The Potential for Mariculture of Yucatán, México

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INTRODUCTION

The Yucatán Península is a karstic area formed chiefly of limestone and other soluble rocks. This geological characteristic propitiates a high permeability which causes rainfall to rapidly infiltrate into aquifers, hence the lack of surface hydrological systems. Sinkholes and other karstic formations are the only surface sources of water (Stringfield and LeGrand, 1974).

Such geohydrological conditions were taken as a basis for stating that this region, especially the State of Yucatán, on the northern portion of the Península, did not have any potential for the development of economic activities, such as aquaculture.

The State of Yucatán has 378 km of littoral, along which lie a series of coastal lagoons, plains and marshes. In 1988, a series of preliminary investigations on soil characteristics and water quality concluded that over 1,200 Ha of a long coastal strip of Yucatán offered adequate conditions for the mariculture of many commercially important species.

This work presents the results of those preliminary studies, and tries to provide an overall panorama of the stage of development of mariculture in Yucatán and discusses problems and perspectives.

THE COASTAL ZONE OF YUCATÁN

The coastal fringe of Yucatán is an almost continuous barrier island formed by sediment deposition and wave generated coastal circulation. It is separated from the coastal plain of the mainland by almost continuous salt water marshes or coastal lagoons. The coastal plain is a compact mass of land constituted of sedimentary cretacic rocks, covered by a layer of fine-particle sediments (Tamayo, 1981). The natural slope of these plains is less than 1%, and this makes the coastal marsh as wide as 5 km in some points. Inland, the fine-soil layer becomes thinner and the land rises gradually so that pitted, calcareous rocks scarred by solution, becomes the surface layer.

The coastal lagoons have little communication with the open sea and most of them are natural evaporation basins. The most important of these lagoons are

Celestun on the northwest, Chelem and Dzilam on the north and Río Lagartos on the northeastern part of the state (Figure 1).

Freshwater flows seaward from the inland water table complex which runs from south to north discharging 9 billion m^3 per year (Lesser, 1976). These conditions generate salinity gradients, the amplitude of which goes from freshwater to hyperhaline conditions in some locations. Additionally, this groundwater discharge provides a considerable amount of nutrients that fertilize the coastal lagoon systems. All these factors together help to maintain a diverse aquatic fauna which includes a variety of commercially important species (Flores-Nava, 1990b; Herrera-Silveira *et al.*, 1991).

The major economic activities in the coastal areas of Yucatán are fisheries, production of salt, and to a lesser extent tourism. The most important fisheries are that of the grouper *Epinephelus morio* (18,000 tons/year); octopus *Octopus maya* (11,000 tons/year) and lobster *Panulirus argus* (150 tons/years). All fishery activities are carried out at an artisanal level. Production of salt is another important activity with more than 300 thousand MT of salt per year from salt pans (Herrera-Silveira *et al.*, 1991). The other growing activity is tourism although it still is an incipient industry in the region.

These major economic activities compete among each other and with other users for space, water and basic services.

PRELIMINARY STUDIES TO EVALUATE THE AQUACULTURE POTENTIAL OF COASTAL YUCATAN

The karstic nature of the Península and the lack of surface hydrological systems, led to the conclusion that Yucatán had no possibilities for any type of aquaculture. This misconception kept the region from having access to important government aquaculture-support schemes. However, in 1988 CINVESTAV-Mérida, initiated a series of basic field studies to have a better idea of the environmental factors of the Peninsula. These studies made it possible to draw more objective conclusions on the possibilities for coastal aquaculture (Flores-Nava *et al.*, 1990b).

A series of field trips were carried out to a number of sites on the coast, so that the whole of the coastal zone was sampled and represented. The environmental factors evaluated were: 1) Soil chemical and physical characteristics; as well as its availability for pond construction purposes, 2) Marine and ground water quality, and 3) Tidal pattern and height of the plain with respect to maximum sea level. The results of these basic studies performed on 5 samples taken in each of the 12 sites along the coast of Yucatán from Celestún to San Felipe (Figure 2), are presented in Tables 1 and 2.

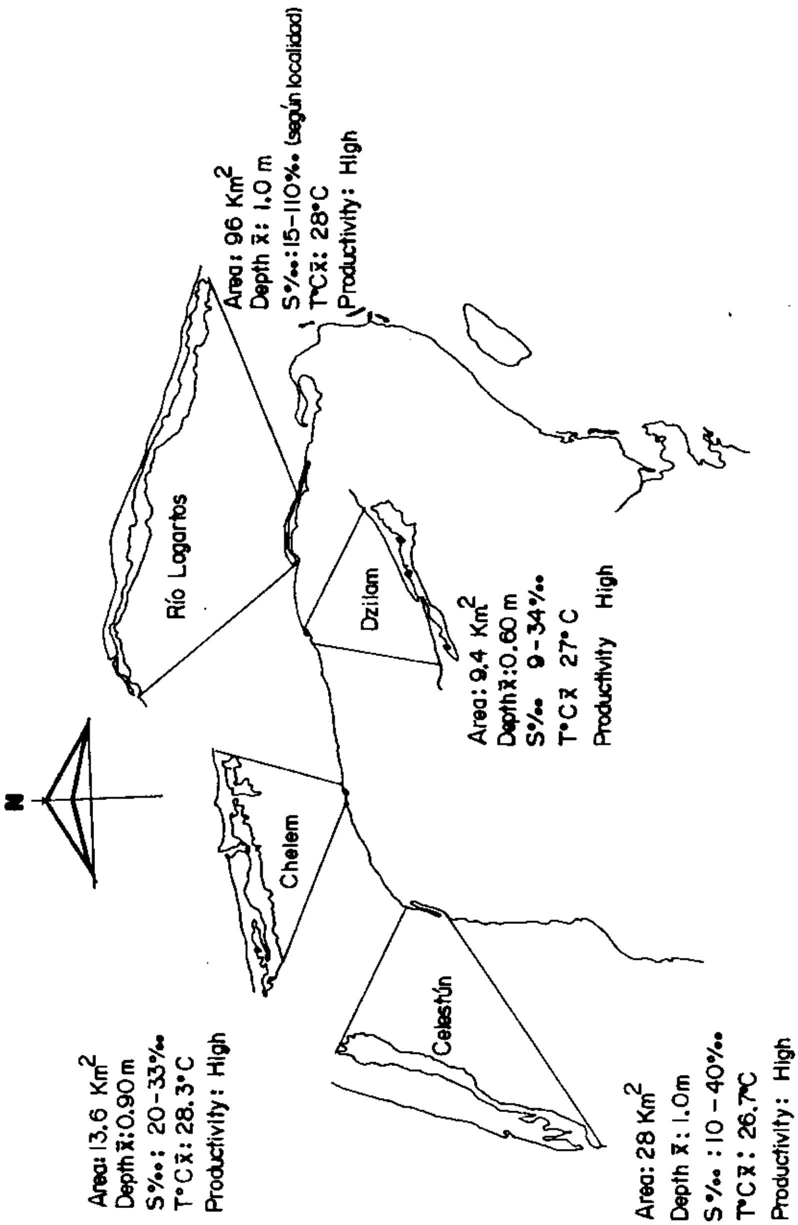

Figure 1. Coastal lagoons of Yucatán.

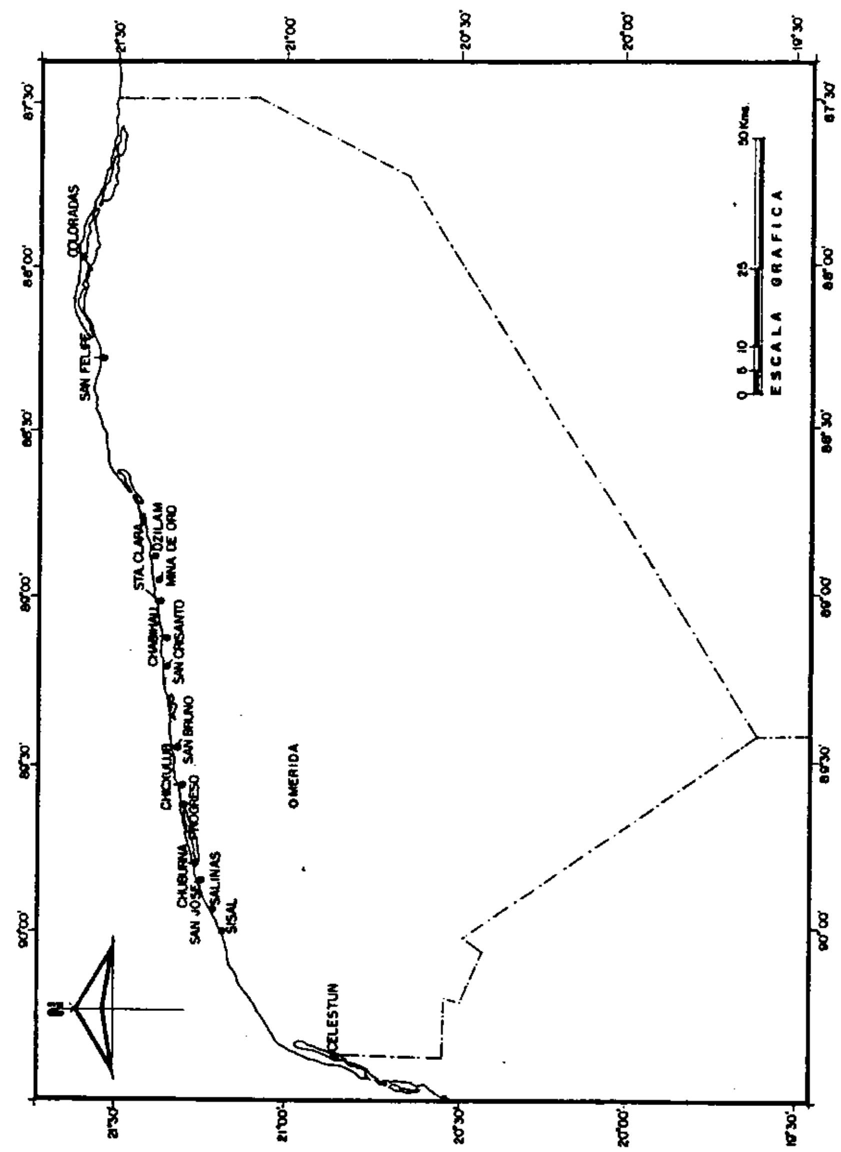

Figure 2. Selected sampling sites for soil and water quality on the coast of Yucatán.

Table 1. Physical and chemical properties of soils in the coastal areas of Yucatan.

TEXTURE	GRAVEL:	< 5 %
	SAND:	22-23%
	SILT/CLAY:	53-62%
(k) PERMEABILITY	AVERAGE:	1.62 X 10^{-6} cm/sec
PLASTICITY	MODERATE TO HIGH	
LOAD CAPACITY (RESISTENCE)		250 - 400 G/Cm^2
CHEMISTRY	pH:	6.9 - 8.6
ORGANIC MATTER: 0.5 - 2.5%		

Soil Physical Properties and Permeability

There is a clear homogeneity in terms of soil texture all along the coastal plains. Also the high content of fine-particle soils which provide a high impermeability (< 1.65 x 10^{-6} cm/sec) and plasticity (moderate to high) were similar between sites.

Figure 3 shows a stratigraphic chart, drawn from measurements of soil depths from the surface to limestone. This allowed us to make an estimate of the amount of available material for pond construction in terms of m^3 of usable soil/m^2 of surface area. This estimate may be very unrealiable, since in some sites the depth of the consolidated material varied significantly among test wells located within a radius of 25 m; however, it does provide a starting point for further evaluation of this important factor. The higher figure for "usable" soil availability corresponds to points 3,4 and 5 in the area of Chuburná Puerto, where average soil depth 2.2 m, meaning 2.2 m^3 of usable soil/m^2 surface area. The smallest figure was found in San Bruno (0.65 m soil depth). This low soil depth would imply the need to use larger surface area to construct each cubic meter of a pond dike.

Soil Chemistry

Soil chemistry was also found to be very homogeneous throughout the sampling points. Table 1 shows the average representative results. Alkaline conditions (pH 7.30 to 8.8) is a common feature as well as low organic matter content (0.5 to 2.5%). These chemical features favour pond productivity (Boyd, 1989) and may also reduce the risk of bottom soil acidification processes. On the other hand, these alkaline soils tend to limit the efficiency of some fertilizers, since reactive phosphorus is chemisorbed onto calcium ions which precipitates

Table 2. Average recorded figures of physicochemical parameters in selected representative sites along the coast of Yucatan.

					PARAMETER			
	TEM. °C	SALINITY	pH	D.O.	NO_3	NO_2	NH_3+NH	PO_4
SITE				mg/l	mg/l	mg/l	$_4$mg/l	mg/l
CELESTUN	o31.0	o34.8	o7.9	o5.5	o0.15	o0.03	o0.12	o0.11
	g28.0	g3.5	g7.5	g3.6	g3.44	g0.11	g1.10	g0.10
SISAL	30.5	37.0	7.9	6.7	0.24	0.08	0.16	0.15
	28.0	3.5	7.7	2.3	3.83	0.42	0.40	0.18
SALINAS	31.0	36.5	8.0	6.6	0.20	0.06	0.13	0.09
	28.0	4.5	7.4	1.8	3.90	0.16	0.23	0.17
SAN JOSE	31.0	37.0	8.0	8.2	0.20	-	-	-
	26.5	1.8	7.3	2.9	3.1	-	-	-
CHUBURNA	31.0	36.5	7.9	8.0	0.17	0.08	0.18	0.12
PTO.	26.0	1.8	7.5	3.1	4.0	0.62	0.60	0.18
CHICXULUB	28.0	37.0	8.2	8.3	0.18	0.06	0.07	0.09
	26.5	3.0	7.0	1.8	11.02	1.18	0.46	2.03
SAN BRUNO	28.0	37.0	8.2	5.8	0.31	0.05	0.06	0.07
	26.5	5.7	7.6	4.3	4.84	0.40	0.17	0.08
SN CRISANTO	28.0	38.0	8.0	6.7	0.27	0.07	0.13	0.08
	27.0	5.0	7.4	3.3	4.32	1.07	0.23	0.09
CHABIHAU	29.5	37.0	8.2	7.0	0.30	0.08	0.07	0.07
	26.5	3.5	7.6	5.2	3.86	0.90	-	-
M. ORO	30.0	38.0	8.1	7.7	0.18	0.07	0.12	0.11
	27.0	3.0	7.4	5.5	2.66	0.3	0.20	0.4
SAN FELIPE	31.0	38.5	8.2	6.5	0.7	0.07	0.15	0.06
	27.0	6.0	7.5	3.2	8.9	1.03	0.83	0.17

o = ocean water
g = ground water

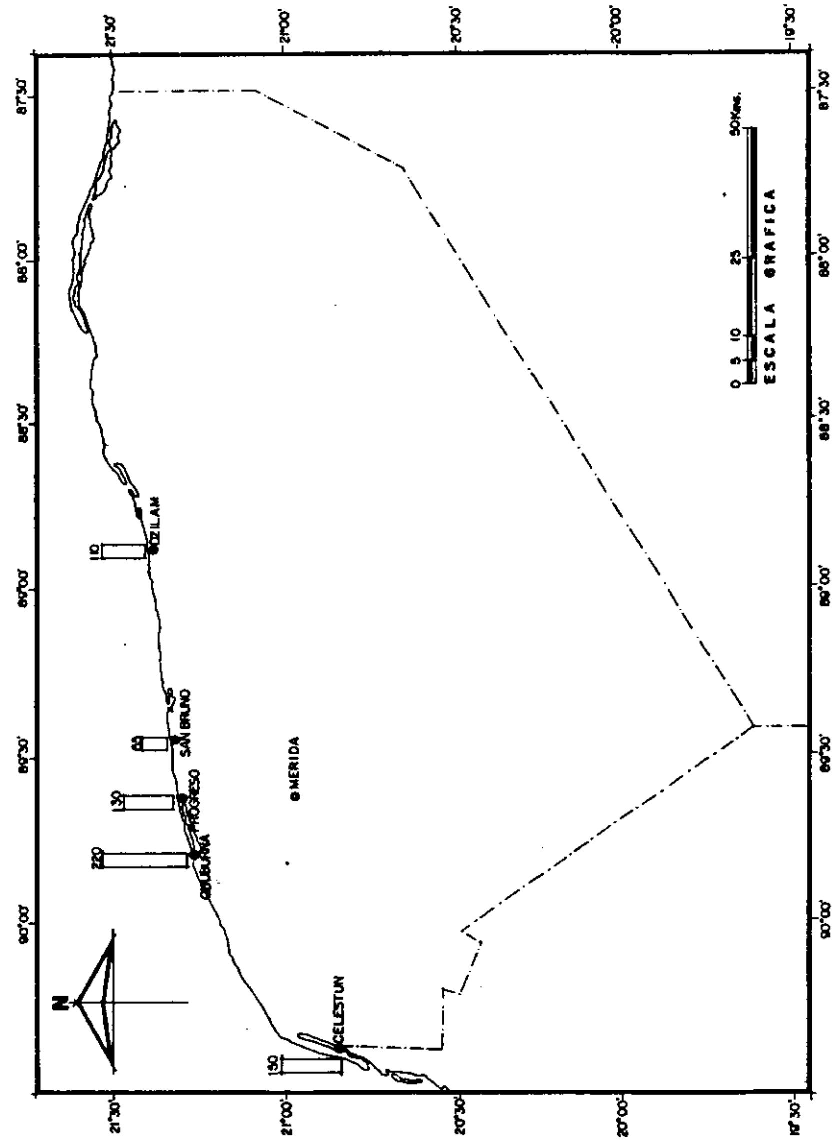

Figure 3. Soil depth in selected coastal sites of Yucatán.

as calcium phosphate. However, some trials have shown that the fertilizer Diammonium phosphate works well in local soils and could be an important alternative (Flores-Nava, 1990c).

Water Quality

Table 2 shows the means of some of the basic water quality parameters for five representative sampling sites of coastal Yucatán. Samples correspond to ocean and brackish water obtained from artesian wells. An interesting feature is the high stability of temperature and pH both in the open sea and in the wells. These figures come not only from the preliminary field studies carried out for aquaculture purposes, but also from a series of water quality monitoring programmes carried out over a number of years in coastal lagoons, open sea sites and coastal artesian wells (Parra, 1990; Concha, 1992). The lowest temperature recorded has been 23°C during January of 1989 (Flores-Nava, 1990b), this is not an ordinary reading. The average temperature of ocean waters in the area is 28.2°C and 26°C in artesian wells.

As mentioned originally, ground water is influenced by a marine water intrusion which, during the dry season, pushes the freshwater lens of lower density backwards, for several kilometers.

The salinity of oceanic watert is constant throughout the year. Parra (1990) found that salinity was not affected during the wet season in the oceanic waters in several points along the coasts of Yucatán, suggesting that turbulence plays an important role.

Conversely, during the wet season the rainfall infiltrates into the aquifers, this increases freshwater discharge into coastal waters and pushes back seawater intrusion. These movements of the water lens creates salinity gradients; therefore, artesian wells excavated near the coastal dunes can provide naturally-filtered brackish water for aquaculture processes.

Minimum and maximum recorded salinities from coastal wells are 1‰ and 8‰, respectively, depending on the season. Wells that reach the interface (marine/freshwater) or are near it, can easily provide water with salinities that fluctuate between 12 and 26‰. If the dynamic level of the well is beyond the confinement layer that physically separates the freshwater table from the more brackish water of surface layer, then it is possible to obtain pure freshwater.

There is enough evidence to suggest that large amounts of nutrients are discharged into coastal waters via the aquifers (Concha, 1992). This was reflected in the overall high concentrations of nitrogen and phosphorus, in the coastal wells. However, there is high variability among sampling sites, with higher levels of nutrients corresponding to sites close to population centres. Some areas of the coast are heavily populated and domestic sewage is in most cases discharged into septic tanks from which it can reach the aquifers. From the samples taken, the highest nitrogen and phosphorus concentrations corresponded to Chicxulub, suggesting contamination from antropogenic sources. The rest of the sites sampled show waters of overall good conditions for aquaculture.

Land Elevation and Tidal Pattern

This is an important factor for hydraulics in an aquaculture system and, cannot be separated from the tidal pattern in a given site or region. In general terms, Yucatan's littoral present a relatively low tidal oscilation, with a maximum of 0.90 m. This is the case for most of the Gulf of Mexico. The advantage of this low oscilation is that it is possible to pump water for 24 hours, year round. On the other hand, since land elevation is too low, during maximum high tide complete drainage of ponds is impossible, because pond bottom is lower than sea water level. There are also small elevation differences along the coast; in general terms, northwestern coastal plains are at a lower level than those of the northeast. Within this broad selection it was possible to observe that Chubuerná Puerto and adjacent zones, which are affected by Chelem coastal lagoon, are the lowest in altitude with respect to sea water level. Whereas, Dzilam, Telchac and San Bruno presented the highest elevation. Elevation is important since drainage of ponds and slopes of inlet and outlet canals are dependent on land height and the sea level. These factors demanded a serious consideration of the design when constructing pond structures.

DEVELOPMENT OF COASTAL AQUACULTURE IN YUCATAN

The results of the above evaluations led to the conclusion that there is a considerable potential for coastal aquaculture in the region, provided that construction processes and design of the infrastructure are adapted to the local conditions. The potential in terms of "usable" soil for pond construction, together with good water quality conditions and access to basic services, was first estimated to be 6,500 Ha, of which aproximately 5,000 were on the north and northeast and 1,500 on the northwest of the State.

As a direct result of the above studies, public interest motivated the start of a first commercial pilot-scale mariculture project. That is the construction and operation of a semi intensive shrimp farm at the vicinity of Dzilam, on the NE. The design provided inflow of water through a canal opened from the beach to a pumping station, from which water would be pumped up to an earthen distribution channel whose floor (lowest point) was above water level in the ponds, thus distributing water by gravity. Ponds had 1 Ha of bottom surface, and each had a smaller (0.3 Ha) pond for the nursery stage duplex-system (Figure 4). Pond walls were constructed by excavating the soil on both sides so that internal and external drainage canals were constructed simultaneously. Since some lower points of the farm were below maximum sea level at high tide, the main drainage canal has a sluice gate for controlling water movement. To overcome this drainage problem especially at harvest time, a dual alternative

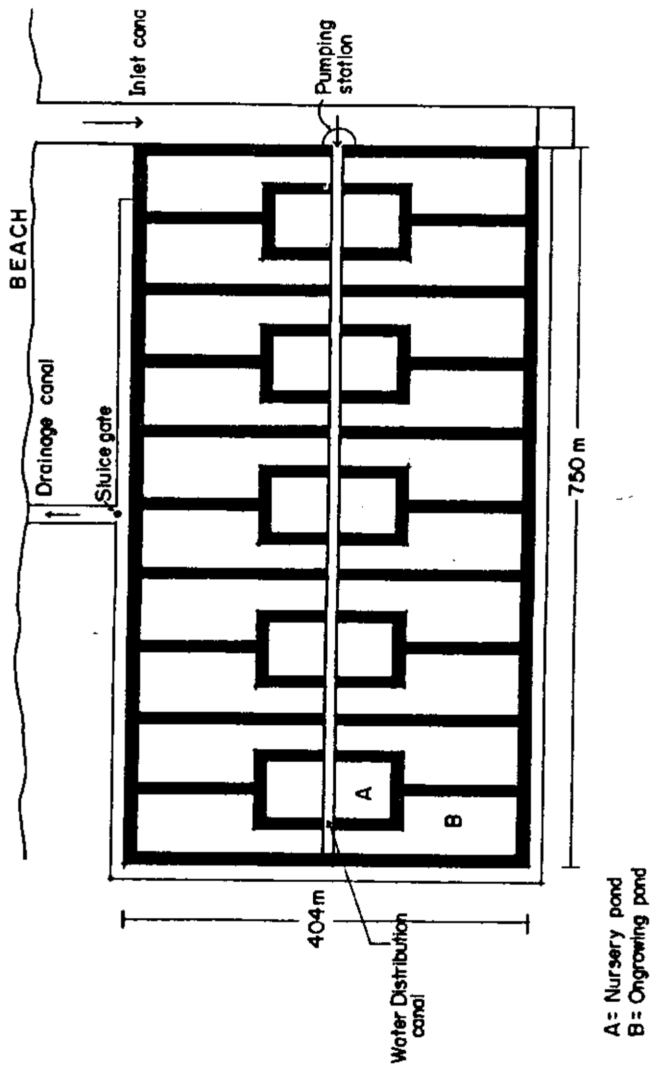

Figure 4. Lay-out of the pilot-scale shrimp form of Dzilam, Yucatán.

internal/external harvest structure was included in each pond. That is, if harvest has to be carried out during high tide, shrimp could be concentrated in an internal harvest area. If harvest is carried out during low tide, the pond could be drained completely and the shrimp collected in the external harvest structure in the drainage canal.

Even though this first project was never completed, 35% of the infrastructure was built and hydraulic tests were carried out. This showed that the soil was adequate for pond construction and that specific modifications in the design could overcome drainage limitations.

After this first approach, some smaller mariculture projects were started in the Yucatan. An *Artemia* demonstration farm was constructed in San Crisanto, close to Dzilam. The aim of this project, run by the central Bank of Mexico, is to produce adult Artemia biomass for the regional ornamental fish market. The farm is a semi-intensive complex of 10 - 0.1 Ha earthen ponds which are regularly inoculated with laboratory hatched nauplii of a local strain of *Artemia*. The farm has a deep well which provides almost freshwater (3-5 ‰) for mixing processes. Hyperhaline water (90-170 ‰) is generated in two 0.2 Ha adjacent ponds through solar evaporation. Feeding is done by applying organic (cattle manure) fertilizers into the ponds as well as finely-ground rice husks.

Three pilot-scale blue crab (*Callinectes sapidus*) production projects were initiated in fishing villages of Dzilan, Teidrac and Chelem. Blue crabs are the only bait used for octopus fishing, this imposes an extremely high demand for the crustacean during the octopus fishing season (August through December). It is during this time of the year that prices of blue crab rocket. This moved some fishing cooperatives to look for technical assistance to set up some extensive aquaculture systems for blue crab. The systems consist of pens of 1 to 4 Ha placed in shallow, sheltered inner lagoons where juvenile crabs are stocked and fed trashfish. Once they reach 11.5 cm in approximately 4 months, they are harvested and sold locally.

REGIONAL SPECIES WITH POTENTIAL FOR AQUACULTURE

There is a rich fauna in the coastal systems of Yucatan, which include fish, crustaceans and mollusks of commercial importance, some have aquaculture potential. Table 3 presents a summary of species and the state of development of their culture/fishery technology. The white shrimp *Penaeus setiferus* has been experimentally reared with promising results in the region (Flores-Nava, 1990b), as well as the local strain of *Artemia* whose biological and nutritional attributes are currently under research (Torrentera *et al.*, 1991). Grouper is also a promising prospect although much research on its biology is still needed before trying its cultivation in the region. Other important fish species present in the area although not abundant in the catches are the red snapper *Lutjanus*

Table 3. Species with potential for mariculture in Yucatán.

Species	Common Name	Degree And Type Of Exploitation	Aquaculture Development In The Region	Reference
FISH				
Epinephelus morio	Mero (S)	High, Fishery	Under Research	Brulé *et al.*, 1991
Lutjanus campechanus	Huachinango (S) Snapper (E)	Fishery	Moderate, Nonexistent	Arreguín *et al.*, 1987
**Oreochromis* sp	Tilapia (S, E)	Low, Aquaculture	Incipient	Suresh & Lin, 1992
CRUSTACEANS				
Penaeus setiferus	Camarón blanco (S)	High, Fishery	Experimental	Flores-Nava, 1990a
Artemia sp	Artemia (S, E)	Low, Aquaculture	Pilot Scale 1991	Flores-Nava,
Callinectes sapidus	Jaiba (S) Blue Crab (E)	High, Fishery	Pilot Scale	Martínez, 1992 pers. comm.
MOLLUSKS				
Strombus gigas	Caracol Blanco (S) Queen Conch (E)	High, Fishery	Under Research	Aldana & Brulé, 1993

S = Spanish
E = English

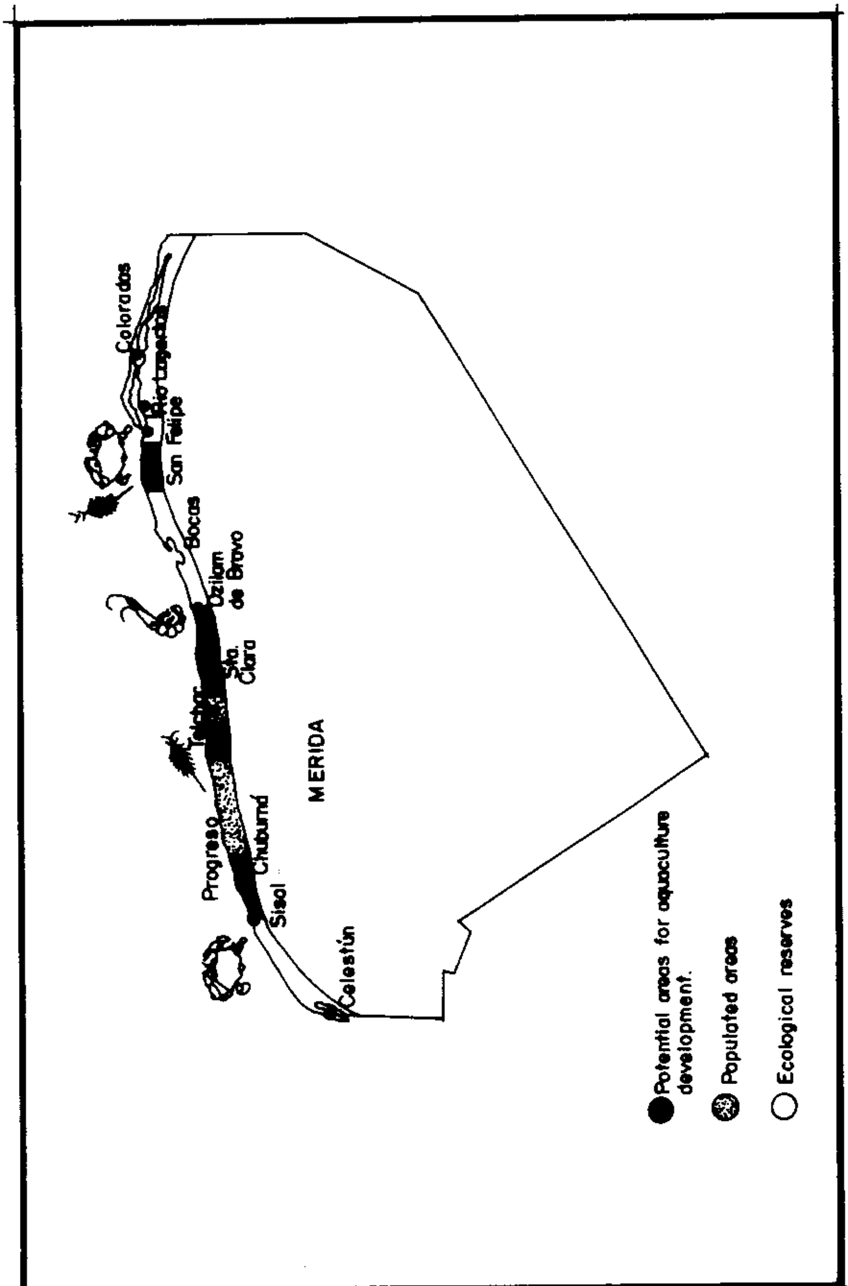

Figure 5. Potential areas for coastal aquaculture development in Yucatán.

campechanus and Mullets *Mugil* sp. which are already cultured in other countries (Bardach *et al.*, 1986).

As far as mollusks is concerned, considerable effort is currently being put into research and management of conch (*Strombus gigas*) because of heavy fishing and stock depletion (Aldana and Brulé, 1993).

PERSPECTIVES

As mentioned before, the coastal areas of Yucatán are the platform for a variety of socio-economic activities, which compete among each other for space and water resources. Of the 6,500 Ha of coastal plains and marshes that were detected as potential for coastal aquaculture development, more than 220 km of coastline and adjacent areas are part of ecological reserves, as well as some 35 Km of population centres and touristic infrastructure. Of the balance (123 Km of coastline) an estimated 1,250 Ha could be available for coastal aquaculture (Figure 5).

The State of Yucatán has an important road system which connects the coast with major ports such as Progreso, and to international airports like Merida's. Basic services, electricity, feed plants, higher education on marine sciences and growing regional market for sea products all give the region a potential for industrial coastal aquaculture.

Expansion of aquaculture activities will depend very much on demonstration units as well as government incentives, which stimulate public interest on non-traditional activity.

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