
Westerly Town Landfill
WESTERN SAND AND GRAVEL
Barrington Landfill #4
East Greenwich Landfill
Glocester Landfill
Manton Ave Landfill
Woonsocket City Dump

Table 5. Landfills with Potential for 0.5 - 1 MW Solar Power Generation

Narrow Lane Landfill
Smithfield Town Landfill
New Shoreham Town Landfill
Warwick City Dump

Table 6. Landfills with Potential for 0 - 0.5 MW Solar Power Generation

Cooks Landfill
Hugh Cole School Road Landfill
Newport City Dump
North Kingstown Landfill #2
North Scituate Town Dump

Table 7. Landfills with No Potential for Solar Power Generation

Arkwright Dump
Barrington Landfill #1
Barrington Landfill #2
Central Falls Dump
Elm Tree Dump
Firestone Landfill
Greenwood Avenue Disposal Area
Jamiel Park Landfill
Kent Heights Landfill
Little Compton Town Dump
Lonsdale Narrows
Perry Wood Street
Pontiac Enterprises
STAMINA MILLS
Warren Town Landfill
West Warwick Town Landfill

Table 8. Landfills with Insufficient Parcel Data

A. Macera Disposal Landfill
Cece-Macera Landfill
CENTRAL LANDFILL
CENTREDALE MANOR
Cumberland Municipal Landfill
Dupraw Dump
East Greenwich Dump
Exeter Landfill #1
Exeter Landfill #2
Exeter Town Dump
Gorham Textron Disposal area
Hi-Lo Ciprianos Dump
Hope Town Dump
J. Vinagro Landfill
L. Vinagro Landfill
Narragansett Town Dump
NAVAL CONSTRUCTION BATTALION CENTER
NAVAL EDUCATION AND TRAINING CENTER
Providence City Dump
Rocky Hill Disposal Area
Sachuest Point NWR Landfill
Scituate Town Landfill
Steve Macera Disposal Area
Tuckers Industrial Dump
West Greenwich Town Landfill

The distribution of landfill solar resources in Rhode Island varies significantly across land uses. Figure 12 displays the breakdown of estimated potential solar capacity across ALL land use classes for all landfill parcels (on flat areas < 6% slope and south-facing slopes). Note that Figure 12A has a different scale than Figure 12B (forest and waste disposal land uses). Figure 12B demonstrates that the vast majority of land with potential for solar generation is forested. If all forested areas on landfill parcels were clear-cut, approximately 215 MW of power could be generated. The grand total of landfill solar power potential on all land use areas is 391 MW.

Table 9 shows the total estimated power potential of flat and sloped areas in the land use classes deemed "appropriate" for solar development: waste disposal, agriculture, brushland, and vacant/barren land. Flat areas with less than a 3% slope could generate approximately 63 MW of power, flat areas between 3% and 6% slope could generate approximately 24 MW of power, and that south-facing slopes on all landfills in Rhode Island could generate approximately 24 MW of power. Total power potential on agricultural lands is approximately 10 MW, total power potential on brushland is approximately 14 MW, total power potential on vacant lands is approximately 27 MW, and total power potential on waste disposal land is approximately 60 MW. The grand total of landfill solar power potential on "appropriate" land use areas is approximately 110 MW.

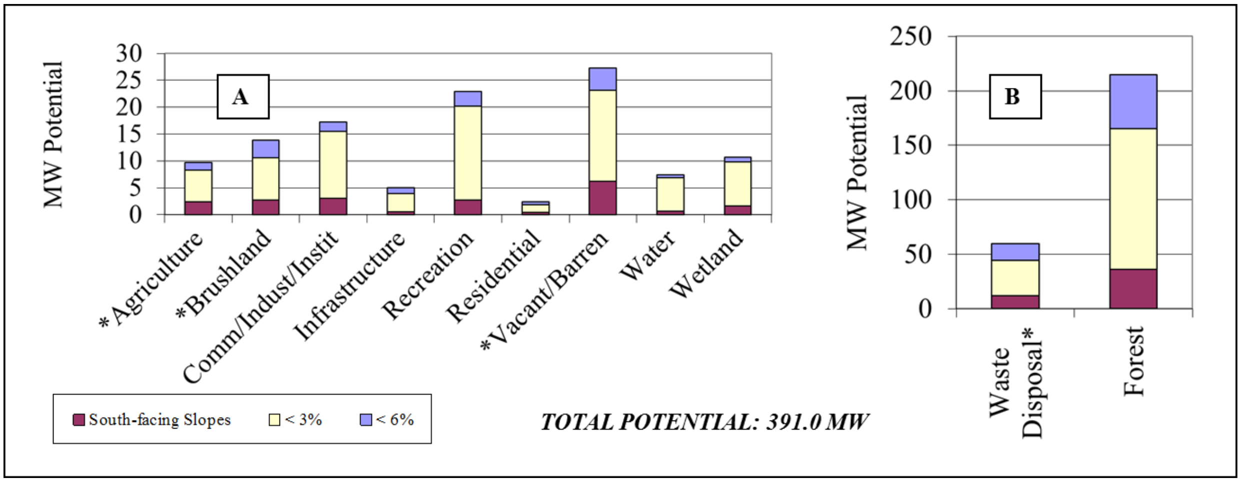


Figure 12. Landfill Solar Power Potential by Land Use Class ("Appropriate" land use classes are starred)

Table 9. Total Landfill Solar Power Potential by Appropriate Land Use Class

	Agricultural	Brushland	Vacant/Barren	Waste Disposal	Total MW Potential
Flat Areas (<3%)	5.8	7.9	16.9	32.6	*63.2*
Flat Areas (3-6%)	1.4	3.2	4.3	15.2	*24.0*
South-facing Slopes	2.4	2.8	6.2	12.1	*23.5*
					Grand Total
Total MW Potential	*9.7*	*13.8*	*27.3*	*59.9*	***110 MW***

Filtering the landfill sites by appropriate slopes and land uses allowed an identification of land areas with high potential for solar development. Despite high solar potential, however, a landfill may not necessarily be immediately suitable for solar development. For example, a landfill parcel might contain a large amount of vacant area on a gently sloping southern exposure. This area, however, may have been developed into athletic fields, or, the landfill may be unreasonably far from a connection point to the electrical distribution grid. Additionally, a waste disposal site may not be currently capped according to RIDEM standards, and could possibly require some form of remediation before development. Finally, the ownership status of the landfill is a key determinant of acquiring site control, consequently, some landfills may be easier to develop than others depending on who owns the site.

Therefore, the landfills were further classified by several site suitability characteristics identified in partnership with RIDEM. These measures of site suitability help gauge the ease of bringing high-potential sites to “shovel-ready” status for solar development. The following site suitability screening criteria were selected:

- Location: Urban/suburban or rural location provides a generalized sense of interconnection feasibility.
- Site Control: Site control must be obtained in order to develop a landfill for solar. Private ownership versus municipal ownership implicates different sets of barriers to establishing necessary site control.
- Remediation Requirements: Listing on the National Priorities List (NPL) indicates that significant remediation would likely be required at the landfill site.
- Presence of Cap: Presence of a cap is a prerequisite for constructing PV systems on the portion of a site containing disposed waste.
- Reuse: Current use is an indicator of whether the landfill is available for solar development or whether the landfill has been repurposed for another use (or plans exist to repurpose it in the future).

4.5.1 Location

Landfill sites were evaluated for proximity to grid infrastructure and population centers. Sites closer to higher capacity distribution or transmission lines provide a greater ease of interconnection to the electrical grid. EPA and NREL use a value of 0.5 miles as the maximum feasible interconnection distance (EPA and NREL no date). On a site-specific level, however, ease of connection to Rhode Island's electrical grid depends on a variety of factors including distance to the nearest line, capacity of the line, and current load on that line. Much of this information can be obtained by the electric distribution company. In Rhode Island, National Grid services virtually all of the state. As of the time of this writing, information was being gathered in conjunction with National Grid to provide interconnection data on a state level.

Pending more specific information by National Grid, an indicator was developed and assigned to each landfill in partnership with RIDEM Landfill Closure Program staff. Landfills were classified as either urban/suburban or rural: The value "U" signifies a urban/suburban location; while the value "R" signifies a rural location. Both indicators can be used as a proxy for distance to higher capacity electrical distribution lines and/or population centers. Twenty-four of the landfills are considered to be in rural locations, while 39 are in urban or suburban location, 3 are in mixed use areas and 21 have insufficient data (Figure 13). Figure 14 shows the breakdown of interconnection feasibility by capacity class.

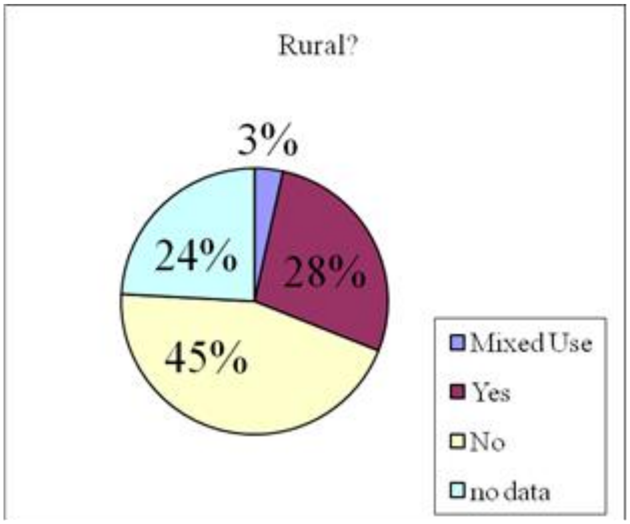


Figure 13. Urban & Rural Landfills in Rhode Island

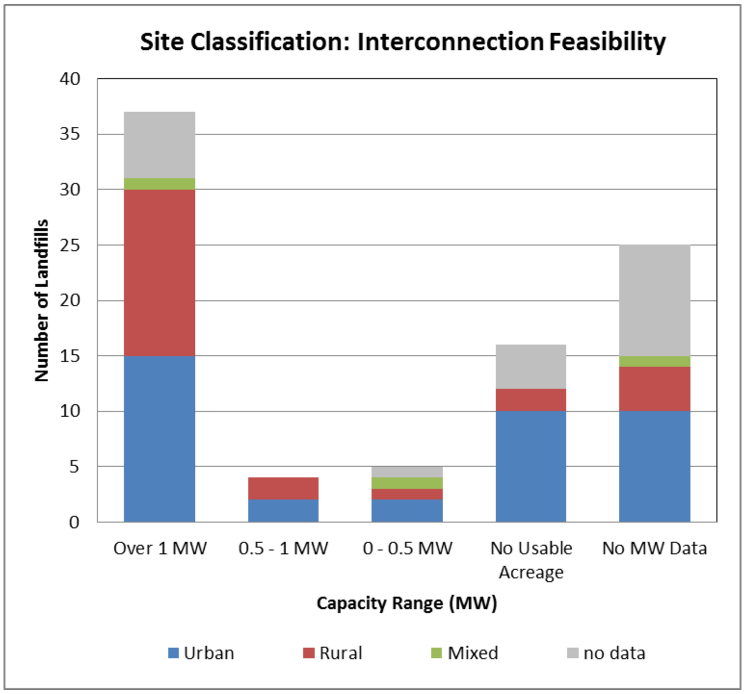


Figure 14. Site Classification: Interconnection Feasibility

4.5.2 Site Control

Landfills were classified by ownership status as a means of characterizing site control. Site control is the process by which a project owner secures the legal rights to build on and use the land on which the project takes place. Landfills may be municipally owned, privately owned, state-owned, on federal land, or a mixture of the above. Seventy-one of the landfills had information about ownership, with 36 of these wholly owned by municipalities (Figure 15). The other 61 sites are either mixed ownership, on federal lands, privately owned, or there is no ownership information on file (Appendix A). Figure 16 shows the breakdown of site control information by capacity class.

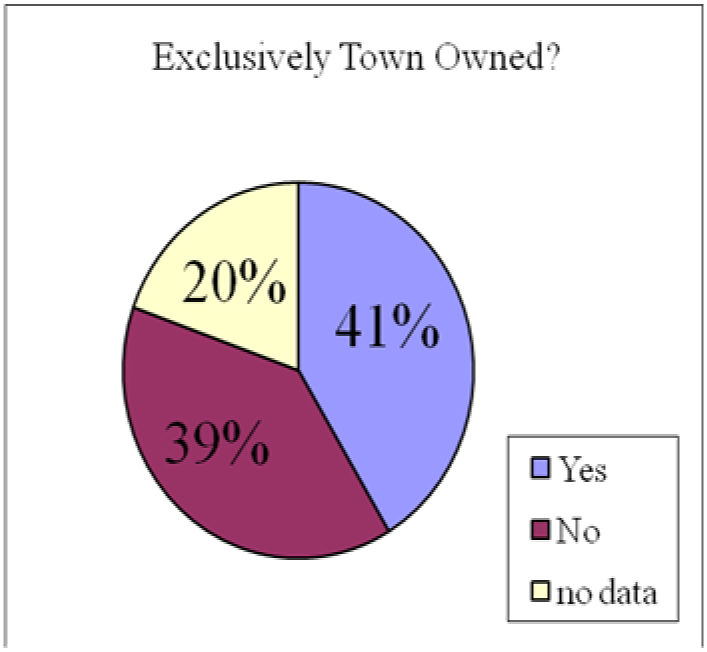


Figure 15. Landfill Town Ownership

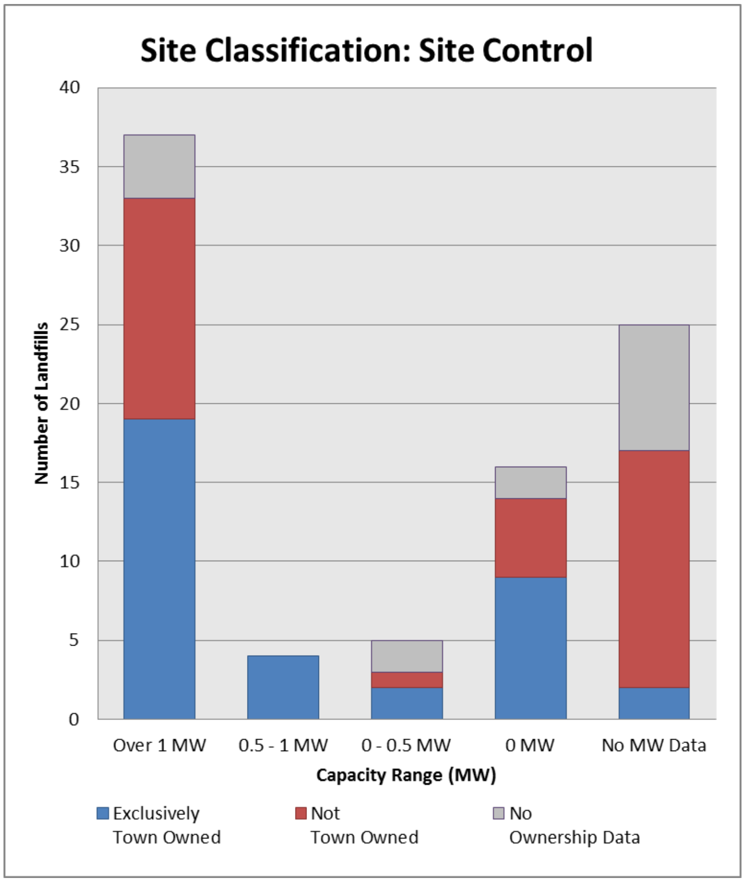


Figure 16. Site Classification: Site Control

4.5.3 Remediation Requirements

Landfills on the National Priorities List (NPL) were identified. These sites represent the most heavily contaminated waste disposal locations in the state, and would likely require significant remediation before formal closure and solar development could occur. Once sites listed on the NPL are fully remediated and certified through the RIDEM Landfill Closure Program, however, they may present suitable conditions for solar energy development. EPA approval of this secondary use is necessary prior to development of such sites. NPL landfill sites in Rhode Island with greater than 1 MW of solar power potential are listed in Table 10.

Table 10. Rhode Island NPL Sites with >1 MW Solar Power Potential

NPL Sites with >1 MW power potential	Location
DAVIS LIQUID WASTE	Smithfield
GSR LANDFILL	Glocester
LANDFILL AND RESOURCE RECOVERY (L&RR)	North Smithfield
PETERSON-PURITAN	Cumberland
PICILLO FARM	Coventry
ROSE HILL REGIONAL LANDFILL	South Kingstown
WEST KINGSTON/URI LANDFILL	West Kingston
WESTERN SAND AND GRAVEL	Burrillville

4.5.4 Presence of Cap

Before a PV system can be constructed, the landfill site must be capped according to RIIDEM specifications. In Rhode Island, a number of landfills have already been capped or are formally undergoing closure and capping through the RIDEM Landfill Closure Program (LCP).

Information on the cap characteristics of existing landfills is summarized below (Figure 17) and may be found in more detail in Appendix A. Sixteen sites were simply capped with two feet of soil; eighteen sites have more complex engineered caps. Thirty-nine sites have no cap at all and 12 have no data on capping. Additionally, two landfills are active in the state. Landfills that have not been properly capped according to RIDEM procedures were included in this study’s analysis, but the costs of bringing them up to current standards have not been factored in. Figure 18 shows the breakdown of cap information by capacity class.

Additional information on the cap characteristics of each site can be found in site investigation and site assessment reports contained in Appendix F of this document, or in person at RIDEM. The LCP staff are also a good resource for understanding the particulars of each site.

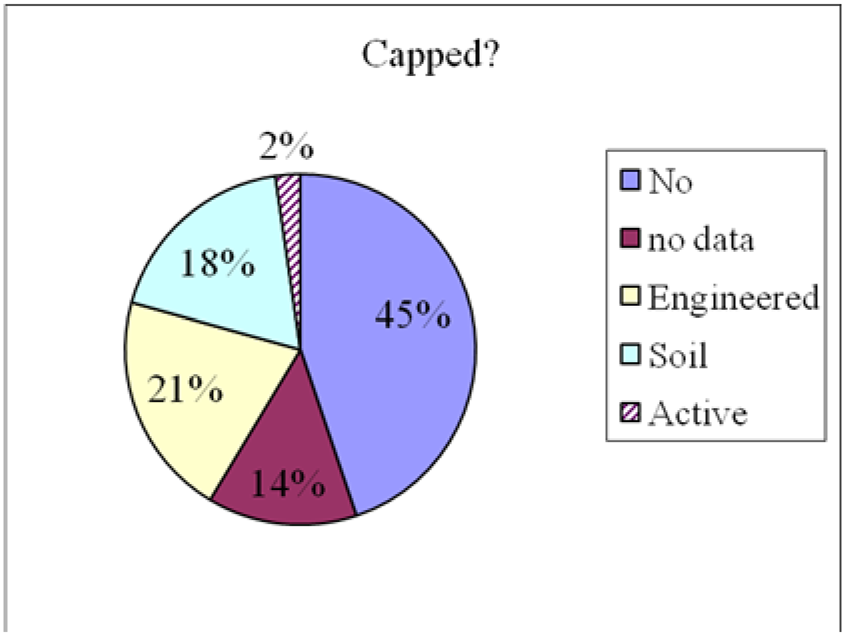


Figure 17. Capped Landfills in Rhode Island

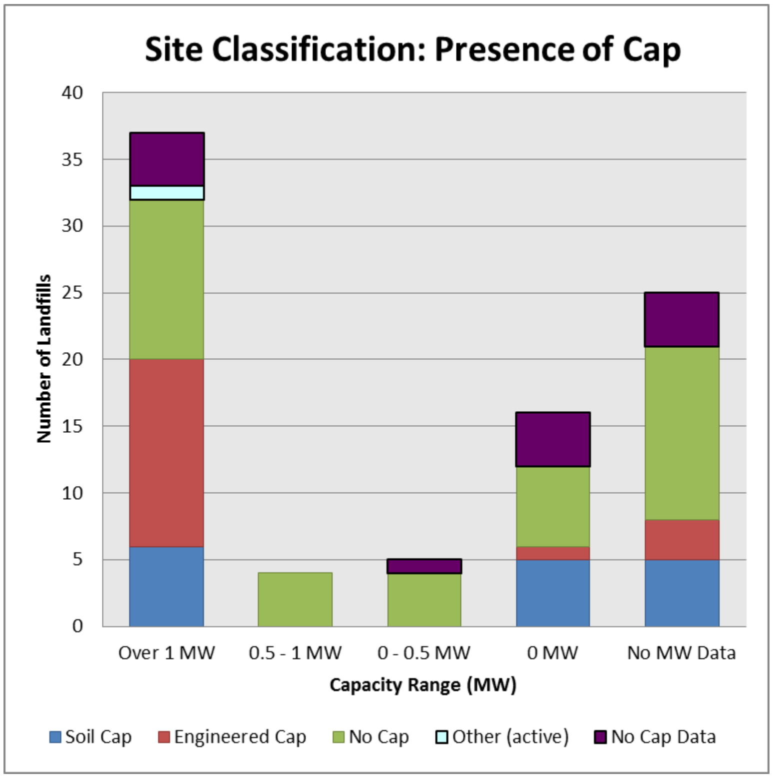


Figure 18. Site Classification: Presence of Cap

4.5.5 Reuse

Information was also obtained through personal communication with RIDEM LCP staff concerning the reuse of each landfill site. The information supplied by RIDEM indicates that 42 of the landfills are currently being used in some fashion, many for recreational purposes. Figure 19 displays the breakdown of reuse information by capacity class.

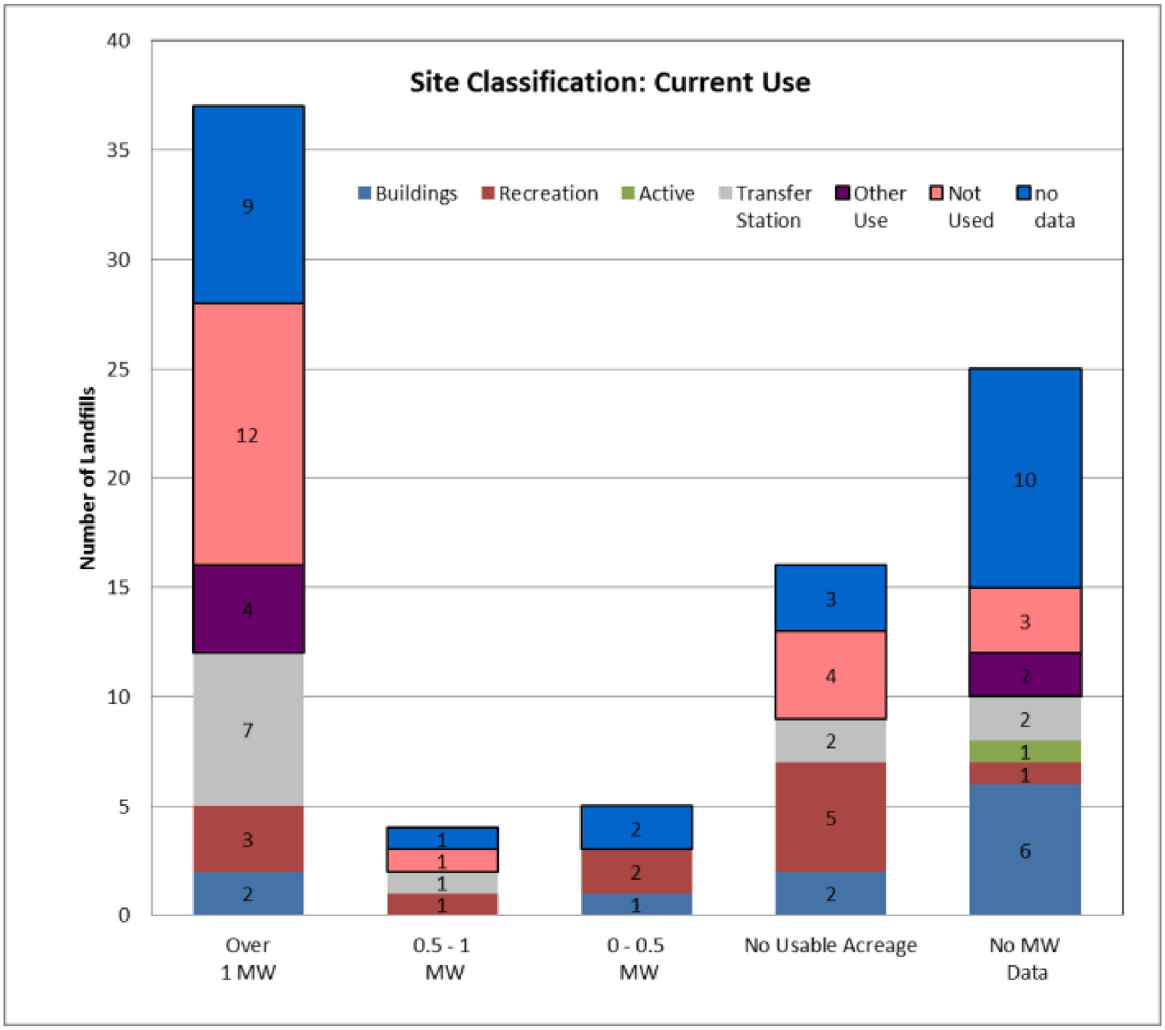


Figure 19. Site Classification: Current Use

5. CONCLUSIONS

There are many opportunities for solar photovoltaic generation on closed landfills in Rhode Island. Even given the conservative assumptions of this screening analysis, the majority of the 58 landfills with available parcel data could support solar arrays larger than 1MW (generally considered to be utility-scale systems). Siting PV facilities on suitably sloped land with appropriate land uses could generate over 110 MW of power via fixed tilt rigid panels on flat-lying ground and flexible panels on south-facing landfill slopes.

Despite the theoretical availability of utility-scale solar power potential at many landfill sites in Rhode Island, developing these resources will require a ground-truthing process and site-specific investigations. As noted above, the waste disposal land use class contains almost 60 MW of theoretical power potential, however, some portion of this represents active transfer stations. Although many sites lie inactive, a significant number are being used for new purposes, such as recreation, which may or may not be reflected in the RIGIS land use categories used to generate power potential estimates. Additionally, because the slope gradient screening analysis lumped together suitable sloped land areas without regard for continuity, site-specific landfill resources may be split into different, non-adjacent areas within the parcel.

Nevertheless, this study finds that landfill solar resources in Rhode Island offer a significant opportunity for communities to harvest a renewable source of energy on contaminated properties within their borders. As the pace of renewable energy generation accelerates and renewable resources account for a larger portion of the state's energy supply, landfills may present a viable location for constructing solar facilities. If properly suitable for development, a landfill site once considered to be a public liability can now become a community asset.

6. LIST OF APPENDICES

6.1 Appendix A: Master Rhode Island Landfill Spreadsheet (also available online at RI Energy.org)

6.2 Appendix B: Spreadsheet Tool for the Estimation of Photovoltaic Energy Potential of Rhode Island Landfill Sites (also available online at RI Energy.org)

6.3 Appendix C: Landfill Solar Sites in the United States

6.4 Appendix D: Landfill Site Investigation & Site Assessment Reports (only available online at RI Energy.org)

Appendices A, B, and C have been inserted at the end of Technical Report #8. Appendix D can be found online at RI Energy.Org.

7. REFERENCES

Card, B. 2011. Personal communication with Brian Card of Rhode Island Resource Recovery Corporation, October 2011.

EPA and NREL. no date. RE-Powering America's Land Initiative: Solar Photovoltaic Decision Tree. Environmental Protection Agency - Office of Solid Waste and Emergency Response (OSWER) and National Renewable Energy Laboratory, 18 p. Available online at: epa.gov/oswercpa/docs/solar_decision_tree.pdf

EPA. 2011(b). Policy Driven and/or Utility Scale Photovoltaic (PV) Solar Energy Generation Potential Maps. US Environmental Protection Agency, RE-Powering America's Land Initiative. Last updated November 4, 2011. Available online at: epa.gov/renewableenergyland/maps_utility_pv.htm. Last accessed March 15, 2012.

EPA. 2011(c). Re-Powering America's Land: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites – Anywhere the Sun Shines: Developing Solar Energy on Contaminated Land. Environmental Protection Agency: November 7, 2011. 2 p. Available online at: epa.gov/oswercpa/docs/solarmarket_analysis_overview.pdf

Grady, T. 2011. Personal communication with Terry Grady, Assistant Director of Air, Waste and Compliance with RIDEM. September 2011.

Grady, T. 2012. Personal communication with Terry Grady, Assistant Director of Air, Waste and Compliance with RIDEM. February 2012.

MassDOER. 2012. The Guide to Developing Solar Photovoltaics at Massachusetts Landfills. Massachusetts Department of Energy Resources, 38 p.

Newsham, G.R. and Bowker, B.G. 2010. The Effect of Utility Time-Varying Pricing and Load Control Strategies on Residential Summer Peak Electricity Use: A Review. July 1, 2010. Energy Policy, Vol. 38, Issue 7. pp. 3289-3296.

NREL. 2011(a). "Derate Factors for AC Power Rating at STC." National Renewable Energy Laboratory – US Department of Energy, Office of Energy Efficiency and Renewable Energy. Last updated: June 6, 2011. Available online at: nrel.gov/rredc/pvwatts/changing_parameters.html#dc_rating. Last accessed March 21, 2012.

NREL. 2011(b). PVWatts (Version 1). Golden, CO: National Renewable Energy Laboratory – US Department of Energy, Office of Energy Efficiency and Renewable Energy. Retrieved February 15, 2012. Available online at: nrel.gov/rredc/pvwatts/

NREL. no date(b). "National Solar Radiation Data Base - 1991-2005 Update: Typical Meteorological Year 3." Renewable Resource Data Center - National Renewable Energy Laboratory – US Department of Energy, Office of Energy Efficiency and Renewable Energy. Available online at: rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

NREL. no date(c). "National Solar Radiation Data Base." Renewable Resource Data Center - National Renewable Energy Laboratory – US Department of Energy, Office of Energy Efficiency and Renewable Energy. Available online at: rredc.nrel.gov/solar/old_data/nsrdb/

RIDEM. 2007. Closure Policy for Inactive or Abandoned Solid Waste Landfills. Rhode Island Department of Environmental Management – Office of Waste Management. Policy Number WM-SW-2007-02. 2nd Revision (March 2001). 6 p. Available online at: dem.ri.gov/programs/benviron/waste/pdf/landclos.pdf

RIRRC. 2006. Rhode Island Comprehensive Solid Waste Management Plan - State Guide Plan Element 171. Rhode Island Resource Recovery Corporation - Rhode Island Department of Environmental Management, Rhode Island Statewide Planning Program. Available online at: dem.ri.gov/programs/ombuds/outreach/integsw/pdf/swcomp06.pdf

Sampson, G. 2009. Solar Power Installations on Closed Landfills: Technical and Regulatory Considerations. Environmental Protection Agency, 30 p.

Sanyo Corp. 2008. HIT Power 200 Photovoltaic Module Specifications. Sanyo Energy (USA) Corp. - Solar Division. Frisco, TX: July 1, 2008. Available online at: solarelectricsupply.com/pdf/Sanyo/Sanyo-HIT-200-RZ.pdf

SolarDesignTool.com. 2012. Solyndra SL-200-220 (220W) solar panel specifications. Available online at: http://www.solardesigntool.com/components/module-panel-solar/Solyndra/SL-200-220/specification-data-sheet.html;jsessionid=FB659F9291306714757547CA740DEAF8. Last accessed March 14, 2012.

Stafford, B., Robichaud, R., and Mosey, G. 2011. Feasibility Study of Economics and Performance of Solar Photovoltaics at Massachusetts Military Reservation. National Renewable Energy Laboratory Technical Report NREL/TP-6A20-49417, 29 p.

Wilcox, S. and Marion, W. 2008. Users Manual for TMY3 Data Sets. National Renewable Energy Laboratory – US Department of Energy, Office of Energy Efficiency and Renewable Energy. Technical Report NREL/TP-581-43156. May 2008. 51 p. Available online at: nrel.gov/docs/fy08osti/43156.pdf

Rhode Island Landfill Solar Resource Assessment and Screening Analysis

Appendix A

Master Rhode Island Landfill Spreadsheet (Excel Spreadsheet)

Available online at RI Energy.org

NAME	**Ballpark MW Potential <3%**	**Ballpark MW Potential <6%**	**sloped Acres for flexible PV panel area**	**MW from flexible PV panels**	**flat (<6%) Acres for Rigid PV panel area**	**MW from rigid PV panels (<6%)**	**flat (<3%) Acres for rigid PV panel area**	**MW from rigid PV panels (<3%)**	**Acres for flat (<3%) + flexible PV panel area**	**MW from flat (<3%) + flexible PV panels**	**Acres for flat (<6%) + flexible PV panel area**	**MW from flat (<6%) + flexible PV panels**
A. Macera Disposal Landfill												
Allen Harbor Landfill	>1	>1	1.2	0.2	12.2	2.0	10.4	1.7	11.6	1.9	13.4	2.17
Arkwright Dump												
Barrington Landfill #1												
Barrington Landfill #2												
Barrington Landfill #3	>1	>1	1.6	0.3	8.1	1.3	5.8	0.9	7.4	1.2	9.7	1.59
Barrington Landfill #4	0.5-1	>1	0.2	0.04	6.7	1.1	3.7	0.6	4.0	0.6	6.9	1.11
Bristol Landfill	>1	>1	0.01	0.002	30.6	4.9	30.5	4.9	30.5	4.9	30.6	4.89
Burrillville Landfill #1	>1	>1	4.6	0.8	12.6	2.0	9.8	1.6	14.5	2.4	17.2	2.84
Burrillville Landfill #2	>1	>1	2.6	0.5	7.0	1.1	7.8	1.2	10.4	1.7	9.6	1.58
Cece-Macera Landfill												
Central Falls Dump												
CENTRAL LANDFILL												
CENTREDALE MANOR												
Charlestown Sanitary Landfill	>1	>1	2.4	0.4	9.5	1.5	4.9	0.8	7.4	1.2	11.89	1.95
Cooks Landfill	<0.5	<0.5	0.01	0.002	0.2	0.04	0.2	0.03	0.2	0.0	0.2	0.04
Coventry Municipal Landfill	>1	>1	0.7	0.1	7.8	1.2	6.4	1.0	7.1	1.1	8.5	1.37
Cranston Sanitary Landfill	>1	>1	3.9	0.70	19.1	3.1	13.8	2.2	17.7	2.9	23.0	3.75
Cumberland Municipal Landfill												
DAVIS LIQUID WASTE	>1	>1	2.1	0.4	16.7	2.7	13.6	2.2	15.7	2.6	18.8	3.05
Dupraw Dump												
East Greenwich Dump												
East Greenwich Landfill	0.5-1	>1	0.8	0.1	5.6	0.9	4.3	0.7	5.1	0.8	6.4	1.05
Elm Tree Dump												
Exeter Landfill #1												
Exeter Landfill #2												
Exeter Town Dump												
Fields Point City Dump	>1	>1	4.63	0.84	15.7	2.5	11.1	1.8	15.7	2.6	20.4	3.35
Firestone Landfill												
Forbes Street Landfill	>1	>1	5.8	1.0	29.5	4.7	21.4	3.4	27.2	4.5	35.3	5.76
Foster Landfill	>1	>1	0.7	0.1	9.2	1.5	7.2	1.2	8.0	1.3	9.9	1.60
Glocester Landfill	0.5-1	>1	1.7	0.3	4.6	0.7	3.0	0.5	4.6	0.8	6.2	1.03
Gorham Textron Disposal area												
Greenwood Avenue Disposal Area												
GSR LANDFILL	>1	>1	2.5	0.46	14.3	2.3	7.1	1.1	9.6	1.6	16.9	2.75
Hi-Lo Ciprianos Dump												
Hometown Properties Landfill	>1	>1	3.7	0.7	5.7	0.9	4.1	0.7	7.8	1.3	9.4	1.58
Hope Town Dump												
Hopkinton Landfill	>1	>1	4.1	0.7	7.4	1.2	2.7	0.4	6.8	1.2	11.4	1.91
Hugh Cole School Road Landfill	<0.5	<0.5			4.7E-05	7.5E-06	4.6E-05	7.4E-06	0.0	0.0	0.0	0.00
J. Vinagro Landfill												
Jamestown Landfill	>1	>1	2.1	0.4	8.2	1.3	4.3	0.7	6.4	1.1	10.2	1.68
Jamiel Park Landfill												
Kent Heights Landfill												
L. Vinagro Landfill												
LANDFILL AND RESOURCE RECOVERY (L&RR)	>1	>1	5.5	1.0	16.8	2.7	9.4	1.5	14.9	2.5	22.3	3.67
Little Compton Town Dump												
Lonsdale Narrows												
Manton Ave Landfill	0.5-1	>1	1.1	0.2	5.0	0.8	4.5	0.7	5.7	0.9	6.2	1.01
Narragansett Town Dump												
Narrow Lane Landfill	<0.5	0.5-1	0.2	0.03	3.4	0.5	2.6	0.4	2.8	0.4	3.6	0.58
NAVAL CONSTRUCTION BATTALION CENTER												
NAVAL EDUCATION AND TRAINING CENTER												
New Shoreham Town Landfill	0.5-1	0.5-1	1.02	0.184	3.9	0.6	2.5	0.4	3.5	0.6	4.9	0.80
Newport City Dump	<0.5	<0.5	0.5	0.1	1.2	0.2	0.9	0.1	1.4	0.2	1.7	0.28
North Kingstown Landfill #1	>1	>1	5.2	0.9	16.5	2.6	9.7	1.6	14.9	2.5	21.7	3.57
North Kingstown Landfill #2	<0.5	<0.5	0.2	0.03	1.2	0.2	1.0	0.2	1.1	0.2	1.3	0.22
North Providence Landfill	>1	>1	2.2	0.4	10.1	1.6	5.9	0.9	8.1	1.3	12.3	2.02
North Scituate Town Dump	<0.5	<0.5	0.01	0.002	0.6	0.1	0.1	0.02	0.1	0.0	0.6	0.09
Pawtucket Incinerator Residue Landfill	>1	>1	1.8	0.3	7.8	1.2	5.5	0.9	7.2	1.2	9.5	1.56
Perry Wood Street												
PETERSON-PURITAN	>1	>1	7.1	1.3	14.7	2.3	11.6	1.9	18.7	3.1	21.7	3.62
PICILLO FARM	>1	>1	2.2	0.4	10.7	1.7	8.4	1.3	10.6	1.7	12.9	2.10
Pine Hill Road Dump	>1	>1	7.3	1.3	31.9	5.1	26.6	4.2	33.9	5.6	39.3	6.43
Pontiac Enterprises												
Portsmouth Town Dump	>1	>1	3.0	0.5	18.3	2.9	13.3	2.1	16.3	2.7	21.3	3.47
Providence City Dump												
Richmond Town Landfill	>1	>1	2.6	0.5	8.2	1.3	6.3	1.0	8.9	1.5	10.8	1.79
Rocky Hill Disposal Area												
ROSE HILL REGIONAL LANDFILL	>1	>1	4.9	0.9	27.5	4.4	18.0	2.9	22.9	3.8	32.4	5.28
Sachuest Point NWR Landfill												
Scituate Town Landfill												
Smithfield Town Landfill	<0.5	0.5-1	1.3	0.2	3.6	0.6	1.5	0.2	2.8	0.5	4.8	0.80
STAMINA MILLS												
Steve Macera Disposal Area												
Tiverton Town Dump	>1	>1	1.7	0.3	6.5	1.0	4.6	0.7	6.3	1.0	8.2	1.34
Tiverton Town Landfill #2	>1	>1	7.9	1.4	19.2	3.1	10.0	1.6	17.9	3.0	27.1	4.50
Truk Away Landfill	>1	>1	5.1	0.9	21.6	3.5	19.2	3.1	24.3	4.0	26.7	4.38
Tuckers Industrial Dump												
Warren Town Landfill												
Warwick City Dump	0.5-1	0.5-1	0.8	0.2	5.1	0.8	4.5	0.7	5.3	0.9	6.0	0.97
West Greenwich Town Landfill												
WEST KINGSTON/URI LANDFILL	>1	>1	11.6	2.1	28.7	4.6	21.3	3.4	32.9	5.5	40.3	6.68
West Warwick Town Landfill												
Westerly Town Landfill	>1	>1	4.6	0.8	25.0	4.0	15.1	2.4	19.7	3.2	29.6	4.83
WESTERN SAND AND GRAVEL	>1	>1	5.8	1.0	22.7	3.6	16.1	2.6	21.9	3.6	28.5	4.67
Woonsocket City Dump	0.5-1	>1	0.9	0.2	5.4	0.9	4.9	0.8	5.8	0.9	6.3	1.02

NAME	TOWN	ADDRESS	PROJCT_CDE	ON_CERCLIS	CERCLIS	NPL
A. Macera Disposal Landfill	Johnston	SCITUATE AVENUE	AMRP-HWM	TRUE	RID987467958	
Allen Harbor Landfill	North Kingstown					
Arkwright Dump	Coventry	OFF MAIN STREET	ARK-HWM	TRUE		
Barrington Landfill #1	Barrington	PRINCESS HILL AVENUE	BL#1-SFA	TRUE	RID981064314	
Barrington Landfill #2	Barrington	PRINCESS HILL AVENUE	BL#2-SFA	TRUE	RID981064371	
Barrington Landfill #3	Barrington	UPLAND WAY	BL#3-SFA	TRUE	RID981064439	
Barrington Landfill #4	Barrington	UPLAND WAY	BL#4-SFA	TRUE	RID981064496	
Bristol Landfill	Bristol	MINTURN ROAD		TRUE	RID980512693	
Burrillville Landfill #1	Burrillville	Pole 32 Whipple Ave.	BUR1-SFA	TRUE	RID981063753	
Burrillville Landfill #2	Burrillville	NEW ROUTE 102		TRUE	RID981063936	
Cece-Macera Landfill	Johnston	PLAINFIELD PIKE	CECE-SFA	TRUE	RID981063647	
Central Falls Dump	Central Falls	LONDALE AVE.	CFD-SFA-SR	TRUE	RID982544116	
CENTRAL LANDFILL	JOHNSTON	Shun Pike	CL-NPL	TRUE		NPL
CENTREDALE MANOR	NORTH PROVIDENCE	2072 Smith Street	CLMN-NPL	TRUE		NPL
Charlestown Sanitary Landfill	Charlestown	SAND HILL ROAD		TRUE	RID981064553	
Cooks Landfill	East Providence	DEY STREET		TRUE	RID980910665	
Coventry Municipal Landfill	Coventry	ARNOLD ROAD	CMLF-SFA	TRUE	RID980734164	
Cranston Sanitary Landfill	Cranston	PONTIAC AVE.	CRSL-HWM	TRUE	RID084812577	
Cumberland Municipal Landfill	Cumberland	ALBION ROAD	CML-SFA	TRUE	RID980512701	
DAVIS LIQUID WASTE	SMITHFIELD	Tarklin Road	DAVD-NPL	TRUE		NPL
Dupraw Dump	Lincoln	LIMEROCK ROAD	SUP-SFA	TRUE	RID980520142	
East Greenwich Dump	East Greenwich	5835 POST ROAD		FALSE		
East Greenwich Landfill	East Greenwich	ROCKY HOLLOW ROAD	EGL-SFA	TRUE	RID981063522	
Elm Tree Dump	Lincoln	New England Way		FALSE	RID980520167	
Exeter Landfill #1	Exeter	ROUTE 102	EX1-SFA	TRUE	RID982190175	
Exeter Landfill #2	Exeter	ROUTE 102		TRUE	RID982542300	
Exeter Town Dump	Exeter	NOOSENECHK HILL ROAD AND RTE 10		TRUE	RID987467990	
Fields Point City Dump	Providence	Harborside Blvd		FALSE	RID987467933	
Firestone Landfill	Tiverton	BRAYTON ROAD		TRUE	RID981885049	
Forbes Street Landfill	East Providence	Greenwood Ave.		TRUE	RID981063514	
Foster Landfill	Foster	SALISBURY ROAD		TRUE	RID982543993	
Glocester Landfill	Gloceester	CHESTNUT HILL ROAD	GTLA-SFA	TRUE	RID981064611	
Gorham Textron Disposal area	Providence	ADELAIDE AVENUE	GTSC-HWM	TRUE	RID982542318	
Greenwood Avenue Disposal Area	East Providence	GREENWOOD AVE		TRUE	RID982544058	
GSR LANDFILL	GLOCESTER	Tarklin Road	GSR-NPL	TRUE		NPL
Hi-Lo Ciprianos Dump	Johnston	HARTFORD AVENUE	HILO-HWM	TRUE	RID982543936	
Hometown Properties Landfill	North Kingstown			TRUE	RID981064132	
Hope Town Dump	Scituate	HOPE FURNACE ROAD		TRUE		
Hopkinton Landfill	Hopkinton	STUBTOWN ROAD		TRUE	RID981064678	
Hugh Cole School Road Landfill	Warren	Cole School Road		FALSE		
J. Vinagro Landfill	Johnston	59 SHUN PIKE		TRUE	RID981064322	
Jamestown Landfill	Jamestown	NORTH ROAD		TRUE	RID982543878	
Jamiel Park Landfill	Warren	MARKET STREET	JAMI-HWM	FALSE		
Kent Heights Landfill	East Providence	Clyde Ave.		TRUE	RID987467941	
L. Vinagro Landfill	Johnston	GREEN HILL ROAD		TRUE	RID981064264	
LANDFILL AND RESOURCE RECOVERY (L&RR)	NORTH SMITHFIELD	OXFORD ROAD	LRR-NPL	TRUE		NPL
Little Compton Town Dump	Little Compton	COLD BROOK ROAD	LCD-SFA	TRUE	RID982544280	
Lonsdale Narrows	Lincoln	Lonsdale Ave.	LDN-SFA-SR	TRUE	RID980520159	
Manton Ave Landfill	Providence					
Narragansett Town Dump	Narragansett	south pier road		FALSE		
Narrow Lane Landfill	Charlestown	Narrow Lane		TRUE	RID982542367	
NAVAL CONSTRUCTION BATTALION CENTER	NORTH KINGSTOWN	Oxford Road	NCBC-NPL	TRUE		NPL
NAVAL EDUCATION AND TRAINING CENTER	NEWPORT, MIDDLETOWN, PORTSMOUTH	Burma Road	NETC-NPL	TRUE		NPL
New Shoreham Town Landfill	New Shoreham	WEST BEACH ROAD	NSTL-SFA	TRUE	RID981064736	
Newport City Dump	Newport	Admiral Kalbfus Rd		FALSE		
North Kingstown Landfill #1	North Kingstown	HAMILTON-ALLENTON ROAD	NK#1-SFA	TRUE	RID981063464	
North Kingstown Landfill #2	North Kingstown	OAK HILL ROAD	NK#2-SFA	TRUE	RID981063878	
North Providence Landfill	North Providence	SMITHFIELD ROAD		TRUE	RID981064793	
North Scituate Town Dump	Scituate	Danielson Pike		FALSE	RID982542375	
Pawtucket Incinerator Residue Landfill	Pawtucket	OFF SMITHFIELD AVE	PWSB-SFA	TRUE	RID980196265	
Perry Wood Street	Bristol	Perry and Wood Streets		FALSE		
PETERSON-PURITAN	CUMBERLAND	Martin Street	PP-NPL	TRUE		NPL
PICILLO FARM	COVENTRY	Perry Hill Road	PIC-NPL	TRUE		NPL
Pine Hill Road Dump	Richmond	PINE HILL ROAD		TRUE	RID982542425	
Pontiac Enterprises	Warwick			TRUE	RID069857541	
Portsmouth Town Dump	Portsmouth	PARK AVENUE	PLF-SFA	TRUE	RID987467917	
Providence City Dump	Providence	Hartford Ave				
Richmond Town Landfill	Richmond	51 BUTTONWOODS ROAD	TRLF-SFA	TRUE	RID981064207	
Rocky Hill Disposal Area	East Greenwich	1210 Division Road		FALSE		
ROSE HILL REGIONAL LANDFILL	SOUTH KINGSTOWN	Rose Hill Road	RHL-NPL	TRUE		NPL
Sachuest Point NWR Landfill	Middletown	Sachuest Point Rd.		TRUE	RI4143690010	
Scituate Town Landfill	Scituate	WASHINGTON HIGHWAY		TRUE	RID981064116	
Smithfield Town Landfill	Smithfield	RIDGE ROAD	STLF-SFA	TRUE	RID981063704	
STAMINA MILLS	NORTH SMITHFIELD	Main Street	SMD-NPL	TRUE		NPL
Steve Macera Disposal Area	East Greenwich	CARR'S POND ROAD		TRUE	RID982544173	
Tiverton Town Dump	Tiverton	BULGAR MARSH ROAD		TRUE	RID980520175	
Tiverton Town Landfill #2	Tiverton	MAIN ROAD		TRUE	RID095970000	
Truk Away Landfill	Warwick	INDUSTRIAL DRIVE	TRUK-SFA	TRUE	RID987493822	
Tuckers Industrial Dump	Johnston	GREENVILLE AVENUE	TID-HWM	TRUE	RID981063290	
Warren Town Landfill	Warren	BIRCH SWAMP ROAD	WTLF-SFA	TRUE	RID981063589	
Warwick City Dump	Warwick	Sandy Lane		FALSE		
West Greenwich Town Landfill	West Greenwich	BATES TRAIL	WGLF-SFA	TRUE	RID982544231	
WEST KINGSTON/URI LANDFILL	SOUTH KINGSTOWN	Plains Road	WK-NPL	TRUE		NPL
West Warwick Town Landfill	West Warwick	HAY STREET	WWTL-SFA	TRUE	RID981063761	
Westerly Town Landfill	Westerly	OAK STREET		TRUE	RID981064104	
WESTERN SAND AND GRAVEL	BURRILLVILLE	Douglas Pike	WSGD-NPL	TRUE		NPL
Woonsocket City Dump	Woonsocket	DAVISON ROAD		TRUE		

NAME	REPORTLAT	REPORTLONG	GIS_LONGX	GIS_LATY	REPORTPLAT_LOT	REPORT_ACRE	GIS_ACRES	PARCELS_ OBTAINED
A. Macera Disposal Landfill	41.8014	-71.5138	-71.5138	41.8014	P31 L10	13.0		No
Allen Harbor Landfill			-71.4172	41.6234			14.73	Yes
Arkwright Dump	41.7297	-71.5369	-71.5369	41.7297	M104 L10	4.7	4.75	Yes
Barrington Landfill #1	41.7417	-71.3083	-71.3155	41.7410	P22 L441, 505, 673	6.5	5.09	Yes
Barrington Landfill #2	41.7428	-71.3150	-71.3139	41.7406	P23 L309	4.8	3.62	Yes
Barrington Landfill #3	41.7406	-71.3283	-71.3283	41.7405	P19 L12	10.5	9.47	Yes
Barrington Landfill #4	41.7436	-71.3278	-71.3231	41.7436	P21 L1, 31	5.3	12.88	Yes
Bristol Landfill	41.6778	-71.2612	-71.2532	41.6780	P158 L25	45.0	90.51	Yes
Burrillville Landfill #1	41.9636	-71.6581	-71.6581	41.9636		8.0	76.90	Yes
Burrillville Landfill #2	41.9636	-71.6617	-71.6617	41.9636		16.0	32.12	Yes
Cece-Macera Landfill	41.7961	-71.5464	-71.5464	41.7961	P32 L30, 31, 32, 37, 38, 39, 40, 41, 42, 43	0.0		No
Central Falls Dump	41.8974	-71.4017	-71.4011	41.8972	P4	2.0	4.78	Yes
CENTRAL LANDFILL			-71.5376	41.8071				No
CENTREDALE MANOR			-71.4863	41.8563				No
Charlestown Sanitary Landfill	41.3778	-71.6140	-71.6120	41.4077	P23 L123	8.5	69.19	Yes
Cooks Landfill	41.8250	-71.3481	-71.3493	41.8249	M505 B2 L1, 2; B3 L3-5; B4 L3-4; B5 L1-10; B7 L1-4; B8 L1-6	5.0	12.40	Yes
Coventry Municipal Landfill	41.6653	-71.5481	-71.5481	41.6653	M15 L96	10.0	9.95	Yes
Cranston Sanitary Landfill	41.7354	-71.4594	-71.4594	41.7354	P13 L1	40.0	41.47	Yes
Cumberland Municipal Landfill	41.9577	-71.4502	-71.4502	41.9577		26.0		No
DAVIS LIQUID WASTE			-71.5759	41.9216			39.37	Yes
Dupraw Dump	41.9172	-71.4300	-71.4300	41.9172		5.0		No
East Greenwich Dump								No
East Greenwich Landfill	41.6500	-71.4544	-71.4544	41.6500		13.0	14.68	Yes
Elm Tree Dump	41.9278	-71.4808	-71.4808	41.9278	P L49, 110, 111, 122	6.0	36.10	Yes
Exeter Landfill #1	41.5786	-71.6178	-71.6178	41.5786	P22 B2 L3	8.5		No
Exeter Landfill #2	41.6194	-71.6017	-71.6017	41.6194	P35 B2 L4	13.0		No
Exeter Town Dump	41.5967	-71.6472	-71.6472	41.5967	P7 B3 L1	1.5		No
Fields Point City Dump	41.7861	-71.3806	-71.3817	41.7870	P56 L257, 288, 296	20.0	25.54	Yes
Firestone Landfill	41.6078	-71.1653	-71.1653	41.6078	M3-8 P116 L5A	4.0	7.61	Yes
Forbes Street Landfill	41.7793	-71.3418	-71.3434	41.7768	M511 B2 P1	229.0	231.40	Yes
Foster Landfill	41.7917	-71.7583	-71.7583	41.7917	P10 L67	80.0	86.65	Yes
Glocester Landfill	41.9038	-71.6765	-71.6765	41.9038	P10 L129, 130	9.0	35.14	Yes
Gorham Textron Disposal area	41.7978	-71.4297	-71.4297	41.7978	P51 L170	37.0		No
Greenwood Avenue Disposal Area	41.8377	-71.3542	-71.3536	41.8404	M403 B23 P1	2.5	17.59	Yes
GSR LANDFILL			-71.5895	41.9183			52.23	Yes
Hi-Lo Ciprianos Dump	41.8333	-71.5194	-71.5194	41.8333	P54 L34	10.0		No
Hometown Properties Landfill	41.5428	-71.5053	-71.5080	41.5439	P78 L2	14.0	20.17	Yes
Hope Town Dump								
Hopkinton Landfill	41.4988	-71.7711	-71.7711	41.4988	P13 L27, 26	21.0	83.79	Yes
Hugh Cole School Road Landfill	41.7267	-71.2572	-71.2581	41.7273	P19 L70	5.2	12.43	Yes
J. Vinagro Landfill	41.9636	-71.6581	-71.6581	41.9636		20.0		No
Jamestown Landfill	41.5607	-71.3739	-71.3739	41.5606	P2 L47-51	12.0	17.74	Yes
Jamiel Park Landfill			-71.2780	41.7316			14.40	Yes
Kent Heights Landfill	41.8000	-71.3583	-71.3542	41.8048	M408 B17 P16	24.0	24.07	Yes
L. Vinagro Landfill	41.7994	-71.5322	-71.5322	41.7994		0.0		No
LANDFILL AND RESOURCE RECOVERY (L&RR)			-71.5882	41.9798			38.24	Yes
Little Compton Town Dump	41.5455	-71.1450	-71.1450	41.5455	P40 L84-85	16.0	21.94	Yes
Lonsdale Narrows	41.8994	-71.4017	-71.4024	41.9010	P4 L32, 33, 83	5.0	20.77	Yes
Manton Ave Landfill			-71.4669	41.8322			22.92	Yes
Narragansett Town Dump								No
Narrow Lane Landfill	41.3933	-71.6313	-71.6309	41.3955	P20 L197	9.0	8.14	Yes
NAVAL CONSTRUCTION BATTALION CENTER								No
NAVAL EDUCATION AND TRAINING CENTER								No
New Shoreham Town Landfill	41.2083	-71.5761	-71.5761	41.2083	P2 L39-40	8.0	8.97	Yes
Newport City Dump	41.5061	-71.3131	-71.3131	41.5061	P4 L12, 81; P9 L421	17.7	22.49	Yes
North Kingstown Landfill #1	41.5583	-71.4776	-71.4776	41.5583	P80 L1	95.0	98.24	Yes
North Kingstown Landfill #2	41.5494	-71.4576	-71.4576	41.5494	P95 L1-2	15.0	41.81	Yes
North Providence Landfill	41.8694	-71.4761	-71.4772	41.8694	P21 L790, 1035	38.0	42.85	Yes
North Scituate Town Dump	41.8219	-71.6117	-71.6111	41.8302	P32 L9, 98	30.0	29.54	Yes
Pawtucket Incinerator Residue Landfill	41.8744	-71.4111	-71.4053	41.8689	P58 L12-14, 8	13.5	20.43	Yes
Perry Wood Street	41.6797	-71.2744	-71.2744	41.6797		6.0	4.11	Yes
PETERSON-PURITAN			-71.4240	41.9247			37.10	Yes
PICILLO FARM			-71.7083	41.6720			95.62	Yes
Pine Hill Road Dump	41.4669	-71.6690	-71.6702	41.4802	P7c, 8c L17	2.0	330.10	Yes
Pontiac Enterprises	41.7269	-71.4669	-71.4669	41.7269	P274 L204; P275 L38, 52	8.0	30.23	Yes
Portsmouth Town Dump	41.6000	-71.2417	-71.2389	41.6241	P19 L89; P20 L1	10.0	42.21	Yes
Providence City Dump								No
Richmond Town Landfill	41.5211	-71.6776	-71.6776	41.5211	P4c L26, 27, 29	13.0	25.10	Yes
Rocky Hill Disposal Area								No
ROSE HILL REGIONAL LANDFILL			-71.4945	41.4718			79.12	Yes
Sachuest Point NWR Landfill	41.4844	-71.2482	-71.2482	41.4844		21.0		No
Scituate Town Landfill	41.7653	-71.6732	-71.6732	41.7653		3.0		No
Smithfield Town Landfill	41.8731	-71.4767	-71.4767	41.8730	P42 L91	4.0	22.28	Yes
STAMINA MILLS			-71.5645	41.9964			5.77	Yes
Steve Macera Disposal Area	41.6381	-71.5453	-71.5453	41.6380	P15d L2	6.0		No
Tiverton Town Dump	41.6226	-71.1802	-71.1786	41.6221	M2-9 P116 L29	4.0	41.58	Yes
Tiverton Town Landfill #2	41.5824	-71.1863	-71.1863	41.5824	M2-5 L3	15.0	96.19	Yes
Truk Away Landfill	41.5806	-71.4222	-71.4187	41.7145	P342 L2, 3, 5, 429	36.0	66.30	Yes
Tuckers Industrial Dump	41.8567	-71.5181	-71.5181	41.8567	P50 L4; P51 L17	7.0		No
Warren Town Landfill	41.7456	-71.2686	-71.2684	41.7439	P22 L39	8.0	11.63	Yes
Warwick City Dump			-71.4155	41.7099			42.62	Yes
West Greenwich Town Landfill	41.6222	-71.5500	-71.5500	41.6222	P58 L10	3.0		No
WEST KINGSTON/URI LANDFILL			-71.5336	41.4963			143.30	Yes
West Warwick Town Landfill	41.7171	-71.5154	-71.5154	41.7171	M261 L1	28.0	28.73	Yes
Westerly Town Landfill	41.3778	-71.8021	-71.8021	41.3778	P59 L1	23.0	71.41	Yes
WESTERN SAND AND GRAVEL			-71.5955	41.9722			86.48	Yes
Woonsocket City Dump			-71.4932	41.9914			44.61	Yes

NAME	REPORTMAP	REPORTOWNER	USE_REUSE
A. Macera Disposal Landfill		Private	Proposed industrial park
Allen Harbor Landfill			
Arkwright Dump	No		?
Barrington Landfill #1	Yes	Town	Proposed Athletic Fields
Barrington Landfill #2	Yes	Town	Proposed Athletic Fields
Barrington Landfill #3	Yes	Town	none
Barrington Landfill #4	Yes	Town	Transfer Station/ Athletic Fields
Bristol Landfill	Yes	Town	solar?
Burrillville Landfill #1	Yes	Town	none
Burrillville Landfill #2		Town	none
Cece-Macera Landfill		Mixed Private	
Central Falls Dump	Yes	Town	
CENTRAL LANDFILL	No		Active Landfill
CENTREDALE MANOR	No		Active Retirement Home
Charlestown Sanitary Landfill	Yes	Town	adjacent composting, dog shelter, TS
Cooks Landfill	Yes	Mixed Private	?
Coventry Municipal Landfill	Yes		none
Cranston Sanitary Landfill	Yes	Private	none
Cumberland Municipal Landfill		Town	none
DAVIS LIQUID WASTE	No		Active quarry operation
Dupraw Dump		Private	
East Greenwich Dump	No		?
East Greenwich Landfill		Town	Bike Path
Elm Tree Dump	Yes	Mixed	Proposed development on 1 priately owned lot
Exeter Landfill #1		Private	none
Exeter Landfill #2		Private	Transfer Station
Exeter Town Dump		Private	?
Fields Point City Dump	Yes	Mixed	Save the Bay Educ. Center
Firestone Landfill	Yes	Private	none
Forbes Street Landfill	Yes	Town	compost area/ solar project
Foster Landfill	Yes	Private	none
Glocester Landfill	Yes	Town	Transfer Station/ animal shelter
Gorham Textron Disposal area			School
Greenwood Avenue Disposal Area	Yes	Private	none
GSR LANDFILL	No		NONE
Hi-Lo Ciprianos Dump		Private	
Hometown Properties Landfill	Yes	Private	ONLY C&D ENG CAP
Hope Town Dump			?
Hopkinton Landfill	Yes	Mixed	none
Hugh Cole School Road Landfill	Yes	Town	althletic fields
J. Vinagro Landfill		Private	solid waste management facilty
Jamestown Landfill	Yes	Town	Trans sta./ proposed DPW Garage
Jamiel Park Landfill	No		Park and athletic field
Kent Heights Landfill	Yes	Town	Athletic Fields
L. Vinagro Landfill			None
LANDFILL AND RESOURCE RECOVERY (L&RR)	No		Non active Landfill
Little Compton Town Dump	Yes	Town	Xfr Station, Cell Phone Tower
Lonsdale Narrows	Yes		munic. supply well, athletic field not currently in use
Manton Ave Landfill	No		
Narragansett Town Dump	No		?
Narrow Lane Landfill	Yes	Town	none
NAVAL CONSTRUCTION BATTALION CENTER	No		Commercial/ recreation/ military
NAVAL EDUCATION AND TRAINING CENTER	No		Military/Federal use
New Shoreham Town Landfill	Yes	Town	transfer station
Newport City Dump	Yes	Private	Newport Grand
North Kingstown Landfill #1	Yes	Town	
North Kingstown Landfill #2	Yes	Town	
North Providence Landfill	Yes	Town	
North Scituate Town Dump	Yes	Town	baseball field
Pawtucket Incinerator Residue Landfill	Yes	Mixed	transfer station
Perry Wood Street	Yes		none
PETERSON-PURITAN	No		Commercial and industrial
PICILLO FARM	No		None
Pine Hill Road Dump	Yes	Private	?
Pontiac Enterprises	Yes	Private	
Portsmouth Town Dump	Yes	Private	
Providence City Dump	No		school
Richmond Town Landfill	Yes		Transfer station
Rocky Hill Disposal Area	No		Part of NEIT expansion
ROSE HILL REGIONAL LANDFILL	No		NONE
Sachuest Point NWR Landfill			wildlife refuge, recreational
Scituate Town Landfill		Town	?
Smithfield Town Landfill	Yes	Town	
STAMINA MILLS	No		Industrial and commercial
Steve Macera Disposal Area		Private	?
Tiverton Town Dump	Yes	Private	?
Tiverton Town Landfill #2	Yes		
Truk Away Landfill	Yes		Owned by State
Tuckers Industrial Dump		Private	
Warren Town Landfill	Yes	Town	compost/ trans sta./DPW
Warwick City Dump	No		Athletic Fields
West Greenwich Town Landfill		Town	Trans. Station
WEST KINGSTON/URI LANDFILL	No		NONE
West Warwick Town Landfill	Yes	Town	Athletic Fields/ proposed walking paths
Westerly Town Landfill	Yes	Town	shooting range
WESTERN SAND AND GRAVEL	No		Industrial and commercial
Woonsocket City Dump	No		Athletic Fields/ Bike Path

6.1 Master Rhode Island Landfill Spreadsheet (also available online at RI Energy.org)

NAME	RIDEM_NOTES	URBSUB_RURAL	ENGIN_CAP	TOWN_OWNED	LANDFILL_CAP
A. Macera Disposal Landfill	?	u		n	Yes soil
Allen Harbor Landfill					
Arkwright Dump		?		n	No
Barrington Landfill #1	Recreational resource	u		Y	soil cap
Barrington Landfill #2	Recreational resource	u		Y	soil cap
Barrington Landfill #3	Recreational resource	u		Y	no
Barrington Landfill #4	Recreational resource	u		Y	no
Bristol Landfill	Currently researching solar	u		Y	multilayer
Burrillville Landfill #1	Part is used by DPW	r		Y	soil cap
Burrillville Landfill #2	Currently closed with eng. cap, large, some tresspassing issues	r	yes	Y	multilayer
Cece-Macera Landfill	privately owned covered with approved soil cap	u			No but pretty good cap on there now
Central Falls Dump	Too small by itself but located next to Lonsdale Narrows	u		Y	no
CENTRAL LANDFILL		U	Yes	N	
CENTREDALE MANOR		U	No	N	
Charlestown Sanitary Landfill		r	yes	Y	multilayer
Cooks Landfill				?	?
Coventry Municipal Landfill	Currently undergoing closure somewhat complicated relationship between owner, town and Resp. party doing work	u		N	in process multilayer
Cranston Sanitary Landfill	Currently undergoing closure under BUD approval to redo top of cap	u	yes	n	multilayer
Cumberland Municipal Landfill	Lots of tree cover, fairly steep slope, high tension wires go through site as well as gas line	u		Y	no
DAVIS LIQUID WASTE		R	No	N	
Dupraw Dump	Lots of tree cover, very odd bowl shaped configuration in rock quarry, complicated ownership	mix		n	no
East Greenwich Dump				?	?
East Greenwich Landfill	Recreational resource (bike path)	u		Y	soil cap
Elm Tree Dump	Lots of trees and wetlands, mostly town owned no work has been done. High tension wires nearby	u		Y	no
Exeter Landfill #1		r		?	no
Exeter Landfill #2	Large property, a small part is dump	r		?	no
Exeter Town Dump				?	no
Fields Point City Dump	Low, wet but high levels of methane, lots of open area good infrastructure for Port, J&W university. Save the Bay on property	u		N	no
Firestone Landfill	Lots of trees and ongoing dispute between owner and responsible party			no	no
Forbes Street Landfill	Currently well on way in solar project	u		Y	in process soil
Foster Landfill	Far from infrastructure, private owner, some tree cover	r		N	no
Glocester Landfill	Part of site used by DPW, underwent formal closure w/ soil cap	r		Y	soil cap
Gorham Textron Disposal area		u		N	mix pavement, soil, etc.
Greenwood Avenue Disposal Area	Lots of trees, material is only gypsum but is not very physically stable	u		N	soil cap
GSR LANDFILL	Overgrown need to clear	R	No	N	
Hi-Lo Ciprianos Dump		u		N	?
Hometown Properties Landfill	Only C&D disposed here. Has engineered cap and landfill gas collection. Private owner	u		N	multilayer
Hope Town Dump				?	NO
Hopkinton Landfill	May be far from electrical infrastructure	r		Y	no
Hugh Cole School Road Landfill	Recreational resource	u		Y	no
J. Vinagro Landfill	ongoing use for waste mangement			no	no
Jamestown Landfill	Far from infrastructure also use the site for xfr station and compost	r		Y	no
Jamiel Park Landfill	recreational resource	u		Y	soil cap
Kent Heights Landfill	recreational resource	u		Y	no
L. Vinagro Landfill	Still subject to enforcement action, ownership in flux.			no	no
LANDFILL AND RESOURCE RECOVERY (L&RR)		R	Yes	N	
Little Compton Town Dump	May be relatively small and already has cell tower	r		Y	soil cap
Lonsdale Narrows	May wish to consider together with CF dumpsite. Abondoned athletic field due to contaminants in soil. Much of site is low and somewhat wet. Highly irregular configuration of fill. Generally dump is very shallow	u		Y	no
Manton Ave Landfill					
Narragansett Town Dump				?	no
Narrow Lane Landfill	Fairly large open area, may be far from developed areas	r		Y	no
NAVAL CONSTRUCTION BATTALION CENTER	Federal Government still owns some; State and Town own multiple contaminated sites	U	Yes	Y/N	
NAVAL EDUCATION AND TRAINING CENTER	Federal Government still owns; multiple contaminated sites	R	Yes	N	
New Shoreham Town Landfill	Fairly small site	r		Y	no
Newport City Dump	used as parking lot for Newport Grand?	u		N	no
North Kingstown Landfill #1	Very good location. Elec substation and high tension wires nearby. Large area with soil cover, will need grading as part of closure. Good vehicle access and large open area, surrounded by woods	mix		Y	no
North Kingstown Landfill #2	recreational resource	mix		Y	no
North Providence Landfill	Capped landfill, near highly developed area, town is open to other uses.	u	yes	Y	multilayer
North Scituate Town Dump	recreational use, far from city	r		?	n
Pawtucket Incinerator Residue Landfill	In densely populated area	u		Y	n
Perry Wood Street	?	?		?	?
PETERSON-PURITAN	Private and town owned; multiple sites	U	Yes	N	
PICILLO FARM	Tax lien on Property	R	Yes	N	
Pine Hill Road Dump				?	?
Pontiac Enterprises	?	?		N	?
Portsmouth Town Dump	Site is fairly low, undergoing closure now with soil cap. Land is very low (in coastal flood plain). Near developed area	u		N	in process soil cap
Providence City Dump	School	u		?	No except soil cap on Save the Bay
Richmond Town Landfill		r		Y	no
Rocky Hill Disposal Area	Dump is quite small and NEIT is doing expansion in the area	u		N	in process soil
ROSE HILL REGIONAL LANDFILL		R	Yes	Y	
Sachuest Point NWR Landfill	recreational and wildlife refuge	?		N	cw
Scituate Town Landfill				?	no
Smithfield Town Landfill	Lots of trees onsite, only feasible if part of project on nearby North Providence landfill. Lots of trash on surface, would need to do closure along with it.	u		Y	no
STAMINA MILLS		R	Yes	N	
Steve Macera Disposal Area				n	no
Tiverton Town Dump				?	?
Tiverton Town Landfill #2	Currently active although they accept very small volume, no cap yet, but will need eng cap when they close	?		Y	active
Truk Away Landfill	Site has very high levels of contamination, FAA restrictions as it is next to airport and airport may want option of using it in future.	u		N	no
Tuckers Industrial Dump	Lots of tree cover	?		N	gj
Warren Town Landfill		u		?	joan?
Warwick City Dump	recreational use	u		Y	no
West Greenwich Town Landfill		r		Y	in process soil cap
WEST KINGSTON/URI LANDFILL	Owned by Towns and URI	R	Yes	Y/N	
West Warwick Town Landfill	recreational use	u		Y	
Westerly Town Landfill	Currently under consideration	?		Y	multilayer and soil depending on area
WESTERN SAND AND GRAVEL		R	Yes	N	
Woonsocket City Dump	recreational use	u		Y	multilayer

NAME	NOTES_GIS	NOTES_GIS2	SCAN_COMPLETION
A. Macera Disposal Landfill		No Parcels for this area	
Allen Harbor Landfill		Digitized from aerial	No reports scanned
Arkwright Dump	Intersection of highland ave and Potter Court, Coventry		No Appendices, screenshot of large map taken
Barrington Landfill #1		Digitized from Plat Lot infor online. Not Lot 673 because it is a private home	
Barrington Landfill #2		Digitized from Plat Lot infor online	
Barrington Landfill #3		Digitized from Plat Lot infor online	
Barrington Landfill #4		Digitized from Plat Lot infor online	
Bristol Landfill			
Burrillville Landfill #1		No Plat Lot Info.	
Burrillville Landfill #2	west of wastewater treatment plant	No Plat Lot Info	No Appendix A
Cece-Macera Landfill		No Parcels for this area	
Central Falls Dump		Digitized via PDF map	No Appendix B
CENTRAL LANDFILL		But clearly a landfill so it could be digitized if we had a pdf map	No reports scanned
CENTREDALE MANOR		Mill so not very useful anyways	No reports scanned
Charlestown Sanitary Landfill	Total parcel 68 acres		
Cooks Landfill			
Coventry Municipal Landfill			
Cranston Sanitary Landfill			No Appendices
Cumberland Municipal Landfill	Total parcel 52	No Plat Lot Info	
DAVIS LIQUID WASTE			No reports scanned
Dupraw Dump	aka Dexter Quarry	Shows up in Lincoln not Johnston	No Appendices
East Greenwich Dump		No Parcels for this area	Mark Dennen: Not much information
East Greenwich Landfill		No Parcels for this area. Digitized via aerial	
Elm Tree Dump	Off Albion Rd. Most likely extends onto neighboring properties		
Exeter Landfill #1	Total acreage 57	No Parcels for this area	Not all appendices
Exeter Landfill #2	Totla lacreage 150	No Parcels for this area	Not all appendices
Exeter Town Dump	Total acreage 31	No Parcels for this area	
Fields Point City Dump	Total parcel 35 acres	Everything but lot 296 because it does not exist in parcel data	
Firestone Landfill	Pole #46 on Brayton Rd. Total parcel 178 acres.		Not duplicate copies of reports
Forbes Street Landfill			No 'Screening Site Inspection' Appendices, '2009 Site Reassessment Report'
Foster Landfill			
Glocester Landfill	31 arce parcel		
Gorham Textron Disposal area	aka Mashapaug Pond	No such Plat Lot	
Greenwood Avenue Disposal Area			
GSR LANDFILL			No reports scanned
Hi-Lo Ciprianos Dump	parcel size 13.6	No Parcels for this area	No "Expanded Site Inspection Report", "Site Assessment Decision" Appendices
Hometown Properties Landfill	Parcel size 20.3		
Hope Town Dump			
Hopkinton Landfill	5 acres extends onto adjacent private parcel		No Attachments
Hugh Cole School Road Landfill			Not all appendices
J. Vinagro Landfill	Green Hill Road; Adjacent to L. Vinagro Landfill	No Parcels for this area	Not report with post-its (did copy the maps)
Jamestown Landfill	parcel size 15.6		No Appendices, DOH Lab Results
Jamiel Park Landfill		Located on Google Maps	File is unscannable/big “The Town of Warren (the Town) owns an inactive landfill.... for the purposes of this investigation, we have expanded the site boundary to also include Lots 1 and 18. A site location map is provided as Figure 1.” (page 1 of report Mark Dennen retrieved)
Kent Heights Landfill	Current Site Of Kent Heights playground		
L. Vinagro Landfill	Abuts J. Vinagro landfill property	No Parcels for this area	No Appendices
LANDFILL AND RESOURCE RECOVERY (L&RR)			No reports scanned
Little Compton Town Dump	Parcel size 21.4	Everything but Plat 40 Lot 84 because it does not exist in parcel data	No Attachments
Lonsdale Narrows	Parcel size 20.3		
Manton Ave Landfill		Located on Google Maps	File is unscannable/big Currently a Stop and Shop
Narragansett Town Dump		No Plat Lot Info	Mark Dennen: Not significant enough to be on list
Narrow Lane Landfill	Parcel size 8.6		No Attachments
NAVAL CONSTRUCTION BATTALION CENTER		Too large. Not specific	No reports scanned
NAVAL EDUCATION AND TRAINING CENTER			No reports scanned
New Shoreham Town Landfill	Parcel size 10.5		No Appendices for any of the 3 files, stapled packet
Newport City Dump	Newport Jai Alai built on top		
North Kingstown Landfill #1			
North Kingstown Landfill #2			
North Providence Landfill	On Smithfield Road just south of Smithfield/N Prov town line	Digitized via PDF map	No Attachment A
North Scituate Town Dump			No Attachment B
Pawtucket Incinerator Residue Landfill	Small area extends onto Lot8		
Perry Wood Street	NW of intersection between Perry and Wood Sts. Includes portions of school complex and athletic fields.	No Plat Lot Info	Not B&W aerial photos
PETERSON-PURITAN			No reports scanned
PICILLO FARM			No reports scanned
Pine Hill Road Dump	Parcel size 470	Everything but 8C L17 because it doesn't make sense	
Pontiac Enterprises	Total area 28.5		
Portsmouth Town Dump			
Providence City Dump		No Plat Lot Info	Mark Dennen: Having difficulty locating this, probably very old and very small
Richmond Town Landfill	Total area 18 acres		
Rocky Hill Disposal Area		No Parcels for this area	File is unscannable/big It’s in East Greenwich. “The (plus/minus) 74 acre Rocky Hill Fairgrounds Property (Plat 12, Lot 75) … (see page 5 and figure 2)
ROSE HILL REGIONAL LANDFILL			No reports scanned
Sachuest Point NWR Landfill	aka Middletown landfill	No Plat Lot Info	No Appendices, folded maps
Scituate Town Landfill	Total acreage 37	No Plat Lot Info	
Smithfield Town Landfill	Total acreage 13		
STAMINA MILLS			No reports scanned
Steve Macera Disposal Area	Total acreage 64	No Parcels for this area	No Stapled "Expanded Site Inspection Report"
Tiverton Town Dump	Total acreage 38		
Tiverton Town Landfill #2	Total acreage 109		
Truk Away Landfill	Total acreage 52		
Tuckers Industrial Dump	aka Cioci Porperty off Greenville Road. Total Acreage 150.	No Parcels for this area	Only copied a couple items from binder
Warren Town Landfill	Total acreage 12		
Warwick City Dump		Found with Parcels and Plat Lot infor	Mark Dennen: Not much info available, landfill is on Plat 349 Lot1 (mickey stevens sports complex) very old landfill
West Greenwich Town Landfill	Total acreage 72	No Parcels for this area	
WEST KINGSTON/URI LANDFILL			No reports scanned
West Warwick Town Landfill			
Westerly Town Landfill	Total acreage 55		
WESTERN SAND AND GRAVEL			No reports scanned
Woonsocket City Dump		Located on Google Maps	File is unscannable/HUGE Mostly engineering reports. Some large maps. “CITY OF WOONSOCKET MAP D5 LOTS 28-13 MAP E5 LOTS 29-46, 29-47, & 29-42 MAP F5 LOTS 32-10, 32-9, & 32-7 DAVISON AVENUE WOONSOCKET, RHODE ISLAND PARKING & ACCESS EASEMENT”

Rhode Island Landfill Solar Resource Assessment and Screening Analysis

Appendix B

Spreadsheet Tool for the Estimation of Photovoltaic Energy Potential of Rhode Island Landfill Sites

Available online at RI Energy.org

Estimation of Photovoltaic Energy Potential of Rhode Island Landfill Sites - An Example

Introduction: This spreadsheet serves as an example how commonly available information can be utilized to estimate the photovoltaic energy potential of landfills or similar sites. The user has to choose a specific PV model and manually enter its technical specifications into the spread sheets. Links to websites from which such information can be obtained are provided. In this example, a fairly efficient Sanyo HIP-200BA19 Photovoltaic Module was selected. It is assumed that the PV modules are mounted on a fixed frame facing south (Azimuth=180o). Further, it is assumed that the PV modules are installed at a 30 degree tilt angle.

Yellow cells designate important input variables.

Panel Type		
PTC ratings for PV modules:	http://www.gosolarcalifornia.org/equipment/pv_modules.php	
STC ratings for PV modules:	http://www.wholesolarpower.com/solar-panels-2/worldwide-pv-panel-efficiency/	
Panel (Manufacturer):	Sanyo HIP-200BA19 Photovoltaic Module⍰	
Web site:	http://www.solarelectricsupply.com/pdf/Sanyo/Sanyo-HIT-200-RZ.pdf	
Type	Fixed tilt, monocrystalline cells 5 Year Workmanship Warranty, 20 Year Power Output	
STC DC rated:	200	Watts
Panel length (L)	1.319	m
Panel width (W)	0.88	m

Packing Factor			
Tilt Angle	30	degrees	
Top height of panel:	0.44	m	
Baselength of tilted panel:	0.76	m	
Area of panel in plain view:	1.01	m2	
Sun Angle (Dec. 22)	12.6	degrees	RI default value
Row Spacing:	1.97	m	
Row Area (per base length of panel; L):	2.60	m2	
Packing Factor:	**0.28**		

DC output from the solar array must be converted to alternating current (AC) before it can be used to offset power coming from the electric utility grid.

Overall DC-to-AC derate factor	0.71		See Table to the right
AC Rating	142	Watt per PV panel	Based on STC Nameplate DC power rating

Derate Factors		
Component Derate Factors	**Defaults**	**Range of Acceptable Values**
PV module nameplate DC rating	0.95	0.80 - 1.05
Inverter and Transformer	0.92	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.9	0.30 - 0.995
System availability	0.98	0.00 - 0.995
Shading	0.975	0.00 - 1.00
Sun-tracking	1	0.95 - 1.00
Age	1	0.70 - 1.00
Overall DC-to-AC derate factor	**0.71**	0.09999–0.96001

http://www.nrel.gov/rredc/pvwatts/changing_parameters.html#dc_rating

Number of Panels				
AC Energy output per m2 of (tilted) PV panel	141.4708	Watts/m2		
Desired energy output	1.00	MW		
Number of Panels needed	7031.937			
Area covered by PV panels	7068.594	m2		
Min. Area (+5%) needed to generate output	**26,592**	**m2**	**or:**	**6.6 acres**

Rhode Island Landfill Solar Resource Assessment and Screening Analysis

Appendix C

Landfill Solar Sites in the United States

Name	City	State	Solar Acres	Total Landfill Acres	power (MW)	# of panels	landfill Inactive date	solar power date*	solar permit approval date	acres / MW
Adams Landfill	Adams	MA	5	13	1.1	3,927	1996	2013	2012	5
Barnstable Municipal Landfill	Barnstable	MA	52	66	4.0		1996	2013	2011	13
Brewster Landfill	Brewster	MA	16	15	1.2		1998	2013	2012	13
Brightfields	Brockton	MA	4	41	0.5	1,512	1989			8
Brookhaven National Laboratory	Upton	NY	208	18	32.0	164,312				6
Canton Landfill	Canton	MA	15	26	5.6		1989	2013	2012	3
Chatham Landfill	Chatham	MA	17	21	1.9		1993	2013	2012	9
Cottage Street Landfill	Springfield	MA	53		4.9			2013		11
Eastham	Eastham	MA	10	14	0.6		1993	2013	2012	17
Fairhaven Sanitary Landfill	Fairhaven	MA	3	33	0.6		1997	2013	2011	5
Forbes St. Landfill	East Providence	RI	70	70	10.0		1979	2012		7
Grasso Landfill	Agawam	MA	10	13	2.0		1986	2013	2012	5
Harwich Municipal Landfill	Harwich	MA	28	39	4.0		1999	2013	2012	7
Indian Orchard	Springfield	MA	12		2.3	8,200		2011		5
Lancaster Landfill	Lancaster	MA	3	17	0.5		1991	2013	2011	6
Norfolk Landfill	Norfolk	MA	2	10	0.6		1992	2013	2012	3
Norfolk Landfill	Norfolk	MA	4	10	1.1		1992	2013	2011	3
Oliver St Landfill	Easthampton	MA	16	25	2.3	9,620	1993	2012	2011	7
Otis ANGB	Cape Cod	MA	47	100	7.7					6
Pittsfield Municipal Landfill	Pittsfield	MA	9	36	2.0		1998	2013	2011	5
Scituate Landfill	Scituate	MA	6	25	3.0	12,936	1999	2013	2011	2
Silver Lake	Pittsfield	MA	8		1.8			2010		4
South Hadley Landfill	South Hadley	MA		37	0.1		2010	2013	2011	
Sylvester Ray Construction & Demolition Debris Landfill	Marshfield	MA	27	41	3.9		1988	2013	2012	7
Tisbury Landfill	Tisbury	MA	15	8	1.2		1994	2013	2012	13
Ward Hill Neck Landfill	Haverhill	MA		67	0.5		1989	2013	2011	
Westerly Landfill	Westerly	RI	12		2.0			2011		6
Winchendon Landfill	Winchendon	MA		41	2.4		1999	2013	2011	
Wisdom Way Landfill	Greenfield	MA	23		2.0					12
Bee Ridge Landfill	Sarasota	FL	0.64		0.25	1,200	1998	2008		3
Fort Carson	Carson City	CO	12		2.0	27,876	1973	2008		6
G.R.O.W.S. Landfill	Falls Township, Bucks County	PA	16.5		3.7	16,500		2008		4
Holmes Rd	Houston	TX	150		10.0		1975	2010		15
Nellis AFB		NV	140		14.2	72,416	1966	2007		10
Pennsauken Sanitary Landfill	Pennsauken	NJ		39	2.6			2006		
Hickory Ridge	Conley	GA	10	45	1.0	6,984		2011		10
Madison County	Madison County	NY	0.5		0.05			2011		10
Tessman Rd	San Antonio	TX	6			1,050		2009		
Range of currently operating rigid panel sites in the Northeast										
high			208	100	32.0	164,312	1993	2012	2011	12
low			4	18	0.5	1,512	1979	2010	2011	4
average			44	51	6.7	45,911	1987	2011	2011	7
count			9	5	9	4	3	5	1	9
Range of flexible panel sites										
high			10	45	1.0	6984		2011		10
low			1	45	0.1	1050		2009		10
average			5	45	0.5	4017		2010		10
count			3	1	2	2	0	3	0	2
Range of all sites										
high			208	100	32.0	164,312	2010	2013	2012	16.5079365
low			1	8	0.1	1,050	1966	2006	2011	2.1
average			30	33	3.7	27,211	1991	2012	2012	7.4
count			34	26	37	12	26	34	20	33

* Solar Power Date of 2013 means we assume the solar farm will be up and running about then (Post-Closure Use Permit Application was filed with MassDEP in late 2011 / early 2012). Used to calculate landfill settlement yrs.

Name	panels / acre	panels / MW	solar acres / total landfill	Settlement Time (yrs)	type of panels
Adams Landfill	785	3,570	38%	17	fixed axis 20° tilt
Barnstable Municipal Landfill			79%	17	
Brewster Landfill				15	
Brightfields	409	3,231	9%		fixed axis 42° tilt
Brookhaven National Laboratory	791	5,135			
Canton Landfill			58%	24	
Chatham Landfill			79%	20	
Cottage Street Landfill					
Eastham			72%	20	
Fairhaven Sanitary Landfill			9%	16	
Forbes St. Landfill				33	
Grasso Landfill			74%	27	
Harwich Municipal Landfill			72%	14	
Indian Orchard	683	3,565			
Lancaster Landfill			16%	22	
Norfolk Landfill			17%	21	
Norfolk Landfill			37%	21	
Oliver St Landfill	601	4,257	65%	19	fixed axis 30° tilt
Otis ANGB			47%		fixed axis 42° tilt
Pittsfield Municipal Landfill			25%	15	
Scituate Landfill	2086	4,312	25%	14	fixed axis 20° tilt
Silver Lake					
South Hadley Landfill				3	
Sylvester Ray Construction & Demolition Debris Landfill			66%	25	
Tisbury Landfill				19	
Ward Hill Neck Landfill				24	
Westerly Landfill					
Winchendon Landfill				14	
Wisdom Way Landfill					
Bee Ridge Landfill	1875	4,800		10	
Fort Carson	2323	13,938		35	
G.R.O.W.S. Landfill	1000	4,459			
Holmes Rd				35	
Nellis AFB	517	5,100		41	single axis tracking
Pennsauken Sanitary Landfill					

Hickory Ridge	698	6,984			flexible
Madison County					flexible
Tessman Rd	188				flexible
Range of currently operating rigid panel sites in the Northeast					
high	791	5,135	65%	33	
low	409	3,231	9%	19	
average	621	4,047	40%	26	
count	4	4	3	2	
Range of flexible panel sites					
high	698	6984			flexible
low	188	6984			flexible
average	443	6984			flexible
count	2	1	0	0	flexible
Range of all sites					
high	2,323	13,938	79%	41	
low	188	3,231	9%	3	
average	996	5,396	46%	21	
count	12	11	17	25	

Name	Reference	Name
Adams Landfill	MassDEP, 2012(a); RIDEM, 2012	Adams Landfill
Barnstable Municipal Landfill	MassDEP, 2011(a); RIDEM, 2012	Barnstable Municipal Landfill
Brewster Landfill	MassDEP, 2011(b); RIDEM, 2012	Brewster Landfill
Brightfields	MassDOER, 2012; RIDEM, 2012	Brightfields
Brookhaven National Laboratory	Atney et al., 2009	Brookhaven National Laboratory
Canton Landfill	MassDEP, 2011(c); RIDEM, 2012	Canton Landfill
Chatham Landfill	MassDEP, 2011(d); RIDEM, 2012	Chatham Landfill
Cottage Street Landfill	MassDEP, 2011(o)	Cottage Street Landfill
Eastham	MassDEP, 2011(e); RIDEM, 2012	Eastham
Fairhaven Sanitary Landfill	MassDEP, 2010(a); RIDEM, 2012	Fairhaven Sanitary Landfill
Forbes St. Landfill	Coutu et al., 2011	Forbes St. Landfill
Grasso Landfill	MassDEP, 2012(b); RIDEM, 2012	Grasso Landfill
Harwich Municipal Landfill	MassDEP, 2011(h); RIDEM, 2012	Harwich Municipal Landfill
Indian Orchard	Solarserver.com, 2011	Indian Orchard
Lancaster Landfill	MassDEP, 2011(i); RIDEM, 2012	Lancaster Landfill
Norfolk Landfill	MassDEP, 2011(k); RIDEM, 2012	Norfolk Landfill
Norfolk Landfill	MassDEP, 2011(l); RIDEM, 2012	Norfolk Landfill
Oliver St Landfill	Abel, D., 2011; MassDEP, 2011(f); MassDOER, 2012; RIDEM, 2012	Oliver St Landfill
Otis ANGB	Stafford et al., 2011	Otis ANGB
Pittsfield Municipal Landfill	MassDEP, 2011(m); RIDEM, 2012	Pittsfield Municipal Landfill
Scituate Landfill	Abel, D., 2011; MassDEP, 2011(n); RIDEM, 2012	Scituate Landfill
Silver Lake	Northeast Utilities Service Company, 2012	Silver Lake
South Hadley Landfill	MassDEP, 2010(b); RIDEM, 2012	South Hadley Landfill
Sylvester Ray Construction & Demolition Debris Landfill	MassDEP, 2011(j); RIDEM, 2012	Sylvester Ray Construction & Demolition Debris Landfill
Tisbury Landfill	MassDEP, 2011(p); RIDEM, 2012	Tisbury Landfill
Ward Hill Neck Landfill	MassDEP, 2011(q); RIDEM, 2012	Ward Hill Neck Landfill
Westerly Landfill	Broadhead, J., 2010	Westerly Landfill
Winchendon Landfill	MassDEP, 2011(r); RIDEM, 2012	Winchendon Landfill
Wisdom Way Landfill	MassDEP, 2011(g)	Wisdom Way Landfill
Bee Ridge Landfill	ENS, 2008; FPL, 2006	Bee Ridge Landfill
Fort Carson	EPA, 2009; Sampson, G., 2009	Fort Carson
G.R.O.W.S. Landfill	Conergy, 2010; Haavind, R., 2009	G.R.O.W.S. Landfill
Holmes Rd	Sampson, G., 2009	Holmes Rd
Nellis AFB	Sampson, G., 2009; Whitney, R., 2007	Nellis AFB
Pennsauken Sanitary Landfill	People's Power and Light, 2008; Sampson, G., 2009	Pennsauken Sanitary Landfill

Hickory Ridge	Carlisle Energy Services, 2011(b)	Hickory Ridge
Madison County	Carlisle Energy Services, 2011(c)	Madison County
Tessman Rd	Johnson, J., 2009; Sampson, G., 2009	Tessman Rd

Notes
East Rd Landfill; 13.05 acres (limits of landfill cap)
Flint St. Landfill; 65.91 total acres (SA - ?)
Run Hill Rd.; 15.43 acres (Extent of Known Waste)
MA Solar spreadsheet has 2 landfills: closed 1980 and 1989, 40.18 and 1.11 acres (total) from EWK
26.07 acres Approximate Extent of Waste
Sam Ryder Rd.; 20.76 acres Approximate Extent of Waste
Old Orchard Rd.; 8.23 acres unknown acreage data origin; also Weir Rd landfill: 6.15 acres Parcel Boundary
Actually <3 acres; Bridge St.; 32.86 acres unknown acreage data origin
Various refernces to power potential anywhere between 5 - 15 MW. Accepted waste from 1969-1979 (only household and commercial waste)
Main St. Landfill; 12.86 acres Approximate Extent of Waste
Queen Anne Rd.; 38.74 acres total unknown acreage data origin
17 acres total Approximate Extent of Waste
2 Norfolk Landfill solar projects listed…, both on Medway Branch Rd.; 9.5 total acres unknown acreage data origin
2 Norfolk Landfill solar projects listed…, both on Medway Branch Rd.; 9.5 total acres unknown acreage data origin
also saw 11 acres mentioned. MA Solar spreadsheet says closed 1992, 24.68 acres (total) from Approximate Extent of Waste
was a Superfund site. Also says 65.3 acres
36.46 total acres Approximate Extent of Waste
also saw 0.5 MW mention. 25.1 landfill acres - unknown acreage data origin
37.45 total acres (Extent of Known Waste)
40.89 acres total "Perimeter of Assigned Area"
High Pt. Lane; 7.91 total acres unknown acreage data origin
66.94 acres unknown acreage data origin
River St.; 40.98 acres Approximate Extent of Waste
construction debris landfill
sketchy info
also saw 2.1 and 1.09 MW and 2008 date mention. Somewhere > 39 acres

saw a mention of 7 acres.
9 MW of power includes methane gas generation

Rhode Island Landfill Solar Resource Assessment and Screening Analysis

Appendix D

Landfill Site Investigation & Site Assessment Reports

Only available online at RI Energy.org

RESP TECHNICAL REPORT #9

RHODE ISLAND HYDROPOWER RESOURCE ASSESSMENT

By

Edson Okwelum, Danny Musher, Tiffany Davis, and Christopher Damon

University of Rhode Island,

Kingston Campus

June, 2012

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The following study considers the resource and economic potential of developing conventional hydropower (exclusively low-head, excluding conduit and marine hydrokinetic opportunities) on existing dams in Rhode Island. Estimates of hydropower potential were quantified at existing dam locations in Rhode Island using geospatial measurements, published data and empirical analysis. Using historic stream flow data from stream gages maintained by the U.S. Geological Survey (USGS), regional empirical flow duration curves (FDCs) were developed for the existing dam sites. The empirical flow duration curves were then used to predict the FDCs at ungauged dam sites. To develop the regional empirical FDCs, a regional regression model was employed, which relates FDC parameters to a site's basin and topographic characteristics. Following the works of Dingman (1978) and Searcy (1959), it was assumed that the FDCs could be fully described by as few as two parameters: basin relief and drainage area. Hydropower resource potential was then estimated at each dam site using flow values from the FDCs and assumed available net head from published dam height data. Finally, RETScreen^{TM}, a tool developed by Natural Resources Canada, was used to perform a first blush economic viability analysis for a set of undeveloped sites.

2. FLOW DATA

2.1 Generating Empirical Flow Duration Curves for the Gaged Dam Sites

The flow duration curves for the gaged sites were developed using parametric (analytical) procedures[1] (Fennessey and Vogel, 1990). Alternatively, one can generate the flow duration curve directly via a graphical method, i.e. by plotting the observed time series of daily flow values measured by the stream gage. The graphical method uses a process of ranking the daily flows q_i $i=1, 2, 3, \ldots, 365n$ in an ordered structure from the largest to the smallest. The flow duration curve is obtained by plotting each ordered observation q_i against its plotting position, p_i (exceedance probability defined in equations 1 & 2), where q_p represents the mean daily streamflow that is exceeded p% of the time. Because of the very large sample size used in this study (we harvested up to 12,400 daily streamflow data available from USGS, which translates to over 34 years of historical data), there is no statistical disadvantage in using analytical methods to generate the curves (

Figure 1).

The analytical procedure involves the following steps:

- Using the average daily flow values from stream gages, we developed empirical exceedance curves.

---

[1] We follow the procedure described in N. Fennessey and R. M. Vogel, Regional Flow Duration Curves for Unguaged Sites, Journal of Water Resources Planning & Management, Vol. 116, No. 4, Jul/Aug 1990.

- In line with Beard (1943), we assumed that these flow values are distributed log normally, and therefore, the natural log of the daily flow values should follow a normal distribution. Thus we can rewrite equations 1 and 2 in the form provided in equations 3 and 4:

$$p = P(Q > q_p) \tag{1}$$

$$p = 1 - P(Q \leq q_p) \tag{2}$$

$$p = 1 - (2\pi)^{-1/2} \int_{-\infty}^{z_p} \exp\left(-\frac{1}{2}t^2\right) dt \tag{3}$$

$$p = g(q_p|\mu, \sigma) \tag{4}$$

And $z_p = \left[In\left(q_p\right) - \mu\right]/\sigma$, is defined as the *pth* percentile of a normally distributed random variable with a mean of zero and variance of 1. In equations 3 and 4, μ and σ represent the mean and standard deviation of the log of daily streamflows. Equation 4 is the probability of obtaining the daily streamflow that is exceeded *p%* of the time given the mean and standard deviations of μ and σ respectively[2].

- Using the Maximum Likelihood estimators in MATLAB, we determined the asymptotically unbiased estimates of the μ and σ, denoted as $\hat{\mu}$ and $\widehat{\sigma}$ respectively. These values ($\hat{\mu}$ and $\widehat{\sigma}$) and other basin characteristics such as drainage area[3], are provided in Table 1 below.
- Subsequently, a standardized normal distribution was used to obtain the z values from an approximation of z as a function of the probability (p). These z-values were then converted to flow rates using the mean and standard deviations
- Then, the standard normalized distribution was used to obtain z values from an approximation of z as a function of probability (p).
- Next, the z values were converted to flow rates using the mean and SD ($\hat{\mu}$ and $\widehat{\sigma}$ respectively). Following Turkey (1960), we can approximate z_p by using equation 7.
- The empirical flow duration curves for the gaged stations were developed by plotting q_i, the ordered streamflows, against a corresponding percent exceeded point p_i defined as:

---

[2] **μ** and **σ** are the mean and variance respectively of the natural log of daily stream flow.
[3] The contributing drainage area information for each stream gage stations is readily available at http://waterdata.usgs.gov/nwis/dv?referred_module=sw

$$p_i = \left(\frac{i}{365n+1}\right) * 100 \qquad 5)$$

Where n is the number of years of available data, and i = 1,……, 365n. With the estimated ($\hat{\mu}$ *and* $\hat{\sigma}$), we then estimate q_p, the p^{th} quantile of daily mean streamflow by inverting equations 3 and 4 above to obtain:

$$q_p = \exp(\hat{\mu} + z_p\hat{\sigma}) \qquad 6)$$

$$z_p = 4.91[(1-p)^{0.14} - p^{0.14}] \qquad 7)$$

- Using the optimal parameters of ($\hat{\mu}$ and $\hat{\sigma}$), we generated regression equations of the form in equations 9 and 10 for the mean and standard deviations respectively. These fitted equations are then used to obtain the mean and standard deviations at the ungauged sites.
- As a check on the procedure, we then plotted the flow duration curves using the values from the fitted equations. This was then compared to the flow duration curves obtained by plotting the observed daily flow values at the gaged sites. These two are then compared as shown in
- Figure 1.

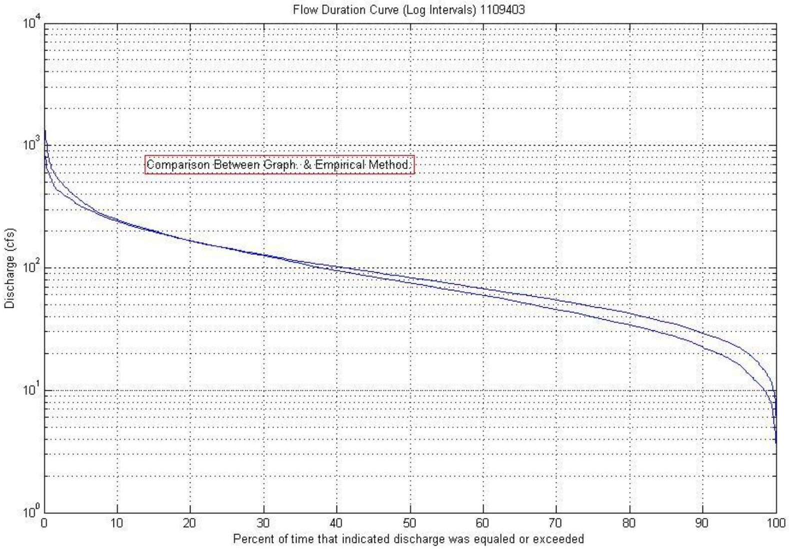


Figure 1. Comparison between Graphical and Analytical Flow Duration Curves for Ten Mile River, Pawtucket.

Table 1. Basin Characteristics and Flow Duration Curve Parameters for 37 Sites

U.S. Geologic Survey gage number*	Site Name*	Record Length (Yrs)*	Drainage Area A (sq mi)*	Basin Relief H (ft)**	µ***	σ***
01109403	TEN MILE	34	53.10	13.56	4.416	0.834
01111300	NIPMUC	34	16.00	113.65	2.878	1.208
01111410	CHEPACHET River	20	19.20	106.68	3.211	1.022
01111500	BRANCH RIVER	34	91.20	62.41	4.700	1.068
01112268	MILL RIVER	20	33.10	47.92	3.544	1.209
01112382	PETERS RIVER	20	12.60	53.48	2.762	1.033
01112500	BLACKSTONE @ WOONSOCKET	34	416.00	35.25	6.349	0.956
01113695	CATAMINT BROOK	21	3.55	52.18	1.920	0.878
01113760	ABBOTT RUN	21	26.90	19.15	3.868	0.568
01113895	BLACKSTONE @ ROOSEVELT	34	474.00	10.75	6.595	0.858
01114000	MOSHASSUCK		23.10	109.37	3.310	0.902
01114500	WOONASQUATUCKET	17	38.30	32.19	4.616	0.600
01115098	PEEPTOAD BROOK		4.96	102.2	3.489	0.728
01115187	PONAGANSET RIVER	34	14.00	107.85	2.823	1.187
01115190	DOLLY COLE	34	4.90	103	2.077	1.011
01115500	PAWTUXET R @FISKEVILLE	34	102.00	47.5	4.043	0.905
01115630	NOOSENECK R. @NOOSENECK	34	8.23	77.12	2.671	0.954
01116000	SOUTH BRANCH	34	62.80	85.33	4.673	0.779
01116500	PAWTUXET R. @ CRANSTON	34	200.00	8.32	5.630	0.762
01116905	HUNT R 250 FT DS	17	16.00	103.91	3.232	1.038
01117000	HUNT R. @ EAST GREENWICH	34	22.90	2.55	3.488	1.031
01117350	CHIPUXET R. @ WEST KINGSTON	34	9.59	30.18	2.847	0.896
011173545	QUEEN R 1400 FT UPSTR WM REYNOLDS	15	3.78	48.15	1.891	0.834
01117370	QUEEN R AT LIBERTY RD LIBERTY	34	19.60	37.4	3.304	0.950
01117410	USQUEPAUG R. @ RT 138 USQUEPAUG	15	32.75	33.23	3.782	0.884
01117420	USQUEPAUG R NEAR USQUEPAUG	34	36.10	30.21	4.019	0.871
01117424	CHICKASHEEN BROOK AT WEST KINGSTO	22	4.82	29.99	2.003	0.767
01117430	PAWCATUCK RIVER AT KENYON	23	72.70	25.97	4.700	0.797
01117468	BEAVER RIVER NEAR USQUEPAUG	34	9.22	34.5	2.732	0.867
01117471	BEAVER R SHANNOCK HILL RD, SHANNO	15	11.20	27.01	3.032	0.669
01117500	PAWCATUCK RIVER AT WOOD RIVER JUN	34	100.00	14.92	5.059	0.806
01117600	MEADOW BROOK NEAR CAROLINA	22	5.53	22.47	2.124	0.864
01117800	WOOD RIVER NEAR ARCADIA	34	35.20	41.85	4.015	0.862
01118000	WOOD RIVER AT HOPE VALLEY	34	72.40	21.04	4.774	0.864
01118010	PAWCATUCK RIVER AT BURDICKVILLE	22	205.00	12.32	5.779	0.759
01118360	ASHAWAY RIVER AT ASHAWAY	34	28.60	9.87	3.597	1.039
01118500	PAWCATUCK RIVER AT WESTERLY	34	295.00		6.113	0.895

*Data available at USGS: http://waterdata.usgs.gov/nwis/dv?referred_module=sw

**Data provided by the URI Environmental Data Center

*** Values are natural logs

2.2 Generating Flow Duration Curves for the Ungauged Dam Sites

Using the parameters from the empirical flow duration curves obtained from above, we then estimated regional regression equations for ($\hat{\mu}\, and\, \hat{\sigma}$) using multiple linear regression equations of the form:

$$Y = \gamma X_1^{\beta} X_2^{\delta} \qquad 8)$$

Where Y is the dependent variable representing the mean daily streamflow that is being estimated at the ungauged sites, X_1 represents the drainage area, X_2 is the basin relief and γ, β and δ are model parameters. Previous studies by Zacharias and Brutsaert (1985) found that basin relief is a function of slope and can be estimated by taking the difference between the basin summit elevation and the channel outlet elevation[4]. The basin summit elevation is defined as the average of the highest peaks along the drainage divide and the two peaks either side of it.

We used an ordinary least square (OLS) method to estimate the regional regression equations 9 and 10 for ($\hat{\mu}\, and\, \hat{\sigma}$) using the data in Table 1.

$$\hat{\mu} = \beta_0 + \beta_1 Ln(X_1) + \epsilon_i \qquad 9)$$

$$\hat{\sigma} = \beta Ln\, X_2 + \epsilon_j \qquad 10)$$

Applying the OLS method to the data in Table 1, we obtained the following regional regression equations for ($\hat{\mu}\, and\, \hat{\sigma}$):

$$\hat{\mu} = 0.712 + 0.912\, Ln\, (X_1) + \varepsilon$$

The t-statistic for the slope term is 20.755, demonstrating that it is significant at the 5% level with an adjusted R-squared value of 0.9247 and an F-value of 430.79. These values show that the regional equation is a good estimator of the m values.

$$\hat{\sigma} = 0.207\, Ln(X_2) + \eta$$

Similarly, the t-statistic for the above equation is 14.646 with an adjusted R-squared value of 0.8312 and an F-value of 214.52. The high t-ratios and high R^2 indicate the high precision of each of the model parameters.

Using equations 9 and 10, we can obtain $\mu'\, and\, \sigma'$, which are used to generate q_p for ungauged sites using a variation of equation 6 (Vogel et al. 1960; Vogel & Kroll 1989). Flow duration curves estimated using the method described above may be found in Appendix A.

---

[4] Zaccarias, Y.B. and Brutsaert, W, Ground surface slope as a basin scale parameter." Water Resour. Res., 21(12), 1895-1902

3. HYDRAULIC HEAD DATA

Hydraulic head[5] data for each dam site were obtained from a master dam spreadsheet maintained by the Rhode Island Department of Environmental Management Office of Water Resources (Appendix B). Data for dam height and hydraulic head in the DEM dam database derive from dam inspection reports and other files maintained by dam owners. There are known inaccuracies and inconsistencies with some of the head data as included in the DEM spreadsheet, however, the numbers were deemed sufficient for the purposes of the state-level analysis involved in this study. Field verification of these numbers was beyond the scope of this investigation, however, in the future, instrumental measurements at individual sites will help constrain the hydraulic head values further.

Hydraulic head measurements were used when available, and dam height measurements were used as a proxy for hydraulic height when hydraulic height data was missing. Several simplifying assumptions were made due to the scale of the assessment and limitations on available head data. This study assumed a constant net head based on the published data (assumed to be "gross head"). In reality, however, gross hydraulic head can change as a function of flow, and headwater and tailwater levels may be independently variable based on channel morphology. This study also did not consider the use of a bypass reach, which may be used to increase hydraulic head by diverting and discharging water some distance downstream from the intake. Such configurations generally raise environmental concerns regarding maintenance of critical habitat functions within the area of river spanned by the bypass reach.

4. HYDROPOWER POTENTIAL

4.1 Calculating Hydropower Potential at Dam Sites

The hydropower potential at each dam site is primarily a function of available hydraulic head and the flow duration curve (amount of flow and its distribution). The following formula[6] was used to estimate each site's hydropower potential (kW):

$$P = \frac{Q_{des} H \varepsilon}{11.8}$$

where:

P = power (kW),
Q_{des} = the design flow is defined as the maximum flow that can be used by the turbine and primarily depends on flow (hydrology) available at site. The optimum design flow is usually close to the flow that is equaled or exceeded about 25% of the time. (ft^3/s),
H = head available (ft),

---

[5] The hydraulic head is defined with respect to a column of water and a reference to a common datum. It is usually the vertical distance from the water surface in the impoundment to the center of the turbine in feet.

[6] ACSE, Civil Engineering Guidelines for Planning and Developing Hydroelectric Developments, Vol. 4

ε = hydropower average water-to-wire efficiency (in decimal fraction, a value of 0.9 was used for this study), and
11.8 = conversion constant.

4.2 Estimating Plant Capacity

Three estimates of plant generating capacity were generated at each site based on three simplifying assumptions related to available stream flows: 70% exceedance capacity, average capacity[7], and design capacity[8]. The three estimates represent a range of scenarios. For example, the 70% exceedance capacity is intended to be representative of plant performance during low-flow years. The design capacity, on the other hand, represents the rated installed capacity of a plant, which oftentimes is sized according to a higher flow value, usually the 25% exceedance flow (ASCE 1989).

To compute the capacity estimates, flow values were obtained using the analytical flow duration curves developed for each site. For the 70% exceedance capacity, flows in the 70% exceedance range were used (i.e. flow equaled at least 70% of the time). For average capacity, the mean flow value was used. For the design capacity, a calculated design flow was used (flow exceeded 25% of the time) (RETScreen, 2010; US DOI, USCE, USDOE).

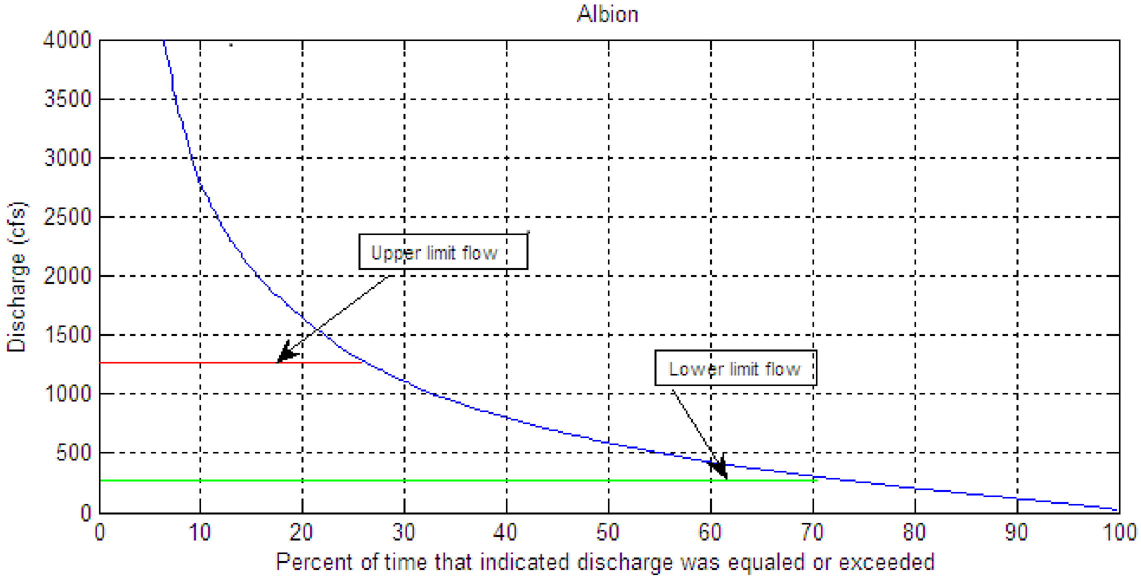


Figure 2. Flow Duration Curve for the Albion Dam

For example, to determine the plant capacity at Albion Dam (Figure 2), the upper limit flow line (25% exceedance) and the lower limit flow line (70% exceedance) are plotted on the

---

[7] Average capacity - the average rate at which electricity is generated (average power) over a given period - typically one year - determined by the average annual flow and average available hydraulic head (Douglas Hall, Idaho National Laboratory)

[8] Design capacity - the rate at which electricity is generated (design power) when a hydropower turbine is operating at its design head and flow rate usually corresponding to optimal turbine efficiency (Douglas Hall, Idaho National Laboratory)

analytical flow duration curve. In this case, the upper and lower limit turbine flows are 1182 cfs and 320 cfs, respectively. Therefore the design flow is 1182 cfs. The 70% exceedance flow is 320 cfs and the mean flow is 809 cfs.

Using the relationship for Power-Flow shown above, we have:

$$P = \frac{1182 * H * 0.9}{11.8}$$

With a hydraulic head of 12 ft at the site, we obtain an installed design capacity of 1080 KW. At the 70% exceedance, we obtain a value of 292 KW. The average capacity is estimated at 739 KW. Using the installed capacity and assuming a capacity factor of 54%[9], annual energy produced for this site is estimated at 4,730 MWH. Estimated capacities and average annual generation for all the dams evaluated are provided in Appendix C.

4.3 Resource Assessment

A comprehensive inventory of the 742 known existing dams in Rhode Island was obtained through the Rhode Island Department of Environmental Management (RIDEM) (Appendix B). It was deemed necessary to cull the list to a more manageable size for the purposes of analysis. A subset was assembled, with dams included if they met any of the following three criteria[10]: drainage area (over 40 square miles), height (over 18 feet), and hydraulic height (over 18 feet). A total of 90 dams met at least one of these criteria, with many meeting more than one; a final tally of 57 dam sites were analyzed after removing some outstanding small dams. All major dams in the state fell on the final list and all potential sites are run-of-the-river[11] projects. The list also includes all dams with existing hydropower facilities currently licensed by FERC and all dam sites with pending pre-permits at FERC yet to be developed. Because many dams in the state are of insignificant size and account for a negligible portion of overall hydropower potential, the refined list maintains a reasonably representative picture of the state's total hydropower potential, even while eliminating a majority of sites from the analysis outright.

Total estimated design capacity for the 57 sites is approximately 20,715 kW (Appendix C). The total estimated average capacity is approximately 14,935 kW. Capacity estimates for each site range from a few dozen KW to over 1 MW (Figure 3). At some of the sites with existing facilities, our estimates for hydropower potential suggest that opportunities may exist to increase plant capacity above the original licensed or pre-permitted FERC capacity. In the short

---

[9] Capacity factor is the ratio of annual generation to ideal annual generation at nameplate capacity. Since annual generation = average power x 8760 hrs and ideal generation = nameplate capacity x 8760hrs, (DG, Hall)
National average capacity factors ranges from 47% to 55% for small hydropower plants of sizes 100KW-5MW, Navigant Consulting Inc. California Energy Commission Statewide Hydropower Resource Assessment, 2006.

[10] Measurements for each of these characteristics are found in the DEM database (Appendix B). Height and Hydraulic Height were used, because for many dams, values exist for only one or the other.

[11] "Run-of-the-river" refers to a mode of hydropower generation where the plant only uses water available from the natural flow of the river, meaning that inflows equal outflows, and implying minimal water storage.

term, modifications or improvements could be made to the turbines installed at these sites to increase the energy produced. Total annual energy that could be produced by all the sites is estimated at over 90 GWH.

These figures for hydropower potential are in line with previous estimates by the Idaho National Laboratory (2006) (14 MW) and the Rhode Island Department of Environmental Management (~15-20 MW). This study considered existing dam sites with and without hydropower in Rhode Island; the INL study considered all stream reaches, but subtracted out the capacity of existing hydropower plants. Even with the stringent assumptions of no dams and only using half the flow rate for power production, the INL study produced a total capacity for feasible projects of 14 MW design capacity[12] (Personal communication, Douglas Hall).

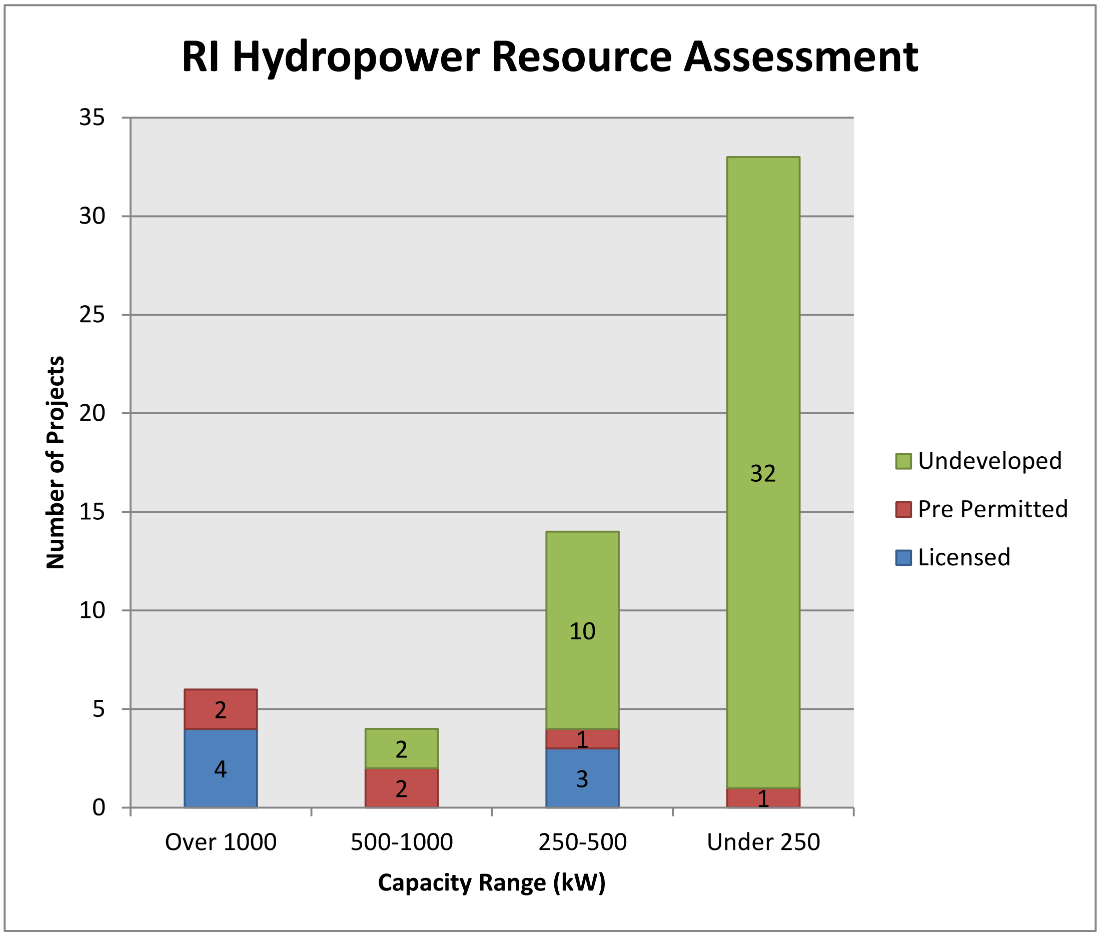


Figure 3. Hydropower Resource Assessment

---

[12] Total feasible average annual hydropower capacity is estimated at 7 MWa, therefore assuming a capacity factor of ~50%, total feasible design capacity should be 14 MW.

The sites were further classified into three major categories based on the following criteria. Please refer to Table 2 and Figure 4 below:

1. Licensed Sites: These sites have been issued permits for hydropower generation. Our assessment indicates that additional capacity could be added at some sites. There are presently 7 projects with power generation permits in Rhode Island.
2. Pre-Permit Sites: These sites have pending applications with FERC for permission to generate power.
3. Undeveloped Sites: These sites do not have issued licenses nor are they currently seeking approval from FERC for hydropower generation. The undeveloped sites account for a sizeable portion of hydropower potential in the state with capacity of over 9 MW. However, the undeveloped sites also account for the vast majority of sites analyzed, reflecting the fact that this power potential is spread over a large number of dams (i.e. smaller hydropower potential per dam).

Table 2. Hydropower Potential for State of Rhode Island

Classification	Number of Projects	Nameplate Capacity (MW)	Estimated Annual Energy Generated (MWH)
1 Licensed	7	6.66	29,193
2 Pre-Permit	6	4.82	21,131
3 Undeveloped	44	9.23	40,407
State Total	57	20.71	90,731

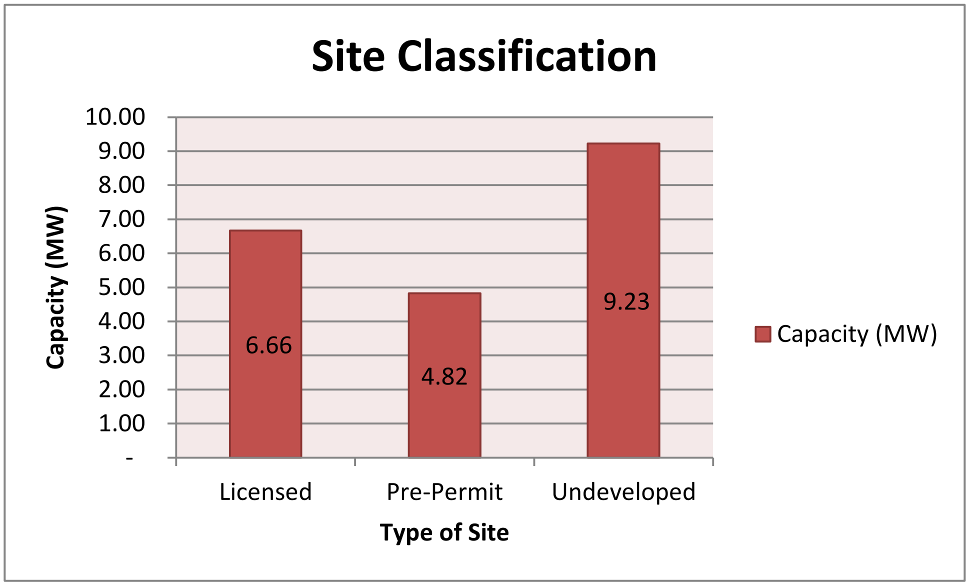


Figure 4. Site Classification

The results of this resource assessment confirm previous findings that hydropower resources are unevenly distributed across Rhode Island. As seen in

Figure 5, the vast majority of potential resides in the northern parts of the state along the state's largest river, the Blackstone. Almost 13 megawatts of nameplate potential exist on the Blackstone, apportioned among 19 sites, all but one with >100 kW capacity. Eighteen sites on the Pawtuxet, all but one with >100 kW capacity, account for over five MW of potential. The remaining watersheds contain approximately 2.75 MW of hydropower potential.

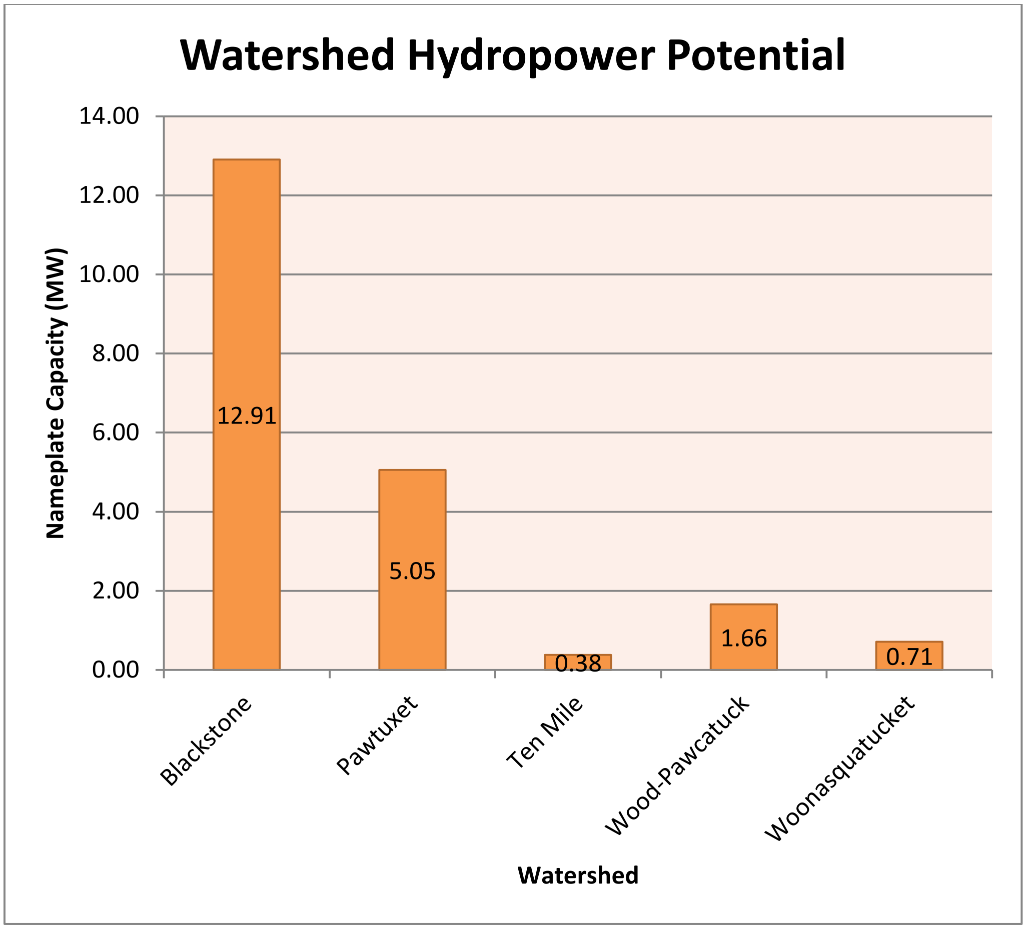


Figure 5. Watershed Hydropower Potential

4.4 Revised Potential Figures with Field Measurements

Other Rhode Island hydropower feasibility studies conducted by the Essex Partnership, LLC found significant discrepancies between published dam height data and the available hydraulic height at dam sites based on field measurements. We produced revised numbers for potential at the sites with available recent head measurements for the purposes of comparison.

Table 3. Hydropower Potential – Reported vs. Measured Hydraulic Head Values

Dam Site	Published Head (DEM Database) (ft)	Measured Head (Essex Partnership) (ft)	Nameplate Hydropower Potential (RESP) (MW)	Hydropower Potential (using measured head values) (MW)	% Change
Manville	19	13.4	1622	1144	-29%
Albion	12	10.8	1080	972	-10%
Ashton	10	7.9	835	660	-21%
Hunt's Mill	22	14.5	187	123	-34%

The revised numbers indicate that field measurements of hydraulic head differ from the numbers found in the DEM dam database. This discrepancy reinforces the need for field verification of head data in order to produce more accurate hydropower potential numbers.

5. ECONOMICS

Economic case studies for a number of dam sites[13] in Rhode Island are included below. To perform the economic analysis, RETScreen™, a tool developed by Natural Resources Canada, was used.

The purpose of these evaluations is to provide ballpark, order-of-magnitude estimates of the financial viability of hydropower development. The numbers should be interpreted with caution, as the economics and technical viability of hydropower projects are highly site-specific.

5.1 Equipment Selection

To run the model, a turbine type for each site must be selected. The turbines for each site were selected based on the hydrologic site characteristics and with the aid of RETScreen. Because of

---

[13] These dam sites were chosen to reflect the range of sites available, from smaller to larger undeveloped sites.

the wide variations in head data obtainable at the sites, we settled on turbines that could operate efficiently over a wide range of flows. Based on the range of flows and heads available at the proposed sites, the Bulb and Kaplan models are the best fit for Rhode Island site characteristics (Figure 6a and Figure 6b). However, this report used the Kaplan model as the basis for the all computations.

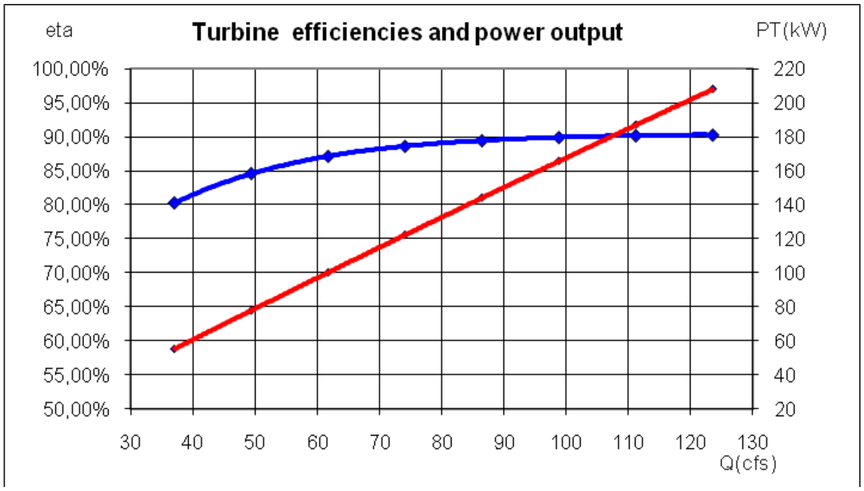


Figure 6. Turbine Efficiency Curve for Kaplan Turbines (Source: Mavel, N.A.)[14]

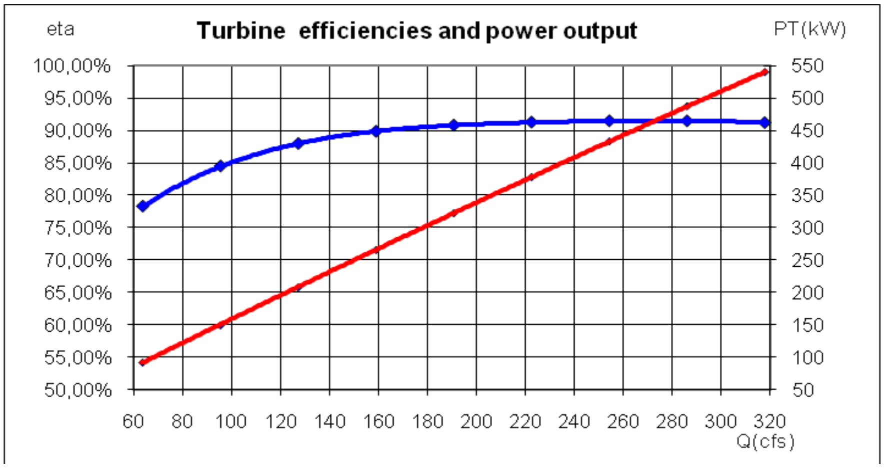


Figure 7. Turbine Efficiency Curve for Bulb Turbines

Compared to the Kaplan type turbine, the Bulb models provide the most efficient solutions for low heads below 30m. Their smaller sizes also reduce the civil work leading to lower costs. In some cases, cost reductions of up to 25% can be obtained. Additionally, Kaplan

---

[14] *For both curves: blue line = turbine eff. (left y-axis) / red line = power (kw) (right y-axis).*

and Bulb models are considered more fish friendly than other models, such as Crossflow turbines.

Kaplan – Both the blades and the wicket gates are adjustable (i.e. "double regulated Kaplan"), which increases efficiency over a wide range of operating flows. They are usually mounted in a vertical setting with variable pitch blades. This allows the wicket gate assembly to permit placing the unit such that it can regulate the load, speeds and shut down. Kaplan turbines can also be arranged in horizontal and slant settings.

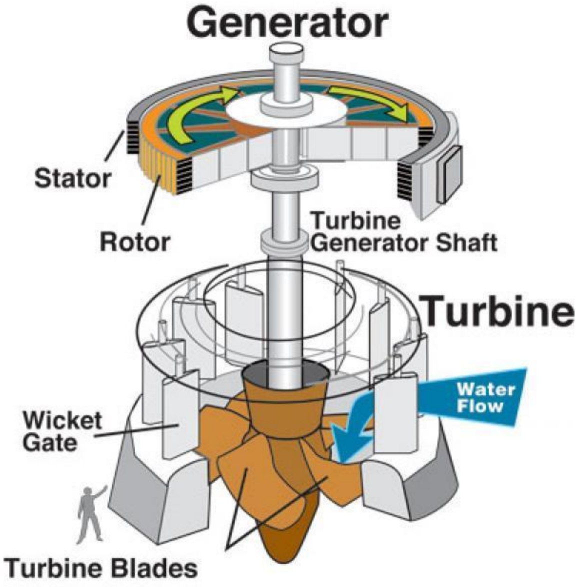


Figure 8. Kaplan Turbine (Source: Axco Motors)

Bulb – The turbine and generator are sealed, compact units placed directly in the water stream. The turbines are horizontal, and the propellers connected directly to the generator. Bulb turbines come in both fixed and variable pitch blade designs; they can also come with or without the wicket gate mechanism. Because water passage is straight, bulb turbines can provide about 2% higher efficiency than vertical turbines (e.g. Kaplan types). The compact structure results in reduced powerhouse floor space and height and therefore lower infrastructure costs compared to a vertical Kaplan.

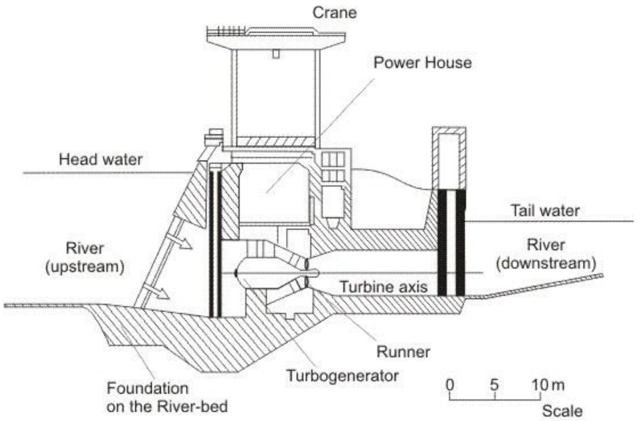


Figure 9. Schematic of Bulb Turbine Power Generating Station (*Source: NPTEL, 2012)*

5.2 Equipment Efficiency

Turbine types were selected based on available head and flow characteristics. Based on a site's location and characteristics (flow and head ranges), the efficiency of Kaplan and Bulb turbines ranges from about 72% at 40% flow to over 93% at 100% flow (Kane et al. 2006; RETScreen^{TM} 2010). To achieve low efficiency losses and ease of operations, it is recommended that these turbines be operated at head ranges of between 60% and 140% of design head. Below 30 to 40 percent of flow, all turbine technologies lose efficiency rapidly as the percent of flow diminishes. While turbine technologies vary in their efficiencies, this study assumed that generator efficiencies are identical as they are independent of the driver (turbine) efficiency. We have used 90% efficiency for this evaluation at different sites; this is comprised of 95% turbine efficiency and 95% efficiency due to tailwater (head) fluctuations[15], which is a reasonable, conservative value for hydropower resource evaluation.

5.3 Economic Viability & Financial Analysis

Five of the largest dam sites and one smaller site were chosen as case study locations to assess economic viability of hydropower development. The projects were evaluated with a discounted cash flow technique using the pretax all equity cash flows before income tax as well as after-tax cash flows. Table 4 shows the inputs to the model. The financial indicators are nominal values. This section provides key assumptions used in the economic analysis placing emphasis on the economic benefits of hydropower generation and costs of project operation. Several alternatives scenarios are considered: first, a "base" case; second, a "middle-of-the-road" case, and finally, an "enhanced" case. The base case scenario does not assume any availability of RECS, the middle of the road case assumes improved commodity prices over the base case scenario, and the enhanced case assumes significant improvements in commodity prices and availability of RECS, state and federal incentives.

---

[15] Source: Civil Engineering Guidelines for Planning and Designing Hydroelectric Developments, 1989. RETScreen, 2012

The following economic analysis is partly based on the same set assumptions that went into determining ceiling prices for the Rhode Island Distributed Generation Standard Contracts enactment of 2011. The analysis did not account for any major modifications to appurtenant dam infrastructure such as dams, canals, canal drop structures, pipelines, etc. The condition of an existing dam at the site can dramatically affect the cost of a project. If the existing dam is in poor condition, it may not meet current dam safety standards, in which case an appropriate adjustment can be made to the cost of equipment and construction.

Generally, hydropower projects have useful lifespan of over 50 years; however, in this analysis, projects were evaluated over a 30 year period. As with technical viability, economics of hydropower projects vary according to site-specific factors of each development project. The economic viability of hydropower projects also depends on the availability of incentives and the ability of the project to earn renewable energy credits.

Capital Costs - Actual installed costs vary significantly based on site conditions and the amount of civil work and mitigation required. In a 2006 study on the cost of hydropower projects, Navigant consulting estimates that for sites with an existing dam, it costs on average $3,250/KW to develop a small hydropower project ($3,670/KW in 2012 values) (IEPR, 2007)[16]. The cost is comprised of $1,500/KW for equipment and construction and $1,750/KW towards licensing and mitigation efforts. These figures are based on Idaho National Lab and Navigant Consulting estimates for facilities constructed where a dam is already in place. Actual costs for any specific site could vary significantly from these generalized estimates; anecdotal evidence from New England hydropower developers suggests that the cost estimate per installed KW may be higher for this region.

The capital cost breakdown per item is described below. Note that the breakdown of the capital cost per class or item is general and does not represent any specific projects.

- A site feasibility study will cost in the range of 9-11%;
- Development costs will be in the range of 7-9%;
- Engineering costs ranges from 10-13%;
- Equipment costs (turbine and related equipment) accounts for about 35-55%;
- The balance of plant costs 10-40% typically includes a number of items, such as access roads, interconnection, penstocks, canals, tunnel and other civil works costs.

---

[16] Navigant Consulting, IEPR: Levelized Cost of Generation Model: Renewable Energy, Clean Coal and Nuclear Input, 2007.

Table 4. Parameter Assumptions for Economic Analysis[17]

No	Input	Remarks
1	Overnight Costs ($/KW)*	$3,670
1.1	Equipment & Installation Costs ($/KW)*	$1,690
1.2	Licensing & Mitigation Costs ($/KW)*	$1,976
2	Fixed O&M ($/KW-yr)*	$13
3	Variable O&M ($/MWh)*	$3
4	Energy Price	$50/MWH (Base Case) $200/MWH (Middle-of-the-Road Case) $275/MWH (Enhanced Case)
5	Residual Value	50% of initial value at the end of study period
6	Renewable Energy Certificates (RECs)	$15/MWH
7	Compliance payments for REC	10% of Total REC Revenue
8	Discount Rate	6.75%
9	Project Tenure	30 Years
10	Insurance (premium)	0.5% per annum
11	Major Plant Overhauls (8,16, 24 yrs)	$300,000/Overhaul
12	Grants	5% of eligible costs-Costs of equipment used in actual electricity generation
13	Contingency	30% of initial capital
14	Required Annual DSCR	1.45 (Industry Average)
15	Interest Rate on Term Debt	6.75%
16	Target After-Tax Equity IRR	15%
17	Federal Investment Tax Credit	2.2 cent/KWh –first 10 Years
18	Debt Term	14 Yrs

We utilized RETScreen International™ (RI) for the economic analysis. Selecting the Hydro Formula Costing Method in RI, we input the parameter assumptions and other site specific characteristics such as power potential, costs, financial parameters, hydrologic parameters (head, flow, turbine type, road construction length), transmission line length, grid connection type, and voltage. Some of these parameters were estimated in terms of their lower and upper bounds—for example, difficulty of terrain (on a 1–6 scale), and rock at dam site (yes or no). From the analysis, we obtained economic parameters such as levelized cost of energy (LCOE), after tax IRR, net present values, benefit cost ratio, simple payback period.

---

[17] Source: *INEEL Hydropower Resource Economics Database (IHRED);″California Small Hydropower and Ocean Wave Energy Resources″; 2005 IEPR, April 2005; Natural Resources Canada RETScreen® Energy Model -Small Hydro Project; INL State Resource Assessment

- Net benefit-cost (B-C) ratio: is the ratio of the net benefits to project costs. Net benefits represent the present value of annual revenues (or savings) less annual costs, while the cost is defined as the project equity.
- Net present value: this is the value of all future cash flows, discounted at the discount rate, in today's dollar values. The difference between the present values of these cash flows, called the NPV, determines whether or not the project is generally a financially acceptable investment. Positive NPV values are an indicator of a potentially feasible project. Both the after-tax and pre-tax cashflows are used to calculate the economic parameters. However, we report only the after-tax NPV values calculated using the cumulative after-tax cash flows.
- LCOE: is the constant unit cost (per kWh or MWh) of a payment stream that has the same present value as the total cost of building and operating a generating plant over its life. It is the value that, when assigned to the avoided cost of energy, results in a NPV of zero and thus the after-tax IRR is equal to the discount rate.

Table 5. Project Economics for Six Rhode Island Dam Sites

Project Name	Natick Pond	Phenix Mill Pond	James Turner	Horseshoe Falls	Hope Dam at Scituate	Slatersville Upper
Installed Capacity (KW)	873	488	406	200	48	566
Initial Capital Cost ($/KW)	3,760	3,760	3,760	3,760	3,760	3,760
Assumed Installed Costs						
Hard Cost ($'000)	3,283	1,834	1,527	752	182	2.128
Soft Cost ($'000)	1,129	630	524	259	62	731
Total Cost ($'000)	4,411	2,465	2,051	1,011	244	2,860
Base Case Project Economics - $50/MWH Energy Price and $150/REC						
Project After-Tax Return						
30-Year IRR	3.9%	2.1%	1.3%	4.2%	negative	4.7%
30-Year NPV $'000 @ 6.75%	-2,475	-1,505	-1,132	-697	-375	-1,471
Simple Pay Back Period (Yrs)	17.2	17.6	18	16.1	18	18
Levelized Cost of Energy (LCOE)						
30-Year Nominal ($/MWh)	131	138	132	153	307	125
Benefit Cost Ratio	-0.0	-0.22	0.20	0.28	-2.1	0.03
Middle-of-the-Road Case - $350/MWH All in product price (Energy + REC) and 2% Incentives						
Project After-Tax Return						
30-Year IRR	12.3%	11.9%	11.9%	9.7%	negative	12.3%
30-Year NPV $'000 @ 6.75%	1,991	1,031	863	290	-138	1,287
Simple Pay Back Period (Yrs)	5.7	6.7	6.1	7.2	18	5.0
Levelized Cost of Energy (LCOE)						
30-Year Nominal ($/MWh)	121	124	128	150	304	122
Benefit Cost Ratio	1.90	1.84	1.84	1.57	-0.14	1.90
Enhanced Case - $425/MWH All in product price (Energy + REC) and 5% Grant						
Project After-Tax Return						
30-Year IRR	13.0%	18.1%	17.9%	16.5%	negative	17.6%
30-Year NPV $'000 @ 6.75%	2, 212	2,131	1,742	739	-31	1,473
Simple Pay Back Period (Yrs)	4.1	4.4	6.3	6.0		6.0
Levelized Cost of Energy (LCOE)						
30-Year Nominal ($/MWh)	113	120	123	145	298	118
Benefit Cost Ratio	2.00	2.74	2.70	2.20	0.74	2.75
GHG Reduction Cost ($/tCO2)	(146)	(252)	(247)	(213)	298	(254)

6. DISCUSSION OF RESULTS

Using the assumptions noted in the tables above, the levelized cost of energy, net present value, internal rate of return, simple payback, cost of greenhouse gas reduction and Benefit Cost Ratio were estimated. Three different scenarios were examined—a base case, a middle-of-the-road case, and an enhanced case. Results are presented in Table 5. The first panel describes the potential sites and cost estimates while the second, third and fourth panels presents results of the economic analysis for the base case, middle-of-the-road and enhanced case respectively.

It should be noted that the results of this economic analysis are intended for illustrative purposes only. They are useful for analyzing a range of cases and understanding the effect of changing market conditions on project economic viability. Assumptions used in this study may depart significantly from real-world conditions. Added uncertainty exists related to costs incurred in hydropower development projects, which vary significantly based on site-specific factors. It is possible that costs could be much greater (or perhaps less) at sites, altering the economic viability of the project in question.

***Base Case* -** The base case examines economics of five sites not licensed or pre-permitted under FERC (at the time of this writing). Under the base case scenario, the wholesale electricity price is $50/MWH**.** As seen in Table 5, all of the sites have negative NPV figures. The IRR evaluated over a 30 year period ranges from 1.3% for the James Turner site to 4.7% for the Slattersville Upper Dam site; the IRR for the Hope Dam at Scituate is negative under these conditions. The nominal LCOE values for the 6 sites range from $125/MWH to $307/MWH. The simple payback period averages approximately 18 years. The reported Benefit-Cost Ratios of less than 1 for all the projects means that the projects cost more than their estimated benefits. Under the base case, the economic indicators suggest poor economics for these potential hydropower sites.

Middle-of-the-Road Case - The middle-of-the-road case assumes an all in product price of $350/MWH and that project will be financed through the issue of municipal bonds thereby attracting favorable interest rates of 2%. Under these assumptions, the projects become marginally economic with simple payback period of approximately 6 years. In all the cases, the NPV values are positive except for the Hope Dam site and range from $290,000 for Horseshoe Falls site to about $2 million for the Natick Pond site. The benefit cost ratio in all the cases are greater than 1 (except for the Hope Dam at Scituate which is negative), with values from 1.57 for the Horseshoe Falls location to 1.90 for the Natick Pond site. The IRR values range from a negative value for the Hope Dam site to 12.3% for the Natick Pond site.

***Enhanced Case* -** This case assumes an all in product price of $425/MWH and a preferential interest rate of 2% or 5% grant. The 2% interest rate assumes that the project will be financed through the issue of municipal bonds. The results show that under these assumptions, all the projects become viable except for the Hope Dam as shown by the values of the economic indicators used. The NPV values range from $739,000 for the Horseshoe falls Dam site to $2.21 million for Natick Pond Dam. The IRR increases significantly for all the sites to over 13%, peaking at 18.1% for the Phenix Mill dam site. The payback period under these assumptions averages approximately 5.36 years, and the Benefit Cost Ratio for all sites is over 2.0.

7. CONCLUSIONS

This study evaluated the resource opportunities and economic viability of developing conventional hydropower at existing dams. Although Rhode Island waterways contain hundreds of dams, few are likely candidates for conventional hydropower development. Regional geographic limitations associated with slope gradients, hydraulic head, and hydrological conditions account for the limited resource potential of Rhode Island’s dams.

Using regional regression analysis, statistical models were established for the estimation of low flow characteristics and flow duration curves at ungauged sites. These flow duration curves were then combined with simplifying assumptions on the water to wire relationship to estimate the hydropower potential of 57 of the largest existing dams in RI, including 7 FERC-licensed projects and 6 sites with preliminary FERC permits. Total estimated power potential is approximately 21MW, of which approximately 7 MW is associated with currently licensed projects. This suggests by developing sites with preliminary permits and undeveloped sites, Rhode Island has the opportunity to approximately triple its hydropower capacity. However, the majority of the sites without preliminary permits have relatively small hydropower potential on a per-site basis, and under existing technology and cost structures are not viable for development.

The economics analysis presented herein demonstrates the nonlinear economies of scale involved in the development of small scale hydropower projects. Although some of the sites individually are cost-effective, others sites that can only produce tens of KW are not economical under current technologies, equipment prices, and existing regulations on hydropower development. This report uses average capital costs of $3,670/KW (national average) to develop a site, however, some sites in the New England region could cost as high as $6-7000/KW. Like all energy technologies, favorable market conditions are required for hydropower development and these principally drive the commodity price structure. However, once these projects are developed, and have started operations, they have the ability to provide power over several decades at very competitive operating costs. This analysis concludes that with proper incentives, hydropower development at undeveloped sites in Rhode Island is an economically viable option.

8. LIST OF APPENDICES

8.1 Appendix A: Flow Duration Curves for Rhode Island Dam Sites (only available online at RI Energy.org)

8.2 Appendix B: Master Rhode Island Dam List (Excel Spreadsheet) (DEM Office of Water Resources, 2011) (only available online at RI Energy.org)

8.3 Appendix C: Rhode Island Hydropower Resource Assessment Spreadsheet (Excel Spreadsheet)

Note: Appendix C is located on the next page, and is also available online at RI Energy.org**.**

NatID	Name	CumDrain_mi2	Basin Relief (ft)	Predicted m	Predicted σ	Gross Head (ft)	70% Exceedance	Mean Flow (cfs)	25% Estimated Design Flow (cfs)	70%KW	MeanKW	25%KW	MWH Generated	FERC License	FERC Capacity	Additional Efficiency?
RI00809	MANVILLE	334.44	99.11	6.02	0.95	19	251	657.2	1121	363	951	1622	7103	PRE PERMIT	1026	Yes
RI00808	ALBION	337.98	127.20	6.03	1.00	12	320	809	1182	292	739	1080	4730	PRE PERMIT	1200	No
RI00807	ASHTON	342.52	85.72	6.04	0.92	10	337.4	652	1096.9	257	496	835	3658	PRE PERMIT	1000	No
RI00402	ELIZABETH WEBBING	378.52	37.15	6.13	0.75	11	372	710.6	877.4	312	595	735	3219	PRE PERMIT	745	No
RI01409	POTTER HILL	240.27	112.34	5.72	0.98	8	184	502	600	112	306	365	1601	PRE PERMIT	390	No
RI01002	JAMES V TURNER RESERVOIR	53.75	13.08	4.35	0.53	22	58.9	89.2	111.8	99	149	187	820	PRE PERMIT	300	No
RI83001	BLACKSTONE (TUPPERWARE)					31	294	633	814	694	1,494	1,921	8,415	LICENSE	2000	No
RI03902	WOONSOCKET FALLS	272	138.22	5.83	1.02	18	260	561	959	356	769	1314	5757	LICENSE	1100	Yes
RI00401	VALLEY FALLS POND	348.09	52.16	6.05	0.82	14	343.9	590	1004.5	367	629	1071	4690	LICENSE	818	Yes
RI03802	ARCTIC	72.18	51.60	4.62	0.82	26	65.4	139	240.4	129	275	476	2084	LICENSE	478	No
RI04271	PAWTUCKET LOWER	379.1	27.94	6.13	0.69	17	390	723	907.3	505	936	1174	5144	EXEMPTION	1675	No
RI04367	RIVERPOINT POND UPPER	72.49	65.98	4.62	0.87	20	80.4	145.4	251	122	221	382	1674	EXEMPTION	225	Yes
	SLATERSVILLE UPPER INTERMEDIATE	86.04	102.44	4.78	0.96	19	72.8	189	225.4	105	273	326	1428	EXEMPTION	360	No
RI03801	NATICK POND	182.38	137.53	5.46	1.02	25	237	388.4	455.3	451	739	867	3796			
RI04270	PAWTUCKET UPPER	379.09	43.47	6.13	0.78	8	379.6	636.1	1066	231	387	649	2844			
RI02501	SLATERSVILLE RESERVOIR UPPER	86.04	102.44	4.78	0.96	27	72	192	228.7	148	395	470	2059			
RI04038	HARRIS POND	104.74	125.93	4.96	1.00	19	83	232	280.9	120	336	406	1780			
RI03501	FRUIT OF THE LOOM	197.93	143.40	5.54	1.03	10	146	445	515	111	339	392	1717			
RI04370	PHENIX MILL POND	106.36	57.82	4.97	0.84	15	116	205.4	341	132	235	389	1706			
RI01407	ALTON POND	87.4	43.47	4.79	0.78	15	79.5	165.5	275.6	91	189	315	1379			
RI00802	DIAMOND HILL RESERVOIR	18.71	88.25	3.39	0.93	71	17.4	45.7	55.6	94	247	301	1316			
RI04039	ARKWRIGHT POND	103.71	30.76	4.95	0.71	16	20.9	181.2	228.9	25	221	279	1221			
RI02502	SLATERSVILLE RESERVOIR MIDDLE	89.65	84.17	4.82	0.92	15	76.8	189.3	234.5	88	216	268	1173			
RI03901	HARRIS POND DAM	34.19	34.83	3.94	0.74	40	35.5	67	84.7	108	204	258	1130			
RI03005	HOPE	100.28	147.49	4.92	1.04	12	78.8	231.8	277	72	212	253	1109			
RI02504	FORESTDALE POND	91.27	75.60	4.83	0.90	14	77	185.6	222.2	82	198	237	1037			
RI03003	BARDEN RESERVOIR	33.24	110.39	3.91	0.98	30	29	76	92.4	66	174	211	924			
RI04366	RIVERPOINT POND LOWER	72.56	40.85	4.62	0.77	14	83	135.1	192	88	144	205	896			
RI04015	NASONVILLE POND	73.2	89.47	4.63	0.93	14	63.2	153	189.3	67	163	202	884			
RI02503	SLATERSVILLE RESERVOIR LOWER	89.67	19.57	4.82	0.62	14	89.5	150	187.7	95	160	200	876			
RI04037	QUIDNICK POND UPPER	67.67	39.29	4.56	0.76	14	77.9	127.5	182	83	136	194	850			
RI03108	GEORGIAVILLE POND	31.92	116.96	3.87	0.99	27	28.6	78.9	94	59	162	193	846			
RI03803	CENTERVILLE POND	71.7	98.59	4.61	0.95	12	61.8	165.6	198	56	151	181	792			
RI04190	HOPE VALLEY MILL POND	74.09	85.21	4.64	0.92	12	63.9	161	196.1	58	147	179	785			
RI02901	HORSESHOE FALLS	90.48	94.16	4.82	0.94	10	74.9	192.6	232.2	57	147	177	774			
RI03804	CROMPTON LOWER	70.18	52.22	4.59	0.82	8	62	140.3	273	38	85	166	728			
RI00608	WASHINGTON POND UPPER	63.21	112.99	4.50	0.98	12	54.5	149	180	50	136	164	720			
RI04231	PAWTUXET RESERVOIR LOWER	232.84	57.88	5.69	0.84	3	240.6	417.1	700	55	95	160	700			
RI01406	WOODVILLE POND	86.37	93.75	4.78	0.94	9	73	187.8	226.3	50	129	155	679			
RI00803	PAWTUCKET RESERVOIR	19.61	120.10	3.43	0.99	33	18	49.9	59.8	45	125	150	658			
RI01401	WYOMING UPPER	57.86	72.78	4.42	0.89	13	52	124.3	150	51	123	148	650			
RI01001	OMEGA POND	56.1	25.15	4.39	0.67	15	57	100.7	126.49	65	115	144	633			
RI04043	CROMPTON UPPER	68.35	48.54	4.57	0.80	8	63	133	222.5	38	81	136	594			
RI04278	ATLANTIC MILLS POND	45.19	66.20	4.19	0.87	10	54	96.13	162	41	73	123	540			
RI03001	GAINER MEMORIAL	5.2	0.20	2.22	-0.33	96	5.76	13.4	16.7	42	98	122	535			
RI03101	STILLWATER RESERVOIR	24.03	121.52	3.61	1.00	20	22.8	61.3	73.2	35	93	111	488			
RI03601	WHITE ROCK	290.37	71.03	5.89	0.88	8	60.9	146.6	179.1	37	89	109	478			
RI04286	KENYON MILL POND	72.9	84.81	4.63	0.92	7	62.7	154.7	191.6	33	82	102	447			
RI00312	OAKLAND POND	66.93	85.67	4.55	0.92	7	58.9	144	173	31	77	92	404			
RI02402	LYMANSVILLE	41.93	91.89	4.12	0.94	10	37.9	93.5	114.5	29	71	87	382			
RI04280	RISING SUN POND	46.25	25.06	4.21	0.67	9	48	83.4	105.94	33	57	73	318			
RI04044	QUIDNICK POND LOWER	67.94	33.89	4.56	0.73	6	65	124	156	30	57	71	312			
RI04279	PARAGON POND	46.2	44.31	4.21	0.79	6	45	93.6	156	21	43	71	312			
RI04387	BARBERVILLE POND	54.49	137.69	4.36	1.02	6	47.5	132	155.4	22	60	71	311			
RI04277	MANTON MILL POND	42.51	43.09	4.14	0.78	6	51.8	86.2	122	24	39	56	244			
RI02601	TEN MILE RESERVATION	44.98	13.56	4.19	0.54	7	49.6	76.3	94.8	26	41	51	221			
RI04207	WYOMING POND LOWER	57.87	11.32	4.42	0.50	4	63.3	93.1	116.2	19	28	35	155			
										6,915	14,935	20,715	90,731			

9. REFERENCES

www.retscreen.net/

http://waterdata.usgs.gov/nwis/dv?referred_module=sw

ACSE, *Civil Engineering Guidelines for Planning and Developing Hydroelectric Developments, Vol. 4*

Alejandrino, A. A., T. A. McNally, and others. 'Regionalized Flow Duration for Philippines'. *Journal of Water Resources Planning and Management* 109 (1983): 320.

Brutsaert, W., and J. P. Lopez. 'Basin-scale Geohydrologic Drought Flow Features of Riparian Aquifers in the Southern Great Plains'. *Water Resources Research* 34, no. 2 (1998): 233–240.

Consulting, N. 'IEPR Committee Workshop on the Cost of Electricity Generation: Levelized Cost of Generation Model—Renewable Energy'. *Clean Coal and Nuclear Inputs* (2007): 58.

Dingman, S. L. 'SYNTHESIS OF FLOW-DURATION CURVES FOR UNREGULATED STREAMS IN NEW HAMPSHIRE1'. *JAWRA Journal of the American Water Resources Association* 14, no. 6 (1978): 1481–1502.

Duffield, J. W., C. J. Neher, and T. C. Brown. 'Recreation Benefits of Instream Flow: Application to Montana's Big Hole and Bitterroot Rivers'. *Water Resources Research* 28, no. 9 (1992): 2169–2181.

Fennessey, N., and R. M. Vogel. 'Regional Flow-duration Curves for Ungauged Sites in Massachusetts'. *Journal of Water Resources Planning and Management* 116, no. 4 (1990): 530–549.

Francfort, J and Rinehart, B. *US Hydropower Resource Assessment for Rhode Island*. Idaho National Laboratory. July 1995.

Hall, D. G. *Feasibility Assessment of Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants*. Department of Energy (DOE), 2006.

Hall, D. G., R. T. Hunt, K. S. Reeves, and G. R. Carroll. *'Estimation of Economic Parameters of US Hydropower Resources'. Idaho National Engineering and Environmental Laboratory* (2003).

Holmes, M. G. R., A. R. Young, A. Gustard, R. Grew, and others. 'A Region of Influence Approach to Predicting Flow Duration Curves Within Ungauged Catchments'. *Hydrology and Earth System Sciences* 6, no. 4 (2002): 721–731.

Kroll, C. N. 'Regional Geohydrologic-geomorphic Relationships for the Estimation of Low-flow Statistics'. *Water Resources Research* 28, no. 9 (1992): 2451–2458.

Richardson, 2005. Modified Aquatic Base Flow (RI-ABF) for Rhode Island. March, 2005. http://www.dem.ri.gov/programs/benviron/water/withdraw/pdf/riabf.pdf

Searcy, J. K. *Flow-duration Curves*. US Government Printing Office, 1959.

Strahler, A. N. 'Quantitative Analysis of Watershed Geomorphology'. *Transactions of the American Geophysical Union* 38, no. 6 (1957): 913–920.

Tukey, J. W. 'The Practical Relationship Between Common Transformations of Percentages or Fractions and of Amounts'. *The Collected Works of John W. Tukey* 6 (1960): 211–219.

USDOI, USDOE and US Army Corps of Engrs., 'Potential Hydroelectric Development at Existing Federal Sites', *For Section 1834 of the Energy Policy Act of 2005, 2005.*

Vogel, R. M., and N. Fennessey. 'Flow-duration Curves. I: New Interpretation and Confidence Intervals'. *Journal of Water Resources Planning and Management* 120, no. 4 (1994).

Yu, P. S., and T. C. Yang. 'Using Synthetic Flow Duration Curves for Rainfall–runoff Model Calibration at Ungauged Sites'. *Hydrological Processes* 14, no. 1 (2000): 117–133.

Yu, P. S., T. C. Yang, and Y. C. Wang. 'Uncertainty Analysis of Regional Flow Duration Curves'. *Journal of Water Resources Planning and Management* 128 (2002): 424.

Zecharias, Y. B., and W. Brutsaert. 'Ground Surface Slope as a Basin Scale Parameter'. *Water Resources Res* 21, no. 12 (1985): 1895–1902.

RESP TECHNICAL REPORT #10

ASSESSING FINANCIAL FEASIBILITY AND ECONOMIC IMPACTS OF RENEWABLE ENERGY PROJECTS

By

James J. Opaluch

Department of Environmental and Natural Resource Economics

University of Rhode Island

Kingston Campus

June, 2012

Table of Contents

List of Tables

1. INTRODUCTION

Like many places across the nation, Rhode Island communities are considering investing in renewable energy infrastructure. However, communities often do not have adequate technical expertise to judge whether renewable energy facilities are a wise investment, which is especially problematic in difficult economic times. In some cases, a community might want to carry out a preliminary analysis of the financial feasibility of renewable energy facility without investing a lot of time and money hiring contractors to carry out the analysis on their behalf. Communities also might not want to have to rely entirely on the expertise of contractors and developers who are in the business of planning and constructing renewable energy projects. And communities may not always be in a good position to negotiate reasonable rates of compensation for hosting privately owned renewable energy facilities within their town. So for a variety of reasons, Rhode Island communities could be assisted by having access to independent information on the likely financial and economic consequences of developing a renewable energy facility in their town.

Because of this common nationwide need for independent information on the financial and economic consequences of renewable energy facilities, federal governments have undertaken considerable investments in creating easy to apply spreadsheet-based tools to help communities undertake low cost, initial financial assessments. These tools are equally helpful for communities that are considering whether to build a renewable energy facility that they would own and operate on their own, or for negotiating contractual arrangements with private industry, who owns and operates the facilities within the community and provides financial compensation to the community that hosts the facility. These spreadsheet tools allow communities to assess many different scenarios for renewable energy facilities quickly and at low cost. The tools also provide a high degree of transparency, and can help to level the playing field by serving, in effect, as an objective third party in cases where a community is conferring with a private contractor, who generally has much more knowledge and expertise on the costs of renewable energy facilities.

The major goal of RESP is "to provide technical expertise about the effects renewable energy may have on the people, wildlife and natural resources of Rhode Island." This Section describes available tools that have been developed to help communities assess the financial and economic effects that renewable energy projects could have on the people and communities in Rhode Island. It should be emphasized that these tools are not intended as a substitute for detailed project-specific analyses. Rather, they are intended as screening tools to determine whether a community might want to go ahead with a more detailed and expensive project-specific analysis.

First the Section discusses some of the key economic concepts embodied in financial and economic assessments of proposed projects. The intent is to provide a brief overview of key metrics that are used in the spreadsheet tools, to serve as an aid to readers who may not have a background in economics and finance. Next, the Section briefly summarizes three spreadsheet-based models that have been developed to apply these concepts to help communities assess renewable energy projects. The three models described in this Section are the Cost of Renewable Energy Spreadsheet Tool (CREST), Jobs and Economic Development Impact Model (JEDI) and RETScreen. We briefly describe each tool, discuss the information needed to apply each tool, and indicate what information can be obtained by applying each tool. The intent of this is to help the reader determine which tool or tools are right for them, given the data they have available and the information they are looking for from a tool. Finally, the Section provides some example runs of the models to show how the models might be used, and to compare the results of the models to actual experience in the State.

2. ECONOMIC CONCEPTS IN THE SPREADSHEET MODELS

This section briefly describes some of the basic economic concepts that are used in financial and economic impact analyses for assessing renewable energy projects. Note that the explanations below are intended to be illustrative, in order to convey the basic concepts, and are not intended to be comprehensive, nor detailed. Many complex issues arise in the various measures described below. For example, below we describe a "tax rate", when in fact tax calculations can be very complex when accounting for differential tax treatments of various capital expenditures, accelerated depreciation, renewable energy tax credits, etc. Similarly, many uncertainties are faced, and many assumptions are necessarily made in forecasting costs and revenues over the life of the project. The descriptions and related calculations presented below are not intended to account for the many complicating factors, but rather are intended provide simple illustrations to explain the basic concepts.

2.1 Discounted Cash Flow Analysis

Discounted cash flow analysis is widely used to evaluate the financial viability of projects in fields like investment finance, real estate development, and corporate financial management. Discounted cash flow analysis can be used to assess the overall financial viability of projects based on the concept of the time value of money. A dollar today is not worth the same as a dollar 20 years from now, even after correcting for inflation. For example, if a community issues a bond, or if a company takes out a loan from a bank today, and the obligation is paid back over a 20 year time interval, the entity has to pay back the amount borrowed, and additionally it must make interest payments over time on the remaining debt. Or if a company or town uses its own internal funds to finance a project internally, it must set aside money that could otherwise be productively used for other purposes. In either case, there is a "cost" associated with investing money today in order to earn a return in the future. This cost is sometimes referred to as the "cost of capital"—either an explicit cost, such as interest payments on a bank loan, or an implicit cost of giving up an alternative use of funds in order to invest in the project at hand.

As a consequence, discounted cash flow analysis compares costs and revenues over time using the net present value, where future values are discounted at an assumed rate of "interest" (the discount rate). The net present value is the lump sum amount of money at a given point in time that is "equivalent" to a flow of revenues and costs over time. Discounted after-tax net present values in each year are then added up over the duration of the project. The after-tax net present value is calculated as follows:

$$\mathrm{NPV} = \sum_{\mathrm{i}=0}^{\mathrm{T}} (1-\mathrm{t})(\mathrm{Rev(i)} - \mathrm{Cost(i)}) \left(\frac{1}{1+\mathrm{r}}\right)^{\mathrm{i}}$$

where NPV is the net present value, i represents the time period, T is the project duration, t is the applicable tax rate[1], Rev(i) is the project revenue received at time i, Cost(i) is the project-related cost paid at time i and r is the discount rate. A project is judged to be "financially viable" if the after-tax net present value of the project is positive. Or a set of mutually exclusive projects could be ranked according to their respective net present values.

Note that in the calculations, the project duration and the associated costs and revenues should be defined broadly enough to include all prospective project-related costs and revenues, such as any future costs of planning, initial capital expenditures, decommissioning costs, and revenues from salvage, or the scrap value, if any. But the calculations should only include costs directly attributable to the project going forward, and should not include costs that will be incurred irrespective of whether the project goes forward or not, such as "sunk" costs that have already been fully committed and cannot be reversed.

As indicated above, the discounted cash flow calculations are directly analogous to calculating profitability of an investment in a project, where a loan is taken out at the beginning of the project, and net revenues are used to pay back the loan over time, including interest payments on the balance of the loan. And the net present value calculations are treated identically whether the entity making the investment decision is a for-profit entity, like a firm, or a non-profit entity, like a town. Furthermore, the net present value calculations are treated analogously, independent of the extent to which the project is financed through debt by borrowing, or by equity by using available cash. In the former case, r represents an explicit cost of capital—the interest rate on the loan. In the latter case, r is a discount rate reflecting an implicit "opportunity cost" of capital.

---

[1] If the entity making the investment is non-taxable entity, like a town, then the tax rate is zero, but if the entity is a for-profit corporation, then the tax rate will typically be non-zero.

2.2 Internal Rate of Return (IRR)

The internal rate of return is sometimes used as an alternative to net present value as a means of assessing the financial viability of projects. The IRR calculation works similarly to the discounted cash flow, and in most cases IRR can be expected to give the same results regarding desirability of an investment. Indeed, the IRR calculation uses the same formula as net present value, but IRR determines the discount rate at which the net present value equals zero. That is, IRR is calculated as follows:

$$\mathrm{NPV} = \sum_{\mathrm{t}=0}^{\mathrm{T}} (1-\mathrm{t})(\mathrm{Rev}(\mathrm{i}) - \mathrm{Cost}(\mathrm{i}))\left(\frac{1}{1+\mathrm{IRR}}\right)^{\mathrm{t}} = 0$$

That is, IRR is the rate of interest at which the project just breaks even, in that its net present value equals zero. And IRR can be thought of as a measure of the annual rate of return on funds invested in the project.

The internal rate of return is sometimes used to analyze the financial desirability of a project by comparing the IRR to a target for the minimum acceptable for rate of return (MARR), to the rates of return of alternative projects in which the entity could potentially decide to invest, or by comparing IRR to interest rates at which the entity could borrow. In the terms described above, an investment is judged to be financially justified if the internal rate of return of the investment is greater than the cost of capital. If a firm seeks investments that have an after tax rate of return of at least 15%, then a project would be judged “financially viable” if the IRR is 15% or greater. The term “hurdle rate” is sometimes used to indicate the minimum acceptable rate of return for a project to be deemed financially viable. The MARR will commonly depend upon the risk faced. For example, a more risky investment is commonly required to have a higher internal rate of return to be judged financially viable than a less risky investment.

Although IRR is commonly used to assess financial desirability of investments, for technical reasons, the net present value is the conceptually preferred way of carrying out project analysis, as IRR may give incorrect guidance on investments in some cases when comparing projects that are mutually exclusive, when comparing projects of different durations, or when selecting among projects with limited investment funds.

2.3 Payback Period

Payback period is the amount of time required for the return on an investment to repay the initial investment, and is a measure of how long it takes an investment to “pay for itself”. For example, if a community spends $3 million to build a wind turbine, and the wind turbine saves $300 thousand per year in the town’s electricity bill, then the payback period is 10 years

(=$3 million/$300 thousand per year). All else equal, a shorter payback period is better than a longer payback period.

The payback period is easy to apply, the concept is easy to understand, and in certain circumstances it can be very useful. But the concept has serious limitations, and should only be applied in limited circumstances. First, payback period does not consider the time value of money. Consider, for example, a case of two investments costing $3 million. Suppose one of the investment pays back $300 thousand each year, and the other pays back zero for 9 years, and pays back the full $3 million at the end of year 10. Both have payback periods of 10 years, but the former is a better investment from a purely financial perspective, since money flows in over time, while for the latter investment there is no return at all until 10 years later. For example, if a town borrowed money to make the investment, half of the debt on the first investment could be paid off in five years, so the town would not have to make interest payments on that portion of the debt. While in the latter investment, the town would carry the full debt for 10 years, and would have to pay interest on the entire $3 million for that full time.

Also, payback period does not capture returns on the investment following the payback period. For the example above, suppose the first investment described above continued to provide revenues of $300 thousand per year in perpetuity, while the 2nd investment only had a one-time payment of $3 million in year 10, with no additional revenues in the future. Both have the same payback period of 10 years, but in fact the former provides a much more desirable revenue stream over the life of the project. The same would be true if the 2nd investment required $500 thousand in equipment replacement in year 12, while the former investment did not require any equipment replacement. In these cases such as these, payback period would be an extremely misleading metric of the preferred investment, while net present value would give correct guidance in choosing between the two.

Nevertheless, in simple cases where all expenses come in the beginning of a project, and an even flow of revenue occurs in future years, payback period can be a simple and easy to understand measure of financial viability. For example, payback period might provide a useful indicator of the desirability of switching a building from incandescent to compact florescent bulbs. If compact florescent bulbs pay for themselves in less than a year, they are probably a good investment.

2.4 Cash Flow Considerations

In addition to the “bottom line” assessments, such as net present value or the internal rate of return, the cash flow over the duration of a project can be an important consideration for financial viability of a project. It may be, for example, that taken as a whole, a project is profitable over the full 20-year project duration. But the project may not generate sufficient revenue over the first 5 years to cover required loan payments, and the entity might be forced to default on the loan if it does not have sufficient cash reserves to cover costs over this interval.

One relevant measure of cash flow from a project is the Debt Service Coverage Ratio (DSCR). DSCR is the cash available for debt servicing divided by the required payments on principal and interest for each year of the project lifespan. So DSCR is measured each year in order to ensure that there is sufficient cash available to meet annual interest and principal payments on debt when due. DSCR greater than 1 in every time period means that the entity can expect to have sufficient cash available to meet the debt payments over the duration of the loan.

In some cases assessing financial viability of a project involves placing a constraint on DSCR to ensure that payments can be made when necessary, with a sufficient cushion to account for possible uncertainty. For example, a wind energy facility might have a year with lower than expected power production, and hence revenue, due to unfavorable wind conditions or due to an unusually large down time for to repairs or maintenance. As a consequence, a bank may require a DSCR greater than 1 (e.g., 1.25) in order to ensure availability of sufficient cash, even in unusually bad years that might be faced over the duration of the project. A high DSCR is often an important criterion for obtaining a loan, or for getting a favorable interest rate on a loan.

2.5 Economic Impacts

The concepts above are related to the financial viability of an individual project viewed from the perspective of the financial returns to an investor in the project. In contrast, Economic Impact Analysis assesses the effects that a given project will have on the broader economy. This includes such elements as jobs, wages, tax payments, expenditures on related businesses, etc. It is important to note that economic impacts are measures of the *expenditures* on a project—the costs—not the *benefits* of a project.

Depending on the interests of the entity carrying out the assessment, Economic Impact Analysis can be carried out on a local, state-wide, regional or national basis. For example, a town might be concerned about how a project affects businesses within the town or taxes collected by the town, but not about tax revenues to other towns or to the state as a whole. In comparison, a state agency such as the Department of Economic Development might be concerned about all of economic impacts within the State as a whole, but not economic impacts accruing to other states. The federal government might be concerned about economic impacts to the country as a whole, but not those to other countries.

Economic impacts include (1) direct effects, (2) indirect effects, and (3) induced effects. Direct effects are economic impacts directly associated with the activity. For example, building a solar energy facility requires activities associated with construction, repair, operations and maintenance, all of which require labor, pay wages and taxes, purchase goods from other businesses, etc.

Indirect effects are economic effects traced back through the supply chain for the facility. Solar arrays are made up of components, such as glass, steel, silicone, etc. The indirect effects trace jobs, wages and tax payments through the supply chain of producers of these various components. For example, producing a solar array requires a set of inputs, such as steel. But producing the steel requires other inputs, such as iron, labor, electricity, etc. The indirect effects are the economic impacts associated with the inputs (e.g., steel), and the inputs required to producing those inputs (iron), etc.

Induced effects are expenditures made by employees receiving wage payments associated with a project. For example, induced effects include the expenditures that construction workers might make on restaurants, hotels, or other goods and services. Together, the indirect and induced effects are sometimes referred to as secondary effects.

These economic effects are sometimes controversial. For example, how do we know that building a wind tower will really create jobs in the steel industry? Perhaps steel used to create wind towers will just be taken from excess inventories already in place that will otherwise go unused, or perhaps existing steel workers can produce the small amount of steel necessary for a project. Or even if the steel industry does hire new workers to produce the steel, perhaps these new employees will be displaced from other jobs, so no “new” jobs are created. Typically, one would expect that projects are more likely to create new jobs and wages when unemployment rates are high, rather than under conditions of a full employment economy when workers are more likely to be bid away from other jobs. Indeed, statutes such as the American Recovery and Reinvestment Act design economic stimulus packages with precisely such a goal in mind: jump starting a flagging economy by creating new jobs and associated expenditures. In cases of moderate unemployment rates, practitioners sometimes recommend that multipliers be adjusted downward.

Another issue is the size of the region within which direct, indirect and induced effects take place. For example, from the perspective of the State of Rhode Island, employment, wages and taxes paid in Rhode Island are the major concern. But a company hired to construct a solar power facility might come from out of state. All jobs and wages might go to non-residents of Rhode Island. The solar panels that are used might be imported from China. In this case, indirect employment in the industries producing inputs to production of solar panels do not go to Rhode Island residents—or even US citizens—but to Chinese workers.

Regional economists use the term “leakage” to refer to these expenditures that flow outside of the region of concern. The fraction of expenditures that occur within the region of interest is sometimes referred to as the “capture rate”. Calculating economic impacts captured by a given community (e.g., a town or a state) requires one to specify how much of each economic impact occurs within the community of interest, and how much “leaks” out to other communities.

In general, the smaller the region of concern, the larger the leakage rate. Economic impacts that flow to Providence are leakage if the region of concern is South County, but not if the region is the state of Rhode Island or the nation as a whole. Economic impacts in

Massachusetts are “leakage” when Rhode Island is the region of concern, but not when the U.S. is the region of concern.

Consider a simple example where solar panels are purchased from retail firms located in Rhode Island, but the panels were manufactured outside of Rhode Island. In this case, building a solar energy facility might support employment for Rhode Island retail companies selling solar panels, but the economic impacts associated with manufacturing occur outside of Rhode Island. Most likely the economic impacts associated with inputs for the production of solar panels (e.g., steel, etc.) flow outside of Rhode Island.

Data are sometimes difficult to obtain on what is produced within a town or State, and what flows outside the region. But in other cases, it is fairly straightforward. For example, there are no steel mills in Rhode Island, so all steel produced is “leakage” from a State perspective. But so many scenarios are possible, and it is simply not feasible to trace out each and every case. Instead, “average” or “representative” assumptions are made, based on available datasets. This means the economic impact analysis is more readily applicable to assessing averages from large programs, such as achieving a goal for overall production of renewable energy within the State of Rhode Island, as compared to forecasting the economic impact from one hypothetical wind turbine where economic impacts are likely to be highly project specific.

2.6 Input-Output Models

Input-output models quantify the interdependences among the various sectors of the economy, and are commonly used to quantify economic impacts. Input-output models work by tracing flows of expenditures through the sectors of the economy. For example, in order to produce a wind tower, inputs of steel, energy, machinery, labor, etc. are required. These inputs, in turn, also require their own inputs. Therefore, an increase in demand in one sector (e.g., purchases of wind turbines) will have a ripple effect associated with purchases of inputs that propagates through the economy. Building more wind turbines increases demand for inputs to production wind turbines, such as steel, labor, etc. This in turn increases demand for inputs to production of steel, such as iron, labor, etc., thereby increasing demand for inputs into the production of iron, etc.

Input-output models can quantify these linkages, so we can, for example, forecast how total employment changes throughout the entire supply chain when demand for wind turbines increases. These effects include the direct effects (e.g., employment in the construction of wind towers), the indirect effects (employment in producing the steel needed to produce wind turbines, and employment in the production of the iron that is required to produce steel, etc.) and the induced effects, such as the purchases of goods and services made laborers who are paid to work on the project.

An input-output table is a square matrix that quantifies the linkages among sectors such as these in the economy. The I-O matrix has a row and a column that corresponds to each sector.

Reading down a column of the input-output matrix indicates the purchases that the corresponding sector makes on inputs from each sector to produce a unit of output. Reading across a row indicates the sales of inputs that the corresponding sector makes to all sectors in the economy.

An actual input-output table would be made up of many sectors. But as a simple illustration, consider an economy made up of three sectors: manufacturing, energy and consumers. The associated input-output table is a 3x3 matrix, where each sector has an associated row and an associated column. Reading down the column corresponding to the energy sector indicates the inputs that the energy industry purchases from each sector: inputs purchased from the energy sector (e.g., natural gas used by a power plant to produce electricity), the equipment manufacturing (e.g., turbines), and consumers (laborers hired). The elements across the row corresponding to energy indicate the energy outputs sold to all sectors in the economy. Simple matrix operations are applied to the input-output matrix to calculate the overall ripple effects of the policy as they propagate through the economy.

Input-output models can be applied at the global, national or regional levels, and they are often used as planning tools. Input-output analysis is also commonly used for measuring the economic impacts of public investments or other public programs.

2.7 Multiplier Effects

Input-output analysis can be used to construct what is sometimes called “multiplier effects” to account for indirect and induced effects, discussed above. For example, if an input-output analysis finds that indirect and induced effects are twice the direct effect, then a given initial purchase on local businesses is multiplied by 3 to account for the indirect and induced “cascade effects” through the economy. These economic multipliers are calculated from input-output tables, and often applied directly, without actually applying an input-output model.

Economists are often skeptical of the use of economic multipliers, especially when applied during periods with low rates of unemployment. Economists generally believe that multiplier effects are small (or even zero) when the economy is near full employment, since additional spending on inputs to produce one product (e.g., a wind turbine) may simply offset spending that would otherwise have occurred, since they compete for the same resources. Multipliers are more likely to be larger in cases of significant unemployment rates, when there is excess labor, productive capacity and other materials that are currently unutilized. Multipliers are also small when considering economic impacts on small regions (like the State of Rhode Island), because there will likely be considerable “leakage” outside of the region of interest. As a consequence, multiplier effects need to be used judiciously.

2.8 Social Accounting Matrix

The Social Accounting Matrix (SAM) is an extended version of an input-output matrix, with additional elements of social significance that lie outside of market transactions. The SAM matrix is created by expanding the input-output matrix by linking it with "satellite" accounts that link economic transactions with other metrics of social concern, such as pollution emissions, land use change, tax payments, etc. For example, a SAM matrix might be used to track reductions in carbon dioxide emissions that occur when wind or solar energy replaces electricity produced by coal-fired power plants.

For example, given appropriate data to support the SAM, it could be used to determine whether there is a net increase or decrease in wages paid to skilled labor and to unskilled labor when electricity produced by wind turbines is substituted for electricity that was previously produced from coal, accounting for the effects as they ripple through the supply chains for both wind and coal. Or a SAM might be constructed to track a policy's ripple effect on pollution emissions throughout the economy, accounting for direct effects of pollution emitted by the facility (e.g., burning coal to produce electricity), air pollution from the indirect effects associated with the inputs used (e.g., coal mining and transport), and their inputs (e.g., producing the machinery needed to mine coal), etc. In this way, a SAM matrix might be used to calculate the ultimate net effect on air pollution emissions of reducing coal burning, including the effects as they propagate through supply chain of coal fired power plants.

3. OVERVIEW OF SPREADSHEET-BASED TOOLS

This section provides a brief overview of three easy to apply spreadsheet-based tools that use the economic concepts outlined above to assess the financial and economic effects of renewable energy projects. The goal of this Section is to introduce the interested reader to some of the available tools, and to provide a brief overview of the information that can be obtained from each of the tools to illustrate which tool(s) might be most useful for a particular purpose. Readers who are interested in more details of the various models are referred to the documentation of the models cited below.

The tools described in this Section are the Cost of Renewable Energy Spreadsheet Tool (CREST), Jobs and Economic Development Impact (JEDI) Model and RETScreen. All three tools are Microsoft Excel spreadsheets, and all employ macros to carry out sophisticated sets of calculations. It is important to note that the models are fully functional only with Microsoft Windows machines, and functionality is limited at best with Apple computers.

For those interested in a more detailed analysis, NREL also provides the Systems Advisor Model (SAM), which is a more comprehensive tool. But SAM require much more detailed information to operate, and is better left for a more advanced step in analyzing renewable energy options. The NREL website has a detailed description of SAM (https://sam.nrel.gov/).

3.1 Cost of Renewable Energy Spreadsheet Tool (CREST)

The CREST model was developed in 2010 by a partnership of the National Renewable Energy Laboratory (NREL), the U.S. Department of Energy (DOE), Solar Energy Technologies Program (SETP), and the National Association of Regulatory Utility Commissions (NARUC). The model was created by Sustainable Energy Advantage (SEA), a private corporation, funded by and working under the direction of NREL. The CREST models are available for free on-line (https://financere.nrel.gov/finance/content/crest-model), and the CREST User Manual is available at http://www.nrel.gov/docs/fy11osti/50374.pdf .

The primary purpose of CREST is to help regulatory bodies, such as public utility commissions, design cost-based incentives, such as feed-in tariffs[2] (FITs), tax credits, and similar policies, to ensure that efficiently operated renewable energy generators can be financially viable. CREST is a set of three spreadsheet tools, one each for solar, wind and geothermal. The general structure and architecture of the three CREST models are similar for the different energy technologies, although the specifics obviously vary to capture essential elements of the three different energy technologies.

CREST provides a discounted cash flow analysis to determine the cost of producing energy, where the user inputs capital costs, operating cost, performance efficiency and various other financial parameters. The primary outputs of CREST are the cost of energy (COE), net present value of profits, internal rate of return, and cash flow. Each of these measures can be calculated under private or public ownership, under alternative structures for state and federal incentives, and with different assumptions for capital and operating costs, interest rates, performance efficiency, etc.

CREST can be used for various purposes. The State of Rhode Island used the CREST model to set feed-in tariffs for wind and solar energy projects. But a community might use also use CREST to calculate a lease payment that could be charged to a private company that operates a renewable energy facility within a town, and still allow the company to receive a fair return on investment, given the economic environment in terms of prices, available financial incentives by the State and Federal government, etc.

The flexibility of CREST also allows it to provide an understanding of how COE and the financial viability of a project are affected by factors such as the size of a project, its location, interest rates on loans, etc. This also allows a user to identify which factors are the most critical in determining the financial viability of a project. For example, CREST could be used to compare the COE for two sites for a wind turbine, one of which has a better wind resource, while the other site has better access to the grid, and therefore a lower interconnect cost.

---

[2] Feed-in tariff (FIT) is a long-term contractual price paid for energy from renewable sources that is typically based on the cost of producing energy from the particular technology. A FIT is used to encourage investment in renewable energy by providing a higher, cost-based price, which is intended to ensure that efficiently operated renewable energy facilities can be financially viable.

CREST allows a user to employ “simple”, “intermediate” or “complex” approaches to entering cost data. In the absence of any detailed information, one can use the “simple” approach to input the most general cost data (e.g, the capital cost per KW nameplate capacity, and the operations and maintenance cost per KW). This allows the model to be used in situations for a community that wants to carry out a quick, exploratory assessment of the financial viability of a renewable energy facility where very little background information is available. Or a state agency might want to carry out a policy-level analysis of the profitability of wind energy facilities in coastal areas of Rhode Island, where specific developers, sites and products have not yet been identified. In this case, the user might employ rough estimates of facility costs that are representative of facilities built elsewhere, or the user might want to consider a range of estimates for costs of facilities.

But for users who have already done background research on the equipment they plan to use, CREST allows for entry of much more detailed cost information. This means potential investors in a renewable energy facility can carry out simple “back-of-the-envelope” calculations based on readily available cost information. But the options to use “intermediate” or “complex” inputs allow users to carry out much more refined assessments based on more detailed information in cases where the user has more information.

3.2 RETScreen

The RETScreen Clean Energy Project Analysis Software (RETScreen) determines the economic feasibility of many different clean energy projects, including wind, solar, natural gas, hydro, etc., and even including energy efficiency measures and cogeneration (combined heat and power). In addition to an analysis of financial feasibility, RETScreen also conducts analyses of energy production, emissions reductions associated with clean energy technologies, and analyses of sensitivity to key parameters.

RETScreen is managed by CanmetENERGY research center that is part of Natural Resources Canada, a department of the Canadian federal government. It was developed by a collaboration of a large number of experts from the government, industry and academia. RETScreen and its documentation can be downloaded for free at http://www.retscreen.net/ang/home.php.

RETScreen metrics of financial feasibility include internal rate of return and payback period. But it is important to note that RETScreen does not include default values for capital and operation/maintenance costs. Rather, RETScreen requires the user to enter these costs in order to calculate profitability of the project. Hence, either the user must have project-specific cost information to run RETScreen, or the user might adopt a range of “representative” cost estimates from other facilities to get some initial rough indicator of the potential financial feasibility of a project.

While RETScreen does not have default cost data, it has a set of embedded databases that may help the user to assess energy production. For example, a user can select from different locations for the facility, and the database can populates the spreadsheet with relevant location-specific data, such as temperatures, wind speeds, solar radiance, barometric pressure, etc. This data is based on 4,700 ground-based stations around the world and NASA's satellite data. The RETScreen database has 4 locations within Rhode Island—Block Island airport, Newport, Pawtucket and Providence. Or users can input their own climatological data, if available. The user can also select from a large number of specific renewable energy products, based on manufacture and model number. For example, RETScreen contains such information as power curves[3] for a large number of specific wind turbines, and manufacturers are encouraged to submit data on their products to keep RETScreen up-to-date.

The user can employ RETScreen calculations for the capacity factor[4] using the climate database and the specifications of the manufacturer and model of the specific product, or the user can enter the capacity factor manually. But the user must enter capital and operating costs.

3.3 Jobs and Economic Development Impacts (JEDI) Models

The Jobs and Economic Development Impact (JEDI) models are a set of user-friendly tools that estimate the economic impacts of constructing and operating power generation and biofuel plants at the local (usually state) level. It was first developed by NREL's "Wind Powering America" program to model wind energy jobs and impacts. Since that time, JEDI has been expanded to cover biofuels, solar power, coal, and natural gas power plants. JEDI and its documentation are available for free at http://www.nrel.gov/analysis/jedi/.

Based on user supplied, project-specific and default inputs derived from industry norms, JEDI estimates effects on the local economy, defined in terms of the number of jobs, wages and other economic impacts that might reasonably be expected from a power generation project. JEDI uses its own database to determine the economic impacts at the state level, but a user can enter custom data if they wish to define the region at a different level. For example, one might want to understand potential economic impacts of a project to a region smaller than the state (e.g., South County), or larger than the state (e.g., Southern New England). The JEDI economic impact coefficients are based on data from the IMPLAN model (http://www.implan.com/V4/), which a leading regional economic impact analysis tool. IMPLAN is an input-output tool with state-specific Social Accounting Matrices and associated economic multipliers.

The JEDI models designed to provide representative profiles of investments such as the construction of a solar or wind energy facility to forecast likely implications for employment and

---

[3] Power curves indicate the power generated by a specific wind turbine at different wind speeds.

[4] Capacity factor is a fraction that accounts for the fact that no energy facility will continuously deliver power at it maximum possible capacity. For example, solar panels don't produce electricity at night, and wind turbines operate at less than full capacity when the wind speed is low. Capacity factor is the ratio of expected actual energy production at a particular site divided by the nameplate capacity.

other economic impacts during the construction and operating period. Of course, there are substantial variations in power plant costs, and differences in patterns of expenditures over different projects and over time. As a consequence, JEDI is not designed to provide a precise forecast of economic impacts, but it is intended to provide rough estimates of economic impacts associated with a set of scenarios. JEDI also provides estimates on land lease and property tax revenues.

JEDI is estimates economic impacts, but not the potential financial viability of a project. Although costs are calculated, JEDI does not calculate electricity production, revenues, net present values or internal rate of return. Also, since JEDI focuses on economic impact, it is intended more for Statewide programs for renewable energy development, rather than a single small-scale project. Nevertheless, JEDI can be applied to a single project.

At a minimum, JEDI requires a user to enter basic information on the project, such as the state in which the project(s) are being built, the year in which construction occurs and some basic information about the project. For example, in the case of solar photovoltaic, the user enters the system application (e.g., residential vs. commercial vs utility-scale), the type of system (e.g., solar panel vs. thin film), tracking system (single axis versus fixed mount), number of units installed and nameplate capacity per unit.

The model has default values for base installed system cost ($/KW) and operations and maintenance costs ($/KW) that vary across the type of unit described above. For example, the cost per KW is higher for a residential unit than for a commercial unit, and the cost is higher for a residential retrofit than for new residential construction. But it should be emphasized that costs vary substantially across different units, and these are intended only as rough indicators of the costs that can be expected, not precise measures. A user can choose to accept the default data, but more precise results can be obtained if the user has reliable project-specific estimates. Or a user might want to consider a range of costs around the default values provided by the models.

JEDI calculates economic impacts at the State level, and it uses default values from IMPLAN for the fraction of different components that are purchased from Rhode Island suppliers, and that are manufactured in Rhode Island. The user can use the default values, or enter custom values. This allows JEDI to assess scenarios such as how economic impacts to Rhode Island would change if components are locally sourced and locally manufactured. So one could carry out alternative scenarios, for example, depending upon whether or not Quonset is developed as a major site for manufacturing renewable energy projects.

The primary outputs of the model are jobs, earnings and expenditures during the construction period and during operations, in total and within the State. Of course, just like no single renewable energy project will make a significant effect on Statewide energy production, no single project will make a significant effect on Statewide employment or economic impacts.

But JEDI could be used to get an idea of what can be expected from individual projects, and total impacts of a set of projects could determine by aggregating over projects.

3.4 Summary of the Models

CREST, RETScreen and JEDI are all free and easy-to-use spreadsheet tools to assess financial and economic effects renewable energy facilities. But the three models were designed for different purposes, and as a consequence they each have different strengths and weaknesses that make them useful for different uses, and the models may perform complementary roles in for users. The primary purpose of each model, and their advantages and disadvantages are summarized in Table 1.

CREST is designed to be used by public utility commissions and other regulators who wish to estimate financial incentives to ensure profitability of efficiently operated renewable energy facilities. CREST estimates the cost of energy, revenues, internal rate of return, cash flow, cash reserves, etc. under different cost-based incentives (e.g., tax credits, feed-in tariffs, etc.), which can also be very useful information for a user who is interested in assessing the financial feasibility of a renewable energy facility. CREST can calculate profitability of a renewable energy facility under a broad set of financial conditions. In addition to calculating bottom line measures like cost of energy or internal rate of return, CREST calculates cash flow over the life of the project, and can calculate metrics such as DSCR.

At the same time, CREST only has a single default value for the capital cost/KW and a single default for operating costs/KW, which does not reflect scale economies associated with facilities of vastly different capacities. The default cost estimates also do not vary by location, and so the results do not reflect regional differences in wages and other costs. CREST also has a single default value for capacity factor for wind, but the capacity factor varies by state for solar. Also, CREST is currently only applicable to wind, solar and geothermal energy facilities, which is a narrower range of renewable energy technologies than the other models.

The purpose of JEDI is to assess economic effects of energy facilities on the larger regional economy—typically at the State level. The relevant economic effects include such things as jobs created, wages paid, expenditures on local businesses and other economic impacts of renewable energy projects. JEDI also calculate cost of facilities, and unlike CREST, JEDI has default values for costs that differ for facilities of different scales. JEDI is applicable to many different types of energy facilities including biofuels, coal, concentrated solar, solar photovoltaic, natural gas, wind and hydrokinetic.

JEDI is not designed to assess the financial viability of renewable energy projects. So JEDI calculates such metrics as expenditures, jobs, wages, etc., but not energy production, associated revenues, internal rate of return or cash flow. As a consequence, JEDI cannot be used to assess the potential financial viability of a proposed energy project.

RETScreen was developed to provide decision makers with tools to carry out financial and environmental analyses of energy projects. It calculates financial feasibility of energy production facilities, and it does so for the largest number of different technologies, even including energy efficiency and co-generation of heat and power. More uniquely, RETScreen has databases for key climate parameters for many locations, and for production characteristics for specific equipment, by manufacturer and model number. RETScreen can use these databases to calculate the capacity factor reflecting the specific product selected and the climatic conditions at the location.

But RETScreen has no default data for capital, operation and maintenance costs. A user in the initial stages of exploration might not have these data in hand, and the user interested in a quick back-of-the-envelope calculation would have to obtain the data from elsewhere. Also, RETScreen does not calculate cash flow metrics, but focuses only on bottom line metrics, such as internal rate of return and payback period.

Given the different strengths and weaknesses of the three models, a user might combine information from the various models to carry out an exploratory analysis to get a rough idea of whether a renewable energy facility might be financially viable and worthy of additional exploration. For example, default values for costs from JEDI might be used as a starting point for an analysis using the RETScreen model. A State or Regional authority might be interested in emissions reductions associated with a renewable energy program, in addition to the statewide or regional economic impacts. In this case, RETScreen might be used to carry out an emissions analysis, and that information might be combined with economic impact analysis from JEDI.

Also, the various models might be used together to help users understand the likely range outcomes. Some models have more conservative estimates for the some metrics, and less conservative for others. A user might want to consider outputs from all of the models to get an appreciation the range of likely results for different metrics across the various models.

4. EXAMPLE APPLICATIONS OF THE MODELS

This Section provides example applications of the three models described above to renewable energy facilities in Rhode Island. Ideally, one would want to carry out a rigorous program of model validation by applying the models to a number of actual Rhode Island cases to compare model forecasts to the local experience at real sites. But model validation is also very challenging because we do not have a lot of experience with renewable energy facilities in Rhode Island. Every renewable energy facility is unique in some ways, particularly since renewable energy technologies are not mature, and so we have a moving target.

While a rigorous validation program is beyond the scope of this report, we believe it is instructive to run the models for a few case studies to illustrate how to use the models, to show what kind of information can be derived, to demonstrate how the models might be used together and to compare model results to actual experience, where possible. First we apply the three models to the Portsmouth High School wind turbine to compare the results of the models to the actual experience in Portsmouth. Then we apply JEDI to estimate economic impacts associated with a set of hypothetical solar photovoltaic energy facilities located on various closed landfills across the State of Rhode Island.

4.1 Comparison of Results of the Models to Portsmouth Experience

The Town of Portsmouth contracted with AAER of Canada for construction of a 1.5 megawatt nameplate capacity wind turbine located at Portsmouth High School. Construction occurred in 2008-09, with the official groundbreaking taking place on in June 2008, and the wind turbine operations commenced in March 2009. Detailed information on the Portsmouth wind turbine can be found at http://www.portsmouthrienergy.com/windpower.htm.

The RESP project received detailed cost and production data from the town of Portsmouth to help validate the renewable energy models Attached is Table 2 comparing some key metrics from Portsmouth wind turbine data with the estimates from CREST, JEDI, and RETScreen, where possible. The metrics we consider are capital costs, operating/maintenance costs, capacity factor and energy production. As indicate above, not all models produce estimates for all of these metrics. JEDI does not provide estimates of energy production or capacity factor, and RETScreen does not provide default estimates for capital costs or operation/maintenance costs.

As can be seen in Table 2, CREST significantly overestimates both capital costs ($3.75M versus $2.9M) and operation/maintenance ($105 thousand versus $70 thousand) costs relative to the Portsmouth data. The JEDI estimate of capital costs is very close to the Portsmouth data ($3.0 M versus $2.9M), but JEDI underestimates operation/maintenance costs ($30 thousand versus $70 thousand). It is important to note that JEDI gives this result for operations and maintenance costs, but also specifically gives the warning for this case that “costs may be below industry standards”.

In comparing energy production, CREST significantly overstates both capacity factor (32% versus 23.8%) and annual energy production (4.2 GW versus 3.7 GW). In contrast, RETScreen *underestimates* both capacity factor (18.6% versus 23.8%) and energy production (2.45 GW versus 3.7 GW).

Again, it should be emphasized that there is considerable variation in the various parameters, so while a validation study may be informative, no generalizations can be made from a single validation study. But these results certainly suggest that users must be cautious when using the results of the models with default values. The fact is, there are significant differences in costs and production from different facilities built at different times in different locations. And the experience for a given project may be very different than industry averages.

4.2 Economic Impacts from a Rhode Island Program for Wind Energy

Above we compared cost and production estimates from the three models to the actual experience in Portsmouth. But because the JEDI provides estimates of the economic impacts on the overall State economy, it is best applied to a broader program for developing renewable energy, rather than a single small-scale facility. Just like no single small-scale renewable energy facility will have a significant effect on overall energy production in Rhode Island, no single project will likely have an appreciable effect on jobs in the overall State economy. But a larger program to create a set of facilities may have a detectable effect. As a consequence, this section considers jobs and wages created for a scenario for broader production of electricity from wind turbines around the State.

We base this application on the goals for nameplate capacity of renewable energy over a four year period set forth in the recently enacted Rhode Island Distributed Generation Standard Contracts Act (DG-SCA), as representative of a desirable near term outcome for renewable energy in Rhode Island. The stated Rhode Island goals are 5 MW by 2011, 20 MW by 2012, 30 MW by 2013 and 40 MW by 2014.[5]

The JEDI results for jobs and wages are shown in Table 3. As can be seen, most jobs (243) and wages ($9.4 Million) are associated with construction over the first 4 years of the program. The secondary effects (indirect plus induced) are roughly double the direct effects on employment and wages. Operating and maintenance employment and wages increase with capacity over the first four years, and then stabilize at about 9 full-time equivalent jobs paying $930 thousand in wages per year. The jobs and wages associated with operation over 20-year result in a total of about 178 job-years paying total wages of around $18.6 million.

---

[5] DG_SCA sec. 39-26.2-4(a)

In summary, JEDI estimates that most jobs occur during construction, and the secondary effects (indirect and induced effects) are estimated at roughly twice the direct effect. However, it should be noted that as argued above, these secondary effects could be overstated, especially during periods of low unemployment. But in the current economic environment in Rhode Island with double-digit unemployment rates, the JEDI estimates of indirect and induced effects might not be unrealistic. This argument is especially relevant if the State makes a concerted effort to create and sustain jobs that support renewable energy industries, such as recent proposals to develop a hub for renewable energy manufacturing and staging at Quonset Point.

4.3 Economic Impacts from Hypothetical Solar Facilities at Closed Rhode Island Landfill Sites

This example application uses JEDI to estimate economic impacts associated with development of solar photovoltaic energy facilities. Similar to the discussion above, the JEDI economic effects are intended to represent outcomes from a broad program for renewable energy development, rather than a single small-scale project. As a consequence, we use JEDI to assess the hypothetical economic impact from a set of twelve closed landfill site in Rhode Island that could potentially be used for solar energy generation. CREST and RETScreen are used to estimate annual energy production from these same twelve sites, and CREST and JEDI are used to estimate costs.

The specific closed landfills considered in this example application are listed in Table 4, with nameplate capacities ranging from 1 MW to 4.6 MW, and total capacity of 27.2 MW. The JEDI forecasts for economic impacts are also shown in Table 4, and the detailed JEDI output for each site is contained in the Appendix. JEDI estimates that a total of 443.8 full time equivalent jobs directly associated with the facilities during the construction period, and associated earnings of about $28 million. JEDI estimates an additional full time equivalent about 2.9 jobs per year during operations, paying wages of about $192 thousand. Indirect and induced jobs are estimated at nearly 1,300 full time equivalent jobs during construction, with total earnings of about $68 million, and 11.3 full time equivalent jobs per year during operations, with earnings of about $521 thousand per year. The total of direct, indirect and induced jobs are estimated to be about 1,730 during construction with wages of about $97 million, and a total of about 14 jobs per year during operations, with wages of about $700 thousand per year.

Next we use the models to estimate energy production at these twelve sites. Since JEDI does not estimate energy production, we use CREST and RETScreen to estimate annual electricity production at these same landfill sites. For CREST, the capacity factor for solar PV facilities in Rhode Island is 16.5%, and annual energy production ranges from about 1.4 GWH to 6.7 GWH, with total annual production of 39.4 GWH from all sites (See Table 5).

Applying RETScreen is somewhat more complicated, because RETScreen has many different manufacturers and models for solar PV production, and the capacity factors can vary somewhat across products. Perhaps more importantly, capacity factor varies with project-specific design factors, such as whether the facility uses fixed mounts, single axis solar tracking or double axis tracking; the slope of the solar collectors; and efficiency losses (e.g., inverter losses). In our case, we are considering a hypothetical scenario, where these factors have not been determined. As a consequence, we compared a few products, and found a representative capacity factor of around 20% with single axis tracking. For simplicity, we assume an overall 5% loss in efficiency, which may somewhat overstate power production.

Annual energy production with RETScreen ranges from roughly 1.7 GW to 8 GW, with total energy production of roughly 47 GW. So RETScreen implies somewhat higher levels of energy production, but using more realistic data on efficiency losses, or assuming fixed mounts with no tracking could reduce this discrepancy between the two models.

Since only CREST and JEDI have built in default values for costs, we use these two models to estimate costs associated with the facilities (see Table 5). It should be emphasized that the cost results below do not consider any costs specific to developing closed landfill sites, such as any possible issues associated with hazardous wastes. Rather, we use default values for the models, treating these sites just like any other potential site.

For CREST, installed costs are estimated at $97.9 Million, while JEDI estimates installed costs at $202 Million, which is a large differential. Since we use the “simple” cost estimate with CREST, costs are not broken into components, so we have no way to identify the key elements of this large discrepancy. CREST estimates operating costs at $652 thousand per year, and JEDI estimates operating costs at $326.1 thousand per year. So the CREST estimate for operating cost is twice the JEDI estimate. Again, we do not have sufficient information to identify the source of this discrepancy.

In summary, the cost estimates for these two models are very different, and users should be cautioned about using default estimates for costs, since they vary so widely across models. This likely reflects the simple fact that renewable energy projects differ greatly, and as a consequence the costs of renewable energy facilities can be very context specific. So nation-wide experience from a broad range of renewable energy facilities may not provide very useful guidance for cost of a specific project in Rhode Island, and users may be cautioned against placing much confidence in the applicability of the default cost estimates from the models.

Perhaps a better approach to carrying out an exploratory analysis is to run one or more of the models using cost data from a smaller set of judiciously selected projects with similar characteristics to the project being considered, and that have been undertaken in this region. Or to carry out a more expensive analysis based on project-specific cost estimates.

Table 1. Summary of Advantages and Disadvantages of the Various Spreadsheet Tools

Model	Best Uses	Advantages	Disadvantages
CREST	Determine levels of incentives needed to make renewable energy profitable (e.g., investment tax credits, feed-in tariffs, etc.) Calculate Cost of Energy (COE) in $/KWH. Determine whether operations are financially viable under different scenarios.	Can calculate profitability under a broad set of scenarios for financial incentives. Allows detailed descriptions of financial environment. Calculates cash flow metrics, as well as "bottom line" values for profitability.	Only has a single default value for capital and operating costs/KW, etc., which means user will probably want to provide estimates. A single default value for capacity factor for wind; default value for capacity factor for solar varies by state. Only applicable for wind, solar and geothermal.
JEDI	Estimates State or Regional economic impacts of proposed facilities. Determine costs of producing energy with wind, solar and geothermal energy facilities.	Estimates economic effects on the larger regional (typically state) economy, including indirect and induced effects. Applicable to many different energy facilities, including biofuels, coal, concentrated solar, solar photovoltaic, natural gas, wind and hydrokinetic. Has option to use default values of capital and operating costs for facilities of different scales, and default values vary by state to account for regional differences	Does not estimate energy production, revenues, profitability, etc. Does not consider financial incentives, such as investment tax credits or feed-in tariffs.
RETScreen	Determine whether a clean energy project is financially viable. Calculate reductions in Greenhouse Gas Emissions.	Estimates financial feasibility of clean energy production facilities. Has modules for the largest number of different clean energy technologies, even including energy efficiency and co-generation. Has database for climate characteristics for different regions and production characteristics for specific energy products (manufacturer and model). Can estimate capacity factor based on databases, or user can enter custom value. Estimates changes in greenhouse gas emissions, in addition to financial analysis.	Requires user to input capital, operating and maintenance costs. Does not calculate cash flow metrics.

Table 2. Comparison of Portsmouth Data with Modeled Results

	Portsmouth Data	CREST	JEDI	RETScreen
Capital Costs ($000)	$2,980.	$3,750.	$3,001.	-----
Operation/Maintenance Costs ($000)	$70.	$105.	$30.[6]	-----
Capacity Factor	23.8%	32.0%	-----	18.6%
Energy Production (Megawatt Hrs./Yr)	3,712	4,205	-----	2,450

---

[6] Note that JEDI provides this estimate for operation and maintenance costs, but warns that these estimates of "costs may be below industry standards". This warning appears to occur because JEDI is primary intended to assess larger statewide renewable energy programs, rather than a single wind turbine facility.

Table 3. JEDI Forecasts of Jobs and Wages from Rhode Island Wind Development Plan

		2011	2012	2013	2014	2015	2016	2017	2018
Nameplate Capacity (MW)		5	20	30	40	40	40	40	40
Electricity Production (GW)		10.4	41.7	62.5	83.4	83.4	83.4	83.4	83.4
Jobs									
Construction	Direct	10.0	29.9	20.0	20.0	0	0	0	0
	Indirect	14.9	44.6	29.8	29.8	0	0	0	0
	Induced	5.5	16.5	11.0	11.0	0	0	0	0
	Total	30.3	91.0	60.7	60.7	0	0	0	0
Operations	Direct	0	0.5	1.8	2.7	3.6	3.6	3.6	3.6
	Indirect	0	0.4	1.5	2.2	3.0	3.0	3.0	3.0
	Induced	0	0.3	1.2	1.7	2.3	2.3	2.3	2.3
	Total	0	1.1	4.4	6.7	8.9	8.9	8.9	8.9
Total	Direct	10.0	30.4	21.8	22.7	3.6	3.6	3.6	3.6
	Indirect	14.9	45.0	31.2	32.0	3.0	3.0	3.0	3.0
	Induced	5.5	16.7	12.1	12.7	2.3	2.3	2.3	2.3
	Total	30.3	92.2	65.1	67.3	8.9	8.9	8.9	8.9
Wages									
Construction	Direct	$0.55	$1.65	$1.10	$1.10	0	0	0	0
	Indirect	$0.77	$2.32	$1.55	$1.55	0	0	0	0
	Induced	$0.25	$0.74	$0.49	$0.49	0	0	0	0
	Total	$1.57	$4.72	$3.14	$3.14	0	0	0	0
Operations	Direct	0	$0.03	$0.11	$0.16	$0.21	$0.21	$0.21	$0.21
	Indirect	0	$0.02	$0.08	$0.11	$0.15	$0.15	$0.15	$0.15
	Induced	0	$0.01	$0.05	$0.55	$0.57	$0.57	$0.57	$0.57
	Total	0	$0.06	$0.23	$0.82	$0.93	$0.93	$0.93	$0.93
Total	Direct	$0.55	$1.68	$1.21	$1.26	$0.21	$0.21	$0.21	$0.21
	Indirect	$0.77	$2.34	$1.62	$1.66	$0.15	$0.15	$0.15	$0.15
	Induced	$0.25	$0.75	$0.55	$1.04	$0.57	$0.57	$0.57	$0.57
	Total	$1.57	$4.77	$3.38	$3.96	$0.93	$0.93	$0.93	$0.93

Table 4. JEDI Estimates of Jobs and Wages Associated with PV Facilities at Closed Landfill Sites

		Direct Effects				Indirect & Induced Effects				Total			
		Construction		Operating		Construction		Operating		Construction		Operating	
Landfill Site	Capacity (KW)	Jobs	Earnings ($000)	Annual Jobs	Annual Earnings ($000)	Jobs	Earning ($000)	Annual Jobs	Annual Earnings ($000)	Jobs	Earnings ($000)	Annual Jobs	Annual Earnings ($000)
Burrillville Landfill	1,000	16.3	$995.0	0.11	$7.1	47.3	$2,507.9	0.42	$19.2	63.6	$3,502.9	0.5	$26.2
Barrington Landfill	1,200	19.6	$1,194.0	0.13	$8.5	56.7	$3,009.4	0.50	$23.0	76.3	$4,203.5	0.6	$31.5
Landfill & Resources	1,300	21.2	$1,293.5	0.14	$9.2	61.4	$3,260.2	0.54	$24.9	82.7	$4,553.7	0.7	$34.1
Foster Landfill	1,400	22.8	$1,393.0	0.15	$9.9	66.2	$3,511.0	0.58	$26.8	89.0	$4,904.0	0.7	$36.7
Picilo Farm	1,500	24.5	$1,492.5	0.16	$10.6	70.9	$3,761.8	0.62	$28.7	95.4	$5,254.3	0.8	$39.3
Allen Harbor	1,800	29.4	$1,791.0	0.19	$12.7	85.1	$4,514.2	0.75	$34.5	114.5	$6,305.2	0.9	$47.2
Peterson Puritan	2,200	35.9	$2,189.0	0.23	$15.5	104.0	$5,517.3	0.91	$42.2	139.9	$7,706.3	1.1	$57.7
Portsmouth Town	2,700	44.1	$2,686.5	0.29	$19.1	127.6	$6,771.2	1.12	$51.7	171.7	$9,457.8	1.4	$70.8
West Kingston	3,000	48.9	$2,985.0	0.32	$21.2	141.8	$7,523.6	1.25	$57.5	190.8	$10,508.7	1.6	$78.7
Truck Away Landfill	3,200	52.2	$3,184.0	0.34	$22.6	151.3	$8,025.2	1.33	$61.3	203.5	$11,209.2	1.7	$83.9
West Sand Gravel	3,300	53.8	$4,660.3	0.35	$23.3	156.0	$8,276.0	1.37	$63.2	209.8	$12,936.3	1.7	$86.5
Pine Hill Road	4,600	75.1	$4,577.1	0.49	$32.5	217.4	$11,536.2	1.91	$88.1	292.5	$16,113.3	2.4	$120.6
Total	27,200	443.8	$28,441.2	2.89	$192.0	1,285.7	$68,214.0	11.30	$521.2	1,729.5	$96,655.2	14.2	$713.2

Table 5. Electricity Production and Costs of Solar PV Development at Closed Landfill Sites

	Capacity (KW)	Annual Electricity Production (GWH)		Installed Costs ($Million)		Operating Cost ($000/Yr)	
		CREST	RETScreen	CREST	JEDI	CREST	JEDI
Burrillville Landfill	1,000	1.4	1.7	$3.6	$7.5	$24.0	$12.0
Barrington Landfill	1,200	1.7	2.1	$4.3	$8.9	$28.8	$14.1
Landfill & Resources	1,300	1.9	2.3	$4.7	$9.7	$31.2	$15.6
Foster Landfill	1,400	2.0	2.4	$5.0	$10.4	$33.6	$16.8
Picilo Farm	1,500	2.2	2.6	$5.4	$11.2	$36.0	$18.0
Allen Harbor	1,800	2.6	3.1	$6.5	$13.4	$43.2	$21.6
Peterson Puritan	2,200	3.2	3.8	$7.9	$16.4	$52.8	$26.4
Portsmouth Town	2,700	3.9	4.7	$9.7	$20.1	$64.8	$32.4
West Kingston	3,000	4.3	5.2	$10.8	$22.4	$72.0	$36.0
Truck Away Landfill	3,200	4.6	5.5	$11.5	$23.8	$76.8	$38.4
West Sand Gravel	3,300	4.8	5.7	$11.9	$24.6	$79.2	$39.6
Pine Hill Road	4,600	6.7	8.0	$16.6	$34.3	$110.4	$55.2
Total	27,200	39.4	47.1	$97.9	$202.7	$652.8	$326.1

Appendix A

JEDI Application to Rhode Island Goals for Renewable Energy Facilities

Wind Farm - Project Data Summary based on model default values

Project Location	**RHODE ISLAND**
Year of Construction	2011
Total Project Size - Nameplate Capacity (MW)	5
Number of Projects (included in total)	1
Turbine Size (KW)	1250
Number of Turbines	4
Installed Project Cost ($/KW)	$2,005
Annual Direct O&M Cost ($/KW)	$20.00
Money Value (Dollar Year)	2009
Installed Project Cost	$10,023,026
Local Spending	$2,052,621
Total Annual Operational Expenses	$1,650,862
Direct Operating and Maintenance Costs	$100,000
Local Spending	$40,097
Other Annual Costs	$1,550,862
Local Spending	$43,399
Debt and Equity Payments	$0
Property Taxes	$28,399
Land Lease	$15,000

Local Economic Impacts - Summary Results

	Jobs	Earnings	Output
During construction period			
Project Development and Onsite Labor Impacts	10	$0.55	$0.58
Construction and Interconnection Labor	10	$0.52	
Construction Related Services	0	$0.03	
Turbine and Supply Chain Impacts	15	$0.77	$2.11
Induced Impacts	5	$0.25	$0.71
Total Impacts	**30**	**$1.57**	**$3.40**
During operating years (annual)			
Onsite Labor Impacts	0	$0.03	$0.03
Local Revenue and Supply Chain Impacts	0	$0.02	$0.09
Induced Impacts	0	$0.01	$0.04
Total Impacts	**1**	**$0.06**	**$0.15**

Notes: Earnings and Output values are millions of dollars in year 2009 dollars. Construction and operating jobs are full-time equivalent for a period of one year (1 FTE = 2,080 hours). Wind farm workers includes field technicians, administration and management. Economic impacts "During operating years" represent impacts that occur from wind farm operations/expenditures. The analysis does not include impacts associated with spending of wind farm "profits" and assumes no tax abatement unless noted. Totals may not add up due to independent rounding. Results are based on model default values.

Detailed Wind Farm Project Data Costs

RHODE ISLAND 2011

5 MW Capacity

	Cost	Local Share
Equipment Costs		
Turbines	$4,231,218	0%
Blades	$990,586	0%
Towers	$1,096,720	0%
Transportation	$757,091	0%
Equipment Subtotal	$7,075,615	
Balance of Plant		
Materials		
Construction (concrete rebar, equip, roads and site prep)	$1,022,426	90%
Transformer	$115,658	0%
Electrical (drop cable, wire,)	$121,911	100%
HV line extension	$222,691	70%
Materials Subtotal	$1,482,686	
Labor		
Foundation	$176,911	95%
Erection	$200,377	75%
Electrical	$292,010	70%
Management/supervision	$151,525	0%
Misc.	$380,000	50%
Labor Subtotal	$1,200,824	
Development/Other Costs		
HV Sub/Interconnection		
Materials	$70,267	90%
Labor	$21,524	10%
Engineering	$95,616	0%
Legal Services	$52,111	100%
Land Easements	$0	100%
Site Certificate	$24,382	100%
Other Subtotal	$263,901	
Balance of Plant Total	$2,947,411	
Total Project Costs	$10,023,026	

Wind Farm Annual Operating and Maintenance Costs **Rhode Island 2011**

5 MW Capacity	**Cost**	**Local Share**
Labor		
Personnel		
Field Salaries	$21,630	100%
Administrative	$1,978	100%
Management	$4,944	100%
Labor/Personnel Subtotal	$28,552	
Materials and Services		
Vehicles	$2,041	100%
Site Maint/Misc. Services	$796	80%
Fees, Permits, Licenses	$398	100%
Utilities	$1,592	100%
Insurance	$15,308	0%
Fuel (motor vehicle gasoline)	$796	100%
Consumables/Tools and Misc. Supplies	$5,174	100%
Replacement Parts/Equipment/ Spare Parts Inventory	$45,343	2%
Materials and Services Subtotal	$71,448	
Debt Payment (average annual)	$1,162,671	0%
Equity Payment - Individuals	$0	100%
Equity Payment - Corporate	$344,792	0%
Property Taxes	$28,399	100%
Land Lease	$15,000	100%
Total Annual Operating and Maintenance Costs	$1,650,862	

Other Parameters **Rhode Island 2011**

5 MW Capacity

Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Equity Financing		
Percentage equity	20%	
Individual Investors (percent of total equity)	0%	100%
Corporate Investors (percent of total equity)	100%	0%
Return on equity (annual interest rate)	16%	
Repayment term (years)	10	
Tax Parameters		
Local Property/Other Tax Rate (percent of taxable value)	1.0%	
Assessed value (percent of construction cost)	85.0%	
Taxable Value (percent of assessed value)	33.3%	
Taxable Value	$2,839,854	
Taxes per MW	na	
Local Taxes	$28,399	100%
Land Lease Parameters		
Land Lease Cost (per turbine)	$3,750	
Land Lease (total cost)	$15,000	
Lease Payment recipient (F = farmer/household, O = Other)	F	100%
Payroll Parameters	**Average Wage**	**Employer**
Construction Labor	**per Hour**	**Payroll Costs**
Foundation	$15.82	37.6%
Erection	$17.92	37.6%
Electrical	$23.74	37.6%
Management/Supervision	$32.28	37.6%
	Average Wage	**Employer**
O&M Labor	**per Hour**	**Payroll Costs**
Field Salaries (technicians, other)	$21.59	37.6%
Administrative	$13.82	37.6%
Management	$34.55	37.6%

Wind Farm - Project Data Summary based on model default values

Project Location	**RHODE ISLAND**
Year of Construction	2012
Total Project Size - Nameplate Capacity (MW)	15
Number of Projects (included in total)	1
Turbine Size (KW)	1250
Number of Turbines	12
Installed Project Cost ($/KW)	$2,005
Annual Direct O&M Cost ($/KW)	$20.00
Money Value (Dollar Year)	2009
Installed Project Cost	$30,069,077
Local Spending	$6,157,862
Total Annual Operational Expenses	$4,952,585
Direct Operating and Maintenance Costs	$300,000
Local Spending	$120,291
Other Annual Costs	$4,652,585
Local Spending	$130,196
Debt and Equity Payments	$0
Property Taxes	$85,196
Land Lease	$45,000

Local Economic Impacts - Summary Results

	Jobs	Earnings	Output
During construction period			
Project Development and Onsite Labor Impacts	30	$1.65	$1.73
Construction and Interconnection Labor	29	$1.57	
Construction Related Services	1	$0.08	
Turbine and Supply Chain Impacts	45	$2.32	$6.32
Induced Impacts	16	$0.74	$2.14
Total Impacts	**91**	**$4.72**	**$10.19**
During operating years (annual)			
Onsite Labor Impacts	1	$0.08	$0.08
Local Revenue and Supply Chain Impacts	1	$0.06	$0.27
Induced Impacts	1	$0.04	$0.11
Total Impacts	**3**	**$0.18**	**$0.46**

Notes: Earnings and Output values are millions of dollars in year 2009 dollars. Construction and operating jobs are full-time equivalent for a period of one year (1 FTE = 2,080 hours). Wind farm workers includes field technicians, administration and management. Economic impacts "During operating years" represent impacts that occur from wind farm operations/expenditures. The analysis does not include impacts associated with spending of wind farm "profits" and assumes no tax abatement unless noted. Totals may not add up due to independent rounding. Results are based on model default values.

Detailed Wind Farm Project Data Costs

RHODE ISLAND 2012

15 MW Additional Capacity

Construction Costs	**Cost**	**Local Share**
Equipment Costs		
Turbines	$12,693,653	0%
Blades	$2,971,758	0%
Towers	$3,290,161	0%
Transportation	$2,271,272	0%
Equipment Subtotal	$21,226,845	
Balance of Plant		
Materials		
Construction (concrete rebar, equip, roads and site prep)	$3,067,279	90%
Transformer	$346,973	0%
Electrical (drop cable, wire,)	$365,733	100%
HV line extension	$668,072	70%
Materials Subtotal	$4,448,057	
Labor		
Foundation	$530,734	95%
Erection	$601,132	75%
Electrical	$876,031	70%
Management/supervision	$454,574	0%
Misc.	$1,140,000	50%
Labor Subtotal	$3,602,471	
Development/Other Costs		
HV Sub/Interconnection		
Materials	$210,802	90%
Labor	$64,573	10%
Engineering	$286,849	0%
Legal Services	$156,333	100%
Land Easements	$0	100%
Site Certificate	$73,147	100%
Other Subtotal	$791,704	
Balance of Plant Total	$8,842,232	
Total Project Costs	$30,069,077	

Wind Farm Annual Operating and Maintenance Costs	**Rhode Island 2012**	
15 MW Additional Capacity	**Cost**	**Local Share**
Labor		
Personnel		
Field Salaries	$64,891	100%
Administrative	$5,933	100%
Management	$14,832	100%
Labor/Personnel Subtotal	$85,656	
Materials and Services		
Vehicles	$6,123	100%
Site Maint/Misc. Services	$2,388	80%
Fees, Permits, Licenses	$1,194	100%
Utilities	$4,776	100%
Insurance	$45,924	0%
Fuel (motor vehicle gasoline)	$2,388	100%
Consumables/Tools and Misc. Supplies	$15,522	100%
Inventory	$136,028	2%
Materials and Services Subtotal	$214,344	
Debt Payment (average annual)	$3,488,013	0%
Equity Payment - Individuals	$0	100%
Equity Payment - Corporate	$1,034,376	0%
Property Taxes	$85,196	100%
Land Lease	$45,000	100%
Total Annual Operating and Maintenance Costs	$4,952,585	

Other Parameters

Rhode Island 2012

15 MW Additional Capacity

Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Equity Financing		
Percentage equity	20%	
Individual Investors (percent of total equity)	0%	100%
Corporate Investors (percent of total equity)	100%	0%
Return on equity (annual interest rate)	16%	
Repayment term (years)	10	
Tax Parameters		
Local Property/Other Tax Rate (percent of taxable value)	1.0%	
Assessed value (percent of construction cost)	85.0%	
Taxable Value (percent of assessed value)	33.3%	
Taxable Value	$8,519,563	
Taxes per MW	na	
Local Taxes	$85,196	100%
Land Lease Parameters		
Land Lease Cost (per turbine)	$3,750	
Land Lease (total cost)	$45,000	
Lease Payment recipient (F = farmer/household, O = Other)	F	100%
Payroll Parameters	**Average Wage**	**Employer**
Construction Labor	**per Hour**	**Payroll Costs**
Foundation	$15.82	37.6%
Erection	$17.92	37.6%
Electrical	$23.74	37.6%
Management/Supervision	$32.28	37.6%
	Average Wage	**Employer**
O&M Labor	**per Hour**	**Payroll Costs**
Field Salaries (technicians, other)	$21.59	37.6%
Administrative	$13.82	37.6%
Management	$34.55	37.6%

Wind Farm - Project Data Summary based on model default values

Project Location	**RHODE ISLAND**
Year of Construction	2013
Total Project Size - Nameplate Capacity (MW)	10
Number of Projects (included in total)	1
Turbine Size (KW)	1250
Number of Turbines	8
Installed Project Cost ($/KW)	$2,005
Annual Direct O&M Cost ($/KW)	$20.00
Money Value (Dollar Year)	2009
Installed Project Cost	$20,046,051
Local Spending	$4,105,241
Total Annual Operational Expenses	$3,301,723
Direct Operating and Maintenance Costs	$200,000
Local Spending	$80,194
Other Annual Costs	$3,101,723
Local Spending	$86,797
Debt and Equity Payments	$0
Property Taxes	$56,797
Land Lease	$30,000

Local Economic Impacts - Summary Results

	Jobs	Earnings	Output
During construction period			
Project Development and Onsite Labor Impacts	20	$1.10	$1.15
Construction and Interconnection Labor	19	$1.05	
Construction Related Services	1	$0.05	
Turbine and Supply Chain Impacts	30	$1.55	$4.21
Induced Impacts	11	$0.49	$1.43
Total Impacts	**61**	**$3.14**	**$6.80**
During operating years (annual)			
Onsite Labor Impacts	1	$0.05	$0.05
Local Revenue and Supply Chain Impacts	1	$0.04	$0.18
Induced Impacts	1	$0.03	$0.08
Total Impacts	**2**	**$0.12**	**$0.31**

Notes: Earnings and Output values are millions of dollars in year 2009 dollars. Construction and operating jobs are full-time equivalent for a period of one year (1 FTE = 2,080 hours). Wind farm workers includes field technicians, administration and management. Economic impacts "During operating years" represent impacts that occur from wind farm operations/expenditures. The analysis does not include impacts associated with spending of wind farm "profits" and assumes no tax abatement unless noted. Totals may not add up due to independent rounding. Results are based on model default values.

Detailed Wind Farm Project Data Costs

RHODE ISLAND 2013

10 MW Additional Capacity

Construction Costs	**Cost**	**Local Share**
Equipment Costs		
Turbines	$8,462,436	0%
Blades	$1,981,172	0%
Towers	$2,193,441	0%
Transportation	$1,514,182	0%
Equipment Subtotal	$14,151,230	
Balance of Plant		
Materials		
Construction (concrete rebar, equip, roads and site prep)	$2,044,853	90%
Transformer	$231,315	0%
Electrical (drop cable, wire,)	$243,822	100%
HV line extension	$445,381	70%
Materials Subtotal	$2,965,371	
Labor		
Foundation	$353,823	95%
Erection	$400,755	75%
Electrical	$584,020	70%
Management/supervision	$303,049	0%
Misc.	$760,000	50%
Labor Subtotal	$2,401,647	
Development/Other Costs		
HV Sub/Interconnection		
Materials	$140,535	90%
Labor	$43,049	10%
Engineering	$191,233	0%
Legal Services	$104,222	100%
Land Easements	$0	100%
Site Certificate	$48,764	100%
Other Subtotal	$527,803	
Balance of Plant Total	$5,894,821	
Total Project Costs	$20,046,051	

Wind Farm Annual Operating and Maintenance Costs	**Rhode Island 2013**	
10 MW Additional Capacity	**Cost**	**Local Share**
Labor		
Personnel		
Field Salaries	$43,261	100%
Administrative	$3,955	100%
Management	$9,888	100%
Labor/Personnel Subtotal	$57,104	
Materials and Services		
Vehicles	$4,082	100%
Site Maint/Misc. Services	$1,592	80%
Fees, Permits, Licenses	$796	100%
Utilities	$3,184	100%
Insurance	$30,616	0%
Fuel (motor vehicle gasoline)	$1,592	100%
Consumables/Tools and Misc. Supplies	$10,348	100%
Inventory	$90,685	2%
Materials and Services Subtotal	$142,896	
Debt Payment (average annual)	$2,325,342	0%
Equity Payment - Individuals	$0	100%
Equity Payment - Corporate	$689,584	0%
Property Taxes	$56,797	100%
Land Lease	$30,000	100%
Total Annual Operating and Maintenance Costs	$3,301,723	

Other Parameters

10 MW Additional Capacity	Rhode Island 2013	
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Equity Financing		
Percentage equity	20%	
Individual Investors (percent of total equity)	0%	100%
Corporate Investors (percent of total equity)	100%	0%
Return on equity (annual interest rate)	16%	
Repayment term (years)	10	
Tax Parameters		
Local Property/Other Tax Rate (percent of taxable value)	1.0%	
Assessed value (percent of construction cost)	85.0%	
Taxable Value (percent of assessed value)	33.3%	
Taxable Value	$5,679,709	
Taxes per MW	na	
Local Taxes	$56,797	100%
Land Lease Parameters		
Land Lease Cost (per turbine)	$3,750	
Land Lease (total cost)	$30,000	
Lease Payment recipient (F = farmer/household, O = Other)	F	100%
Payroll Parameters	**Average Wage**	**Employer**
Construction Labor	**per Hour**	**Payroll Costs**
Foundation	$15.82	37.6%
Erection	$17.92	37.6%
Electrical	$23.74	37.6%
Management/Supervision	$32.28	37.6%
	Average Wage	**Employer**
O&M Labor	**per Hour**	**Payroll Costs**
Field Salaries (technicians, other)	$21.59	37.6%
Administrative	$13.82	37.6%
Management	$34.55	37.6%

Wind Farm - Project Data Summary based on model default values

Project Location	**RHODE ISLAND**
Year of Construction	2014
Total Project Size - Nameplate Capacity (MW)	10
Number of Projects (included in total)	1
Turbine Size (KW)	1250
Number of Turbines	8
Installed Project Cost ($/KW)	$2,005
Annual Direct O&M Cost ($/KW)	$20.00
Money Value (Dollar Year)	2009
Installed Project Cost	$20,046,051
Local Spending	$4,105,241
Total Annual Operational Expenses	$3,301,723
Direct Operating and Maintenance Costs	$200,000
Local Spending	$80,194
Other Annual Costs	$3,101,723
Local Spending	$86,797
Debt and Equity Payments	$0
Property Taxes	$56,797
Land Lease	$30,000

Local Economic Impacts - Summary Results

	Jobs	Earnings	Output
During construction period			
Project Development and Onsite Labor Impacts	20	$1.10	$1.15
Construction and Interconnection Labor	19	$1.05	
Construction Related Services	1	$0.05	
Turbine and Supply Chain Impacts	30	$1.55	$4.21
Induced Impacts	11	$0.49	$1.43
Total Impacts	**61**	**$3.14**	**$6.80**
During operating years (annual)			
Onsite Labor Impacts	1	$0.05	$0.05
Local Revenue and Supply Chain Impacts	1	$0.04	$0.18
Induced Impacts	1	$0.03	$0.08
Total Impacts	**2**	**$0.12**	**$0.31**

Notes: Earnings and Output values are millions of dollars in year 2009 dollars. Construction and operating jobs are full-time equivalent for a period of one year (1 FTE = 2,080 hours). Wind farm workers includes field technicians, administration and management. Economic impacts "During operating years" represent impacts that occur from wind farm operations/expenditures. The analysis does not include impacts associated with spending of wind farm "profits" and assumes no tax abatement unless noted. Totals may not add up due to independent rounding. Results are based on model default values.

Detailed Wind Farm Project Data Costs

RHODE ISLAND 2014

10 MW Additional Capacity

Construction Costs	**Cost**	**Local Share**
Equipment Costs		
Turbines	$8,462,436	0%
Blades	$1,981,172	0%
Towers	$2,193,441	0%
Transportation	$1,514,182	0%
Equipment Subtotal	$14,151,230	
Balance of Plant		
Materials		
Construction (concrete rebar, equip, roads and site prep)	$2,044,853	90%
Transformer	$231,315	0%
Electrical (drop cable, wire,)	$243,822	100%
HV line extension	$445,381	70%
Materials Subtotal	$2,965,371	
Labor		
Foundation	$353,823	95%
Erection	$400,755	75%
Electrical	$584,020	70%
Management/supervision	$303,049	0%
Misc.	$760,000	50%
Labor Subtotal	$2,401,647	
Development/Other Costs		
HV Sub/Interconnection		
Materials	$140,535	90%
Labor	$43,049	10%
Engineering	$191,233	0%
Legal Services	$104,222	100%
Land Easements	$0	100%
Site Certificate	$48,764	100%
Other Subtotal	$527,803	
Balance of Plant Total	$5,894,821	
Total Project Costs	$20,046,051	

Wind Farm Annual Operating and Maintenance Costs	**RHODE ISLAND 2014**	
10 MW Additional Capacity	**Cost**	**Local Share**
Labor		
Personnel		
Field Salaries	$43,261	100%
Administrative	$3,955	100%
Management	$9,888	100%
Labor/Personnel Subtotal	$57,104	
Materials and Services		
Vehicles	$4,082	100%
Site Maint/Misc. Services	$1,592	80%
Fees, Permits, Licenses	$796	100%
Utilities	$3,184	100%
Insurance	$30,616	0%
Fuel (motor vehicle gasoline)	$1,592	100%
Consumables/Tools and Misc. Supplies	$10,348	100%
Replacement Parts/Equipment/ Spare Parts Inventory	$90,685	2%
Materials and Services Subtotal	$142,896	
Debt Payment (average annual)	$2,325,342	0%
Equity Payment - Individuals	$0	100%
Equity Payment - Corporate	$689,584	0%
Property Taxes	$56,797	100%
Land Lease	$30,000	100%
Total Annual Operating and Maintenance Costs	$3,301,723	

Other Parameters **RHODE ISLAND 2014**

10 MW Additional Capacity

Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Equity Financing		
Percentage equity	20%	
Individual Investors (percent of total equity)	0%	100%
Corporate Investors (percent of total equity)	100%	0%
Return on equity (annual interest rate)	16%	
Repayment term (years)	10	
Tax Parameters		
Local Property/Other Tax Rate (percent of taxable value)	1.0%	
Assessed value (percent of construction cost)	85.0%	
Taxable Value (percent of assessed value)	33.3%	
Taxable Value	$5,679,709	
Taxes per MW	na	
Local Taxes	$56,797	100%
Land Lease Parameters		
Land Lease Cost (per turbine)	$3,750	
Land Lease (total cost)	$30,000	
Lease Payment recipient (F = farmer/household, O = Other)	F	100%
Payroll Parameters	**Average Wage**	**Employer**
Construction Labor	**per Hour**	**Payroll Costs**
Foundation	$15.82	37.6%
Erection	$17.92	37.6%
Electrical	$23.74	37.6%
Management/Supervision	$32.28	37.6%
	Average Wage	**Employer**
O&M Labor	**per Hour**	**Payroll Costs**
Field Salaries (technicians, other)	$21.59	37.6%
Administrative	$13.82	37.6%
Management	$34.55	37.6%

Appendix B

JEDI Application to Solar PV Facilities at Closed Rhode Island Landfills

Photovoltaic - Project Data Summary	**Burrillville Landfill**
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	1000
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	1000
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$7,452,196**
Local Spending	$4,984,221
Total Annual Operational Expenses	$906,600
Direct Operating and Maintenance Costs	$12,000
Local Spending	$9,481
Other Annual Costs	$894,600
Local Spending	$71,000
Debt Payments	$0
Property Taxes	$71,000

Local Economic Impacts - Summary Results

During construction and installation period	Jobs	Earnings $000 (2008)	Output $000 (2008)
Project Development and Onsite Labor Impacts (Direct Effects)	16.3	$995.0	$1,412.2
Construction and Installation Labor	8.6	$679.7	
Construction and Installation Related Services	7.7	$315.3	
Module and Supply Chain Impacts (Indirect Effects)	31.9	$1,828.8	$4,775.5
Induced Impacts	15.4	$679.1	$1,962.7
Total Impacts	**63.6**	**$3,502.9**	**$8,150.5**

During operating years	Annual Jobs	Annual Earnings $000 (2008)	Annual Output $000 (2008)
Onsite Labor Impacts			
PV Project Labor Only (Direct Effects)	0.1	$7.1	$7.1
Local Revenue and Supply Chain Impacts (Direct Effects)	0.1	$3.9	$10.8
Induced Impacts	0.3	$15.3	$44.2
Total Impacts	**0.5**	**$26.2**	**$62.0**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

Burrillville Landfill

Installation Costs	**Cost**	**Purchased Locally (%)**	**Manufactured Locally (Y or N)**
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$392,668	100%	N
Modules	$3,822,536	100%	N
Electrical (wire, connectors, breakers, etc.)	$447,708	100%	N
Inverter	$368,455	100%	N
Subtotal	$5,031,366		
Labor			
Installation	$679,718	100%	
Subtotal	$679,718		
Subtotal	$5,711,085		
Other Costs			
Permitting	$108,025	100%	
Other Costs	$177,062	100%	
Business Overhead	$1,103,828	100%	
Subtotal	$1,388,915		
Subtotal	$7,100,000		
Sales Tax (Materials & Equipment Purchases)	$352,196	100%	
Total	$7,452,196		

PV System Annual Operating and Maintenance Costs	**Cost**	**Local Share**
Labor		
Technicians	$7,600	100%
Subtotal	$7,600	
Materials and Services		
Materials & Equipment	$4,400	100%
Services	$0	100%
Subtotal	$4,400	
Average Annual Payment (Interest and Principal)	$823,600	0%
Property Taxes	$71,000	100%
Total	$906,600	

Other Parameters		**Burrillville Landfill**
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$7,100,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$71,000	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/Hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%

Photovoltaic - Project Data Summary	**Barrington**
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	1200
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	1200
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$8,942,635**
Local Spending	$5,981,065
Total Annual Operational Expenses	$1,087,920
Direct Operating and Maintenance Costs	$14,400
Local Spending	$11,377
Other Annual Costs	$1,073,520
Local Spending	$85,200
Debt Payments	$0
Property Taxes	$85,200

Local Economic Impacts - Summary Results

During construction and installation period	Jobs	Earnings $000 (2008)	Output $000 (2008)
Project Development and Onsite Labor Impacts	19.6	$1,194.0	$1,694.7
Construction and Installation Labor	10.4	$815.7	
Construction and Installation Related Services	9.2	$378.4	
Module and Supply Chain Impacts	38.2	$2,194.6	$5,730.6
Induced Impacts	18.5	$814.9	$2,355.2
Total Impacts	**76.3**	**$4,203.5**	**$9,780.5**

During operating years	Annual Jobs	Annual Earnings $000 (2008)	Annual Output $000 (2008)
Onsite Labor Impacts			
PV Project Labor Only	0.1	$8.5	$8.5
Local Revenue and Supply Chain Impacts	0.1	$4.7	$12.9
Induced Impacts	0.4	$18.3	$53.0
Total Impacts	**0.6**	**$31.5**	**$74.4**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

Installation Costs	Cost	Barrington Purchased Locally (%)	Manufactured Locally (Y or N)
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$471,201	100%	N
Modules	$4,587,043	100%	N
Electrical (wire, connectors, breakers, etc.)	$537,249	100%	N
Inverter	$442,146	100%	N
Subtotal	$6,037,640		
Labor			
Installation	$815,662	100%	
Subtotal	$815,662		
Subtotal	$6,853,301		
Other Costs			
Permitting	$129,630	100%	
Other Costs	$212,474	100%	
Business Overhead	$1,324,594	100%	
Subtotal	$1,666,699		
Subtotal	$8,520,000		
Sales Tax (Materials & Equipment Purchases)	$422,635	100%	
Total	$8,942,635		

PV System Annual Operating and Maintenance Costs	Cost	Local Share
Labor		
Technicians	$9,120	100%
Subtotal	$9,120	
Materials and Services		
Materials & Equipment	$5,280	100%
Services	$0	100%
Subtotal	$5,280	
Average Annual Payment (Interest and Principal)	$988,320	0%
Property Taxes	$85,200	100%
Total	$1,087,920	

Other Parameters		**Barrington**
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$8,520,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$85,200	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/Hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%

Photovoltaic - Project Data Summary

	Landfill and Resource
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	1300
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	1300
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$9,687,854**
Local Spending	$6,479,487
Total Annual Operational Expenses	$1,178,580
Direct Operating and Maintenance Costs	$15,600
Local Spending	$12,325
Other Annual Costs	$1,162,980
Local Spending	$92,300
Debt Payments	$0
Property Taxes	$92,300

Local Economic Impacts - Summary Results

During construction and installation period	Jobs	Earnings $000 (2008)	Output $000 (2008)
Project Development and Onsite Labor Impacts	21.2	$1,293.5	$1,835.9
Construction and Installation Labor	11.2	$883.6	
Construction and Installation Related Services	10.0	$409.9	
Module and Supply Chain Impacts	41.4	$2,377.5	$6,208.2
Induced Impacts	20.0	$882.8	$2,551.5
Total Impacts	**82.7**	**$4,553.7**	**$10,595.6**

During operating years	Annual Jobs	Annual Earnings $000 (2008)	Annual Output $000 (2008)
Onsite Labor Impacts			
PV Project Labor Only	0.1	$9.2	$9.2
Local Revenue and Supply Chain Impacts	0.1	$5.0	$14.0
Induced Impacts	0.5	$19.9	$57.4
Total Impacts	**0.7**	**$34.1**	**$80.6**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

Landfill and Resource

Installation Costs	**Cost**	**Purchased Locally (%)**	**Manufactured Locally (Y or N)**
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$510,468	100%	N
Modules	$4,969,297	100%	N
Electrical (wire, connectors, breakers, etc.)	$582,020	100%	N
Inverter	$478,991	100%	N
Subtotal	$6,540,776		
Labor			
Installation	$883,634	100%	
Subtotal	$883,634		
Subtotal	$7,424,410		
Other Costs			
Permitting	$140,433	100%	
Other Costs	$230,180	100%	
Business Overhead	$1,434,977	100%	
Subtotal	$1,805,590		
Subtotal	$9,230,000		
Sales Tax (Materials & Equipment Purchases)	$457,854	100%	
Total	$9,687,854		

PV System Annual Operating and Maintenance Costs	**Cost**	**Local Share**
Labor		
Technicians	$9,880	100%
Subtotal	$9,880	
Materials and Services		
Materials & Equipment	$5,720	100%
Services	$0	100%
Subtotal	$5,720	
Average Annual Payment (Interest and Principal)	$1,070,680	0%
Property Taxes	$92,300	100%
Total	$1,178,580	

Other Parameters		**Landfill and Resource**
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$9,230,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$92,300	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/Hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%

Photovoltaic - Project Data Summary

	Foster
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	1400
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	1400
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$10,433,074**
Local Spending	$6,977,910
Total Annual Operational Expenses	$1,269,240
Direct Operating and Maintenance Costs	$16,800
Local Spending	$13,273
Other Annual Costs	$1,252,440
Local Spending	$99,400
Debt Payments	$0
Property Taxes	$99,400

Local Economic Impacts - Summary Results

During construction and installation period	**Jobs**	**Earnings $000 (2008)**	**Output $000 (2008)**
Project Development and Onsite Labor Impacts	22.8	$1,393.0	$1,977.1
Construction and Installation Labor	12.1	$951.6	
Construction and Installation Related Services	10.7	$441.4	
Module and Supply Chain Impacts	44.6	$2,560.3	$6,685.8
Induced Impacts	21.6	$950.7	$2,747.8
Total Impacts	**89.0**	**$4,904.0**	**$11,410.6**

During operating years	**Annual Jobs**	**Annual Earnings $000 (2008)**	**Annual Output $000 (2008)**
Onsite Labor Impacts			
PV Project Labor Only	0.1	$9.9	$9.9
Local Revenue and Supply Chain Impacts	0.1	$5.4	$15.1
Induced Impacts	0.5	$21.4	$61.8
Total Impacts	**0.7**	**$36.7**	**$86.8**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

Installation Costs	Cost	Foster Purchased Locally (%)	Manufactured Locally (Y or N)
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$549,735	100%	N
Modules	$5,351,550	100%	N
Electrical (wire, connectors, breakers, etc.)	$626,791	100%	N
Inverter	$515,837	100%	N
Subtotal	$7,043,913		
Labor			
Installation	$951,606	100%	
Subtotal	$951,606		
Subtotal	$7,995,518		
Other Costs			
Permitting	$151,235	100%	
Other Costs	$247,886	100%	
Business Overhead	$1,545,360	100%	
Subtotal	$1,944,482		
Subtotal	$9,940,000		
Sales Tax (Materials & Equipment Purchases)	$493,074	100%	
Total	$10,433,074		

PV System Annual Operating and Maintenance Costs	**Cost**	**Local Share**
Labor		
Technicians	$10,640	100%
Subtotal	$10,640	
Materials and Services		
Materials & Equipment	$6,160	100%
Services	$0	100%
Subtotal	$6,160	
Average Annual Payment (Interest and Principal)	$1,153,040	0%
Property Taxes	$99,400	100%
Total	$1,269,240	

Other Parameters		**Foster**
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$9,940,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$99,400	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/Hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%

Photovoltaic - Project Data Summary	**Picilo Farm**
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	1500
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	1500
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$11,178,293**
Local Spending	$7,476,332
Total Annual Operational Expenses	$1,359,900
Direct Operating and Maintenance Costs	$18,000
Local Spending	$14,221
Other Annual Costs	$1,341,900
Local Spending	$106,500
Debt Payments	$0
Property Taxes	$106,500

Local Economic Impacts - Summary Results

During construction and installation period	Jobs	Earnings $000 (2008)	Output $000 (2008)
Project Development and Onsite Labor Impacts	24.5	$1,492.5	$2,118.3
Construction and Installation Labor	13.0	$1,019.6	
Construction and Installation Related Services	11.5	$472.9	
Module and Supply Chain Impacts	47.8	$2,743.2	$7,163.3
Induced Impacts	23.1	$1,018.6	$2,944.1
Total Impacts	**95.4**	**$5,254.3**	**$12,225.7**

During operating years	Annual Jobs	Annual Earnings $000 (2008)	Annual Output $000 (2008)
Onsite Labor Impacts			
PV Project Labor Only	0.2	$10.6	$10.6
Local Revenue and Supply Chain Impacts	0.1	$5.8	$16.2
Induced Impacts	0.5	$22.9	$66.2
Total Impacts	**0.8**	**$39.3**	**$93.0**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

Picilo Farm

Installation Costs	Cost	Purchased Locally (%)	Manufactured Locally (Y or N)
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$589,001	100%	N
Modules	$5,733,804	100%	N
Electrical (wire, connectors, breakers, etc.)	$671,562	100%	N
Inverter	$552,682	100%	N
Subtotal	$7,547,050		
Labor			
Installation	$1,019,577	100%	
Subtotal	$1,019,577		
Subtotal	$8,566,627		
Other Costs			
Permitting	$162,038	100%	
Other Costs	$265,593	100%	
Business Overhead	$1,655,743	100%	
Subtotal	$2,083,373		
Subtotal	$10,650,000		
Sales Tax (Materials & Equipment Purchases)	$528,293	100%	
Total	$11,178,293		

PV System Annual Operating and Maintenance Costs	Cost	Local Share
Labor		
Technicians	$11,400	100%
Subtotal	$11,400	
Materials and Services		
Materials & Equipment	$6,600	100%
Services	$0	100%
Subtotal	$6,600	
Average Annual Payment (Interest and Principal)	$1,235,400	0%
Property Taxes	$106,500	100%
Total	$1,359,900	

Other Parameters		**Picilo Farm**
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$10,650,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$106,500	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/Hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%

Photovoltaic - Project Data Summary	Allen Harbor
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	1800
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	1800
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$13,413,952**
Local Spending	$8,971,598
Total Annual Operational Expenses	$1,631,880
Direct Operating and Maintenance Costs	$21,600
Local Spending	$17,066
Other Annual Costs	$1,610,280
Local Spending	$127,800
Debt Payments	$0
Property Taxes	$127,800

Local Economic Impacts - Summary Results

During construction and installation period	**Jobs**	**Earnings $000 (2008)**	**Output $000 (2008)**
Project Development and Onsite Labor Impacts	29.4	$1,791.0	$2,542.0
Construction and Installation Labor	15.5	$1,223.5	
Construction and Installation Related Services	13.8	$567.5	
Module and Supply Chain Impacts	57.3	$3,291.9	$8,596.0
Induced Impacts	27.8	$1,222.3	$3,532.9
Total Impacts	**114.5**	**$6,305.2**	**$14,670.8**

During operating years	**Annual Jobs**	**Annual Earnings $000 (2008)**	**Annual Output $000 (2008)**
Onsite Labor Impacts			
PV Project Labor Only	0.2	$12.7	$12.7
Local Revenue and Supply Chain Impacts	0.1	$7.0	$19.4
Induced Impacts	0.6	$27.5	$79.5
Total Impacts	**0.9**	**$47.2**	**$111.6**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

		Allen Harbor	
Installation Costs	**Cost**	**Purchased Locally (%)**	**Manufactured Locally (Y or N)**
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$706,802	100%	N
Modules	$6,880,565	100%	N
Electrical (wire, connectors, breakers, etc.)	$805,874	100%	N
Inverter	$663,219	100%	N
Subtotal	$9,056,459		
Labor			
Installation	$1,223,493	100%	
Subtotal	$1,223,493		
Subtotal	$10,279,952		
Other Costs			
Permitting	$194,446	100%	
Other Costs	$318,711	100%	
Business Overhead	$1,986,891	100%	
Subtotal	$2,500,048		
Subtotal	$12,780,000		
Sales Tax (Materials & Equipment Purchases)	$633,952	100%	
Total	$13,413,952		

PV System Annual Operating and Maintenance Costs	**Cost**	**Local Share**
Labor		
Technicians	$13,680	100%
Subtotal	$13,680	
Materials and Services		
Materials & Equipment	$7,920	100%
Services	$0	100%
Subtotal	$7,920	
Average Annual Payment (Interest and Principal)	$1,482,480	0%
Property Taxes	$127,800	100%
Total	$1,631,880	

Other Parameters		**Allen Harbor**
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$12,780,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$127,800	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/Hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%

Photovoltaic - Project Data Summary

	Peterson Puritan
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	2200
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	2200
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$16,394,830**
Local Spending	$10,965,286
Total Annual Operational Expenses	$1,994,520
Direct Operating and Maintenance Costs	$26,400
Local Spending	$20,858
Other Annual Costs	$1,968,120
Local Spending	$156,200
Debt Payments	$0
Property Taxes	$156,200

Local Economic Impacts - Summary Results

During construction and installation period	Jobs	Earnings $000 (2008)	Output $000 (2008)
Project Development and Onsite Labor Impacts	35.9	$2,189.0	$3,106.9
Construction and Installation Labor	19.0	$1,495.4	
Construction and Installation Related Services	16.9	$693.7	
Module and Supply Chain Impacts	70.1	$4,023.4	$10,506.2
Induced Impacts	33.9	$1,493.9	$4,318.0
Total Impacts	**139.9**	**$7,706.3**	**$17,931.0**

During operating years	Annual Jobs	Annual Earnings $000 (2008)	Annual Output $000 (2008)
Onsite Labor Impacts			
PV Project Labor Only	0.2	$15.5	$15.5
Local Revenue and Supply Chain Impacts	0.2	$8.5	$23.7
Induced Impacts	0.8	$33.6	$97.2
Total Impacts	**1.1**	**$57.7**	**$136.4**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

Peterson Puritan

Installation Costs	**Cost**	**Purchased Locally (%)**	**Manufactured Locally (Y or N)**
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$863,869	100%	N
Modules	$8,409,579	100%	N
Electrical (wire, connectors, breakers, etc.)	$984,957	100%	N
Inverter	$810,601	100%	N
Subtotal	$11,069,006		
Labor			
Installation	$1,495,380	100%	
Subtotal	$1,495,380		
Subtotal	$12,564,386		
Other Costs			
Permitting	$237,656	100%	
Other Costs	$389,536	100%	
Business Overhead	$2,428,422	100%	
Subtotal	$3,055,614		
Subtotal	$15,620,000		
Sales Tax (Materials & Equipment Purchases)	$774,830	100%	
Total	$16,394,830		

PV System Annual Operating and Maintenance Costs	**Cost**	**Local Share**
Labor		
Technicians	$16,720	100%
Subtotal	$16,720	
Materials and Services		
Materials & Equipment	$9,680	100%
Services	$0	100%
Subtotal	$9,680	
Average Annual Payment (Interest and Principal)	$1,811,920	0%
Property Taxes	$156,200	100%
Total	$1,994,520	

Other Parameters		**Peterson Puritan**
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$15,620,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$156,200	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/Hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%

Photovoltaic - Project Data Summary

	Portsmouth
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	2700
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	2700
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$20,120,928**
Local Spending	$13,457,397
Total Annual Operational Expenses	$2,447,820
Direct Operating and Maintenance Costs	$32,400
Local Spending	$25,598
Other Annual Costs	$2,415,420
Local Spending	$191,700
Debt Payments	$0
Property Taxes	$191,700

Local Economic Impacts - Summary Results

During construction and installation period	Jobs	Earnings $000 (2008)	Output $000 (2008)
Project Development and Onsite Labor Impacts	44.1	$2,686.5	$3,813.0
Construction and Installation Labor	23.3	$1,835.2	
Construction and Installation Related Services	20.7	$851.3	
Module and Supply Chain Impacts	86.0	$4,937.8	$12,894.0
Induced Impacts	41.6	$1,833.5	$5,299.3
Total Impacts	**171.7**	**$9,457.8**	**$22,006.2**

During operating years	Annual Jobs	Annual Earnings $000 (2008)	Annual Output $000 (2008)
Onsite Labor Impacts			
PV Project Labor Only	0.3	$19.1	$19.1
Local Revenue and Supply Chain Impacts	0.2	$10.5	$29.1
Induced Impacts	0.9	$41.3	$119.2
Total Impacts	**1.4**	**$70.8**	**$167.4**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

Installation Costs	Cost	Portsmouth Purchased Locally (%)	Manufactured Locally (Y or N)
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$1,060,202	100%	N
Modules	$10,320,847	100%	N
Electrical (wire, connectors, breakers, etc.)	$1,208,811	100%	N
Inverter	$994,828	100%	N
Subtotal	$13,584,689		
Labor			
Installation	$1,835,239	100%	
Subtotal	$1,835,239		
Subtotal	$15,419,928		
Other Costs			
Permitting	$291,668	100%	
Other Costs	$478,067	100%	
Business Overhead	$2,980,337	100%	
Subtotal	$3,750,072		
Subtotal	$19,170,000		
Sales Tax (Materials & Equipment Purchases)	$950,928	100%	
Total	$20,120,928		

PV System Annual Operating and Maintenance Costs	Cost	Local Share
Labor		
Technicians	$20,520	100%
Subtotal	$20,520	
Materials and Services		
Materials & Equipment	$11,880	100%
Services	$0	100%
Subtotal	$11,880	
Average Annual Payment (Interest and Principal)	$2,223,720	0%
Property Taxes	$191,700	100%
Total	$2,447,820	

Other Parameters		**Portsmouth**
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$19,170,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$191,700	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/Hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%

Photovoltaic - Project Data Summary

	West Kingston
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	3000
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	3000
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$22,356,587**
Local Spending	$14,952,663
Total Annual Operational Expenses	$2,719,800
Direct Operating and Maintenance Costs	$36,000
Local Spending	$28,443
Other Annual Costs	$2,683,800
Local Spending	$213,000
Debt Payments	$0
Property Taxes	$213,000

Local Economic Impacts - Summary Results

During construction and installation period	Jobs	Earnings $000 (2008)	Output $000 (2008)
Project Development and Onsite Labor Impacts	48.9	$2,985.0	$4,236.6
Construction and Installation Labor	25.9	$2,039.2	
Construction and Installation Related Services	23.0	$945.9	
Module and Supply Chain Impacts	95.6	$5,486.4	$14,326.6
Induced Impacts	46.3	$2,037.2	$5,888.1
Total Impacts	**190.8**	**$10,508.7**	**$24,451.4**

During operating years	Annual Jobs	Annual Earnings $000 (2008)	Annual Output $000 (2008)
Onsite Labor Impacts			
PV Project Labor Only	0.3	$21.2	$21.2
Local Revenue and Supply Chain Impacts	0.2	$11.7	$32.4
Induced Impacts	1.0	$45.8	$132.5
Total Impacts	**1.6**	**$78.7**	**$186.0**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

West Kingston

Installation Costs	Cost	Purchased Locally (%)	Manufactured Locally (Y or N)
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$1,178,003	100%	N
Modules	$11,467,608	100%	N
Electrical (wire, connectors, breakers, etc.)	$1,343,123	100%	N
Inverter	$1,105,365	100%	N
Subtotal	$15,094,099		
Labor			
Installation	$2,039,155	100%	
Subtotal	$2,039,155		
Subtotal	$17,133,254		
Other Costs			
Permitting	$324,076	100%	
Other Costs	$531,185	100%	
Business Overhead	$3,311,485	100%	
Subtotal	$4,166,746		
Subtotal	$21,300,000		
Sales Tax (Materials & Equipment Purchases)	$1,056,587	100%	
Total	$22,356,587		

PV System Annual Operating and Maintenance Costs	Cost	Local Share
Labor		
Technicians	$22,800	100%
Subtotal	$22,800	
Materials and Services		
Materials & Equipment	$13,200	100%
Services	$0	100%
Subtotal	$13,200	
Average Annual Payment (Interest and Principal)	$2,470,800	0%
Property Taxes	$213,000	100%
Total	$2,719,800	

Other Parameters		West Kingston
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$21,300,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$213,000	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/Hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%

Photovoltaic - Project Data Summary

	Truck Away
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	3200
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	3200
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$23,847,026**
Local Spending	$15,949,508
Total Annual Operational Expenses	$2,901,120
Direct Operating and Maintenance Costs	$38,400
Local Spending	$30,339
Other Annual Costs	$2,862,720
Local Spending	$227,200
Debt Payments	$0
Property Taxes	$227,200

Local Economic Impacts - Summary Results

During construction and installation period	Jobs	Earnings $000 (2008)	Output $000 (2008)
Project Development and Onsite Labor Impacts	52.2	$3,184.0	$4,519.1
Construction and Installation Labor	27.6	$2,175.1	
Construction and Installation Related Services	24.6	$1,009.0	
Module and Supply Chain Impacts	101.9	$5,852.2	$15,281.7
Induced Impacts	49.3	$2,173.0	$6,280.7
Total Impacts	**203.5**	**$11,209.2**	**$26,081.5**

During operating years	Annual Jobs	Annual Earnings $000 (2008)	Annual Output $000 (2008)
Onsite Labor Impacts			
PV Project Labor Only	0.3	$22.6	$22.6
Local Revenue and Supply Chain Impacts	0.2	$12.4	$34.5
Induced Impacts	1.1	$48.9	$141.3
Total Impacts	**1.7**	**$83.9**	**$198.4**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

Installation Costs	Cost	Truck Away Purchased Locally (%)	Manufactured Locally (Y or N)
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$1,256,536	100%	N
Modules	$12,232,115	100%	N
Electrical (wire, connectors, breakers, etc.)	$1,432,665	100%	N
Inverter	$1,179,056	100%	N
Subtotal	$16,100,372		
Labor			
Installation	$2,175,098	100%	
Subtotal	$2,175,098		
Subtotal	$18,275,471		
Other Costs			
Permitting	$345,681	100%	
Other Costs	$566,598	100%	
Business Overhead	$3,532,251	100%	
Subtotal	$4,444,529		
Subtotal	$22,720,000		
Sales Tax (Materials & Equipment Purchases)	$1,127,026	100%	
Total	$23,847,026		

PV System Annual Operating and Maintenance Costs	Cost	Local Share
Labor		
Technicians	$24,320	100%
Subtotal	$24,320	
Materials and Services		
Materials & Equipment	$14,080	100%
Services	$0	100%
Subtotal	$14,080	
Average Annual Payment (Interest and Principal)	$2,635,520	0%
Property Taxes	$227,200	100%
Total	$2,901,120	

Other Parameters		**Truck Away**
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$22,720,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$227,200	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/Hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%

Photovoltaic - Project Data Summary

	West Sand & Gravel
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	3300
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	3300
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$24,592,246**
Local Spending	$16,447,930
Total Annual Operational Expenses	$2,991,780
Direct Operating and Maintenance Costs	$39,600
Local Spending	$31,287
Other Annual Costs	$2,952,180
Local Spending	$234,300
Debt Payments	$0
Property Taxes	$234,300

Local Economic Impacts - Summary Results

During construction and installation period	Jobs	Earnings $000 (2008)	Output $000 (2008)
Project Development and Onsite Labor Impacts	53.8	$3,283.5	$4,660.3
Construction and Installation Labor	28.5	$2,243.1	
Construction and Installation Related Services	25.3	$1,040.5	
Module and Supply Chain Impacts	105.1	$6,035.1	$15,759.3
Induced Impacts	50.9	$2,240.9	$6,476.9
Total Impacts	**209.8**	**$11,559.5**	**$26,896.5**

During operating years	Annual Jobs	Annual Earnings $000 (2008)	Annual Output $000 (2008)
Onsite Labor Impacts			
PV Project Labor Only	0.4	$23.3	$23.3
Local Revenue and Supply Chain Impacts	0.2	$12.8	$35.6
Induced Impacts	1.1	$50.4	$145.7
Total Impacts	**1.7**	**$86.5**	**$204.6**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

West Sand & Gravel

Installation Costs	**Cost**	**Purchased Locally (%)**	**Manufactured Locally (Y or N)**
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$1,295,803	100%	N
Modules	$12,614,369	100%	N
Electrical (wire, connectors, breakers, etc.)	$1,477,436	100%	N
Inverter	$1,215,901	100%	N
Subtotal	$16,603,509		
Labor			
Installation	$2,243,070	100%	
Subtotal	$2,243,070		
Subtotal	$18,846,579		
Other Costs			
Permitting	$356,484	100%	
Other Costs	$584,304	100%	
Business Overhead	$3,642,634	100%	
Subtotal	$4,583,421		
Subtotal	$23,430,000		
Sales Tax (Materials & Equipment Purchases)	$1,162,246	100%	
Total	$24,592,246		

PV System Annual Operating and Maintenance Costs	**Cost**	**Local Share**
Labor		
Technicians	$25,080	100%
Subtotal	$25,080	
Materials and Services		
Materials & Equipment	$14,520	100%
Services	$0	100%
Subtotal	$14,520	
Average Annual Payment (Interest and Principal)	$2,717,880	0%
Property Taxes	$234,300	100%
Total	$2,991,780	

Other Parameters		**West Sand & Gravel**
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$23,430,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$234,300	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/Hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%

Photovoltaic - Project Data Summary	**Pine Hill Landfill**
Project Location	RHODE ISLAND
Year of Construction or Installation	2010
Average System Size - DC Nameplate Capacity (KW)	4600
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (KW)	4600
System Type	Utility
Base Installed System Cost ($/KWDC)	$7,100
Annual Direct Operations and Maintenance Cost ($/kW)	$12.00
Money Value - Current or Constant (Dollar Year)	2008
Project Construction or Installation Cost	**$34,280,100**
Local Spending	$22,927,417
Total Annual Operational Expenses	$4,170,360
Direct Operating and Maintenance Costs	$55,200
Local Spending	$43,612
Other Annual Costs	$4,115,160
Local Spending	$326,600
Debt Payments	$0
Property Taxes	$326,600

Local Economic Impacts - Summary Results

During construction and installation period	Jobs	Earnings $000 (2008)	Output $000 (2008)
Project Development and Onsite Labor Impacts	75.1	$4,577.1	$6,496.2
Construction and Installation Labor	39.7	$3,126.7	
Construction and Installation Related Services	35.3	$1,450.4	
Module and Supply Chain Impacts	146.5	$8,412.5	$21,967.5
Induced Impacts	70.9	$3,123.7	$9,028.4
Total Impacts	**292.5**	**$16,113.3**	**$37,492.1**

During operating years	Annual Jobs	Annual Earnings $000 (2008)	Annual Output $000 (2008)
Onsite Labor Impacts			
PV Project Labor Only	0.5	$32.5	$32.5
Local Revenue and Supply Chain Impacts	0.3	$17.9	$49.6
Induced Impacts	1.6	$70.3	$203.1
Total Impacts	**2.4**	**$120.6**	**$285.2**

Notes: Earnings and Output values are thousands of dollars in year 2008 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs

Installation Costs	Cost	Pine Hill Landfill Purchased Locally (%)	Manufactured Locally (Y or N)
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$1,806,271	100%	N
Modules	$17,583,665	100%	N
Electrical (wire, connectors, breakers, etc.)	$2,059,456	100%	N
Inverter	$1,694,893	100%	N
Subtotal	$23,144,285		
Labor			
Installation	$3,126,704	100%	
Subtotal	$3,126,704		
Subtotal	$26,270,989		
Other Costs			
Permitting	$496,917	100%	
Other Costs	$814,484	100%	
Business Overhead	$5,077,610	100%	
Subtotal	$6,389,011		
Subtotal	$32,660,000		
Sales Tax (Materials & Equipment Purchases)	$1,620,100	100%	
Total	$34,280,100		

PV System Annual Operating and Maintenance Costs	Cost	Local Share
Labor		
Technicians	$34,960	100%
Subtotal	$34,960	
Materials and Services		
Materials & Equipment	$20,240	100%
Services	$0	100%
Subtotal	$20,240	
Average Annual Payment (Interest and Principal)	$3,788,560	0%
Property Taxes	$326,600	100%
Total	$4,170,360	

Other Parameters		**Pine Hill Landfill**
Financial Parameters		
Debt Financing		
Percentage financed	80%	0%
Years financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	1%	
Assessed Value (percent of construction cost)	100%	
Taxable Value (percent of assessed value)	100%	
Taxable Value	$32,660,000	
Property Tax Exemption (percent of local taxes)	0%	
Local Property Taxes	$326,600	100%
Local Sales Tax Rate	7.00%	
Payroll Parameters	**Wage/hr**	**Payroll Overhead**
Construction and Installation Labor		
Construction Workers / Installers	$27.49	37.6%
O&M Labor		
Technicians	$25.00	37.6%