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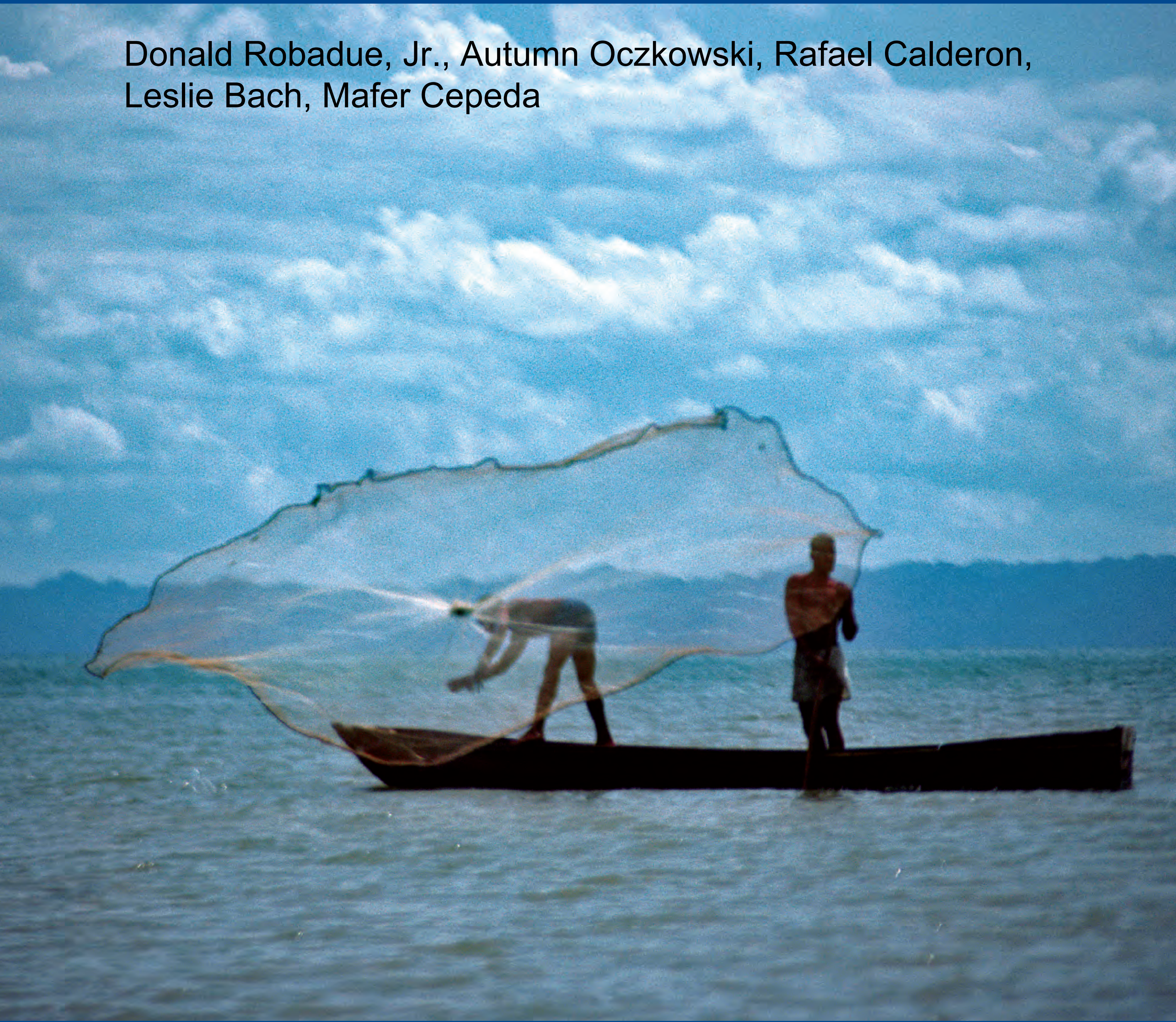
Coastal Resources Center University of Rhode Island

MANAGING FRESHWATER INFLOWS TO ESTUARIES

Characterization of the Region of the Terminos Lagoon: Campeche, Mexico. Plus Draft 1 Site Profile. Draft for Discussion.

Donald Robadue, Jr., Autumn Oczkowski, Rafael Calderon, Leslie Bach, Mafer Cepeda



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Characterization of the Region of the Laguna de Términos
Campeche, Mexico

Level One Profile, Fresh Water Inflow to Estuaries Project
The Nature Conservancy and the University of Rhode Island

Don Robadue, Rafael Calderon, Autumn Oczkowski, Leslie Bach, Maria Fernanda Cepeda
August 25, 2004

1. What are the defining characteristics of the Laguna de Terminos estuary?

1.1 Scale

Terminos Lagoon is the largest lagoon-estuarine ecosystem in Mexico by area and volume[1]. The water body and immediately surrounding shorelands are fully incorporated into a National Flora and Fauna Reserve comprised of 705,016 ha of open water and associated wetlands and upland.[2] It consists of about 200,108 ha of open water including associated lagoons and channels, with an average depth of 4 m, surrounded by about 259,000 ha of mangrove and cattail marsh[3]. Of the surrounding 180,000 ha. of land that is in some productive use 90% is cattle ranching, 6 % is agricultural, and 4% is urbanized, principally the City of Carmen.

It is separated from the Gulf of Mexico by the Carmen Island, a 37 km long, 4 km wide barrier island[4] with two mouths, the Boca del Puerto Real, about 3.2 km wide to the east, and the 3.8 km wide El Carmen to west[5]. Both mouths are now traversed by bridges.

Terminos Lagoon was declared as a federal Zona de Protección de Flora and Fauna in 1994, and is considered a "critical habitat" by the Mexican Environmental Agency, SEMARNAT, in view of its lagoon, mangroves, sea grass, and associated fluvial- lagoon- delta system.[6] A detailed map of the reserve is shown in Figure 9.

1.2 Resources present and their condition

More than 90 % of the protected area is considered in pristine condition.[7] It is the most important bird wintering area in the Gulf of Mexico region of Mexico.[8] The reserve area has 374 species of plants, three of which are threated, and 1468 species of fauna, including 30 endemic species of reptiles, amphibians, birds and mammals, 89 threated species and 132 of commercial value. This high biodiversity is combined with the wide range of functions of the lagoon- wetland- landscape functioning, including its tight coupling to the productivity of Campeche Sound.[9]

The reserve management plan distinguishes six types of habitat for fisheries within the lagoon:

1. Zone affected by marine waters
2. Zone affected by estuarine waters
3. The estuarine mixing zone
4. Freshwater
5. Mouths of the lagoon
6. Waters of the continental shelf.[10]

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[1] Programa de Manejo, p.18.
[2] Carta Nacional de Pesca 2000, Areas naturales protegidas: Laguna de Términos
[3] Yanez-Arancibia, A. et. al. 1994.
[4] Leriche Guzman, p.25.
[5] Programa de Manejo, p.18
[6] Carta Nacional de Pesca 2000, Areas naturales protegidas: Laguna de Términos.
[7] Labougle, p. 30.
[8] Toledo. P 32.
[9] Programa de Manejo, p. 23 et. seq.
[10] Programa de manejo. P 26

Figure 4 below presents additional detail on this manner of classifying Lagoon water areas.

Three types of habitat considered of critical importance to the productivity of the Terminos are the sea grass beds, mangrove ecosystems and the two mouths of the lagoon.[11] (See Figure 1)

There are four main watershed-river systems that flow into interior lagoons surrounding the Terminos. The Candelaria and Mamantel flow into the secondary Laguna Panlao. The Chumpan river feeds the Laguna Balchacah, the Palizada, a branch of the Usumacinta, flows into the Viento- Este- Vapor chain of lagoons. The Rio San Pedro- San Pablo, another branch of the Usumacinta, flows into the Pom- Atasta- Peralta chain of lagoons near the El Carmen mouth.[12] Oyster reefs are associated with the mouths of all of these except the Palizada. (Figure 2) Sea grass beds of *Thalassia testudinum* extend all along the barrier island (Figure 3.)

Yañez-Arancibia et. al., 1983, report:

> "The lagoon is connected to the sea by two inlets and there is a strong water flow towards the western part caused by predominantly eastern winds, the littoral current and the discharge of rivers. Due to this circulation pattern a semipermanent gradient of salinity, turbidity, nutrient level, different kinds of sediments, associations of foraminifera and macrobenthos, and shrimp and fish migrations were found. There exists a great diversity of estuarine environments (subsystems or habitats), which include brackish mangrove masrshes of low salinity, seagrass, grassland, areas of high sedimentation, oyster reef and the central oligohaline basin. Two different sources of sediment exist in the lagoon: fluvial sediments and calcareous sediments originating in beaches of the eastern part of the lagoon. "

Figure 4 locates in general terms these distinct habitats. Note especially that each of the fluvial-lagoon systems, located where the main rivers enter into the Terminos, has distinct characteristics.

Rojas-Galaviz et. al, 1992, further explain that the "Terminos Lagoon, unlike most temperate estuarine ecosystems, has high levels of primary production all year. This is owing to sequential periods of high production by different functional groups of primary producers". This is shown in Figure 5. The authors go on to state:

> "...The dominant species of fish in the lagoon have evolved life cycles that lead to the utilization of different habitats during the period of high productivity. This leads to high food availability and high secondary production. Such a pattern of resource utilization may explain the relationships that have been found among factors such as river flow, intertidal wetland areas, aquatic primary productivity and commercial fisheries catch."

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[11] Programa de manejo, P. 27
[12] Bougle. Atlas Territorial Région de Términos.

Figure 1 Habitats in the Laguna de Terminos (from Rojas-Galaviz, 1992)

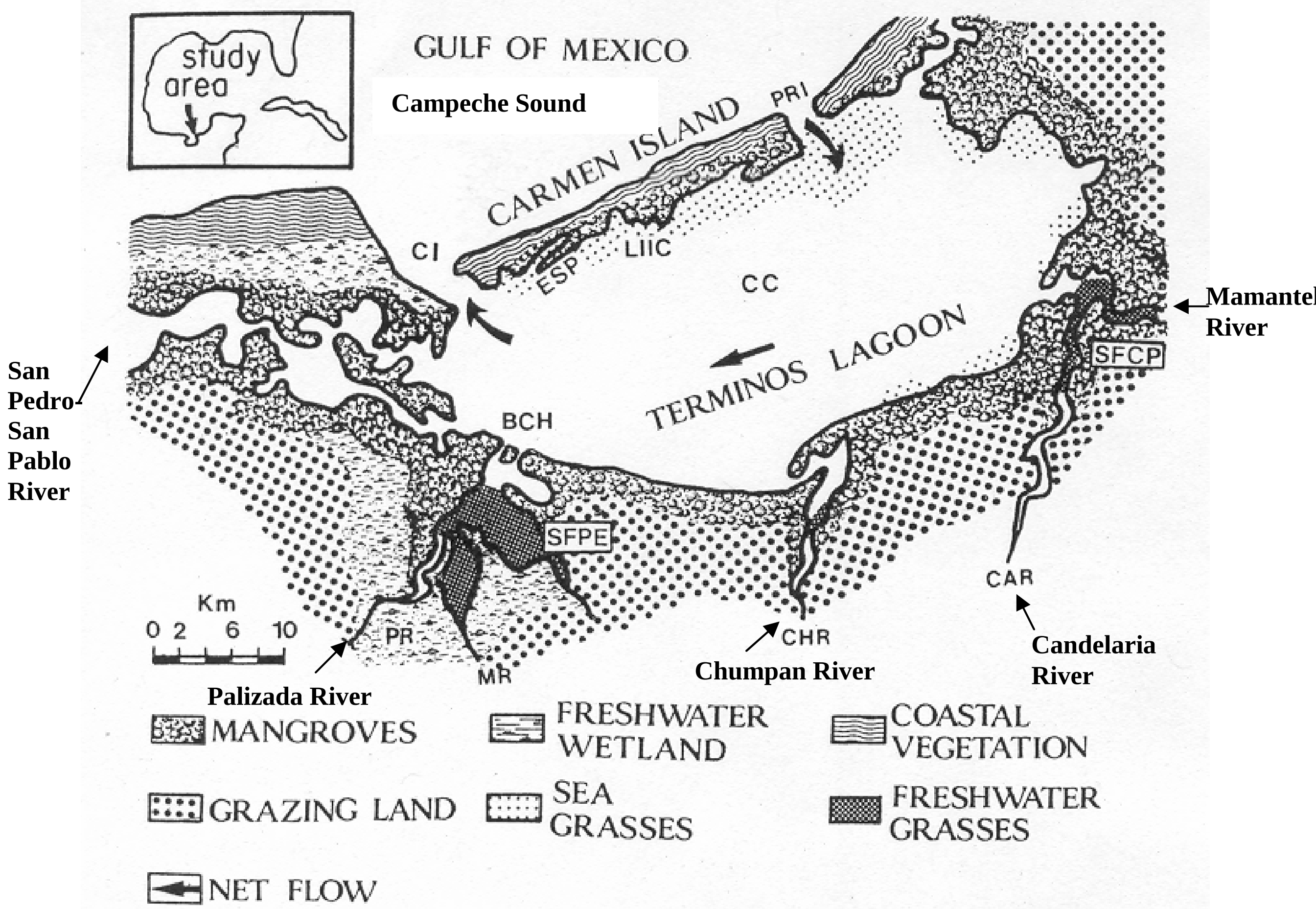


Figure 10.1 The lagoon–estuarine system of Laguna de Terminos in the southern Gulf of Mexico, showing the distribution of the principal primary producers. CI, Carmen Inlet; PRI, Puerto Real Inlet; LIIC, shallow littoral area behind Carmen Island; ESP, Estero Pargo, a high-salinity tidal creek draining fringing mangroves; CC, central basin of the lagoon; BCH, Boca Chica, the mouth of the largest river entering the lagoon; SFPE, fluvial, deltaic system of Palizada-del Este; SFCP, fluvial, deltaic system of Candelaria-Panlau; PR, Palizada River; CHR, Chumpan River; CAR, Candelaria River; MR, Marentes River. The arrows indicate the pattern of net water circulation through the lagoon.

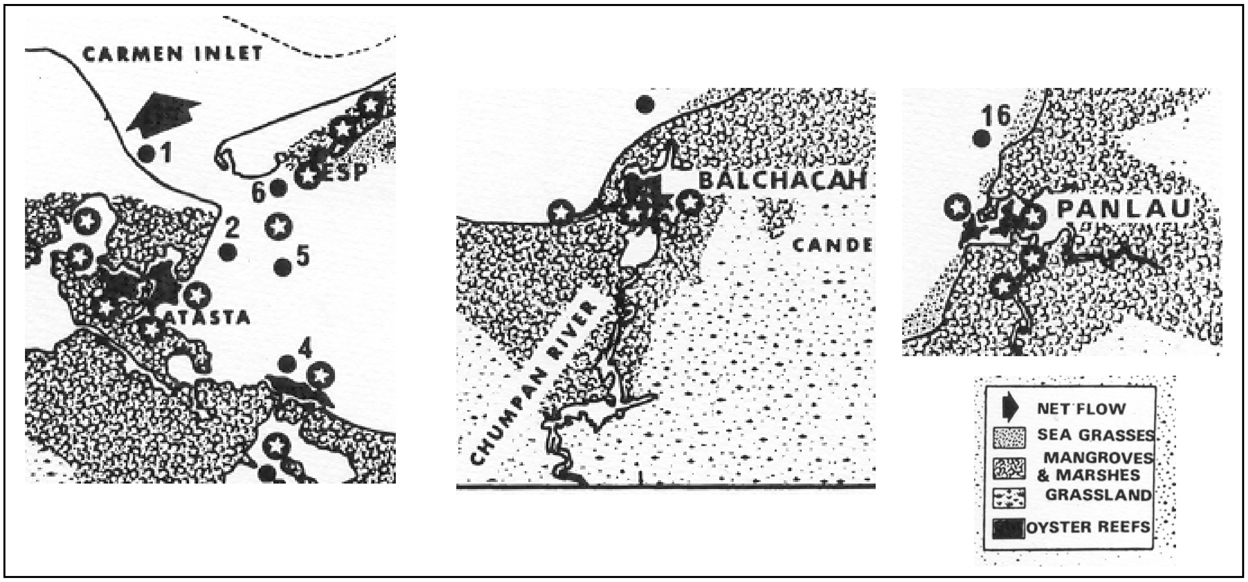


Figure 2 Oyster reefs in the Laguna de Terminos. Source: Yañez-Arancibia, 1983.

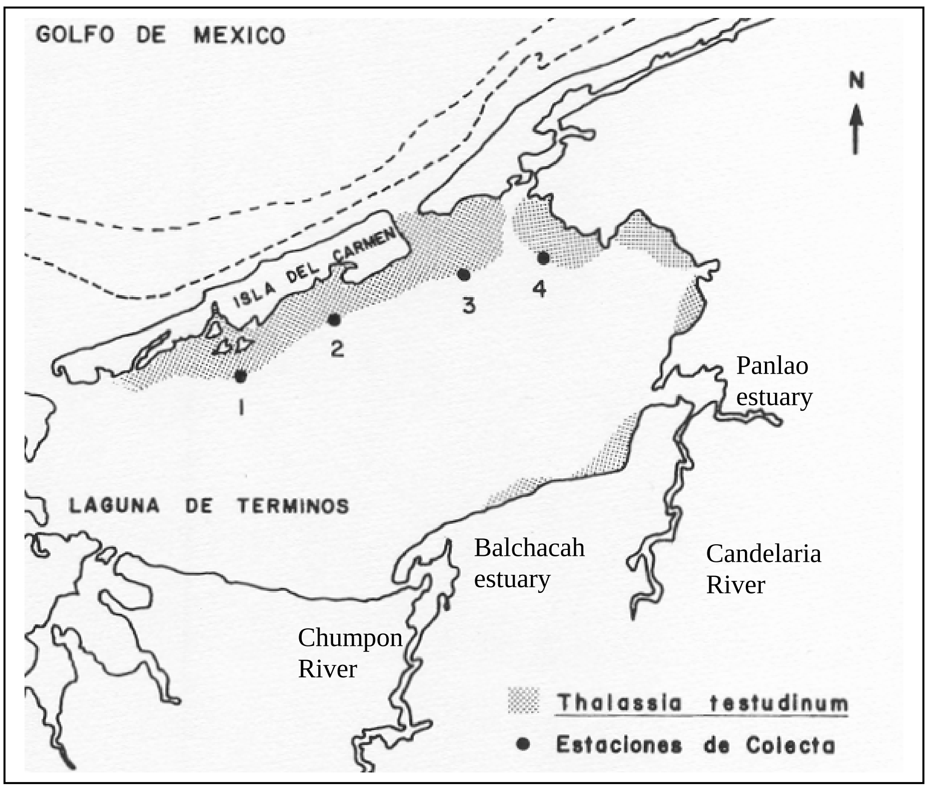


Figure 3 Location of sea grass beds, *Thalassia testudinum* Source: Vargas Maldonado, 1987.

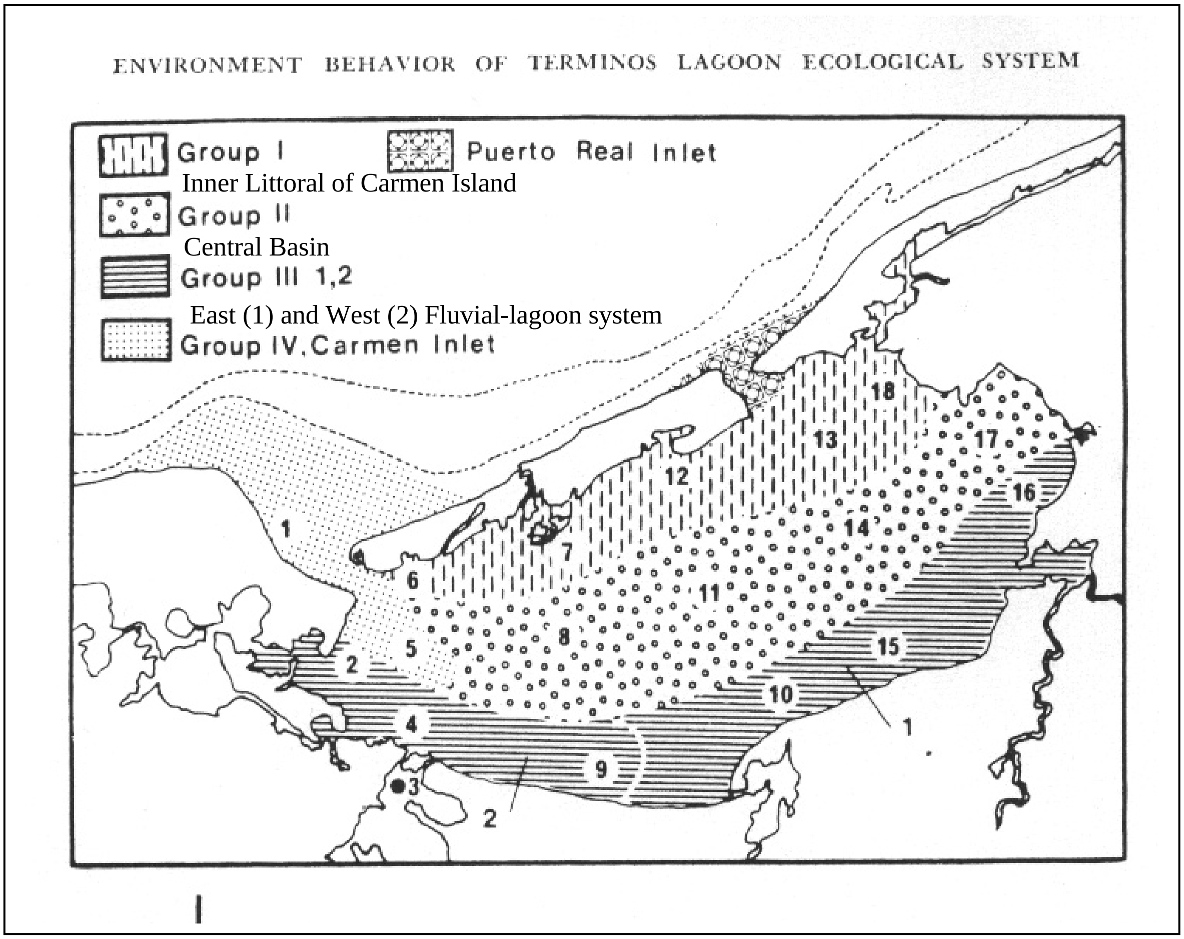


Figure 4 Main Ecological characteristics of subsystems in Terminos Lagoon. Source: Yáñez-Arancibia, 1983. Numbers 1-18 represent sampling stations.

Subsystem	Annual salinity, average, ppt	Transparency %	Sea water influence 1=low, 4= high	Fresh Water influence 1=low, 4= high	Note
I. Puerto Real and Carmen Island inner littoral	29	50	4	1	Strong seawater influence
II. Central Basin	25	43	3	2	Transition zone
III-1 Eastern Fluvial-lagoon	23	45	2	4	Strong riverine influence. Sea grass, mangroves, oyster reefs
III-2 Western Fluvial-lagoon	20	29	1	4	Strong riverine influence, mangroves, oyster reefs
IV Carmen Inlet	25	24	3	3	Variable zone

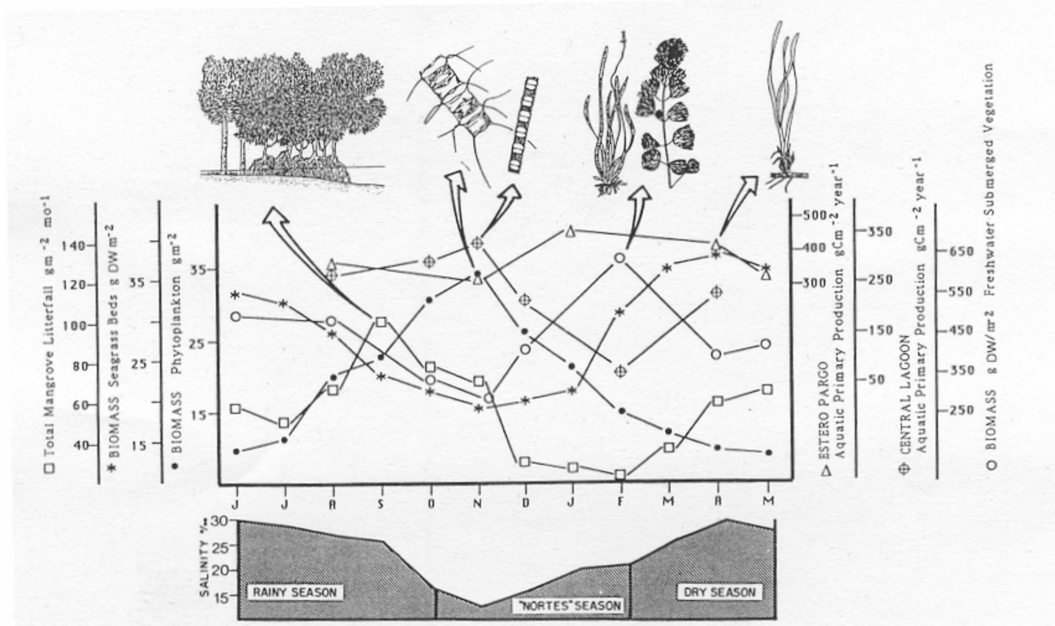


Figure 10.6 The seasonal pattern of production and biomass of the different functional groups of primary producers in Laguna de Terminos. Note that there are sequential periods of high production by each group leading to high year-round production. This *seasonal programming* is discussed further in the text. Below is shown the pattern of salinity for the central basin of the lagoon in the rainy, *nortes,* and dry seasons. The decrease in salinity during the rainy and *nortes* seasons corresponds to the period of high river flow. The illustrations above are (left to right) *Avicenia germinans, Rhizophora mangle, Chaetoceros, Skeletonema, Vallisneria americana, Cabomba palaeformis,* and *Thalassia testudinum.*

Figure 5 The seasonal pattern of production and biomass of functional groups of primary producers in Laguna de Terminos. From Rojas-Galaviz, et. al. 1992

These temporal dynamics are illustrated for four key species in Figure 6.

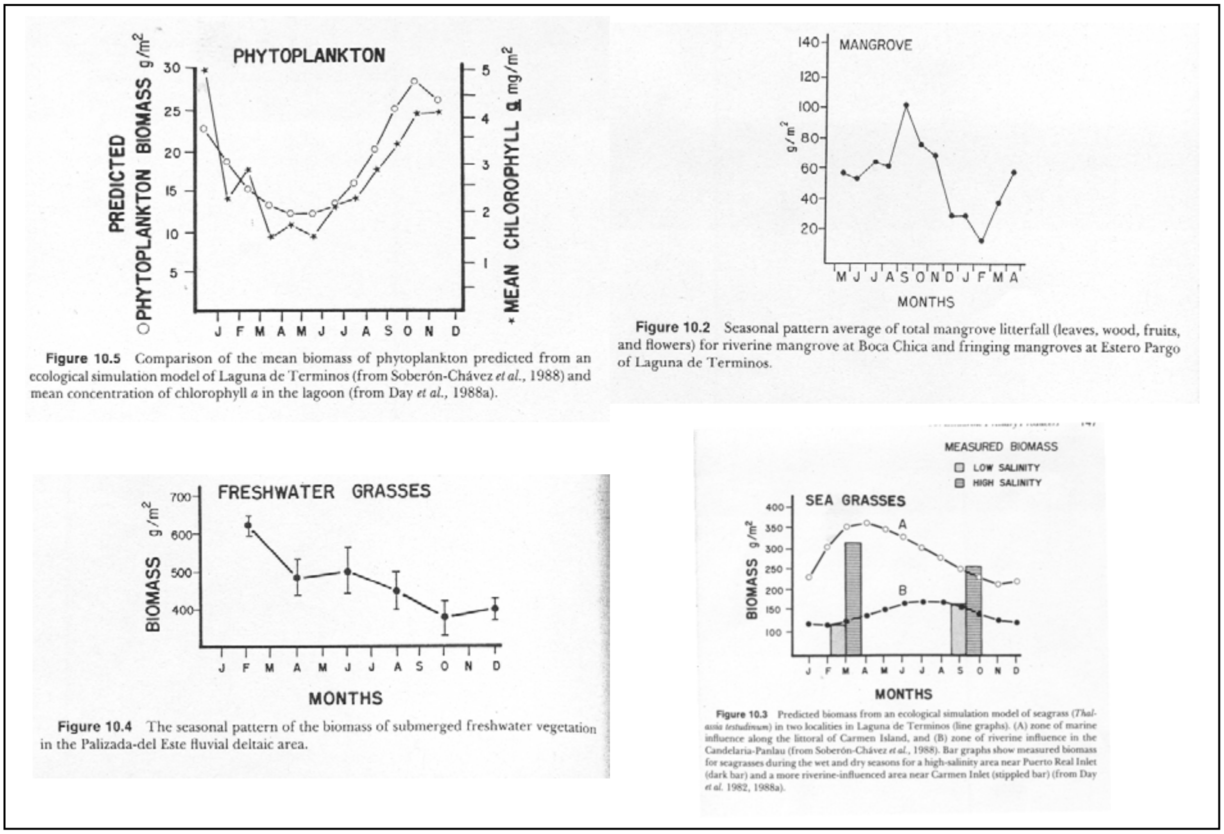


Figure 6 Seasonal variation in primary production of phytoplankton, mangroves, freshwater grasses and sea grasses. From Rojas-Galaviz, et. al. 1992

Yáñez-Arancibia, et. al, (1980), observe:

> In Terminos Lagoon, fish grow faster and life cycles are shorter, with most fish maturing in less than one year. The growing season extends over the whole year and young fish are available for stocking throughout the year. Ecologically complementary species are available to increase yields; many species can withstand poorly oxygenated waters and fish in the lagoon have high availability of food.

Finally, the seasonal dynamics and spatial differences within the Terminos that relate to river flow are important to fisheries. (Amezcua-Linares et. al. 1980) A very brief summary is presented below, detailed lists and data tables are provided in Annex 1.

	Pom Atasta (with flow from Usumacinta)	**Palizada and Del Este**	**Chumpan and Balchacah**	**Candelaria- Panlao**
Number of individuals	851	402	583	2003
Number of total species	33	28	21	33
Total weight (unit?)	24787	15561	30014	56642
Top five species by rank order	*Eucinostomus gula*- jenny mojarro(31%); *Micropogon furnieri*- whitemouth croaker; *spheroides testudineus*- checkered pufferfish; *bairdiella chrysura*-silver perch; *Arius felis*-hardhead catfish	*Arius melanopus*-sea catfish (56%); *Micropogon furnieri*- whitemouth croaker; *spheroides testudineus*- checkered pufferfish; *opisthonema oglinum*-Atlantic thread herring; *Arius felis*- hardhead catfish	*Arius melanopus*-sea catfish (72%); *bairdiella ronchus*- ground croaker; *Anchoa mitchilli mitchilli*-bay anchovy; *Eugerres plumieri*-striped mojarra; *sardinella macrothalmus*	*Eucinostomus gula*- jenny mojarro(20%); *Diapterus rhombeus*-caitipa mojarro; *Arius melanopus*-sea catfish; *Micropogon furnieri*- whitemouth croaker; *bairdiella ronchus*- ground croaker

Table: Variation of predominant fish species in estuaries around the Terminos Lagoon. Source: Amezcua-Linares et.al. 1980.

Researchers have steadily advanced their ability to show the interplay of geography and the dynamic interactions of freshwater inflows and mixing of the Terminos Lagoon as a unique and highly productive ecosystem. A conceptual model highlighting key relationships is shown in Figure 7.

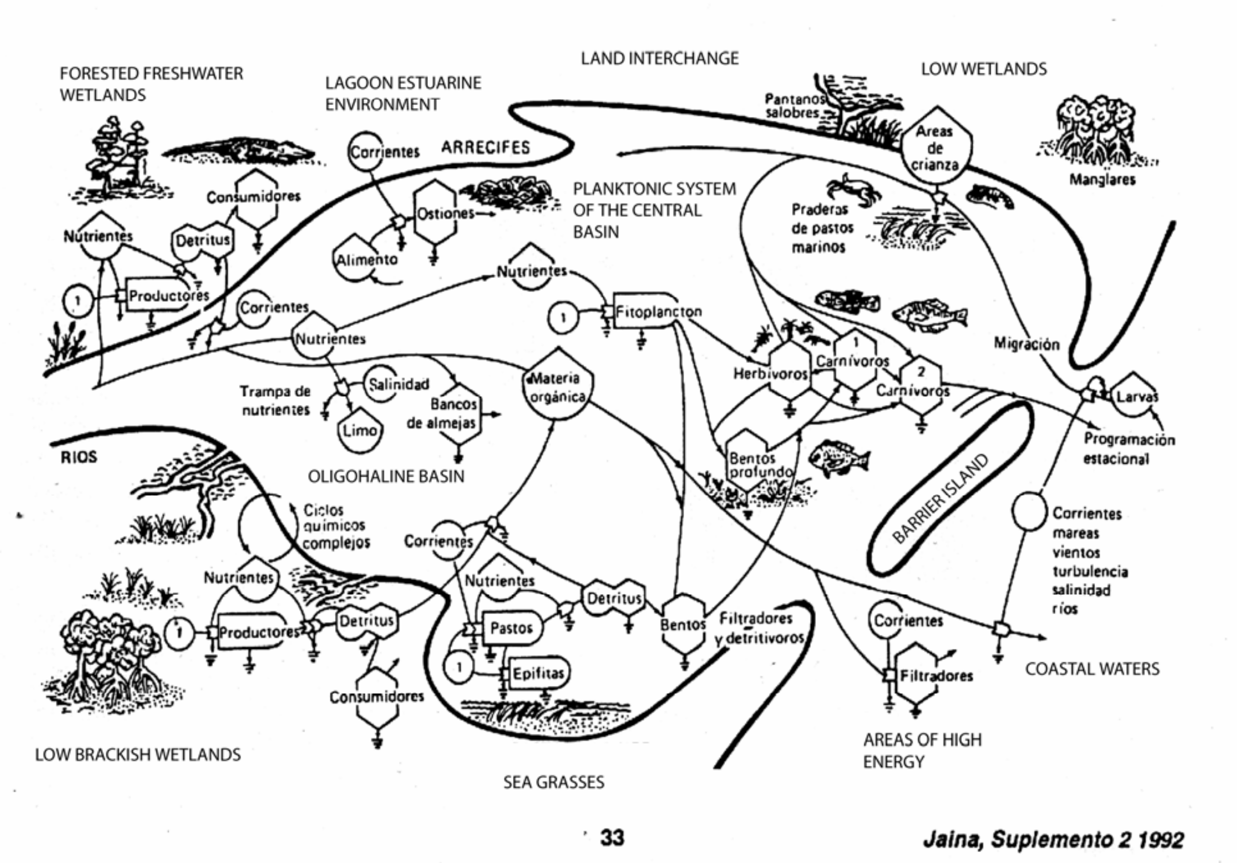


Figure 7 A conceptual ecological model of the Terminos Lagoon showing key components and their relative geographic location. Source: EPOMEX, 1992.

Description of Laguna de Terminos

Terminos Lagoon is the most important lagoon system of the southern Gulf of Mexico. And one of the most studied because of 1) its high diversity in species and habitats; 2) its fish mollusks and crustaceans resources; 3) its interrelations with Campeche Sound (the most important fishing area in the Gulf of Mexico) ; 4) the great industrial development (oil industry) and the general coastal development that is taking place in the lagoon and adjacent areas; 5) because it has not yet reached critical levels of pollution.

Geographic Setting

Terminos Lagoon is a large (~ 2500 km^2), shallow (mean depth 3.5 m) coastal lagoon bordering the southern Gulf of Mexico in Campeche, Mexico (Fig. 1). Offshore is the Bay of Campeche a region supporting one of the largest marine fisheries in Mexico. The lagoon borders two geologic provinces: to the east is the Yucatan Peninsula (low rainfall, calcareous soils, and no significant surface drainage). To the west and south are the lowlands of Tabasco and the highlands of Chiapas and Guatemala, and area of high rainfall and fluvial soils. The Usumacinta-Grijalva river systems discharges in the Gulf through three main rivers: the Candelaria, the Chumpan, and the Palizada (tributary of the Grijalva-Usumacinta).

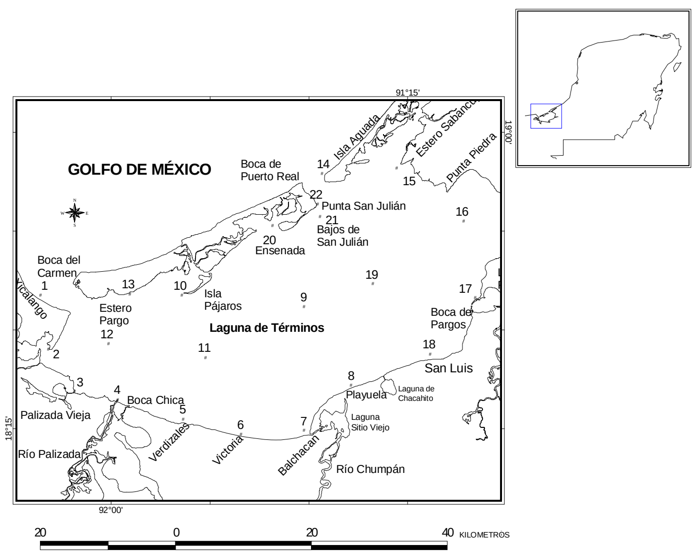


Figure 1. Location map of Laguna de Terminos in Yucatán Peninsula, Mexico (David and Kjerfe, 1998).

The lagoon has moderate seasonal pulses of temperatures and light, and the area has strong near-permanent physical gradients and a high diversity of estuarine habitats (mangroves, submerged sea grasses, marsh grasses, oyster reef, areas of high sedimentation, and low salinity in the oligohaline zone).

Prevailing winds cause a net inflow into the eastern inlet (Puerto Real Inlet) and a net outflow in the western end of the lagoon (Carmen Inlet). The major river discharge is into the western part of the lagoon, creating turbid, nutrient-rich waters with low salinity. Most biological processes including assemblages of benthic and fish populations are strongly influences by these gradients. There is relatively little commercial fishing in the lagoon. The lagoon is important to the fishery as a nursery and feeding area for various fish and shrimp populations

The area presents three climatic seasons; the rainy season (Jun-Sep); the season of Nortes, or winter storms (Nov-Mar), and the dry season (Feb-May).   There is high diversity of estuarine subsystems in the lagoon, including low salinity and brackish-marine mangrove, swamps, sea grasses, marsh grasses, areas of high sedimentation, oyster reefs, and oligohaline areas.

The Lagoon's physical characteristics

Geology/bathymetry

The sediments in the Campeche Bay Shelf grade from carbonate sand and mud to siliciclastic sand and mud from east to west (Lecuanda and Ramos, 1985), forming a transition zone seaward of Terminos Lagoon where sediments range from less than 25 to over 50% carbonate. The area marks a major shifting boundary in the distribution of many groups of organisms, to the east waters are clear, with carbonate sediments and low organic matter content. Benthic vegetation is well developed. To the west, waters are more turbid, with high organic matter content, terrigenous sediments, and no sea grass (Yáñez-Arancibia and Sánchez-Gil, 1986).

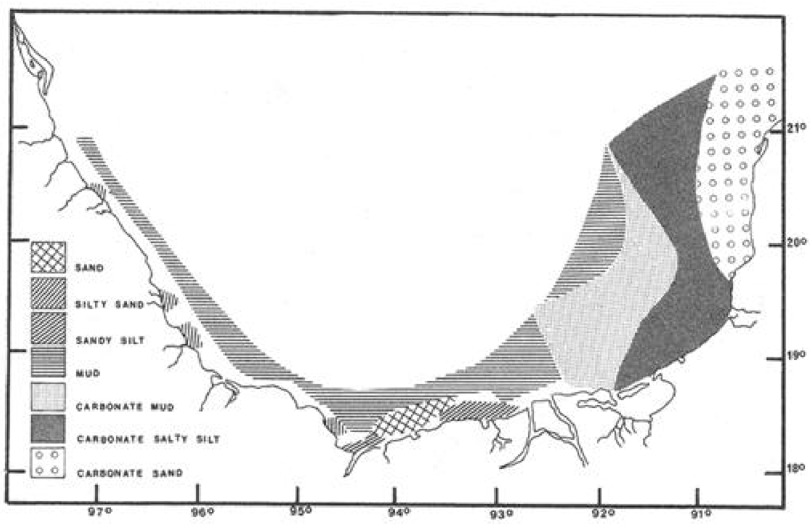


Figure 2. Map depicting the sediment composition and distribution in the Campeche Sound and Southern Mexico (Machain-Castillo, 1989)

The lagoon floor lacks important morphological features except for intertidal channels and deltas. The average depth is 3.0 m with a maximum of 10.0 m in Puerto Real inlet and 7.0 m in Carmen inlet, however in the tidal or artificially dragged channels these depths increase considerably. The center of the lagoon has a large and shallow area with a depth of 4 m that decreases towards the oriental littoral where bottoms of 0.3 m occur. Sediments are distributed in structural units, thus forming an almost tidy arrangement; sediments consist principally of silty and clay sands, which gradually mix with a zone of sand, silt and clay. This arrangement of structural graduation is, however, strongly altered by the sediment sources, topography of the bottom and water circulation. The currents produced by winds are more efficient in the sediment transport of the lagoon's middle portion, than the water currents that enter through the inlets of the estuaries. The transportation by the residual flow of rivers, together with the currents gradually produced by winds from SE and NW, obviously carries a great quantity of sediments towards the lagoon's central part. The major part of the central lagoon sediments contains almost 50%, of $CaCO_3$ (Yáñez Correa, 1963).

The most notable characteristic of these systems is the presence of oyster reefs found at the mouths of the 4 fluvio-lagoonal systems; thus, at inlets those zones are very shallow and only at the outlets of rivers and channels water reaches depths of 2 m. Productivity of phytoplankton and mangrove is higher in riverine areas.
Benthic populations are related to subsystems in the lagoon and are controlled by salinity, river flow, turbidity and sediment types.

The Isla del Carmen is a barrier island that partially isolates the lagoon from the Gulf of Mexico. The formation of the island seems to be due to the development of incipient islands separated by channels filled in by washout fans. The lagoon is highly developed as evidenced by the level or organic matter in its basin, the lack of important bathymetric features, and the accretion of wide flood plains and mangrove swamps.

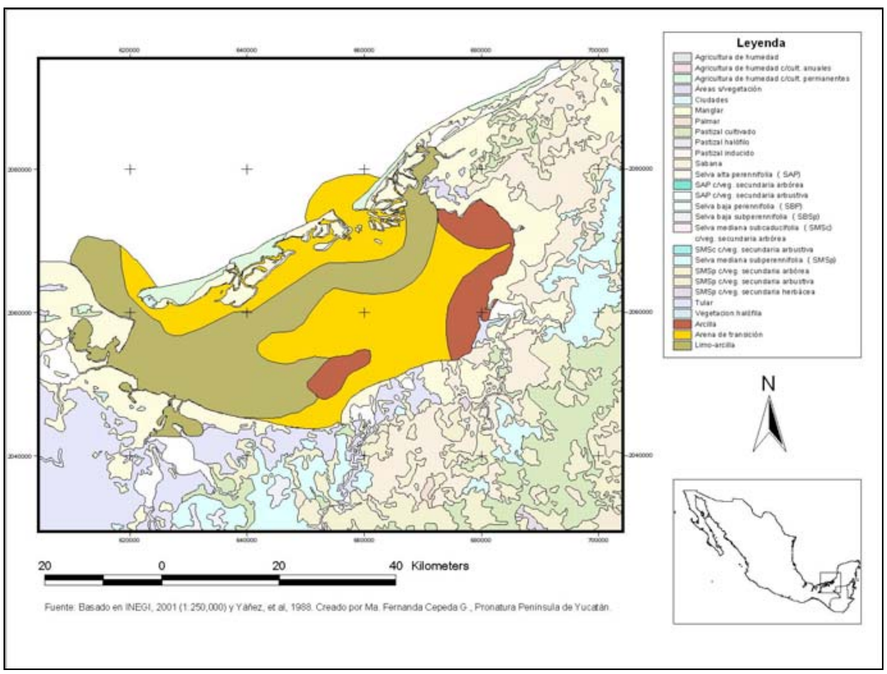


Figure 3. Map showing distribution of Sediment Types in Laguna de Terminos (INEGI, 2001 and Yáñez-Arancibia, 1988).

Water Characteristics

Transparency doesn't show a seasonal pattern and is varied across the lagoon, reaching a high of 100% in the Panlau area during February and a low of 12% in October. In terms of mean transparency values of 24% have been observed in October and 62% in February. Amezcua Linares and Yáñez-Arancibia (1980) reported a transparency of 20 and 40%. Transparency fluctuates highly during any given month and it seems likely that this parameter is being influenced by the characteristic meteorological phenomenon of the area.

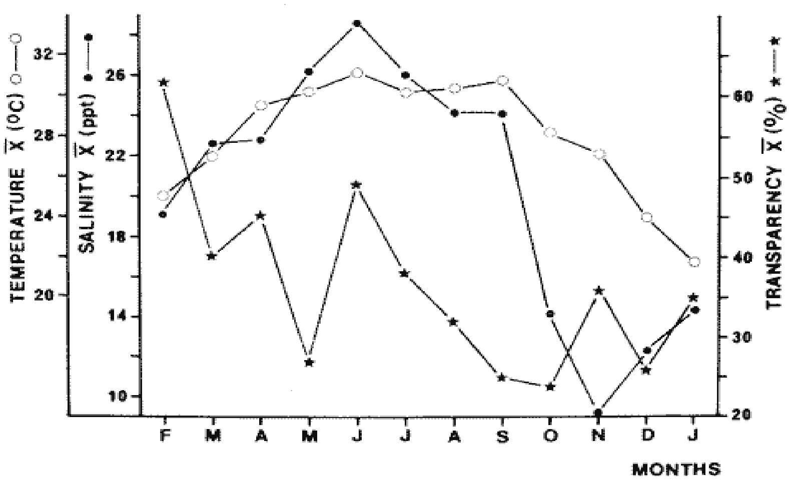


Figure 5. Graph depicting temperature, salinity and transparency values for Laguna de Terminos over a 12 month period (Yáñez-Arancibia, *et al*, 1983).

Since Terminos Lagoon is directly affected by the discharges of several significant rivers, salinity values measured during an annual cycle go from 5 ppt and 32 ppt. The maximum mean salinity value was 28.6 ppt during the dry-wet season (June) and its minimum was 9.2 ppt during the rainy-"nortes" season (November).

By observing Figure 5, which is an interpolation of the existing data on salinity for the Laguna de Terminos, a clear gradient can be seen extending from the borders outward into the basin. This follows in terms of the description of the system as a lagoonal system near the edges with strong influence from the main rivers discharging there and as one moves to the basin and closer to the inlet (Carmen) and outlet (Puerto Real), salinity tends to be more influenced by the Campeche sound (marine influence). The highest salinity area would be the eastern inlet (Puerto Real).

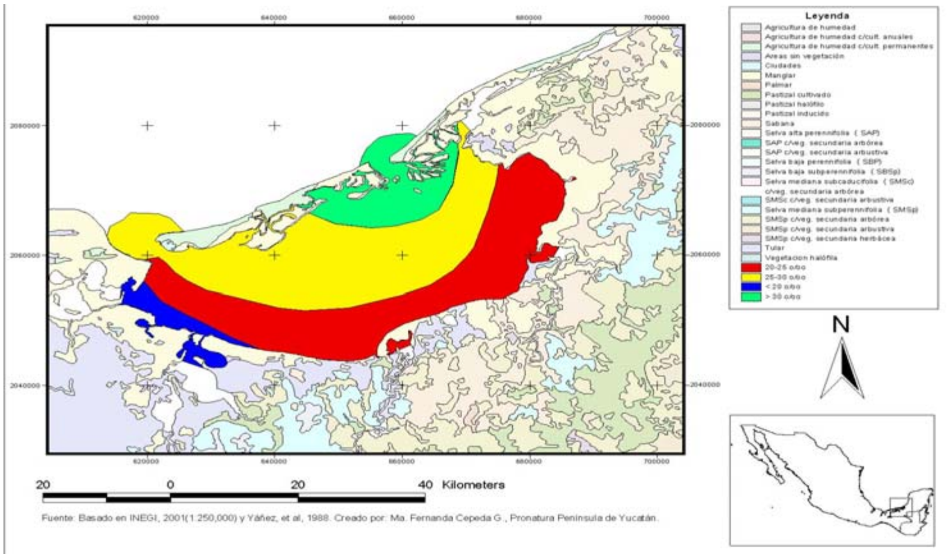


Figure 7. Map depicting the salinity gradient in Laguna de Terminos (Yáñez-Arancibia, *et al*, 1983).

Currents and water circulation

Laguna de Terminos is a two-inlet system. The eastern inlet, Puerto Real has a net inflow of shelf water to the lagoon while the western inlet, Carmen, has net outflow. As the tidal range is small (~0.5 m), there is a gradient within the Lagoon, from strong marine influence to low salinity riverine waters (Day et al. 1982). Further, this region experiences 3 seasons: dry, wet, and nortes. During the wet, or rainy, season the rivers introduce large volumes of freshwater to the Lagoon, and the salinity of the entire estuary decreases. This rainy season spans from June through to the end of September. The dry season is typically from March to May and October through February is the season of nortes, or winter storms. During the nortes, the winds are from the northwest with speeds of ~8 m/s. The rest of the year experiences a sea breeze system with winds from the north-northeast and east-southeast with an average velocity between 4-6 m/s (Yanez-Arancibia & Day 1980).

The rivers draining into Terminos Lagoon show strong seasonal variations, with discharge during the dry season less than one third of what it is during the rainy and nortes. This has important implications for the circulation and salinity distribution of the Lagoon.

As a first pass at understanding the hydrodynamics of the Laguna de Terminos system a water budget was constructed. A literature review suggested that this system behaved differently not only between seasons but in different parts of the lagoon. Specifically, it appeared that the western part of the Lagoon was more strongly influenced by freshwater than the eastern part. The ensuing water budget was created on a seasonal basis separately for the Western 1/3 and Eastern 2/3 of the Lagoon where:

Inputs – Outputs = Net Freshwater Inflow to the Lagoon

[Precipitation + Discharge] – [Evaporation] = Net Inflow

According to the model, the Lagoon behaves differently both seasonally and spatially. The net freshwater inflow to the Laguna de Terminos varies dramatically by season. In fact, during the dry season, in the eastern 2/3 of the Lagoon, evaporation exceeds both precipitation and discharge suggesting a reverse estuary during this period.

Laguna de Terminos Water Budget (cubic meters per second)

	(Discharge +	Precipitation)	- (Evaporation) =	Net Inflow
Western 1/3				
Nortes	331	39	26	344
Dry	92	18	51	59
Rainy	383	67	49	401
Eastern 2/3				
Nortes	104	78	51	130
Dry	29	36	102	-37
Rainy	120	134	98	156

Source: Oczkowski, 2004. Characterizing Seasonal Water Flows in the Terminos Lagoon. Draft. University of Rhode Island

The results are presented as tidally averaged distributions and indicated the complex residual flow patterns in the lagoon. For most conditions, the circulation shows residual transport currents entering through Puerto Real Inlet and exiting through Carmen inlet. The Stokes' drift is oppositely directed but of small magnitude. The residual salinity and suspended sediment distribution patterns indicate that the east and west regions of Terminos Lagoon largely act independently of each other. These model results provide an excellent tool for formulation of hypotheses but await more field data for necessary validation.

The results from simulation runs show that tides, freshwater discharge, and local winds are all major forcing mechanisms of circulation and dispersion in Terminos Lagoon. These results are preliminary and validations of the model has yet to be performed, however the simulation runs represent conditions that may exist under realistic environmental situations, i.e. actual seasonal wind regimes, river discharge conditions, and tidal constituents at the two inlets. In carrying this project one step further, field sampling schemes will be developed in order to provide verification for the model results. During the dry season concentration of inorganic compounds seems to be correlated to the local conditions such as turbulence, kind of sediments, reducing rate and biological activity. Productivity of mangroves as well as phytoplankton are higher in areas of fluvial influence.

Through calculating the residence time of the system one can determine how long the freshwater stays in the estuary. The residence time budget indicates how important freshwater inflow is to a system and further analyses can tweak freshwater inflows to the system and observe how these alterations affect the residence time of Terminos Lagoon

The residence times for the Laguna de Terminos were very long, particularly during the dry season. Water, and thus anything in the water, which is introduced to the Lagoon will remain in the system anywhere from one to five months. Also, any decreases in freshwater inflow will subsequently increase the residence time even further. A blank space in the Residence Time column indicates a negative residence time was calculated and the Lagoon is behaving as a reverse estuary during this time.

	Volume of Freshwater /	Net Inflow =	Residence Time
	m^3	m^3/s	days
Western 1/3			
Nortes	2,222,222,222	344	73
Dry	1,261,574,074	59	146
Rainy	1,833,664,021	401	49
Eastern 2/3			
Nortes	1,749,338,624	130	137
Dry	596,064,815	-37	
Rainy	509,259,259	156	26

The Lagoon's biological values

Habitats and their Distribution

The Laguna de Terminos has been shown to contain gradients of distribution in terms of both physical and biological characteristics. To be able to better characterize his complex large estuarine/lagoon system this report follows the sub-systems developed above: a) the Fluvial-lagoon system, b) Central Basin, c) Inner Littoral of Carmen Island; d) Puerto Real Inlet, and e) El Carmen Inlet.

Fluvial-lagoon system

Various important rivers discharge their waters into Terminos Lagoon. The Candelaria river at the northwestern tip is one of the most important supply source; its basin is situated principally in the Yucatan Peninsula. The supply of freshwater from this river with its tributaries can reach 21.5 m^3sec^{-1}. This river together with the Mamantel river form the Panlau Lagoon which connects the Terminos Lagoon to the Pargos Inlet. This unit forms the Candelaria-Panlau System. The Chumpan river develops in the coastal plain through Salsipuedes and San Joaquin rivers and flows finally into the Balchacah Lagoon situated at the southern tip of Terminos Lagoon. Annual volume of draining reaches 1 368 millions Of m^3. River and lagoon form the Chumpan-Balchacah System.

The Palizada River forms part of the hydrological system of Mexcalapa, Grijalva and Usumacinta rivers. The studies indicate that the Candelaria, Chumpan and Palizada rivers together have provide a minimum flow of 6 X 10 9 m^3 year.

This whole system is based and influenced by the freshwater and hydrologically influenced wetland system known as "Pantanos de Centla". This system is a very large and complex system of lagoons, swamps and periodically inundated areas. The existence of submerged aquatic vegetation (SAV) of importance for biodiversity reasons has been well documented (Yáñez-Arancibia & Day 1980).

Source: Oczkowski, 2004. Characterizing Seasonal Water Flows in the Terminos Lagoon. Draft. University of Rhode Island

Discharge (m³/s)	Palizada River	Chumpan & Candelaria Rivers
Mean Annual	288	90
Nortes	331	104
Dry	92	29
Rainy	383	120

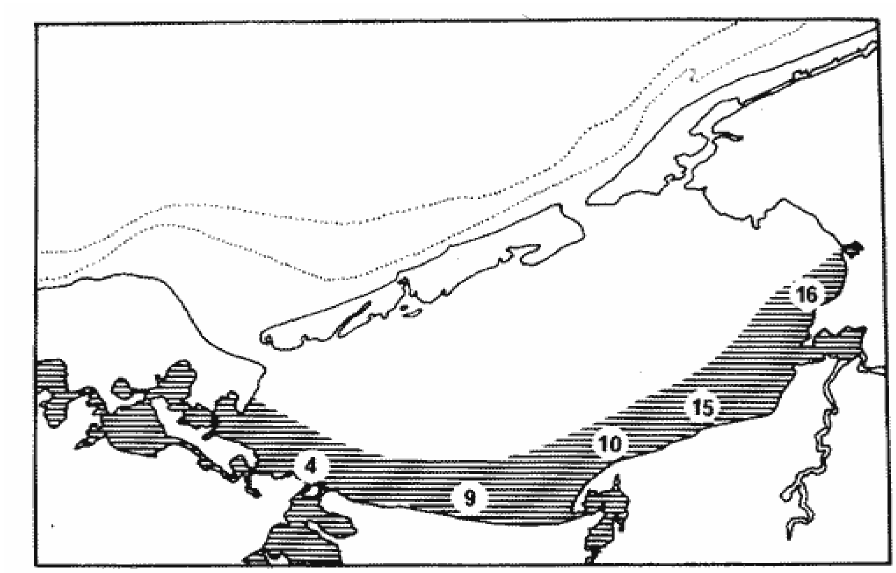


Figure 11. Map depicting the Fluvial-Lagoon sub-system in Laguna de Terminos (Yáñez-Arancibia, *et al*, 1983).

The Palizada River like all the rivers that drain into the Terminos Lagoon forms a fluvial-lagoon-marsh system with tidal influence, whose characteristics are:

1) The physical chemical characteristics of the aquatic body point to their fluvial origin with seasonal modulation determined by river discharge, climatic seasons, and tidal influence.
2) The system receives a permanent alocthonous energy subsidy from nutrients and organic matter of fluvial origin.
3) This environmental framework is utilized by numerous primary producers among whom submerged hygrophytes and mangrove forests stand out.
4) The vegetable groups in the system provide zones for feeding, reproduction, growing, and protection for a fauna community that includes rare species and others that are in danger of extinction, and among the most important aquatic macrofaunistic group in the system are fish assemblages.

This system is the main contributor of fresh water and terrigenous sediments to this coastal region, which is a key factor in the geochemistry of the lagoon-estuary ecosystem (Terminos Lagoon) and the marine system (Campeche Sound) in the adjacent littoral. The system exports nutrients and organic material in diverse states of decomposition whose effect on productivity in the western sector of Terminos Lagoon is important. The high rate of vegetable production and intensive utilization of the zone by numerous fish species of diverse origin demonstrate its value as an habitat and shows that its exporting function also includes a complex ichthyofaunistic community because of which the system represents a zone of great importance with regards to diverse aspects of its biological cycles. The conditions mentioned above demonstrate the existence of closely related biotic and abiotic ecological links between the Palizada System, the Terminos Lagoon, and the immediate marine littoral.

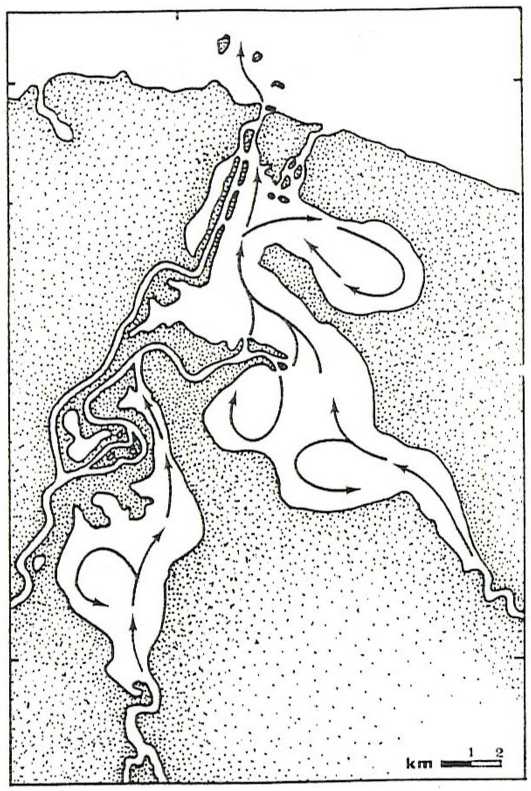


Figure 12. Diagram depicting general circulation patterns in the "Pantanos de Centla" wetland system (Vera-Herrera, *et al*, 1988).

b) Central Basin

The central portion of Términos Lagoon is generally considered to be an area of transition between the more oceanic conditions of the northeastern section and the brackish sections of the southern and western parts. Salinity data show a marine gradient coming from the Gulf of Mexico through Puerto Real Inlet. These higher salinity waters (>25ppt) mix with the waters coming from four large rivers flowing into the lagoon creating a large estuarine environment which then moves into the Gulf of Mexico through Carmen Inlet at the western portion of the lagoon (Botello,1978).

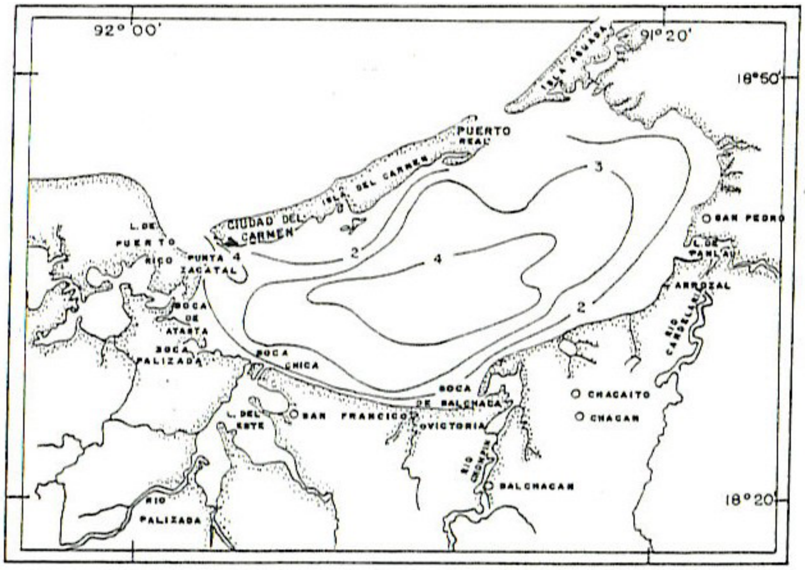


Figure 14. Diagram depicting Bathymetry of the Terminos Lagoon (Botello, 1978).

The center of the lagoon has a large and shallow area with a depth of 4 m that decreases towards the oriental littoral where bottoms of 0.3 m occur. Sediments consist principally of silty and clay sands, which gradually mix with a zone of sand, silt and clay. This arrangement of structural graduation is, however, strongly altered by the sediment sources, topography of the bottom and water circulation. The currents produced by winds are more efficient in the sediment transport of the lagoon's middle portion, than the water currents that enter through the inlets of the estuaries. The transportation by the residual flow of rivers, together with the currents gradually produced by winds from SE and NW, obviously carries a great quantity of sediments towards the lagoon's central part. The major part of the central lagoon sediments contains almost 50%, of $CaCO_3$ (Yáñez Correa, 1963).

c) Inner Littoral of Carmen Island

The northern portion of Terminos Lagoon, next to Carmen Island, presents a persistent marine influence, maintaining elevated salinity and trans parency values. It is important to outline that there is no inflow of fresh water to Carmen Island; therefore, the only fresh water supply is provided by rains during the rainy and "nortes" season

The principal zones of seagrass of the lagoon extend in the inner littoral of Carmen Island, Puerto Real Inlet and Bajos de Sabancuy. The immersed vegetation is composed of seagrass, where *Thalassia testudinum* dominates; macroalgae (Phaeophyceae and Rhodophyceae), large mangrove fields (principally *Rhizophora mangle*), and some. palm groves grow as well. This vegetation is being associated with high salinity values, transparency and the calcium carbonate content.

A narrow strip of sandy, marine sediments is found along Carmen Island, which is possibly deposited by the currents that hold an east-west direction. The eastern part of the island's inner littoral is situated in an area of biogenic accumulation, and the zone of Bajos del Cayo seems to have been the delta of an old inlet. There is a high organic content and $CaCO_3$ in proportions of 40 to 50% (Yáñez Correa, 1963).

The general salinity behavior throughout the annual cycle shows a seasonal pattern that increases from 28.7 ppt (February) to 34.7 ppt (June) when it reaches its highest values. Then in November it decreases to its lowest value (14.9 ppt) but increases once more in December and January. The average value was of 27.7 ppt.

d) Puerto Real Inlet

The Laguna de Terminos is connected with Campeche Sound through the Puerto Real Inlet on the eastern end of it. This inlet is considered to be predominantly a marine area due to the net flow of the Gulf of Mexico oceanic waters into the lagoon, and because there is very little fresh water influence. This is where the highest values of salinity are recorded distributed particularly in the oriental portion of the lagoon, with variable boundaries according to the different climatic periods.

e) El Carmen Inlet

The El Carmen Inlet is on the western section of Terminos Lagoon. It is a zone which is both influenced by fresh water from the adjacent fluvial-lagoon systems and by the Gulf of Mexico oceanic waters. In their work, Mancilla Peraza and Vargas Flores (1980) and Graham *et al.* (1981) show a net flow of sea water that enters through Puerto Real Inlet and discharges into the sea through EI Carmen Inlet. Because of this it presents variable characteristics that depend on the time of the year, even though estuarine conditions prevail. During the rainy season, fresh water conditions stand out, but during the dry season saltier conditions prevails.

Biodiversity and Habitat Types

Coastal and Submerged Vegetation

The region of Terminos has more than 250,000 hectares of mangroves all interconnected by natural canals and waterways. The area boasts trees of more than 30m in height in excellent health. With the exception of Candelaria, the other rivers draining into the lagoon maintain their vitality and harbor a significant number of birds, fish populations that sustain thousands of fishermen, and large oyster reefs. All four species reported for Mexico are present in Terminos: *Rizhopora mangle* or red mangrove on the margins of rivers, lagoons and coast, on soils usually flooded; *Laguncularia racemosa* or white mangrove found over flooded soils with high salinity levels; *Avicennia germinans* or black mangrove over sandy soils that are flooded only during parts of the year or in years of maximum precipitation; *Conocarpus erecta* or botoncillo over mostly sandy and clay soils with low salinity that are occasionally flooded during the rainy season. An estimated 106,000 hectares of pure mangrove stands have been recorded in the last land use study done for the area (EPOMEX, 2004). Productivity of phytoplankton and mangroves is higher in riverine areas. Benthic populations are related to subsystems in the lagoon and are controlled by salinity, river flow, turbidity and sediment types.

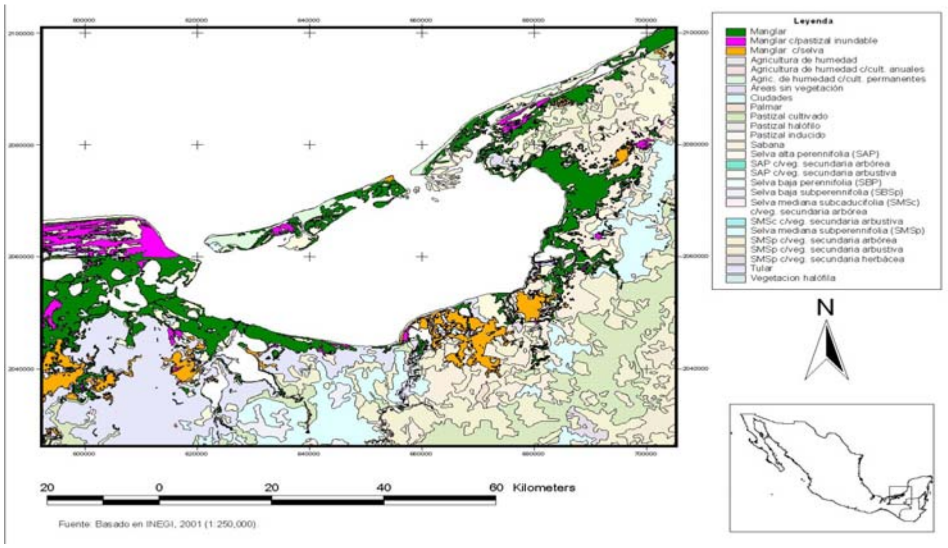


Figure 19. Map depicting distribution and location of Mangrove Systems in the Laguna de Terminos. Experts Workshop during Conservation Area Planning in May, 2004.

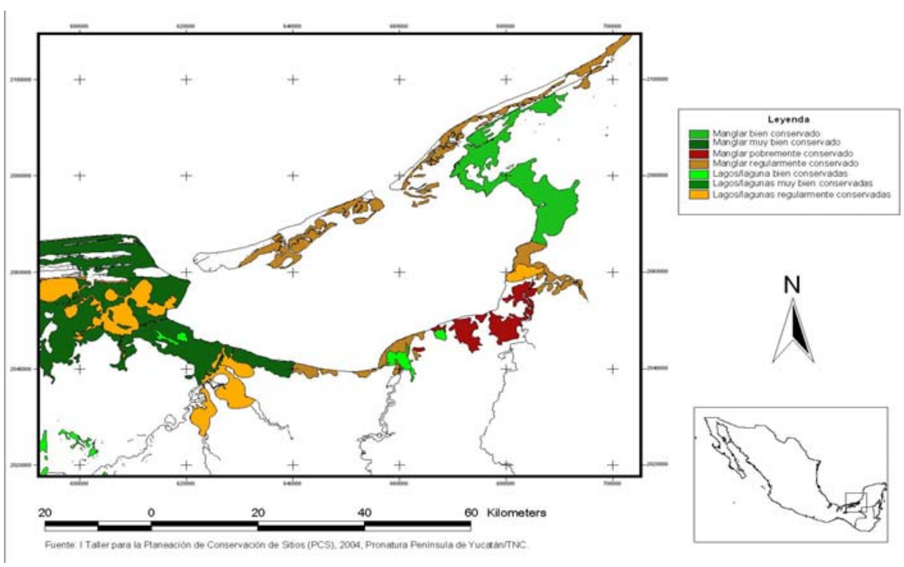


Figure 20. Map depicting distribution and location of Mangroves in the Laguna de Terminos with indications as to their viability or condition per review by experts during Conservation Area Planning in May, 2004.

Mangrove forests play an important role in the functioning of tropical coastal systems. Mangrove forests tend to be net exporters of organic matter. In Mexico very few studies have been done on mangrove forests and there is evident lack of ecological studies mainly from the functional aspects point of view.

Since the lagoon is almost completely surrounded by mangrove forests, the mangroves are a significant part of the lagoon ecosystem. According to a mangrove study by Day et al. (1980), *Rhizophora mangle* was the dominant tree in areas close but not in the riverine system per se. As the riverine influence is more pronounced the dominating species turns to *Avicennia germinans*. *Laguncularia racemosa* has a more even distribution from shore to inland and from site to site.

Submerged Aquatic Vegetation (SAV) can be found all around the Laguna de Terminos. There is evident relation between salinity gradients, freshwater inputs and the distribution of SAVs. Calla lily, *Eichornia crassipes*, cover large extensions toward the higher portion of the Palizada-del Este System. Rush marsh fields (*Typha* sp), as well as fields of reeds (*Phragmites*) can be found in those systems, being most abundant in the Palizada-del Este System. Other types of vegetation submerged in waters with low salinity values are *Vallisneria americana, Myriophylum exalbescens* and *Potamogeton illinoensis.*

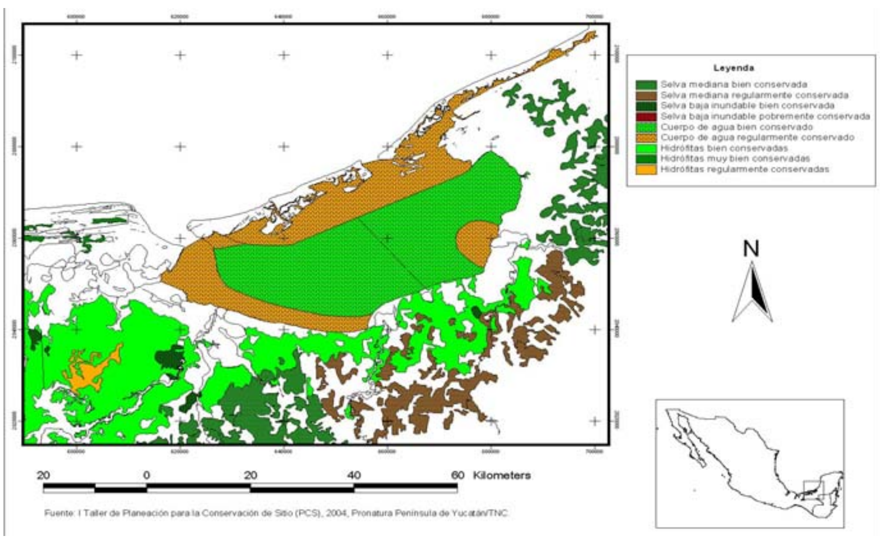


Figure 21. Map depicting distribution and location of Submerged Aquatic Vegetation and Surrounding Inundation Influenced vegetation in Laguna de Terminos Experts during Conservation Area Planning in May, 2004.

The **seagrass communities** within Terminos Lagoon have been demonstrated as playing a key role in maintenance of high productivity in the region. Seagrass communities in Terminos Lagoon are dominated by *Thalassia testudinum* Konig with two other species, *Halodule wrightii* Aschers and *Syringodium filiforme* Kutz occurring occasionally. Vegetation distribution is a function of water transparency and CaCo3 content in the sediments. In clear waters seagrasses are abundant: *Thalassia testudinum, Halodule wrightii* and *Syringodium filiforme*

The macrophytes are distributed primarily along the lagoon shoreline of Carmen Island, through the floodtide delta at Puerto Real and along the littoral zone of the eastern and southeastern lagoon shorelines. These regions are characterized by the highest water transparencies, salinities and percent calcium carbonates in the sediments. *Halodule* occurs on the shallowest flats while *Thalassia* extends to depths of 3 m. Greatest standing crops, leaf lengths and widths of *Thalassia* occur at depths between 1.0 and 2.0 m. Densities decrease with depth while ratios of aboveground to belowground biomass increase.

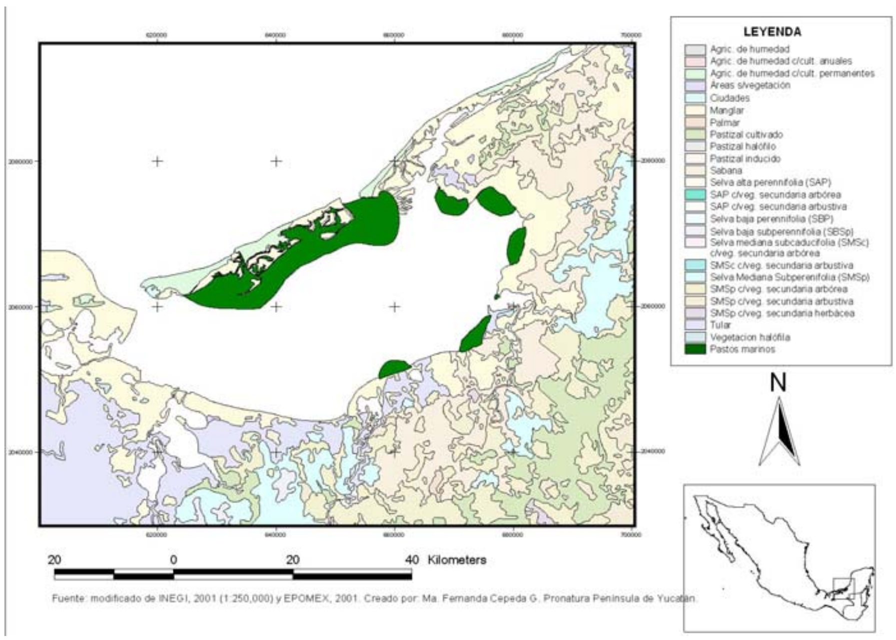


Figure 24. Map depicting distribution and location of seagrass beds in the Laguna de Terminos. Experts during Conservation Area Planning in May, 2004.

Extensive **oysters reefs** are located near the river mouths. The main species is the European oyster *Crassostrea* sp. In general these reefs are mainly found in areas of brackish waters along the fluvial-lagoon sub-system. Along the Mexican coasts a total of 16 oyster species belonging to *Ostrea* and *Crassostrea* genera are known, at present the three most important commercial species belong to *Crassostrea* genus. Reports on the ecology of most of the species in the genus *Crassostrea* (Department of Policy and Economics, 2003). salinity ranges are 20-27ppt. Salinities less than 10 ppt throughout the spring and summer inhibit spawning and reduce larval survival, resulting in poor spatfall. When salinities are mostly greater than 15 ppt, spatfall may be abundant but survival may be poor because of increased fouling, predation and disease.
The water bottom should be firm to support the cultch and prevent the attached oysters from sinking and being smothered by sediment.

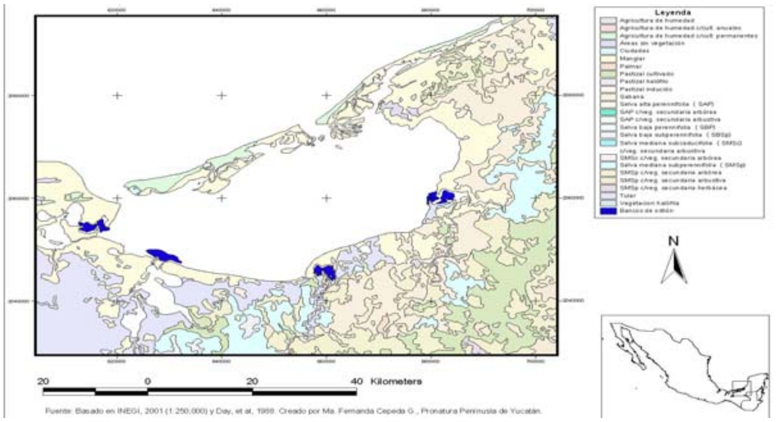


Figure 26. Map depicting reported oyster reefs in Laguna de Terminos. Experts during Conservation Area Planning in May, 2004.

Interior lagoons associated with rivers and characterized by three bivalve species that make up a commercially important community. Lagoons joined to Terminos Lagoon where naturally occurring reefs of American Oyster and their typically associated community are found. The main lagoon central basin where eight species of gastropods and nine bivalve species constitute the mollusk community.

The **Benthos** of the lagoon reflects the circulation and sediment patterns. Specifically the micromolluska are typical of saline bays and nearshore areas and are really more related to open-ocean assemblages than to those in a closed bay. There is a pattern of distribution, diversity and frequency and it is possible to identify and characterize five faunal assemblages, highly correlated with salinity, substrate and primary producers in the different habitats: a) limnetic areas; b) fluvial-lagoon systems; c) inner lagoon; d) central basin and e) marine-influenced areas.

The species of commercial importance associated with these are: *Rangia* sp. in fluvial-lagoon sub-systems; *Crassostrea virginica* in inner lagoons (Pantanos); *Crassostrea rhizophora, Melongena melongena, Pleuroploca gigantea, and Strombus alatus* in marine influenced areas.

Numerous marine and estuarine species of decapoda occur in Terminos Lagoon. The dominant species are those that can be termed slow-swimming like *Callinectes similes, C. sapidus,* and *C. bocourti* as well as four species of penaeid shrimp, *Penaeus setiferus* which is the most abundant in the southwestern area of the lagoon (fluvial-lagoon sub-system), *P. aztecus* in the west side near Carmen Inlet, *P. duorarum* in the east side of the lagoon near Puerto Real Inlet, and *Xiphopenaeus kroyeri* in the western side and in Carmen Inlet. The studies indicate that migration into the lagoon occurs through both inlets but mainly through Carmen Inlet.

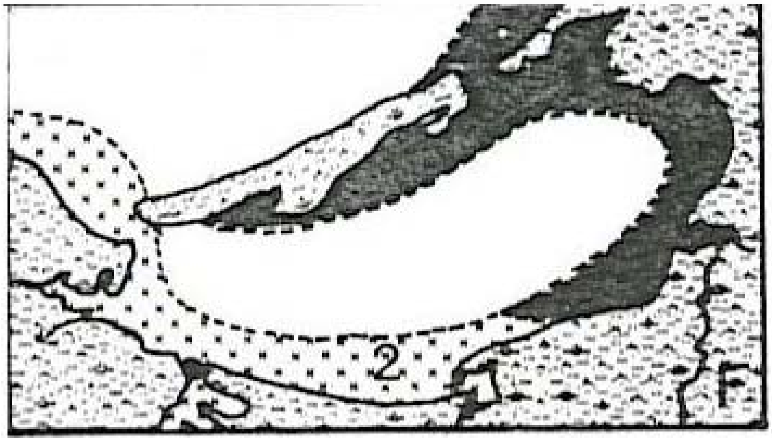


Figure 30. Map depicting Main Distribution of Penaeid Shrimp in Terminos Lagoon. 1) *Penaeus duorarum* an area of marine influence and 2) *P. setiferus* in the area of fluvial-lagoon/riverine influence (Day and Yáñez-Arancibia, 1988).

Even though there is no commercial fishing in the Terminos Lagoon, these two shrimp species are shrimp caught by the industrial fishing occurring just outside the lagoon in the Campeche Sound. This would lead to indicate a clear connection between the lagoon and the fishing grounds (for reproductive or trophic needs of these species). The continental shelf (Campeche Sound) is one of the most important fishery areas in the western central Atlantic region. Campeche Sound (Tabasco/ Campeche) contributes 34% of the total Mexican fishery yield in the Gulf and Caribbean coasts. The Terminos Lagoon ecosystem, including wetlands, marshes, open waters, and estuarine inlets, and its areas of influence towards the Tabasco/Campeche shelf have a minimum potential fisheries estimated in 15,000 ton/year of penaeid shrimp, 13,000 ton/year of mollusks (oysters, cuttlefishes, squid, and snails), 16,000 ton/year of demersal fishes (snappers, grunts, groupers), 100,000 ton/year of pelagic fishes, 6,000 ton/year of sharks and rays, and 6,000 ton/year of fin-fishes.

Results for the 1973-1985 period show that the fishery harvest and the area of Terminos Lagoon are strongly related to freshwater input and physiography; intertidal area is correlated to coastal land slope, length of coastline occupied by the estuary, and inshore open water area; the area of emergent vegetation is related to intertidal areas, rainfall, and river flow; fisheries yield per unit open water is highly correlated to river discharge (r=0.98).

Nekton are a very important component of the fauna of Terminos Lagoon, as well as the Campeche Sound. In studying the ecology of 121 fish species Yáñez-Arancibia et al. (1980) found that 12 species (10%) were permanent residents; 55 species (4 found that 12 species (10%) were permanent residents; 55 species (45%) used the lagoon as a nursery; and 55 species (45%) were occasional visitors probably associated with trophic needs or reproductive cycles.

Ecological analyses and nekton diversity, biomass, distribution, patterns of habitat utilization, and migration from the sea to freshwater marches to the lagoon showed six specific ichthyofaunistic assemblages for specific habitats. This indicates an ecologically complex system in which ecosystem relationships between protected waters and the offshore zone are evident through at least five ecological patterns of fish-habitat utilization.

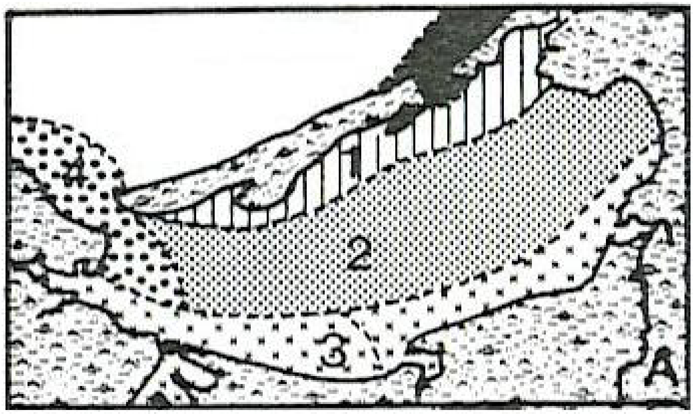


Figure 31. Map depicting Habitats described in terms of different environmental parameters and sets of ichthyofauna: 1) Internal Littoral of Carmen Island and seagrass; 2) Meso-haline Central Basin; 3) Fluvial-Lagoon Systems and areas of oligohaline influence; 4) Carmen Inlet; 5) Puerto Real Inlet (Day and Yáñez-Arancibia, 1988).

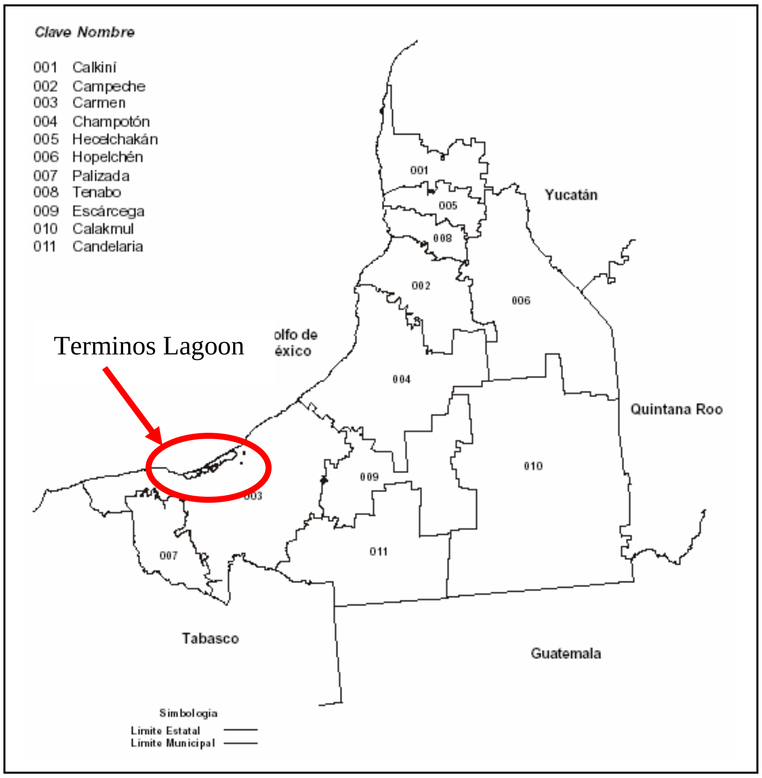
The most conspicuous fauna in the Terminos Lagoon are the **Birds**. The records for Terminos Lagoon (Programa de Manejo de Laguna de Terminos) indicate there are 49 families with 279 species in the complex. This area is considered to harbor at least during part of the year, 33% of the migratory birds moving along the Mississippi route using this area as feeding, sheltering and nesting habitat. Many of them are endangered and the most charismatic of these is the Jabiru Stork (*Jabiru micteria*). Recent studies indicate there are only 20 individuals left in Mexico. Other wetland birds and waterfowl like *Mycteria americana* (american stork), *Anas acuta*, *Anas cyanoptera*, *Mareca americana*, *Aythya affinis*, *Amazona albífrons* and *Chlorocere sp* among others.

In terms of other fauna, the **Reptiles** found in this area are essentially associated with the freshwater wetlands of “Pantanos de Centla” on the western part of the Terminos Lagoon. Here significant populations of caiman (*Caiman crocodilus*) have been reported. This area holds areas where hawksbill turtle (*Eretmochelys imbricata*) and white turtle (*Chelonia mydas*) nest in the beaches of Terminos Lagoon. Because they are threatened species they hold special concern both for the Mexican authorities as well as world conservationists.
Even though they are not easily seen, there are various **Mammal** species that use the Terminos Lagoon. Among them are dolphins (*Tursiops truncatus*) in the inlets connecting the lagoon with the Gula of Mexico oceanic waters. Other mammal species found here are more associated with wetland habitats specifically the “Pantanos de Centla” are otters (*Lutra longicaudis*) and manatee (*Trichechus manatus*).

1.3 Trends in the human uses and impacts upon the estuary

The Laguna de Terminos reserve is located principally within the municipalities of Carmen and Palizada. Their combined population in 1995 was 163,204 and in 2000 180,477.[13] Considerable additional socio-economic information is available online through the National Geography Institute web site.

Figure 7 Municipalities around the Laguna de Terminos and its lower watersheds. Source:



Mexico National Geography Institute,INEGI, Census Map Boundaries, 2000 Census.

The Terminos Lagoon has been an important center of trade and a military outpost used by the Mayans and Chontals well before the colonial era. There are numerous archeological sites of importance on the coast and along the tributary rivers. The region was abandoned after the terrible destruction and loss of indigenous life in the conquest period. Carmen became an important center for Scot, British and Irish pirates in 1558.[14]

At least three boom and bust periods can be identified to describe in broad terms the fascinating, centuries long history of interactions between people and the natural resources of the region.

The export of **"palo de tinte",** *Haematoxullum campechianum*, a thorny tree used to produce ink from a coloring agent, hematoxylin,; began in the earliest colonial times up to the start of the 20th

[13] Estado de Campeche. Sistema estatal de informacion estadistica, geografica y socio-economico. Fuente: INEGI Conteo de Poblacion y Vivienda 1995 y XII Censo General de Poblacion y Vivienda 2000.
[14] Leriche Guzman

century. The trees were logged throughout much of the Terminos watershed, as it grows primarily in flat terrain with clayey soils, deficient drainage, and periodic flooding[15].   This major economic activity was undermined in Europe by the development of aniline dyes and subsequent protectionist trade policy preventing imports of the natural dye. Chicle and other tropical timbers had also been transported from the interior watersheds to the port of Carmen. The 1900s to the 1940s was a period of dramatic economic decline in the Terminos region as no economic activity emerged to take the place of logging.

Fisheries had always been important in the Terminos, but the **era of commercial fisheries** began in earnest when the Mexican government declared shrimp fisheries as the exclusive domain of national fishers organized into cooperatives in 1940. Conflicts with U.S. fishers increased in the 1940s, who brought in technology, frozen shrimp packing and as a result dominated the Mexican fishery through various subterfuges. As various species and stocks of shrimp were discovered, booms cleaned out in succession the white, brown and the "camaron gigante", notwithstanding various, largely ineffective measures to build and maintain the Mexican fishing industry in the face of overfishing, complex organizational problems and dramatically fluctuating prices.

During this same era, much native landscape vegetation was replaced by coconut palm for export production. This also eventually failed, but is a contributing factor to a changed landscape.

In 1954 a Mexican journalist wrote:

> "we have the disgrace of two identical histories, with identical outcomes. When the exploitation of *palo tinte* and precious hardwoods and chicle all ended, all that remained was a wave of vice and misery. Now we know that the enormous economic value of the fisheries, measured in millions, flowed for the most part to foreigners, and our municipality only ended up with the leftovers.[16]

The **era of petroleum development** in the Gulf of Mexico began in the 1970s. Petroleros Mexicanas, or PEMEX, is the state-owned enterprise established to develop, refine, market and export Mexican oil. The environmental damage and social conflicts generated by the early decades of its development, including the dramatic urbanization of the Ciudad de Carmen, is in large measure what led to the declaration of the Terminos Reserve and the Centla Biosphere Reserves in the early 1990s. Oil and gas supplies are expected to last no more than two or three more decades, at which point the regional economy of the Terminos will have to shift again. Investments by the government in agriculture are considered ineffective and unprofitable and not seen as a viable solution to the region’s poverty.

Observers agree that the region of Terminos is ill prepared to face yet another cross-road in the long cycles of boom and bust. The Atlas of the Terminos Lagoon uses the phrase: *Laguna de Términos, a forgotten destiny* ...to characterize a region that has been largely left out of the nation's economic development plans.

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[15] Niembro Rocas, A. no date.
[16] Leriche Guzman, p. 103.

> The region of Terminos...is starting the 21st century with a certain longing for nature's past abundance and without a clear vision of a sustainable economic future. At the same time, it is burdened with the pressing need to meet the social demands of farmers and fishers of the Atasta Peninsula, fulfilling the economic hopes of the fishers and residents of Carmen and the need to integrate the river communities which attract migrants from central and northern Mexico.[17]

1.4 What estuarine resources and activities are at risk?

The marine resources inside the Flora and Fauna Reserve are largely protected, but some illegal fishing still takes place. Rapid growth of development and population on Isla del Carmen vastly outstrips the ability of the Reserve to address the multiple problems of an underserviced urban area. Water quality around the western part of the island are threatened by the inadequately treated waste water from the City of Carmen. Oil spills from offshore wells as well as operations inside the reserve remain a problem as well.

Mangrove forest stands throughout the Terminos are intact but also are impacted by some cutting and environmental changes, such as the continued sedimentation to the inner lagoons. Mangroves are also affected by having channels cut through them, water flow blocked by highways or even fishing gear that traps fish, but also sediment and debris. This affects circulation and sedimentation in the several small lagoons around the edges of the Terminos. Shore areas at the eastern mouth of the Terminos lagoon are eroding. Poor shore uses and "shore protection" devices are in fact cutting off of circulation to mangrove stands and damaging coastal dunes at the eastern end of Carmen Island and the mangroves and barrier spit associated with Estero Sabancuy on the eastern mainland of the Terminos.

1.5. What are the major management issues in the estuary? What is the perception of the importance of changes to FWI compared to other problems and opportunities in the estuary?

The Nature Conservancy, in its 2003 proposal to USAID to carry out new site assessments, summarized the situation in the Laguna de Terminos as follows:

> Immigration, petroleum operations, the declining resource base for traditional fishermen...these and other factors create social and political tensions and add to the complexities of the site. Land tenure within the Reserve is roughly 23% private, only 13% *ejido* land[18], with the rest being federal lands and waters.

It goes on to state that:

> Urbanization, poor wastewater management, industrialization, alteration of the hydrologic regime, agricultural and cattle production, petroleum extraction and fishing are likely to be the most important issues, all related to economic drivers in the protected area and the basins surrounding it.

[17] Labougle, p.43.
[18] Property managed in common by government recognized community level groups.

From the perspective of the Terminos Flora and Fauna reserve, three key thematic areas generate most of the concerns:

- **Managing natural resources** (flora and fauna, agricultural lands, cattle grazing pastures, forests)
- **Addressing social and economic development** (urban development, industry and infrastructure, and archeological resources)
- **Providing for public access and use** (tourism, public education, public involvement, and coordination)

Each of these is addressed in more detail below.

a. Managing natural resources

A key priority for managers is protecting endangered species, and their habitats. The species of most concern include the stork *Jabiru mycteria* , manatee, nutria, crocodiles, and marine as well as fresh water turtles. Reserve managers are also working to develop aquaculture and animal husbandry projects that switch people from capture to raising native species for food or sale. The reserve management program seeks to restore lost ecosystem functionality in the interior lagoons, which may involve freshwater quantity and timing issues, but also spans other dimensions tied to opening up water circulation, removing blockages and better understanding the unique factors which affect each local site

Small scale agriculture utilizes about 25 per cent of the area of the reserve, principally in the Atasta region to the west. Cattle ranching is carried out along the Palizada river and in the east in Sabancuy. Coconut palm and rice are grown on the Isla del Carmen and in the coastal watersheds along the southern reach of the reserve.

These rural fringe areas are adapted to the annual cycle of flooding. Changes in upper watershed land cover such as the Usumacinta, are thought to make the river flow changes respond quicker to rainfall in upper basin, due to faster runoff.[19]

A wide range of problems are generated by the types of agriculture practiced in the region. Fires are set to clear land, mangrove continues to be cut, and exotic plant and animal species continue to be introduced. The irrigation systems, rice for example, are said to be very inefficient, and this is compounded by inputs of fertilizers, medicines, pesticides and herbicides.

The Atasta penisula, which forms the western side of the Terminos Lagoon, has been a source of social unrest and conflict with the petroleum industry. An "Agreement for the sustainable development of Atasta" was signed in 1993. Local groups are organized, such as the Movement of Fishers and Farmers of the Peninsula of Atasta. There is a tradition of blockading roads to get "compensation" through public works, usually funded by PEMEX. The situation remains highly polarized as people express their opposition to petroleum industry, suffer from a scarcity of products for meeting basic needs, and are desperate for economic options to traditional activities such as fishing, seasonal agriculture, hunting and the short term work available in Ciudad de

[19] Personal communication with the Reserve director, April 2004.

Carmen. There is concern about pollution related illness, and a decline in fish and agricultural production.[20]

A PEMEX fund was created , FDESPA...Fund for Sustainable Development of the Peninsula of Atasta, around (1977?). Since then 130 projects have been financed for the benefit of 1,172 producers. Restoration projects are also underway to mitigate earlier damage.

The reserve management plan sets out a broad agenda of actions needed to deal with the difficulties faced by marginalized communities. Part of this involves local people in overseeing enforcement and implementation.

b. Addressing social and economic development impacts

Water pollution and uncontrolled land use and shore development are generated along Carmen Island, especially the western portion where the city and port are located. The reserve director indicates that these are not easily addressed through the reserve management plan, rather to be city plans and ordinances are required. A more thorough characterization of waste water sources and loads is needed.[21]

Extensive network of pipelines and land transport of chemicals and petroleum products link the exploration, production and processing zones of Chiapas, Campeche, Tabasco with port facilities located in the lagoons including Terminos.[22] There is a long history of controversy over oil and gas development and infrastructure in the coastal region, including the local residents of the villages scattered along the edges of small lagoons that feed the Terminos. Road access from petroleum development opens up pristine jungle to colonization, timber cutting, cattle ranching, drug trafficking.[23] Oil spills are said to be on the increase.[24]

Polarization of the remaining fishers and PEMEX persists. For example, in one of its recent informational brochures, PEMEX states that "Marine waters [in Campeche Sound] meet world environmental quality criteria and standards for the survival of aquatic organisms. Therefore the decline in fishing [in the sound] cannot be attributed to the oil sector's activities."[25]

Hurricane Damage and recuperation is important Candelaria region as well as the eastern inlet (Canal Guadalupe).[26] However, our field trip revealed appallingly bad shore protection and dune modification schemes being utilized along the northeastern coast of Isla del Carmen and along the estero Sabancuy.

More broadly speaking, in the Candelaria subregion of the National Water Commission's region XII, public health and sanitation is a key concern. The goal by 2025 is to be able to treat 100 percent of waste water compared to 75 percent by 2005. About half would be with wastewater treatment facilties, the other half with septic systems.

[20] Salazar, 2000. P 70.
[21] Programa XII p 73
[22] Toledo 39
[23] Toledo 40
[24] Toledo 46
[25] PEMEX. Support to Protected and Sensitive Areas Brochure. 2002.
[26] Programa Region XI p. 91. Castilla, I. 2001.

The reserve management plan calls for much more effective land use planning compatible with reserve goals. Since decisions on PEMEX activities are made at the federal level, there is a need for both coordination mechanisms and locally relevant decision making criteria when assessing project impacts. [27]

c. Public access, understanding and use

Toursim is viewed as an economically viable and locally supported development option for the future that would build support for conservation and wise use efforts. Public understanding and awareness of the significance of the Terminos lagoon is seen as vital by the reserve managers. The reserve plan integrates tourism development, public education and public involvement as vital ingredients for success. The completion of bridges on both ends of Carmen Island has greatly increased access to the region but not led to growth in tourism services and use. The potential needs to be accompanied by conventional tourism services concentrated on the Island and carefully regulated ecotourism for the reserve. The reserve management plan includes detailed regulations for the activities of ecotourism businesses and operations. It also recommends tailored education programs for people with small scale economic activities in the reserve, the agriculture and cattle ranching sector, loggers in the watershed, fishers, local industry and service providers, and the general public. The reserve plan also calls for sustaining the level of public involvement and consultation that was carried out during the period in the mid-1990s when the reserve was created and the management plan prepared.

1.6 What is the existing governance framework for the estuary?

The Laguna de Terminos is a federally designated wildlife and land reserve, or "Area de Protección de Flora y Fauna", celebrating its 10th year in 2004. Its boundaries incorporate portions of the lower watersheds of the Candelaria, Chumpon and Palizada, and it is adjacent to the biosphere reserve Pantanos de Centla. Both are operated by the National Parks Commission, CONANP.

The management plan includes a detailed zoning map for conservation and management. (Figure 8) The reserve has only five permanent staff, which greatly limits its ability to carry out enforcement and conduct the public outreach campaigns seen as vital for its success.

The municipality of Carmen has yet to develop a strong planning and zoning component for managing the city, which concentrates about two thirds of the region's population. The municipalities of Carmen and Palizada are not mentioned or featured much in the reserve plan although they factor into implementation of a variety of the policies and proposals. Civil society organizations, cooperatives and the main universities are more frequently mentioned as playing key roles.

[27] The municipality of Carmen is not mentioned in the reserve management plan and contact had not been made with officials during the first field reconnaissance trip in April, 2004.

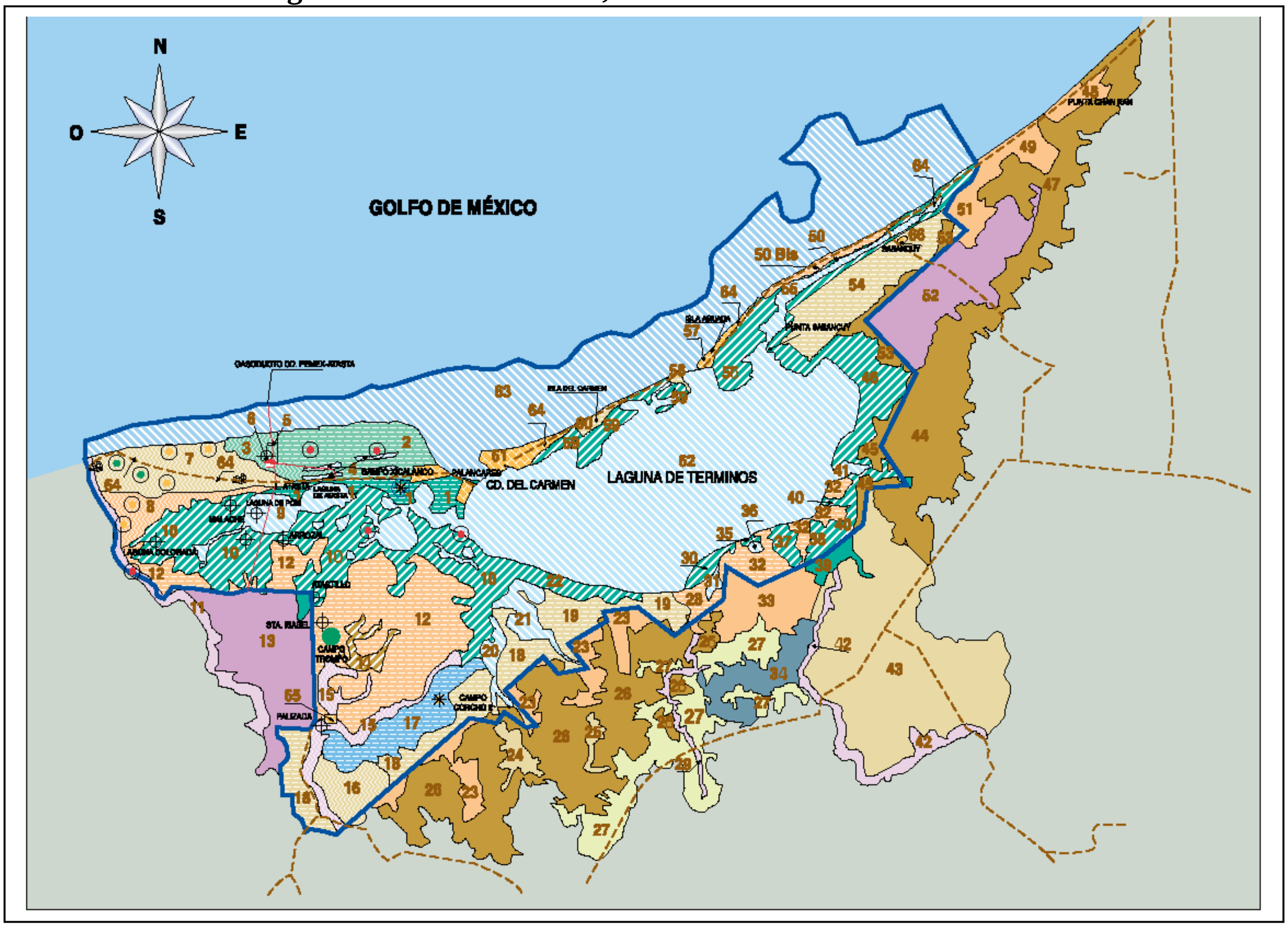
The Terminos reserve plan depends on numerous federal, state and non-governmental actors to carry out the 24 components of its plan. These are listed below in order of the number of components the actor is expected to contribute.

KEY ACTOR IN THE RESERVE MANAGEMENT PLAN	NUMBER OF ACTIONS
Mexican Secretary of Environment and Natural Resources, SEMARNAT:	23
The State of Campeche Development agency:	13
University of Carmen, Autonomous University of Mexico and University of Campeche:	12
Secretary of Agriculture, Livestock and Fisheries:	11
National Water Commission (CNA):	10
Secretary of Tourism (federal agency SECTUR):	10
Secretary of Agrarian Reform:	9
State Secretary of Education:	9
State Health Agency:	9
State Tourism Agency:	9
Federal Electricity Commission:	9
State Water Agency:	8
Secretary of the Navy:	7

Within the Mexico National Environment Agency, SEMARNAT, several line agencies play important roles in park plan implementation. For example the coastal zone agency, ZOFEMATAC, regulates the federal shore zone, while the park agency,CONANP, manages all national parks and reserves. The Terminos Lagoon and Pantanos de Centla reserves are in turn part of a unified, decentralized regional administrative structure. The Terminos reserve has its own director and a very small staff, which reports to its own Consultative Council. The National Water Agency, CNA has also decentralized some decisions to its regions. The Terminos Lagoon watershed crosses two major regions. The Yucatan Peninsula side is Region XII, and has its own water resources management plan and management office separate from Region XI, which is responsible for the Usumacinta watershed. (see below). Candelaria is a subregion within that scheme that pertains to the Terminos and its watersheds. There are also specialized working groups as well as watershed councils at different scales.

Efforts have been made to prepare regional environmental use and zoning plans for Campeche but were most likely not adopted. The Municipality of Carmen likely has some form of land development regulations, however the disorderly growth of the city as well as the barrier island continues to pose a major difficulty for the understaffed park.

Figure 8. Management policies for the Laguna de Terminos. Source: Terminos Lagoon Reserve Mangement Plan. CONANP, 1997.



Reserve Use Zoning Symbols

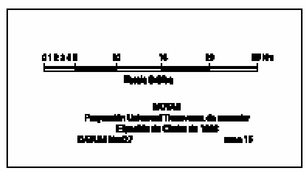
I. Highly restrictive, low use
II: Low intensity use,
III: High intensity use, and
IV: Urban areas.
V. Water bodies

Predominate landscape

Color	Feature
	Mangrove
	Popal and cattail
	Cattail
	Popal
	Jungle
	Pasture
	Fallow area
	Marine Area
	Water body
	Riverbed, floodplain
	Cultivated areas
	Human settlements
	Mangrove- pasture
	Vegetated coastal dunes

Symbols

- Boundary of reserve
- Population center
- Compressor station
- Paved road
- Oil pipe line
- Capped oil or gas well
- Gas production area
- Production suspended
- Gas field to be considered
- Approved well site
- Rejected well site
- Well site under study



As Figure 8 shows, The Reserve lands and water area are classified into four main types of use:

I. Highly restrictive,
II: Low intensity use,
III: High intensity use, and
IV: Urban areas.
V: open water bodies

Together these polygons represent a total of more than 60 distinct landscape and coastal feature zones, each with a specific set of use policies and restrictions drawn from a master list in the adopted management plan. This system of policies and land classification shares elements common to Mexico's state and regional environmental management plans (POETs, or *programas de ordenamiento territorial)*

2. What are the defining characteristics of the watershed?

2.1 Scale?

The Laguna de Terminos is the receiving estuarine water body for a drainage basin of approximately 49,700 square kilometers in the region of Mexico with the among the highest amounts of precipitation. (Figure 9) Four sub-basins are especially important as Table 1 illustrates. Nearly 80 per cent of this basin includes the watershed of the Usumacinta, which has a branch to Terminos Lagoon through the Palizada River. Sixteen percent of the watershed of the Candelaria, which is a major source of fresh water flow to the eastern portion of the lagoon is located in Guatemala. The Usumacinta watershed extends into neighboring states of Tabasco and Chiapas.

Statistics for the rivers discharging into Términos Lagoon. Source: Laura David, LOICZ. 2000.

	Palizada	Chumpon	Candelaria	Mamantel
Total Drainage Basin area (km2)	40,000*	2,000	7,160	540
% Gauged area	97	85	81	81
Adjusted Discharges (10^9 m3 yr-1)				
Mean	9.08	0.57	2.11	0.16
Minimum	3.63	0.01	0.64	0.07
Maximum	16.11	1.58	5.45	0.78
Average Drainage Basin Temp. (°C)	27	25	27	27
Annual Drainage Basin Rainfall (mm)	1,844	1,602	1,457	1,517
Df/r	0.24	0.23	0.18	0.27

* Including the entire Usumacinta drainage basin area.

There is frequent flooding that affects residents in low lying areas, sedimentation at the mouths of the rivers, and causing roads to wash out. This flooding period can last weeks or months.

2.2 Resources present and their condition?

The watersheds have high flora and fauna biodiversity, and have been a source of tropical lumber that has been exported since colonial times. Much of that original land cover has been lost, as well as considerable additional changes to tropical jungle landscape for agriculture. (Figure 10 is indicative of the available online information showing current land cover. The use categories are translated to the right of the original legend.

Figure 9 Regional precipitation patterns in the National Water Commission Region XII (Yucatan Peninsula). Average annual rainfall per year, in mm. Source**:** Comisión Nacional de Agua. 2003. Programa Hidráulico Regoinal 2002-2006 Región XII Península de Yucatán.

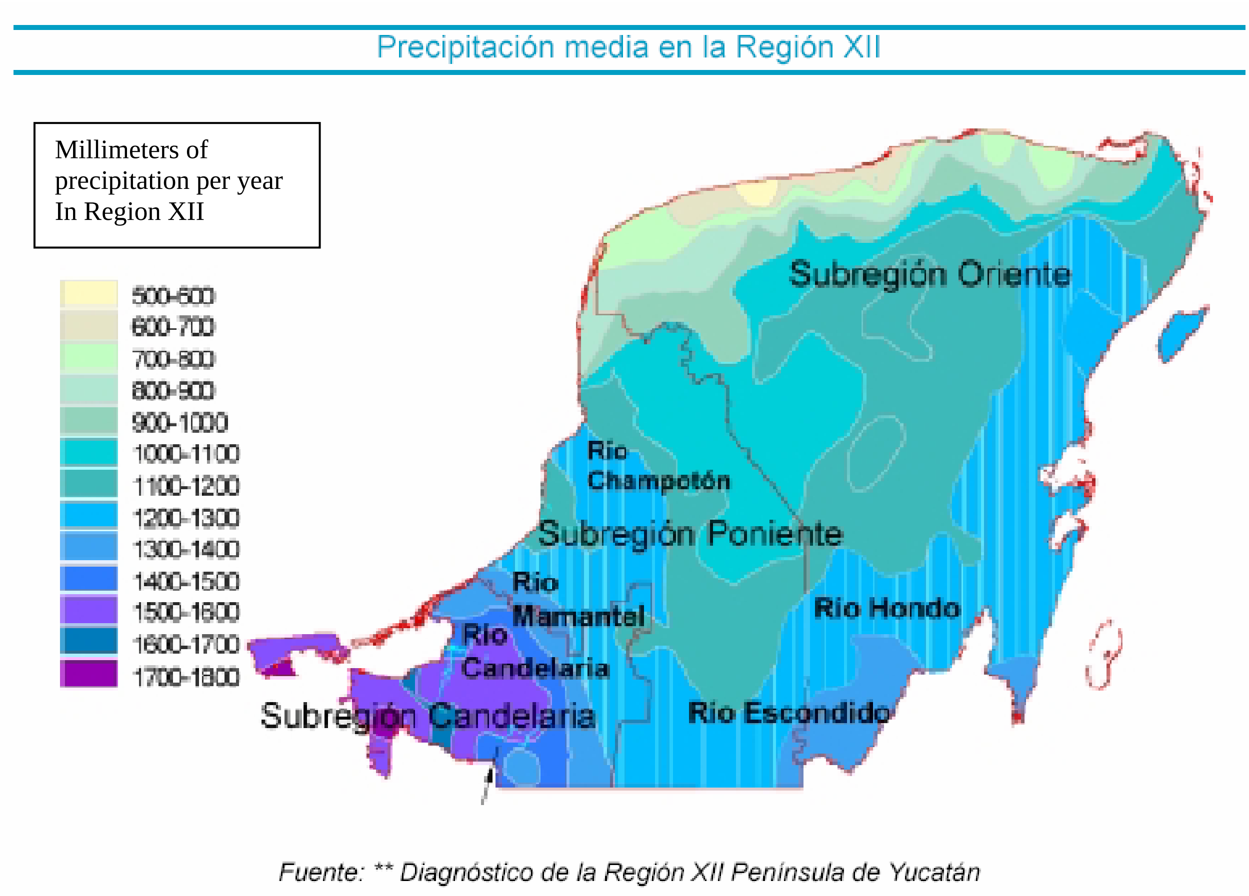
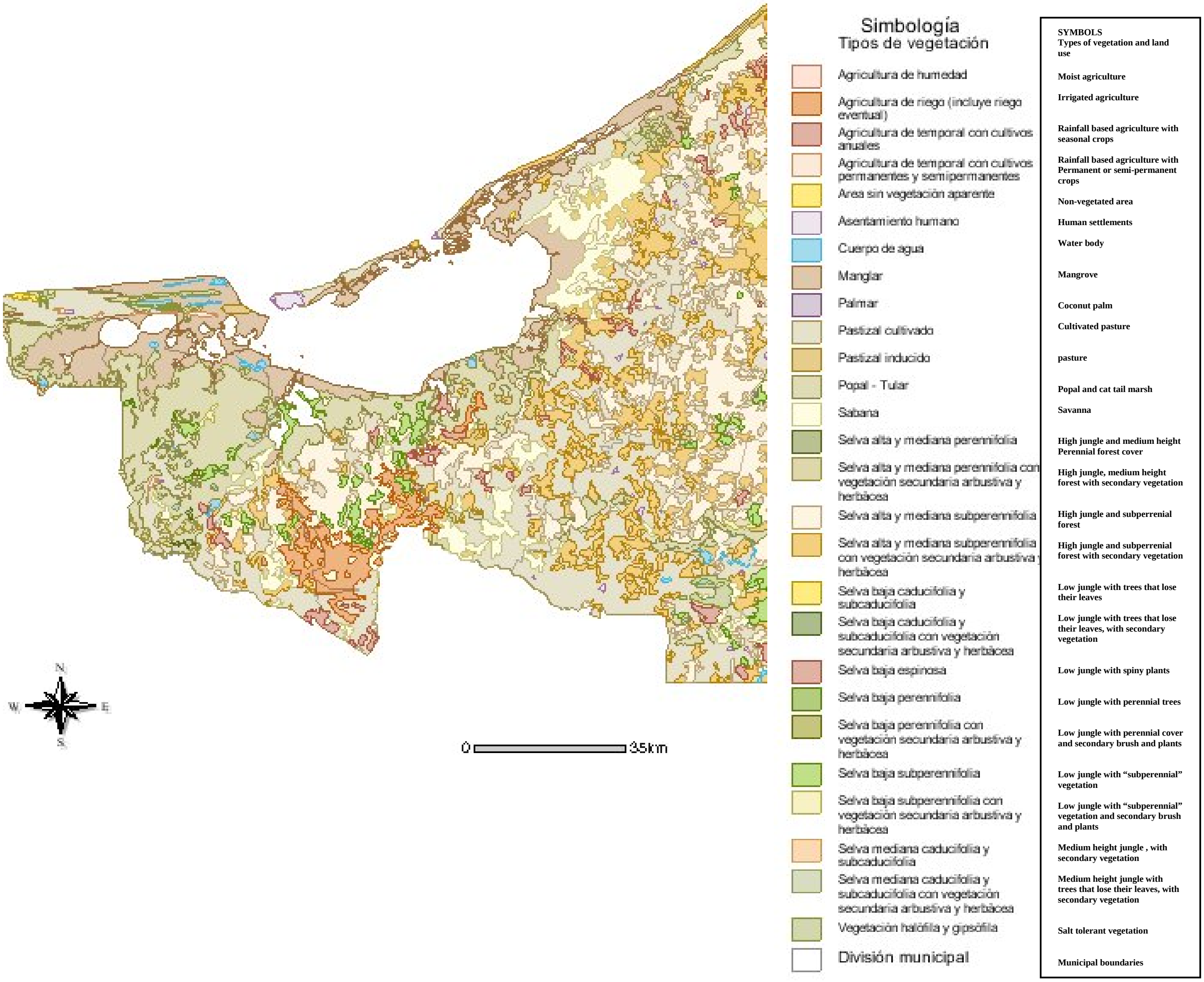


Figure 10 Existing land cover, State of Campeche. Source: State of Campeche, Secretary of Ecology, from online map server.



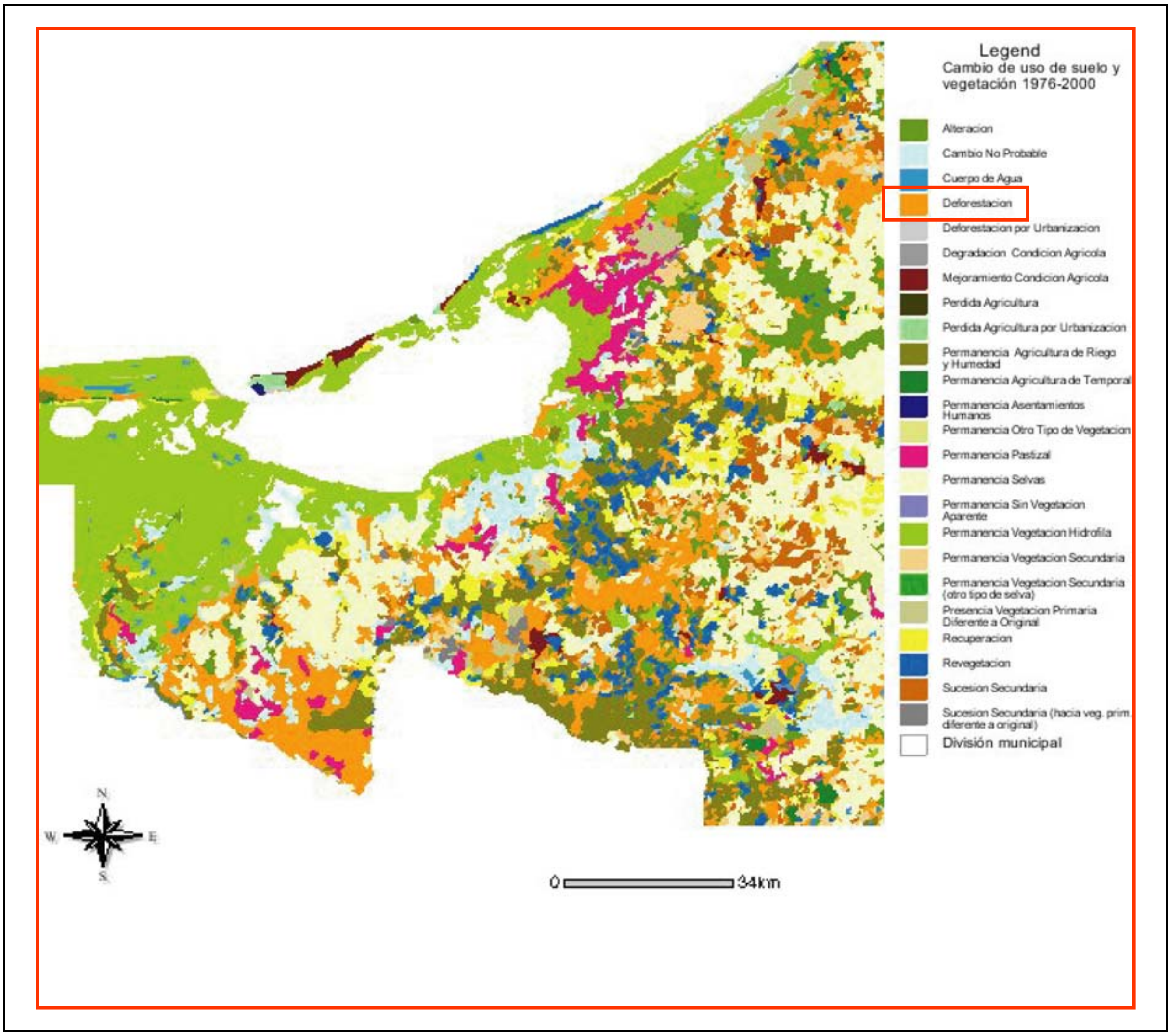


Figure 10 Change in land cover, State of Campeche, 1976-2000. Source: State of Campeche, Secretary of Ecology, from online map server. [28]

A key pattern has been continued deforestation and land cover change for agriculture and other development in the mid watersheds. The extensive light orange areas in Figure 11 show the dramatic extent of deforested lands in the past 25 years. The explosive growth of Carmen City, due to oil industry activities, and accelerated by the second bridge connecting to Villahermosa, has been another important trend.

A high proportion of the population living outside Carmen City in the muncipality of Carmen are very poor. Eighty per cent of the villages and 51% of the population outside the city live in areas with the highest rankings for "marginalization" (4 and 5 out of a scale of 1-5). These rural, isolated settlements by and large lack potable water, sewage, school facilities, and health

[28] Map information available on-line: http://www.ecologia.campeche.gob.mx/arcims/website/consulta-mapas.htm
Note: the GIS interface on this site may require the most recent version of Internet Explorer to work properly.

services. Sixty –three percent of the villages and 32% of the total population in Palizada endures similar conditions.[29]

There is an emerging concern that the original understanding of the Terminos as a large productive region with a strong river culture and close relationship to the environment, has been lost.

2.3 Trends in the human population and patterns of resource use?

The Subregion Candelaria, is the water resources planning area that surrounds the Laguna de Terminos. Located within the National Water Agency's Region XII,. 18,910 km2. Population in 2000 is 268,011 (this includes more than just Carmen and Palizada municipalities)

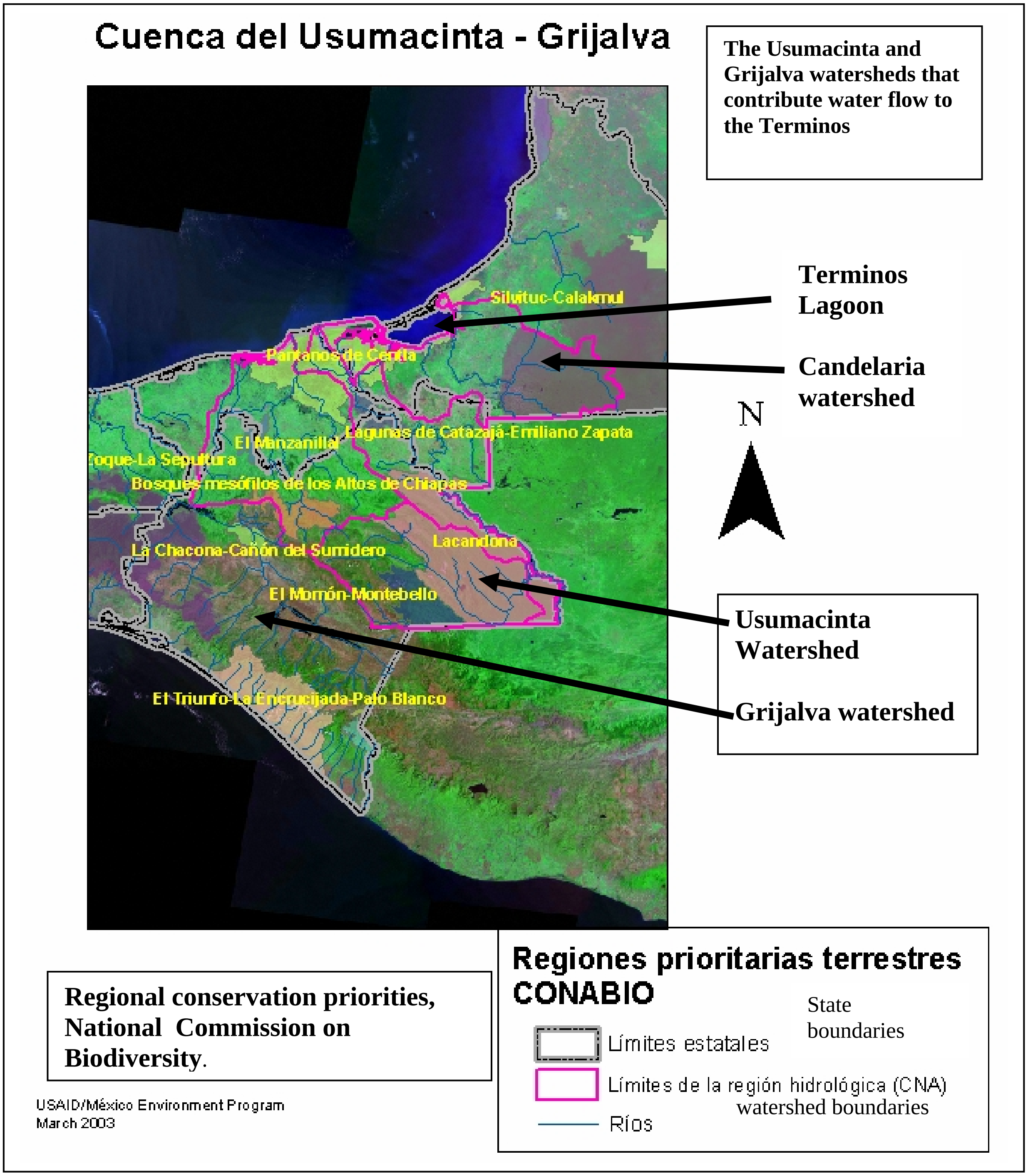
Projected population growth in this planning region are:

2005	2010	2015	2020	2025
303,903	336,137	366,364	394, 727	420,487[30]

Figure 12 shows the overall boundaries of the watersheds of Terminos. Data from the 2000 Census is available by municipality and village, and could be combined to characterize population characteristics in more detail in response to specific questions.

[29] SEDESOL, Campeche. Data for localities is from 1995, calculations by the author.
[30] Programa Region XII p 36

Figure 12 The location of the Usumacinta and Grijalva watersheds that contribute to Terminos Lagoon. Source: USAID Mexico.



2.4 What are the major management issues in the watershed? How important is water use and allocation compared to other social and environmental issues?

The Nature Conservancy, in its proposal to USAID Mexico for funding of its current work in the Terminos and Centla reserves, observed the following:

> Rice production in the Candelaria, for example, changes the water inflows to Laguna de Términos; slash and burn agriculture upland from the site deteriorates primary forests, and the transformation of land use to cattle pasture close to river banks accelerates erosion and sedimentation of stream systems.

The National Water Commission Region XII management program identified the following issues of concern in the watersheds feeding the Terminos:

> Opening of land for agriculture, logging of old forests, infrastructure construction has had a major impact on the watershed. Use of agrochemicals has some effect as well.
>
> Petroleum industry has had an impact, frequent oil spills or breaks in pipelines that create land spills that reach the lagoon. This is why the Terminos is a protected area.[31]
>
> Cited for its high biodiversity, brackish water organisms, aquatic mammals, very high productivity due to nutrients from Chumpán, Mamantel, Candelaria and Palizada. Shrimp and oysters.[32]

A major hydroelectric project, the Boca del Cerro, has been proposed for the Upper Usumacinta watershed. It has been put forward and then deferred numerous times in the past two decades. Its main objective is to generate 4300 Megawatts of hydroelectric power, which is expected to replace 250,000 barrels of fuel oil per year. A second element of the project is a water diversion canal, the Balancan, to transfer flood waters to the Laguna de Terminos.

According to the Third Millenium Project[33], a private initiative to promote development in Mexico:

> "the Boca del Cerro Project, would be located 9.5 kilometers southwest from Tenosique, Tabasco. It would have a 130 meters-high dam creating an artificial lake formed by the 19 550-million cubic meters reservoir. The dam generating power of electricity would be 4 200 megawatts for a 17 400 million kilowatt-hours production (the 67% of hydropower in Mexico, it can save 29 million of fuel-oil barrels).
>
> The project would allow Mexican and Guatemalan countries to undertake industrial, commercial, and tourism development, with all of its social and economic benefits including employment, housing, agriculture and cattle raising, navigation, roads, environmental and ecology protection.
>
> Also, it would set the basis for a future electric interconnection of Central America and Colombia with the Mexican national electricity network."

---

[31] Programa XII, p. 57
[32] Programa XII p 64.
[33] Frias, 2003.

According to the proposal, which is virtually the only publicly available statement that specifies hydrology modifications to the watershed, the joining of Boca del Cerro Project systems with the Balancan diverting canal, would transfer the Usumacinta river flow quantities to Laguna de Terminos, permitting the generation 1 250 million kilowatt-hours in a additional low-head hydropower plant. This proposal is tied to the extensive program of flood control related to the Usumacinta and Grijalva rivers in the state of Tabasco. The proposal claims that the northern and eastern regions of Tabasco, and the southwest of Campeche would both receive significant economic benefits, and permit the construction of much needed sewerage treatment facilities, increase navigation and transportation in the river system and allow for reclaiming of over one million hectares of lands apt for agriculture and cattle raising. Also, it would create large areas for aquaculture development.

2.5 What are the issues raised by an initial river ecosystem flow requirements?

Alejandro Toledo examined the case of the Usumacinta and Grijalva watersheds to illustrate the important connections between rivers, coasts and oceans in Mexico. His summary points give a good overview of the challenges facing the four watersheds contributing to the Terminos estuary

Toledo identifies changes in natural river flow patters and sedimentation of river beds as the most serious issue:

> *...dams constructed to regulate the flows, control flooding and generate electricity...interfere with transport of sediment, affect the process of soil formation and obstruct the critical ecological functions of transport of nutrients and minerals to flood plains, coasts and the highly productive marine zones. .*[34]

The second key issue is the accelerating loss of vegetative cover in the upper watersheds, caused by unplanned and uncontrolled logging, a shift to cattle ranching and agriculture including the cultivation of illegal drugs. In Toledo's view this amounts to "an ecological and social disaster causing irreversible loss to future generations who will live in and have to earn a living from its products".

A third environmental service in jeopardy is the region's soils. In the case of the Grijalva-Usumacinta, 89% of Tabasco's soils are affected by extreme erosion. [35]

Toledo identifies the deterioration of the agricultural, urban and water resources management infrastructure as a fourth issue of concern. Dams are already suffering from sedimentation, and irrigation systems are highly inefficient. Water supply systems suffer similar inefficiencies and are not financially self-sufficient, in the face of a growing, under-serviced urban population and dispersed rural villages.

Water pollution and other sources of contamination affect the watersheds as well. Urban and rural wastewater is discharged largely without treatment and there are few properly designed facilities for handling solid waste, especially the toxic and dangerous materials. For the

[34] Toledo, p. 91 et. seq.
[35] Toledo, p. 93.

Terminos and its tributary rivers, the petroleum industry has long been the principal concern, along with industrial waste in urban effluents, and agrochemicals.

Finally, and perhaps most importantly from the human perspective, is the overarching concern of poverty, marginalization and social inequality evident in the watershed region. As noted in the earlier discussion of the estuary, large extensions of municipalities such as Carmen and Palizada have a high proportion of villages with elevated to extreme levels of marginalization.

Toledo concludes: *The marked differences between the rich biological diversity of the watersheds, and the conditions of poverty and marginalization of the rural and indigenous populations represents a negative balance, in terms of the outcomes of modernization policies undertaken in the region.* The last observation of his passionate and blunt assessment of the situation in the watersheds of southern Mexico is that the costs of this process of modernization have been disproportionately borne by rural and indigenous people.

2.6 What is the existing governance framework for the watershed?

Water use decisions remain centralized in Mexico City. Land use management and controls, on the other hand are left to lower layers of government which have less technical and political ability to make decisions. An attempt to create a regional land plan for the Terminos region was not completed.

The National Water Commission is the federal agency responsible for decision making and managing Mexico's water resources. The overall complex of watersheds, the mega-delta and coastal lagoons spans two of its regional districts, Region XI and Region XII. Overall water management programs have been prepared for both regions. These plans cover a wide range of topics including water supply, agricultural irrigation, water rights, flood control, electricity production, waste and waste water management. The perspective is both national and development oriented, with water seen as a natural resource to be utilized to promote economic development.

Portions of the watershed are shared with Guatemala, plus the adjoining states of Yucatan, Campeche and Tabasco. The National Water Commission (CNA) makes major decisions on water allocation and management. The region XI and XII watershed councils do function, but their operations are not yet focused on decision making or implementation. Consultation processes address mainly sectoral issues, and attempts to carry out integrated, area-wide approaches are rare, especially as they might require consultation across the water shed councils.

Major Environmental Impact Assessments, mostly water projects and PEMEX (Mexican Petroleum Company) decisions also are made at the federal level. There is relatively little local technical capacity to evaluate and make binding decisions on projects which more complex and higher potential impact.

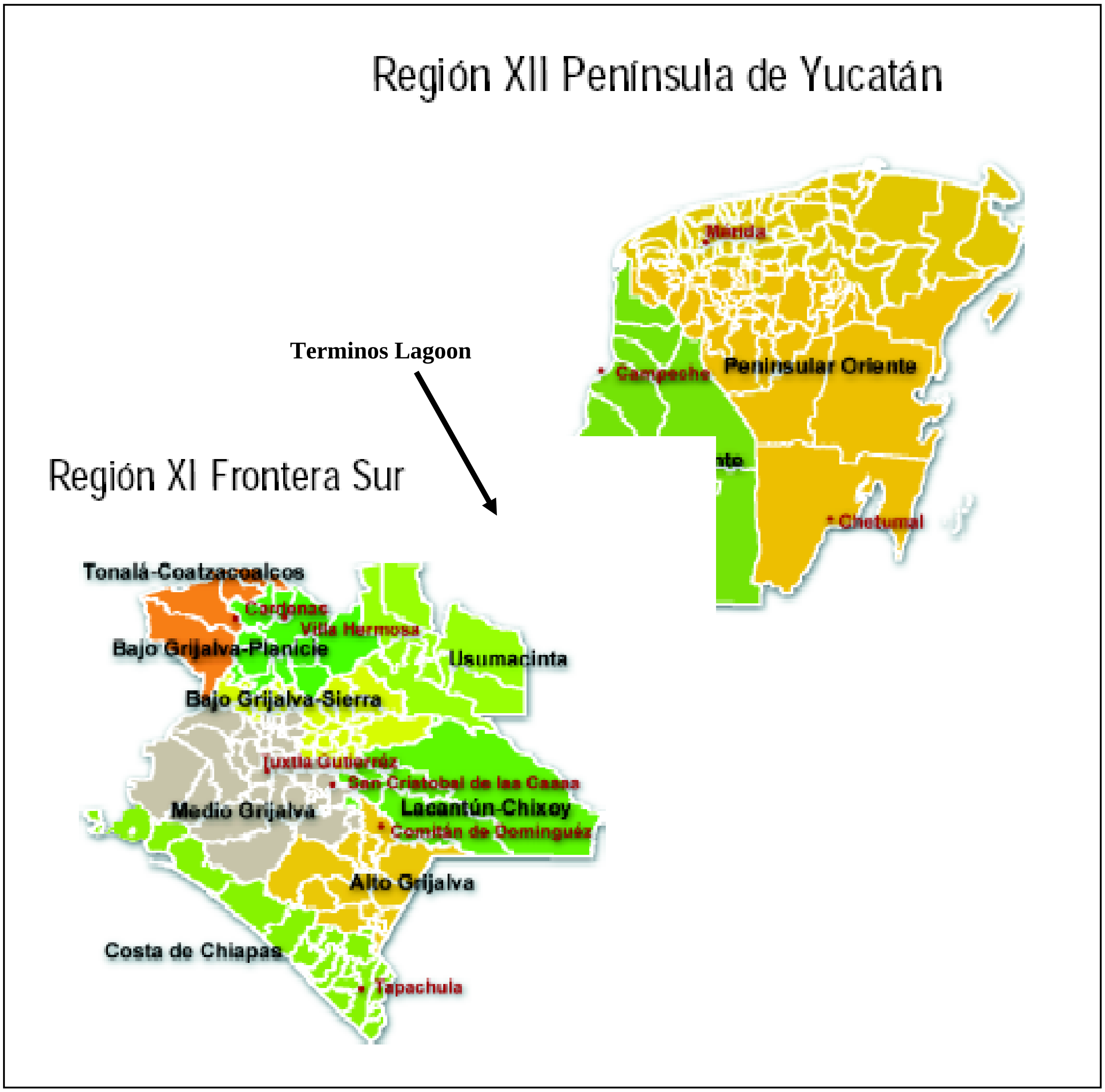


Figure 13 The watersheds of the Terminos Lagoon are managed by two separate regions of the National Water Commission. Region XII has three subregions (Terminos is within the Candelaria), while Region XI has eight (Terminos borders on the Usumacinta subregion). Source: Comisíon Nacional de Agua, Programa Nacional. 2003.

Status of FWI Issues

1. How has FW been managed in the past and what outcomes have been the result?
2. What changes in the quantity, timing and quality of FW inflows are anticipated?
3. What are the causes of such anticipated change?
4. What impacts have been foreseen?

- social and economic costs and benefits?
- environmental consequences?
- challenges for the governance system?

.5. What information/analysis is available on the anticipated change to FWI?

Feasibility of Analysis from Remote Sensing?

What are the sources of data?

What scales and what time series?

Can remotely sensed data be the basis for an initial water balance?

Can available remote sensing contribute to understanding change in this watershed/estuary system?

What other analysis of existing data can provide low cost methods for estimating FW inflow change?

Initial Analysis of Water Management Issues

Develop an initial water budget for the estuary

Characterize the salinity structure of the estuary

Characterize the river flow regime

Develop simple conceptual models for the influence of water flow on key ecosystem features

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