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A SUSTAINABLE SHRIMP MARICULTURE INDUSTRY FOR ECUADOR

Edited by Stephen Olsen and Luis Arriaga

International Coastal Resources Management Project

The University of Rhode Island

Environmental Issues

Impacts of Shrimp Mariculture Practices on the Ecology of Coastal Ecosystems in Ecuador

Análisis del Ecosistema del Estuario del Río Guayas en el Ecuador: Implicaciones para el Manejo de Manglares y la Maricultura del Camarón.

Robert R. Twilley

Resumen

La expansión de la construcción de piscinas para el cultivo del camarón en la zona intermareal ha causado el mayor cambio en el uso del suelo en el área costera. Este crecimiento, en su mayor parte, está ubicado en las provincias de Guayas y El Oro. El mayor río y más importante sistema estuarino de la costa fluye a través de estas provincias hacia el Golfo de Guayaquil. El Golfo y los estuarios adyacentes constituyen el ecosistema estuarino mayor de la costa occidental de Sudamérica. La descarga media del río Guayas es de 1.143,7 m^3/s, con amplias variaciones estacionales que van desde un promedio de 200 m^3/s en la época seca hasta unos1.600 m/s, en la estación lluviosa.

El cultivo del camarón en esta área, se halla influenciado por algunas actividades también en expansión, como la agricultura, exploración de petróleo, desarrollo urbano y pesquerías.

Basándose en la densidad de siembra de postlarvas (pls) por hectárea (ha), los métodos de cultivo son clasificados en: (a) extensivo (siembra de 10.000 - 20.000 pls/ha; rendimientos de 100-400 Kg/ha/año); (b) semi-extensivo (50.000 - 60.000 pls/ha con suplemento alimenticio; obtiene doble producción a la del método extensivo); y, (c) semi-intensivo (100.000 pls/ha; con suplemento alimenticio o fertilización; rendimientos 1.000 - 1.800 Kg/ha).

La existencia de la amplia zona de manglares en la provincia del Guayas (121.464 ha) ha sido atribuída a un gran aporte de la Cuenca del Guayas y a las altas tasas de evapo-transpiración. Esto, asociado a la frecuencia de mareas, ha creado las condiciones fovarables para desarrollo del manglar con densidades de 185 árboles/ha y una área basal de 62,4 m^2, lo que indica mejores condiciones que en Venezuela, Colombia, Malasia y Puerto Rico.

En el estuario del Guayas, la calidad del agua está influenciada por las aportaciones provenientes de la Cuenca del Río Guayas, el intercambio con la zona intermareal y los procesos oceanográficos físicos del Golfo.

El trabajo revisa la influencia de la industria de la maricultura del camarón en la calidad del agua, estimando que la cantidad de agua de recambio entre los esteros y las piscinas, mediante bombeo, es de $20x10^6m^3$ por día, (30.000 has de piscina, tasa de recambio 5%/día), volumen que es tan grande como la descarga del río Guayas durante el período de estiaje. Esto, asociado a la evaporación en las piscinas, indica una gran descarga de aguas hipersalinas en el estuario.

Se discute el efecto de la calidad del agua en el cultivo del camarón y los factores que influyen en la producción como son: pérdidas de manglar; salinización del agua en los esteros; futura operación de la presa Daule-Peripa; enriquesimiento excesivo de nutrientes y posterior anoxia; presencia de sustancias tóxicas como hidrocarburos, pesticidas y metales pesados. También, se realiza un análisis global, desde el punto de vista ecológico, de las interacciones entre la industria del cultivo del camarón y el estuario del río Guayas, especialmente referidas a factores asociados a la calidad del agua, incluyendo las descargas de aguas residuales domésticas e industriales, el incremento de bombeo de agua, la fertilización en las piscinas y perturbaciones climáticos como las originadas en el evento de El Niño.

Las recomendaciones del autor comprenden: efectuar el inventario de la pérdida de manglares; distribución actual del bosque de manglar para identificar impactos actuales y futuros; restauración e integración del manglar en las operaciones de las camaroneras, para control de la erosión, estabilización de sedimentos y tratamiento de efluentes en las camaroneras; estudios sobre balance hídrico en el estuario del Guayas; desarrollar un modelo sobre la calidad del agua para el ecosistema del estuario; establecer un programa para vigilancia de la calidad del agua.

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Introduction

The Incas practiced mariculture in Ecuador 400 years ago by closing off lagoons which were temporarily flooded with seawater and penaeid shrimp larvae. While the Indian shrimp farmers used their harvests themselves, the rapid growth of mariculture as an industry over the last decade in Ecuador has made it the leading farm shrimp producer in the world (McPadden, 1985). The first commercial shrimp operations did not begin there until 1969 (Siddall et al., 1985), and by 1979 farming produced only 4,698 metric tons (m.t.) of shrimp compared to 7,787 m.t. caught at sea. Ecuadorian farmed shrimp production rose dramatically from 1979 to 1984; in 1983, the year of the highest production on record, shrimp ponds produced 29,100 m.t. while production from the sea remained at 7,500 m.t. The export value of the total tonnage in 1983, nearly triple the amount produced in 1979, was U.S. $183 million, ranking shrimp second only to petroleum as an export commodity for Ecuador.

The expansion of the farmed shrimp industry resulting in the construction of ponds within the intertidal zone has caused a major change in coastal land use. Initially shrimp ponds were constructed in more inland, barren intertidal areas (salinas). Locating the ponds closer to the shore lowers costs associated with supplying water and larvae to the ponds. From 1980 to 1984 nearly 10,000 hectares (ha) of ponds were authorized for construction annually, increasing the total to 60,000 ha by 1983 (Figure 1). A recent survey by CLIRSEN (1984) shows that there are currently 89,368 ha of shrimp ponds along the coast of Ecuador (Table 1), many occupying former mangrove habitats.

This expansion of the farmed shrimp industry has been largely confined to the two southern coastal provinces, Guayas and El Oro (Table 1). The largest river and estuarine ecosystem of the coastal lowlands, the Guayas River basin and estuary, flows through these provinces and into the Gulf of Guayaquil. The Gulf of Guayaquil and adjacent estuaries are the largest estuarine ecosystem on the western Pacific coast of South America (Cucalon, 1984). This ecosystem handles 95 percent of the country's imports and 50 percent of its exports, and its coastline includes the most populated city in Ecuador, Guayaquil (Engineering Journal, 1972). The shrimp farming industry developed in an area of the coastal zone that is influenced by several other expanding industries including agriculture, oil exploration, urban development, and coastal fisheries. In addition, this region maintains an extensive area of intertidal communities including nearly 83 percent of all mangroves in Ecuador (Table 1).

One of the major reasons that farmed shrimp production has not returned to high levels observed in 1983 is reduced availability of postlarvae (PL) for stocking ponds. Total production in shrimp was down in 1984 compared to the previous year, not only because of low catch rates in the trawl fishery, but also because of the lack of larvae for shrimp ponds during the second half of the year. It is estimated that during 1985, only half (30,000-40,000 ha) of the shrimp ponds constructed in the Guayas province were in operation because of the lack of postlarvae. The 4 billion postlarvae provided largely by the "laveros" (primarily push net fishermen) represented an annual stocking rate of about 133,000 postlarvae per ha of pond or about 65,000 postlarvae per ha per season, based on two harvests per year. This is fairly intensive mariculture and production rates per ha of pond seem to be decreasing. However, such calculations are tenuous since information on the quality of shrimp sold and the area of ponds actually in operation is somewhat confusing.

Several factors have been associated with the decline of postlarvae in the estuaries along the coast of Ecuador, including lower water temperatures following an El Niño event in 1982-83, loss of mangrove habitat, decline in water quality and overfishing. Poorer water quality has contributed to increase in disease and poor maturation of postlarvae, and lower growth rates and higher mortality of wild shrimp, which affect the availability of wild postlarvae as well as the survival of larvae transported to growout ponds.

Coastal resource management to sustain optimum levels of productivity is complicated by conflicting goals of diverse user groups. Changes in watershed land use and utilization of estuarine waters have prompted concern over possible negative impacts to the quality of coastal resources and resultant damage to the shrimp industry. Also, construction and operation of the shrimp industry itself have raised concerns about its negative impact on the coastal zone.

This paper will show the interactions of various economic enterprises and environmental resources, and will recommend elements for an integrative management scheme for the coastal zone of Ecuador.

Geography

The coastal zone of Ecuador (1^oN to $3^o20's$) consists of four coastal provinces (Esmeraldas, Manabi, Guayas, and El Oro) situated in 284,000 km^2 of lowlands between the Pacific Ocean and the Andean highland (Figure 2). There are three climatic zones along the coast: a moderately wet climate in the south with abundant fresh water from runoff around Guayaquil; an arid central province with very sparse vegetation; and, in the north near Esmeraldas, a more humid, tropical zone with abundant rainfall and runoff. More than 95 percent of the annual precipitation falls during the wet season from January to May (Stevenson, 1981), and varies from less than 500 mm in the central provinces and the coast of the southern provinces to over 3000 mm at Santo Domingo de las Colorados in the north (Engineer Journal, 1972; Schaeffer-Novelli, 1983). Annual mean temperatures (from 24.2^o to 27^o C) vary little along the coast, thus potential evapotranspiration is about 1300 mm per year.

The two major river and estuarine ecosystems of the coast are Rio Esmeraldas in the north and the Rio Guayas which flows into the Gulf of Guayaquil in the south (Figure 2). The Gulf of Guayaquil receives runoff from some 20 rivers with a watershed of 51,230 km^2, equivalent to a watershed: water surface area ratio of 4.3. The Guayas River is the major source of fresh water to the Gulf, which forms 60 km inland at the confluence of Rio Daule and Rio Babahoyo. This fresh water enters the Rio Guayas estuary, and to a lesser extent the Estero Salado, around the city of Guayaquil and then flows 55 km to the Gulf of Guayaquil. The mean discharge of 1143.7 m^3/s for the Guayas river is the highest among the 30 rivers in the coastal zone of Ecuador, representing 39 percent of the total discharge from this lowland region. Mean precipitation in the Guayas River drainage system north of Guayaquil is 885 mm/yr, which may range from less than 400 mm to more than 1800 mm during any one year (Figure 3). Discharge is strongly seasonal ranging from 200 m^3/s during the dry season to 1600 m^3/s in an average wet season (Figure 3). Tides are semi-diurnal and are of equal amplitude (1.8 m) in the Gulf of Guayaquil, but are amplified to 3-5 m in the Rio Guayas estuary near the city of Guayaquil. Flushing time of the Gulf of Guayaquil is about 21 days.

Shrimp Mariculture Management

The methods of shrimp mariculture in the intertidal zone are grouped into three classifications based on the densities of juvenile shrimp stocked in the ponds. Extensive mariculture, using a stocking density of 10,000-20,000 juveniles per hectare (ha), relies little on further supplements from seawater exchange via pumping or from artificial fertilization. Predators are present and annual yields are relatively low at 100-400 kg/ha. An increase in stocking rates to 50,000-60,000* juveniles per ha is a semi-extensive system that requires some supplemental feeding and exchange of seawater to control water quality problems such as decreased levels of dissolved oxygen. Production rates more than double with this program. The most highly managed system is semi-intensive operations that stock ponds at 100,000* juveniles per ha and supply food supplements or fertilize the ponds to increase sources of food. Water exchange with the estuary is higher and annual production rates increase to 1,000-1,800 kg/ha.

The dramatic expansion of the farmed shrimp industry and increased levels of pond management stimulated the development of a new fishery to provide postlarvae and seed shrimp for stocking mariculture ponds. Industry sources estimated that up to 90,000 artisanal fisherman were involved in the 1983 harvest and in 1984 numbers of fishermen working along the coast were even higher (McPadden, 1985). Seed fishing is concentrated in areas of significant fresh water discharge along the coastline, such as El Oro and Esmeraldas, with the highest effort occurring in the Guayas province.

The catches are non-selective, with small fish, penaeid postlarvae and juvenile shrimp including a mixture of *P. vannamei, P. stylirostris, P. occidentalis* and *P. californiensis,* as well as some fresh water *Carid* species. Since only the former two species survive best in mariculture ponds, owners pay according to the proportion of the stock that is *P. vannamei* and *P. stylirostris* (McPadden, 1985). Selection is a post-harvest process and therefore less-valued species are lost from the estuary. The peak of the seed fishing season is from December to March when fisherman may take up to 40,000 postlarvae a day at a size ranging from 7-10 mm.

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* Villalon et al. (this volume) report slightly higher stocking densities.

A major factor associated with the availability of immature shrimp is temperature of offshore water. Temperatures are controlled by the mixture of warm water flowing southward from the Panama Bight with cold waters flowing northward from the Peruvian Humboldt Current. This mixing occurs between Manta and Punta Santo Elena along the coast of Ecuador and gradually moves southward into the Gulf of Guayaquil. The southerly flowing water causes increase in seawater temperature and initiates the onset of the rainy season (Cucalon, this volume; Cucalon, 1984; McPadden, 1985).

Years of abnormally warm water temperatures and high rainfall are associated with El Niño events and have resulted in the explosive populations of white shrimp off the coast of Ecuador. The high availability of postlarvae that supported the expansion of the shrimp industry in 1983 and 1984 has been associated with these offshore processes (Cucalon, this volume).

Reclamation of Mangroves

Eight species of mangroves are distributed along a narrow band of the outer intertidal zone of Ecuador with a non-vegetated area called "salinas" (salt flats) in more inland intertidal areas (Table 2). The existence of 121,464 ha of mangrove in the Guayas province has been attributed to extensive river flow from the Guayas River basin and high rates of evapotranspiration (Schaeffer-Novelli, 1983).

The seaward intertidal zone is colonized by species of mangroves in the *Rhizophoraceae* family, with *Rhizophora harisonii* on the perimeter of the shoreline and mixtures of the other species inland of this zone (Cintron et al., 1981). More inland of this fringe is a mixed zone of *Rhizophora* and *Avicennia germinans*. Still farther inland lies a monospecific stand of *Avicennia*, which yields eventually to shrub plants or Salinas with extreme hypersaline soil conditions. High tidal frequency and river discharge create conditions suitable for mangrove forest structures in the northern provinces with tree density of 185/ha and a basal area of 62.4 m^2/ha. This density is greater than for mangroves in Venezuela, Columbia, Malaysia and Puerto Rico (Cintron, 1981). Mangrove forests are less dense in the southern provinces (Cintron, 1981), particularly surrounding shrimp ponds (Snedaker et al., 1986).

The most obvious exploitation of mangroves along the coastal zone of Ecuador is the construction of ponds for the production of shrimp and fish. This land use pattern in the intertidal zone first involved wholesale destruction of mangroves in Machala and in the southern province of El Oro. Following this period of total mangrove destruction, pond construction was authorized mainly in the Salinas and inland mangrove zones. However, as the area of pond construction increased dramatically in the early 1980s, less of this unvegetated intertidal area was available and mangroves were again heavily impacted by the mariculture industry. Recently, there has been a decree that prohibits new authorization of ponds in mangroves. Several thousand hectares of ponds have already been authorized in the intertidal zone, though construction in many instances has not yet begun.

The exact number of mangroves lost to the construction of ponds along the coastal province of Ecuador is uncertain. A recent survey from CLIRSEN (1984) shows that 79,396 ha or 88.8 percent of the total area of shrimp ponds along the coast of Ecuador is located in the two southern provinces of Guayas and El Oro (Table 1). A diagram representing the potential loss of mangroves based on proportion of ponds constructed in mangrove areas is shown in Figure 4. This diagram demonstrates that if all 52,912 ha of shrimp ponds in Guayas province (Table 1) were built in mangrove areas, the original mangrove area would have been 174,375 ha, and mangrove loss would be 30.3 percent of the resource. At a utilization rate of 10 percent of ponds built in mangroves, the loss of mangrove habitat would be 4.2 percent.

Historical records of the southern coast of the Gulf of Guayaquil in the province of El Oro at Machala give some indication as to the proportion of mangroves used for the construction of ponds (Table 3). From 1966 to 1977 there were 834.2 ha of ponds constructed and, based on the loss of mangroves during this period, 55 percent of these ponds were built in mangrove habitats. This estimate is probably exaggerated since urban areas also apparently increased at the expense of mangroves. If urban expansion was equally divided between salinas and mangroves, then 45 percent of the ponds constructed in this period would have been in mangroves.

From 1977 to 1982, an additional 1496.5 ha of ponds were built, however, there was no corresponding loss of salinas and mangroves. Rather, decreased land use for agriculture was observed, which could account for the additional pond construction and urban expansion. However, assuming that all of the mangrove loss was from pond construction, then 63 percent of the ponds were constructed in mangrove habitats. Based on this range of 45-63 percent of pond construction in mangrove habitat in El

Oro, an estimated 16-21 percent+ of the mangrove in the Guayas province may have been lost to shrimp farming. Recent estimates by CLIRSEN indicate that mangrove loss in the Guayas Province is much less, at about 4 percent+ of the original mangrove cover. This would mean that about 10 percent of the shrimp ponds constructed in this province were built in mangrove (Figure 4).

Factors Influencing Water Quality

Water quality of the Guayas River estuary is influenced by inputs from the watershed, exchanges with the intertidal zone, and physical oceanographic processes in the Gulf of Guayaquil. Activities in the watershed include a dam project that will influence fresh water input, expanding agriculture with associated discharge of chemicals including nutrients and pesticides, sewage from increased urbanization, and toxic substances from industrial activities (Arriaga, this volume). Exchange of estuarine water with the intertidal zone via tides has been replaced with diesel pumps that pump water to improve the productivity of grow-out ponds. Natural resources within the intertidal zone, including mangrove, may also influence water quality, though the function of these communities is still uncertain. Offshore waters influence the temperature and salinity of the Guayas River estuary, most notably during El Niño events and during presence of red tides in coastal waters. These diverse natural and anthropogenic influences on water quality in the estuary complicate water quality management in this coastal ecosystem.

Daule-Peripa River Dam Project

A dam is proposed at the confluence of the Daule and Peripa rivers for water supplies, control of river flow, and hydroelectric power. Water will be diverted with an aqueduct from the Rio Daule to the Santa Elena peninsula for potable water, irrigation for agriculture and industrial use. The dam will also increase the flow of fresh water to the Guayas River estuary during the dry season to prevent salt water intrusion in the lower Daule River and enhance agriculture in this area. The Rio Daule drains one-third of the Guayas River basin and has a mean capacity flow of 11.5 km^3/yr or 365 m^3/s. The total river basin of both the Daule and Peripa Rivers is 420,000 ha and it receives a mean precipitation of 1800 mm per year. A thorough description of the soil characteristics and land use of this watershed are provided in a report by the Guayas River Basin Commission (CEDEGE, 1970).

The dam will create an impoundment with a storage capacity of 6.0 km^3 of water with a surface area of 270 km^2, mean depth of 21 m and volume of 5.4 km^3. The impoundment will supply potable water for 300,000 people at 400 liters per person per day, irrigation water for 42,000 ha of land and 20 million cubic meters per year for industry. Projected industrial use includes a petroleum refinery, nitrogen fertilizer complex, petrochemical complex, and a petrochemical port facility at Monteverde.

The dam will influence the amount of water from the Daule and Peripa Rivers that normally discharge into the Guayas River. Presently the proposed operation of the dam calls for an average annual flow of from 100 to 175 m^3/s (Jenkins, 1979; Arriaga, this volume). This flow will vary from a high of 321 m^3/s during the wet season in April, to a low of 124 m^3/s in August. Compared to the normal flow of the Daule and Peripa Rivers (Figure 5), this modified flow is much lower than the fresh water discharge of up to 1000 m^3/s that usually occurs during the wet season. During the dry season, to control salt water intrusion, the dam will provide water above the average discharge of about 50 m^3/s from supplies stored in the impoundment. Based on average monthly flows, the normal discharge of 343 m^3/s for these two rivers will be restricted to 175 m^3/s, a reduction of about 49 percent (Figure 5). This reduction represents a loss of 15 percent of the fresh water to the Guayas River and 13 percent from the Guayas River estuary. The loss of fresh water from an estuary in a semiarid zone such as the Guayas province may influence the patterns of salinity in the ecosystem.

+ Alvarez et al. (this volume) report slightly different percentages of mangrove loss for 1986-1984.

Nutrient Loading

Sources of nutrients from watersheds to aquatic ecosystems may be described as either diffuse or from some specific point of effluent. Diffuse nutrient inputs include runoff from natural vegetation or from managed landscapes such as agriculture or forestry areas. Much research has gone into developing nutrient loading rates for different types of native vegetation and for specific types of crops in watersheds in various geographic areas. Most of these loading rates have been developed for watersheds located in temperate climates. Less is known about the loss of nutrients from tropical watersheds.

The five principle crops raised along the coast of Ecuador are bananas, rice, sugar cane, cacao, and coffee (Filho, 1983). These agricultural products come primarily from the Guayas lowlands, situated north and east of the city of Guayaquil, and along the eastern shore of the Gulf of Guayaquil (Table 4). Statistics for the Guayas and Los Rios provinces have been combined to represent agricultural activity in the Guayas River basin. Over 50 percent of the agricultural activity described in Table 4 for the coastal zone of Ecuador occurs in the Guayas River basin.

The Guayas River basin is a major producer of rice, with nearly 95 percent of the total rice production along the coast occurring in the Guayas and Los Rios provinces. Rice in the Guayas River basin is of particular significance to the nutrient economy of the Guayas River estuary because of the large area of production (Table 5), the potential expansion of this crop in the watershed once the Daule-Peripa dam is completed (projected at 17,000 ha during the initial phase of the project), and its proximity to waterways.

Point Source Inputs

Point source effluents are associated with urban areas and industry. However, nutrient waste from urban centers can also be diffuse loadings via groundwater transport from septic systems. Loading rates of nutrients from cities are dependent on population density and degree of waste treatment prior to discharge into aquatic systems. In the Guayas River basin, there is very little treatment of domestic waste. Sewage is either released directly to the rivers or estuaries via ditches (referred to as "treated"), or is diverted to septic ponds. Thus nutrient loading from point sources in this watershed is largely related to population density and per capita rates of nutrient input from untreated sewage.

The population in the coastal provinces of Ecuador has increased over the past 35 years, most dramatically in the Guayas province (Figure 6). From 1962 to 1982 the population of this province more than doubled to over 2,000,000 persons. In the last several years, the growth rate has been even greater with a present population of over 2,568,452 (Figure 6). Together with the population of Los Rios, there are 3.14 million people in the Guayas River basin (Figure 6), of which 84 percent is considered urban, with 53 percent of the basin population located in the vicinity of Guayaquil. Currently, only 18 percent of the 34,700 ha city is serviced by sewers. The city's contaminated waters are emptied, untreated, into the Guayas River (El Guasmo pumping station), Daule River (El Progreso pumping station), and Estero Salado.

Initial estimates of the impact of urban waste on the quality of water in the rivers and estuaries of the southern coastal zone of Ecuador are listed in Table 6. These estimates are for the major population centers along the waterways of the Guayas River basin (including the Guayas and Los Rios provinces), and include a total population of 1.7 million people, or 54 percent of the watershed population.

Treated sewage here refers to sewage which is transported directly to the rivers and estuaries, whereas untreated sewage is transported to septic ponds. From the available statistics, waste from 62 percent of the population is pumped to septic ponds (untreated), however, 86 percent of the 54.83 (10)6m^3 of waste generated annually is discharged directly to aquatic ecosystems. Based on these population statistics and per capita rates for each treatment, the loading rates for oxygen demand (biological and chemical), solids (total and dissolved), and nutrients (total nitrogen and phosphorus) have been calculated. This preliminary analysis indicates that the city of Guayaquil discharges over 90 percent of all domestic wastes that enter the river, and an even greater percentage of the nutrients that enter the Guayas River estuary. Solorzano (this volume) claims that domestic and industrial waste has lowered water quality in the Daule and Guayas Rivers by contributing to a high level of bacterial contamination, decreasing dissolved oxygen content and increasing concentration of nutrients.

River Discharge

Rates of nutrient input from rivers discharging into the Guayas River estuary and Estero Salado may be estimated from information on seasonal concentrations relative to periods of high and low river flow (Figure 7). Ammonium concentrations above 15 ug-at/L occur in three of the four rivers surveyed and concentrations as high as 40 ug-at/ occurred in the Rio Milagro. These high concentrations occurred during the low flow season, and thus do not necessarily indicate high input to the Guayas River estuary. However, peak nitrite and nitrate concentrations with values greater than 2.0 and 50.0 ug-at/, respectively, occurred in all the rivers from February to June during periods of high river flow (see Figure 3 for seasonal river flow in the Guayas River basin). The pattern for nitrate was common among the river systems investigated, indicating that this may represent a high input of nitrogen to the estuary (Figure 7). Concentrations of nitrite above 2.0 ug-at/ are indicative of nitrification, which is usually accompanied by decreases in dissolved oxygen concentrations (dissolved oxygen is required for the oxidation of ammonium to nitrate; nitrite is an intermediary ion of this process). Low dissolved oxygen concentrations were observed in the Rio Colorado during the wet season, but the other rivers were nearly saturated with dissolved oxygen throughout the year. High concentrations of silicate and phosphate were also associated with the wet season, but the other rivers were nearly saturated with dissolved oxygen throughout the year. High concentrations of silicate and phosphate were also associated with the wet season, indicating that the delivery of these nutrients may be substantial to the downstream estuaries. This type of information, along with discharge data for each river system, is important for the development of nutrient loading rates to the Guayas River estuary.

Toxic Substances

Pesticides

Agriculture may also contribute toxic substances such as pesticides to rivers and estuaries of the Guayas basin (Table 7). Table 7 is based on the area of rice and soy beans under cultivation in the Guayas and Los Rios provinces, and the specific application rate for each crop. This analysis is only an approximation of the use of these chemicals in the watershed and does not indicate their actual transport to aquatic systems. Dr. Solorzano (personal communication) has expressed concern about the concentrations of pesticides in the estuary, but only traces of pesticides have been detected at the beginning of the rainy season in the Daule River (Solorzano, this volume). A CEDEGE river basin study showed that DDT levels in the rivers flowing into the estuary were low, but little documentation was available.

Petroleum Hydrocarbons

Petroleum is the primary source of foreign income for Ecuador. The impact of oil on coastal provinces was documented (Cintron et al., 1981), and one publication refers specifically to the coastal zone of Ecuador (Filho, 1983). Concentrations of oil hydrocarbons in the Guayas River estuary and Ester Salado range from 0.10 to 2.80 ug/L (Solorzano, this volume). Concentrations are generally less than 2 ug/L except near oil spills or centers of commercial oil vessel activity.

Heavy Metals

There is some mining activity in the Guayas River basin, and several metals have been found concentrated in riverine and estuarine sediments. Solorzano (this volume) gives recent measurements of copper, iron, cadmium in the water columns of the Babahoyo, Daule and Guayas Rivers, and mercury in the sediment of the Guayas. The reader is referred to that report.

Shrimp Farming

Pumping of Estuarine Water

More intense shrimp farming techniques involve stocking ponds at higher densities of juveniles, which necessitates additional fertilization and supplemental feeding to assure an adequate food supply for secondary productivity. This level of pond management requires strict control of water quality since phytoplankton blooms resulting from nutrient additions may deplete dissolved oxygen concentrations to levels that will cause shrimp mortality.

One of the solutions to this potential water quality problem is to increase the exchange of seawater through the ponds by pumping water from the estuary. This exchange rate varies from 3 percent to 8 percent of the volume of the shrimp pond per day under semi-extensive mariculture, and may increase with more intense farming practices. The total volume of water pumped from the Guayas River estuary to shrimp ponds depends on pond management practices and the total area of ponds under operation. Figure 8 shows the volume of estuarine water exchanged with ponds (using a mean pond depth of 1.5 m) based on various exchange rates (percent of pond volume per day), and areas of ponds in operation. These exchange volumes are compared to the low and high flow discharge of the Guayas River. At a present operation of 30,000 ha of ponds under semi-extensive management (5 percent pumping rate), the volume of water exchanged daily with the estuary is approximately 20 $(10)^6$ m^3 (Figure 8). This volume is greater than fresh water discharge from the Guayas River during low flow periods. With intensive pond management (10 percent pumping rate), the same area of ponds would exchange nearly 36 percent of the riverine discharge during high flow periods. These types of reasonable scenarios underscore the importance of the impact of shrimp ponds on the water flow pattern in this estuary.

Most of the water that is pumped into the ponds replaces losses associated with seepage and evaporation. Although there are no data on water budgets for semi-extensive mariculture, observations suggest that less than half of the water removed from the estuary is returned in a flow-through design (P. Maugle, personal communication). The amount of water loss due to evaporation in the ponds is probably higher than in the estuary, since shallowness decreases the heat absorption capacity of the water column. Open water generally loses more water per area to evapotranspiration than wetlands. For example, mangroves in south Florida are known to have lower actual rates of evapotranspiration than potential rates (Twilley, 1982). Therefore, the conversion of intertidal areas originally vegetated by mangroves to shrimp ponds could increase the loss of fresh water from the Guayas River Estuary. This increase in water loss could result in the discharge of hypersaline waters to the estuary. Snedaker, et al (1986) found that water in 22 of 30 ponds surveyed had higher salinities than the source water.

Fertilization

Supplemental feeding and fertilization are required to meet the demand for food at higher stocking densities of postlarvae in ponds. A main source of nutrition for shrimp in growout ponds is phytoplankton blooms that result from urea and superphosphates added prior to stocking. Supplemental feeding is carried out toward the end of the growth cycle, usually in the last four weeks. The impact of these chemicals on the water quality of the Guayas River estuary depends on their fate within the pond and on effluent discharge rates. Much of the nitrogen and phosphate applied to ponds are absorbed by phytoplankton and are thus returned to the estuary in organic form. These organic nutrients represent biological oxygen demand with the decomposition of this plankton biomass. Nutrients released during decomposition may then be available for biological uptake and contribute to the red tides recently observed in the estuary. Therefore, nutrient effluent from ponds may contribute either directly or indirectly to the balance of dissolved oxygen in the estuary.

Mangroves

Since the Guayas estuary is tightly coupled to the intertidal zone via 3-5 meter tides, mangroves may influence these waters in several ways. Sediments suspended in the water column are deposited in mangroves during flooding, enriching these forests. The extensive root system of mangroves enhances the sedimentation process and retards the forces of erosion along the shoreline (Scoffin, 1970). Nixon (1984) observed that total suspended sediment load of an estuary in Malaysia, in which mangroves had been reclaimed for agriculture, was an order of magnitude higher than in an adjacent mangrove-dominated system.

Some preliminary evidence indicates that mangroves may also be a sink for nutrients in coastal waters. This may seem to contradict the theory that mangroves act as a source of detritus to estuarine ecosystems (Odum and Heald, 1972; Twilley, 1985; Twilley et al., 1986). One explanation is that net nutrient uptake may be a balance between inorganic nutrient input and organic nutrient export. Walsh (1967) noticed a decrease in inorganic nutrient concentrations in waters moving through a mangrove in Hawaii. Nedwell (1975) used enclosures to measure nutrient uptake by mangrove sediments and noticed they had a great capacity to remove nitrates, particularly in areas of nutrient enrichment from sewage discharge. The use of mangroves for treatment of nutrient-enriched effluent has received some preliminary investigation (Sell, 1977), but this function is still poorly understood. The loss of mangroves may be a contributing factor to changes in water quality, particularly nutrient levels, in the Guayas River estuary.

Impact of Water Quality on Shrimp Mariculture

Existing information suggests that the production in shrimp ponds has decreased from 1600 to 250 kg of shrimp/ha/yr over the last several years, though stocking rates have been maintained at about 65,000 PL/ha per harvest. Mortality rates in shrimp ponds are estimated at greater than 50 percent (P. Maugle, personal communication), and evidence suggests that maturation rates are also lower. In addition, there has been a decline in the availability of wild PL to the shrimp farming industry, restricting the acreage of ponds in operation. Decrease of wild PL has increased demand for PL from hatcheries. Currently, there are some 68 hatcheries under construction. Twenty hatcheries still in initial phases of operation produced about 500 million postlarvae in 1985.

Good water quality is critical to the productivity of hatcheries because larvae are susceptible to disease. Both PL supply and shrimp growth and mortality in ponds determine the productivity of this industry; and both depend on the quality of water in the estuary.

Mangroves and Fisheries

The loss of mangroves from tropical estuaries may have direct consequence to economically important fisheries through loss of habitat and food. Zimmerman and Minello (this volume) have found that *P. vannamei* and *P. stylirostris* inhabit areas in the mangroves, but it is not known whether these habitats enhance the survival or growth of these and other marine organisms in the Estero Salado. Associations do exist between the production rate of shrimp and the extent of mangrove area (Macnae, 1974; Turner, 1977; Jothy, 1984) because one hectare of mangroves can yield more than 600 kg/yr of shrimp and 100 kg/yr of fish without management (Turner, 1977). Based on an approximate loss of 10,500 ha of mangrove (Figure 4), the reduction in shrimp production from the estuary would be equivalent to 6,300 m.t./yr. Although these statistics do not show causal relationships, they do point out that whenever a productive postlarvae fishery exist, there is the presence of the mangrove habitat as observed in Ecuador (Turner, this volume). Without further information on possible dependance of shrimp larvae and other marine fauna on mangroves for part of their life cycles, the effect of mangrove clearing on natural populations in the Guayas River estuary will remain unknown. Mangrove destruction may also have an indirect effect on fisheries by changing water quality.

Salinization

The Daule-Peripa dam and the pumping of water into shrimp ponds, may influence the distribution and increase the concentration of salinity in the Guayas River estuary. Mangroves that exist in arid environments such as the coast of Ecuador where evapotranspiration is greater than precipitation are very susceptible to slight changes in hydrology. For mangrove forests in arid life zones, small shifts in precipitation result in increased soil salinity followed by an increase in tree mortality and a shift in vegetation from forests to tannes or Salinas (Davis and Hilsenbeck, 1974; Cintron et al., 1978). In Ecuador the diversion of fresh water from the Guayas River estuary must be managed with awareness of possible negative effects on mangroves since they exist in a relatively arid environment. Margalef and Crespo (1979) suggested that the loss of fresh water from the dam will probably not affect mangroves, though the researchers did not take into account the climatic influence of mangrove distribution in the southern provinces.

Increases in salinity due to changes in fresh water supply to the Guayas River estuary may also impact economically important fisheries in this estuarine ecosystem. The Estero Salado, which harbors most of the fishery resources of the inner Gulf of Guayaquil, does not receive fresh water discharges directly from the Guayas River. Therefore, the flushing rate of this section of the inner gulf is less than the more southern sections that are linked directly to discharge from the river. As a consequence of less discharge, the Estero Salado may be more susceptible to increases in the concentration of materials dissolved in the water column. Salinity is a conservative element in the water column and indicates the concentrating nature of this body of water. Precipitation during 1985 was relatively low, and the Estero Salado was hypersaline with values up to 30 parts per thousand (Zimmerman and Minello, this volume). This increase in salinity suggests that other materials, such as toxic chemicals and nutrients may also be concentrated (assuming that their behavior is conservative). Organisms, such as shrimp, that inhabit the Estero Salado are very susceptible to changes in water quality, especially salinity and toxicity which may increase mortality and retard growth rates.

Changes in fresh water supply may also influence seasonal movement or recruitment of organisms into the Guayas River estuary. The recruitment of shrimp into an estuary is important to their life cycle because the estuary provides optimal conditions, such a low predation, during critical stages of maturation. Seasonal timing of recruitment is thought to be dependent on fluctuations in salinity along with influx of offshore water masses. Since the Daule-Peripa dam is designed for a near constant flow of water to the Estero Salado, the potential impact of this project should be evaluated relative to disturbing seasonal fluctuations of salinity in the estuary. Since the mariculture industry relies on shrimp postlarvae that seasonally utilize the estuary, management plans should strongly consider those factors that influence recruitment of fisheries in the estuarine ecosystem.

Nutrient Enrichment and Anoxia

Nutrients that increase the productivity of agriculture and are the by-products of human nutrition also stimulate the primary productivity of aquatic ecosystems. Changes in water quality in response to nutrient enrichment is called eutrophication. Dissolved oxygen is a popular index of water quality; oxygen concentrations below 4 mg/ are considered stressful to many fisheries. The negative effects of low dissolved oxygen to fisheries can also be indirect by disturbing basic food chains. The discharge of organic materials that consume oxygen during decomposition (biological oxygen demand, BOD) and of some inorganic nutrients (chemical oxygen demand, COD), can cause a decrease in concentrations of dissolved oxygen in the estuary. A balance of processes that contribute (photosynthesis and diffusion) and remove BOD and COD dissolved oxygen is necessary for a healthy environment for economically important fisheries.

Anoxia or low dissolved oxygen conditions have been observed historically in some stratified estuaries, such as in the Chesapeake Bay where anoxia of bottom waters was observed in the 1930s (Newcombe and Horne, 1938). A concern regarding the Chesapeake Bay that may be relevant to many estuarine ecosystems is the recent increase in anoxia in greater volumes of water and the persistence of this condition in the water column. The linkage between increased nutrient loading, enhanced production of phytoplankton biomass, and the consumption of oxygen during decomposition of this organic material in the system either in the water column or in the surface sediments may contribute to anoxia in the Chesapeake Bay (Officer et al., 1984). Therefore, nutrient abatement and control becomes a central issue in dealing with similar water quality problems in estuarine ecosystems such as the Guayas River estuary.

Red tides, phytoplankton blooms that discolor the water, are a common occurrence in the Gulf of Guayaquil and in the inland waters of the Guayas River estuary (DeArcos, 1982; Jimenez, 1980; Jimenez, this volume). These blooms vary in species composition, density of cells, and duration. The most direct influence on the estuary is fish kills caused by the presence of toxic organisms such as *Gonyaulax catenella and Gymnodium breve*. *Gonyaulex monilata* occurred in the upper portion of the Gulf of Guayaquil in April 1980, and in March 1986 along the coast of Manglaralto. The 1980 bloom resulted in high fish mortality (Jimenez, 1980), while the 1986 bloom caused significant mortality of shrimp postlarvae in eight hatcheries, interrupting operations for 30-45 days (Jimenez, 1986).

Other red tides in the Guayas River estuary include *Gyrodinium stratum* in September 1982, *Mesodinium rubrum* in August 1984, *Prorocentrum maximum* from February 1985 to February 1986, and a recent bloom of *Nitzschia sp.* (Jimenez, this volume). These blooms caused high mortality in shrimp ponds when phytoplankton contaminated waters were pumped from the estuary.

Anoxic waters are apparently uncommon in the Guayas River estuary, occurring only in areas near sewage outfalls (Arriaga, this volume). A survey of five stations in Estero Salado found that dissolved oxygen concentrations at 1 m depth ranged from 3.5 to 5.3 ml/ (Solorzano, this volume). Concentrations are normally lower near the bottom; for instance, Solorzano and Viteri (1981) measured concentrations of 3.5 ml/ at 1 m depth compared to 2.0-2.5 ml/ near the bottom at two stations adjacent to the city of Guayaquil. The strong tides with amplitudes from 3 to 5 m in the Guayas River estuary are responsible for the well-mixed aerated water column. Even during presence of red tides in the estuary, anoxic problems in ponds are not caused by pumping anoxic water from the estuary; rather, anoxia in pond water develops when water that contains materials that may promote low oxygen conditions is pumped into the less well-mixed shrimp ponds.

Toxic Substances

Hydrocarbons

Hydrocarbons can be lethal to fish at relatively low concentrations (Table 8). However, current information suggests that the concentrations of hydrocarbons in Estero Salado are less than 2 ug/, an order of magnitude less than concentrations that may affect the natural resources of this ecosystem.

Pesticides

Crustaceans, especially larvae, are usually more sensitive to low concentrations of pesticides than are other marine organisms (Costlow, 1982). The extensive use of these chemicals in the estuarine watershed creates a potential hazard to the shrimp mariculture industry in Ecuador. Table 9 shows the amount of pesticides imported into Ecuador in 1979 and 1980. For example, Endrin, which is applied at an approximate rate of 145 m.t. per year in the rice paddies of the Guayas River basin significantly reduced growth rates of rapidly growing juvenile *Mysidopsis bahia* (McKenney, 1986), at concentrations of 60 mg/L. In addition, physiological measurements of metabolic dysfunction in *mysids* exposed sublethally to pesticides in laboratory and field conditions showed lower growth and reproductive capacity in these organisms during later stages of their life cycle (McKenney, 1986). Daugherty (1975) noted that decreased shrimp yields in El Salvador probably resulted from the heavy use of pesticides in cotton farming during the 1960s and early 1970s. Pesticides have a tendency to become more concentrated along the food chain and thus may stress predators and higher trophic levels such as fish. Before this problem can be solved, more information is needed on the ambient concentration of these chemicals that are toxic to certain fisheries, and on their fate in the aquatic environment.

Metals

High concentrations of heavy metals in certain areas of the estuarine ecosystem demonstrate the affects of urban development and industry. Solorzano (1986) expressed particular concern for the concentration of copper, cadmium and mercury in the water column and sediments of the Guayas River estuary. Copper concentrations are higher than 10 ug/ which is considered innocuous to aquatic species (Ketchum, 1975), although these concentrations could be due to natural processes. Cadmium is also present in concentrations that could impact aquatic organisms (Ketchum, 1975), and sediments showed significant mercury contamination (Solorzano, 1986).

The Ecosystem and Shrimp Mariculture

The interactions of the shrimp farming industry with the Guayas River estuarine ecosystem are summarized in Figure 9. Water quality influences the supply of wild PL as well as the successful production of PL by hatcheries. Water quality also determines the survival and growth rates of PL once they are stocked in growout ponds. Although water quality of ponds depends principally on the type of management used, characteristics of the water pumped from the estuary can also determine the number of shrimp produced in the ponds. Activities in the Guayas River basin affect the quality of water in the estuary and, therefore, the shrimp industry through chemicals such as nutrients and pesticides from agriculture, sewage from the large population centers around the estuary, and heavy metals from industry. The distribution and turnover rate of these pollutants and salinity in the estuarine water column of the estuary are influenced by the discharge of fresh water from the watershed. Thus a dam on the Daule-Peripa Rivers must be evaluated in terms of its potential impact to water quality in this estuary, given the strong seasonal nature of its fresh water inputs.

There are also many natural occurrences that influence water quality and the shrimp industry in this ecosystem (Figure 9). For example, elevated water temperatures in the Gulf of Guayaquil may be a dominating factor in the tremendous recruitment of shrimp into the inner estuaries during climatic disturbances known as El Niño. Red tides are also recruited from the Gulf of Guayaquil to the estuaries, in addition to the blooms that occur in situ. The extensive areas of mangroves are considered nurseries for economically important shrimp larvae as well as possibly influencing nutrient and sediment dynamics in this turbid estuary. Tides affect water quality in the estuary by mixing the water column and preventing stratification that could lead to problems with low levels of dissolved oxygen. Considering the huge amounts of untreated sewage that is discharged into this system, there are few accounts of anoxia with in the estuary, a pattern that has been attributed to the presence of strong tidal currents within the system.

The many interactions of the human and natural resources of this estuarine ecosystem underscore the complexity inherent in questions regarding the fluctuations of PL supply and the apparent decrease in pond production of shrimp in the past several years. The shrimp industry is not only affected by changes in the quality of water pumped from the estuary, but it also contributes to the problem by loading nutrients (fertilization), increasing fresh water loss (pumping), and destroying mangrove forests (construction) (Figure 9). The benefits of pond management involving these practices must also be evaluated in the context of their possible negative effects on water quality and the shrimp industry itself.

There is now a general feeling in Ecuador that the loss of mangrove habitat has contributed to the decline of wild postlarvae, particularly during periods of normal recruitment. In fact, new authorizations forbid construction of ponds in mangroves. In order to accommodate these laws and maintain or increase the level of shrimp production in the existing ponds, mariculture operations must be intensified (Siddall et al., 1985). Thus the supply of postlarvae in the estuary has a strong influence on both the rate of pond construction and the type of pond management (Figure 9). The intense utilization of existing ponds would create increased pumping and fertilization of estuarine water which would, in turn, lead to increased loading of nutrients to the estuary. This management alternative may adversely affect water quality of the estuary even though the objective is to lessen negative impacts by preventing the loss of mangroves from the ecosystem. The negative impacts of pond construction on the ecosystem are replaced by increased pumping and fertilization associated with more intensive shrimp pond management (Figure 9). These issues demonstrate the importance of considering shrimp pond management in the context of the ecosystem and, particularly, paying close attention to those factors associated with water quality control (Figure 9).

The shift from extensive to intensive mariculture may not necessarily impact the estuarine ecosystem if mangroves could be utilized in the operation of ponds. Mangroves may act as sinks of several primary nutrients used in the fertilization of ponds, particularly phosphates and nitrogen. Mangrove sediments may also have the the capacity to absorb some of the BOD associated with pond biomass that is high in chlorophyll and as an effluent, may impact the balance of dissolved oxygen in the estuary. Effluents from shrimp ponds could be distributed in nearby mangrove forests for nutrient removal prior to the return of pond water back to the estuary. This use of mangroves as a nutrient buffer, which would most likely enhance mangrove productivity, would serve as a means of minimizing the negative impact of intensive aquaculture on the estuarine ecosystem. Mangroves could also be utilized in pond management to prevent or retard erosion along the shorelines of ponds. Sediment stabilization is an important natural function of mangroves along the coastline, particularly because they minimize the impact of storm surges.

Even though there is a law that denies the construction of newly authorized ponds in mangrove areas, there are thousands of hectares of ponds that were previously authorized but not constructed, and are exempt from this decree. It is only the lack of postlarvae and capital that has controlled the construction of ponds in mangrove habitats. Thus, an increase in the supply of postlarvae by warmer temperatures of offshore waters or increased production from hatcheries, represent a danger to mangroves.

Hatcheries have been viewed as an operation that would save mangrove forests from further destruction. However, if hatcheries and larveros become able to produce enough postlarvae for 45,000-50,000 ha of ponds as predicted, then pressure to utilize mangrove sites for pond construction is likely to develop (present postlarvae levels keep less than 30,000 - 45,000 ha of ponds supplied). Thus, the growth of the hatchery industry to supply postlarvae will have some influence on management decisions to either intensify existing ponds or to construct new ones. If this means more intensive farming techniques, then mangroves should be part of the operational scheme to enhance the production of this industry.

Profit in shrimp farming is income generated from pond production less the costs associated with pond operation The level of shrimp production and operation costs including dredging, construction, pumping, fertilization, and land (authorizations) depend largely on the quality of water that is pumped from the estuary into the ponds. Several factors have been identified in the estuary and the watershed that could influence water quality and, thereby, determine the economy of the shrimp industry. Many of the natural resources such as mangroves and tides provide the shrimp industry with clean water and important habitats that enhance wild PL supply and shrimp production in ponds (Figure 9). The loss of these free services increases the cost of shrimp production, such as the cost of providing PL by operating hatcheries. Negative effects from other industries and shrimp mariculture itself on water quality and natural resources should have some influence on the costs and profits of shrimp farming, since it is so vitally linked with the estuarine ecosystem.

The management practices that are best for the shrimp farming industry in Ecuador point up the need for integrative approaches to coastal zone management. The interactions of the shrimp farming industry with the Guayas River estuary, along with the watershed and offshore waters, indicate the complexity and diversity of management options. For instance, management plans to deal with the fluctuation of PL in the estuary must address the influence of fresh water discharge, offshore water temperatures, loss of mangrove habitat, pesticides from agriculture, and untreated sewage from major population centers. Also the industry itself has a potentially major impact on the ecosystem, so decisions concerning shrimp pond management must consider the possible negative effects on shrimp production and PL supply. The shrimp farming industry must consider the processes and functions of existing natural resources of the estuary in developing plans that will sustain the long term production of mariculture in this coastal zone.

Recommendations

- Document the loss of mangroves from the coastal zone of Ecuador; since mangroves are the center of the controversy on impacts in the coastal zone, then all premises related to this impact will require information on the extent of loss.
- Document the present distribution of mangrove forests to identify present and future impacts on this natural resource.
- Restore and integrate existing mangrove forests into the operation of shrimp ponds. Utilize mangroves for treatment of effluents from ponds in operation, and for erosion control and sediment stabilization in areas of pond construction.
- Develop a water budget for the Guayas River estuary, including a synthesis of existing information and the calibration of current data gathering, to increase the utility of this data base.
- Integrate an analysis of nutrients and toxic substances into the water budget to develop a water quality model for this ecosystem. Include in this model the fate of chemicals in the estuary, and the mode of impact of these chemicals economically important fisheries.

- Institute a water quality monitoring program design to determine the current levels of nutrients, dissolved oxygen (including BOD and COD), pesticides, heavy metals, petrochemical hydrocarbons and physical characteristics (temperature, light, and salinity) in the fresh and estuarine waters of the Guayas River estuary. This program could also be expanded to aid shrimp pond and hatchery operators with decisions concerning water quality management.
- Evaluate the relative contribution of cold/warm water intrusions in the Gulf of Guayaquil, loss of mangrove habitat, nutrient loading and water quality on the mariculture industry of Ecuador.

Table 1.
Land use patterns along the coast of Ecuador (areas in ha)

Land Use	Guayas	El Oro	Manabi	Esmeraldas	TOTAL
Mangroves	121463.5 69.4	24489.3 24.0	7973.4 4.4	21293.2 12.2	175219.4 100.0
Shrimp ponds	52911.8 59.2	26483.9 29.6	8376.6 9.4	2595.5 1.8	89367.8 100.0
Salinas	17340.1 86.6	2520.0 12.6	163.8 .8	4.4 .0	20028.2 100.0
TOTAL	191715.4 67.4	53493.2 28.8	16513.8 5.8	22893.1 8.0	284615.4 100.0

Source: CLIRSEN, 1984

Table 2.
Mangrove species found along the coast of Ecuador

Rhizophoraceae
- *Rhizophora harrisonii* (leachm)
- *Rhizophora racemosa* (GFM Mayer)
- *Rhizophora mangle* (L.)
- *Rhizophora samoensis*

Pellicieraceae
- *Pelliciera rhizophorae* (Planchon and Triana)

Avicenniaseae
- *Avicennia germinans* (L.)

Combretaceae
- *Laguncularia racemosa* L.) Gaertn f.
- *Conocarpus erectus* L.)

Table 3.
Historical records of land use patterns (areas in hectares)
showing the decline in mangroves near Guayaquil (CLIRSEN 1983).
(Area located in Province El Oro, Piloto Machala)

Land Use	1966	1977	1982
Mangrove	4962.9	4231.7	3294.7
Camaroneas	0.0	834.2	2330.7
Salinas	1087.7	478.5	162.6
Agriculture	615.2	730.2	634.7
Vegetation	466.3	332.2	139.4
Urban	256.7	434.7	588.5
Rivers	1437.5	1514.5	1465.7
TOTAL	8556.3	8556.0	8616.3

Table 4.
Cultivation areas in hectares for different crops in the coastal provinces of Ecuador
(data taken from Solorzano 1981)

Crop	Guayas	Los Rios	Guayas River Basin	Manabi	Esmeraldas	El Oro	TOTAL
Rice	35,280	37,058	72,338	1,304	1,918	128	75,688
Cotton		540	540	5,656			6,196
Soya	10,038	24,470	34,508	165	37	90	34,800
Cacao	12,134	116,115	128,249	40,077	12,367	16,117	196,810
Coffee	31,681	42,020	73,701	138,431	11,000	15,176	238,308
TOTAL	89,133	220,203	309,336	185,633	25,322	31,511	551,802

Source; Solorzano, 1981.

Table 5
Areal cultivation of rice associated with the rivers in the coastal region of Ecuador
(from Solorzano 1981)

Rivers	Area
<u>GUAYAS</u>	35,280
Guayaquil	1,600
Daule	7,745
Samborandon	4,198
Balzar	3,038
Yaguachi	8,003
Milagro	1,106
El Triumfo	5,164
Naranjal	4,426
<u>RIOS</u>	37,058
Babahoyo	19,409
Baba	3,033
Vinces	3,000
Urdaneta	1,214
Puebloviejo	2,160
Ventanas	860
Quevedo	7,382
<u>MANABI</u>	1,304
Santa Ana	565
Portoviejo	442
Rocafuerte	297
<u>ESMERALDAS</u>	1,918
Esmeraldas	293
Quininde	1,625
<u>EL ORO</u>	128
Santa Rosa	128

Table 6.
Estimates of the discharge of domestic waste from the Guayas watershed based on the population of the major cities of the Guayas and Los Rios provinces

City	Treatment	Population	Volume	BOD	COD	TSS	TDS	TN	TP
GUAYAS									
Guayaquil	sewer	634,720	46.335	12,504	27,927	12,694	23,167	2094.5	253.8
	untreated	876,520	6.399	6,048	14,024	14,024			
	TOTAL	1,511,240	52.734	18,552	41,951	26,718	23,167	2094.5	253.8
Salinas	sewer								
	untreated	22,360	.163	154	357	358			
	TOTAL	22,360	.163	154	357	358	0	0.0	0.0
La Libertad	sewer								
	untreated	65,450	.478	452	1,047	1,047			
	TOTAL	65,450	.478	452	1,047	1,047	0	0.0	0.0
Naranjal	sewer	4,580	.335	90	202	92	167	15.0	2.0
	untreated	7,480	.055	52	329	329			
	TOTAL	12,060	.390	142	531	421	167	15.0	2.0
Manglaralto	sewer								
	untreated	12,300	.090	85	197	197			
	TOTAL	12,300	.090	85	197	197	0	0.0	0.0
Playas	sewer								
	untreated	18,550	.208	197	457	457			
	TOTAL	28,550	.208	197	457	457	0	0.0	0.0
Santa Elena	sewer								
	untreated	15,670	.114	108	251	251			
	TOTAL	15,670	.114	108	251	251	0	0.0	0.0
LOS RIOS									
Santa Rosa	sewer	6,040	.441	119	266	121	220	20.0	2.0
	untreated	27,530	.201	190	440	440			
	TOTAL	33,570	.642	309	706	561	220	20.0	2.0
TOTAL	sewer	645,340	47.111	12,713	28,395	12,907	23,554	2129.5	257.8
	untreated	1,055,860	7.708	7,286	17,102	17,103	0	0	0
	TOTAL	1,701,200	54.819	19,999	45,497	30,010	23,554	2129.5	257.8

Engineering Journal, 1972.

Table 7.
Application rate and input of pesticides used in the cultivation of rice and soy beans based on the area of each crop in the provinces Guayas and Los Rios, the watershed of the Gulf of Guayaquil

Rice

Pesticide	Treatment		Input
Ronstar 25	2.00	L/ha	144,676
Ronstar 12	4.00		289,352
Machete	4.00		289,352
Saturno	3.00		217,014
Propanil	8.00		578,704
Hormonales	2.00		144,676
Furadan	15.00	Kg/ha	1,085,070
Curater 5-10%			0
Diazinon	1.00		72,338
Ozadin	0.50		36,169
Lorshan	0.50		36,169
Endrin	2.00		144,676
Lannate	2.00		144,676
Dipterex 95%	1.00		72,338
Bin 75	300.00	g/ha	21,701,400
Benlate	250.00	g/ha	18,084,500
Kasumin	0.75	L/ha	54,253.5
Inosin	0.75		54,253.5

Soy Beans

Pesticide	Treatment		Input
Bravo	3.00	L/ha	103,524
Daconil	2.50	Kg/ha	86,270
Afalon	3.00		103,524
Preforan	15.00	L/ha	517,620

Solorzano, 1981

Table 8.
Comparative toxicity of the water soluble fraction of No. 2 fuel oil to different life stages of four marine crustaceans
Concentrations are ppm of total hydrocarbon
(Neff et al., 1976, cited from Neff and Anderson, 1981)

Species	Description	LC-50	CI (95%)
Penaeus aztecus (brown shrimp)	postlarvae	6.6	6.1 - 6.9
	early juveniles	3.7	3.0 - 5.1
	late juveniles	2.9	2.2 - 3.8
Penaeus setiferus (white shrimp)	postlarvae	1.4	0.9 - 2.1
	juveniles	1.0	0.8 - 1.2
Palaemonetes pugio (grass shrimp)	larvae	1.2	1.0 - 1.5
	postlarvae	2.4	2.1 - 2.8
	adults	3.5	2.4 - 4.9
Mysidopsis almyra (opossum shrimp)	postlarvae (1 day old)	1.8	
	postlarvae (7 days old)	1.8	
	adults	.7	

Figure 1 Areas of ponds authorized by the Ecuadorian government for the construction of shrimp ponds.

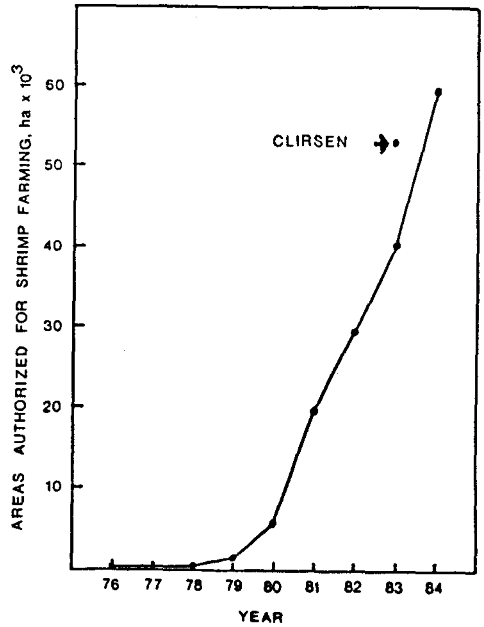


Figure 2 The coastal provinces of Ecuador

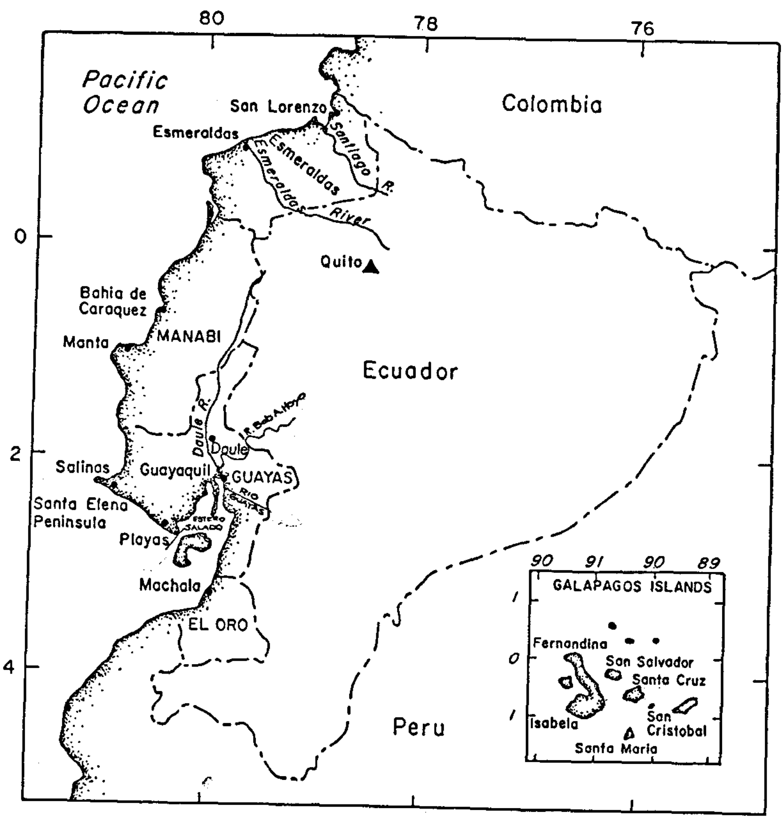


Figure 3 A) Forty year record of annual precipitation in Guayaquil. B) Average monthly discharge of the River Guayas from 1962 to 1964. (Both figures from Stevenson 1981).

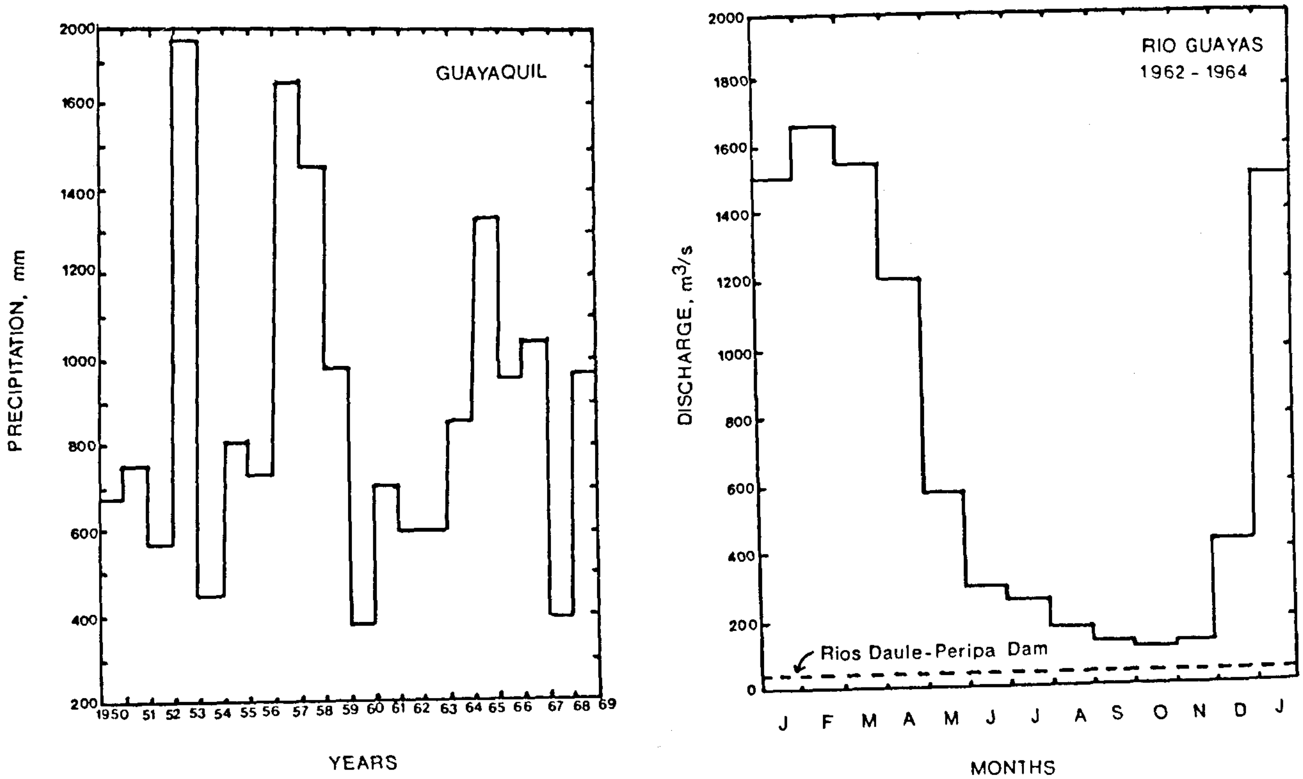


Figure 4 Hypothetical loss of mangroves in the Guayas province, given that a percentage of ponds are constructed in mangrove forest. For example, if all ponds as of 1984 (53,000 ha) had been constructed in mangroves, then 30% of Guayas mangroves would have been cut. (See table 1).

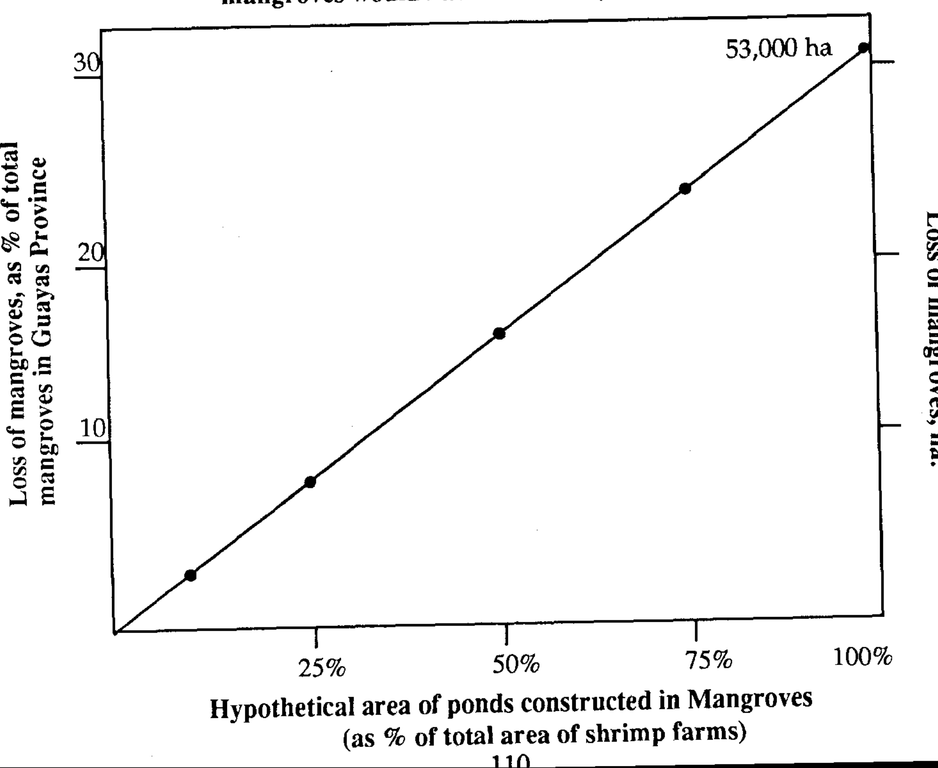


Figure 5 Normal discharge at the confluence of the Daule and Peripa Rivers (solid line) compared to the restricted flow controlled by the proposed dam (dotted line). Slanted lines represent discharge lost from the estuary during the wet season, and the stipuled area is discharge provided by the impoundment during the dry season (From Jenkins 1979).

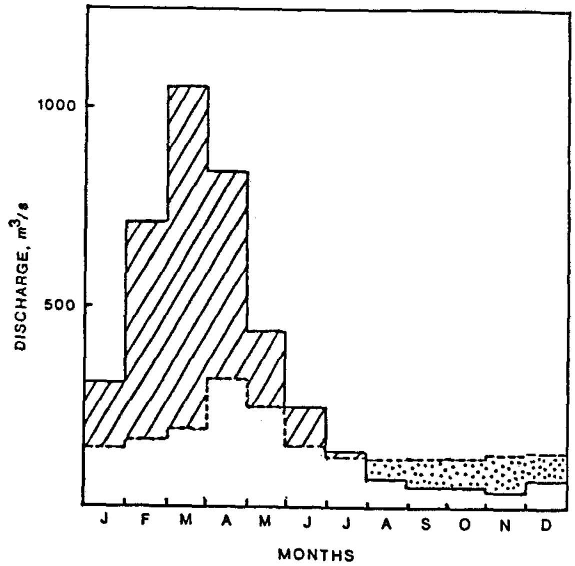


Figure 6 Population during the past 35 years in the coastal provinces of Ecuador (data from Gomez 1986).

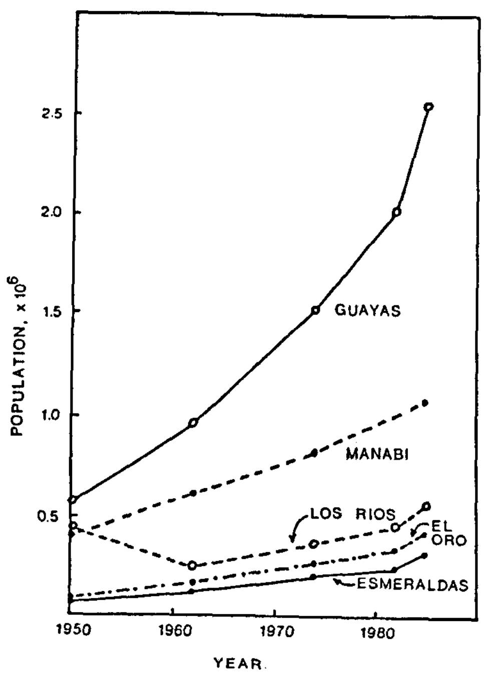


Figure 7 Concentrations of nutrients for different rivers in the Guayas River basin (data from Rendon et al., 1983).

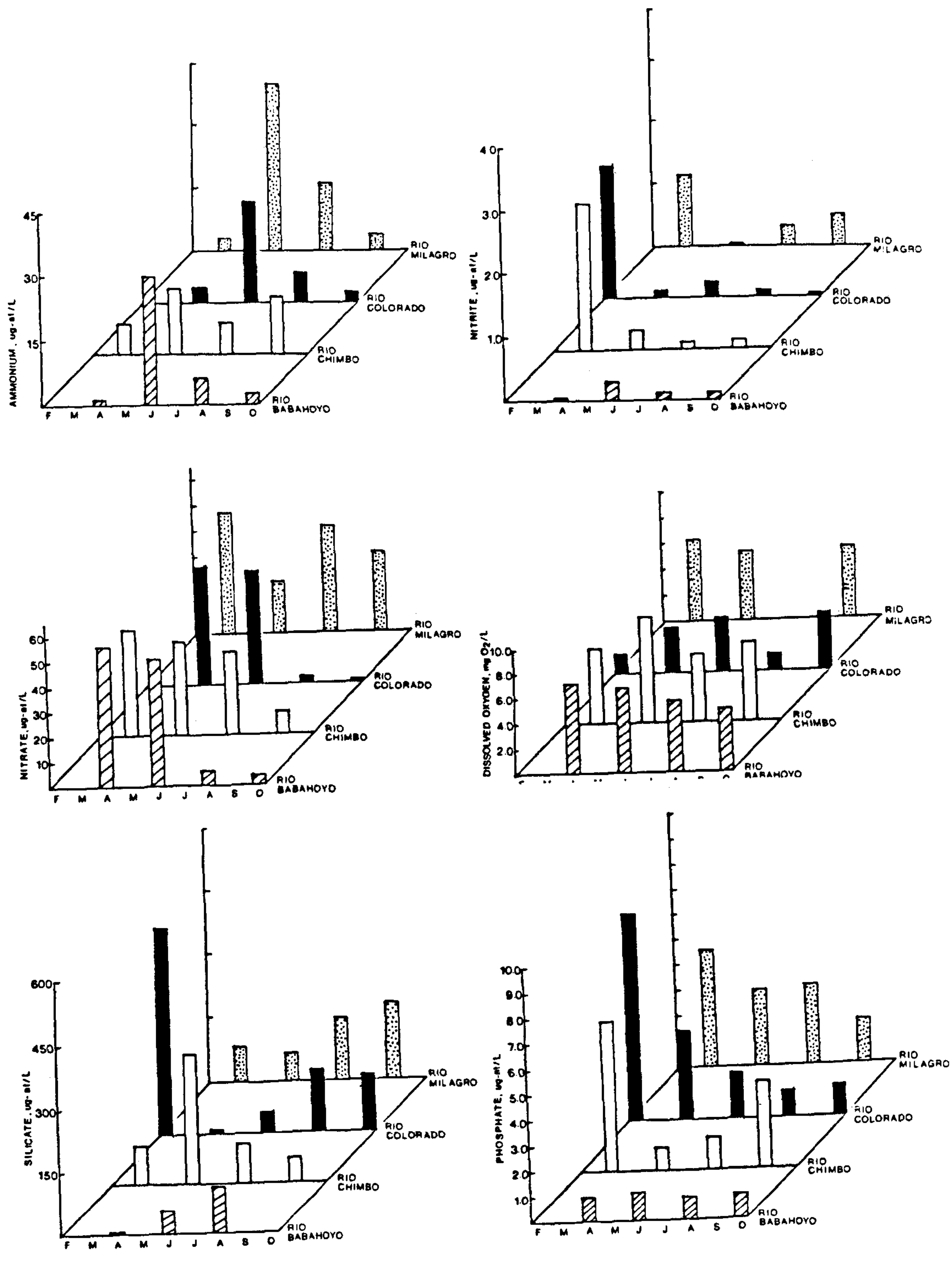


Figure 8 Volumes of water exchanged with shrimp ponds per day at different pumping rates (percentage of the volume of a shrimp pond per day) based on the area of ponds (ha) with a mean depth of 1.5 m (see text).

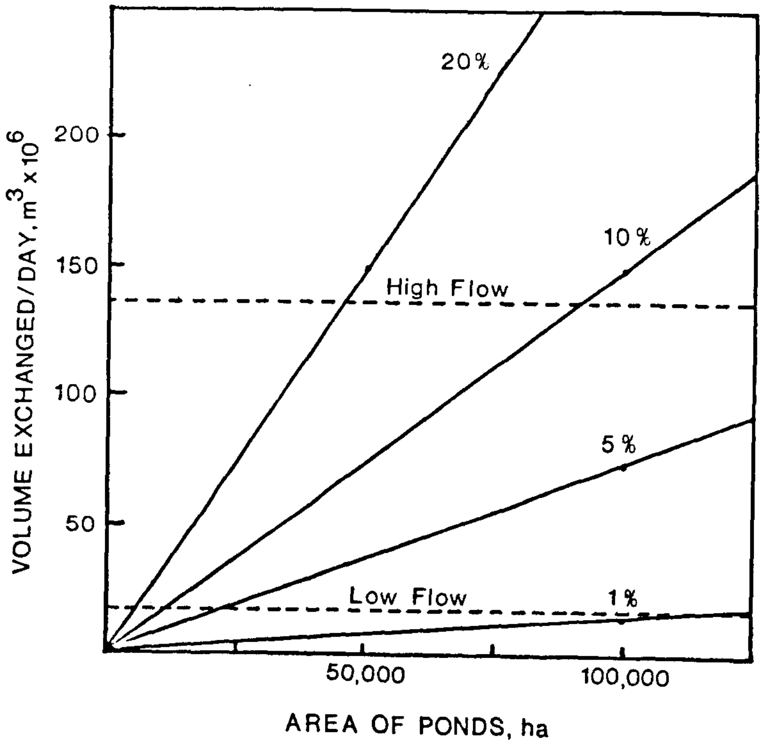
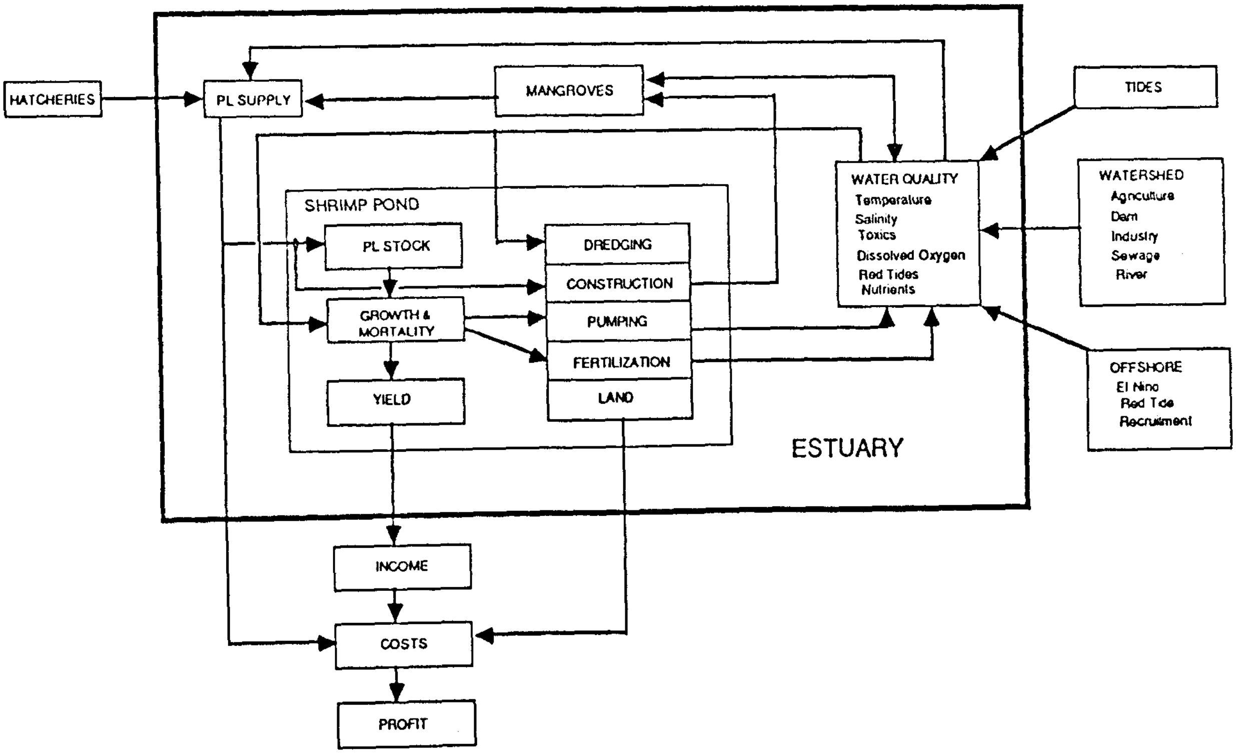


Figure 9 Interactions between shrimp farming and Guayas River estuarine ecosystem.



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