"WATER RESOURCES AND FRESHWATER AQUACULTURE DEVELOPMENT OF YUCATAN, MÉXICO"

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Thesis submitted for the degree of Doctor of Philosophy.

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University of Stirling.
November 1990.

G. a D.

A mis hijos. Por ellos la lucha constante y anhelo de ser mejor.

Nuestra razon de vivir.

A mi adorada esposa Ligia, la companera ideal. No solo por su apoyo permanente, increible paciencia y por compartir el sacrificio, sino por todo lo que representa para mi.

Con amor a mi madre. A ella debo lo que soy.

Gracias por todo senora, con mi carino.

I declare that this thesis has been composed by myself and that it embodies the results of my own research. Where appropiate I have acknowledged the nature and extent of work carried out by others in this thesis

alex Flores

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ACKNOWLEDGEMENTS

I am deeply indebted to my main supervisor, Dr. Michael Phillips, for his guidance and encouragement during this study.

I am especially grateful to Dr. Lindsay Ross for his encouragement and help throughout this study. Thanks to him and Eduardo Mendoza, I am now less ignorant about Geographical Information Systems.

I am also very much indebted to Dr. Malcolm Beveridge for his suggestions and revision of the manuscript.

I would also like to express my deepest gratitude to Allan Stewart, for sparing so much of his time and sharing some of his knowledge on aquaculture economics.

I am especially grateful to Drs. Carlos Martinez and Cristina Chavez for their encouragement, invaluable help and most of all, for their greatly appreciated friendship. In a way they made this possible.

Many people assisted me in those long, hot and tiring days in the field, as well as with laboratory work. Especial thanks are given *to Mr. David Valdes and Mrs Elizabeth Real for their enormous help with the water quality and chemical analysis. Also Manuel Sanchez, Julio Vizcarra, Alicia Garcia, Luis Cancino, Carlos Castro and Eloy Gil and Wilberth Che helped during the land-based surveys, the water quality samplings and the aquaculture trials.*

I would also like to acknowledge the enormous support provided by my Institution, the Centro de Investigacion y de Estudios Avanzados del IPN-Merida, during the course of this work. I am also grateful to the British Council and the Consejo del Sistema Nacional de Educacion Tecnologica (COSNET) for their financial support. Without their aid this could not have been possible.

Last but by no means least, I would like to express my gratitude to all the rural farmers of Yucatan who helped in many ways in the course of this study and even shared some of their food. It is mainly for them that this study was carried out.

ABSTRACT

The suitability of aquaculture for inland water bodies in the State of Yucatan, a karstic area of southeast Mexico was investigated. Five types of water bodies distinct in morphometric and hydrological characteristics were identified through land-based surveys. Representative sites for each were selected for further study: a sinkhole, a permanent aguada (clogged sinkhole), a rain-filled seasonal pond, a small (<1 ha) gravel quarry and a large (>9 ha) gravel quarry. The water quality in all of the sites had a high pH (range 7.2-9.4),alkalinity (range 130-840 mg/l $CaCO_3$) and hardness (range 198-998mg $CaCO_3$/l). . Their nutrient status varied from the permanently stratified and hypereutrophic conditions in the permanent aguada, to oligotrophic conditions in gravel quarries. In general, the water quality resulted adequate for fish culture in the gravel quarries, the sinkhole and in the seasonal pond, but ecological considerations prevented sinkholes for aquaculture development.

Aquaculture trials involving the stocking of fry of the native cichlid

Cichlasoma urophthalmus and O. niloticus in seasonal ponds and a small gravel quarry demonstrated the feasibility of neglected water bodies for small-scale aquaculture. A net yield of 180 Kg/ha/6 months was obtained from a gravel quarry fertilised with grass Panicum virgatum and stocked with C. urophthalmus. Yields from seasonal ponds were 157Kg/ha of O. niloticus from a small (0.010 ha), and 30 kg/ha of C. urophthalmus from a large (1.11 ha) seasonal pond (no fertilisation or feeding).

An environmental impact assessment was carried out at an experimental cage site in gravel quarry. An estimated 0.02 kg of phosphorus was wasted per kg fish produced.

A socioeconomic survey on attitudes towards aquaculture adoption was carried out in four agricultural villages and a fishing port. This led to the construction and operation of a small pond demonstration unit. Results suggest that farmers are receptive and adoption of aquaculture as a complementary activity may be feasible and beneficial to rural development, especially in areas with existing water bodies. Economic modelling of the different production units involved showed returns to

labour higher than the average agricultural wage.

A computer-based Geographical Information System identified areas suitable for aquacultural development. Two major areas were identified: the northern Karst plains where gravel quarries are abundant and suitable for intensive cage-culture.; and the southern hilly region where small-scale seasonal aquaculture could be developed .

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

The expansion of agriculture, industry and human population has resulted in increasing pressure on the use of natural waters, especially those of good quality. It is no exaggeration to state that all human activities on land ultimately influence adjacent water resources. Naturally then, most human civilisations of the past originated in river basins, and over the years man has come a long way towards increasing his influence on such waterbodies (Michael, 1987; Heathcote, 1983).

The need for increasing production of animal protein in third world countries and the parallel necessity of sources of water for their growing populations, is one of the major dilemmas that humanity has to face. There is a dramatic decline in water resources due to an increasing demand of water for several purposes which include recreation, industrial operations, sources of drinking water and in many cases, freshwater water bodies act as receptacles of pollutants from various sources. This increased pressure emphasises the need to use water more efficiently and to assess the potential of alternative water supplies, both for aquaculture and fisheries development (Milstein et.al, 1989; Al-Asgahn and Bedawi, 1984)

Fish production through aquaculture also demands substantial amounts of water supplies. The use of such water resources can either be as a direct environment for the cultured organism (e.g. the deliberate stocking of hatchery-reared fish, or the cultivation of fish in cages placed in the given water body), or indirectly by taking water from a natural aquatic environment to utilise it in land-based infrastructure, namely man-made ponds, where it is used and discharged into the environment again

(Wheaton, 1977; Beveridge, 1987). Both forms of utilisation exert pressure upon the environment and conflicts of use of the resource arise when aquaculture competes with other forms of utilisation (SCPCR, 1983).

A number of water bodies around the world, many of them seasonal, offer some scope for fish production through diverse management strategies. For example flood plains, rain-filled ponds and water bodies resulting indirectly from quarrying operations. Such aquatic ecosystems are often neglected even in regions where food production is badly needed. In other areas of the globe, however, these water resources have been successfully managed, demonstrating that food production can be achieved often at little cost from water bodies which do not offer scope for other uses. Below, an overall review of the aquaculture utilisation of the water resources mentioned above is provided.

1.1 Flood plains

A thorough study of flood plains has been published by Welcomme (1979). A summary of the main factors influencing the formation and ecology of these systems is given below.

Seasonal increases in the volume of water carried by tropical and subtropical river channels result in lateral overspill which inundates low–lying ground flanking the river course (Welcomme, 1979). During the dry season only the main channels and isolated depressions remain filled, the rest of the system becoming dessicated. The chemistry of the water in the system is strongly influenced by the flood cycle. During low water, conductivity and temperature rise dramatically in the standing waters of the floodplain. Dissolved oxygen tensions tend to be low and anoxic conditions may pertain in flood plain pools and under vegetation mats (Welcomme, 1979; Beadle, 1981; Moss, 1988). During the floods conductivity and temperature are normally lower and pH and dissolved oxygen concentrations are higher than during the dry season (Welcomme, 1979). A considerable amount of nutrients come from outside to the aquatic environment, in fact the increase in the area of water during the floods releases nutrients from the terrestrial into the aquatic components of the system (Schmidt, 1970; Welcomme, 1979).

There has been a concentrated effort aimed at the taming of floods for the benefit of agriculture since the ancient Egyptian and Indian cultures established around seasonally flooded river deltas (Toynbee, 1976); however, man's present usage is more intense, with riverine fisheries and agro–aquaculture.

Most of the major seasonal floodplains occur in the tropics and subtropics. In North America, in Mexico, the Grijalva–Usumacinta system, floods during maximum level to cover an area of approximately 9000 km^2, a considerable proportion of which is used for extensive and semi–intensive culture of exotic and native cichlids (Resendez, 1979).

Deliberate stocking of fingerlings of Colossoma macropomum in the floodplains of Catarumbo river in Venezuela in South America, is carried out when the floods have reached 0.60 m, both with the aim of replenishing natural stocks and of rear them in "corrales" or pens during the wet season (Smith, 1981).

Also in South America, the huge floodplains of the Paraguay river, have served for centuries as the main source of protein for the rural communities that have purposely settled on its high levees. Brazil, with its 7 million km2 of the Amazonas basin, harbours more fish species than any other freshwater ecosystem in the world. The sparse human population of the Amazon region, estimated at 4.7 million is also concentrated along the rivers and floodplains, to take advantage of the aquatic fauna during flood time and of rich soils for cattle grazing during the dry season (Smith, 1981).

Welcomme (1979) states that in Europe the Danube is the major river with surviving floodplains, which after reclamation extend for 5000 km2 in Rumania, Hungary and Czechoslovakia. Of this, just a small area is used for integrated aquaculture/agriculture (Sinha and Olah, 1982).

Although nearly all African rivers have extremely well developed fringing floodplains, very few are reported to be making use of them in terms of aquaculture. In Botswana, the greatest fishery resource lies within the natural waters of the Okavango river, which forms a floodplain of approximately 10,000 km2 in the Kalahari dessert during peak volume in its annual cycle. Approximately 54,000 people live along the western and southern fringes of the delta and most of them are involved in fishing on a seasonal basis. There are plans for carrying out fishfarming in a more regular basis (Gilmore, 1978).

In Asia, a good example of the utilisation of floodplains for fish production is Sri Lanka. The floodplains of this country are vegetated land areas seasonally saturated with water, locally known as "villus". The total estimated area of floodplains is 40,000 ha (De Silva, 1988). They differ in size, and the smaller and more manageable are utilised for carp and tilapia culture in a seasonal basis (Thayaparan, 1982). Fish rearing in floodplain rice paddies is widespread throughout Southeast Asia, and the production of major rivers such as the Ganges and Brahmaputra, combine to give some 1.25 million tonnes of fish (Welcomme, 1979). In areas where more developed floodplains exist, the shape of the lagoons are often regularised, and eventually drain–in ponds are dug into the surface of the plain. The fish grow in these ponds and are captured when they are large enough to be commercialised (Jhingran, 1985).

It is clear from the above the importance of floodplains as seasonal resources of food for millions of people around the world. However, even though they provide a considerable amount of fish to sustain large human populations, the simple exploitation of fish stocks does not realise the full potential productivity of the system. Floodplains, as other water resources, are in increasing demand for purposes other than fisheries or aquaculture, hence the need for development of appropriate management strategies for fishculture and fish stock conservation.

1.3 Seasonally rain-filled ponds.-

Temporary ponds are essentially natural water bodies which experience a recurrent dry phase of varying duration. A differentiation should be made between floodplains and rain-filled ponds, in so far as the former, as previously explained, originate only as a result of main river channel overspill, and extend as water sheets covering vast areas, which become dessicated during the dry season; whereas the latter can be the remaining pools left by the flood water when they retract, or in most cases, are land depressions filled directly by rainfall and runoff, and normally hold water for a longer period of time, since they are deeper (Welcomme, 1979; Arredondo, Garcia and Martinez, 1982; Williams, 1987).

Precipitation is the most important factor influencing the formation of cyclical ponds. Rainfall that reaches the soil surface is taken up by filtration. In clayey soils water collects in the surface in small depressions and forms puddles and small trickles. If the intensity of precipitation is greater than the infiltration capacity of the soil, overland flow starts and if the topography is such that the water cannot flow away in a channel, then it collects in a low point and forms a pond (Williams,1987). The cyclic pattern of water levels is normally associated to chemical and physical changes that take place as a result of the interaction of soil, water and vegetation cover (Porras, 1985). As ponds are being filled, conductivity increases as a result of nutrient release from the vegetation cover, but gradually starts to decline due to dilution processes (Arredondo, Garcia and Martinez, 1982). Dissolved oxygen can fluctuate diurnally as a result of photosynthesis and respiration. Turbidity is initially high as a result of an increase in primary productivity, due to high availability of nutrients and to bottom disturbances, but also gradually decline towards maximum water level (Arredondo et.al, 1982). A great number of temporary waters are colonised during the filling stage by diverse species of fish, molluscs and crustaceans, through connecting brooks to permanent water bodies (Williams, 1987).

These seasonal rain-filled ponds are used for aquaculture in many parts of the world, in a variety of different ways.

The Dombes ponds of France are part of a platform to the Northeast of Lyon, consisting of long morainic mounds created by quaternary glaciers. Water for filling these ponds comes either from a larger pond situated at higher elevation or from a series of ditches which lead into the pond and which collect rain water. When filled, each pond is stocked with fish, usually carp. After the fish have been harvested and the pond bed is dry enough to be workable, it is then ploughed and planted with cereals. This rotational system has changed little since the fourteenth century, in an area of ponds of 11,000 ha (Williams, 1987).

In the tropics, basins of floodplains lose water as the dry season increases evaporation, thus they tend to diminish in size with increase in time since the last flood. In Amazonia, in Brazil, a series of depressions located between maximum and minimum flood levels, are filled annually, retaining water and enhancing productivity, reaching a peak once the dry season is well advanced. These are called Varzea Lakes (Goulding, 1981; Williams, 1987). Many young fish enter the Varzea lakes at times of flooding, and are retained there until they die under drought conditions. Many tribes of the Amazonia have made use of these lakes and natural ponds to obtain fish. They just wait for the retained fish to grow and capture them by traditional methods (Goulding, 1981).

Sri Lanka has nearly 30,000 ha of seasonal tanks, which for most purposes are comparable to fish ponds: they are small in size, they dry up for 3–4 months of the year, and they are highly productive (Silva and Davies, 1986; De Silva, 1988). Plans have been drawn up for the use of seasonal tanks for fish production on a larger scale (Thayaparan, 1982). The seasonal tanks usually dry up completely between July and September, and fill during the time of the North–east monsoonal rains by the following December–January. Large quantities of droppings are left behind by cattle who graze in the catchment area as well as in the tank during the dry season. In the rainy season, large amounts of plant material including fallen leaves enter the tank with incoming water.

Terrestrial vegetation which grow within the land depression during low water level, get submerged after the first rains, and increase the organic matter in the tank. All these make the seasonal tanks rich in organic matter and primary productivity (Chandrasoma, 1986). Those tanks which retain water for six to eight months are selected for fish stocking. The species chosen are the Indian major carps such as mrigal, catla Catla catla, rohu Labeo rohita and the Chinese carps Ctenopharyngodon idella (grass carp), Aristhycthys nobilis (bighead carp) and Hypophthalmichthys molitrix (silver carp), which have been successfully artificially spawned in Sri Lanka and high yields are obtained (Wijesekera, 1978; Thayaparan, 1982; De Silva, 1988) (Table 1). Some of these tanks have been provided with sluices so that enriched water from the ponds is passed to rice paddys when early harvests are practiced (De Silva, 1988).

In many parts of Mexico, it is customary to set up cattle farms where land depressions are common, since these are filled during the rainy season and thus serve as water–storage ponds which are water drinking places for the cattle during the dry season. These temporary water bodies are locally known as "Jagueyes" (Arredondo, Garcia and Martinez, 1982). In these cyclic ponds, the droppings of cattle enrich the water thus increasing natural productivity and consequently enhancing production in higher levels of the trophic chain. As the rainfall fills the jagueyes, the nutrient–rich soils and their vegetation cover, release nutrients as they become flooded, triggering algal blooms, which soon die off and stabilise due to dilution as water level increases. Cattle excreta becomes a constant supply of organic fertilizer and productivity in the ponds is maintained high enough to support a fish population which is normally stocked once oxygen levels in the system have stabilised after the initial drastic fluctuation resulting from the oxidation of organic matter at flooding time. Tilapia (Oreochromis spp) and common carp (Cyprinus carpio) are stocked at low densities as juveniles and they are harvested six to eight months later, when the water level has been reduced due to increased evaporation. Yields of 450 kg/ha/year are obtained from these seasonal water bodies (Rosas, 1976; Arredondo, Garcia and Martinez, 1982; Arredondo et.al, 1982; Porras, 1985) (Table 1).

Many industries around the world produce cement, lime, sand and gravel for building purposes. These industries are strategically located in areas where natural occurrence of soils whose physical and chemical properties facilitate the extraction of raw materials for their objectives. These industries base their operations on the excavation of large pits to below the water table, creating ponds, some of them vast in surface area, which since they are connected with underground water, are always filled and fluctuation of the water level are not pronounced. In general terms, the limnological conditions of an excavated quarry are comparable with those of a natural lake. This applies first of all to the thermal dynamics of the water. In temperate climates, an excavated pit undergoes annual thermal periodicity.

Shallow pits stratify only temporarily in temperate climates and may not stratify at all in warm latitudes (Luckowitz, 1979). Since most quarries are isolated and newly filled, their waters tend to be oligotrophic, and their water chemistry dependent almost entirely on the chemical composition of the infiltrating ground water. However, some of these water bodies are located in areas where the topography allows runoff to carry a considerable amount of organic matter into the pits, in which case they become eutrophicated and are able to sustain large populations of fish and other species. There is increasing interest in the use of sand and gravel quarries for fishery purposes.

In North America, in the state of Tabasco, Southest Mexico, a growing number of sand pits are being excavated, many of which present ideal conditions for growth of both exotic and native fish species. Experimental trials of cage culture of Cichlasoma urophthalmus, and C.synspilum, have shown the suitability of such native species for aquaculture in sand pits (Flores–Nava, Olvera and Garcia, 1989a,b). In the same state, the local government has introduced an extension programme aimed to the optimum utilisation of the abandoned sand pits of the region, where tilapia (Oreochromis spp) is being reared in cages with productions of up to 20–40 kg/m3 (Anon, 1986) (Table 1).

In Florida, U.S.A., just in one county 3,000 ha of limestone quarries are reported. In some of these pits, catfish Ictalurus spp are being grown both in cages and free–stocked, with yields of approximately 4.5 tons/ha/year (Conrad, 1988) (Table 1). In the state of Minnesota, in its Mesabi iron range, around 20 abandoned iron ore pits of various sizes have been stocked with rainbow trout with good success, and a project to culture this species in cages at a pilot scale is also being considered (Anon, 1987).

In Europe, large areas of gravel quarries in England, Wales and Germany are being used as put–and–take managed lakes, or as water bodies for cage aquaculture, with excellent results (Behrendt, 1979; Luckowicz, 1979). Clearly, the rapidly increasing number of excavated quarries represent a high aquaculture potential if properly managed, thus giving a productive use to water bodies otherwise neglected.

Table 1. Summary of production figures from diverse water body types around the world.

Type of water body	Yield kg/ha/yr	Country	Author
Dombes ponds–		France	Williams,1987
Varzea Lakes–		Brazil	Smith, 1981
Villus	6,900	Sri Lanka	Chandrasoma,1986
Jagueyes	450	Mexico	Arredondo et al 1982.
Gravel quarries	4,500	U.S.A	Conrad, 1988.
Sand pits	6,500	Mexico	Anon, 1986

1.4 Introduction to study.-

The above review shows that a number of water bodies of different nature and with no other prioritary use present in many countries whose limiting factor for aquaculture expansion is water supply, are being properly managed in many other areas of the globe through aquaculture at different levels.

In the Southeastern part of Mexico, the Peninsula of Yucatan is characterised by its absence of surface hydrological systems, due to the porous limestone that covers most of its soil. Main sources of water for the population of the region are underground. However, a large number of small water bodies of different hydrological nature, many of them seasonal, are present. Nevertheless they are so far either neglected or underutilised. The aims of this work were to carry out a detailed survey of the inland water resources of the state of Yucatan, Mexico, to assess their water quality and potential for aquaculture development, as well as the socioeconomic implications of the introduction of a non–traditional activity into the framework of the overall rural development of the region.

CHAPTER 2

THE STUDY REGION

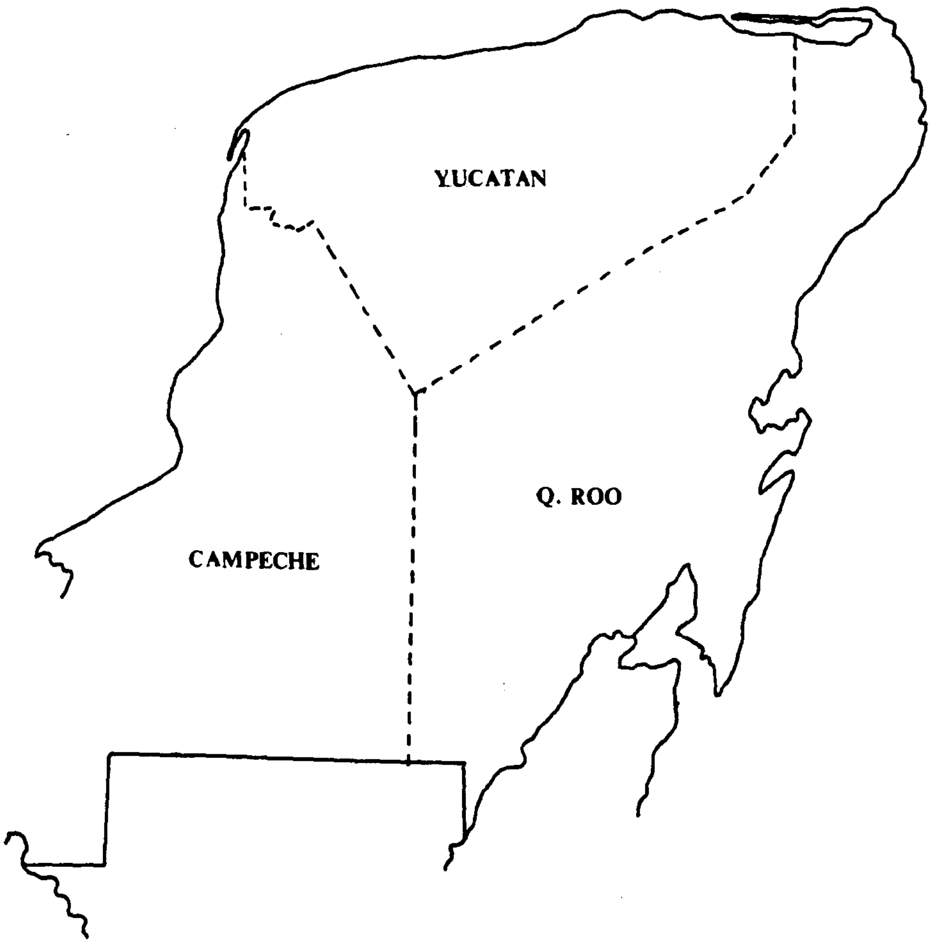
2.1 Geographic location.–

The Yucatan Peninsula is a great thumb–like projection from Mexico and Central America, between the Caribbean sea on the east and the Gulf of Mexico on the north and west. Located between the meridians 87 32' and the parallells 19 06', the Yucatan state forms the northern part of the Peninsula with the same name, flanked by the state of Quintana Roo to the East, and by the state of Campeche to the Southwest (Fig 1).

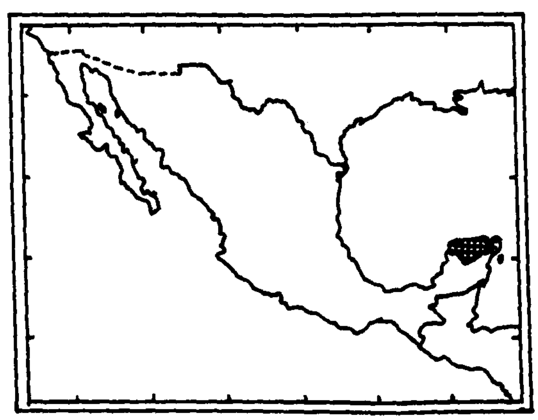
2.2 Hydrogeology.–

The northern third of the Peninsula, as much as 150 km wide, is an almost level karst plain underlain by nearly horizontal tertiary formations consisting chiefly of limestone, marl and gypsum (Stringfield and Le Grand, 1974). It ranges in elevation

Figure. 1. Map showing the geographic location of the Yucatan peninsula, southeast Mexico.

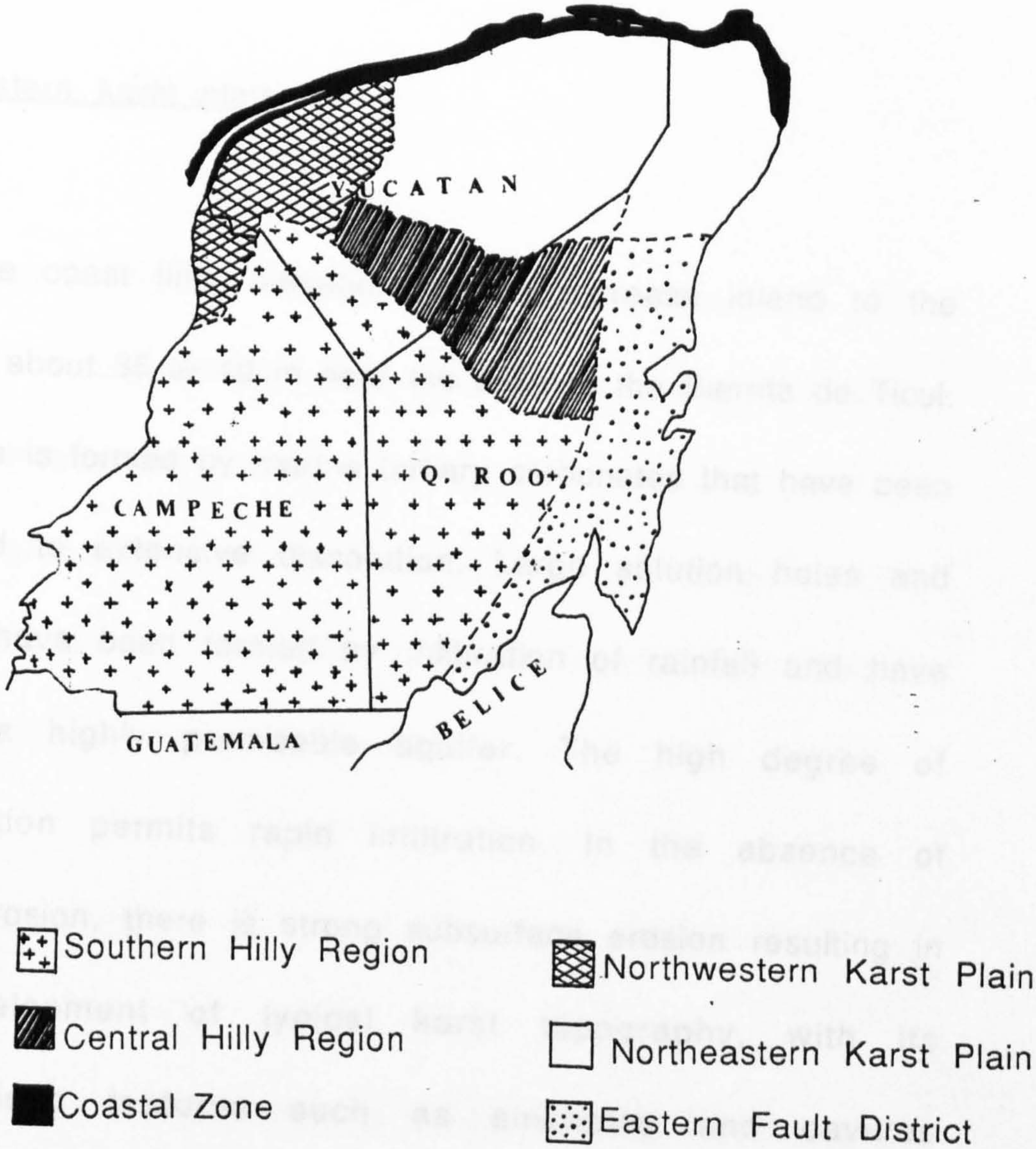


YUCATAN
Q. ROO
CAMPECHE



from sea level along the coast to about 4 m above the sea level in the interior (West, 1967). There are no surface streams. Bare, fluted limestone is exposed over large areas. The limestone is pitted and scarred by solution depressions and small ridges. Southward the land rises gradually with Sierrita de Ticul range creating a boundary between the karst plain and a zone of thicker organic soil at the south. Isphording (1975) subdivided Yucatan into three major physiographic districts: 1) a large submerged shelf, bordered by steep escarpments; 2) a northern coast plain region and 3) an area of hills that extend southward into the foreland of Chiapas State. Back and Hanshaw (1974) had previously proposed a subdivision of such physiographic regions, into five geomorphic regions, also supported in a modified version by Isphording (1975) and later by Lesser and Weidie (1988), which includes the subregions shown in Figure 2 whose main characteristics are given below.

Figure 2. Geomorphic subdivision of the Yucatan peninsula (Modified from Back and Hanshaw, 1974; Isphording, 1975 and Lesser and Weidie, 1988).



YUCATAN
CAMPECHE
Q. ROO
GUATEMALA
BELICE
Southern Hilly Region
Central Hilly Region
Coastal Zone
Northwestern Karst Plain
Northeastern Karst Plain
Eastern Fault District

Northeastern karst plain.–

From the coast line, elevations gently increase inland to the south to about 35 to 40 m near the base to the Sierrita de Ticul. This area is formed by marine tertiary carbonates that have been subjected to extensive dissolution. Large solution holes and cavities have been formed by infiltration of rainfall and have formed a highly permeable aquifer. The high degree of karstification permits rapid infiltration. In the absence of stream erosion, there is strong subsurface erosion resulting in the development of typical karst topography, with its characteristic features such as sinkholes and cavities (Stringfield and Le Grand,1974; Isphording,1975: Gaona–Vizcayno, Gordillo–De Anda and Villasuso–Pino, 1980; Lesser and Weidie, 1988).

Northwestern karst plain.–

The features of this karst region that differ from those of the larger northeastern karst plain, are the higher land elevation toward the southwest of the region, where richer soil and higher humidity give raise to more diversified water body types, hence the presence of sinkholes in larger numbers as well as permanent and seasonal aguadas.

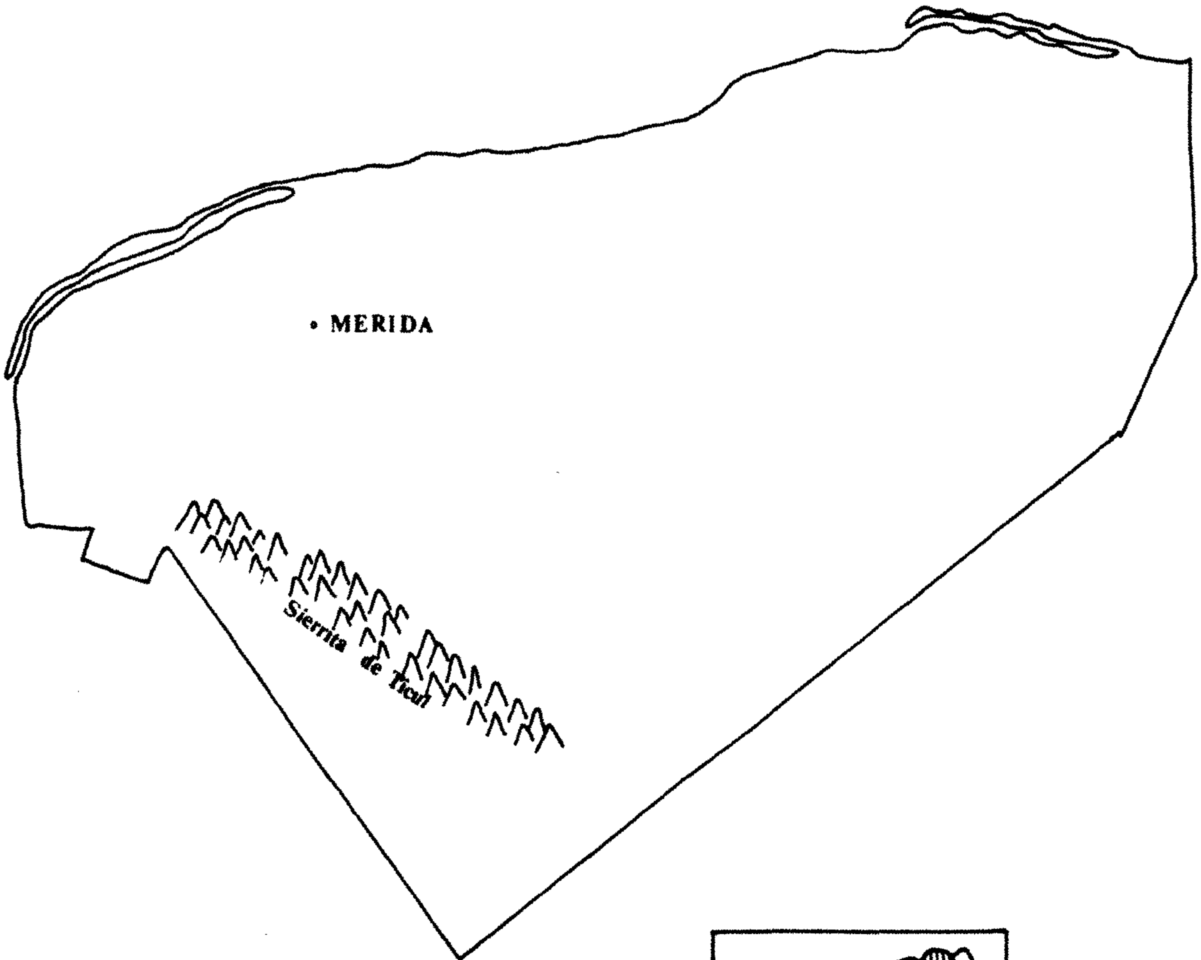
Central hilly region.–

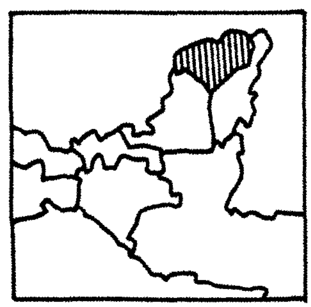
In this zone, the topography is varied. there are isolated, low relief, conical karst hills about 40 m above the surrounding land level. The plain is formed by Eocene carbonates. The high fracture permeability of these carbonates is reflected in low gradients of the water table. In places, the water table is 100 m beneath the surface, making ground water exploitation difficult and costly.

Southern hilly region.–

Between the extensive plains of northern Yucatan and the hills of the south, there occurs an elongated topographic high, known as Sierrita de Ticul (fig 3). It is composed of Eocene limestones, trends northwest to southeast and is 160 km long and 15 km wide (Lesser and Weidie, 1988).

Figure 3. Map showing the Sierrita de Ticul range, separating two geomorphic subdivisions. The central and the southern hilly regions.


MERIDA
Sierrita de Ticul



South of the line of hills, deep sinks are scarce, instead, there are many broad, shallow depressions, locally known as "aguadas", some of which hold permanent small lakes, perched above water table. Infiltration of water in these water bodies is retarded by clay (Back and Hanshaw, 1974).

Eastern fault district.-

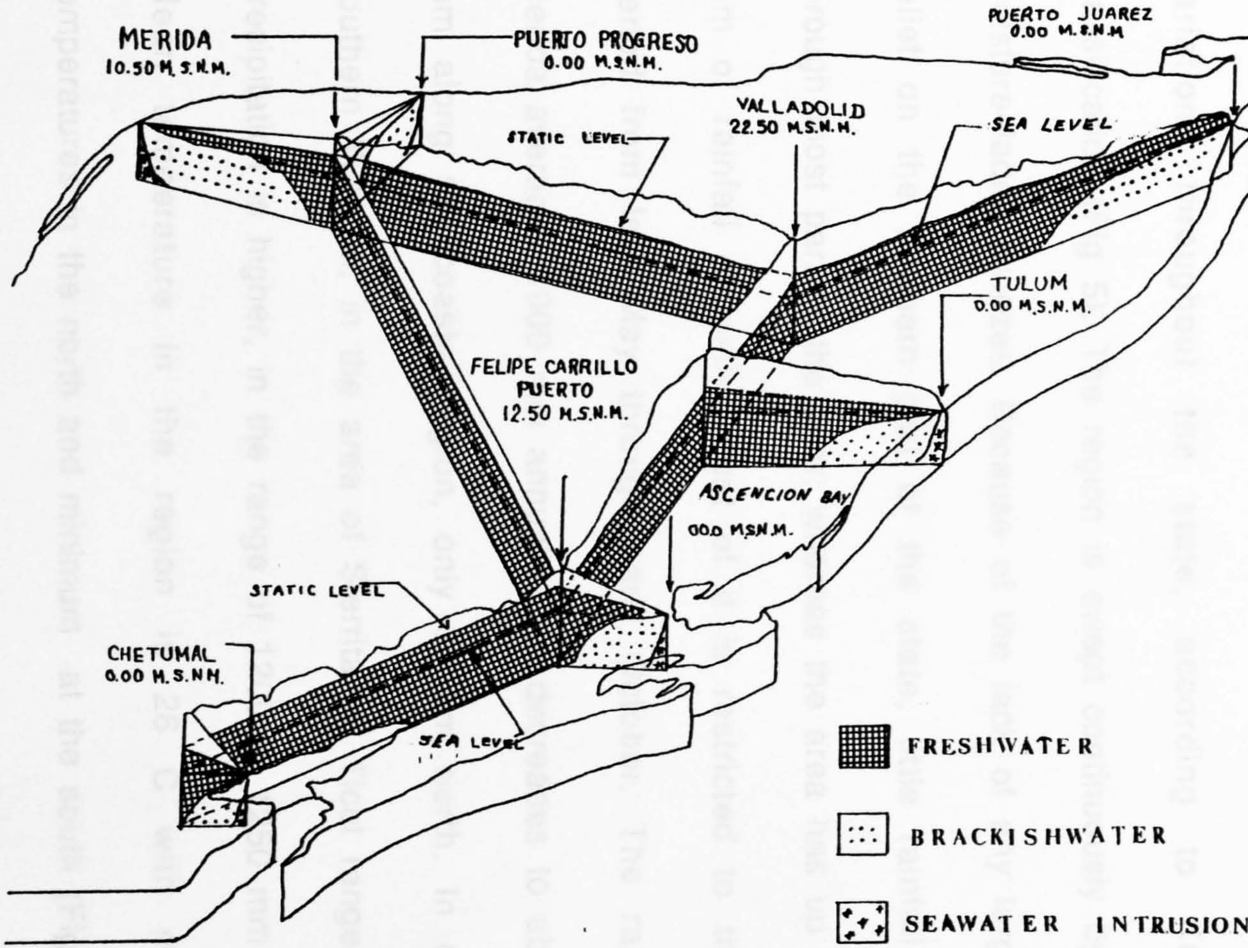
This area about 80 km wide extends from northeast to southwest and covers just over 10 % of the eastern part of the sate of Yucatan. Its main characteristic is that the rock has been faulted by normal faults varying in lengths and displacement. Sinkholes and cavities are also present.

2.3 Ground-water dynamics.-

In the highly permeable rocks of northern Yucatan, a deep, extensive freshwater lens exists above a salt water intrusion that penetrates more than 40 km inland (Back and Lesser, 1981; Gaona–Vizcayno et al, 1985; Perry et al., 1989). In northern and southeastern plains the freshwater lens is 30 to 70 m thick and overlies the saline water, which is found at depths of 40 to 80 m (Lesser and Weidie, 1988) (Fig. 4). Rainfall over Yucatan infiltrates and the fresh ground water moves seaward towards the coastline. There is constant replenishment of freshwater in the upper part of the aquifer, and salinities increase at greater depths. Owing to the high permeability of the carbonates, the water table is only a few centimetres above sea level,

and its altitude increases inland (Perry et.al., 1989). Because of this, the salt water interface is close to the surface, and the water forms a thin wedge. Sea water intrusion occurs in annual cycles. No recharge during the rainy seasons, combined with exploitation of aquifers, permits the advance of saltwater to as much as 40 km inland. During the rainy season with its major recharge and lower pumping rates, there is there is a seaward retreat of the interface (Lesser and Weidie, 1988).

Figure 4. Major groundwater paths in the Yucatan peninsula (Modified from Lesser, 1976).


MERIDA
10.50 M.S.N.M.
PUERTO PROGRESO
0.00 M.S.N.M.
PUERTO JUAREZ
0.00 M.S.N.M.
VALLADOLID
22.50 M.S.N.M.
STATIC LEVEL
SEA LEVEL
TULUM
0.00 M.S.N.M.
FELIPE CARRILLO
PUERTO
12.50 M.S.N.M.
ASCENCION BAY
00.0 M.S.N.M.
STATIC LEVEL
CHETUMAL
0.00 M.S.N.M.
SEA LEVEL
FRESHWATER
BRACKISHWATER
SEAWATER INTRUSION

2.4 Climate.-

The Yucatan Peninsula has a tropical savanna climate, with some variations throughout the state, according to Koppen's classification (Fig 5). The region is swept continuously by warm, moisture-laden breezes. Because of the lack of any large-scale relief on the northern part of the state, little rainfall occurs through most part of the year; whereas the area has up to 1500 mm of rainfall annually, most of it is restricted to the rainy period from late May through early October. The rainfall at Merida averages 1000 mm annually, but decreases to about 500 mm along the coastal region, only 30 km north. In contrast, southern Yucatan, in the area of Sierrita de Ticul range, annual precipitation is higher, in the range of 1200 to 1250 mm (Fig 6). Mean temperature in the region is 26 C with maximum temperatures in the north and minimum at the south (Fig 7). The thermal oscillation is 5-7 C. The rainy season starts in the

Figure 5. Climatic regions of the State of Yucatan.

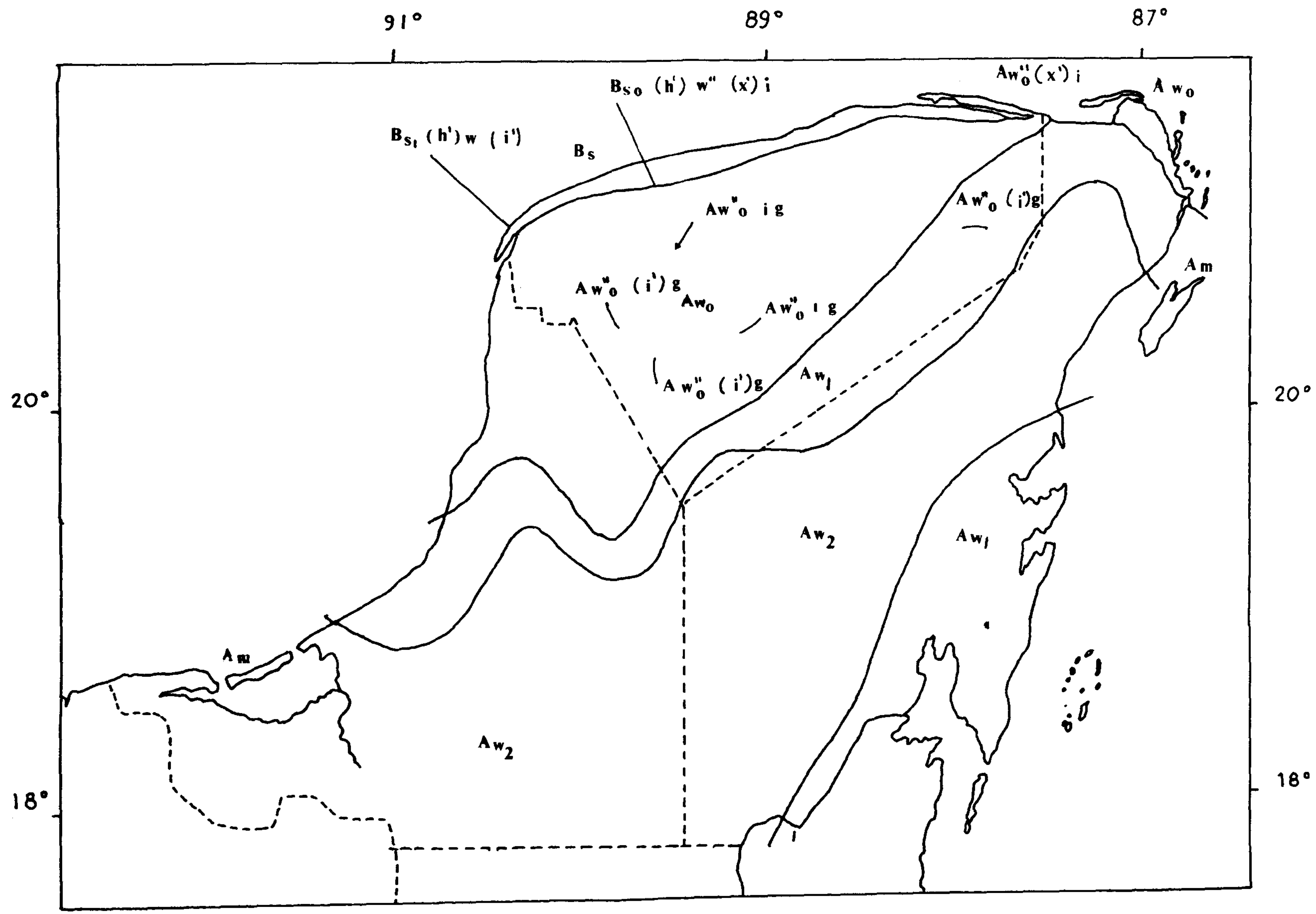

91°
89°
87°
20°
18°
20°
18°
Bs1 (h') w (i')
Bs
Bso (h') w" (x') i
Aw"o (x') i
A wo
Aw"o i g
Aw"o (i') g
Awo
Aw"o i g
Aw"o (i') g
Aw"o (i')g
Aw1
Am
Aw2
Aw1
Am
Aw2

Figure 6. Lines of equal Precipitation in the Yucatan peninsula

(Modified from Lesser, 1976)

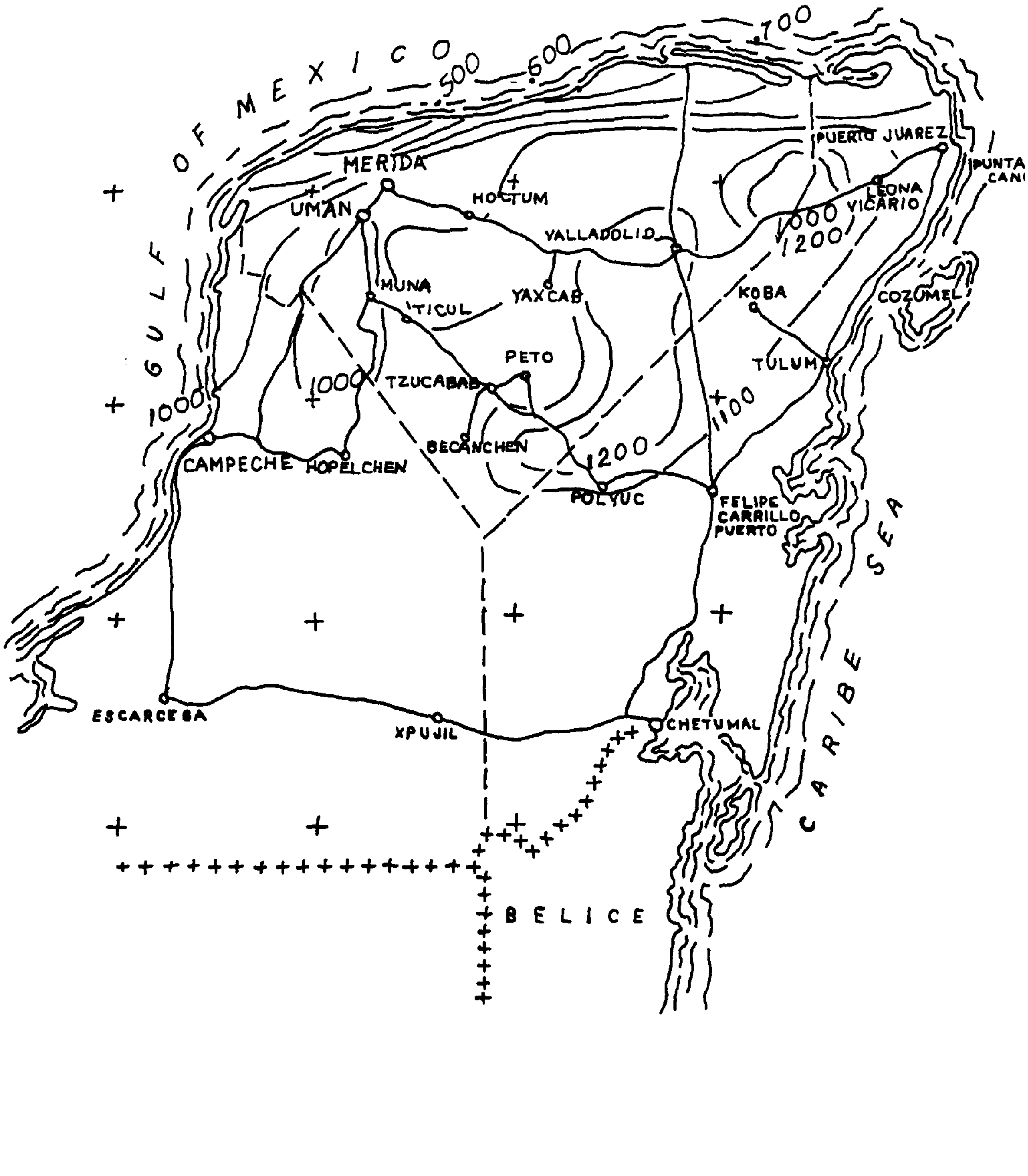
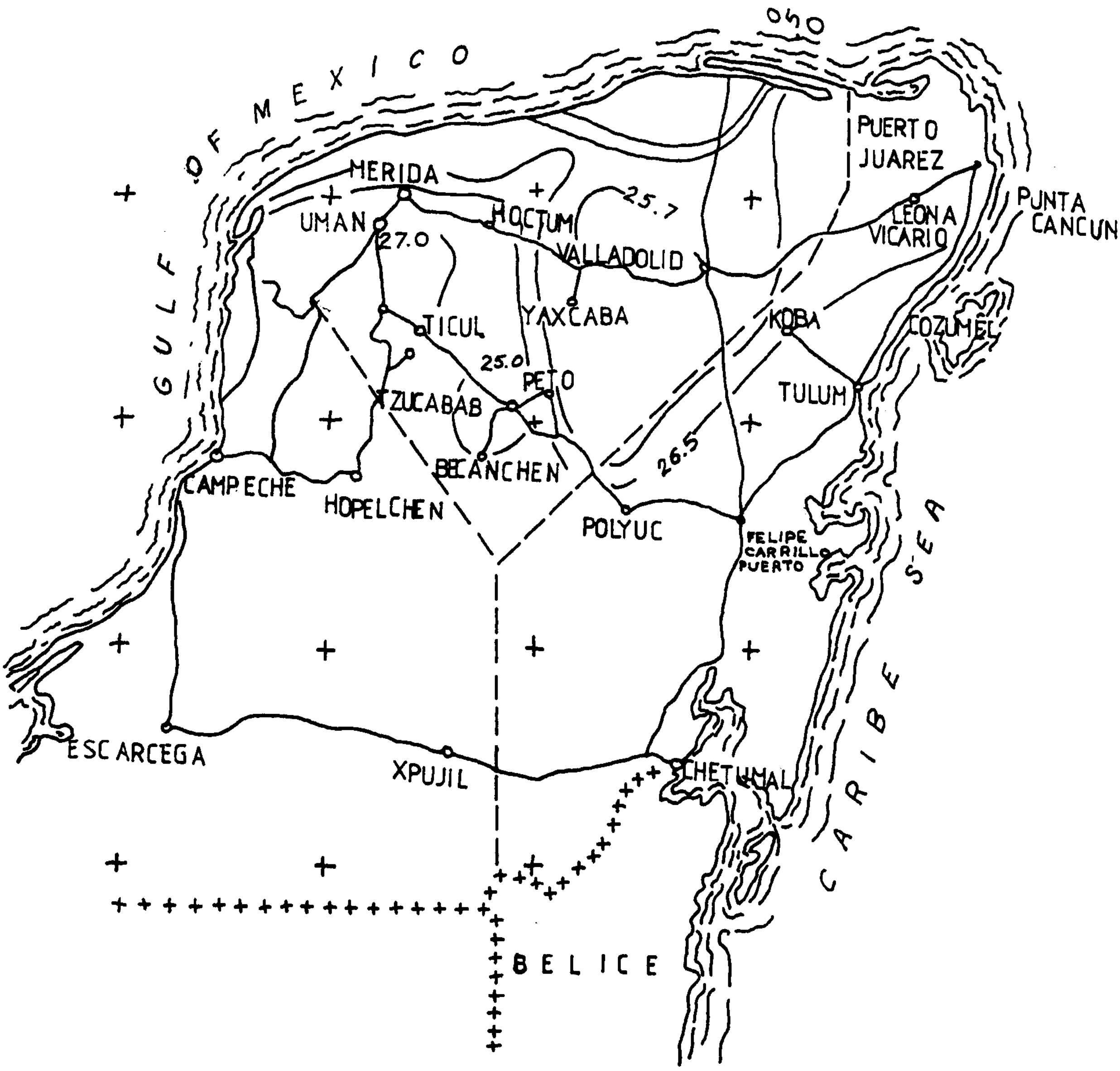

GULF OF MEXICO
CARIBE SEA
MERIDA
UMAN
HOCTUM
VALLADOLID
PUERTO JUAREZ
PUNTA CAN
LEONA VICARIO
MUNA
TICUL
YAXCAB
KOBA
COZUMEL
PETO
TZUCACAB
TULUM
BECANCHEN
CAMPECHE
HOPELCHEN
POLYUC
FELIPE CARRILLO PUERTO
ESCARCEGA
XPUJIL
CHETUMAL
BELICE
500
600
700
1000
1100
1200

Figure 7. Lines of equal temperature in the Yucatan peninsula (Modified from Lesser, 1976)


GULF OF MEXICO
MERIDA
UMAN
HOCTUM
25.7
27.0
VALLADOLID
PUERTO JUAREZ
PUNTA CANCUN
LEONA VICARIO
YAXCABA
TICUL
25.0
PETO
TZUCABAB
BECANCHEN
KOBA
COZUMEL
TULUM
26.5
CAMPECHE
HOPELCHEN
POLYUC
FELIPE CARRILLO PUERTO
CARIBE SEA
ESCARCEGA
XPUJIL
CHETUMAL
BELICE

summer, normally at the end of May, as a result of northward movement of the Intertropical Convergence Zone (ICZ). This coincides with maximum temperatures, although humidity has a cooling effect. Precipitation continues increasing until reaching its maxima at the end of the summer and early autumn. At the end of October, precipitation decreases as the winter circulation hits the region. This lowers the temperature, and brings strong winds with northeast–southwest trends, and velocities of up to 60 km/h at the coastal front (SARH,1989). However, mean temperatures in the winter never fall below 20 C, even though humidity becomes very high. This locally called "windy season" ends in late February, and is in turn replaced by the dry season.

2.5 Soils.–

In general, the soils of Yucatan are calcareous of recent formation. The basal material is constituted of fine calcareous sand with shell fractions on the coastal areas and the northern karst plain, and carbonaceous lime soils with dolomite inclusions, Iron oxide and volcanic clays, towards the south of the state (Aguilera, 1958). The distribution of the different types of soils of Yucatan is shown in Figure 8, and a summary of their main characteristics is presented in Table 2.

Figure 8. Distribution of soil types in the state of Yucatan (Modified from Flores and Espejel,1984)

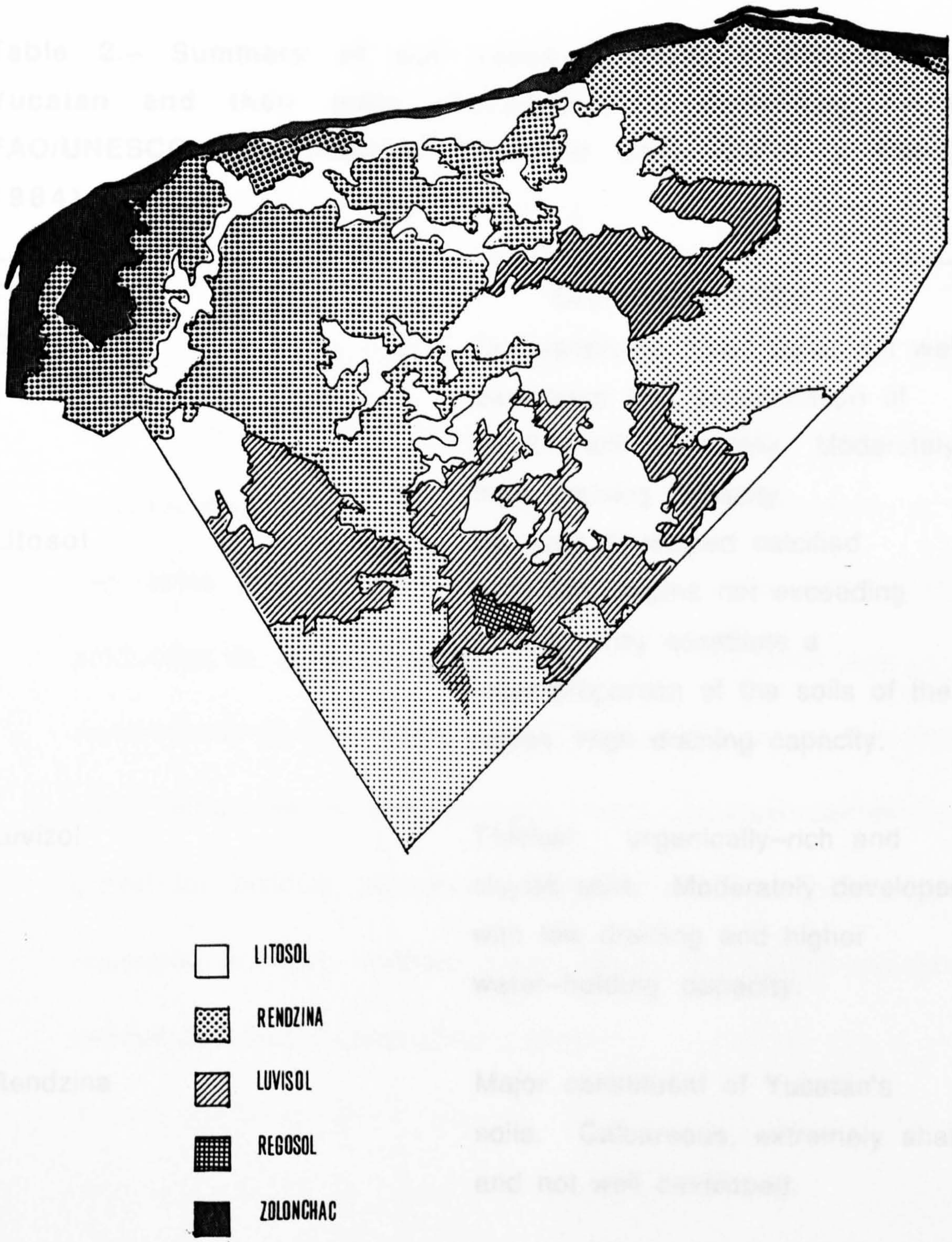

LITOSOL
RENDZINA
LUVISOL
REGOSOL
ZOLONCHAC

Table 2.- Summary of soil types present in the State of Yucatan and their main characteristics, according to the FAO/UNESCO classification. (Modified from Flores y Espejel, 1984).

TYPE OF SOIL	CHARACTERISTICS
Cambisol	Comparatively "new" soils, not well developed with accumulation of calcium and some clay. Moderately high draining capacity.
Litosol	Not well developed calcified soils with depths not exceeding 0.10 m. They constitute a large proportion of the soils of the region. High draining capacity.
Luvizol	Thicker, organically-rich and clayish soils. Moderately developed with low draining and higher water-holding capacity.
Rendzina	Major constituent of Yucatan's soils. Calcareous, extremely shallow and not well developed.
Solonchak	Thick soils with a high content of salts. Mainly found incoastal areas.

2.6 Land use.-

The state of Yucatan covers a total area of 4.37 million ha, of which only 1.12 million are suitable for agriculture and 1.25 million are used for animal production. Due to the poor soils, agriculture is restricted to sisal plantations (80 % of agricultural area), corn and beans (18 %) and some other vegetables (e.g. tomato and chilli) (2 %) (Anon.,1983). Animal production is mainly devoted to poultry, honeybees and pigs, concentrated in the northern and central regions of the state. Major industries in the northern plains produce cement and gravel for building purposes. Highest population densities are registered in these northern areas, where the largest population centres are also located (Anon.,1985).

2.7 Water resources.–

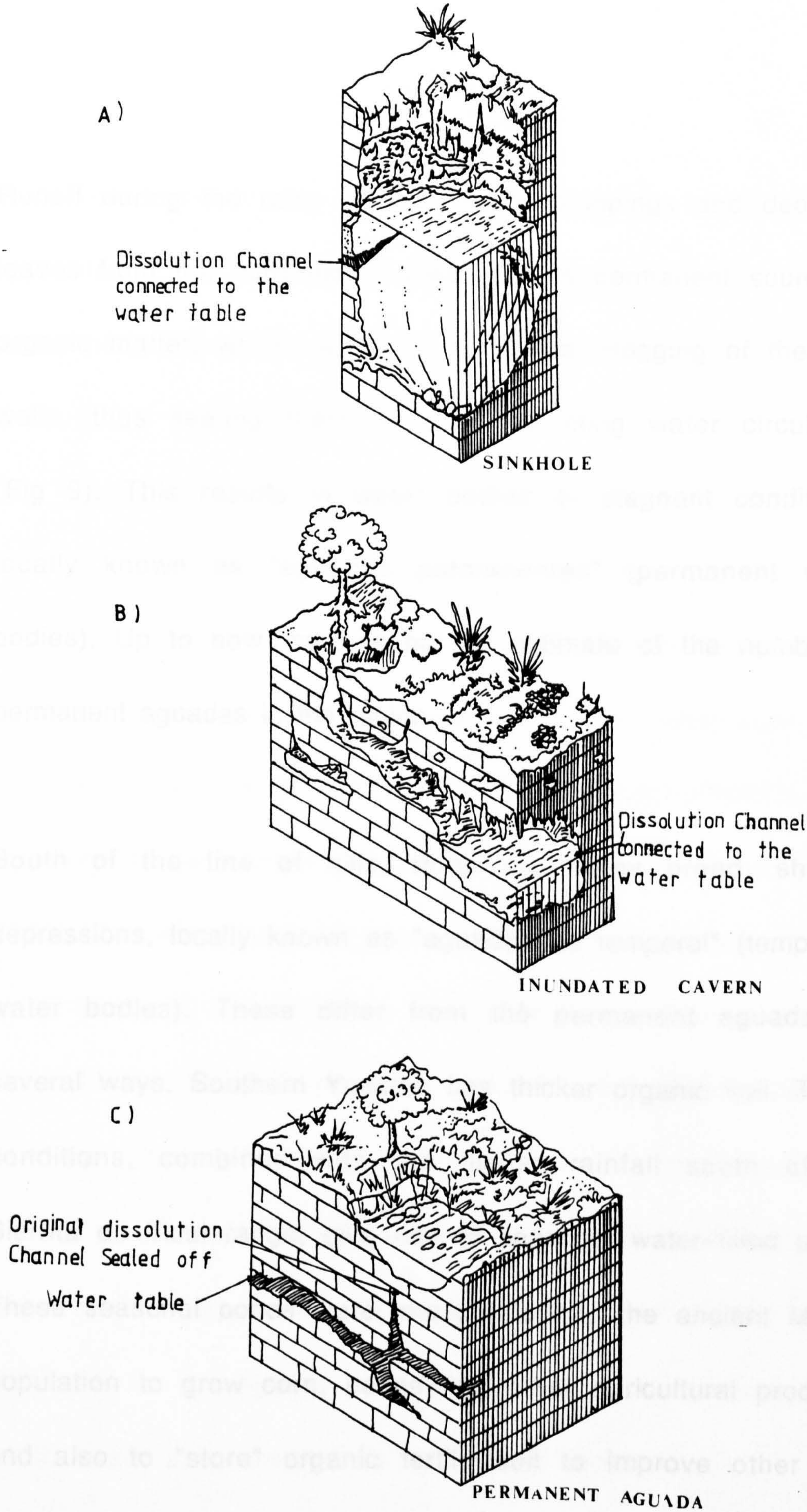
In northern Yucatan, as already mentioned, the limestone is pitted and scarred by solution depressions, hence the only natural bodies of water found in the area are sinkholes (Isphording, 1975). The mechanisms of formation of these karst features are well documented (Stringfield and LeGrand,1974; Isphording, 1975; Gaona–Vizcayno, et al., 1980; Lesser and Weidie, 1988). The general consensus is that rapid infiltration of rainfall into the aquifer results in vertical erosion and lime dissolution by carbon dioxide from rain water, producing large openings and caverns, and the collapse of rocks resulting in sinkholes, locally known as "cenotes" (from the Mayan dzonot=water place). These water bodies are of two types: the open sinkholes, which are circular in shape, with diameters ranging from 15 to 100 m and maximum depths of 125 m (Gaona–Vizcayno, et.al., 1980). They normally have very steep walls and a conic shape toward the bottom. They are connected through dissolution channels to other karst features (Fig 9), and their water movement depends entirely on the dynamics of the ground water table. The second type of sinkhole are the inundated or partially inundated caverns. Their main characteristic is that due to stronger horizontal dissolution, they present just a small fracture or opening at surface soil and a long cavern which in some cases extends for kilometres, following the water table direction (Fig 9). According to Anon. (1985) the estimated surface area of sinkholes in Yucatan is 16,000 ha, scattered along the northern karst plain. In southern Yucatan, the Sierrita de Ticul range separates two areas of somewhat different edaphic conditions. North of the range, deep sinks become scarcer than on the northern karst plain, and vegetation is denser. This provides some organic matter which is drained to the sinkholes present in the area, which here are used as sources of drinking water for cattle.

Figure 9. Types of sinkholes present in Yucatan.

a) Typical open sinkhole

b) Inundated cavern

c) Permanent aguada (clogged sinkhole)


A)
Dissolution Channel connected to the water table
SINKHOLE
B)
Dissolution Channel connected to the water table
INUNDATED CAVERN
C)
Original dissolution Channel Sealed off
Water table
PERMANENT AGUADA

Runoff during the rainy season, cattle droppings and decaying leaves from the surrounding areas, are a permanent source of organic matter, which results in a gradual clogging of the sink walls, thus sealing them off and restricting water circulation (Fig 9). This results in water bodies of stagnant conditions, locally known as "aguadas permanentes" (permanent water bodies). Up to now there is not an estimate of the number of permanent aguadas in the region.

South of the line of hills, there are many broad, shallow depressions, locally known as "aguadas de temporal" (temporary water bodies). These differ from the permanent aguadas in several ways. Southern Yucatan has thicker organic soil. These conditions, combined with the higher rainfall south of the Sierrita de Ticul range, give rise to seasonal water–filled ponds These seasonal ponds were manipulated by the ancient Mayan population to grow corn, beans and other agricultural products, and also to "store" organic fertile soil to improve other less suitable areas of the same region (Turner, 1980). Rough estimates of the area covered by these seasonal ponds give the figure of 6,500 ha, along the south "cone" of the state (Reguero, pers. com.).

The limestone karst in northern Yucatan has given rise to a large number of limestone-based industries, excavation of which has resulted in a growing number of underutilised water filled quarries. These quarries are filled with ground water soon after formation, because of the shallow water table, which is less than one metre in most northern areas (Gaona-Vizcayno, et al., 1980). The sizes of these water bodies vary considerably from small ponds of less than one hectare to several hectares. There exist 26 registered limestone-based industries (INEGI, 1989b), with an estimated mean surface area of excavated quarries of 13 ha, which accounts for 338 ha of quarries. However, rapid expansion of quarrying operations create new ponds, which additional to the already existent water bodies, account for a much larger area covered by water-filled gravel pits.

CHAPTER 3

HYDROBIOCHEMICAL SURVEY OF WATER RESOURCES OF YUCATAN

3.1 Introduction.–

Karst regions are areas with characteristic carbonate rocks with high permeability, thus in most cases they lack surface hydrological systems, and their only surface waters are sinks and fractures which expose the aquifer. Hence the factors most likely to affect the chemical character of water in a karst region are: 1) differences in chemical composition; 2) local contamination by sewage and runoff and 3) solution of carbonate and other minerals present in the rocks. (Back and Hanshaw, 1974).

The hydrochemistry of the Yucatan Peninsula has been studied by a number of authors (Back and Hanshaw, 1974; Stringfield and Le Grand, 1974; Lesser, 1976; Gaona-Vizcayno, et.al., 1980, 1985; Lesser and Weidie, 1988). However, their studies have concentrated on the physical and chemical processes taking place in aquifers, thus most measurements have being carried out in test wells or open sinkholes. However, a number of water bodies both directly influenced by aquifers, and isolated from them, are present in the region. Since the main objective of this work was to assess their potential for aquaculture, a range of water bodies in Yucatan were selected for more detailed study.

The present chapter presents the results of this survey which included various sites chosen to be representative of the different water bodies found inland in Yucatan.

3.2 Methods.–

3.2.1 Selection of study sites.–

A preliminary survey of freshwater resources was made by map and follow-up land based surveys during 1985 to identify the main types of water bodies present in the state of Yucatan. Hydrological and climatological maps from different cartographic services were utilised, as well as aerophotography (scale 1:50,000) of the INEGI (National Institute of Geography and Socioeconomic information). Ten land-based prospections were carried out to the five different subregions in which the state was divided . This subdivision followed the Geological zonification and Physiographic Districts described by Back and Hanshaw (1974), Isphording (1975), and Lesser and Weidie (1988) (see Chapter 2). On the basis of this survey, five water bodies were selected (Table 3) for a more detailed study of water quality and hydrology, over the period 1985–1989. The

TABLE 3.– Geographic Location and Geohydrological Nature of the Study Sites Selected.

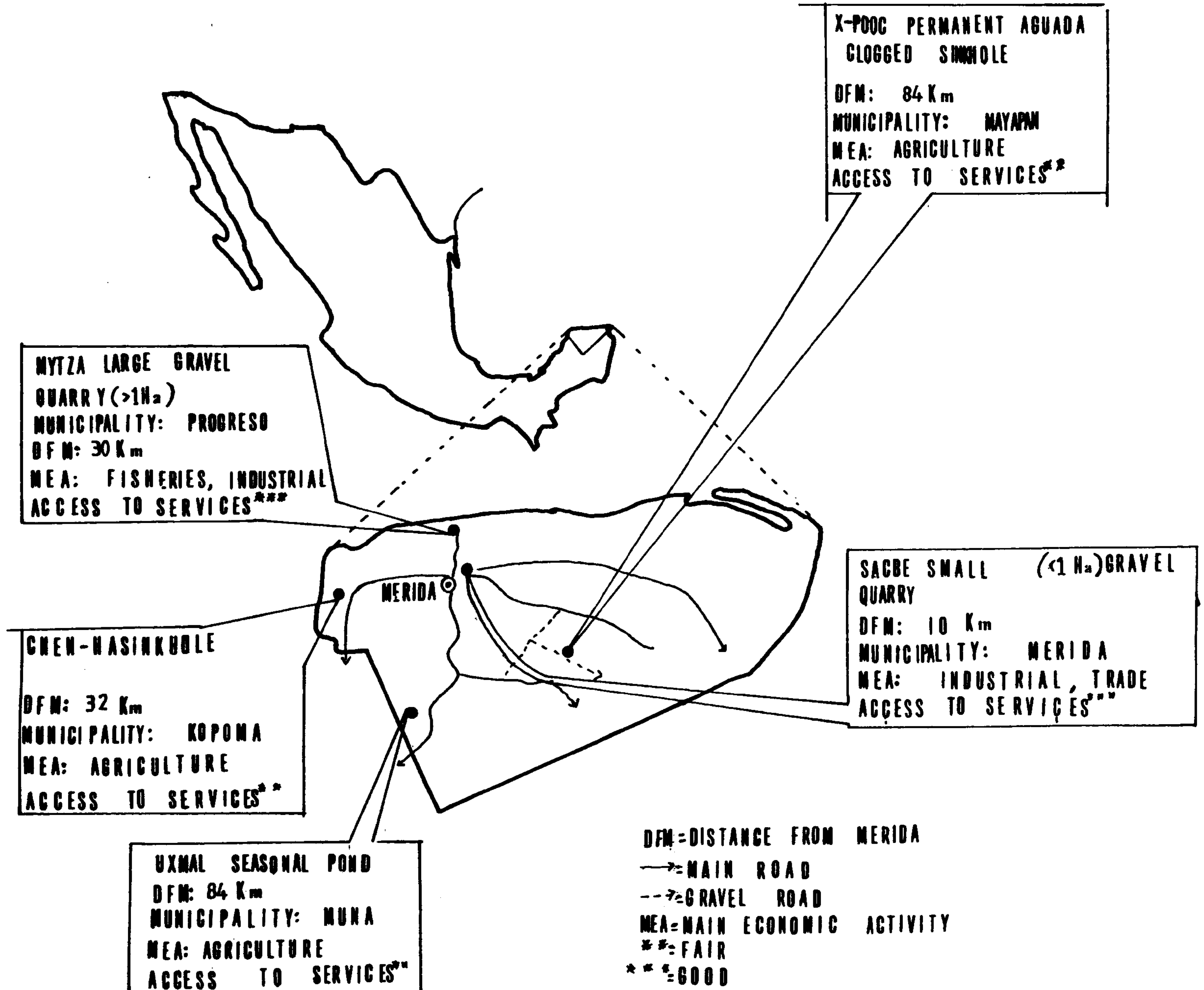
Site	Geographic location	Type of water body
Chen–Ha	20 53'01" LN–89 51'00"IW	Open sinkhole (Dolomite)
X–Pooc	20 49'11" LN–89 35'07"IW	Permanent aguada (Clogged sinkhole)
Uxmal	20 30'12" LN–89 49'13"IW	Temporary Aguada (Rain–filled pond)
Sac–Be	21 01'00" LN–89 40'03"IW	Small (<1 ha) gravel quarry
Mytza	21 26'36" LN–89 41'50"IW	Large (>1 ha) gravel quarry

criteria for the selection of the study sites were based on: a) their representativity as samples of a commonly found type of aquatic ecosystem in the area; b) their accessibility by land and c) their accessibility to basic services (Figure 10).

3.2.2 Morphometry of study sites.-

A detailed study of morphometry was carried out at each site. During the site selection phase, reference points were established, either by spotting land marks or placing them, so that subsequent recognition and mapping could easily be carried out. Geographic location of study sites was determined by measuring the distance between the estimated centre of each water body and two points on the physical limits of the property in which the site lay, so that the intersecting point of the two axes of a right angle could easily be spotted in the Rural and Public property location maps of the SRA (Ministry of the Agrarian Reform).

Figure 10. map showing the location of study sites.


X-POOC PERMANENT AGUADA
CLOGGED SINKHOLE
DFM: 84 Km
MUNICIPALITY: MAYAPAN
MEA: AGRICULTURE
ACCESS TO SERVICES**
NYTZA LARGE GRAVEL
QUARRY (>1Ha)
MUNICIPALITY: PROGRESO
DFM: 30 Km
MEA: FISHERIES, INDUSTRIAL
ACCESS TO SERVICES***
MERIDA
SACBE SMALL (<1 Ha) GRAVEL
QUARRY
DFM: 10 Km
MUNICIPALITY: MERIDA
MEA: INDUSTRIAL, TRADE
ACCESS TO SERVICES***
CHEN-HASINKHOLE
DFM: 32 Km
MUNICIPALITY: KOPOMA
MEA: AGRICULTURE
ACCESS TO SERVICES**
UXMAL SEASONAL POND
DFM: 84 Km
MUNICIPALITY: MUNA
MEA: AGRICULTURE
ACCESS TO SERVICES**
DFM=DISTANCE FROM MERIDA
=MAIN ROAD
=GRAVEL ROAD
MEA=MAIN ECONOMIC ACTIVITY
**=FAIR
***=GOOD

Contour maps of each site were drawn using the triangulation method (Hakanson, 1981), for which land–based wooden 2–m poles were placed on the shore at maximum water storage capacity. The poles were placed in an upright position every 10 metres along the shore of the water body. A "Dinar–3" dumpy level was placed at the northern edge of the site and was zeroed lining it up with the first pole positioned to the southeast in all cases, from which the bearings to each subsequent pole were read and recorded in a clockwise pattern. The bearings were then transferred to graph paper where the contour maps were traced. Direct measuring of distances between the poles was carried out by means of a "Lufkin" 50–m metering tape, with which direct measurements of the perimeter of each site were also carried out. The distance between two opposite poles was measured and this operation repeated five to ten times from different points, so that a mean value of their diameter was determined, and then the formula Πr^2 applied to get the area of circularly–shaped sites (Chen–Ha and X–Pooc). Irregular sites (Sac–Be, Uxmal and

Mytza), were split into different polygonal figures and their individual areas added together to get their total wet surface area (Hakanson, 1981).

The bathymetry of the five study sites was determined by setting a series of transects in each of the study sites at maximum water storage capacity. The distance between the transects varied according to the dimensions of the water body. Buoyed ropes were used as transects, lined up to poles previously placed on the shores. Depth measurements were made at each buoyed point with a conventional lead line, and isobathimetric contours were then drawn on previously constructed morphometric maps (Hakanson, 1981).

3.2.3 Preliminary fish populations assessment.–

In order to assess the fish populations present in each study site, a preliminary survey was carried out. In the shallower water bodies (Sac–Be and Uxmal) and along the shores of Mytza quarry, a hand–made 12–m long, 2,10–m high, 7.8 mm mesh size beach seine was used. It was retrieved from the centre of the site to the shores in a radial pattern. Also a scoop net was used when specimens were at the surface. For deeper sites (Chen–Ha, Mytza and X–Pooc) an experimental floating/sinking monofilament gillnet with twelve panels of four metres each, with mesh sizes ranging from 10 to 75 mm, was set at mid water for at least three occasions during the survey at each site. The captured specimens were preserved in 10% formalin (Chavez, 1973) and transported back to the laboratory where they were identified and counted. Identification was done in most cases to the species level, using different identification keys (Hubbs, 1936; Miller, 1966; Alvarez del Villar, 1970). Some molluscs were abundant at some sites. A quantitative estimate was made and some specimens were preserved in 5 % formalin (Pennack, 1978) and transported back to the laboratory for identification.

3.2.4 Water quality sampling.–

In three out of the five sites studied, water quality sampling was carried out for at least nine months before deciding on further aquaculture assessments, and all with the exception of Chen–Ha sinkhole, which was sampled for eight months only, were sampled so that an annual monitoring cycle was completed. Periods and frequencies of sampling for each site are presented in table 4. Sampling in all cases was carried out between 11:00 a.m. and 15:00 p.m. Diurnal fluctuation determinations were carried out from 8:00 a.m. to the same hour the following morning with 4–hour intervals.

Table 4.– Periods and Frequencies of Water Quality Sampling for each Study Site.

Site	Period of sampling	Frequency (days)	Notes
Chen–Ha	02/87 to 09/87	30	—
Uxmal	01–03/85 04–12/87	30	Dry in 86
Sac–Be	09/86 to 08/87	15	Aq. in 87
Mytza	06/88 to 06/89	30	Aq. in 89
X–Pooc	01/86 to 12/86	30	—

For practical reasons, only one sampling site was established in Chen–Ha, X–Pooc, Uxmal and Sac–Be, at the centre of each water body. At Mytza quarry, this being a much larger water body, four sampling points were established. They were marked with buoys tied to ropes which were in turn attached to a weight on the bottom, to avoid drifting. These sampling points in Mytza were placed to ensure representative sampling of the entire quarry.

Deeper sites were sampled both at upper layers (0.50–1.50m) and bottom layers. In both cases a 2.5 l Van Dorn bottle was used. This was released from a boat right from the sampling point at the surface. In all sites, for each sampling date three samples were taken so that each measurement was carried out with three replicates.

Deeper sites (X–Pooc and Chen–Ha) were measured every metre throughout the water column to detect thermal and oxygen stratification, using a YSI–155 dissolved oxygen/temperature meter with a 25–m long membrane probe. Temperature and dissolved oxygen in shallow sites were also measured using the same device, and readings from mid–water were taken in these cases. The oxygen meter was calibrated prior to each sampling, by the Winkler Iodometric method, with starch as indicator and modified with sodium azide to correct for nitrite interferences (APHA, 1985).pH was measured by means of a Corning–103 portable pH–meter, with calomel probe. The meter was calibrated with two calibration buffers (pH 6.88 and pH 8.86) prior to each sampling.

Integrated water quality samples (2.5 l) were collected from the first 1.5 m and from the deepest reachable point of the sampling position with the Van Dorn bottle. Water samples were transferred into plastic 375 ml bottles, avoiding air–bubbling, stored in a plastic cooler at 4^{o}C (Stirling, 1985) and transported back to the water quality laboratory to be analysed within the following 24–hour period.

3.2.5 Sediment sampling.–

Since anaerobic conditions were found at bottom layers in X–Pooc, additional sediment samples were analysed for hydrogen sulphide in months two, six and eleven of the water quality sampling period. Since the sediments in this water body are not compacted but fairly loose, the Van Dorn bottle was used to take the samples by sinking it approximately 0.30 m into the bottom mud. Once the bottle was lifted, the sediment samples were immediately transferred to 250 ml Erlenmeyer flasks. Approximately 100 ml of sediments were placed in the flask, where ten drops (approximately 10 ml) of 2N zinc acetate had previously been added (APHA, 1985), the flask was then filled up with water from the bottom layers of the aguada, to avoid air contamination, stoppered and transported back to the laboratory for analysis. Soil samples were taken from Uxmal seasonal pond at 5, 10 and 15 cm deep into the bottom mud, at three different sites of the aguada, using a 1.75" (internal diameter) PVC core. This was carried out in April 1988, before the rainy season started. Samples of the vegetation cover of the pond were also taken for analysis, on the same date. For this, a 1-m2 wooden square was placed approximately at the centre of pond, all the vegetation within the square was then cut at soil level. Both soil and plant samples were placed in individual plastic bags, labelled and transported back to the laboratory.

3.2.6 Laboratory analysis of water and sediments.–

Total alkalinity was determined by the titrimetric method, using sulphuric acid 0.1 N and phenolphthalein as indicator (APHA, 1985). Total hardness was determined by titration with EDTA, using Eriochrome Black T as indicator (APHA, 1985). Total ammonia (.NH_3 + NH_4) determination was made spectrophotometrically by the indophenol blue reaction, using the phenol- hypochlorite method described by Solorzano (1969). Nitrate (NO_3) quantification was made by cadmium- copper reduction to nitrite. Nitrite (NO_2) was then determined spectrophotometrically using the sulphanilamide / N – (1 – naphthyl)–ethylendiamine dihydrochloride (NED) colorimetric reaction (APHA, 1985). Dissolved reactive phosphorus was determined spectrophotometrically at 882 nm by the molybdate reaction technique suggested by Eisenrich et al (1975). The concentration of photosynthetic pigments as Chlorophyll–a was determined by filtering a known volume of water sample (0.375

l) through a .45 μm glass fiber filter, which was then mechanically ground to disrupt the algal cells to facilitate extraction of pigments in 90% methanol buffered with magnesium carbonate (Holm–Hansen and Riemann, 1978), measuring their absorbance in a double cuvette spectrophotometer. The absorbance at 750 nm was subtracted from the measured absorbance at 665 nm for inorganic turbidity correction. In all spectrophotometric determinations a PYE–UNICAM SP6–550 Spectrophotometer was utilised.

Quantitative analysis of H_2S, at the water/soil interface was carried out following the Iodometric method, using starch solution as indicator, as suggested by APHA (1985).

Soil and plant samples weighing 5 g each were dried in a Felisa–2500 furnace for 24 hours at 105 ^{o}C. Individual dry samples were labelled and brought to the University of Stirling to be analysed for Carbon and Nitrogen in a Perkin–Elmer–240

C.H.N.– analyser. Determination of total phosphorus in the soil and plant samples was carried out employing a modification of the ammonia reaction method, evaporated with perchloric acid (Strickland and Parsons, 1972).

3.2.7 Analysis and expression of results.–

Time series graphs were plotted for each water quality variable and for each site. Monthly means from the four sampling points at Mytza, mean values of the replicated samples from each of the sampling points in Sac–Be, as well as both surface and bottom waters in deeper sites (X–Pooc and Chen–Ha) were computed for statistical analysis. One–way Analysis of Variance (Bailey, 1981) were used to determine statistically significant differences among means of the sample points of Mytza, as well as among epilimnetic and hypolimnetic water samples in deeper sites. Simple correlation and regression analysis (Bailey, 1981) were applied between levels of photosynthetic pigments, represented by chlorophyll–a, and those bioelements considered to be primarily regulating this parameter, namely orthophosphates, nitrate and ammonia. In the case of Uxmal, since just four chlorophyll–a values were available, the time–corresponding values of PO_4, NO_3, NH_3–NH_4 were selected and compared for both correlation and regression analysis. All water quality results are reported as mg/l.

3.3 Results.–

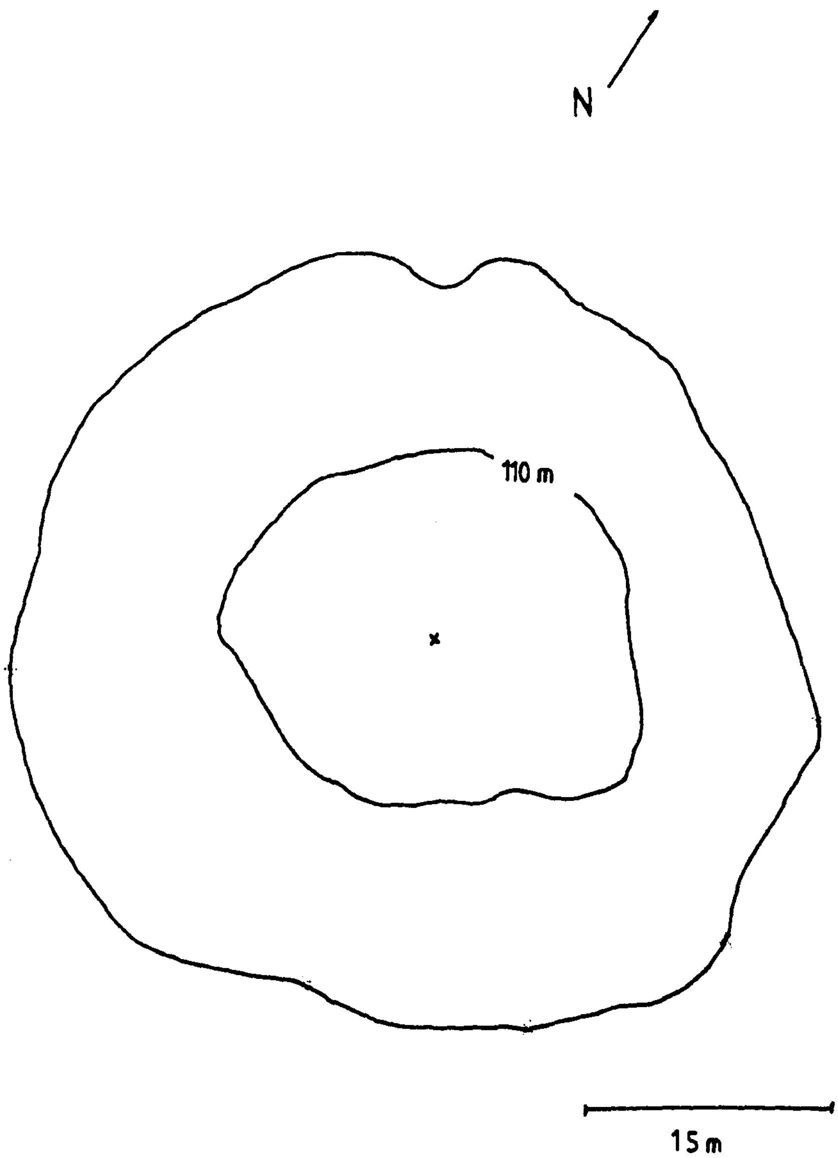
3.3 1 Morphometry of study sites.–

As mentioned previously, as a result of the preliminary survey, five sites were selected for study: a sinkhole, a permanent aguada, a seasonal pond, a small (< 1 ha) gravel quarry and a large (> 9 ha) gravel quarry.

3.3.1.1 Chen-Ha sinkhole.-

This water body is located approximately 32 km west of Merida, capital city of the state of Yucatan, on the northwestern karst plain. It is a circular open "cenote", with vertical porous walls which give it a conical shape in vertical profile. It has a mean diameter of 46 m, and a total surface area of 1666 m2. The only depth recorded, due to the steepness of its walls, in a radius of approximately 700 m2 from the centre, was 110 m (Fig 11). It is permanently fed by an aquifer, and no changes in volume are detectable. The type of soil in the surrounding area is limestone (Litosol, according to the FAO-UNESCO classification). The type of vegetation found in the area is of the lower caducifolia type (Flores and Espejel, 1984).

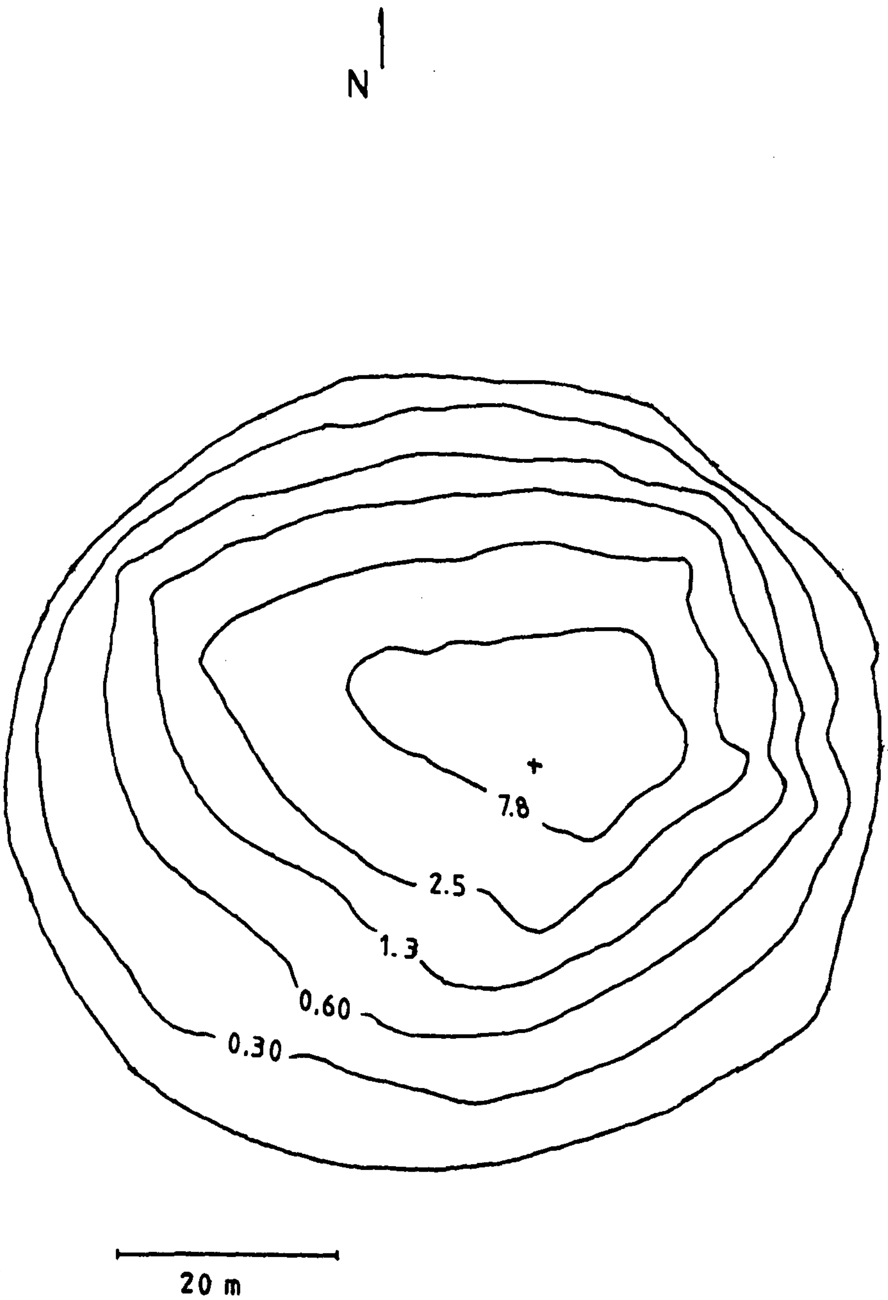
Figure 11. Chen-Ha sinkhole contour map, bathymetry and location of sampling site (x)


N
110 m
15 m

3.3.1.2 X–Pooc permanent aguada.–

X–Pooc is located approximately 84 km south of Merida, on the Central hilly region. It is also a typical circular, open sinkhole, with a mean diameter of 74 m (4300 m2 total surface area), a minimum depth of 0.60 m, a maximum depth of 7.80m and a mean depth of 3.70 m. (Fig 12). Its once permeable walls and bottom have been almost completely sealed off by organic matter, thus virtually isolating it from the aquifer. The surrounding soils are Litozols and Rendzines , but with a distinct layer of litter foil with cattle excreta and dead leaves, since it is located within a cattle farm. The vegetation type is of the mid–caducifolia type, with some perennifolia plants (Flores y Espejel, 1984). Being a sinkhole, X–Pooc lies approximately 6 m below the normal land level in this area of the state. This, together with the moderately dense vegetation of the surroundings, prevents wind–induced water circulation and mixing.

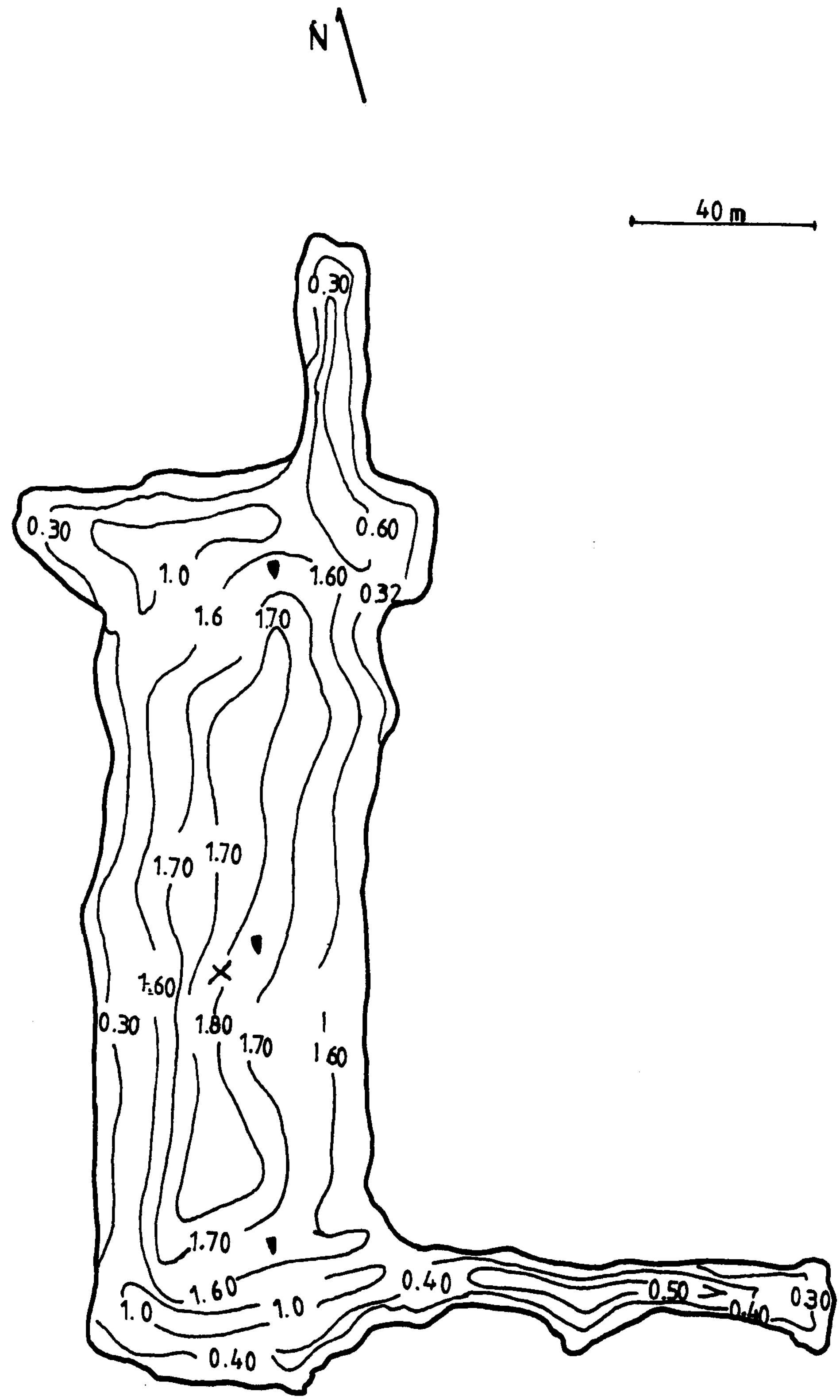
Figure 12. X-Pooc permanent aguada contour map, bathymetry and location of sampling site (x)


N
7.8
2.5
1.3
0.60
0.30
20 m

3.3.1.3 Uxmal seasonal pond.–

This seasonal water body is located approximately 84 km southwest of Merida, on the southern hilly region. it has a somewhat regular rectangular shape, with two narrow distinct arms extending to the north and east from the main body of water. The minimum depth is 0.30m and maximum and mean depths are 1.80 and 1.05 m, respectively (Fig 13). Its basin presents a more or less gentle slope from the littoral zones towards the centre. It is a land depression whose soils consist of organically–rich silty clays. Its main hydrological characteristic is that it normally remains dry for approximately two months during the late months of the dry season (between March and April), and it is then gradually filled until it reaches its maximum volume in a total flooded area of 1.11 ha in late July. It remains at full capacity until the end of august, after which water volume decreases steadily towards the end of the year. By January the pond holds only approximately 30 % of full

Figure 13. Uxmal seasonal pond contour map, bathymetry and location of sampling site (water quality x, soil ▲)



N
40 m
0.30
0.30
0.60
1.0
1.60
0.32
1.6
1.70
1.70
1.70
1.60
0.30
1.80
1.70
1.60
1.70
1.60
1.0
1.0
0.40
0.40
0.50
0.40
0.30

capacity, after which water rapidly evaporates and by late February, the basin is almost completely dry (Fig 14). However, if the annual precipitation is below 800 mm, it is insufficient to saturate the soil and fill the aguada (as in 1985–1986). When dry, dense vegetation rapidly colonises the basin, with a restricted variety of dominating plants which include Phragmites spp, Paspalum spp, Typha spp and Cyperus spp. At the central part of the aguada, there is an ancient Mayan cistern of approximately 3.5 x 1.80 x 1.0 m, which holds water throughout the year when precipitation is within average values. (The depth of this cistern was not considered in the bathymetric contours).

3.3.1.4 Sac–Be gravel quarry.–

This aquifer–fed water body is located 10 km northeast of Merida. It is an abandoned gravel quarry of 0.135 ha of surface area, with maximum, minimum and mean depths of 0.80, 0.30, and 0.50 m, respectively (Fig 15). It lies 7m below land level and

Figure 14. Annual variation in water volume of Uxmal seasonal pond.

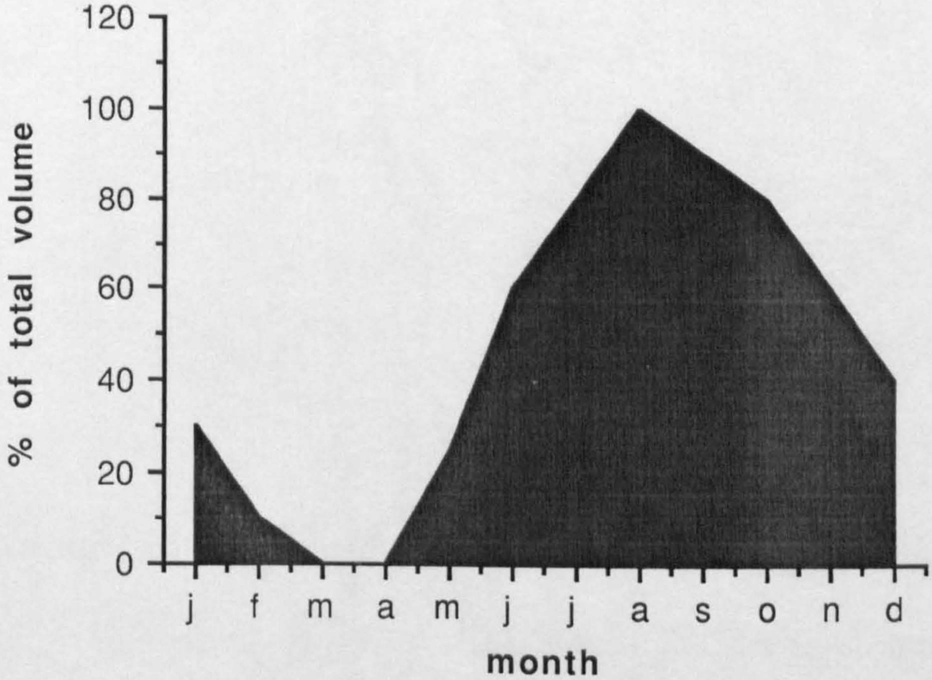
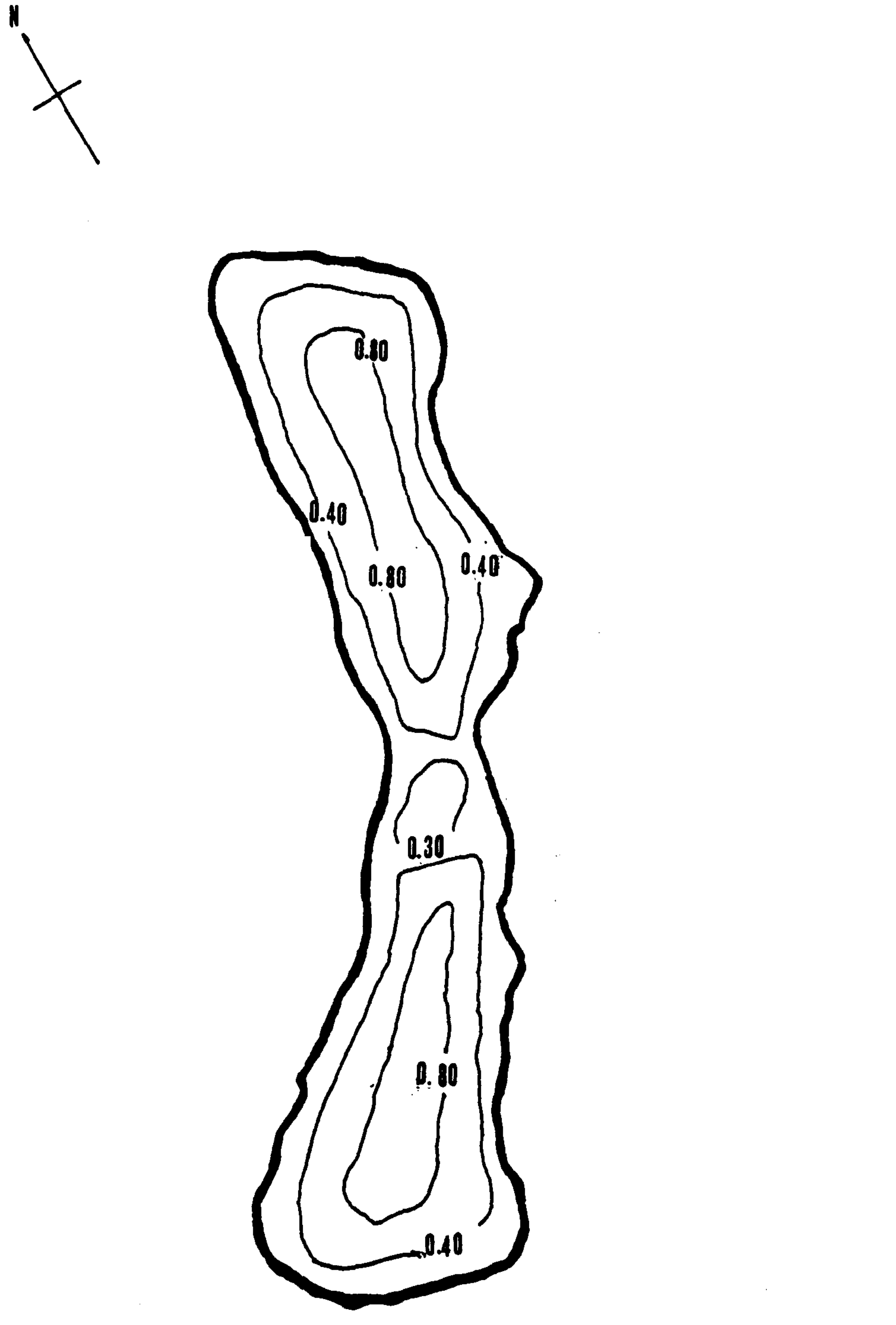

120
100
80
60
40
20
0
% of total volume
j f m a m j j a s o n d
month

Figure 15. Sac-Be gravel quarry contour map, bathymetry and location of sampling site (x)

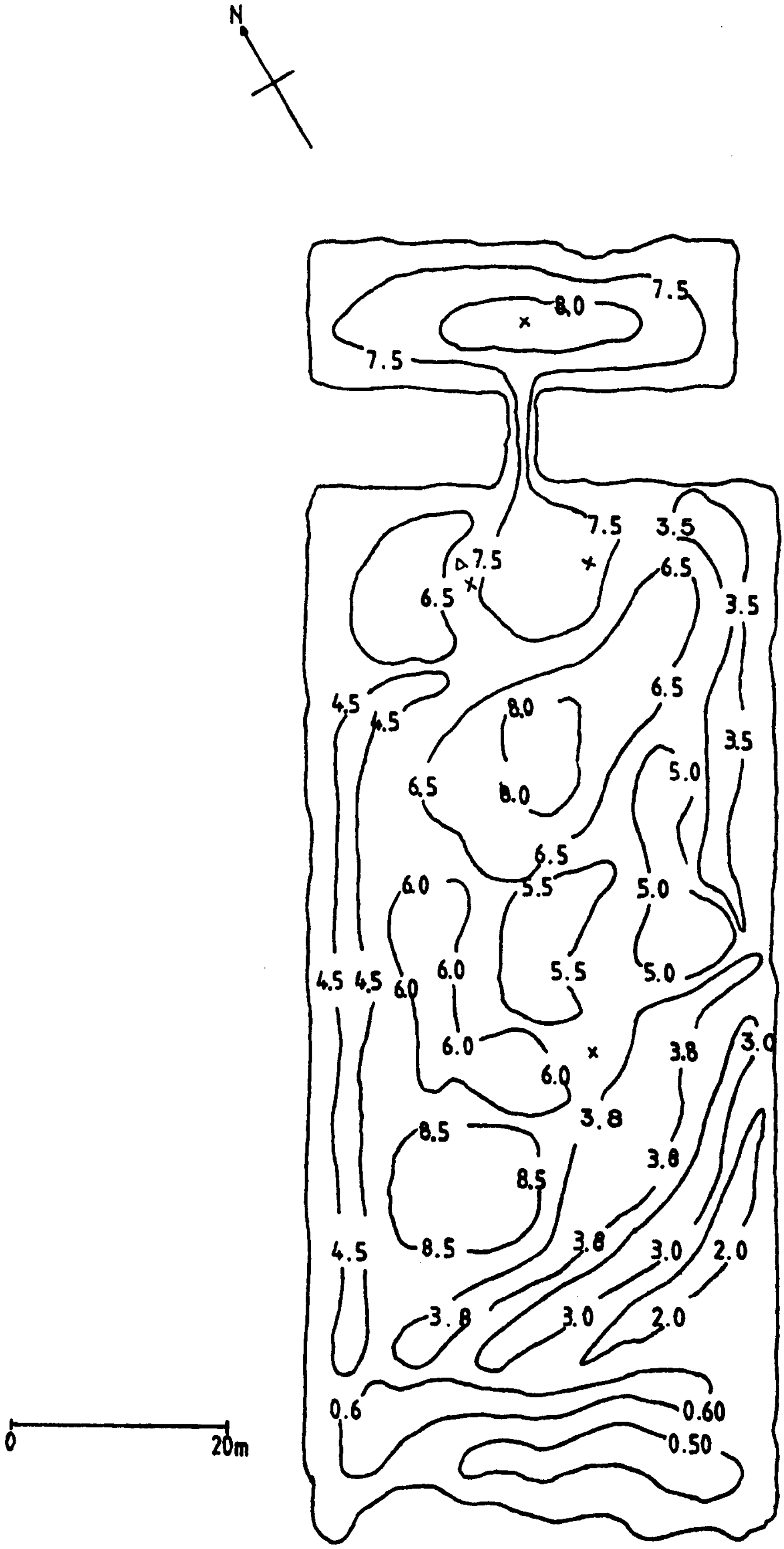

N
0.80
0.40
0.80
0.40
0.30
0.80
0.40
0 20m.

has a rocky bottom with approximately 85 % lime gravel and 15% calcareous sand. No vegetation is present in the catchment area.

3.3.1.5 Mytza gravel quarry.–

This gravel quarry is located 30 km north of Merida. It consists of two rectangularly–shaped quarries of 7.73 and 1.30 ha joined by a narrow channel (7.5 m) at the northern edge of the larger body of water. The quarry has a minimum depth of 0.50 m, and maximum and mean depths are 8.50 and 5.20 m respectively (Fig 16). It is permanently fed by an aquifer through its permeable, almost vertical, walls and its bottom. Mytza is one of several gravel quarries that constitute the lime quarrying complex with the same name. Since vegetation is sparse, the prevailing northeast winds induce permanent mixing of the water column. Due to cracks

Figure 16 Mytza gravel quarry contour map, bathymetry and location of sampling stations (x) and cage site (Δ)


N
8.0
7.5
7.5
7.5
3.5
7.5
6.5
6.5
3.5
4.5
4.5
6.5
8.0
3.5
6.5
8.0
5.0
6.5
6.0
5.5
5.0
4.5
4.5
6.0
6.0
5.5
5.0
6.0
3.0
3.8
6.0
3.8
8.5
8.5
3.8
4.5
8.5
3.8
3.0
2.0
3.8
3.0
2.0
0.6
0.60
0.50
0
20m

in its rocky walls, which connect this quarry with other quarries and karst features, there are a number of introduced fish .

A summary of the morphometric data of the study sites is presented in table 5.

Table 5. Summary of Morphometric Data of the Study Sites.

	Chen-Ha	X-Pooc	Sac-Be	Uxmal	Mytza
Total area (ha)	0.166	0.430	0.135	1.11	9.30
Mean Depth (m)	110	3.05	0.50	1.05	5.20
Maximum Depth (m)	110	7.80	0.80	1.80	8.50
Total Volume (m3)	182,600	13,115	675	11,655	483,600
Max. Length (m)	49	82	90.4	244	484.50
Max. Width (m)	49	82	15	46	187.50

3.3.2 Fish populations of the study sites.–

Table 6 presents the quantitative data derived from the fish populations survey. Since effort was not standardized, quantitatively comparison among sites can only be done in terms of relative abundances.

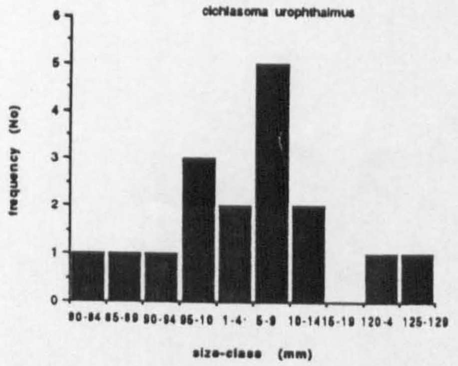
Five fish species were identified during the study, of which the most abundant was the Poecilid Gambusia yucatana which was also present at all sites. Two cichlid species were identified in the survey, these were Cichlasoma urophthalmus and C.meeki; the former in higher proportions and in more than one site (Chen–Ha and Mytza), whereas the latter was only found in Chen–Ha. The "molli" (Mollienisia velifera) was only found in Chen–Ha sinkhole, and another poecilid, Xiphophorus spp was relatively abundant in X–Pooc, Uxmal and Mytza sites.

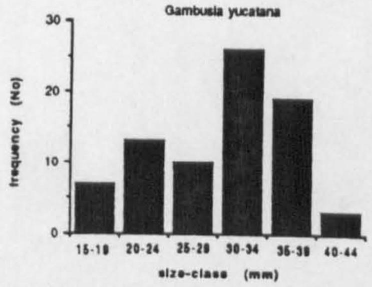
Figures 17 through 21 present the size–frequency distribution of of the fish populations identified in the study sites.

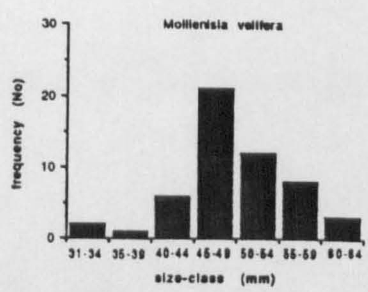
Table 6 - Fish Species Identified and Total Number of Fish Caught in the Study Sites During the Fish Population Survey.

SPECIES.	Chen-Ha	X-Pooc	Uxmal	Sac-Be	Mytza	Total	% of Total
Poecilidae:							
Gambusia yucatana	78	64	65	80	129	416	62
Mollienisia velifera	53	-	-	-	-	53	8
Xiphophorous spp	-	55	11	-	77	143	21
Cichlidae:							
Cichlasoma urophthalmus	17	-	-	-	16	33	5
Cichlasoma meeki	26	-	-	-	-	26	4

Figure 17. Size frequency distribution of the fish populations of Chen-Ha sinkhole.


cichlasoma urophthalmus
frequency (No)
0
1
2
3
4
5
6
80-84
85-89
90-94
95-10
1-4
5-9
10-14
15-19
120-4
125-129
size-class (mm)


Gambusia yucatana
frequency (No)
0
10
20
30
15-19
20-24
25-29
30-34
35-39
40-44
size-class (mm)


Mollienisia velifera
frequency (No)
0
10
20
30
31-34
35-39
40-44
45-49
50-54
55-59
60-64
size-class (mm)

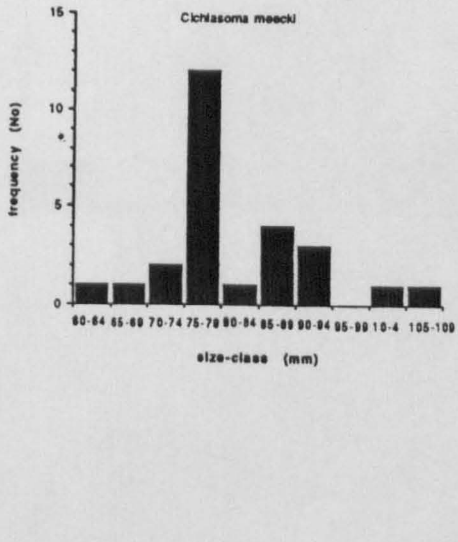
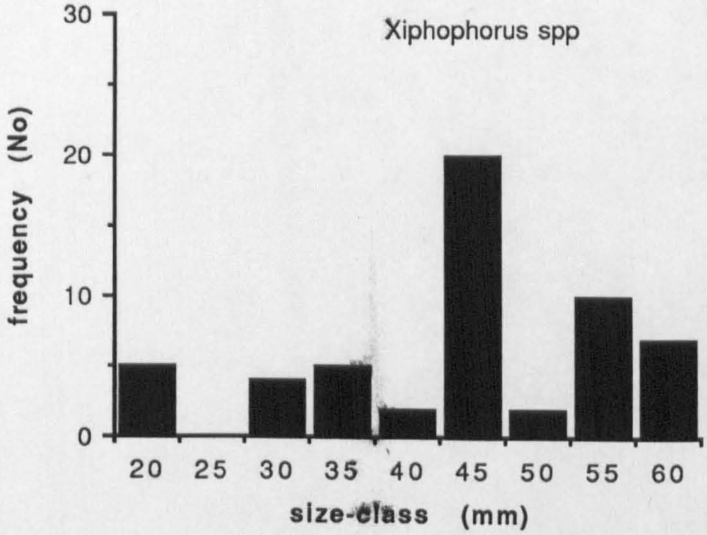

Cichlasoma meecki
frequency (No)
0
5
10
15
60-64
65-69
70-74
75-79
80-84
85-89
90-94
95-99
10-4
105-109
size-class (mm)

Figure 18. Size frequency distribution of the fish populations of X-Pooc permanent aguada


Xiphophorus spp
frequency (No)
30
20
10
0
20 25 30 35 40 45 50 55 60
size-class (mm)

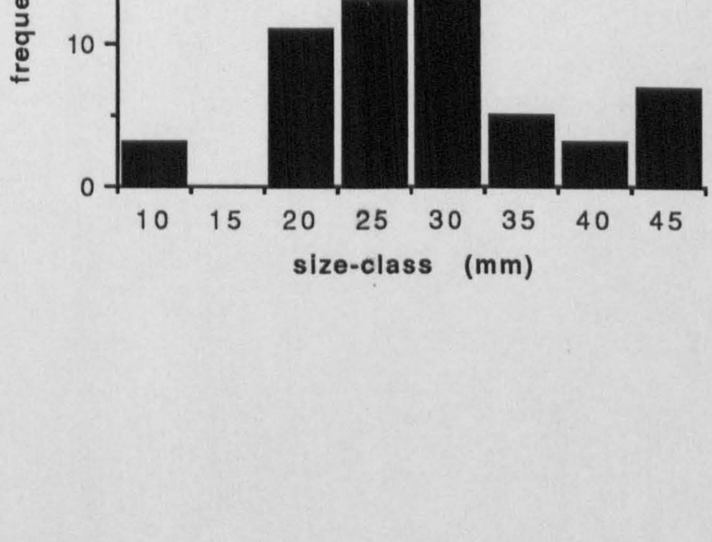
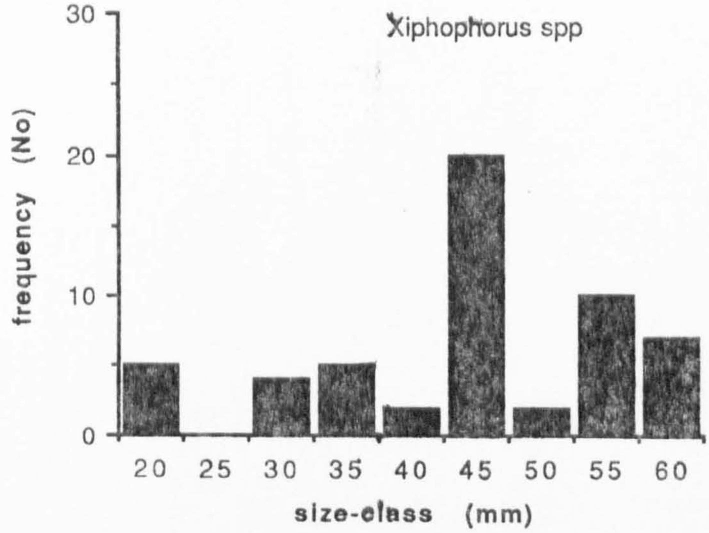

Gambusia yucatana
frequency (No)
30
20
10
0
10 15 20 25 30 35 40 45
size-class (mm)

Figure 19 Size frequency distribution of the fish populations of Uxmal seasonal pond.


Xiphophorus spp
frequency (No)
30
20
10
0
20 25 30 35 40 45 50 55 60
size-class (mm)

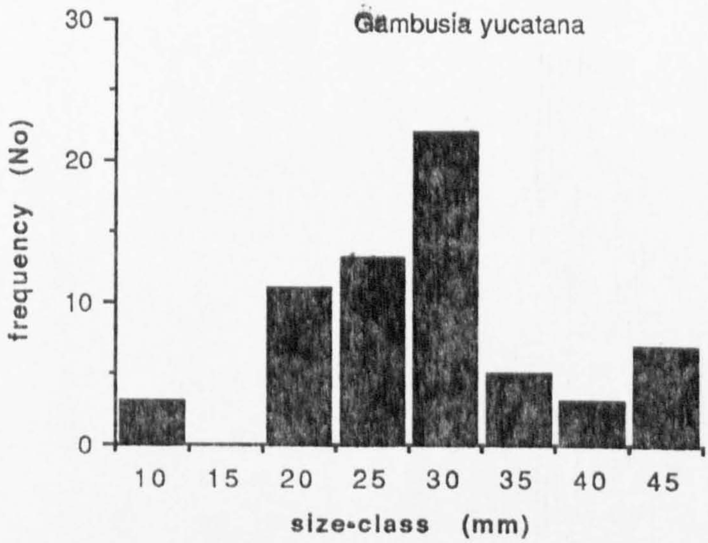

Gambusia yucatana
frequency (No)
30
20
10
0
10 15 20 25 30 35 40 45
size-class (mm)

Figure 20. Size frequency distribution of the fish populations of Sac-Be gravel quarry.

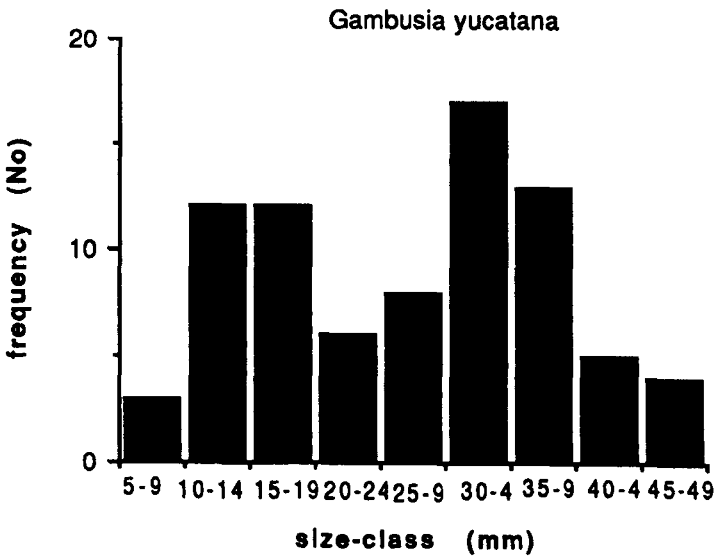
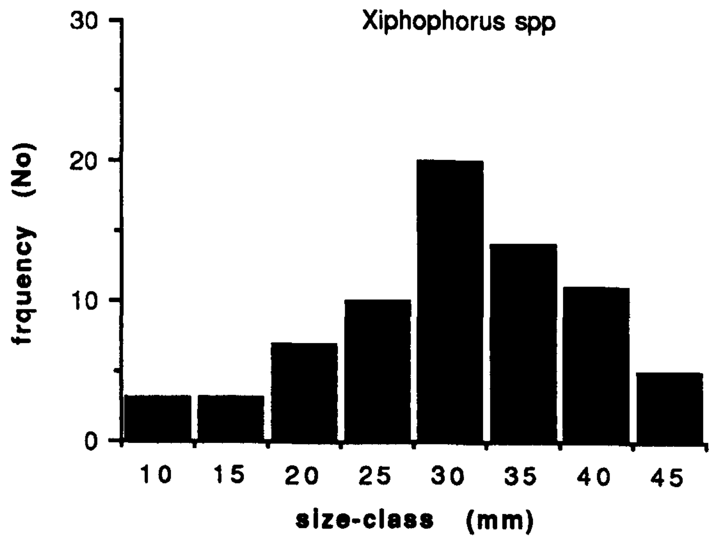
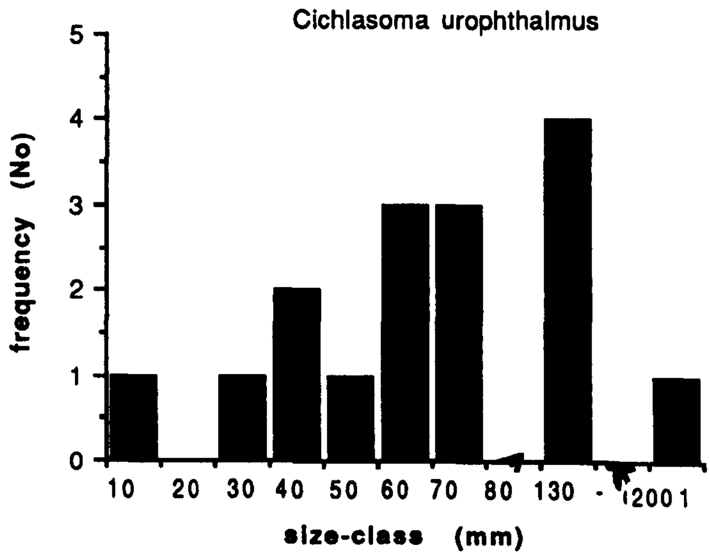

Gambusia yucatana
20
10
0
frequency (No)
5-9
10-14
15-19
20-24
25-9
30-4
35-9
40-4
45-49
size-class (mm)

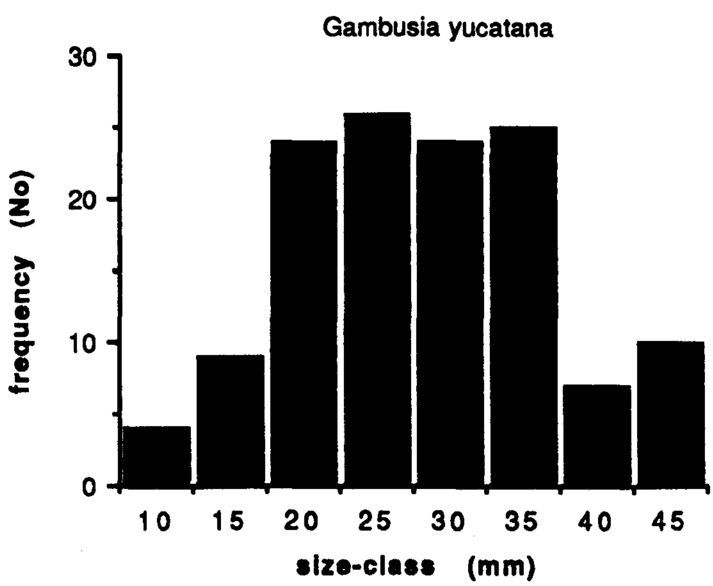
Figure 21. Size frequency distribution of the fish populations of Mytza gravel quarry



Xiphophorus spp
frquency (No)
0
10
20
30
10 15 20 25 30 35 40 45
size-class (mm)



Cichlasoma urophthalmus
frequency (No)
0
1
2
3
4
5
10 20 30 40 50 60 70 80 130
size-class (mm)



Gambusia yucatana
frequency (No)
0
10
20
30
10 15 20 25 30 35 40 45
size-class (mm)

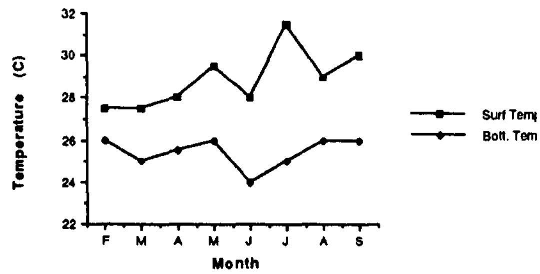
The mollusc, Pomacea paludosa was found in large numbers in both Uxmal seasonal pond and X–Pooc permanent aguada at the time of sampling, and the snail Physa spp, was only found in Sac–Be in moderately high numbers.

3.3.3 Water quality.–

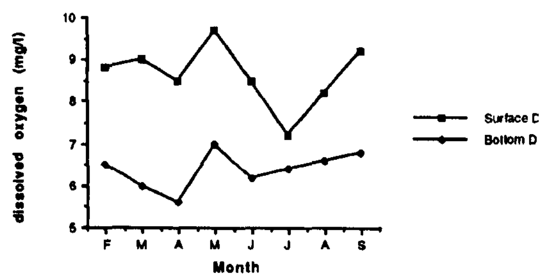
3.3.3.1 Chen–Ha sinkhole.–

Since this water body has a depth of 110m, for practical reasons it was decided to take samples at the surface and at 25m, corresponding with the length of the oxygen meter probe. The results show highly significant differences in temperature between surface and lower layers (3.3 ^{o}C average difference between surface and 25 m depth) ($P<0.01$), although only slight fluctuations were observed during the study period (Fig. 22a).

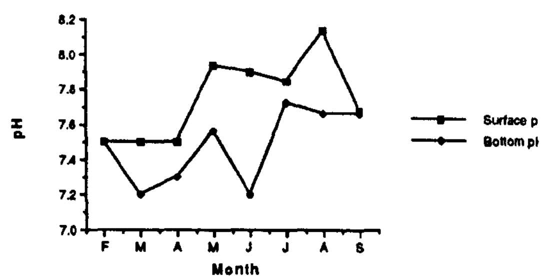
Figure 22a Temporal fluctuations of temperature, dissolved oxygen, pH, total alkalinity and total hardness in Chen-Ha sinkhole



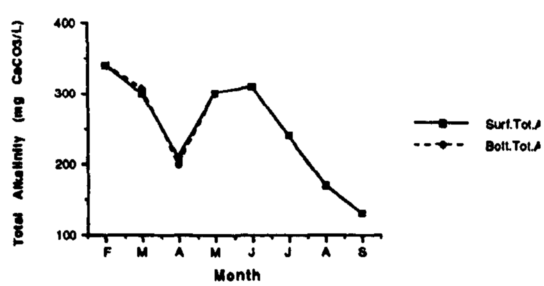
Temperature (C)
32
30
28
26
24
22
F M A M J J A S
Month
Surf Tem
Bott. Tem



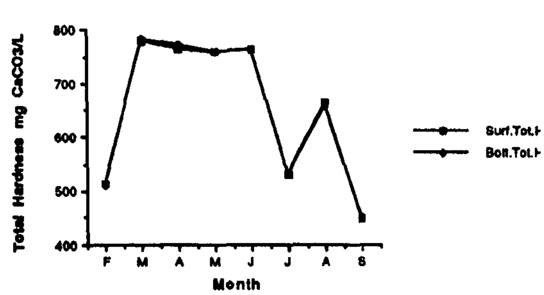
dissolved oxygen (mg/l)
10
9
8
7
6
5
F M A M J J A S
Month
Surface D
Bottom D



pH
8.2
8.0
7.8
7.6
7.4
7.2
7.0
F M A M J J A S
Month
Surface p
Bottom pl



Total Alkalinity (mg CaCO3/L)
400
300
200
100
F M A M J J A S
Month
Surf.Tot.A
Bott.Tot.A



Total Hardness mg CaCO3/L
800
700
600
500
400
F M A M J J A S
Month
Surf.Tot.H
Bott.Tot.H

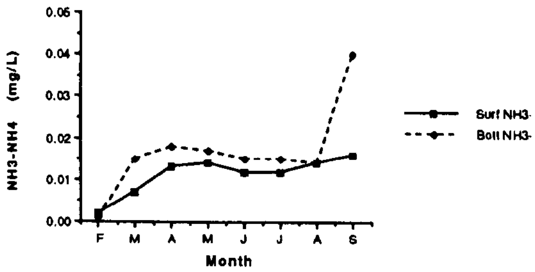
Dissolved oxygen concentration was significantly higher at the surface ($P<0.01$), although lower layers showed good levels of oxygenation (> 5mg/l). Oxygen trends followed a similar pattern throughout the sampling period (Fig. 22a). Monthly fluctuations of pH were also statistically different between upper and lower layers ($P<0.05$) and followed a similar trend during the study period, with levels ranging from 7.2 to 8.14 (Fig. 22a).

Total hardness and total alkalinity are also shown in Figure 22a. High levels of hardness, ranging between 448 and 783 mg $CaCO_3$/ l can be seen for both upper and lower layers, with maximum levels recorded in March and minimum in September. There was no significant difference between epilimnion and hypolimnion hardness values ($P>0.05$). Alkalinity fluctuated between 130 and 340 mg/l, with parallel trends observed for surface and lower waters. No statistical differences were observed between the epilmnion and the hypolimnion ($P>0.05$). Maximum levels were recorded in February and minima in September.

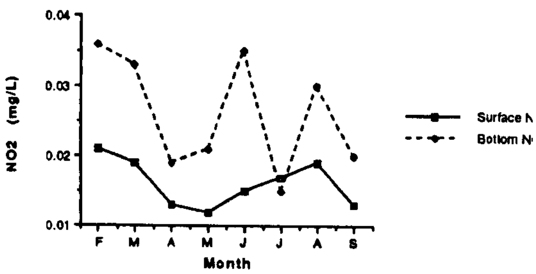
Nitrate levels in lower waters were relatively high (ranging from 2.10 to 3.10 mg/l) and significantly different ($P<0.01$) from upper layers where a fluctuation between 0.40 and 1.50 mg/l was observed (Fig. 22b). Nitrite levels tended to be much lower than nitrates. They were significantly higher ($P<0.01$) in the hypolmnion, with maxima in February and June and minimum in September (Fig. 22b). Ammonia showed minimum levels in February and steadily increased to a maximum concentration of 0.016 mg/l in September in surface waters, while the deeper waters remained with values below 0.018 mg/l throughout most of the study period (Fig 22b). No statistical differences were observed between sets of samples.

Low phosphate concentrations were observed throughout the sampling period, with significantly higher levels at the surface ($P<0.05$). Maximum values were recorded in May (0.018 mg/l) and minimum values in April (< 0.005 mg/l). Lower layers showed little variation in phosphate contents(< 0.005 mg/l) (Fig. 22b).

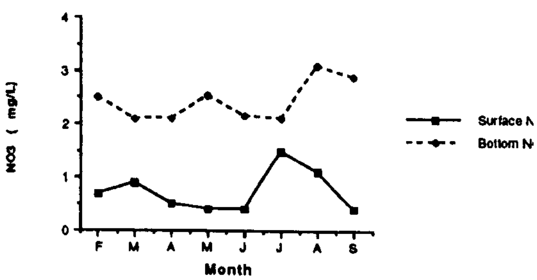
Figure 22b Temporal fluctuations of NO_2-N, NO_3-N, total ammonia, PO_4 and chlorophyll-a in Chen-Ha sinkhole



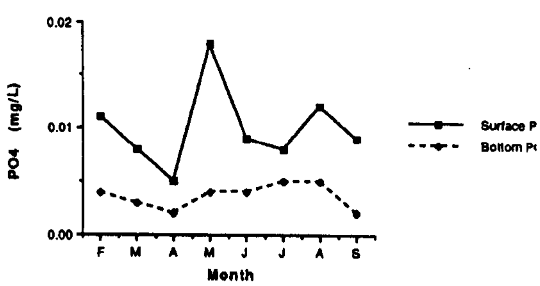
0.05
0.04
0.03
0.02
0.01
0.00
NH3-NH4 (mg/L)
F M A M J J A S
Month
Surf NH3-
Bott NH3-



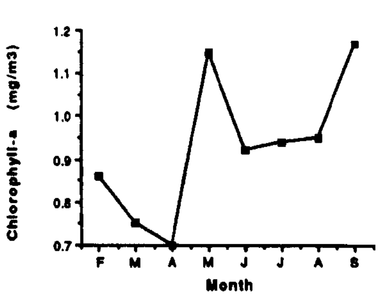
0.04
0.03
0.02
0.01
NO2 (mg/L)
F M A M J J A S
Month
Surface N
Bottom N



4
3
2
1
0
NO3 (mg/L)
F M A M J J A S
Month
Surface N
Bottom N



0.02
0.01
0.00
PO4 (mg/L)
F M A M J J A S
Month
Surface P
Bottom P



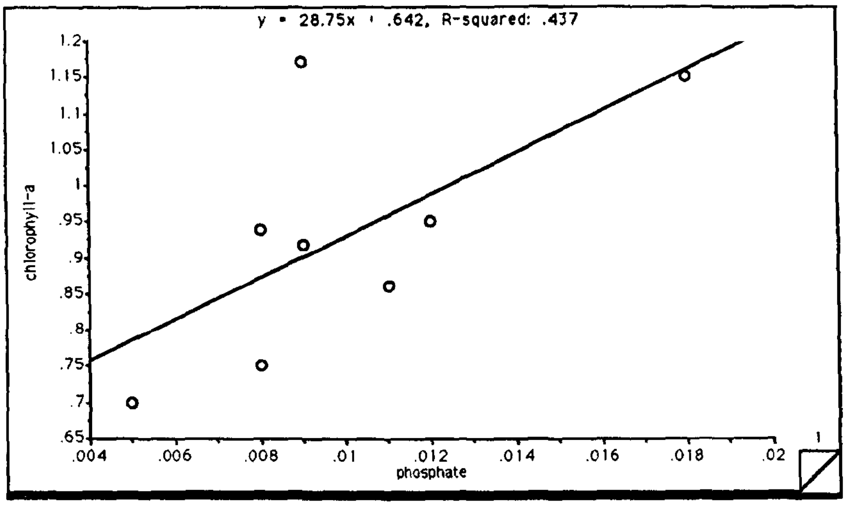
1.2
1.1
1.0
0.9
0.8
0.7
Chlorophyll-a (mg/m3)
F M A M J J A S
Month

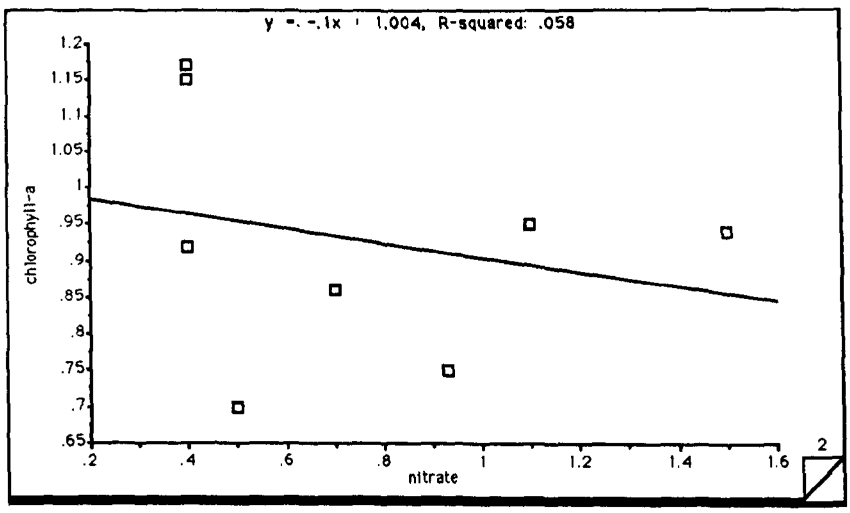
Chlorophyll–a concentrations were in general terms low in this sinkhole, ranging between 0.70 and 1.17 mg/m^3 (Fig 22b). The trend was somewhat coincident with that of PO_4, with minimum levels in April and two peaks in May and September. Correlation analysis showed a moderately high and significant degree of association between chlorophyll–a and orthophosphates ($r=0.661, P<0.05$), and no significant correlation with both nitrate and ammonia, the former showing a negative value. (Figure 23.)

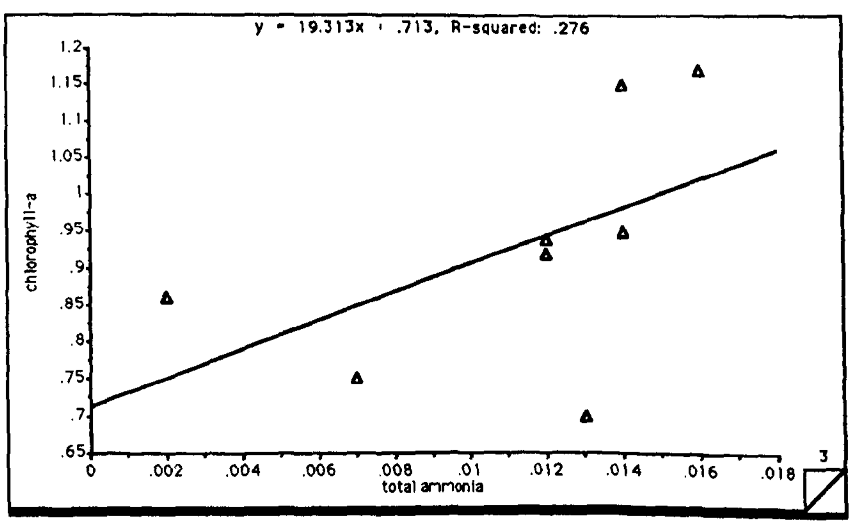
3.3.3.2 X–Pooc permanent aguada.–

The water balance of this water body depends very much on rainfall, runoff from a relatively small catchment area and, to a smaller extent, to water infiltration from the water table. Very stable thermal and oxygen stratifications were found in this water body throughout the year. The epilimnion was determined to be 2.0 m deep, and an average temperature difference of 8.3^oC

Figure 23. Relationships between chlorophyll-a and orthophosphate, nitrate and ammonia levels in Chen-Ha sinkhole


y = 28.75x + .642, R-squared: .437
chlorophyll-a
phosphate
1


y = -.1x + 1.004, R-squared: .058
chlorophyll-a
nitrate
2

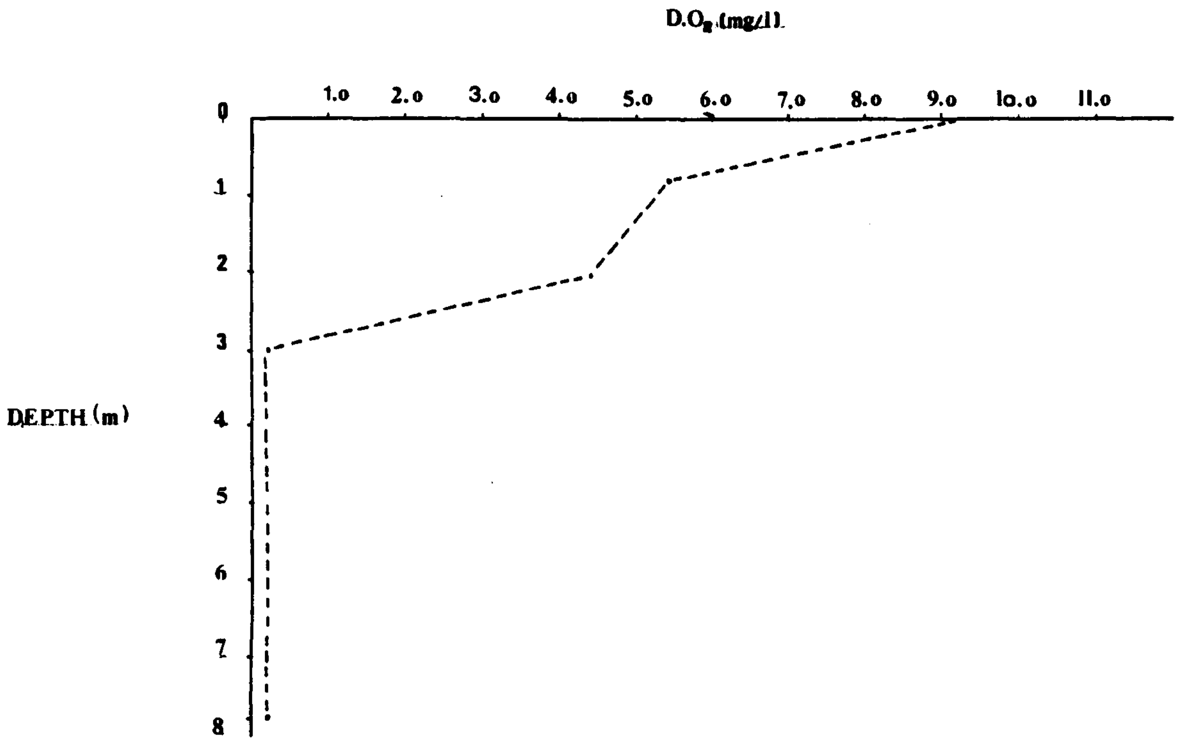

y = 19.313x + .713, R-squared: .276
chlorophyll-a
total ammonia
3

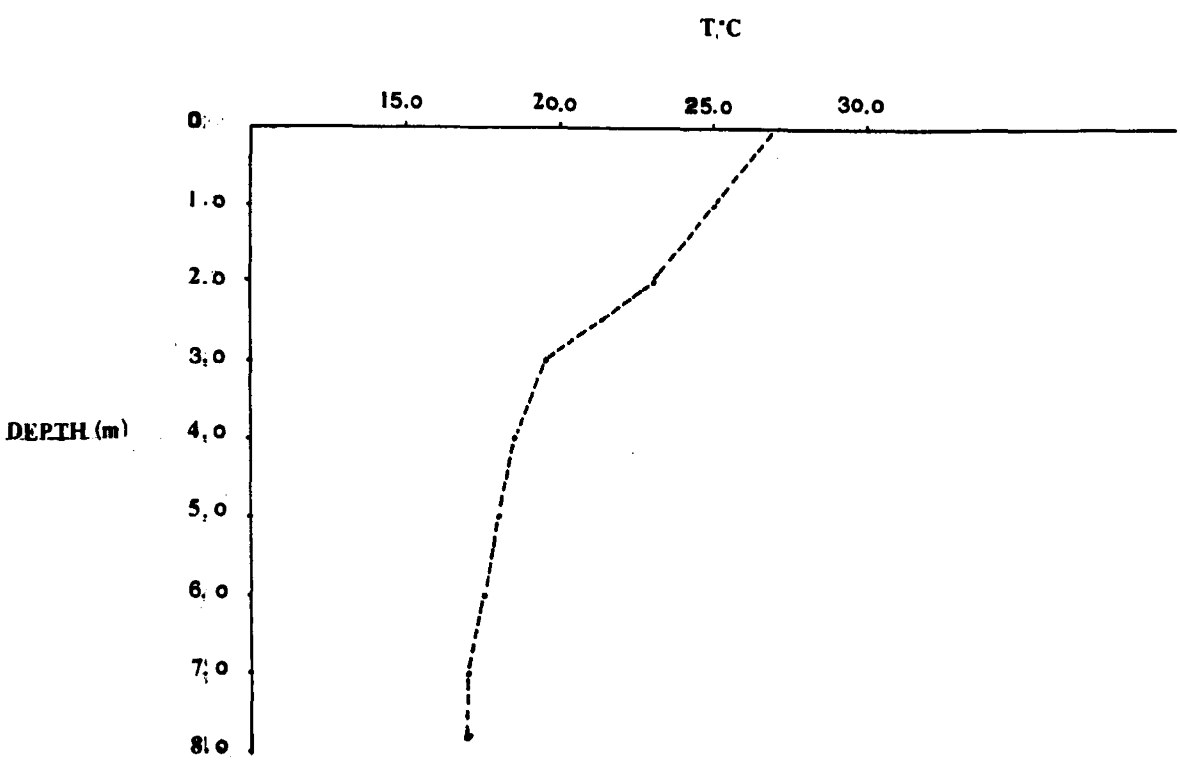
divides the epilmnion from hypolimnetic waters. Maximum temperatures in the upper layers were observed in August and October (33 ^{o}C), and minima in March and April (22 ^{o}C). Minimum and maximum hypolimnetic temperatures were observed in March, April and November (17 ^{o}C), and August and September (21.5 ^{o}C), respectively. Dissolved oxygen levels were high (range 6.5 to 10 mg/l) in the epilimnion, whilst virtually anoxic conditions (<0.5 mg/l) were found throughout the hypolimnion, (Fig 24). X–Pooc waters are very hard and hence are alkaline.

Total hardness and total alkalinity levels showed somewhat parallel trends in both epi– and hypolimnetic waters, with no significant differences (P>0.05) among sampling points

However, whilst the fluctuations of the former were relatively small (range 816–998 mg CaCO3/l) total alkalinity increased markedly between June and October, before decreasing again to

Figure 24. Temperature and dissolved oxygen profiles in X-Pooc permanent aguada

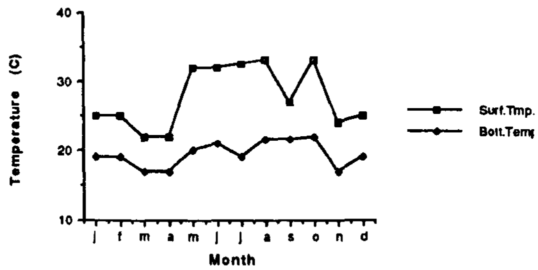

D.O₂ (mg/l)
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0
0 1 2 3 4 5 6 7 8
DEPTH (m)

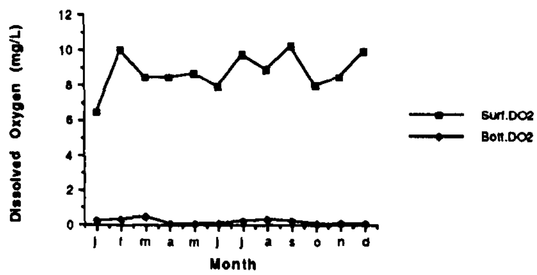

T,°C
15.0 20.0 25.0 30.0
0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0
DEPTH (m)

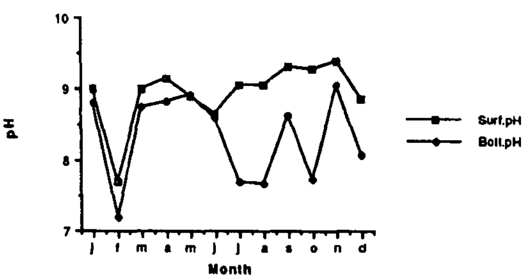
originally recorded levels (Fig. 25a). Levels of pH were consistently high and showed little variations during the year. Both bottom and epilimnetic water pH trends were similar, although statistically significantly different ($P<0.05$), with slightly higher levels observed in the epilimnion (8.97), and hypolimnetic values averaging 7.68 (Fig. 25a).

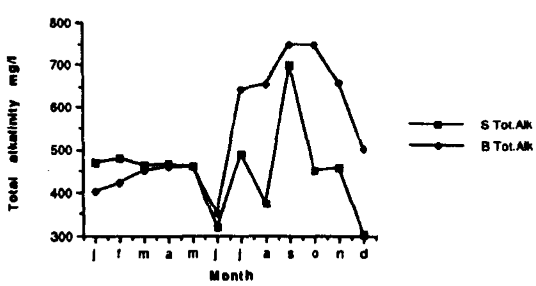
Nitrogen compounds were in general higher in the hypolimnetic waters, although highly variable throughout the study period. Nitrate concentration in hypolimnetic waters ranged from 1.50 mg NO_3–N/l (recorded in September), to 5.09 mg/l observed in May, and were significantly different ($P<0.05$), from values recorded in the upper layers. The pattern of NO_3–N fluctuation differed between the epilimnion and the hypolimnion. Nitrite concentrations followed somewhat parallel trends in both epi– and hypolimnetic waters, with no significantly different values ($P<0.05$), although lower layers showed higher levels between February and June, after which a steep decrease was observed (Fig. 25b).

Figure 25a Temporal fluctuations of temperature, dissolved oxygen, pH, total alkalinity and total hardness in X-Pooc permanent aguada


Temperature (C)
40
30
20
10
j f m a m j j a s o n d
Month
Surf.Tmp.
Bott.Temp


Dissolved Oxygen (mg/L)
12
10
8
6
4
2
0
j f m a m j j a s o n d
Month
Surf.DO2
Bott.DO2


pH
10
9
8
7
j f m a m j j a s o n d
Month
Surf.pH
Bott.pH


Total alkalinity mg/l
800
700
600
500
400
300
j f m a m j j a s o n d
Month
S Tot.Alk
B Tot.Alk

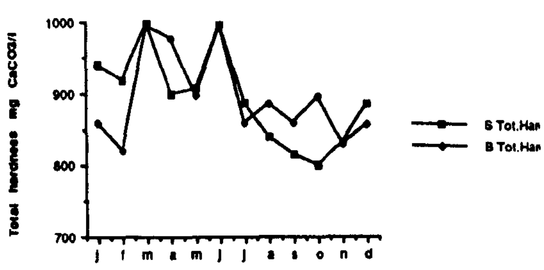
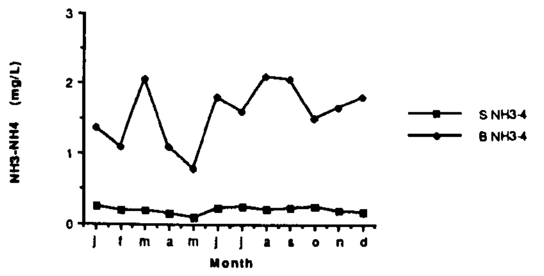
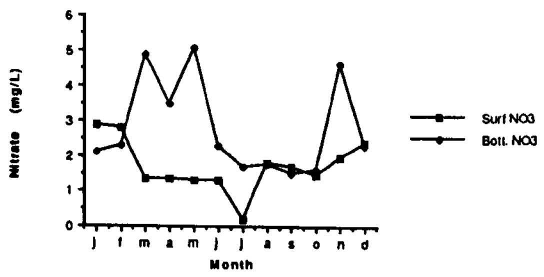

Total hardness mg CaCO3/l
1000
900
800
700
j f m a m j j a s o n d
Month

Figure 25b Temporal fluctuations of NO_2-N, NO_3-N, total ammonia, PO_4 and chlorophyll-a in X-Pooc permanent aguada

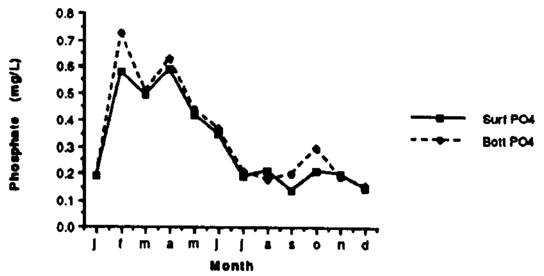


NH3-NH4 (mg/L)
Month
S NH3-4
B NH3-4

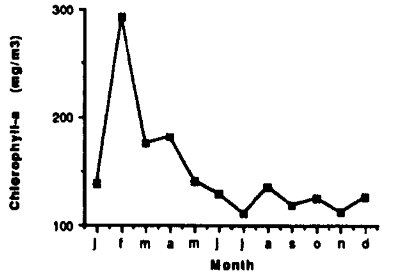
Nitrite (mg/L)
Month
Surf NO2
Bott NO2



Nitrate (mg/L)
Month
Surf NO3
Bott. NO3



Phosphate (mg/L)
Month
Surf PO4
Bott PO4



Chlorophyll-a (mg/m3)
Month

Total ammonia was significantly different ($P<0.01$) between the epilimnion and the hypolimnion. Much higher ammonia concentrations (ranging from 0.78 to 2.10 mg NH_3–NH_4–N/l) were observed in hypolimnetic waters throughout the year, with greater variation, whilst levels in the upper layer were low (<0.25 mg/l), and fluctuated little during the study period (Fig. 25b).

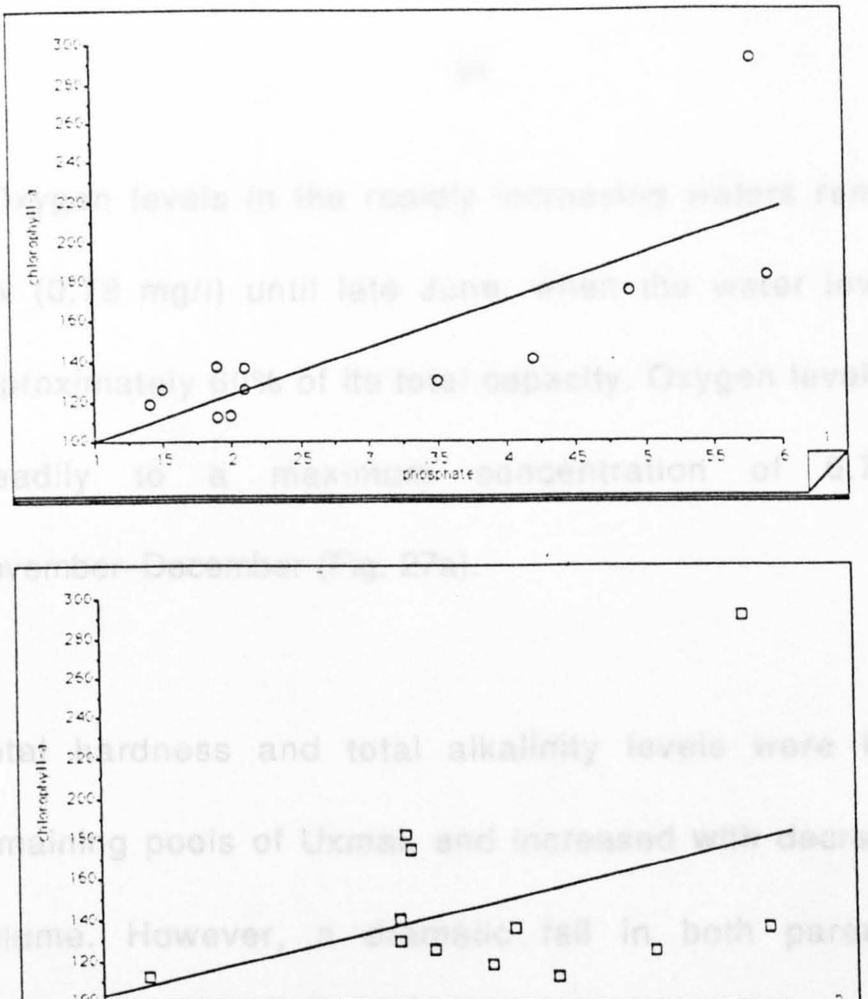
Orthophosphates showed parallel trends in both the epilimnion and the hypolimnion, with no statistically significant differences in concentrations ($P>0.05$), reaching a maximum level of 0.73 mg PO_4–P/l in February, after which a steady decline recurred until August and September (Fig. 25b).

Chlorophyll–a concentrations were consistently high, above 100 mg/m3 (Fig. 25b). A February peak was observed coinciding with the maximum recorded phosphate concentration. A highly significant correlation was found between both parameters (r= 0.784, P<0.01). No significant correlations were observed between chlorophyll-a and both NO_3-N and NH_3-NH_4-N (P>0.05), the latter being negative. (Figure 26). Sediment hydrogen Sulphide concentrations were 2.83, 3.96 and 4.08 mg/l in February, June and November, respectively.

3.3.3.3 Uxmal seasonal pond.-

Uxmal was sampled regularly from January through March 1985, when the aguada dried up. It was not until 1987 that there was sufficient precipitation to fill the aguada, and samples were taken from April to December in order to record this filling stage. Water temperatures were observed to fluctuate between 27 and 34 ^{0}C, (mean = 28 ^{0}C). Oxygen levels fluctuated greatly with values of 2.85 mg/l recorded at the beginning of the year in the remnant puddles and in the ancient Mayan cistern at the bottom of the aguada.

Figure 26 Relationships between chlorophyll-a and orthophosphate, nitrate and ammonia levels in X-Pooc permanent aguada

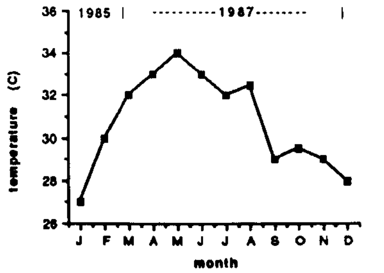

chlorophyll-a
phosphate
1
chlorophyll-a
nitrate
2
chlorophyll-a
total ammonia
3

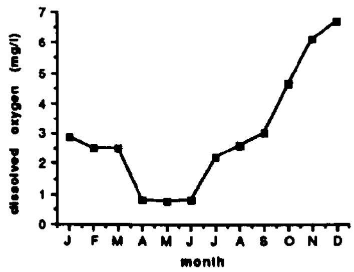
Oxygen levels in the rapidly increasing waters remained very low (0.78 mg/l) until late June, when the water level reached approximately 60% of its total capacity. Oxygen levels then rose steadily to a maximum concentration of 6.7 mg/l in November–December (Fig. 27a).

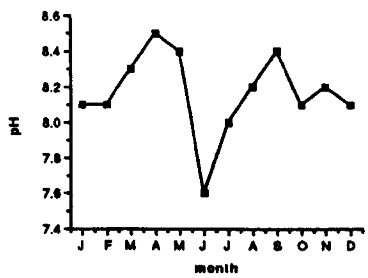
Total hardness and total alkalinity levels were high in the remaining pools of Uxmal, and increased with decreasing water volume. However, a dramatic fall in both parameters was observed immediately after the first rains of the season had fallen in May A gradual increase was then observed in the levels of both parameters from June until July, after which a steady decline was observed (Fig. 27a).

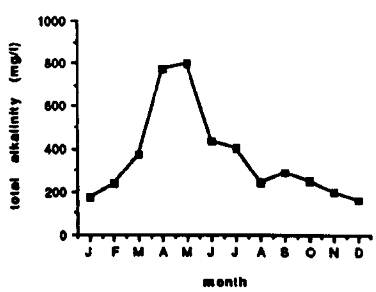
Nutrients showed considerable fluctuations during the study period, depending on the season. Low levels of nitrates, nitrites and ammonia were observed during January – April (Fig. 27b). Marked increases in nitrate levels occurred between March and

Figure 27a Temporal fluctuations of temperature, dissolved oxygen, pH, total alkalinity and total hardness in Uxmal seasonal pond


1985 | ----------1987-------- |
temperature (C)
month
J F M A M J J A S O N D


dissolved oxygen (mg/l)
month
J F M A M J J A S O N D


pH
month
J F M A M J J A S O N D


total alkalinity (mg/l)
month
J F M A M J J A S O N D

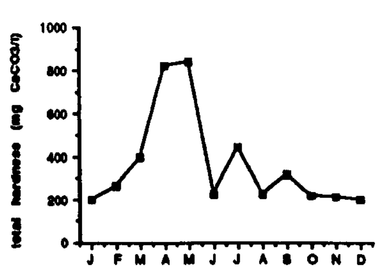
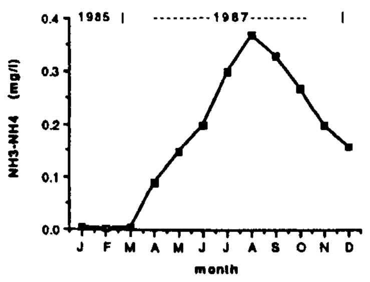
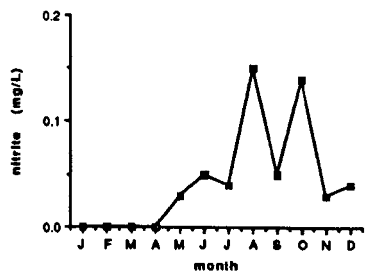
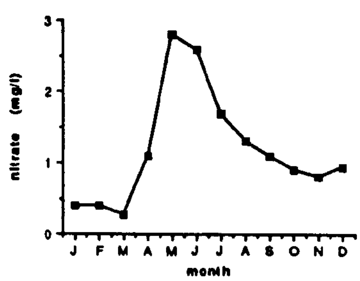
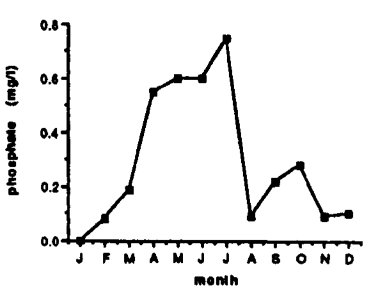

month
J F M A M J J A S O N D

Figure 27b Temporal fluctuations of NO_2-N, NO_3-N, total ammonia, PO_4 and chlorophyll-a in Uxmal seasonal pond


1985 | ---------1987--------- |
NH3-NH4 (mg/l)
0.0
0.1
0.2
0.3
0.4
J F M A M J J A S O N D
month


nitrite (mg/L)
0.0
0.1
0.2
J F M A M J J A S O N D
month


nitrate (mg/l)
0
1
2
3
J F M A M J J A S O N D
month


phosphate (mg/l)
0.0
0.2
0.4
0.6
0.8
J F M A M J J A S O N D
month

May, and in nitrite and ammonia levels during the period April – August. Maximum concentrations of nitrates were recorded in May. Nitrite and ammonia levels were highest in August (Fig. 27b).

Figure 27b shows the trend in phosphate concentrations during the sampling periods in Uxmal. High levels were observed firstly in the remnant puddles between February and April, and then in May when the aguada was filling.

Chlorophyll–a levels were not measured regularly as a result of logistic problems. Levels were low in January (1.83 mg/m3) and February, although samples taken in June showed a much higher value (86.40 mg/m3). Measurements carried out in October again showed much lower chlorophyll–a levels (12.13 mg/m3) and by the end of the year the levels of chlorophyll–a were around 10 mg/m3 (Table 7).

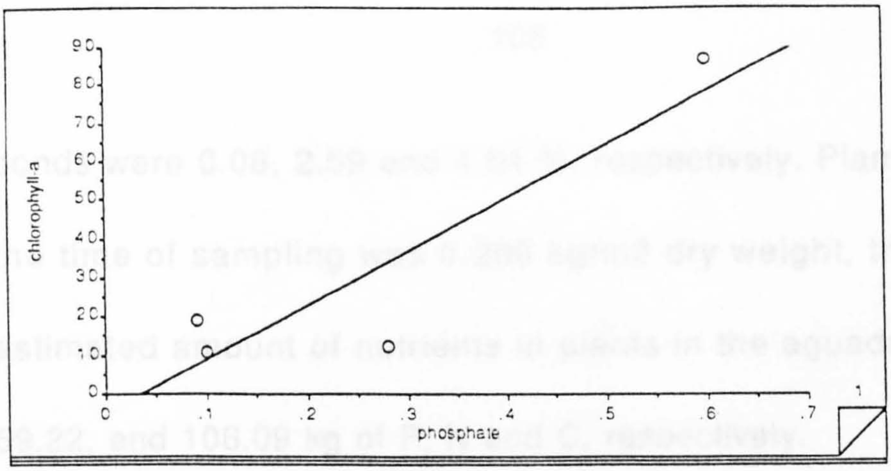
Table 7. Chlorophyll–a Concentrations at Uxmal Seasonal Pond, at Different Times of the Year.

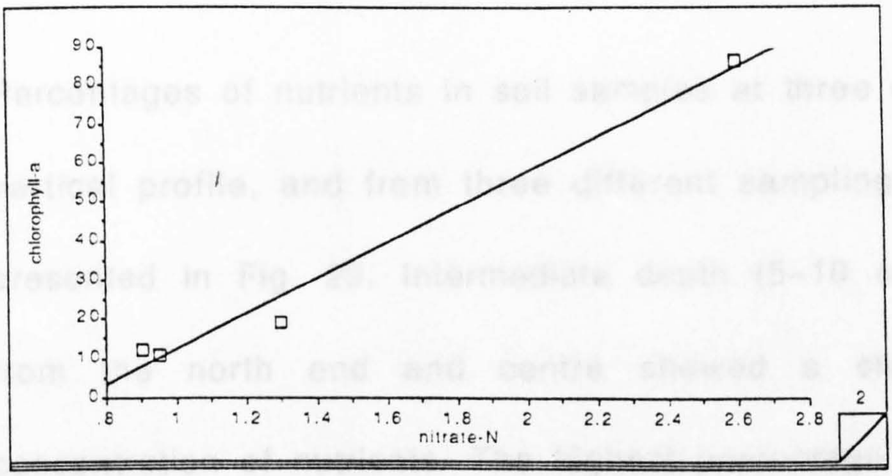
Month	Jan	June	Aug.	Oct.	Dec.
Chlorophyll–a (mg/m3)	1.83	86.40	19.83	12.13	9.86

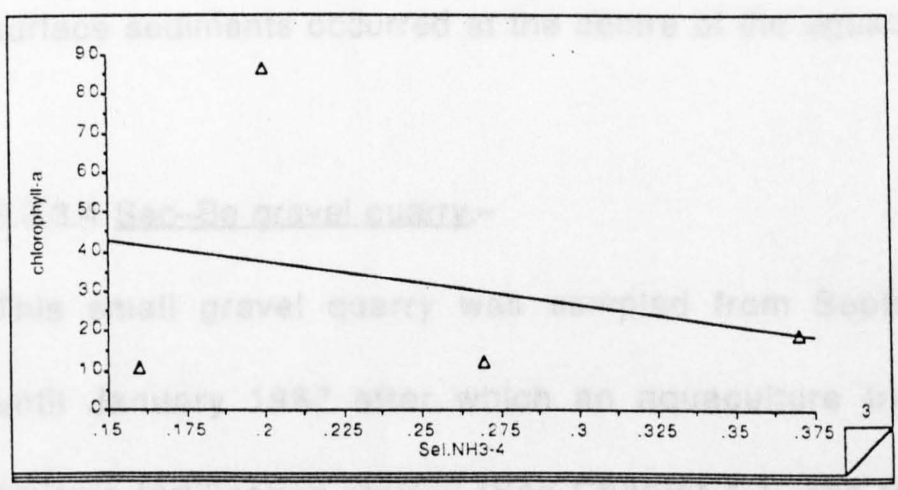
The corresponding monthly values of nutrients were correlated with those of chlorophyll–a, and the results show a strong and highly significant correlation coefficient with nitrate ($r=0.992, P<0.01$) and orthophosphates ($r=0.991, P<0.01$). A negative correlation was obtained by comparing ammonia levels with Chlorophyll–a concentration ($r= -0.273$), reflected in the weakest regression coefficient of the analysis (Fig 28).

Levels of nutrients (phosphorus, nitrogen and carbon) in plant samples from the vegetation cover colonising Uxmal seasonal

Figure 28 Relationships between chlorophyll-a and orthophosphate, nitrate and ammonia levels in Uxmal seasonal pond


chlorophyll-a
phosphate
1


chlorophyll-a
nitrate-N
2


chlorophyll-a
Sel.NH3-4
3

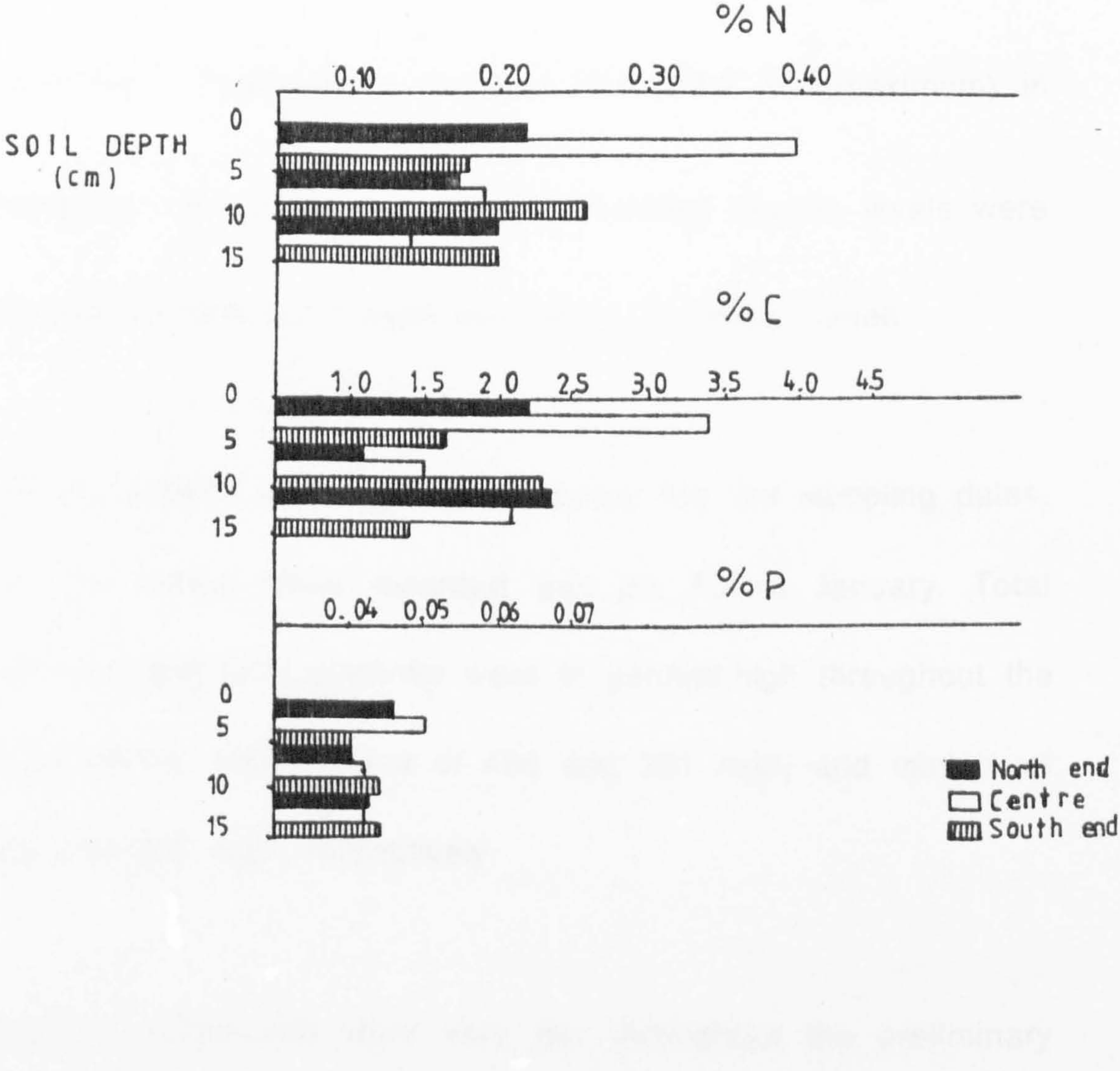
ponds were 0.08, 2.59 and 4.64 %, respectively. Plant biomass at the time of sampling was 0.206 kg/m2 dry weight, thus the total estimated amount of nutrients in plants in the aguada were 1.83, 59.22, and 106.09 kg of P, N and C, respectively.

Percentages of nutrients in soil samples at three depths in a vertical profile, and from three different sampling points are presented in Fig. 29. Intermediate depth (5–10 cm) samples from the north end and centre showed a slightly lower concentration of nutrients. The highest percentage of PNC in surface sediments occurred at the centre of the aguada.

3.3.3.4 Sac–Be gravel quarry.–

This small gravel quarry was sampled from September 1986 until January 1987 after which an aquaculture trial involving organic fertilisation started (See Chapter 4). The results of the water quality assessment throughout a one year cycle, including both the undisturbed and the post–fertilisation periods, are

Figure 29 Carbon, nitrogen and phosphous contents of soil samples at 0-5, 5-10 and 10-15 cm deep from Uxmal seasonal pond



% N
0.10
0.20
0.30
0.40
SOIL DEPTH
(cm)
0
5
10
15
% C
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
% P
0.04
0.05
0.06
0.07
North end
Centre
South end

presented in Figures 35a and 35b (see Chapter 4). However in this section, only the results from the former stage will be presented. Temperature declined from 29.5 ^{o}C (maximum) in September, to 17 ^{o}C in January. Dissolved oxygen levels were consistently high (>7.7 mg/l) throughout the study period.

The pH showed a steady decline during the five sampling dates, and the lowest value recorded was pH 7.2 in January. Total hardness and total alkalinity were in general,high throughout the study period, with maxima of 466 and 281 mg/l, and minima of 320 and 246 mg/l, respectively.

Nitrogen compounds were very low throughout the preliminary sampling period. Total ammonia (NH_3-NH_4) never exceeded 0.086 mg/l. Nitrite levels were the lowest of the nitrogen compounds with concentrations below 0.0055 mg/l. Nitrate showed maximum levels in the order of 0.60 mg/l and minimum levels around 0.47 mg/l.

Orthophosphates were always in the range of 0.01 and 0.03 mg/l, with maximum values recorded in January and minima in October and November. This same trend was observed for chlorophyll-a concentrations, with low levels ranging between 0.17 and 0.41 mg/m3.

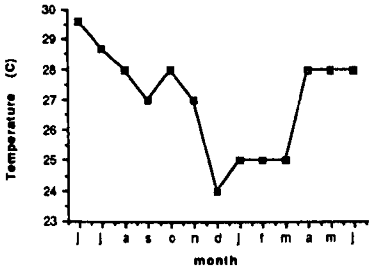
3.3.3.5 Mytza gravel quarry.-

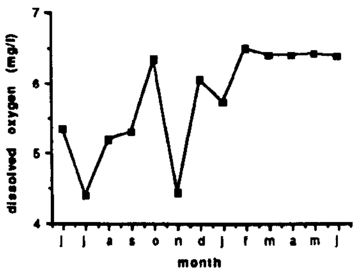
This large (9.30 ha) quarry was sampled from June 1988 through to June 1989. In late April 1989, a cage trial was conducted as part of an ODA-funded research cooperative programme, from which an estimation of the potential environmental impact of aquaculture on these quarries was derived for the present work (See Chapter 4). This section presents the results of water quality throughout the annual cycle.

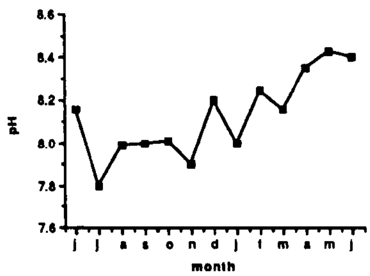
The results of the One–Way Analysis of variance applied to the data from the four sampling stations established in Mytza (Fig. 16) revealed no significant differences among the sets of values for each variable measured ($P>0.05$), showing a fairly well mixed water body. Figures 30a and 30b show the trends followed by the averaged values of the physicochemical parameters analysed. Little variation was found in temperature during the study period (5.6 ^{o}C range), with maximum values observed in June and a minima in December. The waters were well oxygenated, with dissolved oxygen concentrations of 4.40 mg/l in July and November, and maximum values of 6.40 mg/l recorded during February and March.

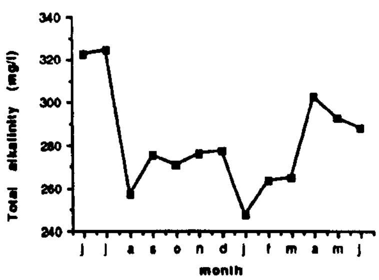
Levels of pH were always above pH 7.8, with maximum values of 8.4 in May, coinciding with the maximum recorded levels of hardness (573.75 mg CaCO3/l) and a high alkalinity concentration (293 mg/l).

Figure 30a Temporal fluctuations of temperature, dissolved oxygen, pH, total alkalinity and total hardness in Mytza gravel quarry


Temperature (C)
30
29
28
27
26
25
24
23
j j a s o n d j f m a m j
month


dissolved oxygen (mg/l)
7
6
5
4
j j a s o n d j f m a m j
month


pH
8.6
8.4
8.2
8.0
7.8
7.6
j j a s o n d j f m a m j
month


Total alkalinity (mg/l)
340
320
300
280
260
240
j j a s o n d j f m a m j
month

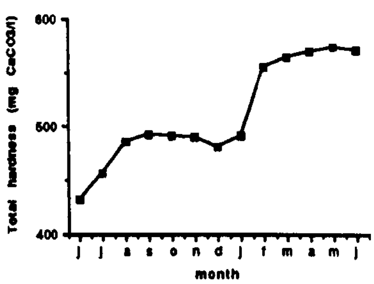
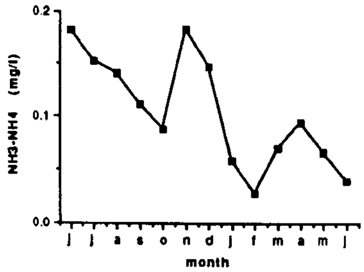
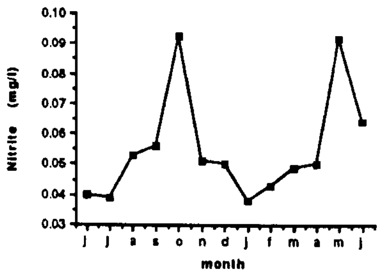
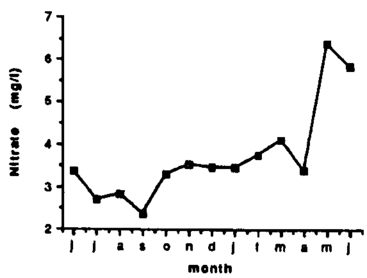
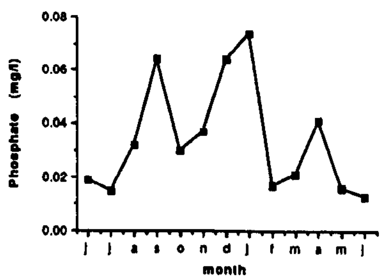

Total hardness (mg CaCO3/l)
600
500
400
j j a s o n d j f m a m j
month

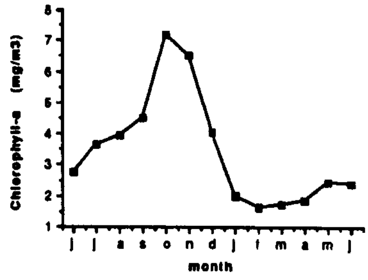
Figure 30b Temporal fluctuations of NO_2-N, NO_3-N, total ammonia, PO_4 and chlorophyll-a in Mytza gravel quarry


NH3-NH4 (mg/l)
0.2
0.1
0.0
j j a s o n d j f m a m j
month


Nitrite (mg/l)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
j j a s o n d j f m a m j
month


Nitrate (mg/l)
7
6
5
4
3
2
j j a s o n d j f m a m j
month


Phosphate (mg/l)
0.08
0.06
0.04
0.02
0.00
j j a s o n d j f m a m j
month

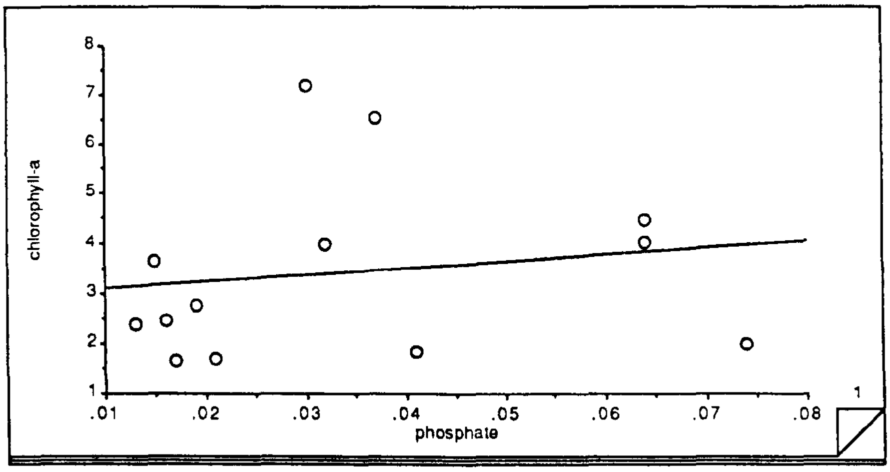

Chlorophyll-a (mg/m3)
8
7
6
5
4
3
2
1
j j a s o n d j f m a m j
month

Nutrient levels showed marked peaks during the year, although on a much smaller scale. Nitrate levels remained low between June and September, 1988, ranging from 3.4 to 2.71 mg NO_3–N/l. Thereafter a steady increase was observed until a peak was observed towards the end of the sampling period (6.38 mg/l). This peak coincided with maximum nitrite concentrations. The trends for nitrate and ammonia tended to be inversely related.

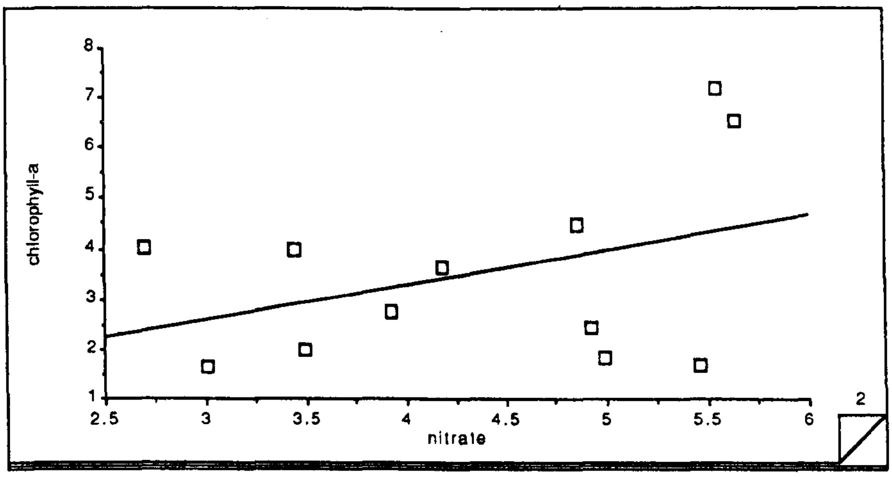
Orthophosphate levels fluctuated markedly during the study period. Maximum PO_4 concentrations were recorded in January (0.074 mg/l), and minimum values in July (0.015 mg/l). Chlorophyll–a levels were generally low, ranging between 1.64 and 7.21 mg/m^3, but showed a well–defined trend, with a steady increase from June to October, and then declining steeply towards the minimum observed in February and March, 1989.

Chlorophyll–a concentrations in Mytza correlated weakly and not statistically significantly with ammonia, nitrate and orthophosphate concentrations ($P>0.05$), (Fig. 31).

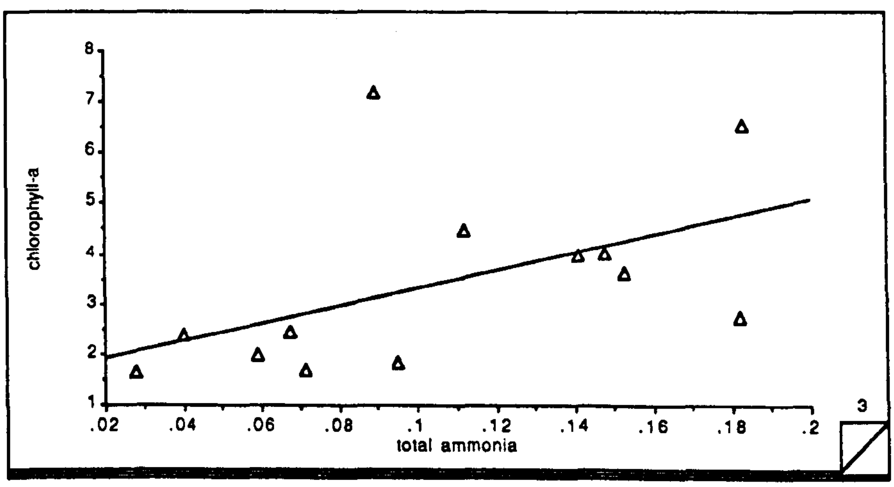
Figure 31 Relationships between chlorophyll-a and orthophosphate, nitrate and ammonia levels in Mytza gravel quarry



chlorophyll-a
8
7
6
5
4
3
2
1
.01
.02
.03
.04
.05
.06
.07
.08
phosphate
1



chlorophyll-a
8
7
6
5
4
3
2
1
2.5
3
3.5
4
4.5
5
5.5
6
nitrate
2



chlorophyll-a
8
7
6
5
4
3
2
1
.02
.04
.06
.08
.1
.12
.14
.16
.18
.2
total ammonia
3

3.4 Discussion.–

It is clear from the above results that the physiographic zonification proposed by Back and Hanshaw (1974) and modified by Isphording (1975) and Lesser and Weidie (1988), which was adopted as a geographic basis to carry out the water resources assessment of this work (Fig 2–Chapter 2), is reflected in the diversity of water bodies present in Yucatan, and consequently on their limnological conditions. Spatial and temporal heterogeneity of physical and chemical parameters within the study region is thus dependent on the geological nature of their basins and on their hydrological sources. For practical purposes the discussion of water quality is divided into three groups, each involving a different type of water body. The first group involves the aquifer–fed water bodies, which are those whose hydrological conditions are entirely dependent on the water table; a second group, termed here as non–aquifer–fed water bodies, include those whose hydrology and water balance depend on sources of water other than groundwater, such as rainfall and runoff. A third group, the permanent aguadas, represents hypertrophic water bodies whose water balance is likely to be deficient (i.e. X–Pooc). The first group includes the open sinkhole Chen–Ha, and both the quarries Mytza and Sac–Be. The non–aquifer–fed waterbodies include the seasonal pond Uxmal, and finally, X–Pooc permanent aguada belongs to the third group.

3.4.1 Aquifer–fed water bodies.–

These water bodies are generally oligotrophic and characteristically have moderately low levels of orthophosphates and chlorophyll–a. However, relatively high levels of nitrate were present in Mytza quarry and the deeper waters of Chen–Ha sinkhole. This may be explained by the fact that the levels of organic loads contaminating the aquifers of Yucatan are reported to be considerable (Back and Hanshaw, 1974; Lesser, 1976). Gaona–Vizcayno, et al. (1985) found levels ranging between 5 and 30 mg NO_3-N/l in 40 m deep water samples from a sinkhole in northern Yucatan. In Chen–Ha sinkhole, the relatively higher levels of nitrate observed in deeper waters may be due to the closer proximity of this sampling point to the dissolution channel which connects the sinkhole with an aquifer. However the even higher levels of nitrate in Mytza quarry may be due to: a) its geographic location, since this quarrying complex is only two kilometres from the point of discharge of ground waters (Lesser, 1976), and thus it is likely to receive significant amounts of nitrate via the aquifers, b) coprogenic origins, since a considerable amount of birds visit the quarry throughout the year , and c) from the experimental cages, even though the six experimental cages installed at the end of the period, appear not to be a major factor influencing nutrient concentrations in the system as judged from the non–significant differences in nutrient levels among sampling points. However, Sac–Be quarry, a more recently formed water body located somewhat out of the direct influence of major ground water paths (see Fig. 4 Chapter 2), presented the lowest nitrogen and phosphorus values during the preliminary water quality survey.

In general terms, none of the aquifer–fed water bodies appeared to be highly influenced by precipitation. This could be due to the high buffering capacity of their hard, carbonaceous waters. Alkaline conditions are a main characteristic of karstic areas, and constitute a major factor regulating the hydrochemical processes. This characteristic implies a high buffering capacity which in most cases does not decrease in response to rainfall, and does not lose its ability to maintain an alkaline environment. Ford and Williams (1989) suggest that weak solutions of HCl occur in nature which react when in contact with CaCO3, dissolving the calcite and releasing CO_2, which in turn dissolves more calcite thus maintaining high alkalinities. This also seems applicable to the reaction induced by the presence of rainwater resulting temporarily in the formation of H_2CO_3. Such conditions seem to play an important role in defining the trophic state of Yucatan's karst features.

It is known that the supply of phosphorus to water bodies depends to a large extent on the solubility of phosphorus found in the sediment and in suspended organic particles (Avnimelech, 1983; Stabel, 1986). Free phosphates are highly reactive and in the presence of $CaCO_3$, phosphates are chemisorbed on these compounds and recrystallised to form hydroxyapatite crystals (Stumm and Leckie, 1971; Avnimelech, 1983). These reactions could be of importance in regulating the phosphorus entering the aquifer–fed water bodies. It is also documented that in high pH, alkaline waters, nitrogen is lost to the atmosphere both as ammonia and as nitrogen gas (Srna, 1976; Goldman and Horne, 1983; Taub, 1984; King and Garling, 1986). This mechanism may be important in controlling nitrogen levels in the water bodies studied here. The literature shows a wide range of nitrogen levels reported for test wells and sinkholes in Yucatan (from 0.4

to 91 mg NO_3–N/l) (Back and Hanshaw, 1974; Lesser, 1976; Gaona–Vizcayno et al 1985). This wide range is mainly due to the geographic location of the sampling point, since nutrient concentrations are bound to be influenced by the cultural activities of the area of influence and by the degree of permeability of its soils. An interesting point in Chen–Ha is the negative relation shown between primary productivity and nitrate concentration, suggesting a decrease in the levels of nitrate by increased plant N–uptake. Has been demonstrated by Schindler (1977), Welch, Sturtevant and Perkins (1978) and Leonardson and Ripl (1980), that the presence of PO_4 in low concentrations, stimulates nitrate uptake by algae. This could be responsible for the suggested high N–uptake.

Even though chlorophyll–a correlates much more weakly with phosphates in Mytza than in Chen–Ha, the N:P ratios in both sites are sufficiently high (>80) to indicate Phosphorus limitation of algal growth. This also applies to Sac–Be when undisturbed. The levels of phosphorus found in the surface waters of Chen–Ha are considerably lower than those of Mytza quarry. Therefore, under lower phosphorus conditions, a marginal increase is expected to produce an important effect on primary productivity. However, Mytza quarry is a much larger and shallower water body located in a more exposed region, and as a result is a very well mixed system where nutrients and organic matter brought in by runoff, together with nutrients from faecal matter contributed by the birds and nutrients from the caged fish , are evenly distributed and continuously recycled. By contrast Chen–Ha sinkhole is a deep sink where allochthonous nutrients are rapidly utilised and a considerable amount bound to dense particles is lost to the bottom. There, under the prevailing aerobic conditions, phosphorus resuspension is largely prevented. Instead, accumulation of organic matter on the bottom and utilisation by the deep sinkhole fauna are more likely to occur. This also seems to be the fate of nutrients brought in by the aquifer which connects to the sink at depth (the water table in this area of the reported to be at approximately 40 m, according to Lesser, 1976).

The relatively high levels of oxygen measured in the lower layers of the sinkhole, where light penetration is undetectable, are likely to be the result of photosynthetic activity of specialised types of algae which thrive in low–light conditions. Revsbech, Jorgensen and Blackburn (1983) found a photosynthetic activity of 15.2 mmol $O_2/m^2/h$ in almost dark conditions in an aquatic microbial mat. No data was found in the literature on oxygen concentrations of deep sinkholes. However, it is well documented that a specialised fauna dwells the deep inundated caverns and sinkholes of Yucatan. The community is adapted to live in dark conditions and largely feeds on detritus (Hubbs, 1936; Reddell, 1977), although none has been reported to utilise oxygen from sources other than the water itself, implying that a considerable amount of oxygen is present at these depths.

The above trophic conditions present in the aquifer–fed water bodies, result in a low faunal diversity. Sinkholes are fragile ecosystems, whose low productivity allows only relatively small fish populations. In this study, the collected specimens in Chen–Ha, corresponded to species reported as typical of karst features of the region (Hubbs, 1936; Reddell, 1977). The size–frequency distribution histograms presented in Figures–17 through–21 show, in the case of C.urophthalmus, a high proportion of the sampled fish within the size range 95 – 114 mm total length, with the largest specimen being within the 125–129 mm size interval. On the other hand, the population of this species in Mytza quarry showed a much wider range of size classes with the largest specimens being over 200 mm. Such differences may be the result of an endemic population of C.urophthalmus in Chen–Ha, where availability of food is more restricted and thus growth and production are limited. On the other hand, Mytza's population probably comprises fish which have grown elsewhere and invaded the systems through the cracks of the rocky walls. The poecilid fish identified in all the water bodies studied are abundant and widely distributed in karst features throughout the Peninsula of Yucatan (Hubbs, 1936; Reddel, 1977).

In general, aquifer–fed water bodies present good water quality conditions for aquaculture. However, sinkholes have a unique flora and fauna adapted to cave–life (Reddel, 1977), whose existence is dependent on the ecological stability of the system. This, together with the fact that sinkholes are also important sources of potable water throughout Yucatan, make this water body type a last option for aquaculture in the region. By contrast,gravel quarries, offer great scope for aquaculture. These water bodies are becoming increasingly common in the Yucatan Peninsula as quarrying operations expand. The land used for quarrying is often leased from poor farmers and there is growing concern about how these pools can be used to generate income, once quarrying operations cease. Both small and large quarries showed good water quality for aquaculture. The relatively low productivity of Sac–Be suggests small ponds are unlikely to be suitable without fertilisation.

The large quarries represent an ideal site for cage aquaculture. They are relatively deep and continuous wind–induced mixing provides good levels of oxygenation and might be and important feature regulating localised cage waste accumulation.

Although ammonia toxicity is known to be associated with high pH (Allabaster and Lloyd, 1982), the highest level of unionised ammonia measured during the present study in both quarries involved, were well below the concentrations reported as harmful for those species likely to be candidates for aquaculture in these water bodies, namely the native cichlid Cichlasoma urophthalmus, and the Nile tilapia Oreochromis niloticus. Alkaline conditions present in these systems, could also help retard eutrophication.

3.4.2 Non aquifer–fed water bodies.–

The limnological characteristics of these seasonal ponds are very distinct from those of the rest of the water bodies present in Yucatan. They differ in several ways. As already mentioned, southern Yucatan has thicker, organically rich soils. These conditions together with the higher rainfall south of Sierrita de Ticul range, give rise to these seasonally water–filled ponds.

The results of the water quality monitoring show very well–defined trends in the physicochemical parameters measured, following the filling and drying stages characteristic of these temporary water bodies (Kalk and Schulten–Seden, 1977; Cole and Fisher, 1979; Arredondo et al, 1982; Chandrasoma, 1986; Thayaparan, 1987). As already mentioned, Uxmal temporary pond was first sampled from January to March, 1985, covering the latter part of the drying out stage. It was not until 1987 when rainfall was again sufficient to saturate the soil of the aguada and refill it, that a full description of the hydrological cycle could be completed.

Nutrient levels increased considerably as the water level started to rise in late April, 1987. Almost certainly the result of the release of nutrients retained in both the soil and the vegetation cover.

Dissolved oxygen concentrations remained above 2 mg/l in the remnant puddles prior to the beginning of the rainy season,coinciding with the results by Arredondo et al (1982) in a tropical seasonal pond. The observed high levels of oxygen in the receding waters may be the result of photosynthetic activity stimulated by a pool of nutrients concentrated in the remaining water. By late April the vegetation cover was already partially flooded, and this time the recorded dissolved oxygen levels were at their minimum (0.78 mg/l), most certainly as a result of plant decomposition and oxidation of organic matter brought in by runoff. This decline in oxygen levels during the filling stage has also been observed by Barclay, (1966).

As nutrients became available in the water, the natural productivity of the system was stimulated. Even though it was not possible to analyse regularly the concentration of chlorophyll–a, the levels of these pigments at the beginning of the year, when the water level was almost 30% of capacity, show the lowest recorded value, probably as a result of phosphorus and nitrogen depletion and overcrowding. However, the maximum chlorophyll–a concentration was observed in June, at which stage the water volume had risen to 90 % of capacity and all vegetation cover had been decomposed and the nutrient levels were at their maximum. Furthermore, a selection of the monthly corresponding values of phosphate and nitrate were correlated to chlorophyll–a concentrations, and even though the small number of observations make it difficult to be certain, the correlation coefficients are extremely high ($r = 0.991$ and 0.992, respectively), and highly significant ($P<0.01$). This increase in primary productivity is also reflected in the trend of alkalinity, and consequently in a rise in pH. Such results agree with the limnological behaviour of seasonal ponds reported by a number of authors (Dabborn and Clifford, 1974; Grobbelaar, 1976; Kalk and Schulten-Seden, 1977 Arredondo, Garcia and Martinez, 1982; Arredondo et.al, 1982; Porras, 1985). However, the peak of nutrients was followed by a rapid decline, most probably as a result of phytoplankton and bacterial uptake. Dabborn and Clifford (1974) also report a rapid orthophosphate decline following a post-filling peak in a temporary pond. Another possible fate for phosphorus under hard water conditions, could have been the binding of phosphates to soil and suspended particles and precipitation as calcium and phosphorus compounds (Avnimelech, 1980), thus decreasing the amount of free available orthophosphates which consequently limited algal growth.

The high levels of hardness present in this water body reflect the calcareous nature of the soils of the catchment area, which are leached from rocks as rainwater runs to the basin. It is worth mentioning that this seasonal pond was used by an ancient

Mayan population as a reservoir, hence the presence of the cistern found at the bottom. Since the water was directed towards the basin from different catchment points located in the nearby archaeological zone, via stony channels, it is likely that most of the $CaCO_3$ present in the pond derives from the rocks of these paths. Hardness levels decreased in Uxmal as water volume rose, as a result of dilution. Moreover, alkalinity and pH were observed to be at their lowest in early June, probably as a result of high CO_2 input from rainwater. Dabborn and Clifford, (1974) state that conductivity and hardness trends in seasonal ponds indicate on a purely volumetric basis, the transient balance between evaporation and precipitation. A rise or fall in either value, reflects the fraction of the pond volume that has been lost through evaporation, or gained by precipitation. As the dry season progressed, evaporation rates became high and water volume decreased rapidly, and by December, the water volume in Uxmal was reduced to 50%, and by January to 30%. At this stage nutrient levels, alkalinity and hardness had decreased considerably, probably as a result of the hydrogeochemical interactions mentioned previously, as well as phytoplankton uptake. However, by late February, a large pool of nutrients had become concentrated in the receding waters, which resulted in rising levels of orthophosphates and nitrogen compounds. Cole and Fisher (1979) stated that lentic ecosystems act as nutrient sinks for terrestrially and atmospherically derived materials. This appears to be the case of temporary waters, and indeed of Uxmal, since almost all nutrients brought in by rainfall and runoff during the rainy season are kept within the system through soil nutrient retention and terrestrial plant uptake during the dry season, as judged by the relatively high levels of nutrients found in the corresponding samples.

As far as the fauna of Uxmal is concerned, the low diversity found in this system is characteristic of ephemeral waters. Species have short life cycles, and are probably transported as eggs (Williams, 1987) from a closed perennial waterbody by birds.

In general, seasonally rain–filled ponds such as Uxmal, offer good scope for aquaculture as water quality is suitable, although variation in rainfall from year–to–year may make them an unpredictable environment.

3.4.3 Permanent aguadas.–

X–Pooc, as already mentioned is representative of a type of water body which was originally an open sinkhole connected to an aquifer, and whose once permeable walls have been almost completely sealed off as a result of high organic loadings such as cattle excreta, organic matter brought in by runoff, and decaying leaves from the surrounding vegetation. Such factors

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phosphorus and nitrogen seem to be derived largely from external sources, mainly of coprogenic origin, since the water body is used as a source of drinking water for cattle. However, a high proportion of the phosphorus present in the system is almost certainly of autochthonous origin, resulting from bacterial activity and phosphorus release from the anaerobic sediments. It is well documented that under such conditions, the solubility of phosphorus increases and the phosphorus bound to particulate matter is released as free orthophosphate, which in turn binds to other particles in the water column thus sinking again to the bottom.(Taub, 1984; Jonasson, 1984; Stauffer, 1985; Sinke et al., 1990). It appears that the large quantities of organic matter that sink into the hypolimnion in X–Pooc, including dead algae, are decomposed in the anoxic sediments. As a consequence, phosphorus is released. However, it is probable that most of the released orthophosphates do not reach the epilimnion again, since it is likely to re–bind to precipitating particles, especially calcite crystals. It has been suggested by a number of authors (Hepher, 1966; Stumm and Leckie, 1971; Avnimelech, 1980) that dilute orthophosphates readily react with CaCO3, forming calcium phosphate complexes. Furthermore, Gliwicz (1979) speculated that a sharp thermocline should result in a decrease of the speed of sinking organic particles into hypolimnetic waters due to an increase in water density and viscosity, thus accumulating organic matter until a number of particles are able to break the tension of the metalimnion and proceed to the bottom. This metalimnetic tension could prove to be a barrier in X–Pooc, preventing released orthophosphates from reaching the epilimnion and instead providing a pool of organic particles to which dissolved reactive phosphorus is most likely to bind eventually sinking back to the bottom. On the other hand, the high levels of phosphates recorded in the epilmnion throughout the study period, reflect a permanent allocthonous supply which exceeds both algal uptake and calcium binding. As mentioned earlier, phosphorus in X–Pooc is almost certainly of largely coprogenic origin, from cattle droppings of the littoral zone. It is possible that the high levels of phosphates found in the epilimnion were originated and transported by bioturbation by the fish present and the cattle itself when walking on the shallow littoral areas. Stauffer (1985) reported that extremely high levels of phosphorus found in a large eutrophic lake, were originated and transported from the littoral zones.

Under anaerobic conditions and high pH, bacterial decomposition also release high quantities of ammonia and denitrification also produces nitrogen gas (Jonasson, 1984; Fry, 1987). The results of this work seem to confirm this, since high levels of ammonia were always present in the hypolimnetic waters whilst very low concentrations were found in the epilmnion, the latter probably as a result of rapid ammonia uptake by phytoplankton.

A moderately strong significant positive correlation was observed between chlorophyll-a and phosphates ($r = 0.786$, $P<0.01$) showing a strong phosphorus influence in primary productivity.

It is probable that nitrogen in algae and organic matter that sink into the hypolimnion is dissimulated releasing ammonia which in turn returns to the epilmnion where it is reutilised by algae.

It is interesting to note that under these extremely hard–water conditions and associated high alkalinity levels and elevated pH,CO2 for photosynthesis be drawn from the large concentration of HCO_3 ions, without any increased fluctuations in pH.

In summary, it appears that under high levels of nutrients, especially phosphorus, the depletion of ammonia by algae in addition to other non–nutrient factors, such as self shading and overcrowding, are the factors limiting further algal growth, as reported for similar environments in Florida (Agusti, et.al., 1990).

High concentrations of H2S were recorded from pore waters of X–Pooc, similar to those reported by Serruya and Leventer (1984) for lake Kinneret in Israel. High sulphate levels have been reported for several sinkholes in different parts of Yucatan, as a result of deep marine water layers believed to lie several tens of metres below the land surface (Back and Hanshaw, 1974). An infiltration of deep groundwater could be the source of sulphate ions of X–Pooc, along with the contribution of some allocthonous sulphur–bearing organic matter, from which sulphate–reducing bacteria produce H2S which is passed into the water column. Under such conditions, a low diversity of small poecilid fish thrive making use of the high primary productivity of the euphotic zone.

Given the prevailing extreme environmental conditions, X–Pooc and similar permanent aguadas, are unlikely to be suitable for aquaculture. High risk of ammonia and H2S toxicity, together with low dissolved oxygen problems, limit managed fish production in these water bodies. Nevertheless, several studies have attempted to improve conditions in stratified eutrophic lakes (Welch, 1984; Henderson–Sellers and Marks, 1987; Bailey–Watts et al., 1988) which theoretically could be used to improve conditions of permanent aguadas. Moreover, biological "stripping" involving the stocking of filter–feeding species as a means to remove excess phosphorus, is another effective and productive way of reversing eutrophication (Sreenivasan, 1980). This could probably be the best alternative for both improving conditions and producing fish through aquaculture in permanent aguadas.

Clearly, the diversity in the physicochemical behaviour of the water bodies studied, responds to differences in the hydrogeological nature of their basin, as well as the water supplies of which their hydrological cycle is dependent. A common characteristic governing water quality in all the sites studied, however, is the high hardness and hence alkalinity of their waters, due to a constant input of base salts from the calcareous soils of the region.

CHAPTER 4

AQUACULTURE TRIALS

4.1 Introduction.-

Aquaculture production in Yucatan has been negligable. The first attempts to initiate aquaculture in the region were marked by the introduction of tilapia (Oreochromis spp) fry which were released in some sinkholes in the early 1970's. However, because there were not monitoring programmes, no published information is available (May, 1985; pers.com). Even though there are two government fishfarms in the State, neither is in operation. The lack of documentation on the environmental behaviour and thus the scope of the natural water bodies present in this area of the country for implementing aquaculture has made it difficult to start aquaculture.

This chapter presents the results of a series of aquaculture trials carried out on the basis of the results from the first phase of this work, in an attempt to provide the necessary background information on the potential for fish culture in Yucatan. Three sites whose characteristics appeared suitable for fish culture were selected: Sac–Be and Mytza quarries, and the seasonal pond Uxmal. Two main culture techniques were used: stocking of fry in Sac–Be and Uxmal, the former with the addition of organic fertilisers, and cage culture in Mytza quarry. There is potential for intensive cage culture to adversely affect the environment (Beveridge, 1987) and in order to investigate this potential problem, an environmental impact assessment was also carried out at the Mytza cage site.

On the basis of the available information, the potential for a variety of management strategies for fish production in the existing water bodies of Yucatan is discussed.

4.2 Methods.–

A summary of the aquaculture trials is presented in Table 8.

4.2.1 Experimental fish.–

In all cases fry of *Cichlasoma urophthalmus* ranging in mean individual weight from 220 to 450 mg and mean individual total length (25 to 34 mm) were utilised. Experimental fish were obtained from the Centro de Investigacion y Estudios Avanzados (CINVESTAV) hatchery, where they are produced under environmentally–controlled conditions. The native species *Cichlasoma urophthalmus* Gunther was selected for most of the trials, because it is widely distributed in the water bodies of the region, hence there is already an established local market for this fish. Also the local availability of fry in sufficient numbers to sustain an initial aquaculture project made it convenient. Moreover, there is currently being carried out a

Table 8 Summary of Aquaculture Trials Carried Out in This Study

Site	Description of Trial	Period	Species used	Stocking Density	Main Objectives
Sac-Be	Extensive monoculture Organic fertilization with fresh cut grass	Feb-Aug 1987	C. urophthalmus	$1\ m^{-2}$ *	Evaluate Limnological changes by organic fertilizer, and potential yields.
Mytza	Enviromental Impact Assessment of Cage farming	Apr-June 1989	C. urophthalmus	$28\ m^{-3}$	Assess potential enviromental impact of cage aquaculture in gravel quarries.
Uxmal	Stocking of fry during wet season. Extensive monoculture	Dec '89 March'90	C. urophthalmus	$0.25\ m^{-2}$	Assess Potential survival rates and yields under natural productivity
Uxmal (small pond)	identical	Oct'89 Feb'90	O. niloticus	$0.50\ m^{-2}$	

* An additional number of fry amounting 16% of the required fish for this density was stocked to allow for sacrifices for stomach content analysis.

comprehensive research project aiming at its cultivation (Martinez and Ross, 1986; Martinez, 1987; Alvarez, 1987; Flores-Nava et.al, 1989a; Martinez, 1989; Martinez, Martinez and Ross, 1990). In one trial, tilapia, Oreochromis niloticus, was tried in order to assess this fish as an alternative species for extensive aquaculture in seasonal ponds, since this exotic species is the only fish that has successfully been introduced in the region.

4.2.2 Water quality monitoring.-

Two of the selected sites for aquaculture were monitored throughout the trial period (Sac-Be and Mytza quarries), but no water quality recording was carried out during trials at Uxmal seasonal ponds. Dissolved oxygen, temperature, pH, total hardness, total alkalinity, orthophosphates, nitrate-N, nitrite-N, total ammonia and chlorophyll-a concentrations were measured using the methods and instruments described in Chapter 3.

Sampling points are shown in figures 13, 15 and 16 (Chapter 3). Two diurnal studies of D.O., Temperature and pH were carried out at Sac–Be quarry, in order to assess the fluctuation of these parameters before and following fertilisation.

4.2.3 Stocking procedures.–

In all cases fish were transported from the rearing unit in oxygenated polythene bags at a density of 10 fry/l (SEPESCA, 1982), and stocked early in the morning after dissolved oxygen concentration and temperature were measured. No acclimation was carried out, since there were no temperature differences between the rearing unit and the stocked water bodies. Fish were released at different points of each water body, in order to ensure homogeneous distribution. In the case of Sac–Be, this was done once fertilisation was carried out and oxygen concentrations had stabilised.

4.2.4 Experimental extensive culture of C.urophthalmus in Sac-Be quarry.

The main objectives of this trial were to observe the limnological changes caused by organic fertilisation on this type of water bodies; as well as to evaluate the potential fish yields from gravel quarries under extensive culture conditions, using the native cichlid Cichlasoma urophthalmus. Fertilisation was considered necessary because of the low nutrient concentrations in the gravel pit and likely low primary productivity and fish production.

4.2.4.1 Fertilisation procedure.-

Fertilisation was carried out with freshly cut grass Panicum virgatum. This was manually chopped and introduced in plastic-meshed sacks, at a rate of 35 kg every three days, over a period of 20 days, with a total input of 0.24 tons (equivalent to

1.8 tons/ha/20 days), following the recommendations of Anon (1982a) and Arredondo (1984). Every third day, the sacks were replaced. Sacks were left to drift and decompose.

4.2.4.2 Stomach contents analysis.–

Between mid–May and the end of August, on every water quality and population growth sampling date, ten fish were removed at random and immediately sacrificed for stomach contents analysis. Fish were dissected open and their digestive tracts removed, individually labelled, and preserved in 10 % formalin (Chavez,1973) for later laboratory analysis. A visual estimation of the degree of fullness of each stomach was made using the scale full, 3/4 full, 1/2 full, trace and empty, as criteria. Once in the laboratory, the tracts were dissected and the stomachs contents emptied in a Petri dish, identified, and quantitatively analysed using the percentage volumetric method described by Hyslop (1982).

4.2.4.3 Macro-plankton analysis.-

The changes in plankton community of Sac-Be, following fertilisation,were examined by collecting a plankton sample with a 0.90 m-long, 0.30 m-inflow diameter, 200 µm mesh size Nytex plankton net (with flow-meter). The net was manually retrieved along the major axis of the quarry three times every sampling date. The plankton collected were immediately preserved in 5 % formalin (De Bernardi, 1984) and transported back to the laboratory for counting and identification. Phytoplankton analysis was carried out in a Newbauer haemocytometer, where mean numbers of cells per ml were extrapolated to total volume of sample (Bold and Whynne, 1978). Zooplankton organisms were directly counted from a known volume of water sample, under a stereoscopic microscope, and the mean of at least three counts, extrapolated to the total volume of the sample (Chavez, 1973).

4.2.4.4 Fish growth.–

Each sampling date, a population sample was randomly netted out, with the purpose–built beach seine net described in Chapter 3. The net was retrieved from the centre of the quarry to the shores and at least 50 fish bulk–weighed to the nearest 0.5 g, with a mechanical spring scale. The mean individual weight was then computed. No repetitive sampling was carried out in this water body, in order to minimise stress and mortality of the fish.

4.2.4.5 Harvesting procedure.–

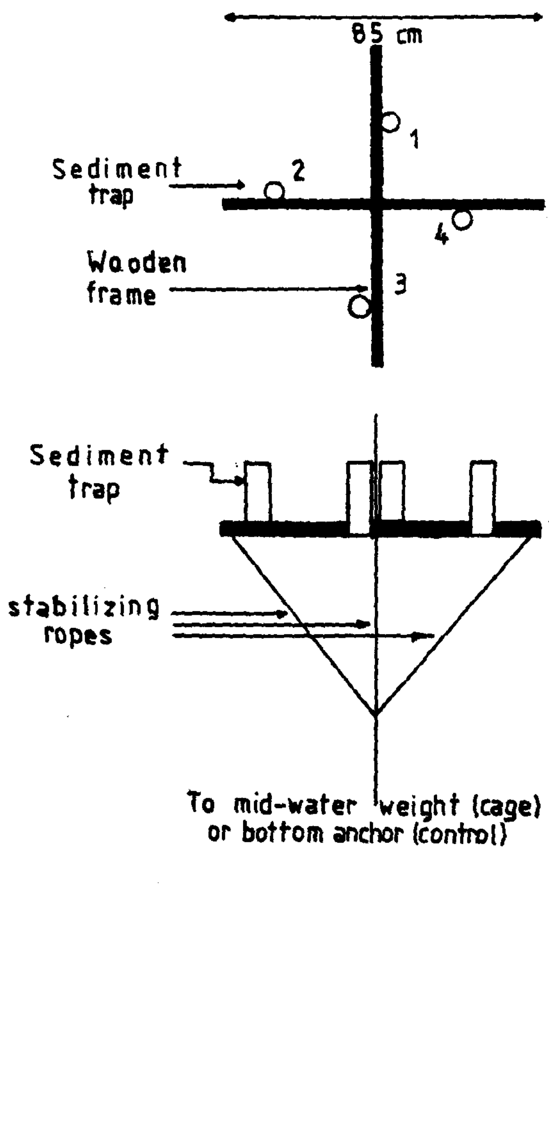
After 165 days, the fish were harvested by thorough seining of the quarry, until approximately 60% of the organisms were recovered. Further removal of the fish by net proved impossible because of the rocky uneven bottom of the quarry. Rotenone was then applied at a concentration of 2 mg/l and after one hour, the remaining fish were removed by hand. Once harvested the fish were bulk–weighed and counted.

4.2.5 Mytza quarry environmental impact assessment.–

The aquaculture cage trial involved had as a main objective the stocking and rearing of hatchery–reared fry of *Cichlasoma urophthalmus*, in a first attempt to grow this species under intensive conditions in cages in gravel quarries. The trial was part of an ODA–funded research project based at CINVESTAV–Merida. Six 3 x 3 x 2 m floating cages were set at the northern end of the larger water body (Fig. 16, Chapter 3). A total of 3,000 19.6 g mean individual weight *C.urophthalmus* juveniles were stocked at a rate of 28/m3 in early April, 1989. The caged fish were fed a 38 % protein diet prepared at CINVESTAV–Merida. The growing period lasted for 14 weeks (Martinez, 1989, unpublished data).

As already mentioned, Mytza quarry was first sampled in June, 1988, before cages were involved. The water quality monitoring continued until June 1989, including the cage trial period. Permission was given to set a series of sediment traps (described below), in order to determine the effects of fish farming activities on the quarry. Sedimentation rates and solid waste loadings from the cages were measured using a series of four 5–cm internal diameter, 30 cm long PVC cylindrical traps attached to wooden planks placed one metre below the bottom of each cage. Stabilising lines and weights were used to keep them in an upright position (Fig. 32). The traps were constructed following the recommendations by Reynolds (1979), cited by Merican and Phillips (1985). Once every week, the traps were carefully lifted, sealed and returned to the laboratory within six hours, where they were rinsed out with double–distilled water into borosilicate glass beakers and dried in a Felisa–2500 oven at 105 ^{o}C in order to determine dry weight. Total organic nitrogen and total phosphorus were then determined by the oxidation

Figure 32 Single array of sediment traps employed in the environmental impact assessment carried out at Mytza cage site.


85 cm
1
Sediment trap
2
4
Wooden frame
3
Sediment trap
stabilizing ropes
To mid-water weight (cage) or bottom anchor (control)

method with 1.5 M NaOH and the ascorbic acid spectrophotometric method, respectively (APHA, 1985). Samples of the feed provided to the caged fish were also analysed, quantifying N and P using the same methods. Ten fish from those which were stocked in the cages were sacrificed and homogenated samples were analysed for phosphorus. This procedure was also carried out on ten fish randomly selected from those harvested at the end of the trial. Fish homogenates were analysed with the aforementioned method. A control site was selected as far away as possible from the influence of the cages.

4.2.6 Stocking of C.urophthalmus and O.niloticus in seasonal ponds at Uxmal.–

The seasonal water body at Uxmal was stocked in December 1989. C.urophthalmus fry were introduced, at a density of 0.5/m2. Two months earlier, a much smaller seasonal pond (approximately 100 m2 surface area), located at approximately 350 m from the southeastern shore of the main body of water (hereafter named the smaller pond), was stocked with tilapia, Oreochromis niloticus, at a rate of 0.5 m2. Such stocking densities were used following recommendations by Rosas (1976) for extensive aquaculture of exotic cichlids in Central Mexico. No water quality or growth data recording was carried out during the course of these trials. Survival and yield from both the smaller pond and Uxmal main water body were obtained at harvest, after 138 and 99 days, respectively.

4.2.5.1 Harvesting procedure.–

In both cases, fish were harvested at the time at which the water level had dropped completely, and in the case of the smaller pond, the fish were easily hand picked from the mud, where they were partially buried and from a remaining puddle at the centre of the pond where most them had congregated. At Uxmal main water body, most fish were concentrated in the Mayan cistern (approximately 85%), from which they were easily removed by scoop net. The remaining fish were also partially buried in the mud, from which they were easily removed by hand. After harvesting, fish were counted, measured (total length), and bulk–weighed.

4.2.7 Analysis of results.–

4.2.7.1 Fish growth and production.–

Growth of the fish was determined in terms of Specific Growth Rate (SGR) by using the formula given by Bagenal (1978):

$$SGR = \frac{\ln wf - \ln wi}{\hat{}t} \times 100$$

Where: wf = Mean final weight of the fish

wi = Mean initial weight of the fish

^t = Growing period

Growth in Sac–Be, was also represented as the sum of the weight increments of the population in each sampling date, as proposed by Hopkins and Cruz (1982). Production (kg/ha) and survival rates (%) are derived from final total biomass and final number of fish at time of harvest, in relation to initial numbers.

4.2.7 2.Environmental impact assessment.–

Sedimentation rates of solid wastes from the cage trial and the control site are presented in terms of $g/m^2/day$ (dry weight). Nutrient sedimentation (N,P) are also expressed in terms of $g/m^2/d$. For this, the total dry weight of the sediment collected under the cages, was divided by 0.047 m^2 (sum of cross sectional areas of all sediment traps), to render figures in a per-square-meter basis, and then divided by the number of days between samplings.

From the results, the phosphorus budget, considered to be the most influential of the elements measured on the trophic state, was estimated using the criteria employed by Beveridge (1984). Student's "t"-tests (Bailey, 1981) were employed to statistically analyse differences between mean sedimentation rates as well as between water quality parameters at both cage and control sites before and following fish stocking in the cages.

4.3 Results.–

4.3.1 Sac–Be trial.–

4.3.1.1 Water chemistry and effect of fertilizer on plankton populations.–

The results of the diurnal fluctuations of dissolved oxygen (D.O.), temperature and pH recorded prior to and during the fertilisation process are shown in Fig. 33. Maximum values of pH and D.O. were recorded at 1600 h in both samples taken before and during fertilisation. Minimum D.O. concentrations were observed before dawn. Nocturnal D.O. levels during fertilisation were lower than those observed prior to fertilisation.

Large phytoplankton and zooplankton numbers showed a highly significant increase ($P<0.01$, t–test) following fertilisation (Fig. 34). In both pre and post–fertilisation samples, a clear dominance of chlorophytes was observed in the phytoplankton community, the most abundant species were Oscillatoria spp and Pleodina spp. Two rotifers (Keratella spp and Brachionus spp) and the copepod Diaptomus spp were identified before

Figure 33 Diurnal fluctuation of temperature, dissolved oxygen and pH in Sac-Be gravel quarry

a) before fertilisation

b) during fertilisation

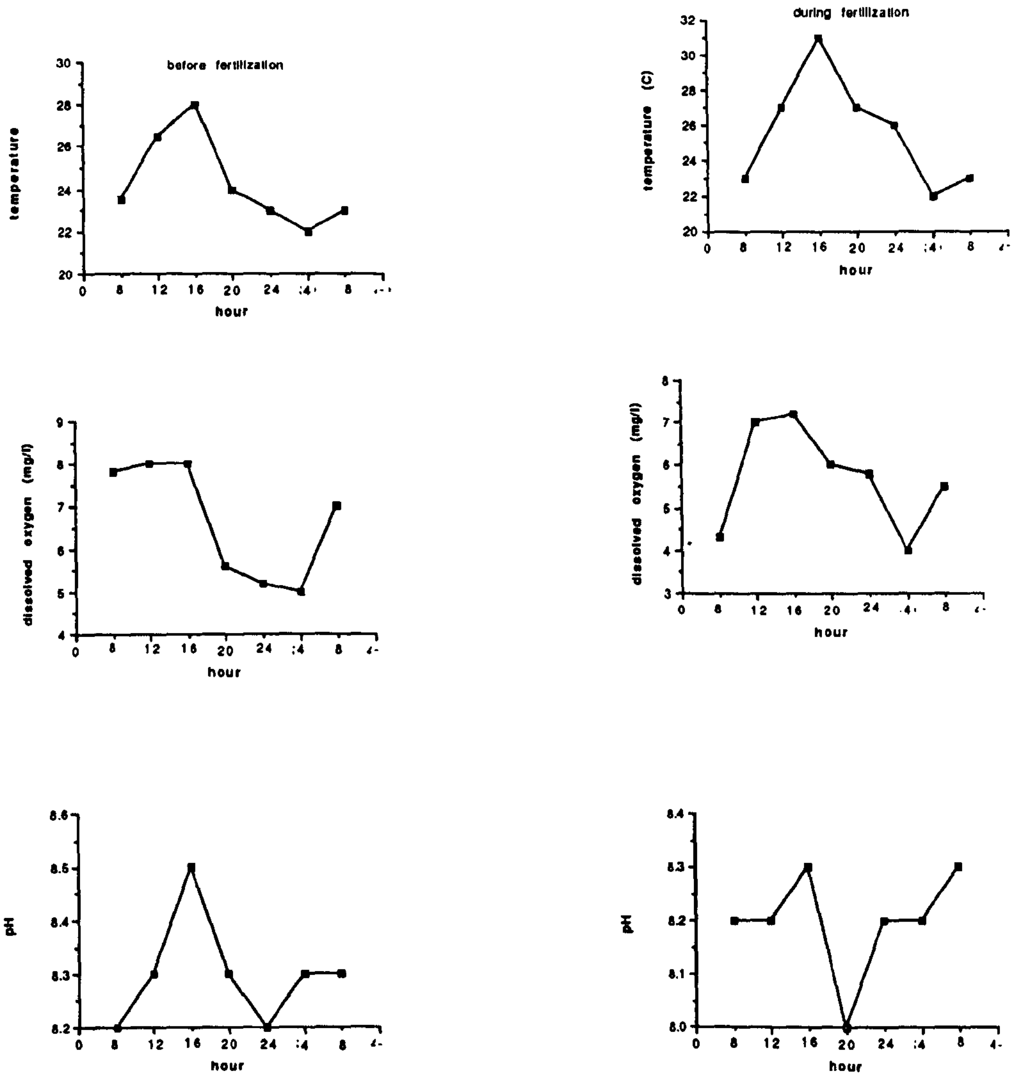
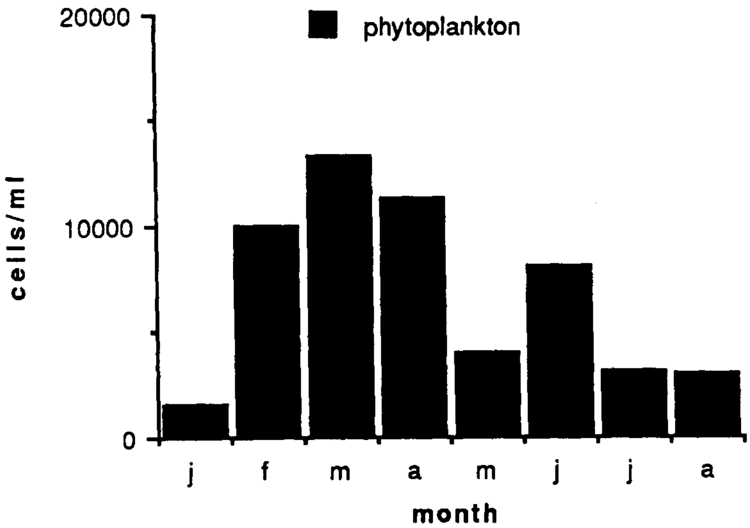
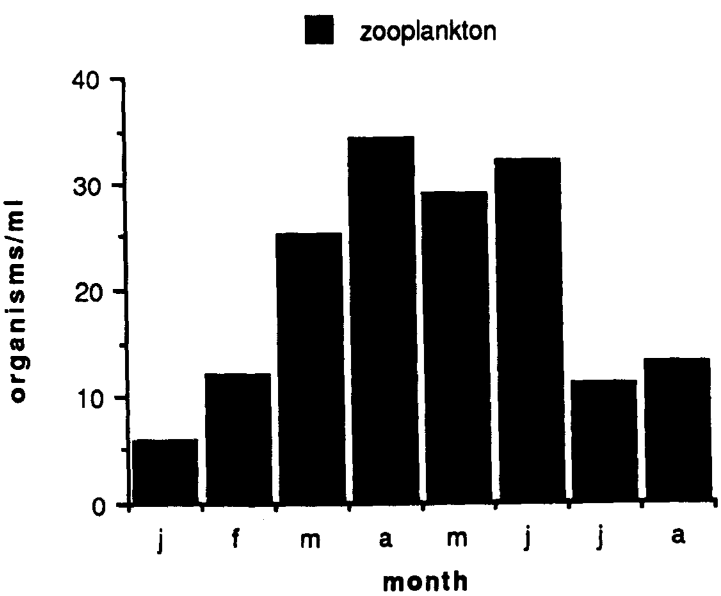

before fertilization
during fertilization
temperature
temperature (C)
dissolved oxygen (mg/l)
pH
hour

Figure 34 Results of the quantitative analysis of plankton in Sac-Be gravel quarry during the study period.



phytoplankton
20000
10000
0
cells/ml
j f m a m j j a
month



zooplankton
40
30
20
10
0
organisms/ml
j f m a m j j a
month

fertilisation. As a result of fertilisation, plankton diversity increased slightly. Coelastrum spp, Closterium spp and Coscinodiscus excentricus were observed for the first time in late February in the large phytoplankton samples. Daphnia spp was identified and became the dominant species of Zooplankton in May. The other two species identified in post-fertilisation samples were Moina spp and the copepod Mesocyclops spp (Table 9).

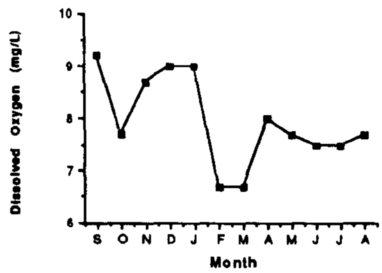
Major changes in nutrient concentrations were also observed as a result of fertilisation. Figs 35a and 35b show the trends of the main physicochemical parameters, where a dramatic increase in orthophosphates, nitrate-N, ammonia-N, nitrite-N and chlorophyll-a concentrations can be seen. Levels of NO_3-N, PO_4 and Chlorophyll-a immediately after the addition of grass were significantly greater ($P<0.01$, t-test), showing an increase of four, twelve and thirty six times the pre-fertilisation values. However, peak concentrations of

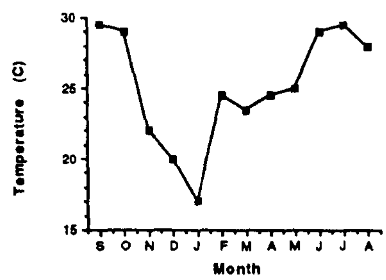
Table 9 - Plankton community in Sac-Be quarry before and after fertilization.

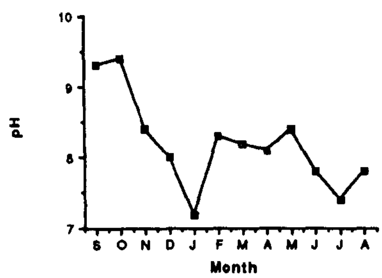
Species	Before	After
Phytoplankton		
Chlorophyta		
Oscillatoria spp	* *	* * *
Pleodina spp	*	* *
Closterium spp		*
Coelastrum spp		* *
Scenedesmus spp		*
Pediastrum spp		*
Chrysophyta		
Navicula spp	*	*
Coscinodiscus excentricus		*
Pinularia spp		* *
Zooplankton		
Rotifera		
Keratella spp	*	* * *
Brachionus spp	*	* *
Copepoda		
Diaptomus spp	*	* *
Mesocyclops spp		*
Cladocera		
Daphnia spp		* * *
Moina spp		*

* = Scarce
** = Abundant
* * * = Very abundant

Figure 35a Temporal fluctuations of temperature, dissolved oxygen, pH, total alkalinity and total hardness in Sac-Be gravel quarry in an annual cycle, including the aquaculture trial.


Dissolved Oxygen (mg/L)
10
9
8
7
6
S O N D J F M A M J J A
Month


Temperature (C)
30
25
20
15
S O N D J F M A M J J A
Month


pH
10
9
8
7
S O N D J F M A M J J A
Month

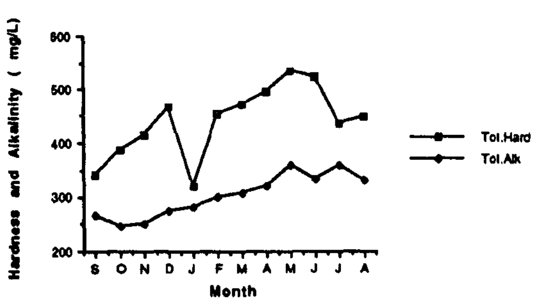
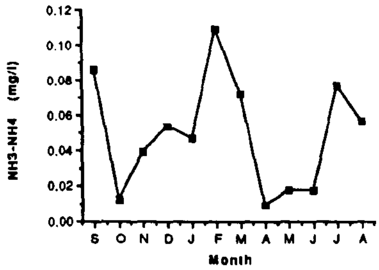
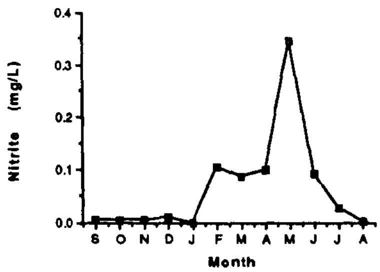
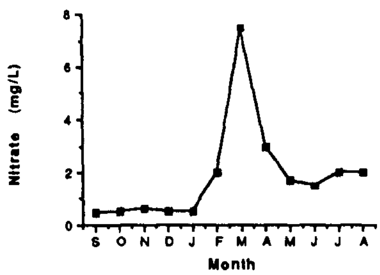
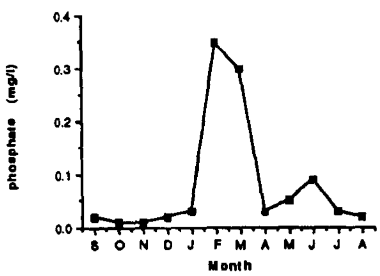

Hardness and Alkalinity (mg/L)
600
500
400
300
200
S O N D J F M A M J J A
Month
Tot.Hard
Tot.Alk

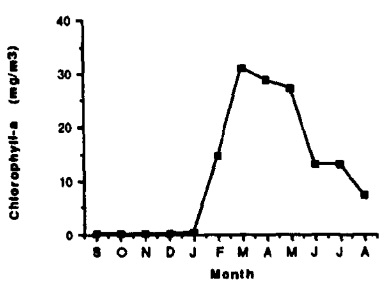
Figure 35b Temporal fluctuations of NO_2-N, NO_3-N, total ammonia, PO_4 and chlorophyll-a in Sac-Be gravel quarry in an annual cycle, including the aquacultural trial.


NH3-NH4 (mg/l)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
S O N D J F M A M J J A
Month


Nitrite (mg/L)
0.4
0.3
0.2
0.1
0.0
S O N D J F M A M J J A
Month


Nitrate (mg/L)
8
6
4
2
0
S O N D J F M A M J J A
Month


phosphate (mg/l)
0.4
0.3
0.2
0.1
0.0
S O N D J F M A M J J A
Month

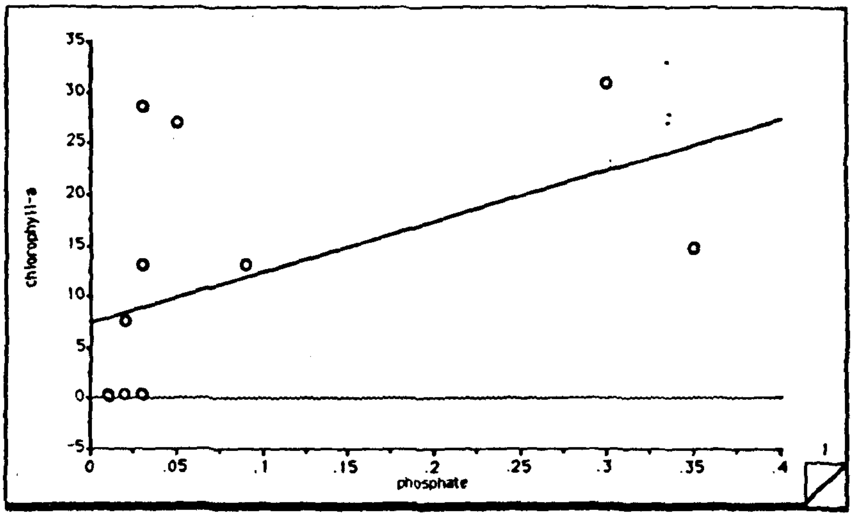

Chlorophyll-a (mg/m3)
40
30
20
10
0
S O N D J F M A M J J A
Month

phosphates and ammonia were followed by a steep and rapid decline during March and April, to levels recorded prior to fertilisation, although the latter rose again in July. Nitrate–N showed its maximum level in March, and a strong and highly significant correlation with chlorophyll-a ($r=0.781, P<0.01$). Figure 36.

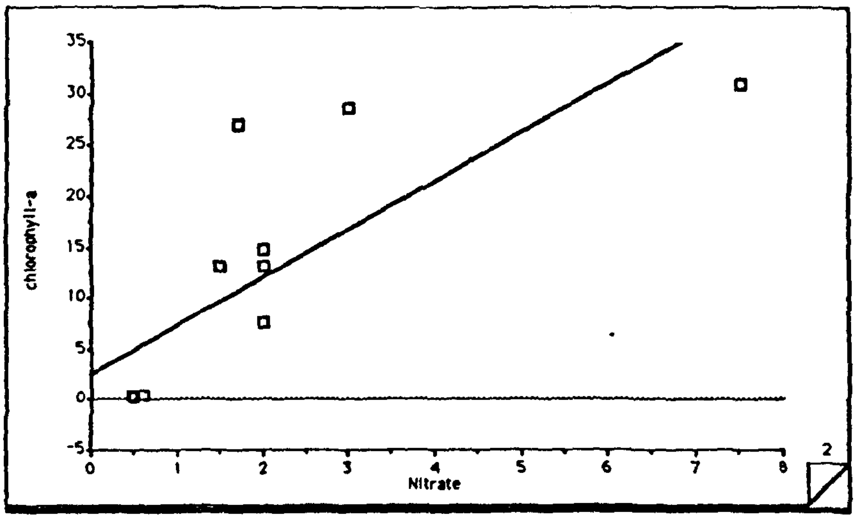
4.3.1.2 stomach contents analysis.–

A high proportion of the fish had full stomachs throughout the trial. Figure 37 presents the dietary preference of *C.urophthalmus* throughout the study period. In general terms, the highest percentage of volume of the stomachs was occupied by material of animal origin, of which the largest proportions consistently observed throughout the study were chironomid

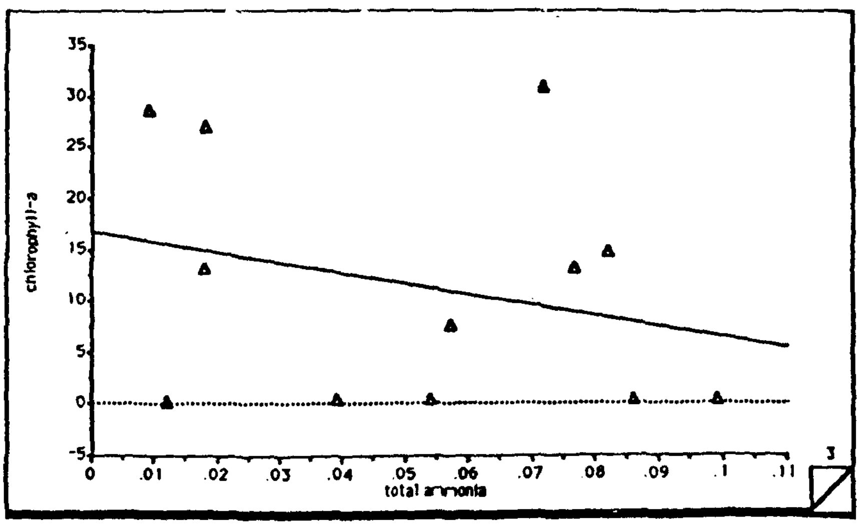
Figure 36. Relationships between chlorophyll-a and orthophosphate, nitrate and ammonia levels in Sac-Be gravel quarry.



chlorophyll-a
phosphate
1

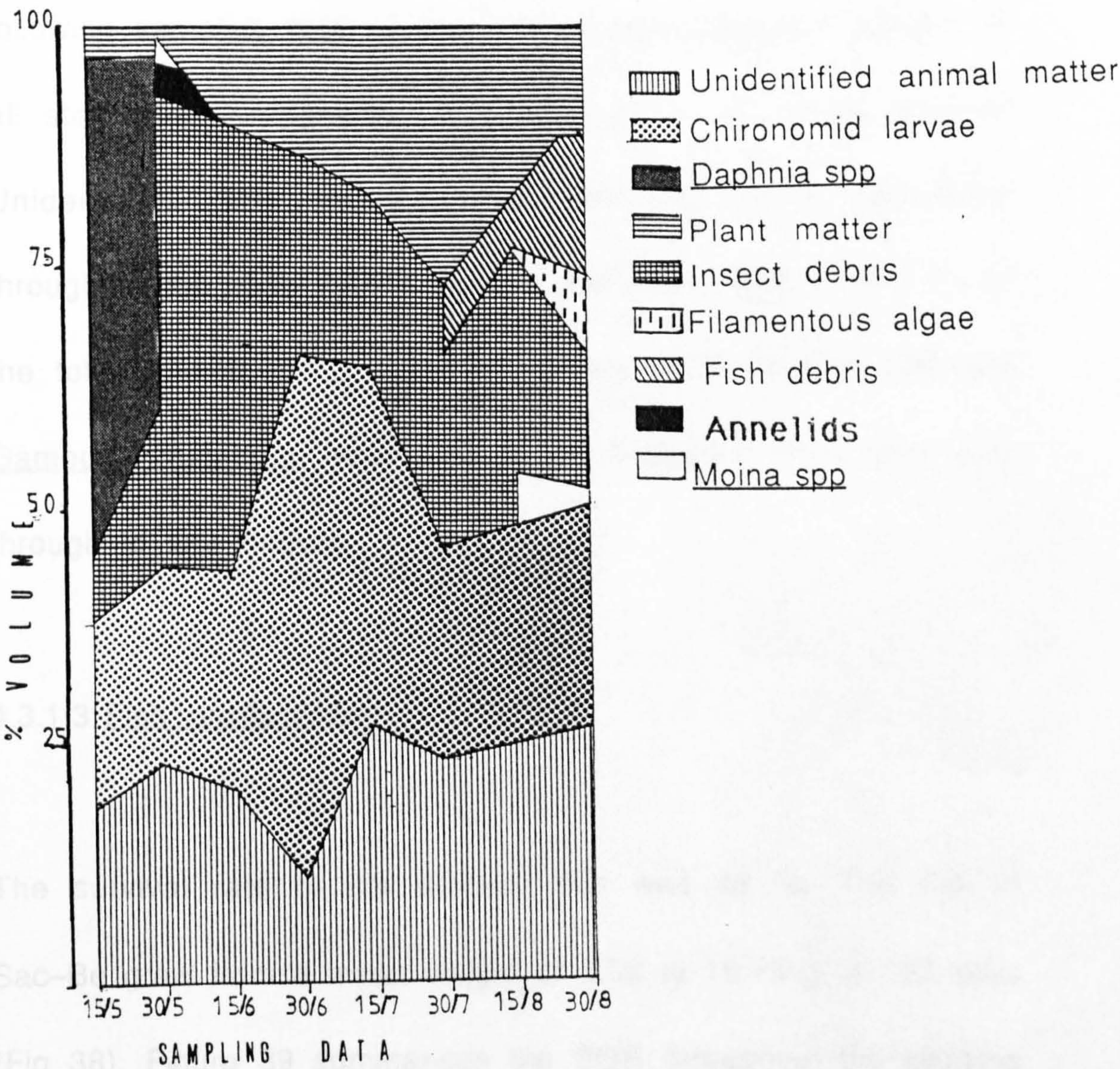


chlorophyll-a
Nitrate
2



chlorophyll-a
total ammonia
3

Figure 37. Results of the stomach contents analysis (volumetric method) of *C. urophthalmus* during the aquaculture trial at Sac-Be gravel quarry



Unidentified animal matter
Chironomid larvae
Daphnia spp
Plant matter
Insect debris
Filamentous algae
Fish debris
Annelids
Moina spp
100
75
50
25
% VOLUME
15/5
30/5
15/6
30/6
15/7
30/7
15/8
30/8
SAMPLING DATA

larvae and various unidentified insect species. In mid–May, animal material comprised 93% and this had risen to 99% on the following sampling date in late May. Daphnia spp was present in all stomachs in mid–May, occupying up to 50 % by volume. Unidentified plant material was observed in all stomachs throughout the study period, with a maximum value of 26.7 % of the total volume being observed. Debris of small fish, probably Gambusia yucatana, appeared in all stomachs from late July through to late August.

4.3.1.3 Fish production.–

The survival rate of the stocked fish was 88 %. The fish in Sac–Be grew from a mean weight of 0.38 to 19.70 g in 165 days (Fig 38). Figure 39 summarises the SGR throughout the growing period. This parameter fluctuated between 5.0 and 0.3 %/day, with an average value of 2.4 %/d. The highest SGR value occurred in late March, and the lowest was recorded in mid–July. The final

Figure 38 Weight increments of C. urophthalmus during the trial at Sac-Be gravel quarry

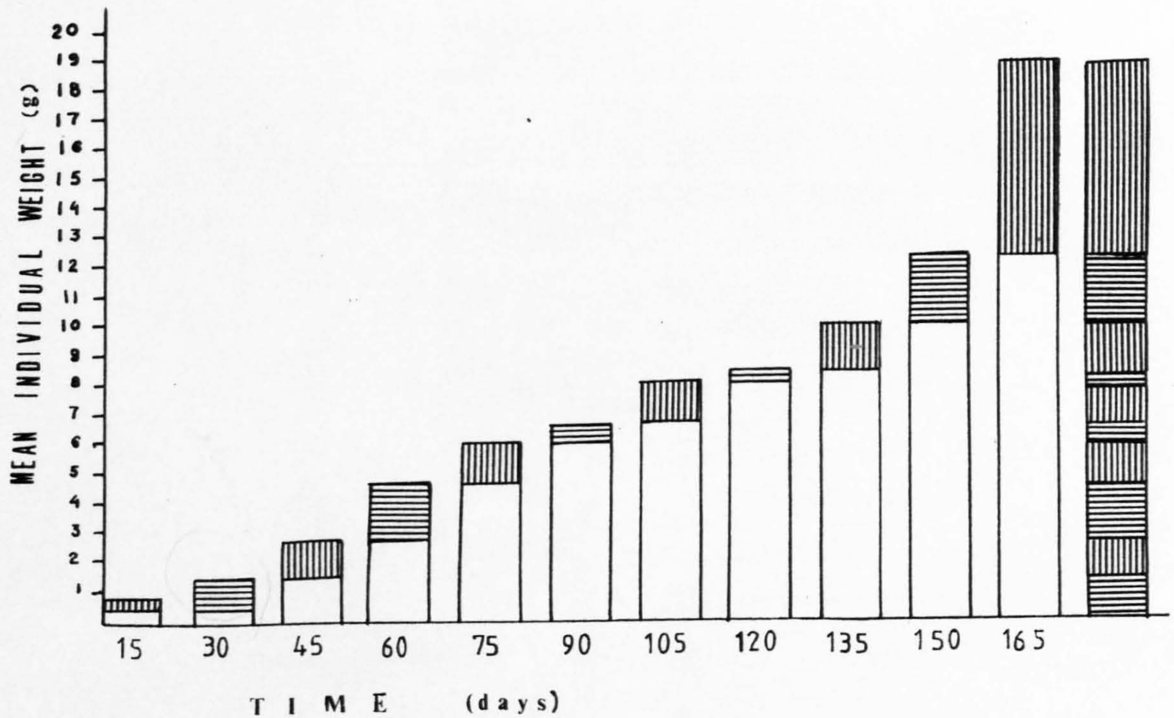
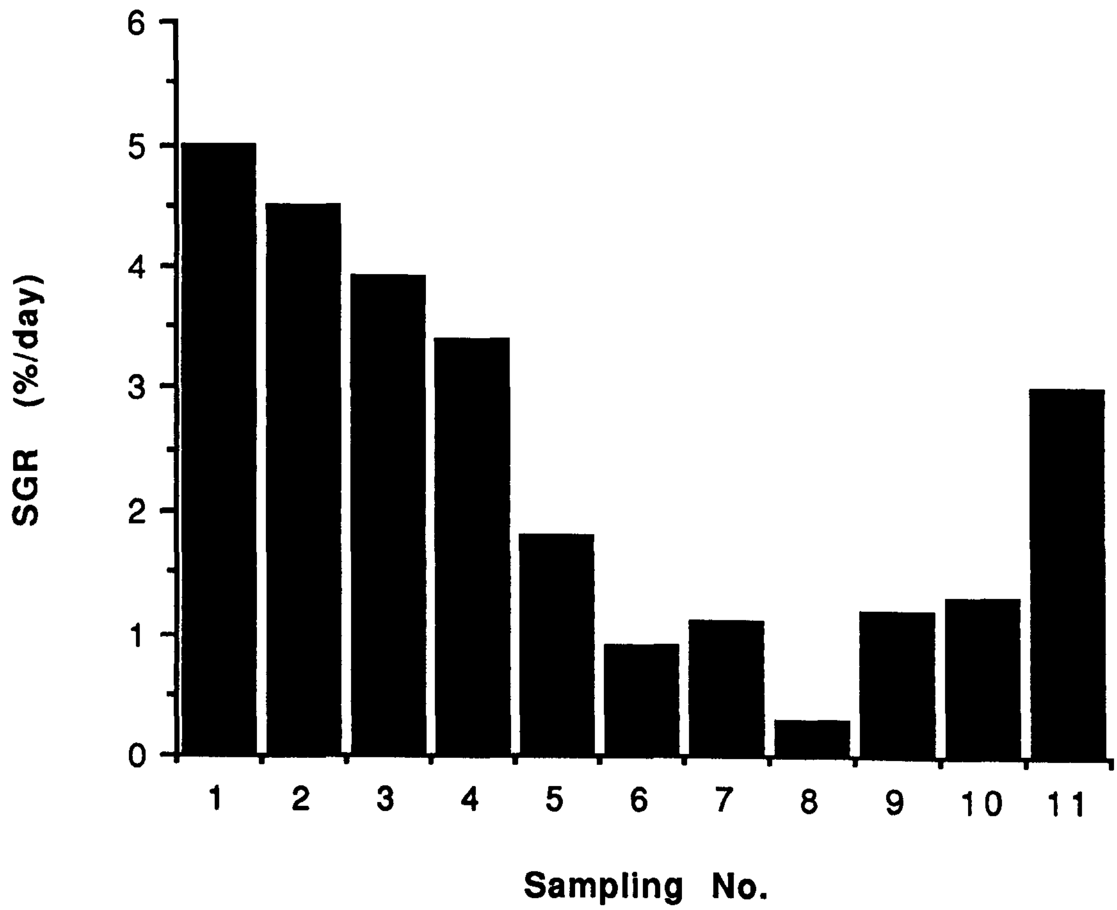

MEAN INDIVIDUAL WEIGHT (g)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
15
30
45
60
75
90
105
120
135
150
165
T I M E (days)

Figure 39. Specific Growth Rate (SGR) of *C. urophthalmus* during the trial at Sac-Be gravel quarry



6
5
4
3
2
1
0
SGR (%/day)
1
2
3
4
5
6
7
8
9
10
11
Sampling No.

population biomass was 24.4 kg, representing a yield of 180.6 kg/ha in 165 days, and a net yield of 180.1 kg/ha.

4.3.2 Mytza quarry environmental impact assessment.–

The experimental cage culture trial in Mytza began in April 1989. The cages were set up two weeks before the fish were stocked, and sediment traps were installed at the same time as the cages, so that samples prior to stocking could also be obtained.

Table 10 presents the Stocking, feeding, survival and production data of the caged fish .

Table 10. Data Summary of the Experimental Cage Culture of *C. urophthalmus* in Mytza Quarry.

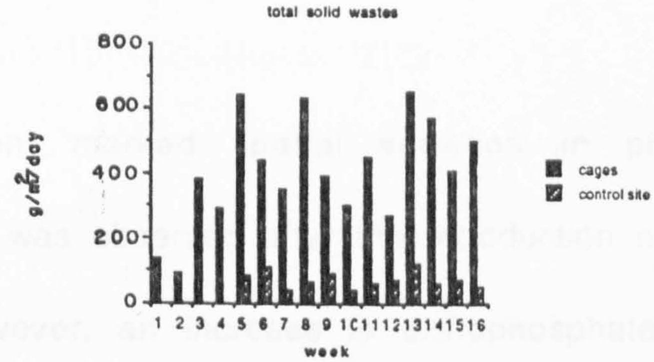
Total number of cages in the trial :	6
Total surface area of bottom of cages (m2)	54
Stocking date:	2–04–89
Stocking density (No/m3)	28
Mean initial individual weight of the fish (g)	19.61
Mean final individual weight of the fish (g)	84.47
Total number of fish stocked:	3,000
Total number of fish harvested:	1,620
Survival Rate (%)	54
Total amount of feed fed (Kg)	194
Feed Conversion Ratio (FCR)	1.88:1.0
Culture period (days)	84
Total Final Biomass (Kg)	136.08

4.3.2.1 Sedimentation rates from the cages.–

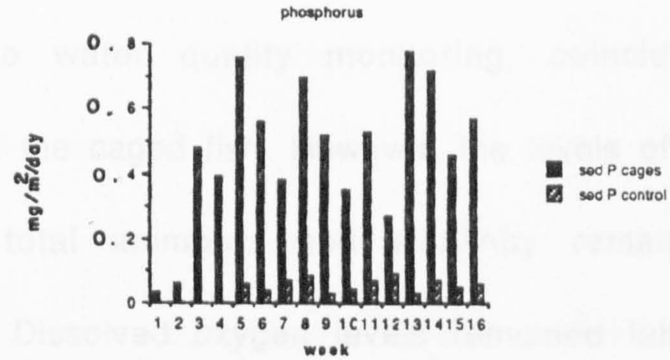
Figure 40 presents the mean sedimentation rates of solid waste from the cages at Mytza. Pre–stocking figures were below 15 g/m2/day, and significantly ($P<0.05$, t–test) lower than post–stocking rates. Post–stocking solid wastes from below the cages were also significantly greater ($P<0.05$, t–test) than those at the control site.

Sedimentation rates of nitrogen and phosphorus from the cages throughout the study period, fluctuated between 0.037 g P/m^2/day prior to the stocking of the fish, to a maximum of 0.78 g P/m^2/d after stocking, and between 0.22 g N/m^2/d, before stocking and 4.25 g N/m^2/day, during the cage trial, and were significantly greater ($P<0.05$, t–test) than those at the control site (Fig. 40).

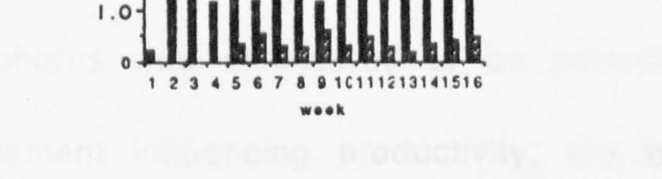
Figure 40 Total solid waste and nutrient sedimentation rates from the cage trial at Mytza quarry.



total solid wastes
800
600
400
200
0
g/m2/day
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
week
cages
control site



phosphorus
0.8
0.6
0.4
0.2
0
mg/m2/day
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
week
sed P cages
sed P control



nitrogen
5.0
4.0
3.0
2.0
1.0
0
mg/m2/day
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
week
sed N cages
sed N control

4.3.2.2 Water chemistry.–

No apparent marked spatial variation in physicochemical parameters was observed after the introduction of the cages at Mytza. However, an increase in orthophosphate and nitrite–N concentrations was observed at all sampling sites towards the end of the water quality monitoring, coinciding with the presence of the caged fish. However, the levels of chlorophyll–a, nitrate–N, total ammonia and alkalinity remained low and unaffected. Dissolved oxygen levels remained fairly high at all sampling points.

4.3.2.3 Phosphorus budget.–

Since Phosphorus was considered to be potentially the most important element influencing productivity, the budget of this element was estimated from the results presented in table 11.

Table 11. Total–P Concentrations Associated With the Aquaculture Trial at Mytza Quarry.

Phosphorus in Feed (%)	1.21
Total feed input (kg)	194
Total Amount of P provided through feed (Kg)	2.35
Phosphorus in Fish(% wet weight)	0.30
Net fish production (kg)	105
Amount of Phosphorus removed with harvest (kg)	0.315
Total amount of phosphorus collected in sediment traps (kg)	0.2

From table 11 it was estimated that of the total amount of dietary phosphorus (2.35 kg), only 13.4 % (0.315 kg) was actually retained by the fish and removed at harvest, thus the remaining

86.5 % being wasted. It was therefore estimated that for each kilogram of fish produced in Mytza, 0.02 Kg of phosphorus were lost in the system.

4.3.3 Stocking of C.urophthalmus and O.niloticus in seasonal ponds at Uxmal.-

4.3.3.1 Stocking of tilapia in the smaller pond.-

Tilapia fry were stocked in the smaller pond adjacent to Uxmal main water body in early October, 1989 and by the time they were harvested, 138 days later, the mean individual weight was 70.3 g. Survival rate amounted to 48% and extrapolated gross yield from this 0.010 ha pond was equivalent to 168.7 kg/ha. The Specific Growth Rate (SGR) of the fish was estimated to be 2.51 %/d, based in the mean weights at stocking and harvest. A summary of the growth and production data is presented in table 12. As mentioned earlier, the fish stocked in these seasonal ponds were not monitored regularly throughout the study period, and no water quality samplings were carried out during the trial.

Table 12. Summary of Data on Growth and Production Performance of O.niloticus Stocked in a Small (0.010 ha) Seasonal Pond in the Vicinity of Uxmal Main Body of Water.

Stocking date	05–10–89
Initial number of fish	50
Stocking density (No/m2)	0.5
Mean initial individual weight of the fish (g)	2.2
Final number of fish	24
Mean final individual weight of the fish (g)	70.3
Specific Growth Rate (SGR) (%/d)	2.51
Harvest date	20–02–90
Growing period (days)	138
Survival rate (%)	48
Yield* (Kg/Ha)	168.7
Net yield (kg/ha)	157.7

*= Extrapolated figure.

4.3.3.2 Stocking of C.urophthalmus in Uxmal main seasonal pond.-

The fish stocked in Uxmal main water body in early December, 1989, reached an average weight of 57 g by mid-March, when they were harvested. A total of 105 small 0.2 g mean individual weight C.urophthalmus, (not included in the production figures) were also collected from the Mayan cistern where most of the surviving stocked fish were concentrated, and were almost certainly part of their brood. The survival rate of the stocked fish in this trial, was 25.5 %, and the net yield was 53.7 kg/ha. The fish had an estimated Specific Growth Rate of 2.73 %/d. Data on growth and performance of the fish in this trial is presented in table 13.

Table 13. Summary of data on the growth and production performance of C.urophthalmus stocked in Uxmal seasonal pond.

Stocking date	08–12–89
Initial number of fish	2778
Stocking density (No/m2) *	0.50
Mean initial individual weight of the fish (g)	3.80
Final number of fish	709
Mean final individual weight of the fish (g)	57.02
Specific Growth Rate (SGR) (%/d)	2.73
Harvest date	18–03–90
Growing period (Days)	99
Survival rate (%)	25.5
Gross Yield (Kg/pond)	40.4
Net yield (kg/pond)	29.9

* It was assumed an area equivalent to 50% the original,for the purpose of calculating the stocking density.

4.4 Discussion.–

The different trials carried out in this work will be dealt with separately. A summary will attempt to bring together the essential points concerning the scope for fish production of the different aquatic ecosystems studied, and make recommendations on the best approach to their utilisation.

4.4.1 Sac-Be trial.–

In the present trial, organic fertilisation was used as a means of increasing primary productivity which, as stated earlier, was originally low in this quarry. The results showed enhancement of phytoplankton biomass through increased nutrient availability. Similar results have been reported by a number of authors, using a wide range of both organic and inorganic fertilisers (Hepher, 1958, 1963; Burns and Stickney, 1980; Hunt and Boyd, 1981; Msiska, 1983; Balls et al, 1989; Green et al, 1989; Yussof and

McNabb, 1989). As a result of nutrient release from the decomposing plants, phytoplankton populations increased substantially, triggering in turn the zooplankton community, as evidenced by the differences in pre and post fertilisation counts. Even though orthophosphate levels were high throughout fertilisation, there was a rapid decline immediately after it stopped. The fates of the nutrients were not examined in detail, but clearly plant uptake could be a major sink, thus also supporting the positive correlation observed between phosphate levels and chlorophyll-a. Balls et al (1989) report the loss within 48 hours of almost all phosphorus added through fertilisation of a pond by phytoplankton uptake. This same trend has been reported by Hepher (1963), Hunt and Boyd (1981) and Msiska and Cantrell (1985). Another factor which could have been equally or more important in the rapid loss of the available phosphate in Sac-Be, was clearly the calcareous nature of its basin. As has been discussed earlier, PO_4-P easily reacts with calcium ions, forming calcium phosphate compounds which then precipitate (Hepher, 1963). Wodka, Effler and Driscoll (1985) state that in hard waters calcium or calcium mineral phases can even compete with plants for available phosphorus.

Nitrogen compounds also showed an initial increase as a result of fertilisation, followed by a rapid decline, suggesting that along with plant utilisation a considerable amount of nitrogen could have been lost as ammonia gas (Moll, 1986). Golterman (1966) found that up to 75 % of the added nitrogen had been mineralised, and partially lost as gas within three days in a fish pond.

Diurnal fluctuations of D.O. were unexpectedly similar in samples taken before and during fertilisation, with good levels of oxygenation being observed even at night.

The rate of fertilisation employed in this experiment was similar to the recommended levels of fertilisation with green manures for Chinese fish ponds (Anon, 1982; Arredondo, 1984; Shan et.al, 1985). However, the yield obtained in Sac-Be was considerably lower than those reported for carps: 3,600–5,160 kg/ha (Anon, 1982; Jian and Shenjie, 1987); tilapia: 700–2,500 kg/ha (Arredondo, 1984) and crawfish: 500–2,500 kg/ha (Huner, 1981; cited by Edwards, 1987) reared using green manures. However, in most instances in which grass or other vegetables are used as additional sources of nutrients, fertilisation is accompanied by the addition of animal manures, or feeding. In the case of hervibores, the grass in itself may constitute the major source of protein for growth when directly ingested (Edwards, 1987; Jian and Shenjie, 1987). In the present trial the addition of 245 kg of P.virgatum over one month, represented an input of 0.17 kg of phosphorus and 1.12 kg of nitrogen which stimulated primary productivity in the system, and proved effective as an inexpensive source of nutrients. However, it is clear that the fertilisation rate applied was insufficient to stimulate secondary productivity to levels which provided sufficient food for good growth of C.urophthalmus. The results show an increase in weight of the fish from stocking to harvest of only 19.32 g in 165 days, a low growth rate. The influence of the lack of adequate food material becomes apparent when SGR values are compared to the dietary components of C.urophthalmus during the study period. Highest SGR values coincided with the presence of large volumes of Daphnia spp in the stomachs in mid– May, and in late July, when a considerable proportion of the stomachs volume was occupied by fish debris, probably Gambusia yucatana as well as some Moina spp. On both sampling dates, these food items largely replaced the plant material which was otherwise ingested, probably because of reduced availability of animal food items. This would coincide with the findings of Martinez and Ross (1988), who reported that regardless of season, the diet of both juveniles and adult of C.urophthalmus mainly consisted of a wide range of food items of animal origin (42–100 % of their total dietary components). As a result, Martinez and Ross (ibid) described C.urophthalmus as "omnivorous with a high tendency to carnivory". Martinez (1987) also reported protein requirements for this species as ranging between 36.42 and 51%, depending on size and temperature.

It seems clear that the carrying capacity of Sac–Be was exceeded, leading to poor growth and to the comparatively low yield (180.66 kg/ha). Since fish production in extensive systems is closely related to the levels of primary productivity (Lin, 1986; Diana, Scheneeberg and Lin, 1988; Yussob and McNabb, 1989), further additions of this fertilizer would surely have improved productivity and yields.

The survival of fish was relatively high (88%), indicating the absence of predators and adequate water quality. In this regard, the concentration of the measured parameters were well within the known ranges of tolerance of C.urophthalmus. The high levels of hardness found in Sac–Be, are lower than those reported for other karst features inhabited by this species (Flores–Nava, Valdes and Sanchez, in press), and were similar to those of the rearing unit from which the experimental fish were obtained. High levels of pH, are reported to influence the proportion of the toxic unionised fraction of ammonia (Alabaster and Lloyd, 1982). However, the maximum calculated concentration of NH3–N in Sac–Be during the aquaculture trial was 0.016 mg/l, which is well below the reported minimum lethal concentration for C.urophthalmus (Alvarez, 1987). The other two important water quality factors likely to influence growth are temperature and Dissolved Oxygen concentration (Smith, 1982). Both parameters in Sac–Be also remained well within the optimum for this species (Martinez and Ross, 1986; Martinez, 1987). Clearly, the water quality of this quarry throughout the trial presented adequate conditions for the experimental fish, and again their poor growth was most probably the result of low food availability.

It is clear from the results that a carnivorous or omnivorous fish with tendencies to carnivory, would not be a good candidate for fairly extensive aquaculture, where fish rely entirely on natural food. However, small quarries might provide an ideal environment for small fry of a range of fish species, including C.urophthalmus . In this way, small quarries could be used as an intermediate stage for young fry to grow on natural food at little cost, until they are large enough to be stocked in cages in larger quarries. However, the present study also indicates that it is important that sufficient fertiliser is added to the system. Another approach to the aquacultural utilisation of these abandoned quarries would be to stock larger fish of a species feeding on lower levels of the trophic chain; such as the tilapia O.niloticus , which is known to be an efficient plankton feeder (Moriarty and Moriarty, 1973), either in monoculture or in polyculture with C.urophthalmus. The latter strategy has proven effective, yielding extrapolated figures of 2,000 kg/ha in experimental groundwater–fed ponds organically fertilised in Tabasco, to the West of Yucatan (Mendoza, pers.com.).

Figure 41 illustrates the proposed alternatives for the aquaculture utilisation of small gravel quarries discussed above.

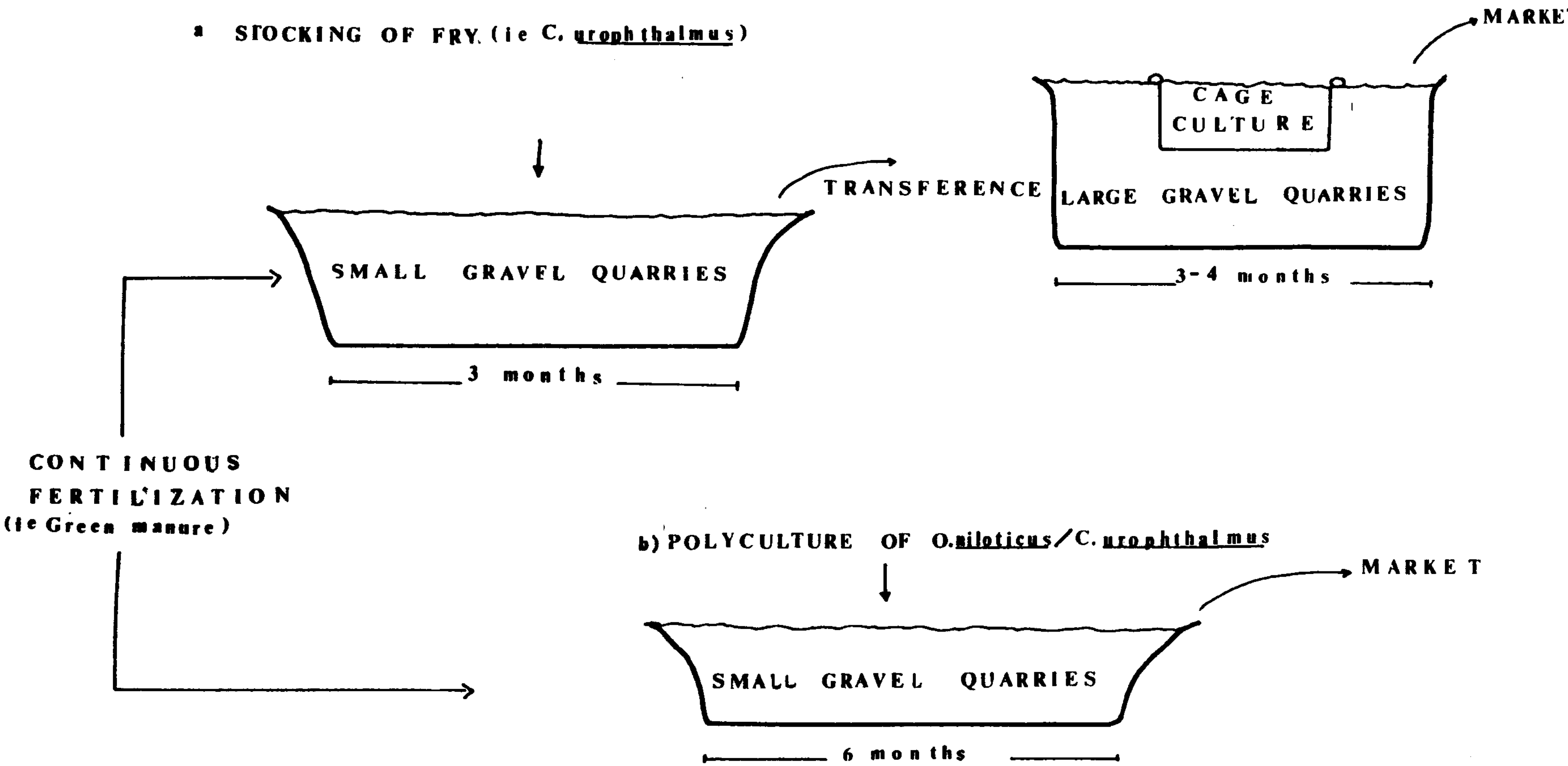
In summary, from the point of view of a suitable aquatic environment for aquaculture, small gravel quarries offer some scope and, indeed, have a number of advantages:

1) The alkaline quarries are well–buffered and have a high assimilation capacity for receiving organic inputs. The process of eutrophication is thus retarded to some extent; 2) through fish culture, the productive use of a vast, otherwise nuisance, area of Northern Yucatan can be achieved; 3) good monitoring of fish stocks can be achieved in these small ponds, thus optimising production; 4) since the number of these quarries is increasing, excavation could be done so that net–harvesting is

Figure 41. Suggested approaches for the aquacultural utilization of small gravel quarries

a) monoculture of C. urophthalmus fry as an intermediate stage

b) polyculture of O. niloticus and C. urophthalmus


a STOCKING OF FRY (ie C. urophthalmus)
SMALL GRAVEL QUARRIES
3 months
TRANSFERENCE
CAGE CULTURE
LARGE GRAVEL QUARRIES
3-4 months
MARKET
CONTINUOUS FERTILIZATION (ie Green manure)
b) POLYCULTURE OF O.niloticus/C. urophthalmus
SMALL GRAVEL QUARRIES
6 months
MARKET

carried out easily, thus maximising harvesting efficiency. Further research is needed to determine appropriate fertilisation rates and the long term water quality changes resulting from aquaculture, as well as the resulting impact on water quality of aquifers.

4.4.2 Aquaculture potential and environmental impact of cage-culture on gravel quarries.-

Before discussing the results of the environmental impact assessment carried out in Mytza quarry, it is worth evaluating the overall performance of the cage trial from which the environmental data were obtained, to give an objective assessment of the scope of gravel quarries for aquaculture.

As mentioned earlier, the cage trial carried out by CINVESTAV-Merida, was the first attempt to evaluate hatchery-reared juveniles of this species in these environments.

The results are encouraging, and demonstrate both the suitability of these gravel quarries for aquaculture, and the potential of C.urophthalmus for managed fish production. Although low survival occurred, this apparently was the result of poaching. In general, the caged fish at Mytza had growth similar to that reported for C.urophthalmus held at higher stocking rates in cages in ground water–fed sand pits in Tabasco, to the west of Yucatan (Flores–Nava, et.al, 1989a). This suggests that provided that appropriate husbandry and management techniques are employed, large gravel quarries can provide a good environment for aquaculture, and high yields can be expected using cage culture techniques (Flores–Nava et.al, 1989a).

Beveridge (1984) described several ways in which cage structures and cage culture operations can affect a water body: 1)cages occupy space, thus potentially competing with other uses (e.g. recreation, navigation, etc.); 2) cages alter flow regimes which govern the transport of oxygen, sediment, plankton and fish larvae; 3) the intensive culture of fish in cages results in high levels of waste production.

In this study, the latter factor was assessed, since it is considered to be the factor of greatest concern in environmental terms (Penzack et.al, 1982; Beveridge, 1984; Phillips, Beveridge and Ross, 1985).

The magnitude of the changes following the introduction of cage culture will depend upon the characteristics of the site, the type of structure used, the species cultured and the size of the venture (Beveridge, 1984). Other important factors include diet presentation, feeding regime and the ability of the caged fish to ingest the feed (Merican and Phillips, 1985).

The results of this study show mean total solid waste sedimentation rates of 450g/m^2/day at the cage sampling point, representing more than five times the sedimentation rates observed at the control site, thus confirming the considerable local increase in the sedimentation rates below the cages. There is a wide range of sedimentation rates reported in the literature. Canfield et.al, (1982) reported natural sedimentation rates ranging from 0.1 to 203 $g/m^2/day$ in freshwater temperate lakes. The mean total sedimentation rate from the present study , was considerably higjher than those reported for cage culture in both temperate and tropical latitudes. Merican and Phillips (1985) reported mean organic loadings of 149.6 $g/m^2/day$ from intensive rainbow trout Salmo gairdneri cage culture. Enell and Lof (1983) reported between 17 and 26 $g/m^2/day$ from Swedish trout farms. Costa–Pierce and Roem (1989) reported mean total sedimentation rates above 13 $g/m^2/day$ from carp (Cyprinus carpio) intensive cages in Indonesia. Such a wide variation in sedimentation rates derived from from aquaculture operations can be attributed to a number of factors, including the magnitude of the venture and differences in feeding regimes, among the most important factors (Merican and Phillips, 1985; Wiesmann, Scheidd and Pfeffer, 1988). The high sedimentation rates observed in the present study can be attributed to considerably to a significant amount of marl dust that settled which was derived specifically from the quarrying operations in the nearby vicinity. It is documented that a considerable part of the organic loading from aquaculture operations, is due to washing out of feed particles during and after intensive feeding (Bergheim et.al. 1982; Chacon, Ross and Beveridge, 1989). The effect of this feature, however, is likely to be of less importance in low-density cage culture operations, such as in the case of the trial at Mytza.

Mean phosphorus sedimentation rates from this study (0.5 g $P/m^2/day$), , are higher than those reported by Costa-Pierce and Roem (1989) for intensive cage farming of Cyprinus carpio in a tropical lake (0.2 $mgP/m^2/day$), but considerably lower than those reported by Merican and Phillips, (1985) for rainbow trout cages in Scotland (4.2 $g/m^2/day$). Again differences in management techniques and degree of intensification may be the main contributing factors to such a variability.

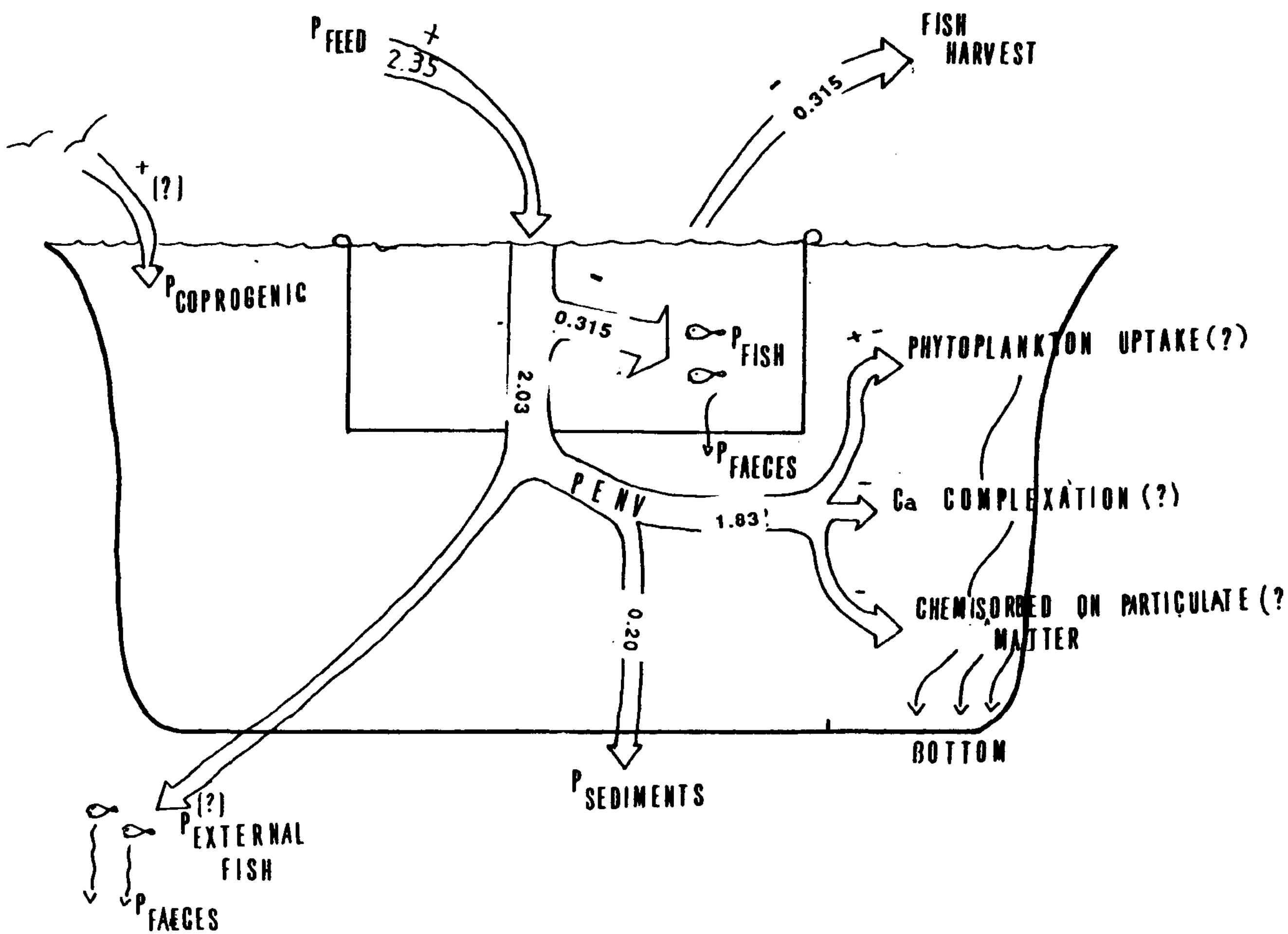
From the results of the present study it was estimated that given that 2.03kg (86.5 %) of the dietary phosphorus input was not retained in the fish harvested, approximately 0.02 kg of phosphorus was wasted per each kg fish produced. These results agree closely with those estimated by Beveridge (1984) for tilapia (0.023–0.029 kg/kg) and those of Penzack et.al (1982), who found that an estimated 0.023 kg of the dietary phosphorus provided to caged rainbow trout was lost per kg fish produced.

However, the results from this study are higher than those reported for common carp cage culture by Costa–Pierce and Roem (1989) (0.2 mgP/kg/day) and lower than those reported by Boyd (1985) (0.036 kg/kg) for channel catfish Ictalurus punctatus. These wasted phosphorus differences reflect differences in excess dietary phosphorus availability, and again, husbandry and management practices may be responsible.

The calculated phosphorus waste figures of the present study, indicate that there is a potential risk of eutrophication if large–scale aquaculture operations are implemented in large gravel quarries. Even though a considerable amount of dietary phosphorus was estimated to have been wasted from the cage trial at Mytza, this was not directly detected in the sediment traps, where only a relatively small proportion of phosphorus was collected (0.2 kg). Costa–Pierce and Roem (1989) also reported a considerable amount of lost phosphorus from intensively–managed carp cage culture in a tropical environment not detected in their collected waste loads. These authors attribute their inability to detect the wasted phosphorus to two main factors: 1) an increase in decomposition processes by increased temperature, and 2) rapid decomposition and nutrient recycling by a "pelagic nutrient recycling system" for which bacteria and phytoplankton are responsible. This latter factor has also been suggested by Currie and Kalff (1984). Nevertheless, in the present study, even though the above factors may have had some influence in phosphorus recycling in Mytza quarry, an important factor to consider when discussing the effect of cage aquaculture wastes in Yucatan is the karstic nature of the quarry basins which, as stated earlier, have high levels of $CaCO_3$ and other calcium compounds, thus making their waters quite hard. Since most of the phosphorus provided in the feed is in the phosphate form (Yamada, 1986b; Steffens, 1990) and this reactive form, as discussed earlier, readily binds to Ca–bearing material, it may be that most phosphorus contained in uneaten pellets is complexed and precipitated, thus making it unavailable to phytoplankton. Unfortunately, logistic problems made it impossible to measure total phosphorus in the water column during the cage trial It is documented that anoxic conditions are a necessary precondition for phosphorus release from sediments (Taub, 1984; Sinke et al, 1990), and since these water bodies are well mixed, it is unlikely that oxygen depletion will occur unless there is localised accumulation of solid wastes. The problem of localised accumulation of organic matter is most likely to occur where intensive cage culture is carried out in structures moored so that they are unable to drift (Beveridge, 1984, 1987). Therefore in considering large–scale intensive cage culture in Large gravel quarries, adequate single–point mooring, swinging structures should be implemented to minimise the risk of sediment accumulation and oxygen depletion.

Phosphorus concentration is currently regarded as the primary limiting factor governing algal biomass and productivity in both temperate and tropical waters (Goldman and Horne, 1983; Beveridge, 1984; Moss, 1988), and thus any increase in supply is likely to alter productivity. A diagrammatic representation of the possible fates of the phosphorus wastes from the fish cages during the trial at Mytza, is shown in Fig. 42. A net input of 2.03 kg of dietary phosphorus was estimated to have been released into the environment, taken into account the fraction of this bioelement retained by the caged fish. Assuming that the amount of phosphorus collected in the sediment traps is truly representative of the amount of phosphorus lost to the sediments in the total cross sectional area of traps ($0.047m^2$) . Then the balance (1.83 kg) (e.g. the dissolved fraction) is available for: a) phytoplankton uptake, b) complexation with Ca–bearing material and c) chemisorption to particulate matter. In this study, the phosphorus wastes from the aquaculture operation that were ingested by the endemic fish, were not evaluated. Nevertheless, fish in considerable numbers, mostly C.urophthalmus, were

Figure 42. Schematic representation of the possible dietary phosphorus fates during the cage aquaculture trial at Mytza quarry. (+) gains (-) losses.



P FEED
+
2.35
FISH HARVEST
-
0.315
+ (?)
P COPROGENIC
-
0.315
P FISH
2.03
P FAECES
P ENV
1.83
+ -
PHYTOPLANKTON UPTAKE (?)
-
Ca COMPLEXATION (?)
-
CHEMISORBED ON PARTICULATE (?) MATTER
0.20
BOTTOM
P SEDIMENTS
(?)
P EXTERNAL FISH
P FAECES

regularly seen ingesting wasted food from the cages. This may be of some benefit, both to the environment and to the farmer. Fish outside the cages can help maximise, through ingestion of wasted food , the utilisation of the artificial feeds which typically accounts for up to 40–60% of the production costs (Hepher and Pruginin, 1981). Wild fish have been shown to be attracted to cages, particularly at feeding times (Phillips, 1982; Phillips et.al 1985). Concentrating the external fish at a point can be done by throwing some extra food and net–harvesting can then be readily carried out, thus ensuring an additional crop. Moreover, by utilising the wasted food, fish are further reducing the addition of bioelements that otherwise would be contributing to the eutrophication of the system. In summary, gravel quarries offer considerable scope for intensive cage culture, which if combined with the deliberate release of fish could maximise production whilst minimising the risks of eutrophication and contamination of aquifers.

Using available models it is not possible to estimate the carrying capacity of these systems, since water exchange is limited to compensatory replenishment of the water lost through evaporation by infiltration from the aquifer. It is thus difficult to estimate the flushing rate of the system. Another impeding factor is the inability to relate open pan evaporation to actual water loss through other paths, such as seaward movement and percolation. Nonetheless, the utilisation of limestone quarries for fish culture is a common practice in the USA (Conrad, 1988), and Europe (Behrendt, 1979; Luckowicz, 1979), and provided that regular monitoring of ground water quality is carried out, aquaculture could prove the best means for the productive utilisation of vast areas of land which are at the present of little or no use.

4.4.3 Stocking of O.niloticus and C.urophthalmus in seasonal ponds.–

As already discussed in Chapter 3, the cyclical fluctuations of physicochemical parameters in this seasonal ponds, are a function of water volume, which in turn is dependent on precipitation levels. It is difficult to compare directly the performance of the stocked fish in the main Uxmal pond and the smaller pond, since the fish stocked are of different species and also there are differences in feeding habits, length of the growing period and degree of exposure of the water bodies, and hence susceptibility to predation. The tilapia were stocked in the smaller of the ponds which was located in a well–sheltered area where dense vegetation made it difficult to observe from above. This might have been a contributory factor in the comparatively high survival rate (48%), since the high numbers of predatory birds (especially diving ducks and cormorants) seen regularly throughout the wet season would have had less difficulty in observing the fish in the main Uxmal aguada. Here, survivorship of C.urophthalmus was comparatively poor (25.5%).

Although the tilapia attained a weight of 70.3 g, almost 19% more than the native cichlid, the growing period of the former was considerably longer (29%). The results from these trials, showed that under extensive conditions, with no feeding or fertilisation, yields of up to 169 kg/ha, could be obtained by stocking a plankton feeder, and yields of 40 kg/ha of C.urophthalmus, could be achieved, provided that the fish are stocked in June as fry, when the water volume of the aguada reaches 60–80% and dissolved oxygen levels have stabilised. However, several considerations must be taken into account. First of all, as stated above, bird predation can be a serious threat in water bodies like Uxmal. The minimum number of birds seen in any occasion was twelve and although no attempt was made to analyse the stomach contents of the birds in Uxmal, it is probable that a considerable amount of the stocked fish was eaten by either predatory ducks or cormorants. A wide range of piscivorous birds, including diving ducks (SEPESCA, 1982) and cormorants (European Inland Fisheries Advisory Committee, 1988) have been reported as causing considerable damage to cultured stocks. A number of inexpensive, yet effective measures to control bird predation, have been developed (EIFAC, 1988), which could be applied to the water bodies of Yucatan, if aquaculture was to be implemented.

Another important factor to consider is the reproductive behaviour of the stocked fish. It is well documented that precocious maturation and reproduction of fish such as tilapia is a serious problem in aquaculture, since energy available for growth is diverted into gonad development and gamete production, thus resulting in large populations of stunted fish (Balarin, 1979; Hepher and Pruginin, 1981). This characteristic was observed in both trials of this study. Few tilapia fry were observed in the much reduced waters of the smaller pond at the time of harvest, possibly because few fish were able to survive such extreme conditions. In Uxmal main pond, a total of 105 small (0.2 g mean weight) C.urophthalmus fry, were collected from the Mayan cistern. There are a number of methods to prevent precocious reproduction in cichlids (Balarin, 1979; Guerrero and Guerrero, 1988), the least expensive and most practical being the stocking of monosex fish. This seems to be a feasible approach in the region, since controlled reproduction and mass production of fry of both experimental fish species is already carried out at a pilot scale locally.

There is a wide range of reported fish yields from seasonal ponds in the literature, from 150 kg/ha (Arredondo et.al, 1982a), to 6,900 kg/ha (Chandrasoma, 1986) (Table 14).

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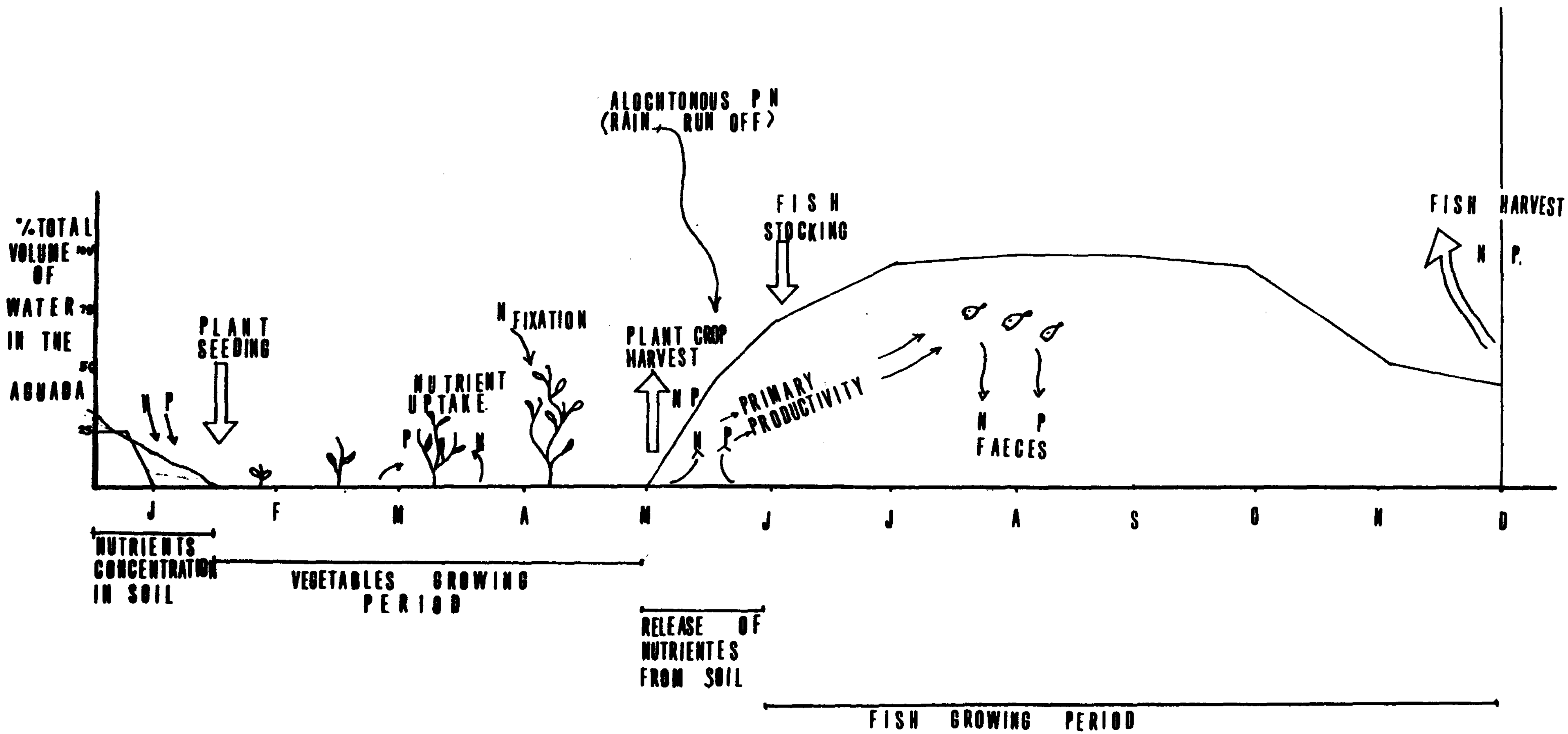
This variation in production can be attributed to differences in size at stocking, stocking density, species, productivity of the system and management strategies employed (i.e. mono/polyculture, feeding, fertilisation, etc.).

It is possible that with improved management (i.e. stocking monosex populations, predation control, higher stocking densities) fish yields in Uxmal and other seasonal ponds of Yucatan can be improved. Furthermore, the cyclical nature of these water bodies, may facilitate optimum use of water and land resources through rotational fish culture/agriculture. Alternation of fish and plant crops is an ancient practice which originated in China, the organic matter remaining in the pond bottom was thought to be an excellent fertilizer for plant crops. Following the harvest of the crop, the crop residues are left in the pond as green manure (Edwards, 1987). Fast (1986) states that alternated agricultural crops in fish ponds tend to increase the productivity of the fish crop by: a) enhancing soil oxidation thus making mineral nutrient sources more available when the pond is re–flooded; b) contributing organic material that promotes the growth of fish food organisms, and c) fixing atmospheric nitrogen, which is released to the water upon re–flooding. Conversely, fish loosen the soil as a result of their swimming and food searching activities, thus aerating the soil, enhancing the decomposition of organic matter and promoting the release of nutrients for the plant crops (Kangmin, 1988).

As discussed earlier, the amount of phosphorus, nitrogen and carbon, taken up by the plants colonising Uxmal during the dry season, were estimated to be 1.83, 59.22 and 106.92 kg respectively, indicating that there is a high level of available nutrients for plant growth when the pond dries. Figure 43 describes schematically, a suggested aquaculture–agriculture rotational approach, for optimum utilisation of seasonal ponds. Concentration of nutrients in soils occurs as water volume decreases as the result of high evaporation during January. It

Figure 43 Schematic representation of a proposed rotational agriculture/aquaculture system for the cyclical utilisation of seasonal ponds of Yucatan.


ALOCHTONOUS P N
(RAIN, RUN OFF)
FISH STOCKING
FISH HARVEST
N P.
%TOTAL VOLUME OF WATER IN THE AGUADA
100
75
50
25
PLANT SEEDING
N P
N FIXATION
NUTRIENT UPTAKE
P
N
PLANT CROP HARVEST
N P
PRIMARY PRODUCTIVITY
N P
N P
FAECES
J F M A M J J A S O N D
NUTRIENTS CONCENTRATION IN SOIL
VEGETABLES GROWING PERIOD
RELEASE OF NUTRIENTES FROM SOIL
FISH GROWING PERIOD

would be possible to plant fast-growing vegetables, such as onions, tomatoes or green chilies, and harvest them in mid-May, as the rains begin to re-fill the aguada. This approach used to be employed in a slightly different way by the ancient Mayan populations, which used these temporary aguadas for storing both water in cisterns constructed at the deepest point of the pond, and organic matter which was collected and utilised for fertilising their agricultural fields (Turner, 1980).

Table 15 presents the potential yields in kg/ha of different agricultural crops commonly grown in this area of Yucatan, which could be employed in the suggested rotational approach.

Table 15. Summary of Potential Yields and Growing Periods of Agricultural Crops Commonly Grown in Southern Yucatan (source: SARH, 1987)

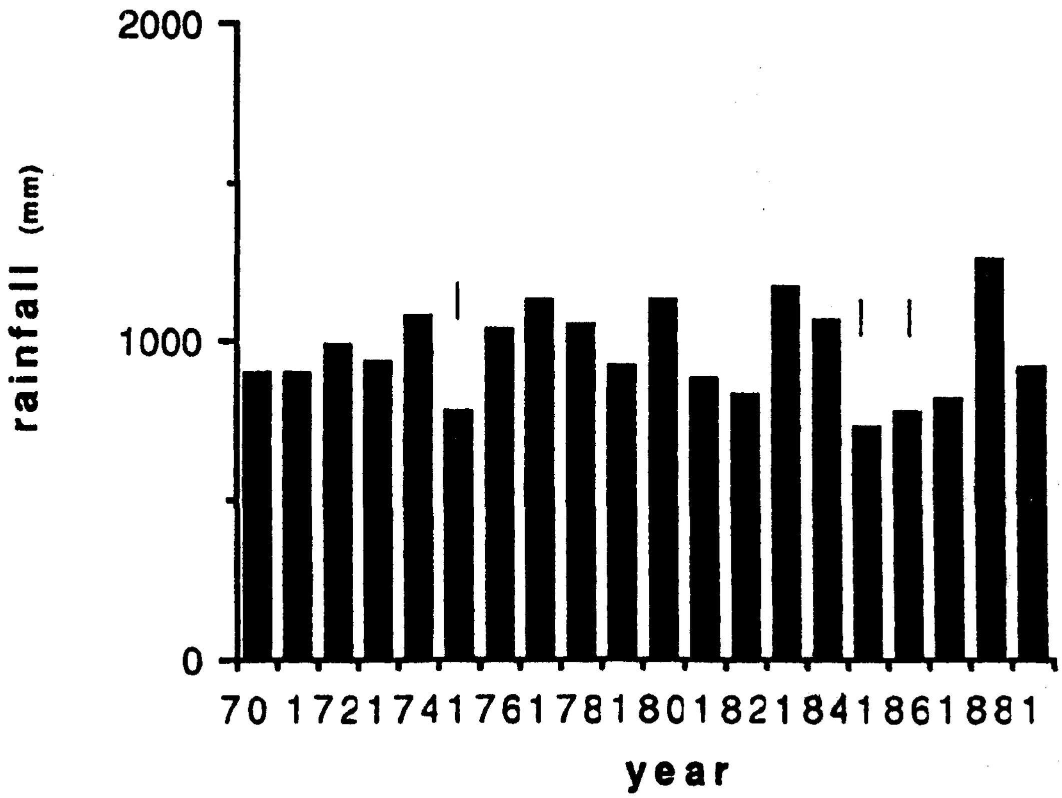
Crop	Growing Period (months)	Yield (Tonnes/ha)*
Corn	4	0.678
Melon	3.5	7.584
Green chilli	3.5–4	2.453
Tomato	3.5	5.283

*Without fertilisation.

Consider, as an example, the stocking of juvenile fish in Uxmal in early June, and a yield equivalent to the mean of the two values extrapolated from the trials carried out in the present study, then it would be possible to obtain approximately 104 kg of fish at the end of the year. If this is done in combination with the culture of green chilli, then an additional crop of 2,723 kg of this vegetable could be produced.

Clearly, a well-managed seasonal pond could produce a reasonable amount of animal protein either for self consumption or for commercialisation, additional to a reasonable amount of highly marketable vegetables, thus making use of these so far neglected cyclical water bodies. However, it is important to note that even though considerable levels of alocthonous nutrients may be gained by the system, an important fraction might be lost through plant and fish harvests. A better understanding of the nutrient pathways and possible sinks is needed to predict nutrient demands in order to maintain high levels of productivity in these systems. Another important factor to consider is the regularity and hence predictability of precipitation levels. Even though Uxmal aguada remained dry for two seasons during the course of the present study, local records of precipitation of over 19 years (Fig. 44) show

Figure 44 Precipitation records for Muna town (26km north of Uxmal) for the 1970-1989 period.



2000
1000
0
rainfall (mm)
70 1721741761781801821841861881
year

that in only 15 % of years, precipitation levels were below 800 mm in this region, the levels that occurred during the 1985–1986 period.

4.4.4 Permanent aguadas.–

Permanent aguadas such as X–Pooc were not evaluated. However, despite the high primary productivity and associated drawbacks, these water bodies might offer some scope for the cultivation of efficient filter–feeding fish species. There is evidence too that a well–managed hypertrophic system can provide an effective waste treatment approach (Belsare, 1986). Fish culture in small hypertrophic ecosystems is common in India, where yields as high as 10,600 kg/ha/year of Indian major carps and tilapia are obtained, thus indicating that cultural eutrophication can actually be reversed by "biological stripping" through high fish harvests (Sreenivasan, 1980). High phosphorus retention by some fish species is also reported as an important factor in combating eutrophication. Chapman, Hubert and Jackson (1987) found that up to 90 % of the phosphorus ingested by grass carp Ctenopharyngodon idella, was retained. This species thus might afford an effective method for removing phosphorus in permanent aguadas where aquatic vegetation is present. Several studies have attempted to improve conditions in stratified eutrophic water bodies by mixing and aeration of the water column (Henderson–Sellers and Markland, 1987; Bailey–Watts et.al, 1988). This type of technology could also theoretically be used to improve water quality conditions for fish culture in these aguadas, although it is doubtful whether the additional cost associated with destratification and mixing could be economically viable.

CHAPTER 5

SOCIOECONOMIC ASPECTS OF AQUACULTURE DEVELOPMENT IN YUCATAN

5.1 Introduction.–

A prerequisite to any proposal for aquaculture development is a clear statement of the objectives. It is essential to consider the socioeconomic and political conditions of the target region, and identify the major constraints facing the proposed development, particularly when considering the introduction of a non–traditional activity.

The alleviation of problems of rural under–development and the stimulation of local rural economies calls for more than the consideration of technological feasibility of any proposed development: the technology must also be appropriate to the specific sociocultural conditions in which it is to be developed

(McGoodwin, 1979; Kent, 1987; Ruddle, 1990).

Traditionally the subsistence economy of the Mayan population that has inhabited Yucatan for centuries, has been based on agriculture and agricultural products. Maize form their staple diet and sisal the basis of their agricultural economy (Turner, 1980). Fish and fisheries have only been important in coastal areas (Whitlock, 1976).

For the past ten years, economic conditions have deteriorated in agricultural villages. Large numbers of small farmers from the central, sisal–producing areas, have migrated to large cities and the coastal areas of the Peninsula, in search of better employment opportunities. One result of this coastal migration has been a dramatic increase in the number of inexperienced fishermen exerting an increased effort on the coastal fishery resources, thus aggravating not only their economic situation but that of traditional fishermen (Batllori, pers.com.).

The objective of any aquaculture development would be to reduce this population drift, by creating better employment opportunities in rural areas, with the associated benefits to coastal regions.

In order to assess the potential socioeconomic impact of small-scale aquaculture development in the study region, a preliminary survey of socioeconomic status and attitude of rural farmers towards aquaculture adoption was carried out between 1988 and 1989, at the end of which a small-scale, family-operated fish pond demonstration unit was constructed and operated in a rural agricultural village. A range of potential small-scale production systems were also modelled, to investigate the likely economic contribution of aquaculture to farmers incomes.

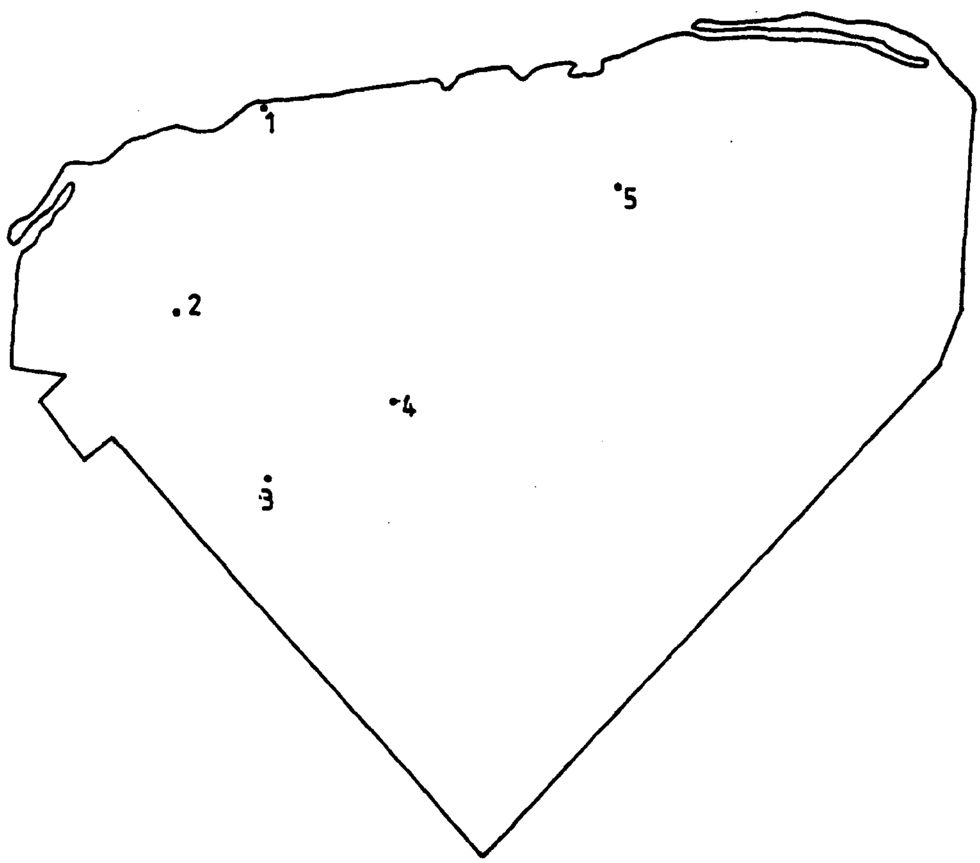
This chapter presents the results of these analyses and discusses socioeconomic aspects which might influence the potential for developing aquaculture in rural areas of Yucatan.

5.2 Methods.–

5.2.1 Socioeconomic survey.–

A series of interviews were conducted, involving 100 individuals from five different communities. A standardised questionnaire, consisting of open-ended questions (see Appendix I), was employed to obtain basic information on occupation, educational attainment, communal organisation, land tenure and awareness and attitude towards aquaculture. Interviewees were chosen at random. Once the survey was completed, vague or ambiguous answers were discarded from the results. The regions where this preliminary survey was carried out were selected on the basis of the presence of water bodies which appeared to be suitable for aquaculture during the water resources survey carried out in this study. Three agricultural villages and a coastal town were selected. Their location is presented in Figure 45.

Figure 45. Geographic location of towns involved in the socioeconomic survey carried out in this study



1. Progreso, Fishing Port (n=15)
2. Chochola/Kopoma. Agricultural Villages (n=23)
3. Santa Helena. Agricultural Village (n=17). Pond Site.
4. X-Canchacan. Agricultural Village (n=8).
5. Sucila. Agricultural Village. (n=20). 1. Progreso, Fishing Port (n

5.2.2 Site selection and construction of the demonstration unit.– The village of Santa Helena (Fig 45) was selected for the development of a family–operated demonstration unit, consisting of three ponds. The criteria for the selection of this site were three–fold: 1) Santa Helena is located in the Southern Hilly Region, where soil is thicker and organically–rich, therefore excavation of ponds is feasible; 2) the presence of an irrigation system from which good quality water can be obtained and 3) the farmers of this community are entirely devoted to agricultural crops, hence the results in terms of any change of attitude towards the adoption of aquaculture were more likely to be objective than in any other community where farmers are more aware of aquaculture.

From the results of the socioeconomic survey, three out of the 17 farmers interviewed (17.6 %), were willing to cooperate with the trial. The individual selected to operate the ponds was considered to be more influential in the local community.

No water quality or soil chemistry problems were detected during the site survey.

Three 10 x 5.0 x 1.20 m earthen ponds were constructed by the farmer and members of his family. A series of introductory talks provided them with basic information on general aquaculture, and on the design and construction of ponds. Further assistance was provided regularly during the construction phase. Previous in situ measurements of soil permeability showed that the seepage rate could reach 0.036 cm/sec. It was therefore decided to line the ponds with polythene sheets. Ponds were constructed adjacent to an irrigation canal, which conveys water from a well point to the agricultural plots. The ponds were excavated so that their bottom slope was approximately 2.5%, in order to facilitate drainage and harvesting operations. Three 3" (internal diameter) PVC pipes were placed in the irrigation canal to provide an inlet for each pond. The outlet and level controls were swinging 3" (i.d.) PVC pipes and elbows, which discharge into an external ditch (Figure 46).

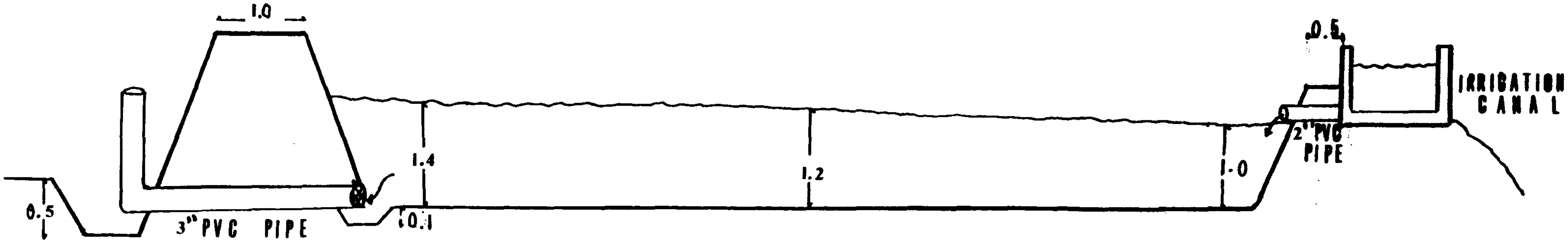
5.2.3 Pond preparation and management.–

A five–centimetre layer of local soil was spread over the pond lining, to provide a source of organic matter to encourage bacterial activity, and the natural productivity of the pond.

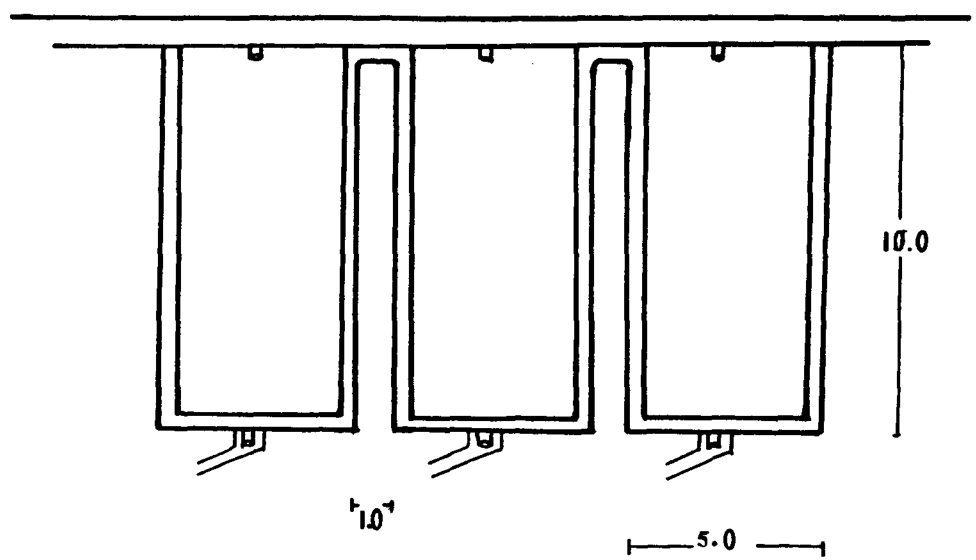
Once husbandry and management information was provided, juveniles of *Cichlasoma urophthalmus* (8.2 g mean individual weight), were stocked in the ponds at a rate of 2/m2. Three husbandry approaches were used to investigate the influence of alternative management strategies on productivity and profitability of these ponds. Fish in pond 1 were fed an inexpensive, 35% protein pelleted diet prepared with locally

Figure 46 Layout of the three-pond demonstration unit constructed at Santa-Helena village

1)


1.0
0.5
3" PVC PIPE
0.1
1.4
1.2
1.0
0.5
2" PVC PIPE
IRRIGATION CANAL

2)


10.0
1.0
5.0

ESC: 1:15 m

available materials, at a rate of 5 % body weight per day. Pond 2 was fertilised with combined inorganic fertilisers (Triple superphosphate and Urea, 1:3 ratio), at a rate of 12.30 g/week (Arredondo, 1984). Fish were fed with the pelleted diet, at 50% the rate provided in pond 1. Pond 3 was fertilised as in pond 2, but no supplementary feed was provided. The pelleted feed formulated for this demonstration trial, was the standard feed used for C.urophthalmus at CINVESTAV–IPN, Merida (see Flores, Olvera and Garcia, 1989a,b). The inorganic fertilisers used are cheap, locally available and widely employed by the local farmers.

5.2.4 Economic analysis.–

Economic models, using simple cost/benefit analysis on an annual basis, were based on current local prices. The yields obtained in the trials of this study, as well as certain assumptions based on experiences from other types of aquaculture, were utilised in the models. For practical purposes, all monetary figures are presented in US dollars.

Labour opportunity cost was allocated a monetary value, equivalent to the average income per day of the farmers interviewed during the socioeconomic survey ($2.0/day). Labour inputs for the production units modelled, were estimated from the aquaculture trials carried out in this study. In all cases, an account of the number of hours spent in each activity involved in the management of the unit was recorded and converted into man–days labour. This allowed evaluation of the potential of aquaculture development in terms of returns to labour ($/day) in comparison with the average agricultural income.

For all production units modelled, inputs are divided into cash and non cash costs. The returns are presented as returns to labour ($/day), and net returns after deducting the assumed value of labour. Basic implements such as nets for harvesting, is likely to be shared by members of production organisation (i.e. ejidos) therefore the cost to individual farmers is likely to be insignificant, and was thus not included in the models.

In the pond fish farm model capital costs (pond construction) are incurred. For the purposes of the analysis, all capital costs (cash and non cash), were depreciated (straight line method) over 10 years (assumed lifespan of the pond), and included as a cash component of the annual costs.

The opportunity cost of capital (real) was determined by subtracting the current inflation rate of Mexico (19 %) to the current interest rate (39 %). Sensitivity analysis were carried out for each model to assess the impact of fluctuation in the main economic parameters on the viability of the systems modelled.

5.3 Results.–

5.3.1 Socioeconomic survey.–

5.3.1.1 Age of respondents.–

The structured statistical results of the socioeconomic survey showed that the respondents were normally the heads of households, whose ages reflect the life span during which the majority of the rural population are economically active and responsible for decision–making. More than one third (36 %) were within the 31–40 year group of age. One third (34 %) were within the 41–50 age group, and the remaining third divided almost equally between the less than 30 and more than 50 years of age (Table 16).

Table 16 - Age of Respondents in the Socio-economic Survey

	Progreso		Sta. Helena		Chochola/Kopoma		X-canchacan		Suclia		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
20-30	-	-	6	35.3	4	17.4	-	-	8	40	18	21.7
31-40	6	40	3	17.6	11	47.8	2	25	8	40	30	36.1
41-50	7	46.6	6	35.3	7	30.4	6	75	2	10	28	33.7
51-60	2	13.4	2	11.8	1	4.4	-	-	2	10	7	8.4

Table 16 - Age of Respondents in the Socio-economic Survey

	Progreso		Sta. Helena		Chochola/Kopoma		X-canchacan		Suclia		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
20-30	-	-	6	35.3	4	17.4	-	-	8	40	18	21.7
31-40	6	40	3	17.6	11	47.8	2	25	8	40	30	36.1
41-50	7	46.6	6	35.3	7	30.4	6	75	2	10	28	33.7
51-60	2	13.4	2	11.8	1	4.4	-	-	2	10	7	8.4

5.3.1.2 Educational attainment.–

Only one of the interviewees in the total sample attended higher education (1.2%). Two thirds attended at least one year of basic education in primary school, and 29 (35%) of the total sample did not attended school at all (Table 17).

5.3.1.3 Occupation.–

The majority of respondents from Chochola/Kopoma, Sucila, Santa Helena and X–canchacan were farmers (66%), whereas two thirds of the respondents of Progreso were fishermen, comprising 12% of the total sample. The remaining 34 % of the total sample, represented members of six different occupational groups, which included traders, brick layers, small shop owners, a taxi driver, a manager of an agricultural equipment dealer, a local government officer and the owner of a family–based hammock factory (Table 18).

Table 17 - Eduactional Attainment of Interviwees in the Socio-economic Survey

	Progreso		Sta. Helena		Chochola/Kopoma		X-canchacan		Suclia		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Primary School Grades (1-6)	15	100	8	47	15	65.2	6	75.0	10	50.0	54	65
Middle School (7-12)	8	53.3	2	11.7	3	13.0	-		6	30.0	19	23
College/University	-		-		1	4.3	-		-		1	1.2
Not-educated	-		9	53.0	8	34.7	2	25.0	10	50.0	29	35
Extension Courses	15	100	7	41.1	19	82.6	-		-		41	49.4

Table 18 - Occupational groups of interviewees in the Socio-economic Survey.

	Progreso		Sta. Helena		Chochola/Kopoma		X-canchacan		Sucila		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Fishermen	10	66.6	-	-	-	-	-	-	-	-	10	12.0
Traders	2	13.3	-	-	4	17.4	-	-	-	-	6	7.2
Farmers	-	-	17	100	16	69.5	8	100	14	70.0	55	66.3
Other	3	20.1	-	-	3	13.1	-	-	6	30.0	12	14.5

5.3.1.4. Land ownership.–

All respondents owned at least one plot of land, and the majority (71 %), held small (1–2 Ha) land plots granted by the government (Table 19). Of these plots, 41 % were located in irrigated land areas (20.5 % in the Chochola/Kopoma region and 20.5 % in the Santa Helena region). From the remaining 59%, some farmers use wells (25%), some sinkholes and permanent aguadas (16%), while the rest (18%), living in major non agricultural villages, use tap water for their domestic activities, (Fig 47).

5.3.1.5 Fish consumption.–

An estimate was made of the frequency of fish consumption by the sampled households (Table 20). Only 26.5 % of all interviewees consumed fish once a week, of which 15 people

Table 19 - Land Ownership of Respondents in the Socio-economic Survey

	Progreso		Sta. Helena		Chochola/Kopoma		X-canchacan		Sucila		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
< 1 ha	13	86.6	-	-	5	21.7	-	-	2	10	20	24.1
1-2 ha	1	6.7	15	88.2	17	74.0	8	100	18	90	59	71.1
> 2 ha	1	6.7	2	11.8	1	7.3	-	-	-	-	4	4.8

Figure 47 Main sources of water of the interviewees of the socioeconomic survey.

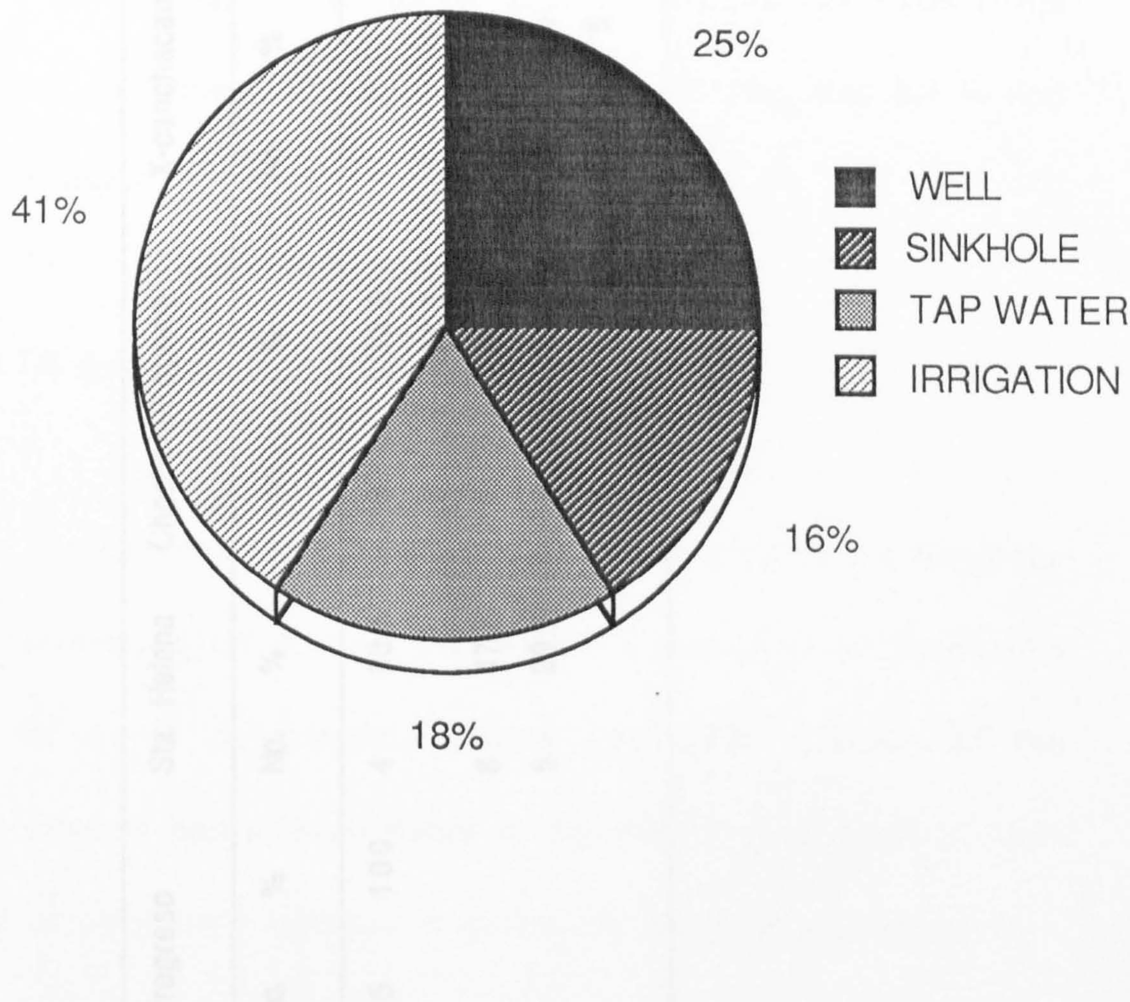

25%
41%
16%
18%
WELL
SINKHOLE
TAP WATER
IRRIGATION

Table 20 - Frequency of fish consumption of respondents in the socioeconomic survey

	Progreso		Sta. Helena		Chochola/Kopoma		X-canchacan		Sucila		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Weekly	15	100	4	23.5	3	13.0					22	26.5
Fortnightly					6	26.1			4	20	10	12.0
Monthly			8	47.0	8	34.8			10	50	26	31.3
Seldom			5	29.5	5	21.7	2	25	6	30	18	21.7
Never					1	4.4	6	75			7	8.4

were from the coastal town, normally taking fish home from their catches. Of the remaining (7), only two ate fresh fish, which they buy in Merida, the rest only consumed canned fish from local shops. One third of the total number of respondents sample consumed fish only once a month (31.3%), and 8.4 % had never eaten fish.

5.3.1.6 Awareness of aquaculture.-

The respondents were asked if they were aware of the existence of techniques for raising fish either for commercial production or for home consumption (Table 21). Forty percent of the interviewees had at least heard of the subject, and 16 % of them had actually been involved in communal aquaculture projects in

Table 21 - Awareness of aquaculture in the Group of Respondents in the Socioeconomic Survey

	Progreso		Sta. Helena		Chochola/Kopoma		X-canchacan		Sucila		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Aware	15	100	4	23.5	13	56.5	-	-	8	40	40	48.2
Not Aware	-	-	13	76.5	10	43.5	8	100	12	60	43	51.8

Progreso and Chochola/Kopoma(these were not continued). In general, the highest percentage of respondents aware of aquaculture and willing to participate in fish production projects, were found in Progreso and Chochola/Kopoma. Seventy six percent of the respondents in Santa Helena and all the respondents of X–canchacan, had never heard of aquaculture activities.

5.3.1.7 Attitude towards aquaculture adoption.–

A high proportion of respondents (86 %), expressed an interest in attending basic introductory sessions on aquaculture if they were provided (Table 22). The least interest was expressed by the respondents of Santa Helena (53 %), whilst the respondents of Progreso and Sucila Chochola/Kopoma, expressed more interest. More than half (58 %) expressed an interest in providing free labour for communal pond construction, in areas of suitable soil, and/or stocking and raising fish in natural water

Table 22. - Attitude of Respondents Towards Aquaculture Adoption

Willingness To:	Progreso		Sta. Helena		Chochola/Kopoma		X-canchacan		Sucila		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Attend aquaculture talks :	15	100	9	52.9	20	86.9	8	100	20	100	72	86.7
Provide free manpower for communal pond construction :	10	66.7	3	17.6	21	91.3	2	25	12	60	48	57.8
Convert an area of his land into ponds if money was provided :	10	66.7	3	17.6	14	60.8	-	-	8	40	35	42.2
Invest in aquaculture :	4	26.7	-	-	1	4.3	-	-	-	-	5	6.0

bodies. A greater willingness to convert an area of land plots into fishponds (if technically feasible), was found in both Progreso (66 %) and Chochola/Kopoma (61 %) than in Sucila (40 %), Santa Helena (17 %) or X–canchacan (0 %).

5.3.1.8 Organisation.–

The majority of the respondents (77 %) were members of Ejidos (communal agrarian organizations through which rural farmers granted with land plots by the government, carry out their agricultural activities interdependently, i.e. sharing cost of communal infrastructure, or organising to commercialise their individual crops in a cooperative basis) (Table 23). Of the remaining 23 %, 15 were members of fishing cooperatives, all of them from the coastal town sample group. Only 4.8 % of the total sample did not belong to any production organisation.

Table 23 - Type of Production and Economic Organization of Respondents in the Socioeconomic Survey

	Progreso		Sta. Helena		Chochola/Kopoma		X-canchacan		Sucila		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Ejidatario	-	-	17	100	19	82.6	8	100	20	100	64	77.1
M.embers of cooperative	15	100	-	-	-	-	-	-	-	-	15	18.1
non-member	-	-	-	-	4	17.4	-	-	-	-	4	4.8

5.3.2 The pilot-scale demonstration unit.-

Fish in pond 1 (feed only), reached 51.4 g mean weight in 106 days, and the survival rate in this pond was the highest (91%). The fish in pond 3 (Only fertilizer), reached only 29.8 g mean weight, with a survival rate of 84% over the same period. Pond 2 was accidentally drained after 99 days and the fish were killed. Only 54 fish (54 %)were recovered with a mean individual weight of 36.8 g.

Extrapolated yields from the demonstration ponds were as follows: Pond 1 yielded the equivalent of 934 kg/Ha/year; pond 2 yielded 397.4 kg/Ha/year, and pond 3 yielded 500.6 kg/Ha/year.

At the beginning of the trial, three members of the family appointed by the head of the household were trained to look after the fish; but by week three, at least half a dozen individuals (family members and others), visited the pond site regularly and were willing to help sampling, feeding or fertilising.

At the end of the trial, the fish harvested were distributed among relatives and friends.

An informal post–trial survey was conducted in the community, which showed that the number of households willing to dig small fish ponds in their farm plots as long as professional assistance and fry were provided, was more than double (7) the original number. The main reason they gave for the change in attitude was realisation of the labour input required for managing the ponds, was less than expected. They therefore thought that fish farming would not conflict with their farm labour requirements.

5.3.3 Economic analysis.–

The results of the simple economic (cost/benefit) models employed to assess the economic contribution of small–scale rural aquaculture in Yucatan, are presented in Tables 24 through 31. The assumptions made for the base cases are summarised in Table 32.

5.3.3.1 Extensive monoculture of C.urophthalmus in gravel quarries.–

Table 24 presents the model corresponding to the extensive monoculture of *C.urophthalmus* in gravel quarries. The results show that managing a 0.135 ha quarry (base case) extensively (Table 24) could provide a return to labour of US $65.03 (US$4.01/man–day). Assuming two farmers would be required to

Table 24 Economic Model for the Production of C. urophthalmus in Gravel Quaries:-

Costs and Revenue	Actual System From Which the Data Were Derived (0.135 Ha)			Case Study (1ha)		
Annual Operating Costs	Cash	Non cash	Total	Cash	Non cash	Total
Fry	19.26		19.26	142.80		142.80
Fertilizer	4.59		4.59	136.00		136.00
Labour		32.40	32.40		43.20	43.20
Interest on Operating Capital	4.77		4.77	55.76		55.76
Total Costs	28.62	32.40	61.02	334.36	43.20	377.76
Revenue						
Crop Value	93.65			694.27		
Return to Labour	65.03			359.71		
Return to Labour per day	4.01			16.65		
Net Revenue	32.63			316.51		

manage the system, and a labour input of 16.2 man–days, this would provide an additional income equal to the average current agricultural wage. If a 1–ha quarry was exploited, employing the same approach (case study), (an estimated 21.6 man–days required), then the actual returns to labour would be $16.65/day ($8.32/farmer), representing an increase of over 4 times the average agricultural wage. In the base case, a net revenue of $32.63 is obtained ($16.31/production cycle), whilst a 1–ha quarry could provide a net revenue of $316.51 ($158.25/production cycle).

The sensitivity analysis for this model (Table 25) shows that a reduction of 30 % in either fish market price or yield, can bring the returns to labour to $43 ($2.7/day), in which case each farmer would get an additional income equivalent to 135.5 % the average agricultural wage. Changes in fry costs produced only a marginal effect on the returns.

Table 25 : Sensitivity Analysis of the Monoculture of *C. urophthalmus* in Gravel Quarries:-(Figures correspond to the actual size quarry from which the data were derived)

a)

Economic Parameters	Changes in Fish Market Price (%) BC:$1.92/kg					
	D10	D20	D30	I10	I20	I30
Yield (kg/yr)	48.78	48.78	48.78	48.78	48.78	48.78
Total Costs	61.02	61.02	61.02	61.02	61.02	61.02
Crop Value	84.87	78.04	71.70	102.92	112.2	121.76
Returns to Labour	56.25	49.42	43.08	74.3	83.58	92.84
Net Revenue	23.85	17.02	10.68	41.9	51.18	60.44

b)

Economic Parameters	Changes in Yield (%) BC: 48.78 kg/Year					
	D10	D20	D30	I10	I20	I30
Market Price	1.92	1.92	1.92	1.92	1.92	1.92
Total Costs	61.02	61.02	61.02	61.02	61.02	61.02
Crop Value	85.13	78.04	72.03	103.00	112.37	121.74
Returns to Labour	56.51	79.72	43.41	74.38	83.75	93.12
Net Revenue	24.11	17.02	11.01	41.98	51.35	60.78

c)

Economic Parameters	Changes in cosy of Fry (%) BC:$7.14/1000					
	D10	D20	D30	I10	I20	I30
Cash Costs	25.59	23.85	22.06	30.0	32.32	34.62
Total Costs	57.99	56.25	54.46	63.4	60.7	67.0
Returns to Labour	68.06	69.8	71.59	63.65	61.33	59.03
Net Revenue	35.66	37.4	39.19	30.25	28.95	26.65

D = Decrease
I = Increase

5.3.3.2 Extensive polyculture of O.niloticus (80%) and C.urophthalmus (20%).-

The extensive polyculture of O.niloticus and C.urophthalmus approach for the management of gravel quarries, was introduced in the set of production systems analysed because it has proven a highly effective alternative for fish production involving little cost in similar groundwater-fed pits in Tabasco, to the West of Yucatan (Mendoza, pers.com.). From the results of this model (Table 26), it can be seen that if this polyculture system is employed in a relatively small quarry area (250 m2, actual quarry size), it could provide a return to labour of $175.9 p.a. ($10.85/day), which shared by the assumed two farmers, would represent over 2.7 times the average agricultural wage. For a 1-ha quarry, if the assumptions of the case study are met, then the returns to labour per day could theoretically increase as much as over 2000 % to $311.85/day. This high return reflects the fact

Table 26 Economic Model for the Production of _Oreochromis niloticus_ (80%) and _C. urophthalmus_ (20%) in Polyculture in Gravel Quarries:-

Annual Costs And Revenue	Actual Pond From Which Data Were Derived (250m^2)			Case Study (1ha)		
Annual Operating Costs	Cash	Non Cash	Total	Cash	Non Cash	Total
Fry	7.1		7.1	285.6		285.6
Fertilizer	6.8		6.8	136		136
Labour		32.4	32.4		43.2	43.2
Interest on Operating Capital	2.78		2.78	84.32		84.32
Total Costs	16.68	32.4	49.08	505.92	43.2	549.12
Revenue						
Crop Value	192.0			7,232		
Returns to Labour	175.92			6,726		
Returns to Labour per Day	10.85			311.38		
Net Revenue	142.92			6,682.8		

that relatively little inputs are required, together with the ability of tilapia to take advantage of natural productivity. Assuming that the larger quarry would require a total labour input of 21.6 man–days in the operation.

The sensitivity analysis for the small (250 m2) quarry (Table 27), shows that none of the economic scenarios analysed is likely to affect the viability of the production system: even with reductions in price or yield of 30 % the returns to labour are still significantly above the basic agricultural wage.

5.3.3.3 Extensive monoculture of cichlids in seasonal ponds.–

The model for the extensive monoculture of cichlids in seasonal ponds (Table 28), shows that if the assumed yield of 104 kg/ha/year is achieved in these seasonal ponds, then each hectare of these water bodies could theoretically provide a comparatively high return to labour per day for each farmer ($5),

Table 27 : Sensitivity Analysis for the Polyculture of <u>O.niloticus</u> and <u>C. urophthalimus</u> in Gravel Quarries: - (Base case)

a)

Economic Parameters	Changes in Fish Market Price (%) BC:$1.92/kg D10	D20	D30	I10	I20	I30
Yield (Kg/yr)	100	100	100	100	100	100
Total Costs	49.1	49.1	49.1	49.1	49.1	49.1
Crop Value	174.0	160.0	147.0	211.0	230	247
Returns to Labour	157.3	143.3	130.3	194.3	213.3	230.3
Net Revenue	124.9	110.9	97.9	161.9	180.9	197.9

b)

Economic Parameters	Changes in Yield (%) BC: 100 kg/year D10	D20	D30	I10	I20	I30
Market Price	1.92	1.92	1.92	1.92	1.92	1.92
Total Costs	49.1	49.1	49.1	49.1	49.1	49.1
Crop Value	174	160	147	211	230.4	249.6
Returns to Labour	157.3	143.3	130.3	194.3	213.2	230.3
Net Revenue	143.3	130.3	105.9	161.9	180.9	197.9

c)

Economic Parameters	Changes in cost of Fry (%) BC:$7.14/1000 D10	D20	D30	I10	I20	I30
Cash Costs	15.9	15.2	14.7	17.5	18.2	19.2
Total Costs	48.3	47.6	47.1	49.9	50.6	51.6
Returns to Labour	176.1	176.8	177.3	174.5	173.8	172.8
Net Revenue	139.6	144.4	144.9	142.1	141.4	140.4

Decrease
Increase

Table 28 Economic Model for the Extensive Monoculture of Cichlids (either O niloticus or C. urophtalmus) in Seasonal Ponds:-

Costs and Revenue	Actual System From Which the Data Were Derived (1.11ha)			Case Study (1ha)		
Annual Operating Costs	Cash	Non cash	Total	Cash	Non cash	Total
Fry	19.77		19.77	17.85		17.85
Labour		35.4	35.4		35.4	35.4
Interest on Operating Capital	3.95		3.95	3.57		3.57
Total Costs	23.72	35.4	59.12	21.42	35.4	56.82
Revenue						
Crop Value	219.64			199.68		
Return to Labour	196.92			179.26		
Return to Labour per day	11.06			10.07		
Net Revenue	160.52			142.86		

which would be equivalent to 2.5 times the actual average income of the farmers from traditional agriculture, since the estimated labour input for the management of these seasonal ponds is equivalent to 17.7 man–days.

The sensitivity analysis for this model (Table 29), shows that a reduction of 30 % in either yield or fish market price still leaves the returns to labour well above the break even point (the average agricultural wage). Changes in other parameters were not significant.

5.3.3.4 Construction and operation of small earthen ponds.–

Table 30 presents the model corresponding to the operation of small (50 and 200 m^2) excavated ponds, based on the results of the demonstration unit of this study. The model shows that if the smaller (50 m^2) pond is operated, a return to labour of $0.68/day can be expected, which would be equivalent to 34% the average

Table 29 : Sensitivity Analysis for the Monoculture of Cichlids in Seasonal Ponds:-

a)

Economic Parameters	Changes in Fish Market Price (%) BC:$1.92/kg					
	D10	D20	D30	I10	I20	I30
Yield	104	104	104	104	104	104
Total Costs	56.8	56.8	56.8	56.8	56.8	56.8
Crop Value	181	166.4	153	218.4	239.2	260
Returns to Labour	145.6	131	117.6	183	203.8	224.6
Net Revenue	124.2	109.6	96.2	161.6	182.4	203.2

b)

Economic Parameters	Changes in Yield (%) BC:104 kg/Year					
	D10	D20	D30	I10	I20	I30
Market Price	1.92	1.92	1.92	1.92	1.92	1.92
Total Costs	56.8	56.8	56.8	56.8	56.8	56.8
Crop Value	181.4	166.2	153.6	219	239.6	260
Returns to Labour	146	131	118	183.6	204.2	224.6
Net Revenue	124.6	109.4	96.2	162.2	182.8	203.2

c)

Economic Parameters	Changes in cosy of Fry (%) BC:$7.14/1000					
	D10	D20	D30	I10	I20	I30
Cash Costs	21.5	19.71	18.24	26.02	28.39	30.75
Total Costs	56.9	55.11	53.64	61.42	63.79	66.15
Returns to Labour	198.14	199.93	201.4	193.62	191.25	188.89
Net Revenue	162.74	164.53	166.0	158.22	155.85	153.49

D = Decrease
I = Increase

TABLE 30 : Economic Model For The Operation of Small Excavated Ponds.

Annual Costs And Revenue	Actual Pond From Which Data Were Derived (50m^2)				Case Study (200m^2)			
Capital Costs	Cash	Non Cash	Total	Deprec/Annum	Cash	Non Cash	Total	Deprec/Annum
Pond Construction		49.50	49.50	4.95		197.54	197.54	19.75
Other Items	22.50		22.50	2.25	22.50		22.50	2.25
Interest on Capital	4.50		4.50	0.75	4.50		4.50	0.45
Total Capital Costs	27.0	49.50	76.50	7.65	27.0	197.54	224.54	22.45
Operating Costs	Cash	Non Cash	Total		Cash	Non Cash	Total	
Fry	2.42		2.42		9.71		9.71	
Feed	8.33		8.33		33.34		33.34	
Fertilizer	0.40		0.40		1.62		1.62	
Labour		29.6	29.6			31.5	31.5	
Interest on Operating Capital	2.23		2.23		8.92		8.92	
Depreciation	7.65		7.65		22.45		22.45	
Total Operation	21.03	29.6	50.63		75.9	31.5	107.4	
Revenue								
Crop Value		30.46			121.93			
Returns to Labour		9.43			46.03			
Returns to Labour per Day		0.68			2.92			
Net Revenue		(20.17)			14.53			

daily income of the farmers derived from their traditional agricultural activities. However, the results of the operation of the proposed 200 m^2 pond (case study), could theoretically provide a return to labour of $2.92/day, which represent a 46% increase in the current average farmers income.

The sensitivity analysis for the 50 m^2 pond operation (Table 31) shows that this production unit is most sensitive to changes in either fish market price or yield. An increase of 30 % in either parameter, would theoretically produce a return to labour of $1.25/day, equivalent to 62.5% of the agricultural wage, whereas a decrease of 30% in either parameter, would bring the returns to labour per day down to $0.18, representing only 9% of the current average farmers income. Changes in other parameters are insignificant.

TABLE 31 : Sensitivity Analysis For the Operation of Small Excavated ponds (Base case, 50m²)

a)

Economic Parameters	Changes in Fish Market Price (%) BC:$1.92/kg D10	D20	D30	I10	I20	I30
Yield	15.87	15.87	15.87	15.87	15.87	15.87
Total Costs	50.63	50.63	50.63	50.63	50.63	50.63
Crop Value	27.61	25.39	23.64	33.48	36.50	39.51
Returns to Labour	6.58	4.36	2.4	12.5	15.4	18.5
Net Revenue	(23.03)	(25.23)	(27.03)	(17.1)	(14.1)	(11.1)

b)

Economic Parameters	Changes in Yield (%) BC:15.87 kg/YEAR D10	D20	D30	I10	I20	I30
Market Price	1.92	1.92	1.92	1.92	1.92	1.92
Total Costs	48.63	48.63	48.63	48.63	48.63	48.63
Crop Value	27.7	25.4	23.42	33.50	36.48	39.60
Returns to Labour	6.7	4.4	2.4	12.5	15.4	18.5
Net Revenue	(23)	(25)	(27)	(17.1)	(14.1)	(11.1)

c)

Economic Parameters	Changes in cosy of Fry (%) BC:$7.14/1000 D10	D20	D30	I10	I20	I30
Cash Costs	20.7	20.5	20.3	21.3	21.6	21.8
Total Costs	50.3	50	49.9	50.9	51.1	51.4
Returns to Labour	9.7	10	10.2	9.2	8.9	8.7
Net Revenue	(19.8)	(19.6)	(19.4)	(20.4)	(20.6)	(20.9)

d)

Economic Parameters	Changes in Feed Cost (%) BC:$0.35/kg D10	D20	D30	I10	I20	I30
Cash Costs	20.1	19.3	18.7	22.0	23.0	24.0
Total Costs	49.7	48.9	48.3	51.6	52.6	53.6
Returns to Labour	10.4	11.2	11.8	8.5	7.5	6.5
Net Revenue	(19.2)	(18.4)	(17.8)	(21.1)	(22.1)	(23.1)

D = Decrease
I = Increase

Table 32 Summary of Assumptions for the Economic Models.

I) Costs.

Fry: $7.14/1,000

Fertilizer:

organic (manure): $34/ton.

inorganic (TSP* + urea): $0.28/kg

Labour costs:

operation and management: $2/man–day.

pond construction: $11.90/man–day.

II) Labour inputs.

Management:

Gravel quarries:

Monoculture: 16.2 man–days/year in actual pond, and 21.6 man–days/year in a 1–ha quarry.

Polyculture: 16.2 man–days in actual pond, and 21.6 man–days in a 1–ha quarry.

Seasonal ponds:

Monoculture: 17.7 man–days/ha.

Excavated earthen ponds: 13.8 man–days for a 50 m^2–pond (actual

Table 32 continued

size), and 15.7 man–days for a 250 m^2–pond (case study).

Pond construction: One man–day was estimated to yield 15 m^3 of earth moving.

III) Rates of fertilisation:

using organic fertilizer: 4 t/ha/year.

using inorganic fertilizer: 290 kg/ha/year.

IV) Yields:

Monoculture C.urophthalmus in gravel quarries: 361.6 kg/ha/year.

Polyculture of O.niloticus (80%) and C.urophthalmus (20%): 2,000 kg/ha/year.

Monoculture of either O.niloticus or C.urophthalmus in seasonal ponds: 104 kg/ha/year.

Culture of C.urophthalmus in earthen ponds: 934 kg/ha/year.

V) Fish market prices:

C.urophthalmus: $1.92/kg (fresh whole).

O.niloticus: $1.78/kg (fresh whole).

5.4 Discussion.-

Three distinct groups of respondents can be identified from the results of the socioeconomic survey. Firstly, those respondents whose occupation is related to fisheries activities, in the coastal town Progreso; second, those respondents devoted to agricultural activities who have participated in, or at least are aware of aquaculture, and third, those respondents who work in agriculture and have never had contact with aquaculture.

Because the economic activities and status of individuals from Progreso are significantly different from those in other areas, this discussion will consider these groups separately.

The first group, from Progreso, expressed the greatest interest in participating in aquacultural projects, mainly because they have already had some experience in coastal aquaculture. However, it is doubtful whether the scale of aquaculture described above would be economically attractive to fishermen, since it is unlikely that they can generate a greater cash income from small–scale aquaculture than from existing activities. Previous aquaculture experience in this group involved the culture of highly–priced marine species such as prawn, generating revenues significantly higher than those expected from the extensive exploitation of small quarries. Consequently, with the possible exception of the polyculture with tilapia, freshwater aquaculture is is unlikely to be economically attractive. Any aquaculture development for this group would require greater returns than those from the systems described above. More intensive aquaculture could possibly be developed, as stated in earlier chapters, in the larger gravel quarries present along the northern karst plains, although the commercial viability of these alternative options was not investigated.

It is possible, however, that small–scale aquaculture in small gravel quarries in this region could provide an important alternative occupation for some of the farmers that migrate to the coastal area from central agricultural regions.

For the second and third groups, the results show that a considerable proportion of respondents from the Northern agricultural villages, namely Chochola/Kopoma (56 %) and Sucila (40 %) (group 2) were aware of fish raising techniques. Moreover, some of these respondents had actually participated in a government project aimed at the stocking of tilapia in sinkholes of this region. Even though the lack of fry and further assistance to the farmers involved did not allow the project to continue, people showed willingness to readopt aquaculture.

The results of the socioeconomic survey also show that the overall educational attainment of the interviewees is low in rural Yucatan. This reduces the opportunities for a rural farmer to get a better employment, even if willing to migrate. The other major problem of rural Yucatan is malnutrition (Murguia, pers.com.). Yucatecan farmers have traditionally been maize and sisal farmers, and in the past, when rural communities were more self sufficient, they preferred to remain on the farms rather than seeking alternative types of employment. This is not longer true today, and poverty and unemployment have induced a large scale migration of farmers into urban areas.

For these reasons, it is likely that small-scale aquaculture would be more beneficial to the second and third groups of respondents (Chochola/Kopoma, Santa Helena, Sucila and X-canchacan) than to the first group (Progreso).

The results of the socioeconomic survey, and the demonstration trial carried out in this study, demonstrate that Yucatecan farmers do appear to be receptive and accept new technologies, when they clearly understand the benefits that can be derived. This was reflected in the high percentage of respondents that expressed some interest in raising fish (57 %) if assistance was provided and in the change of attitude observed as a result of the trial (an increase from 3 farmers to 7 willing to convert a part of their agricultural plot into a fish pond).

This interest could be stimulated through efficient extension services so that aquaculture, where viable, could contribute nutritionally and as a supplementary occupation in rural areas of Yucatan.

The potential nutritional contribution of small-scale aquaculture in rural agricultural areas of Yucatan could be very significant. The staple diet of rural Yucatan is restricted to corn, chilli and black beans (Whitlock, 1976). Hence, provided that promotion of fish consumption is carried out through extension services, the increased supply of fish and other animal products from integrated livestock farming activities, would provide badly needed animal protein to improve the rural diet. In an attempt to estimate the potential nutritional contribution of small-scale aquaculture in rural Yucatan, an estimate was made of the likely production of protein from fish cultured in the natural water bodies and the small fishpond system assessed in this study. For this the following assumptions were made:

1) The daily average per capita requirement of protein in rural areas is 37.8 g. (Edwards, 1983).

2) The edible weight of fish accounts for 70 % of the total wet weight (SEPESCA, 1982).

3) The protein content of C.urophthalmus is 15.4 % of the wet weight (Martinez, 1987).

4) The protein content of tilapia is 18 % wet weight (Edwards, 1983).

5) The estimated yields from the different production systems are those obtained in this study, in a per–Hectare–per–year basis.

6) The average number of members of a family were assumed to be five.

7) Each production system, with the exception of the operation of excavated ponds, requires the involvement of two farmers,

therefore two families are directly benefited from each hectare of water resources. The results of these estimates are presented in Table 33.

Table 33 Estimated Nutritional Contribution of Small-scale Aquaculture to Rural Families of Yucatan.

Type of System	Species	kg Protein produced/ha/yr	Contrib.to A.Pc.P.R.	Cont.to A.F.P.R.
Small Gravel Quarries	C. urophthalmus	38.9	145.2 %	28.2 %
small gravel quarries	O.niloticus/ C. urophthalmus	487.4	1767.3 %	353.4 %
Seasonal ponds	C. urophthalmus	10.9	39.6 %	7.9 %
Dug out ponds*	C. urophthalmus	2.4	17.7 %	3.5 %

A.Pc.P.R.= Annual per capita protein requirement.

A.F.P.R. = Annual Family Protein Requirement.

* 200 m^2

From the above estimates it is clear that if the annual animal protein requirement of a family of five members is 68.6 Kg, even fairly extensive seasonal aquaculture of O.niloticus could theoretically provide almost 8 % of the requirements at a very low cost. Each hectare of organically enriched gravel quarries could, in theory, provide more than 28 % of the annual protein requirements of a rural family, if stocked the native cichlid C.urophthalmus, and the polyculture of both species may contribute with more than 5 times those requirements, substantially more than the more capital–demanding small ponds, which could contribute only with 3.5 % of the annual family protein requirements. Clearly an important nutritional contribution can be expected from small–scale aquaculture in rural areas of Yucatan, if fish raising is introduced as a supplementary activity., it has to be remembered however that such hypothetical figures could only be reached if two households happen to have access to one hectare of a given water body, and if the benefited families consume the fish produce.

Nevertheless, a large proportion of these so–far neglected aquatic environments are located in areas that belong to the Ejido (the agrarian community), therefore if aquaculture activities were to be developed in this region, a large number of farmers are likely to directly benefit. Moreover, as stated by Pollnac, Peterson and Smith (1982), even if fish produce are sold and not consumed, the overall local protein consumption can be increased as a result of increased availability.

It is not possible to accurately estimate, with the available information the area covered by water bodies with suitable conditions for aquaculture in the region (see Chapter 6). In consequence it is difficult to predict the actual number of people likely to benefit from any aquaculture development.

However, a rough estimate is that there are 6,500 ha of seasonal ponds in Southern Yucatan (Reguero, pers.com.). If at least 50 % of this area was suitable for aquaculture production, and assuming that two men are required to manage one hectare, theoretically more than 6,000 households could directly benefit from aquaculture.

In theory, and as judged by the apparent change of attitude towards a more positive response of the farmers after the demonstration trial, the ejidatarios would probably be the most willing to adopt small-scale aquaculture in Yucatan. McGoodwin (1979) also concluded from a similar study that the ejidatarios were the group most likely to adopt aquaculture in a rural community of Sinaloa, to the northwest of Mexico: They are already accustomed to agricultural production, and small-scale animal husbandry, they are involved in long-term economic planning, and have some experience with regional extension agents. They also organise themselves in a cooperative basis to commercialise their crops and to deal with development banks.

Whether small-scale aquaculture is adopted as a part-time, rotational or off-season occupation by small farmers, this level of operation lends itself very well to integration into a rural economy, and can have an important role in overall rural development (Pillay, 1977; McGoodwin, 1979).

The results of the economic analysis of extensive fish production units, suggest that where existing water bodies are used, small-scale aquaculture is an economically viable activity, giving returns to labour well above the agricultural wage, mainly because of the low cash costs involved. The construction and operation of fish ponds, however, provide only 34% of the average agricultural wage. Nonetheless, as labour is assumed to be provided by the community, it is not a cash expense: performance can be measured in terms of returns to labour and management. In some situations, where there are no other employment or production opportunities, it may be appropriate to attribute zero opportunity cost to the labour required to operate the pond. In such cases, the operation of 200 m_2 family–operated dug out ponds, could be attractive to farmers. It is important to remember, that even if little cash costs are involved in small–scale aquaculture operations, most farmers have only limited capital. The development banks however, could provide the initial capital required, as in other parts of the country, since, as shown in the models, interest on operating capital could easily be paid back.

During the socioeconomic survey carried out in this study, it was possible to estimate that the average daily income of a small land plot owner (ejidatarios), was $2.00, by selling his crop at the end of each growing season Hence, if aquaculture was introduced as a part–time, off–season or integrated activity, the rural farmer's income could be substantially increased.

Table 34 Estimated Potential Economic Contribution of Small-scale Aquaculture in Natural Water Bodies to Daily Income of Agricultural Farmers of Yucatan.

Production system	Ret.labour/ cash cost ratio*	Returns/ day	%Average agric.wage/man
M.GQ	2.27	4.01	100
Pol.GQ	10.54	10.85	271
M.S.P.	8.25	11.06	276
Exc.ponds	0.44	0.68	34

M.GQ= Monoculture in gravel quarries.

Pol.GQ= Polyculture in gravel quarries.

M.S.P.= Monoculture in seasonal ponds.

*Figures correspond to base cases.

Estimates of the potential contribution to daily income are shown in Table 34. In all cases where a natural water body is exploited the return after deducting cash cost, is greater than the average agricultural wage suggesting these production systems could offer an important complimentary activity for the farmers. The viability of excavated ponds is less certain, since the returns to labour calculated here are less than the average agricultural wage. There may be situations however where these lower returns would still be considered acceptable.

In most cases agricultural work is seasonal and alternative employment opportunities become so scarce in rural villages that farmers are prompted to search for jobs in larger cities. Therefore again it is likely that the real labour opportunity cost of many rural areas of Yucatan is zero. Under such circumstances, the introduction of small-scale aquaculture would largely benefit rural farmers economically.

Since the actual labour input required for extensive aquaculture operations is substantially lower than that required by traditional agriculture (Pollnac, 1982) and labour may be in surplus, farmers could adopt it without decreasing productivity in the rest of the local economy.

Ruddle (1990) states that only technologies that offer a better way of doing things or yield a better result than customary practices will be adopted. This could imply an easier transition towards integrating aquaculture into Yucatecan agriculture, especially if underutilised resources such as seasonal ponds are rotationally exploited through agriculture during the dry season and aquaculture during the wet season, as proposed in Chapter 4.

There are other technological and socioeconomic considerations that have to be taken into account if fish farming is to realise its potential, including resource availability. In this regard, demand for fish fry in Yucatan in an initial stage could easily be met by the current production in a regional research institution, based in Merida, as well as one of the two government hatcheries, based in Celestun to the northwest of the state.

As far as the availability of fertilisers is concerned, most farmers have at least few livestock at their house sites, from which some manure could be regularly collected and used as a source of fertilizer. In addition, a considerable amount of crop residues are left after each harvest, which can also be as an inexpensive source of fertilizer and which could be combined with other agricultural byproducts to produce cheap supplementary food for the fish and livestock. At present, such by-products are wasted, mainly because farmers are already familiar with the use of inorganic fertilizer which are locally available and inexpensive, hence fish raising activities could also contribute to the optimisation of those misused resources. Furthermore, integrated agro-aquaculture represents an innovative approach toward resolving some of the problems faced in semi-subsistence farming sectors, where suitable land and water resources are available and nutrition and employment opportunities are a critical need (Pillay, 1977; Hatch and Engle, 1987).

According to Hatch and Engle (1987), poor farmers constitute a semi-subsistence economy characterised by scarcity of the resources necessary to increase production. Even if off-farm employment opportunities exist, nutritional levels are rarely increased without increasing basic farm output. This highlights the potential role of small-scale aquaculture development integrated in rural Yucatan. By improving efficiency utilisation, i.e. through integrated agricultural, livestock and fish production, a considerable protein production could be achieved.

Aquaculture operations combined with agriculture and/or animal production, can be particularly important in integrated rural development programmes. In view of the similarities in operational procedures and production concepts, there is much to be gained by close integration, including the sharing of common services (Pillay, 1977). Integrated aquaculture can complement and improve the overall efficiency of many types of farm; for instance, the more efficient use of water and labour, as well as waste recycling into fish are two obvious examples. Conversely, livestock and arable crop production may be the only source of feeds and fertilisers at low enough cost to make fish culture possible (Little and Muir, 1987).

Another important factor to consider in aquaculture development is species choice. There are strong arguments for the use of native species: they are more readily marketed and physical conditions for their culture already exist. However, unless the local fish have distinct advantages over exotic species, it is not wise to discard the possibility for the cultivation of a non–indigenous species (Smith and Peterson, 1982).

It is important to note that in most of the trials carried out in this study, including the demonstration trial, the native cichlid C.urophthalmus was used, since this species is widely spread in the region and the people in Yucatan are more familiar with this fish than with other exotic species; moreover a comprehensive research programme is currently underway in the region. However, yields of tilapia O.niloticus are expected to be much higher, since food habits of this species are based on lower links of the food chain (Moriarty and Moriarty, 1973), thus introducing this species in aquaculture development schemes should not be discontinued. As mentioned earlier, in some areas this species has already been used. Successful rural aquaculture development projects have been based on the cultivation of several tilapine species (Echandi, 1982; Edwards, 1983; Gaite, et al, 1983; Gonzales, 1984; Hatch and Engels, 1987; Gopalakrishnan, 1988) Thus, provided that pertinent ecological considerations are evaluated, tilapia could prove an ideal candidate for extensive aquaculture in the region.

It is important however to remember that radical changes in dietary traditions may be difficult to introduce and maintain due to long historical and cultural processes (Grivetti, 1982; Ruddle, 1990). Therefore unless a sound extension programme is developed aimed at providing basic nutritional education without drastically changing dietary patterns, success of exotic species such as tilapia may be limited.

Suitable marketing arrangements are also essential for small-scale aquaculture development. According to Pillay (1977), in subsistence-level or small-scale operations limited to serve the dietary needs of a family or a small community, there is usually no marketing problem. The word is passed round and consumers come to the fish pond or water body to buy fish as soon as harvested.

However, the situation may be different if the cultivated fish has low consumer appeal. In such cases the need arises for product development, consumer education and demonstration marketing, which can be included as part of the extension services (Pillay, 1977; Shaw, 1985). Again, in rural Yucatan the type of marketing organisation already employed by the ejidatarios could be advantageously utilised for fish marketing in the community, thus simplifying marketing channels.

Development should start by addressing people's most pressing needs and then work outward (McGoodwin, 1979). If the scale of farming adopted by the rural communities of Yucatan is sufficient to contribute a reasonable income, as suggested in this study, it can help improve not only the rural diet, but the amelioration of the problem of migration of people from rural areas to cities. Aquaculture is but one of several potential strategies for improving rural diet and rural economy. Others include small livestock improvement and intensification of agricultural techniques, etc. (Grivetti, 1982).

Based on the results of this study, the potential role of pond culture in rural development is uncertain, particularly for the monoculture of C.urophthalmus. It is likely, however, that tilapia culture in small ponds could provide higher yields and improved economic viability of ponds.

Aquaculture could offer an ideal alternative for the productive utilisation of a potential large area covered by neglected water resources present in rural areas of Yucatan, thus contributing to the overall rural development.

CHAPTER 6

THE IMPLEMENTATION OF A GEOGRAPHICAL INFORMATION SYSTEM FOR THE IDENTIFICATION OF POTENTIAL AREAS FOR INLAND AQUACULTURE DEVELOPMENT IN THE YUCATAN PENINSULA.

6.1 Introduction.-

Compared with most agricultural systems, aquaculture still has a great need for structured decision-making and planning, especially for feasibility studies for development projects. One significant constraint for long-term planning and rational development in aquaculture is the lack of environmental information on potential areas for development or expansion (Duncan, 1985; Kapetsky, et. al., 1987). However, once the appropriate data is available, the means to facilitate such evaluation are available through the use of computer–based Geographical Information Systems (GIS), which have developed rapidly in the past 20 years (Duffield and Coppock, 1975; Borrough, 1980; Cliff and Ord, 1981; Borrough, 1986). These tools enable the user to store, manipulate, and spatially analyse thematic maps, in order to identify suitable areas for development or other purposes.

This Chapter deals with the compilation of a PC–based GIS, consisting of a series of thematic maps containing spatial information on environmental and socioeconomic factors, considered to be relevant for aquaculture development in the Yucatan Peninsula. The information on water resources distribution in the area, as well as the criteria for the regional assessment, are based on the results of the field work carried out in this study, in order to identify, as a preliminary approach, those areas of the region that offer adequate conditions for the development of aquaculture.

6.2 Methods.–

6.2.1 Geographic coverage of the analysis.–

The spatial analysis comprised the zone between 19 10' and 21 30', latitude; and 86 30' and 90 30' longitude, ensuring the coverage of the entire Peninsula.

6.2.2 Selection of production functions.–

Nine spatially variable production functions were identified for the analysis. Those variables related to basic infrastructure and availability of services, were considered necessary for aquaculture development in all systems, regardless of their geohydrological nature (e.g. roads and closeness to large and mid–sized population centres). Other environmental production functions such as precipitation, land elevation or soils, were considered selectively necessary, depending on their influence on the specific water body (e.g. precipitation on seasonal ponds); or whether the variable was a precondition for a specific system, such as soil type on suitability for pond construction.

Both the production functions selected and the sources of data for each layer are presented in Table 35. Each production function was allocated an arbitrary numeric scoring (Table 36).

The spatial variables were selected so that the most important environmental and socioeconomic factors likely to determine the viability of a given area for aquaculture development were assessed.

Land elevation was considered important in relation to depth to the water table, which could be used as an alternative source of water for aquaculture in ponds.

Table 35 Spatially Variable Parameters Associated With Suitable Location For Aquaculture Development In The Yucatan Peninsula.

Parameter	Source of Data
Land Elevation	Topographic Chart (Scale 1:1,000,000) of the Yucatan Peninsula (INEGI,1985)
Precipitation	Precipitation Chart (Scale 1:1,000,000) of the Yucatan Peninsula (INEGI,1985)
Soils	Edaphological Chart (Scale 1:1,000,000) of the Yucatan Peninsula (INEGI,1985)
Distribution and area covered by water resources (Sinkholes, Permanent Aguadas, Seasonal Ponds, Lakes and Quarries)	Induvidual Maps were constructed (Scale 1:1,000,000) based on the results of the land-based surveys of this study, aerial photography (1:50,000) and literature survey.
Land Use	A map was constructed (Scale 1:1,000,000) compling information provided by the agricultural chart of the Yucatan Peninsula (INEGI,1985), from Gobierno of Campeche (1988) and from INEGI (1990).
Villages	Roads, villages and administrative division chart of the Yucatan Peninsula (INEGI,1985) (Scale 1:1,000,000)
Roads	Roads, villages and administrative division chart of the Yucatan peninsula (INEGI,1985) (Scale 1:1,000,000)

Table 36 Numerical Scoring for the Spatial Variables Included in the GIS Employed to Identify Suitable Areas for Aquaculture Development in the Yucatan Peninsula.

Variable	Scoring
Land elevation.	5= 5–30 m ASL
	4= 31–50 m ASL
	3= 51–70 m ASL
	2= 71–90 m ASL
	1= >90 m ASL
Precipitation.	5= > 2,000 mm
	4= 1,000–2,000 mm
	3= 800–999 mm
	2= 600–799 mm
	1= < 600 mm
Soils.	5= Luvisols
	4= Rendzines
	3= Cambisols
	2= Litosols
	1= Others

Table 36 continued.

Land Use.	5= Idle land.
	4= Extensive or seasonal agriculture.
	3= Mechanised agriculture.
	2= Densely populated urban centres.
	1= Industrial areas and ecological reserves.
Population centres.	6= Towns of > 20,000 inhabitants.
	5= 10,000–19,999 inhabitants.
	4= 5,000–9,999 inhabitants.
	3= 1,000–4,999 inhabitants.
	2= < 1,000 inhabitants.
	1= unpopulated areas.
Distribution and abundance of gravel quarries.	6= Areas with >8 ha of quarries.
	5= 4–8 ha of quarries.
	4= 2–3.9 ha of quarries.
	3= 1–1.9 ha of quarries.
	2= <1 ha of quarries.
	1= no quarries present.

Table 36 continued.

Distribution and abundance of seasonal ponds.	5= Areas with >20 seasonal ponds.
	4= 11–20 seasonal ponds.
	3= 3–10 seasonal ponds.
	2= 1–2 seasonal ponds.
	1= no seasonal ponds present.
Distribution and abundance of freshwater lakes.	4= Areas where lakes cover >10 km^2
	3= Areas where lakes cover 3–9 km^2
	2= Areas where lakes cover 1–3 km^2
	1= Areas where lakes cover <1 km^2.
Distribution and abundance of permanent aguadas.	5= > 6 permanent aguadas present.
	4= 5–6 permanent aguadas present.
	3= 3–4 permanent aguadas present.
	2= 1–2 permanent aguadas present.
	1= no permanent aguadas present.

Soil type determines the feasibility of pond construction. Organically–rich clayish soils (Luvizols) are more impermeable hence their water holding capacity is higher than other types of soils.

Levels of rainfall influence the water balance, and influence the formation of seasonal ponds in areas where land depressions are abundant and the soil is clayish.

The distribution of water resources in the study region represented a determinant production function for each water body type in the spatial analysis. Highest scorings were allocated to those areas presenting larger number of a given water body type, with the exception of sinkholes.

Land use was considered important to establish whether aquaculture activities were likely to be compatible with other uses of the available land and water resources.

Permanent accessibility to the potential areas for development was considered to be of paramount importance, since transport of goods to the sites and harvested fish from the aquaculture sites to wholesale markets would need to be carried out in a regular basis.

Closeness to medium–sized and larger population centres was also an important production function related to accessibility both to services and to potential markets for aquaculture products.

6.2.3 Raster data structures.–

Grid–based maps of each layer (variable) were constructed by overlaying a transparent 40 x 60 cell grid on a previously constructed 1:1,000,000 scaled base map. Each cell represented an area of 49 km2 of land surface. Tracing was carried out so that those cells which were more than 50% inside the boundary line were included, and those cells which were less than 50% inside the boundary were excluded. This was considered to be sufficiently accurate at the scale used. Rows and columns were numbered, and geographic data was then encoded on a row/column coordinated basis using the system of scoring described above.

6.2.4 Data encoding.–

Encoded data were entered into a data base in the GIS package OSU–map–for–the–PC (University of Ohio, 1989), using two different encoding procedures. Run–length encoding allowed the scored points of each mapping unit to be entered by row, in terms, from left to right, of a start cell and an end cell. Point encoding, allowed allocation of values according to their grid coordinates and was useful for detailed data entry and editing.

6.2.5 Spatial data analysis.–

Three–dimensional overlay arrangements were carried out by using the "cross" model included in the GIS software package OSU–Map–for–the–PC (University of Ohio, 1989). Using this technique, layers for each water body type layer could be crossed with layers corresponding to those spatial variables considered to be most important in each case. A new ranked value could then be assigned to those pairs of overlapping values representing the best combination and meeting the requirements of the original scoring criteria, as shown in Figure 48. The model responded to the Boolean logic operation of the form U = f (A B C) (Burrough, 1986), represented by the Venn diagram shown in Figure 49. The analysis was carried out in a series of steps, for each particular water body type, so that the set of selected spatial variables considered most important for the given water body type, were overlapped and the less

Figure 48. Three dimensional overlay arrangements employed using the GIS to identify spatial suitability for aquacultural development in the Yucatan peninsula

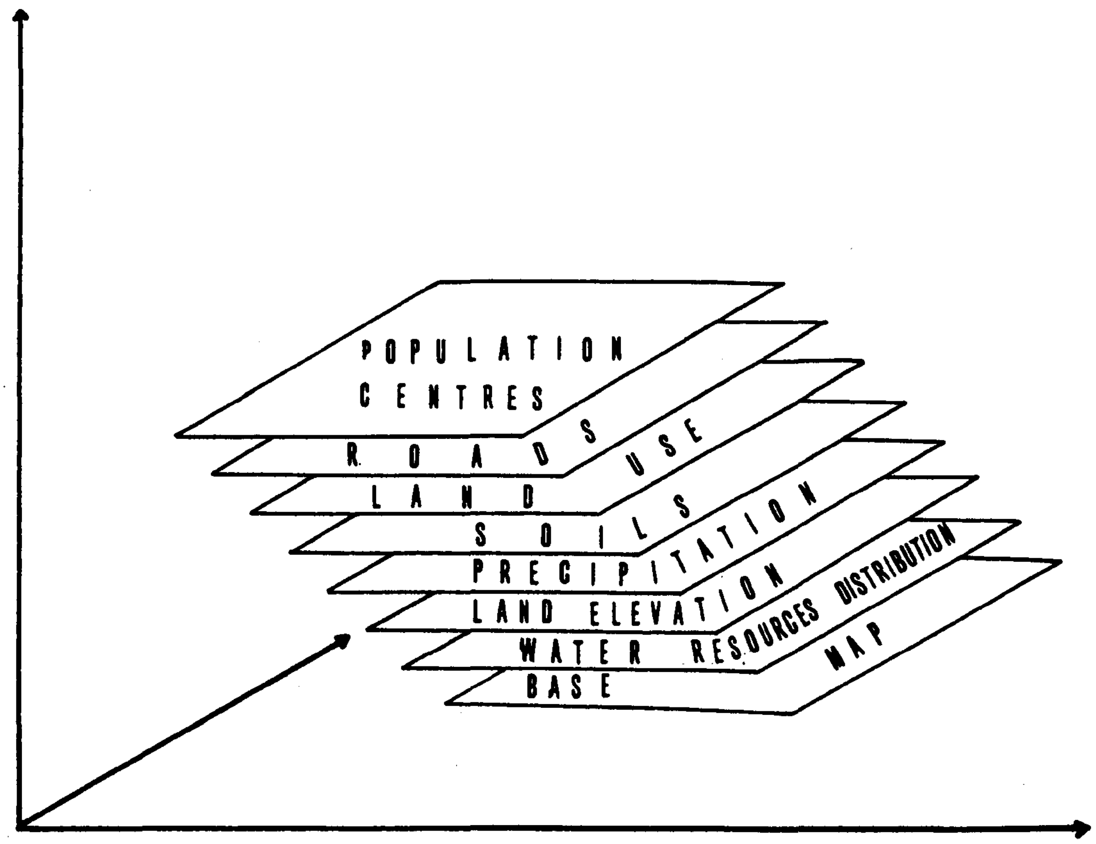
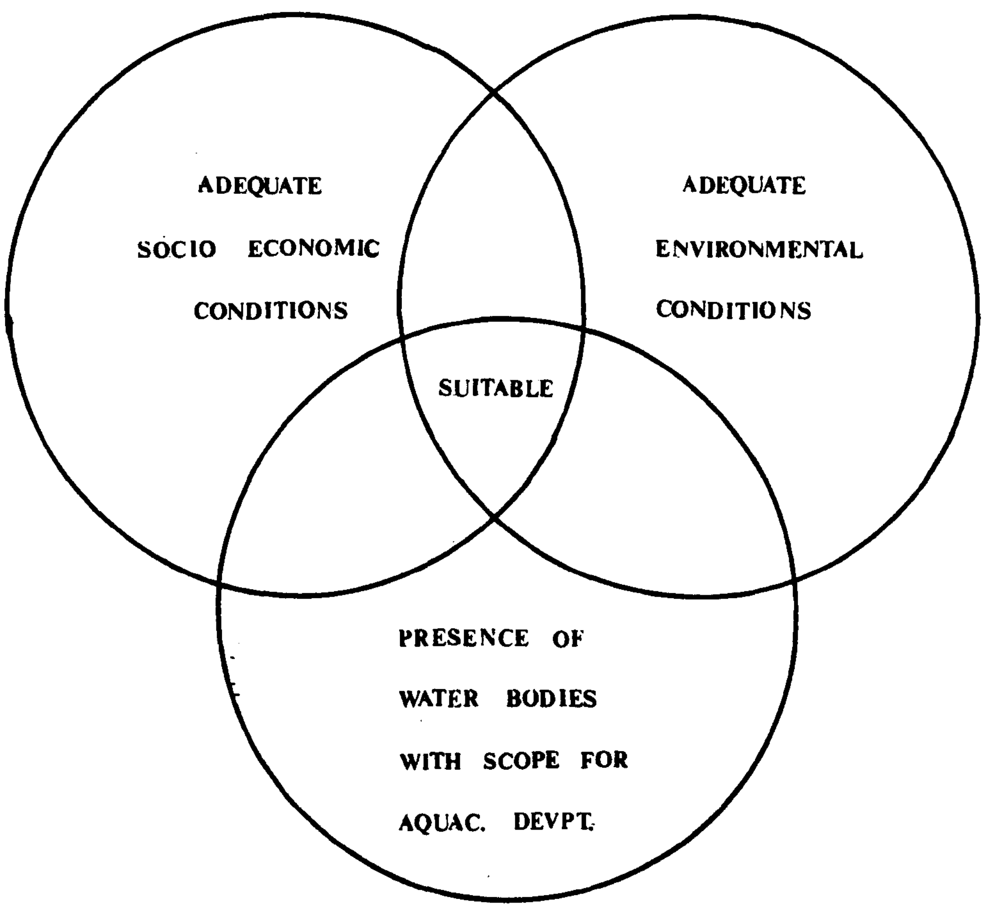

POPULATION CENTRES
ROADS
LAND USE
SOILS
PRECIPITATION
LAND ELEVATION
WATER RESOURCES DISTRIBUTION
BASE MAP

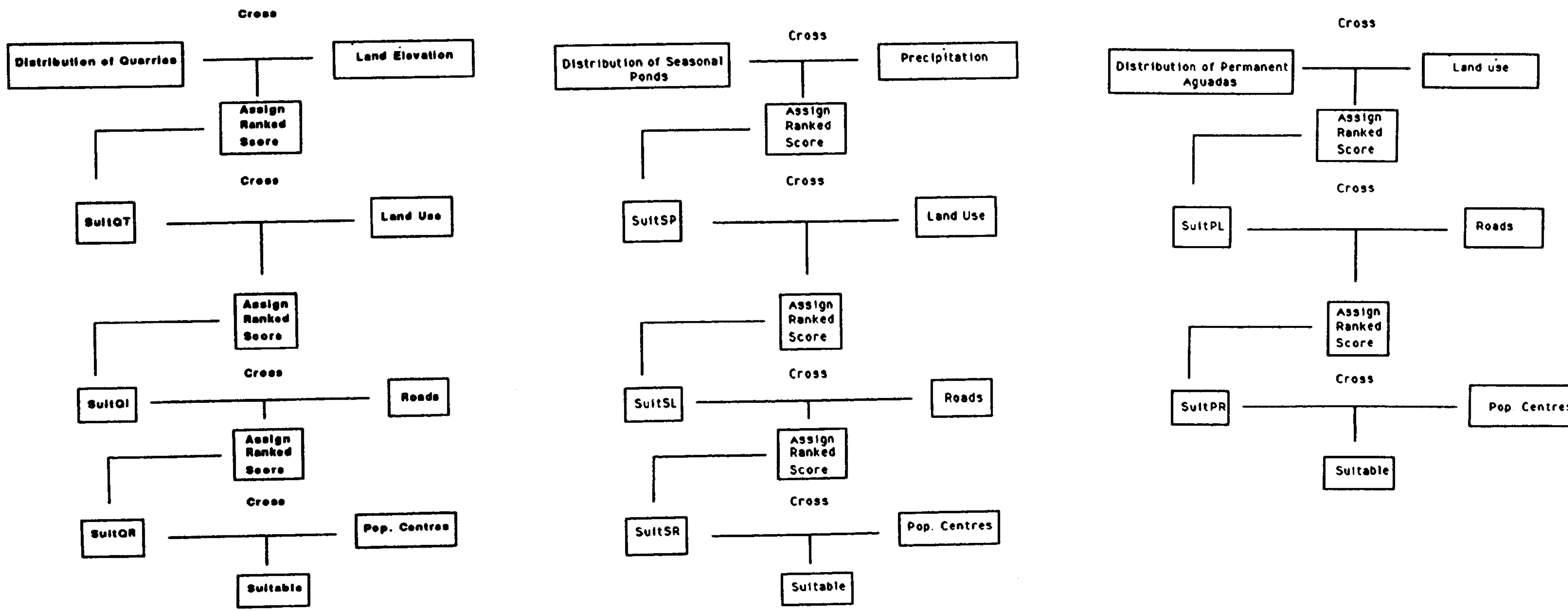
Figure 49. Venn diagram representing the Boolean logic operation employed as a criterion for the spatial suitability for aquaculture.


ADEQUATE
SOCIO ECONOMIC
CONDITIONS
ADEQUATE
ENVIRONMENTAL
CONDITIONS
SUITABLE
PRESENCE OF
WATER BODIES
WITH SCOPE FOR
AQUAC. DEVPT.

suitable areas for aquaculture development, according to the assessment criteria, were screened off as a result of crossing and rescoring, until the output layer <SUITABLE> was obtained by the intersection operations. Figure 50 presents a schematic representation of the step–by–step cross model employed for each water body type.

Reclassification of the original stored source maps of water resources distribution allowed the development of a final output map containing the geographic location of water resources of the Yucatan Peninsula. The resulting map–layers of the various steps of the spatial analysis were then output to a HP–7475A plotter.

Figure 50. Flow diagram of the spatial analysis using the "cross" model in the GIS.


Cross
Distribution of Quarries
Land Elevation
Assign Ranked Score
SuitQT
Cross
Land Use
Assign Ranked Score
SuitQI
Cross
Roads
Assign Ranked Score
SuitQR
Cross
Pop. Centres
Suitable
Cross
Distribution of Seasonal Ponds
Precipitation
Assign Ranked Score
SuitSP
Cross
Land Use
Assign Ranked Score
SuitSL
Cross
Roads
Assign Ranked Score
SuitSR
Cross
Pop. Centres
Suitable
Cross
Distribution of Permanent Aguadas
Land use
Assign Ranked Score
SuitPL
Cross
Roads
Assign Ranked Score
SuitPR
Cross
Pop Centres
Suitable

6.3 Results.–

The spatial analysis carried out using the GIS, provided a rapid means of manipulating environmental and socioeconomic data to investigate the suitability of broad areas of the Yucatan Peninsula for inland aquaculture development. The individual output layers and source maps on which the spatial analyses were based are presented in Appendix II.

This section presents the resulting geographic information, which is arranged following the original physiographic classification employed in the land–based survey of this study (Figure 2, Chapter 2).

6.3.1 Water resources distribution.–

Figure 51 shows the distribution of the diverse types of water body found in the region. Even though this map is by no means a

Figure 51. Water resources distribution output layer, constructed by using the GIS Osu-map-for-the-PC.

WATRES2
sea
lakes
quarries
sinkholes
seasonal ponds
permanent aguada

definite inventory of water resources of the region, it does provide an accurate panorama of their geographic distribution and a first chart of surface hydrological resources of the Peninsula, since the location of the mapped water bodies was based either on the results of the land–based surveys or, in a smaller proportion, on literature reports on their specific location. Overall, sinkholes are abundant in northern Yucatan and Quintana Roo states, on the northeastern and northwestern karst plains. Sinkholes, however, were not included in the later spatial analysis, since, as stated in earlier Chapters, the use of these karstic features would be ecologically counterproductive and probably economically unviable. Quarries of various dimensions are mostly found in this same region, although concentrated around large cities like Merida, Campeche and Cancun, as these represent major markets for gravel and lime. In contrast, seasonal ponds are most abundant in the Southern hilly region, following a strip along the southern areas of the Sierrita de Ticul Range, and covering large areas at the South of the Peninsula, approximately between 88° 25' and 90 15' longitude.

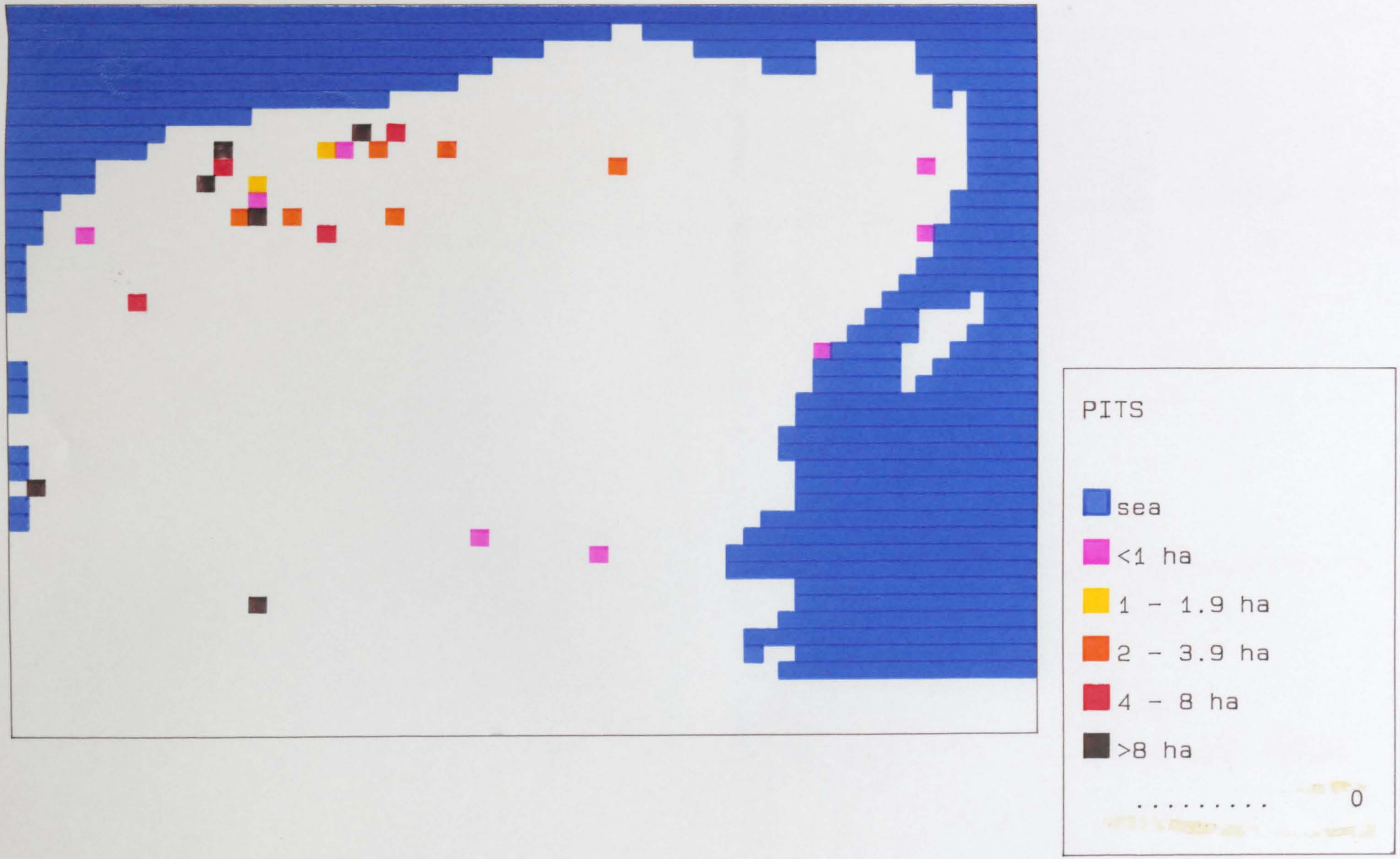
The northwestern portion of the Central hilly region contains the largest number of permanent aguadas, although these were the least abundant of the water resources of the area. It is also in this Southern hilly region, in its eastern portion, that the only permanent freshwater lakes of the peninsula are located, covering significant areas of Quintana Roo (Villanueva, 1986).

6.3.2 <u>Spatial suitability for aquaculture</u>.-

The cross model allowed the spatial analysis to be carried out independently for each water body type, using a specially selected set of spatial variables for each type (Fig 50).

With the exception of sinkholes, which were not considered in the spatial analysis, the original number of cell points representing the water body types studied was reduced by the cross operations. An original area covered by quarries represented by 26 cells, the majority of which were concentrated in the northern plains and a few in the southern regions of Campeche State (Fig 52), was reduced by 15 % after rescoring the lowest values to those pairs of crossed cells representing areas of highest land elevation, namely the Southern Hilly Region, as well as the quarries located at sea level (Fig 53). In the following step of the analysis for suitable quarry areas, the "land use" layer screened off those areas which the assessment criteria considered incompatible for aquaculture development, thus discarding the quarries present within the industrial zone of Merida city and those in areas of intensive animal farming (Fig. 54). Further screening of the output layer resulted in a reduction of cell points with suitable characteristics of an additional 60 % of the remaining cell points, derived from poor accessibility and closeness to mid-sized population centres (Fig. 55).

Figure 52 Original PITS layer, representing the distribution and abundance of gravel quarries in the Yucatan peninsula



PITS
sea
<1 ha
1 - 1.9 ha
2 - 3.9 ha
4 - 8 ha
>8 ha
0

Figure 53. Resulting output layer of analysing quarry areas most suitable in relation to land elevation.


SUITQT
sea
suitable elevat.
.... 0

Figure 54. Resulting output layer, representing areas suitable in relation to Land use.

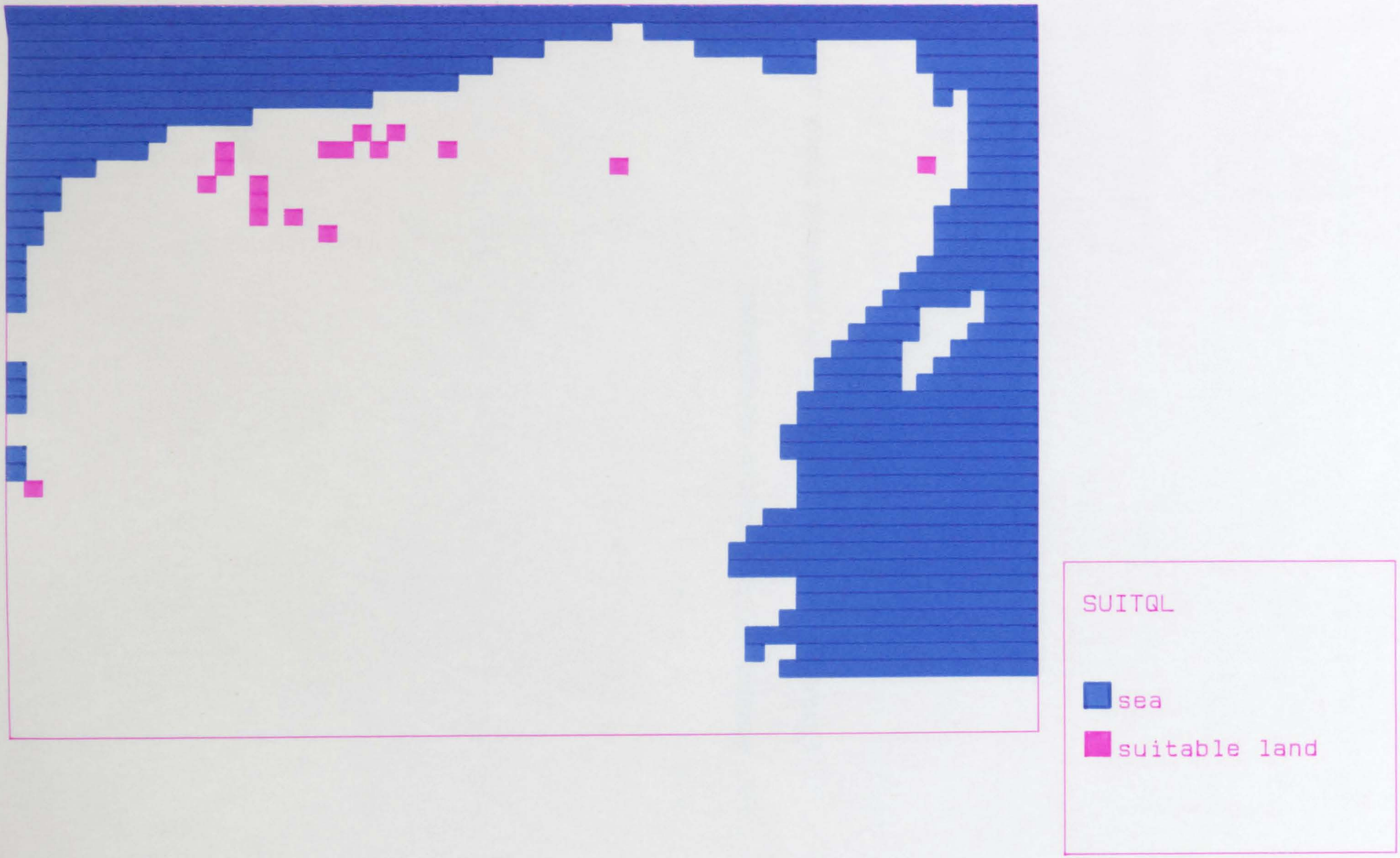
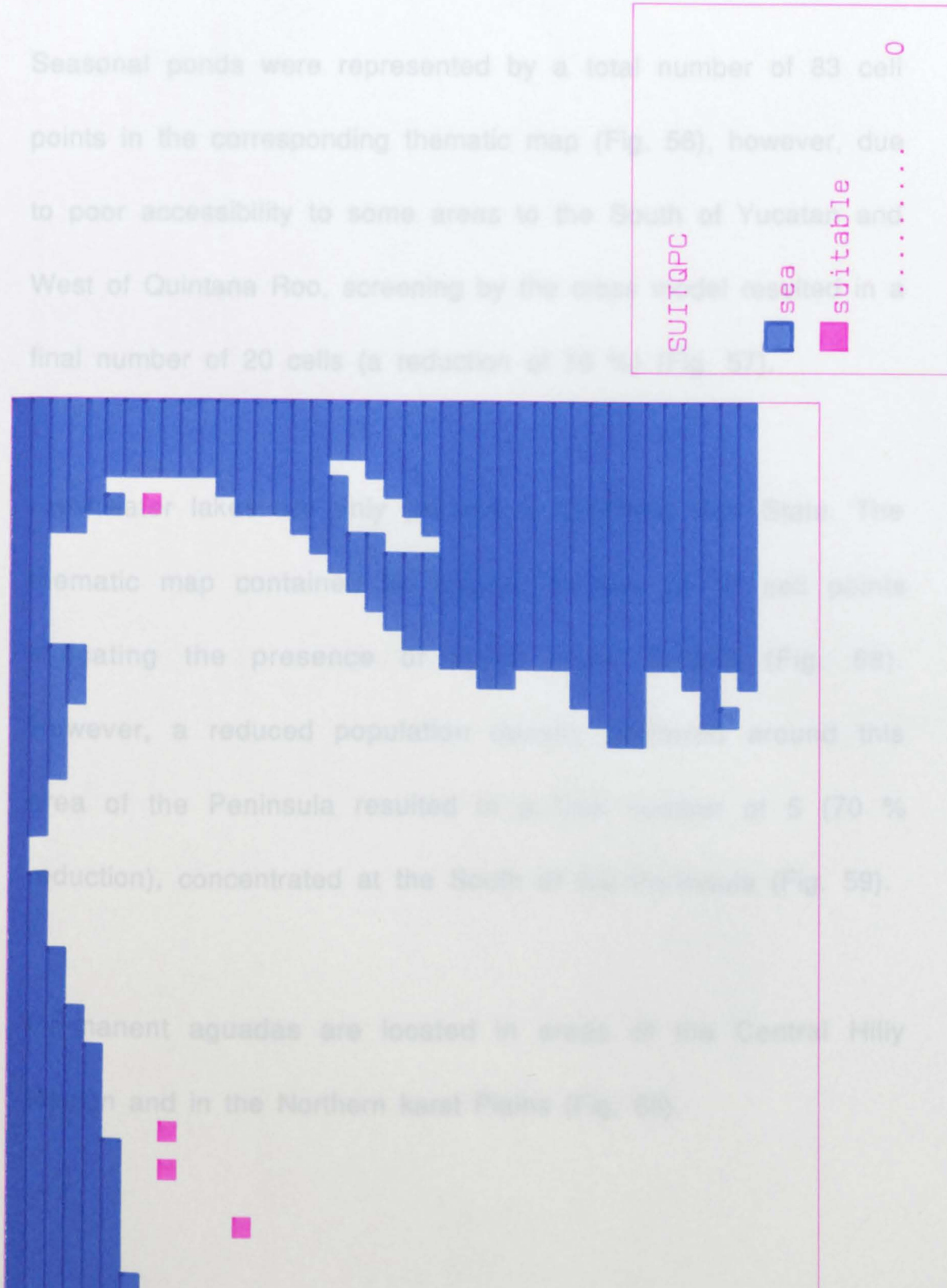

SUITQL
sea
suitable land

Figure 55 Resulting output layer of analysing quarry areas most suitable for aquacultural development.


SUITQPC
sea
suitable 0

Seasonal ponds were represented by a total number of 83 cell points in the corresponding thematic map (Fig. 56), however, due to poor accessibility to some areas to the South of Yucatan and West of Quintana Roo, screening by the cross model resulted in a final number of 20 cells (a reduction of 76 %) (Fig. 57).

Freshwater lakes are only present in Quintana Roo State. The thematic map contained an original number of 17 cell points indicating the presence of these water bodies (Fig. 58). However, a reduced population density scattered around this area of the Peninsula resulted in a final number of 5 (70 % reduction), concentrated at the South of the Peninsula (Fig. 59).

Permanent aguadas are located in areas of the Central Hilly Region and in the Northern karst Plains (Fig. 60).

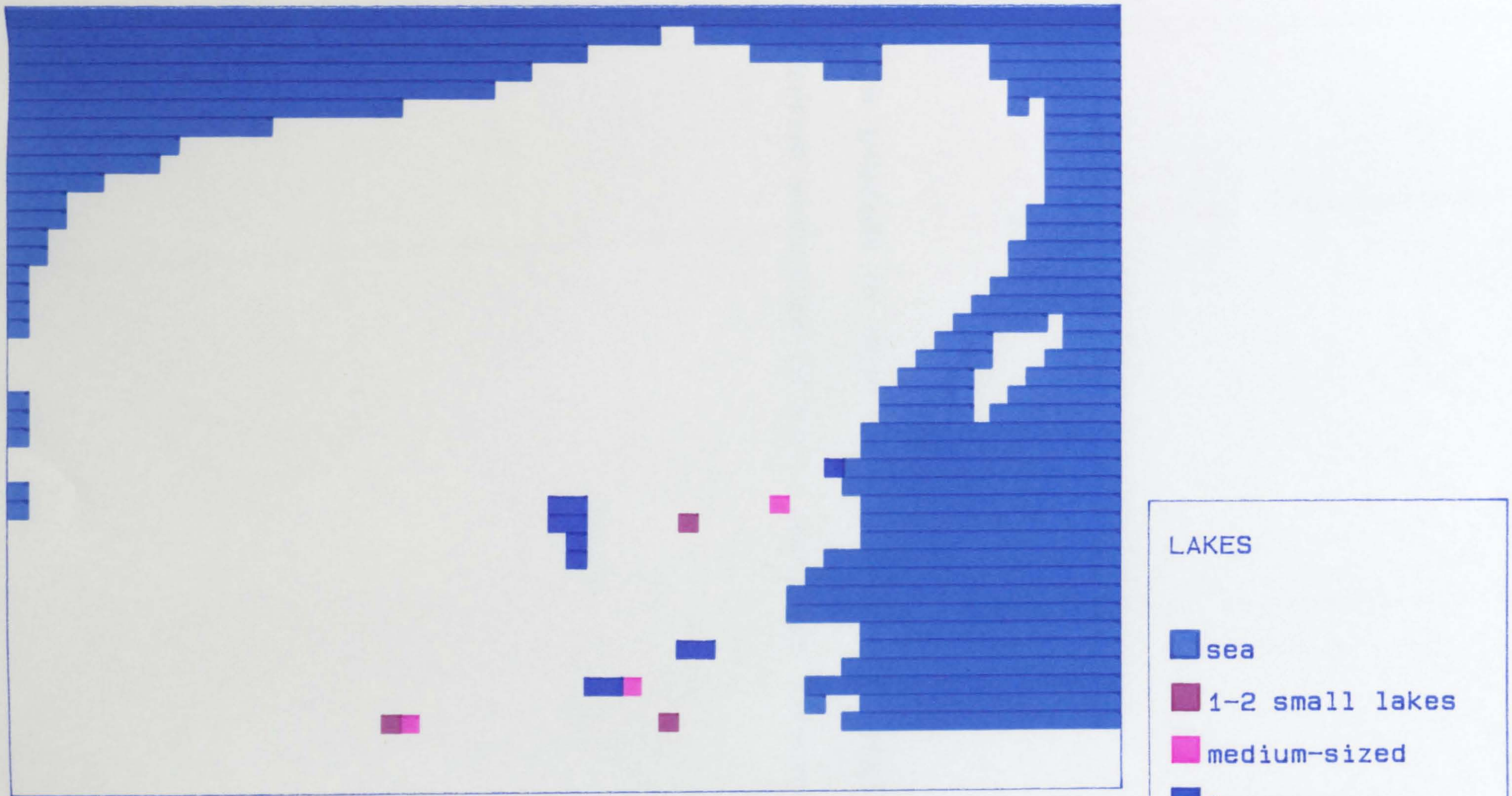
Figure 56 Original SEASONAL layer, representing the distribution and abundance of seasonal ponds in the Yucatan peninsula


SEASONAL
sea
1-2 ponds
3 to 10 ponds
10-20 ponds
>20 ponds
.... 5383

Figure 57 Resulting output layer of analysing areas with seasonal ponds most suitable for aquacultural development.


SUITSEAS
sea
suitable
.... 0

Figure 58. Original LAKES layer, representing the distribution and abundance of freshwater lakes in the Yucatan peninsula



LAKES
sea
1-2 small lakes
medium-sized
large areas
.... 4114

Figure 59. Resulting output layer of analysing areas with freshwater lakes most suitable for aquacultural development.


SUITLAKE
sea
suitable

Figure 60. Original PERMAGUA layer, representing the distribution and abundance of permanent aguadas in the Yucatan peninsula


PERMAGUA
sea
1-2 water bodies
3-4 water bodies
5-6 water bodies
>6 water bodies
.... 5383

The spatial analysis of regions where this water body type is present resulted in only three suitable locations, to the West of Tizimin city on the northeastern karst plain, and in the northern portion of the central hilly region (Fig. 61).

A final output SAFAD (Suitable Areas for Aquaculture Development) layer was then compiled and is shown in Figure 62.

Suitability for aquaculture can be considered on a regional basis, the principal areas being the Northeast and Northwest karst plains and the Southern hilly region. The aquaculture potential at these regions, based in the results of the GIS employed in this study are described below.

Figure 61. Resulting output layer of analysing areas with permanent aguadas most suitable for aquacultural development.

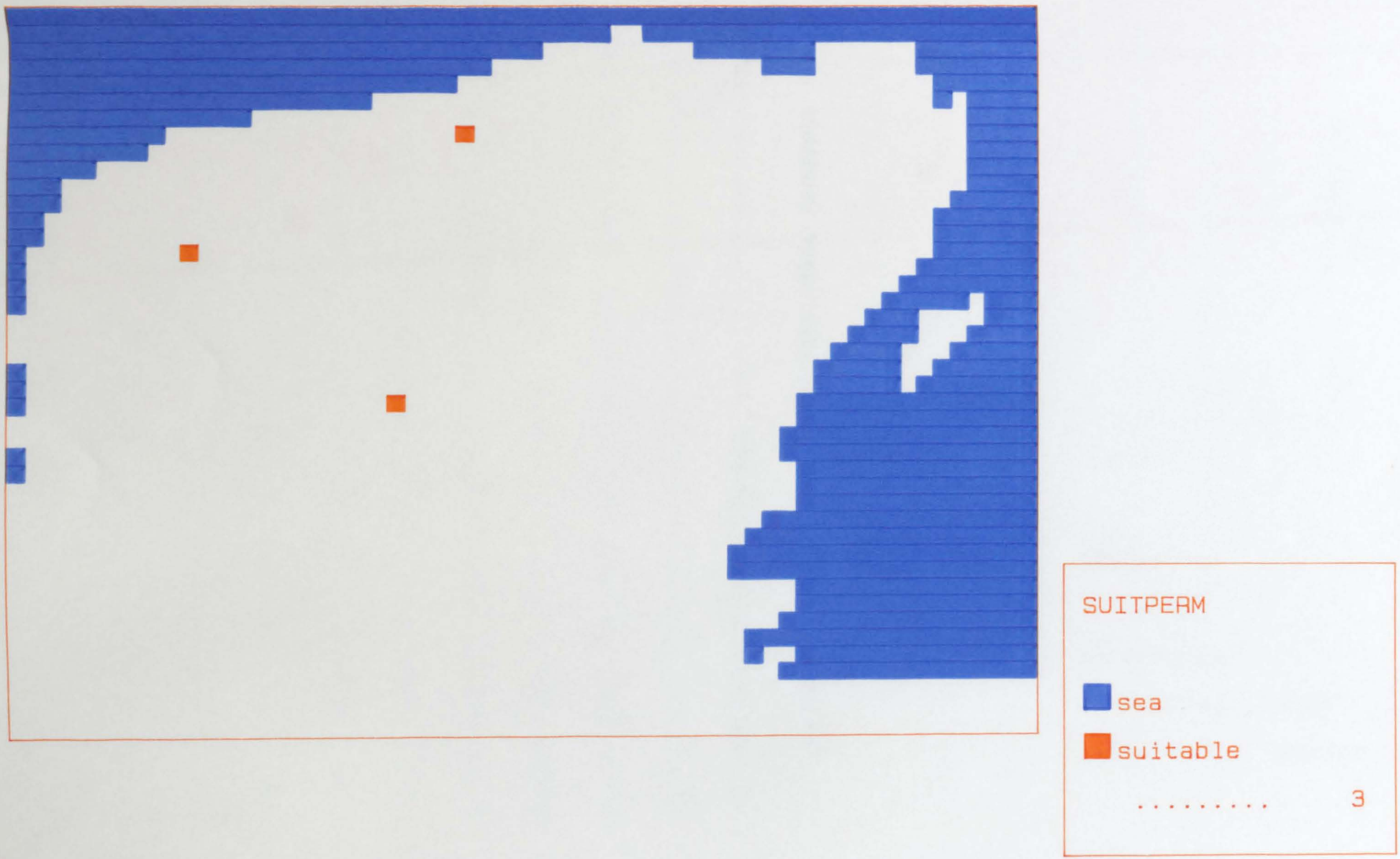
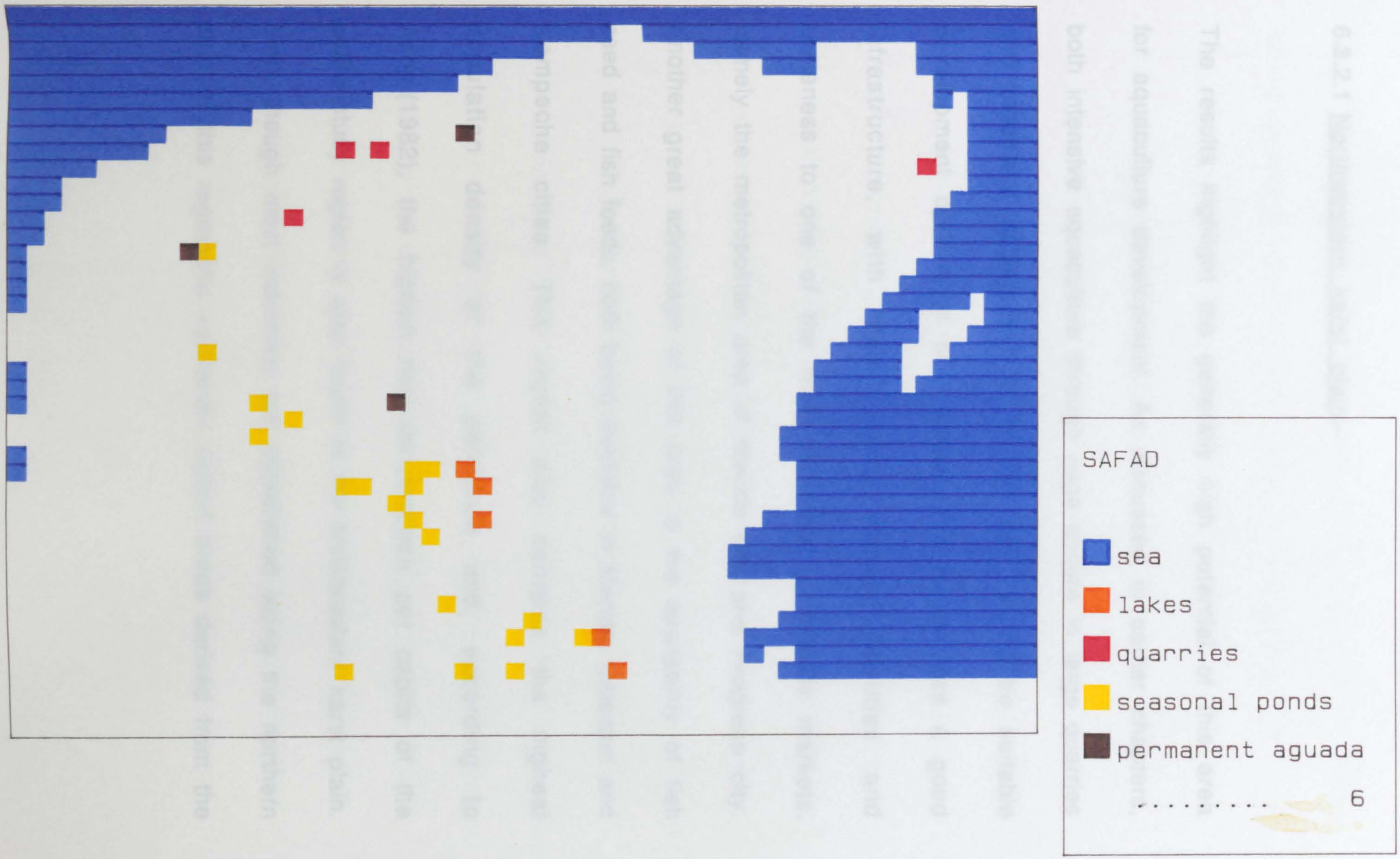

SUITPERM
sea
suitable
.... 3

Figure 62 Final SAFAD output layer (suitable areas for aquacultural development)


SAFAD
sea
lakes
quarries
seasonal ponds
permanent aguada
.... 6

6.3.2.1 Northwestern karst plain.-

The results highlight the generally high potential of this area for aquaculture development. As discussed in earlier chapters, both intensive aquaculture through cage culture in large quarries and extensive aquaculture in smaller pits would be suitable development options in this sector. The region has a good infrastructure, with main roads, storage facilities and closeness to one of the most important wholesale markets, namely the metropolitan area of Merida city and Progreso city. Another great advantage of this area is the availability of fish seed and fish feeds, both being available in Merida, Celestun and Campeche cities. This region also contains the highest population density of the peninsula and, according to Anon.(1982), the highest fish consumption per capita of the entire study region is also found in the northwestern karst plain. Even though most industries are established along the northern strip of this region,the <suitable> output areas derived from the spatial analysis are principally located outside of those areas having potential hazards from industrial pollution (Fig. 54).

6.3.2.2 Northeastern karst plain.–

The analysis suggests a limited scope for aquaculture development in this area of the peninsula, reflected by patchy localised cells with high scoring. This is because, although a good basic infrastructure is present, the actual presence of water bodies with adequate conditions for fish culture, namely limestone quarries, is restricted to the northeastern area of the state of Quintana Roo, where quarrying operations are significant in the vicinity of the other most important market, the city of Cancun. This, together with good roads, communications and availability of fertilisers favoured this area in the analysis; nevertheless, the nearest current source of fish seed would be Merida city, approximately 320 km to the west.

The other potential area highlighted by the GIS analysis, was the northern and central portion of this region, around the town of Buctzotz, where a number of permanent aguadas are present. Infrastructure in this area is good and fish consumption was found to be one of the highest in the state of Yucatan (Anon, 1982), however, as discussed in earlier chapters, the actual aquaculture potential of this type of water body is limited by the extreme environmental conditions.

6.3.2.3 Central hilly region.–

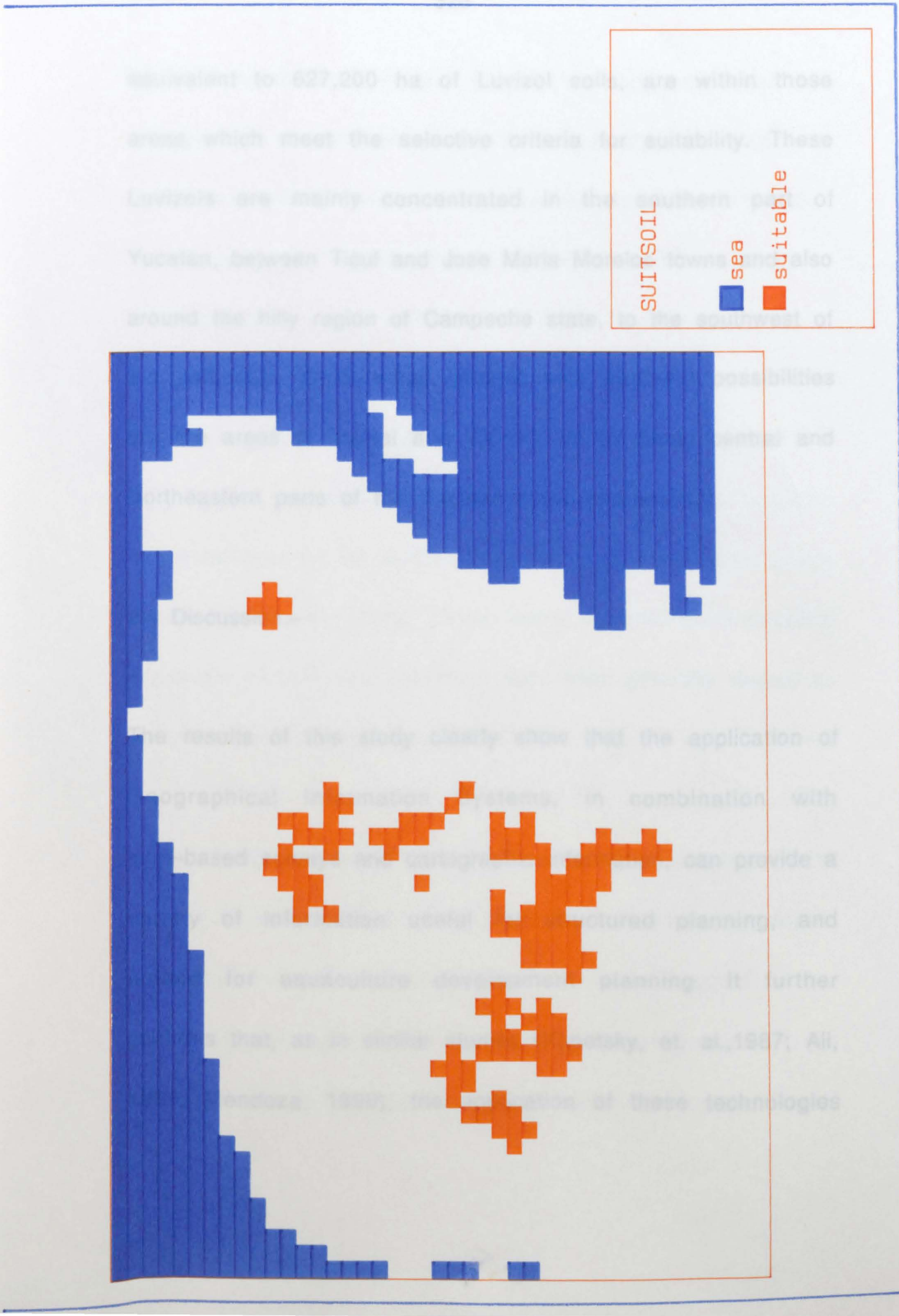
This area scored well in the spatial analysis because of the considerable number of seasonal ponds and comparatively larger areas covered by lakes. These factors, together with good basic infrastructure and potential for local wholesale markets in mid–sized towns, resulted in larger numbers of high–scoring cells in this region. Geographically, the areas with most suitability for aquaculture, follow a strip along the southern region of the Sierrita de Ticul Range, between the town of Muna in Yucatan, at approximately 20^{o} 30' latitude and 89^{o} 40' longitude, and the city of Valle Hermoso in the State of Quintana Roo, at approximately 19^{o} 30' and 88^{o} 25' longitude (Fig. 50). Here, most of the irrigated agricultural areas are located, and the installed pumping irrigation systems thus provide an inexpensive source of good quality groundwater. In these most southern areas of the peninsula, the population density is lower than that of northern regions; nonetheless, mid-sized cities like Valle Hermoso (8,200) and Carrillo Puerto (32,800) could provide skilled labour, fertilisers, storage facilities, and , most important, fish seed from a local government hatchery which produces fry of both native cichlids such as C.urophthalmus and exotic species such as Oreochromis spp. Although this is mainly an agricultural area, there are small-scale artisanal lake fisheries for C.urophthalmus, C.synspilum, and Oreochromis spp (Bravo, pers.com.).

Land elevation is highest around the Sierrita de Ticul range, but becomes lower as the southeastern portion of the peninsula is approached. Precipitation is also highest in this area, where an average of more than 2000 mm/year can maintain land depressions full of water for more than six months of the year.

6.3.3 Areas of suitable soil for pond construction.–

The highest scoring for suitable soils as far as pond construction is concerned was allocated to those areas of the study region which met the requirements for <SUITABLE> according to the selective criteria, whose soils were of the Luvizol type. These soils, according to Aguilera (1956), are those with a high proportion of fine particles, including clays, and are organically rich. Figure 63 shows that that 128 cellpoints,

Figure 63. Areas of suitable soil for pond construction in the peninsula of Yucatan.


SUITSOIL
sea
suitable

equivalent to 627,200 ha of Luvizol soils, are within those areas which meet the selective criteria for suitability. These Luvizols are mainly concentrated in the southern part of Yucatan, between Ticul and Jose Maria Morelos towns and also around the hilly region of Campeche state, to the southwest of the peninsula. Other small patches with apparent possibilities are the areas of Izamal and Tizimin, in the North central and Northeastern parts of the Yucatan state, respectively.

6.4 Discussion.–

The results of this study clearly show that the application of Geographical Information Systems, in combination with land–based surveys and cartographic information, can provide a variety of information useful for structured planning, and indeed for aquaculture development planning. It further confirms that, as in similar studies (Kapetsky, et. al.,1987; Ali, 1989; Mendoza, 1990), the application of these technologies makes it possible to quickly identify the locations which are marginal or outright unsuitable for aquaculture development, thus human and financial resources can be focused on areas that are apparently optimum for further, more detailed investigations.

As the results indicate, there are clearly defined areas of the region which contain an adequate basic infrastructure, including fish seed supplies as well as fertilisers and other basic goods available in nearby towns. There, towns also represent potential wholesale markets, and the areas have been generally ranked as "suitable" in the spatial analysis.

No distinction, however, was made with regard to the potential level of intensification at which aquaculture could be developed. As stated in earlier chapters, this will be a function of the particular hydrogeological characteristics presented by the different water bodies of the region. Since the type of water body is in turn very much dependent upon the physiographic region where it is located, then it is possible to propose a categorisation of possibilities for inland aquaculture on a regional basis.

6.4.1 Intensive aquaculture.-

As pointed out in Chapter 3, this type of aquaculture, which would primarily involve the cultivation of both native and exotic cichlids in cages, would be confined to large gravel quarries, where environmental conditions are suitable. Such water bodies, as can be seen in Figure 51, are mostly concentrated around larger cities of the northern karst plains, such as Merida, Campeche and Cancun, which also offer some scope for local commercialisation of reasonable amounts of freshwater fish, provided that prices are competitive with their marine counterparts. Moreover, these quarries are located in a geographically strategic situation, since the major export centres of the region are Merida and Progreso cities. The sea and air freight facilities at these centres could be critical if production from these groundwater–fed ponds was maximised, so that the already–established and greedy Florida market for fresh cichlid fillets were to be exploited.

Since quarrying operations are rapidly expanding along the northern karst plains of the peninsula, the so–far under–utilised local fry and fish feed production capacities could be fully harnessed, thus developing the activity.

6.4.2 Small–scale aquaculture.–

The GIS analysis defined a distinct area along the southern side of the Sierrita de Ticul range, where seasonal ponds are abundant, and the presence of the only freshwater lakes, mainly in southeastern Quintana Roo, provide apparent optimum conditions for small scale aquaculture development. This is helped by the fact that fish fry are conveniently available within a distance of 100 km from the farthest point of this region, which also has a good road network. So far the fisheries department of the state of Quintana Roo distributes fish fry locally for restocking of lagoons and small family–operated ponds. This is not the case in Yucatan even though conditions in this southern hilly region are similar. In this agricultural region which has clay soils, as opposed to the rocky areas of northern plains, small–scale aquaculture in both existing water bodies and excavated ponds could be easily integrated into the farmers' economic activities (see Chapter 5). Although further detailed localised information is needed on the water–holding capacity of soils of the peninsula of Yucatan, the results of this study indicate that more than 600,000 ha of the region have some potential for pond construction.

The elevation of the Yucatecan portion of this southern hilly region was highest, which could make the operation of small excavated ponds economically unviable if water was to be obtained from ground sources. However, since this region possesses approximately 60 % of the pumped gravity irrigation system of the region, then small family–operated dug–out ponds could be developed in this area, provided that the fish ponds were fed from irrigated canals.

There are several sources of error which can appear in the results obtained by the GIS approach, namely the accuracy of the data used, the type of parameters employed for the assessment and their spatial variability, the analytical approach to the problem, and the restrictions imposed on the spatial model utilised. It is important to note that given the information available, it was not possible to directly relate the area represented by a cellpoint to the actual area covered by water bodies, since depending on their morphometric characteristics, water bodies differ greatly in size. Hence, the charts developed in this implementation of the GIS reflect the location and number of the water bodies found during the first phase of the present study.

This study was intended as a preliminary identification of those areas of the Yucatan peninsula whose environmental and socioeconomic conditions appear to be suitable for inland aquaculture development. The results of the GIS analysis clearly satisfied the primary objectives, and also opened more objective avenues for detailed localised research in those areas classified as <SUITABLE>.

CHAPTER 7

GENERAL DISCUSION

One of the Mexican government's priorities is to increase the standard of living of the vast poor rural population of the country, especially in those areas where natural resources are scarce. An integrated approach to rural development included in the National Development Programme is to introduce aquaculture to increase food production and to generate increased cash income for small farmers (Anon., 1988). However, semi-arid regions such as Yucatan have so far benefited less from financial support for developing this activity. Since there has long been a misconception that, because of the lack of a surface hydrological system in the region, aquaculture would only be limited to sinkholes. However, the results of the present study clearly demonstrate the suitability of different water body types for aquaculture in Yucatan.

There is a range of factors to consider if aquaculture development is to be implemented in any region or country. First of all, the question of technical feasibility arises. In this regard, the study region presents, as discussed in previous chapters, a variety of suitable environments for fish culture. Characteristic feature of the water quality at all study sites were a high pH, high alkalinity and total hardness. These are a result of dissolution of base salts from the predominantly limestone geology of the area.

Water quality in the cenote Chen–Ha is suitable for fish culture. However, the sinkholes of Yucatan have a unique flora and fauna showing adaptations to cave life (Hubbs, 1936; Reddel, 1976) whose existence is dependent on the ecological stability of the system. This, together with the fact that they are also interconnected via aquifers, which are an important source of potable water throughout the region (Lesser, 1976), make these water bodies a last option for managed fish production in Yucatan.

By contrast, gravel quarries present good water quality conditions and an underutilised water resource, thus offering good scope for aquaculture if well managed, so that the increasing number of these otherwise nuisance water bodies can be productively reclaimed. Alkaline conditions may help retard eutrophication, and the high "stirring capacity" resulting from permanently wind-induced mixing of these relatively shallow pits can provide excellent environmental conditions for properly managed aquaculture.

The relatively low productivity of smaller quarries can be improved, as demonstrated in this study through inexpensive fertilisers, and adequate species selection can give reasonable yields at little cost.

The larger quarries represent ideal sites for cage culture. Several species may be suitable. The native species Cichlasoma urophthalmus proved a good candidate for cage aquaculture in these environments (Martinez, 1988, unpublished data), and in similar pits in Tabasco, to the West of Yucatan (Flores–Nava, et al, 1989a). Nile tilapia Oreochromis niloticus can also be cultured in cages and, provided that water quality is maintained, high yields can be expected. Another species which has also been successfully cultured in cages at a commercial scale in gravel quarries in a karstic region, has been the channel catfish Ictalurus punctatus (Conrad, 1988).

Although considerable amounts of organic matter are expected to be released from the cages, the high hardness of these waters may help prevent rapid eutrophication. Thus as long as a water quality monitoring programme is implemented, and concentration of bioelements are maintained within safe levels, intensive cage culture may be developed. The combination of rearing caged fish and ranching fish is another alternative for aquaculture in large limestone quarries, since lost food from the cages can be used by free organisms around the structures, thus providing an additional crop and minimising the risks of eutrophication.

Seasonal ponds are highly productive and have good levels of oxygenation during the entire wet period. Although the unpredictability of the precipitation levels can be a disadvantage, rainfall statistics for the region show, however, high consistency, making the rainy season of 1985–1986 a rather unusual one. Nitrogen and phosphorus retention by both soils and plants ensure that allocthonous nutrients stay within the system. This can advantageously be used to produce fish and agricultural products in a rotational basis, as proposed in this study. The exploitation of seasonal ponds through aquaculture is already successfully carried out in similar environments both in Mexico (Rosas, 1976; Arredondo, et.al., 1982), and abroad (Williams, 1987; Thayaparan, 1988).

Finally, the permanent aguadas or clogged sinkholes, present permanent hypereutrophic conditions, providing an unhealthy environment for aquatic life. However, it is possible to revitalise them and convert them into economically productive systems through the aquaculture methods discussed in chapter 4, which are already been applied in similar environments around the world.

It is important to note that, as pointed out in previous chapters, the distribution of the water resources of Yucatan is a function of the hydrogeological characteristics of the physiographic region in which they lie. An attempt was made during the course of this study to construct an inventory of the water resources of the study region, through cartographic research, supported by the land-based surveys carried out during the study period. However, for a number of reasons, many of the water bodies present are not recorded or mapped. First of all, the most abundant water body type of the region are sinkholes, many of which are surrounded by dense vegetation, and are thus not detected by remote sensing imagery or even aerial photography.

Secondly, most of the water resources in the southern regions of Yucatan are seasonal, and are therefore less likely to be identified if remote sensing means are employed during the dry season. Another difficulty arises with regard to man-made water bodies such as gravel quarries, since these water resources are rapidly increasing in number due to the expansion of quarrying operations in the northern karst plain, therefore the area covered by such pits is varying from year to year.

During the land-based surveys carried out in this study, a considerable number of water bodies of diverse hydrological nature were recorded which, together with those reported both in the literature and in geographical charts, were used to produce a first surface water resources map of Yucatan. This map, obtained through the implementation of the GIS (Fig 51 Chapter 6) is, as pointed out earlier, by no means a definitive one, and more aerophotographic as well as follow-up land-based surveys need to be carried out, before the actual surface area covered by inland water bodies in this semi–arid region can be accurately quantified. Nevertheless, if the available information is used to broadly estimate the area of water resources in Yucatan, then according to Anon (1985) the area covered by sinkholes is 16,000 ha. However, the source of this estimate is not provided. In the course of this study, a total number of 307 sinkholes were identified during the land–based survey and from cartographic research. Assuming that the average diameter of these water bodies is 60 m, then the average surface area would be 0.28 ha. This would account for only 86 ha of sinkholes, thus representing only 0.53 % of the reported area.

Of the water body types that offer scope for aquaculture, the Ministry of Agriculture has estimated through aerial photoghrametry that there are approximately 6,500 ha of seasonal ponds in southern Yucatan and the west of Quintana Roo State (Reguero, pers.com.).

In addition, as mentioned in Chapter 2, the total number of registered quarrying companies in the State of Yucatan until 1989 was 26, and assuming an average area of excavated pits of 13 ha per quarrying site, the total area covered by these water bodies would be 338 ha. Nonetheless, as mentioned above, rapid expansion of quarrying operations implies the creation of additional pits every year.

It is not possible to estimate the actual area covered by permanent aguadas. During this study, a total of 28 water bodies with these characteristics were identified, although it is likely that many more permanent aguadas are present in the region.

Clearly, a large area of neglected water bodies with potential for aquaculture are present in Yucatan.

The geographic distribution of water resources may provide the baseline for aquaculture development in the region. In northern

Yucatan gravel quarries are abundant, therefore intensive aquaculture in cages could be developed, taking advantage of the infrastructure, availability of fish seed and fish feed, as well as storage and processing facilities.

Small–scale aquaculture could be developed in southern areas, by making use of the seasonal ponds present in the region. The results of this study show that it is possible to produce fish extensively with little cash and management input, thus integration of aquaculture to traditional agricultural activities of this southern region is technologically feasible, and the use of integrated livestock/aquaculture/agriculture, could be economically attractive to rural farmers.

Species selection is one of the most important factors influencing the success of aquaculture (Bardach, 1972; Pillay, 1977; Huet, 1979; Hepher and Pruginin, 1981). The selection of species is dependent upon a) the local environmental conditions and b) the purpose of culture.

In the course of the present study, the native cichlid C.urophthalmus was employed in the trials because being an indigenous fish, most regional farmers are already familiar with this species. Moreover, as mentioned earlier, this species is currently the subject of multidisciplinary research locally, hence current availability of fry made it convenient. However it is clear that the nutritional requirements of C.urophthalmus may be incompatible with small–scale extensive aquaculture. Instead, this cichlid is more likely to be a good candidate for intensive cage aquaculture in the large quarries of northern Yucatan. The other species tried in this study was the nile tilapia (Oreochromis niloticus), which showed a comparatively good performance under extreme conditions. Such a species appears to be a good candidate for extensive aquaculture in Yucatan, either in monoculture or in polyculture with C.urophthalmus.

Several developing countries have prohibited the introduction of exotic species, claiming that local ones should be used first. However, many of these countries have waited in vain for the production of a good native candidate for aquaculture (Echandi, 1982).

There is enough evidence from the literature that the nile tilapia offers good potential for small-scale extensive aquaculture, as indicated by successful development programmes in Africa (Gopalakrishnan, 1988) Asia (Edwards, et.al 1983, 1987; Gaite et.al 1988) and America (Echandi, 1982; Hatch and Engle, 1988).

O.niloticus was introduced in Mexico in 1964 (Morales, 1974), and since then its distribution in the country includes up to 70 % of the states with inland waters. It was introduced in Yucatan in the early 1970's and although very few isolated stockings of this species are known to have been carried out, the farmers that participated in such projects are already familiar with the species. Moreover, O.niloticus fry production is currently being carried out at a pilot-scale in a research Centre based in Merida.

An additional species suggested in earlier chapters, was the grass carp Ctenopharyngodon idella, as a means of trying to reverse the hypertrophic status of permanent aguadas, as this has been successfully implemented in similar environments in other countries (Sreenivasan, 1979). This species is already part of the imported ichthyofauna of Mexico (Altamirano and Arredondo, 1976). However, fry of this species are only available in the central part of the country, hence economic problems associated with transport of fry might make it economically unviable.

It is, however, important to acknowledge the potential ecological implications of introducing an exotic species into an aquatic environment. Nonetheless, since all of the studied water body types with the exception of sinkholes are closed, isolated environments, risks of unwanted hybridisation and displacement of endemic populations may be remote.

There exists a wide range of indigenous freshwater fish species in southeast Mexico, such as Cichlasoma synspilum and C.pearsei which have been suggested as good candidates for aquaculture (Resendez, 1981; Micha et.al, 1984; Arrivillaga, 1988; Flores-Nava et.al, 1989b), which need to be studied in order to identify potential alternative species for aquaculture in the region. Meanwhile both the species utilised in the trials of this study, offer scope for the initiation of fish production through aquaculture in Yucatan.

The other most important factor to consider when aquaculture development is to be part of integrated rural development in any region is related to the social and economic impact of the activity on the overall rural economy. This should include examination of the potential cultural, political and economic constraints (Pollnac, Peterson and Smith, 1982). In this regard, the objective of the socioeconomic survey as well as the operation of a demonstration unit in a rural agricultural community carried out in the present study, were to assess the attitude of farmers towards aquaculture adoption, as well as identify ways in which aquaculture could be integrated into their agricultural activities.

It was pointed out earlier that both the rural economy and rural diet of Yucatan are based on agricultural products, namely sisal and corn. This is of importance since it has to be remembered that it is among the poorest classes that food habits and preferences are much stronger (Pillay, 1977). However, although

8.4 % of the respondents in the socioeconomic survey carried out in this study had never eaten fish products, the main reason was unavailability of such a commodity. In a market survey carried out in Yucatan in 1982 (Anon., 1982), the results showed an average fish consumption per capita of 0.06 kg per week (3.18 kg/year). This suggests not only a potential local market for fish, especially in medium–sized population centres, but also implies that fish products are included in the diet of a significant proportion of the population of the region, however minor the significance of this inclusion might be. It would thus seem feasible, through efficient extension services, to promote fish consumption among the rural populations and encourage the participation of rural farmers in aquaculture development.

Aquaculture may not be the only solution to rural Yucatan food problems, but it has the potential to make important contributions to the diet in rural areas if developed properly.

The results of the present study also provide evidence of the receptiveness of farmers to adopt aquaculture as means of generating increased cash income and fish for food.

In rural areas, where agricultural by–products are available and often underutilised, integration of aquaculture into the framework of agricultural activities offers the advantage of additional production from livestock, aquaculture and the main plant crops already being produced, thus optimising resource utilisation.

Aquaculture operations combined with agricultural and/or animal production activities are particularly important and essential in integrated rural development programmes. In view of the similarities in operational procedures and production concepts, there is much to be gained by close collaboration, including the sharing of common services (Pillay, 1977). Integrated aquaculture can compliment and improve the overall efficiency of many types of farm; for instance, the more efficient use of water and labour, as well as waste recycling into fish, are two obvious examples: conversely, livestock and arable crop production may be the only source of feeds and fertilisers at low enough cost to make fish culture possible (Little and Muir, 1987).

Integrated agriculture/aquaculture can offer good scope for efficient resource utilisation in rural areas of Yucatan, thus also enhancing animal protein production at little expenditure.

The hypothetical estimate of the potential contribution of aquaculture to the family–income in rural Yucatan showed that a significant economic return to labour can be derived from small–scale fish culture. Moreover, unskilled labour can be so abundant that the actual labour opportunity cost might be almost zero at certain times of the year. Thus taking some workers away from traditional activities and putting them to work in aquaculture may provide them with extra cash income and may not decrease productivity in the rest of the local economy.

Although the structurisation of development strategies is beyond the objectives of the present thesis, it is possible to define some major priorities for further technical and socioeconomic research and programme–implementation for inland aquaculture development of Yucatan:

–Extension services.–

Experience in many parts of the world has clearly shown the key role of effective extension services in aquaculture development.

Both large–scale and small–scale programmes would need the services of extension workers, but they are of relatively greater importance for the small–scale farmer who has to depend to a large extent on their guidance and technical assistance (Pillay, 1977; Pollnac, Peterson and Smith, 1982). Besides, the advice and the assistance that an extension agent may provide through periodic visits to the farms, should be available to the farmer at short notice to deal with emergencies. In this regard, Mexico's Ministry of fisheries has a Directorate of Extension, which has a section in Yucatan with staff trained in aquaculture; therefore if aquaculture development was undertaken by the fisheries Ministry at a regional basis, the extension agents already trained in the field would have an important role to play, and no additional investment on training would have to be allocated. It is important, however, that a link is developed between the extension agents of the Ministry of Agriculture who are already in contact with the farmers and those of the Ministry of Fisheries, to coordinate efforts.

-Marketing.-

Suitable marketing arrangements are essential for both small-scale and large-scale aquaculture enterprises. Aquaculture systems can most often respond flexibly to market requirements and there is usually scope for adjustments and choice of alternatives in accordance with marketing needs (Pillay, 1977; Shaw, 1986). According to Pillay (1977), In subsistence-level operations, limited to serve the dietary needs of a family or a small community, there is usually no marketing problem. The word is passed round and the consumers flock to the fish pond or water body to buy the produce as soon as harvested. This system is currently employed in some parts of southeast Mexico, where small-scale aquaculture operations are already a part of the rural activities. However, a potential advantage for marketing fishery products in rural Yucatan would be the utilisation of the already existing marketing channels of the ejidos (the agrarian communities organised under a cooperative basis), which are more likely to be adopted. However, promotion of fish products in rural Yucatan should be an essential factor for the success of any aquaculture project, and this could be primarily carried out through extension agents.

Aquaculture products frequently are highly perishable, thus planning must include preservation and sanitation facilities. In this regard those areas selected as <Suitable> by the GIS employed in this study (Chapter 6), have already taken into account the availability of ice making and storage facilities in both areas with adequate conditions for small and large scale aquaculture. Such considerations, however, add to the distribution costs of the product if this is not to be sold locally, and care should be taken to ensure that higher costs do not make aquaculture less available to low–income target groups.

Potential important markets for intensive aquaculture in northern areas of the Peninsula, are Miami, Florida, where there is already an established market for fresh cichlid fillets; as well as, at a smaller scale, the cities of Cancun, Merida and Campeche, where fish consumption is highest in the region (Anon, 1982). However, a detailed economic analysis with realistic costs and benefit figures is needed to assess the economic viability of intensive operations in the region.

–Financial support.–

Implicit in the decision about appropriate technology and required skill levels is the need for capital (Pollnac, Peterson and Smith, 1982). It is clear that subsistence–level producers usually do not perceive innovations as feasible, because they frequently do not have slack funds for investment (Pollnac, 1982). Generally, a substantial part of the capital needed to develop the activity would have to be supplied by the government (i.e. to build lacking basic infrastructure); however, some local financing is also needed if the venture is to be self–maintaining.

It was discussed in earlier chapters that even though the actual cash costs involved in the small–scale operations studied in this Thesis were small enough to be accessible to farmers involved, the benefits of the operations themselves could cover the interest derived from credits obtained from local development banks. Two major development banks already finance aquaculture development projects in many rural communities of the country, and also support Yucatecan farmers in agricultural projects. Thus the public sector involvement in small–scale aquaculture development in Yucatan would obviously be considerable but would be justified more by the socioeconomic benefits likely to be derived for the community as a whole.

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Appendix 1. Questionnaire Employed During the Socioeconomic Survey.

Locality ______________________________________

date__________

1.– Age of respondent_______

2.– Educational attainment.

Have you attended basic (secondary) (high) (other) school?

Primary ( ) Secondary ( ) High school ( ) Higher ( )

3.– Occupation.

What is your principal occupation?______________________

Do you have another source of income? ________________

How much do you earn (weekly) (monthly) (per year)? ______

4.– Organisation.

Are you a member of an (ejido) (cooperative) (other)?

Ejido ( ) Cooperative ( ) Other ( )_____________

5.– Land Ownership.

Do you own a farm plot (house site)? how large is it?

Farm plot ( ) house site ( ) <1 ha ( ) 1–2 ha ( ) >2 ha ( )

Appendix 1 continued.

6.– Water source.

Where do you get the water you need for your crop (house)?

Irrigation system ( ) Well ( ) Sinkhole ( ) Other ( )_____

7.– Fish consumption.

Have you ever eaten fish? Yes ( ) No ( )

if yes: Do you usually eat fish?, how frequently?

Once a week ( ) Once every fortnight ( ) Monthly ( ) Seldom ( ).

What type of fish do you eat? ____________________________

Where do you get the fish you consume?___________________

If not: Why? ____

8.– Awareness of aquaculture.

Are you aware of the existence of techniques for cultivating fish? Yes ( ) No ( ).

If Yes: How do you know? ______________________________

9.– Attitude towards aquaculture adoption.

Would you like to know how to raise fish in aguadas?

Yes ( ) No ( )

Appendix 1 continued.

Would you spare some time to learn about these techniques if introductory talks are provided?

Yes ( ) No ( )

Would you allow us to investigate if the soil of your plot is good for constructing fish ponds?

Yes ( ) No ( )

Would you provide your labour for constructing a collective fish pond?

Yes ( ) No ( )

Would you spare an area of your farm plot to convert it in fish ponds if the soil is adequate, if money is provided?

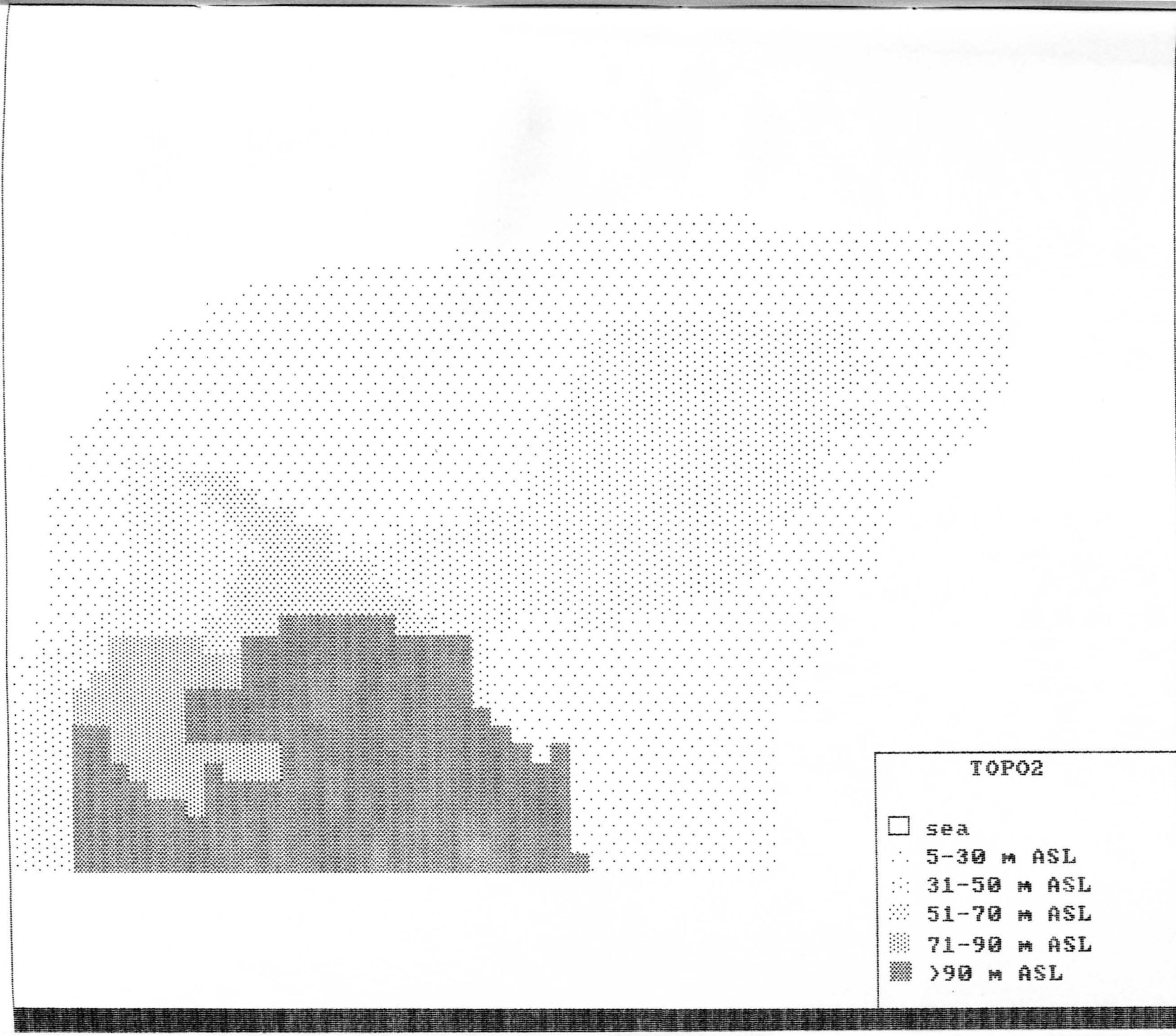
Yes ( ) No ( )

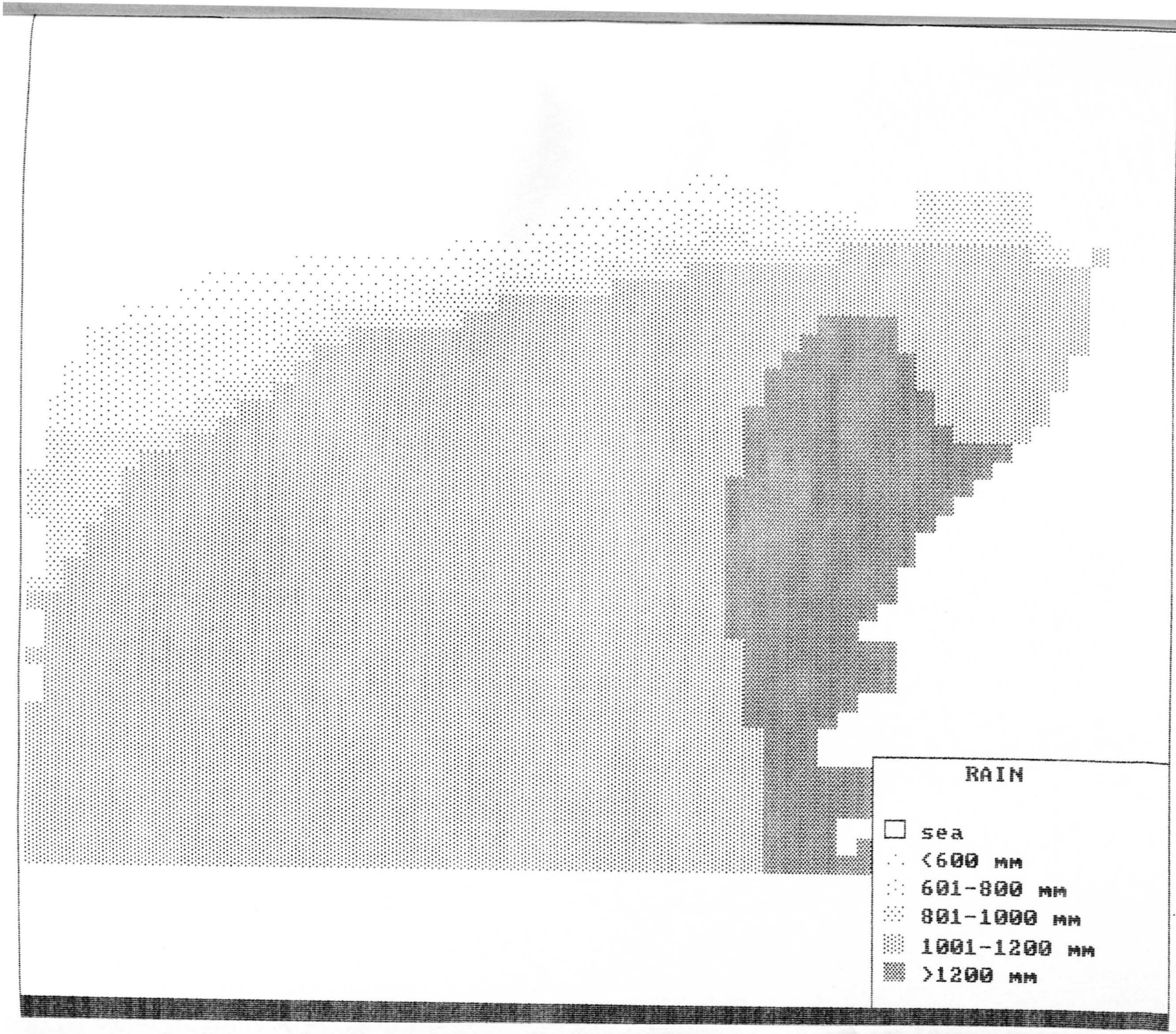
Would you invest your money in fish raising, if you knew that it can provide at least an equivalent sum to that what you get from your agricultural crop?

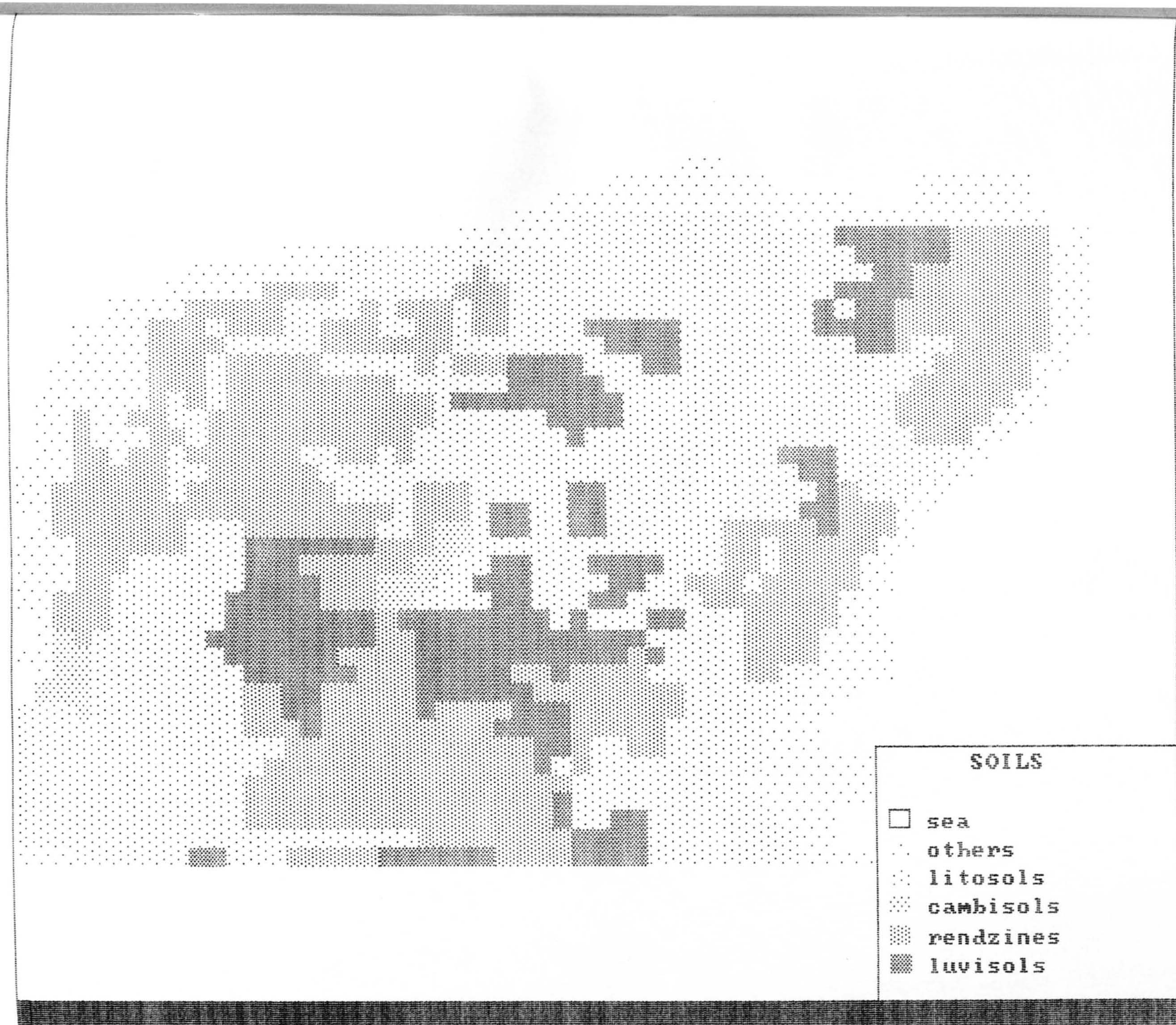
Yes ( ) No ( )

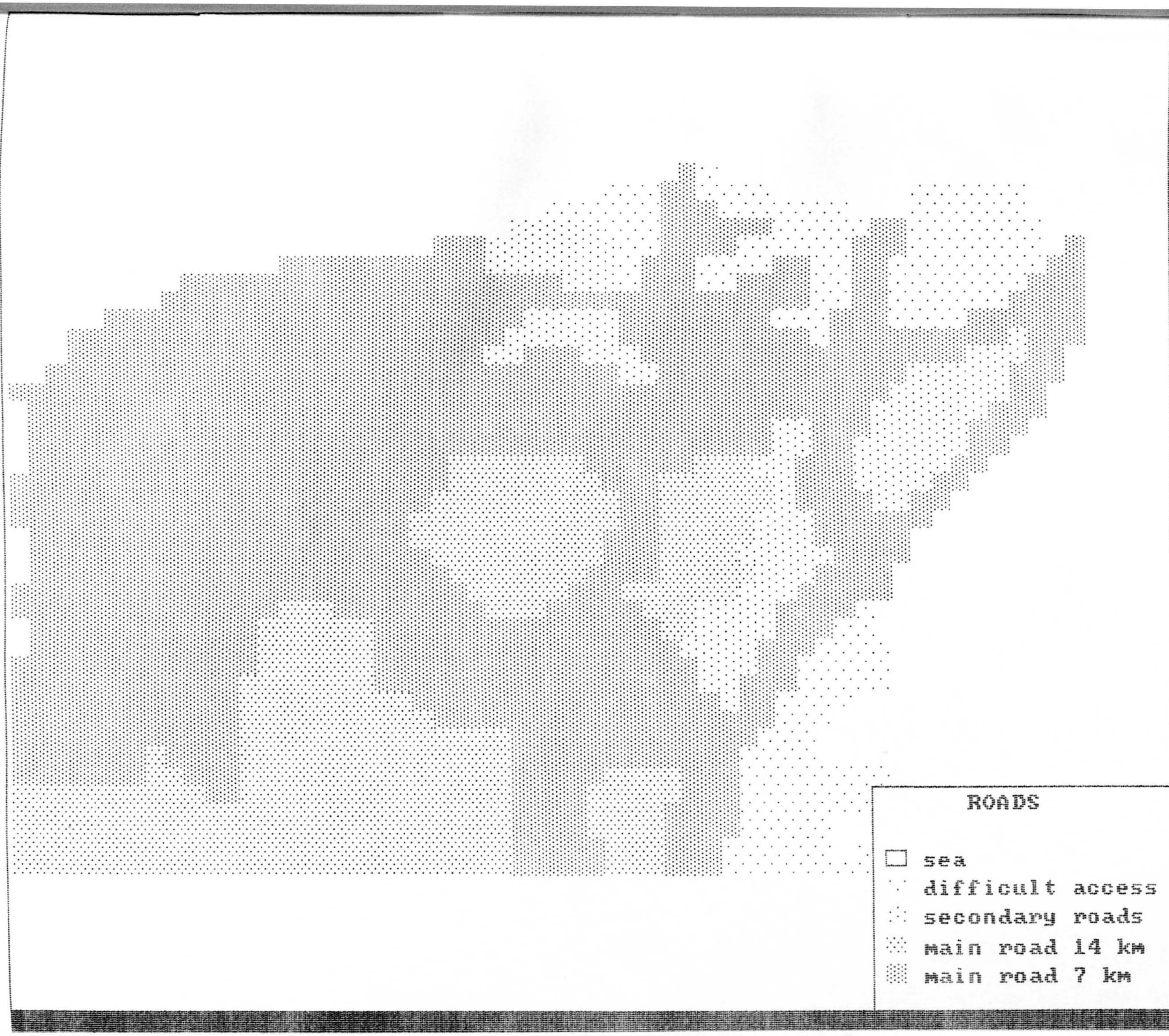
Appendix 2 Map layers utilized in the spatial analysis employing the Geographical Information System.

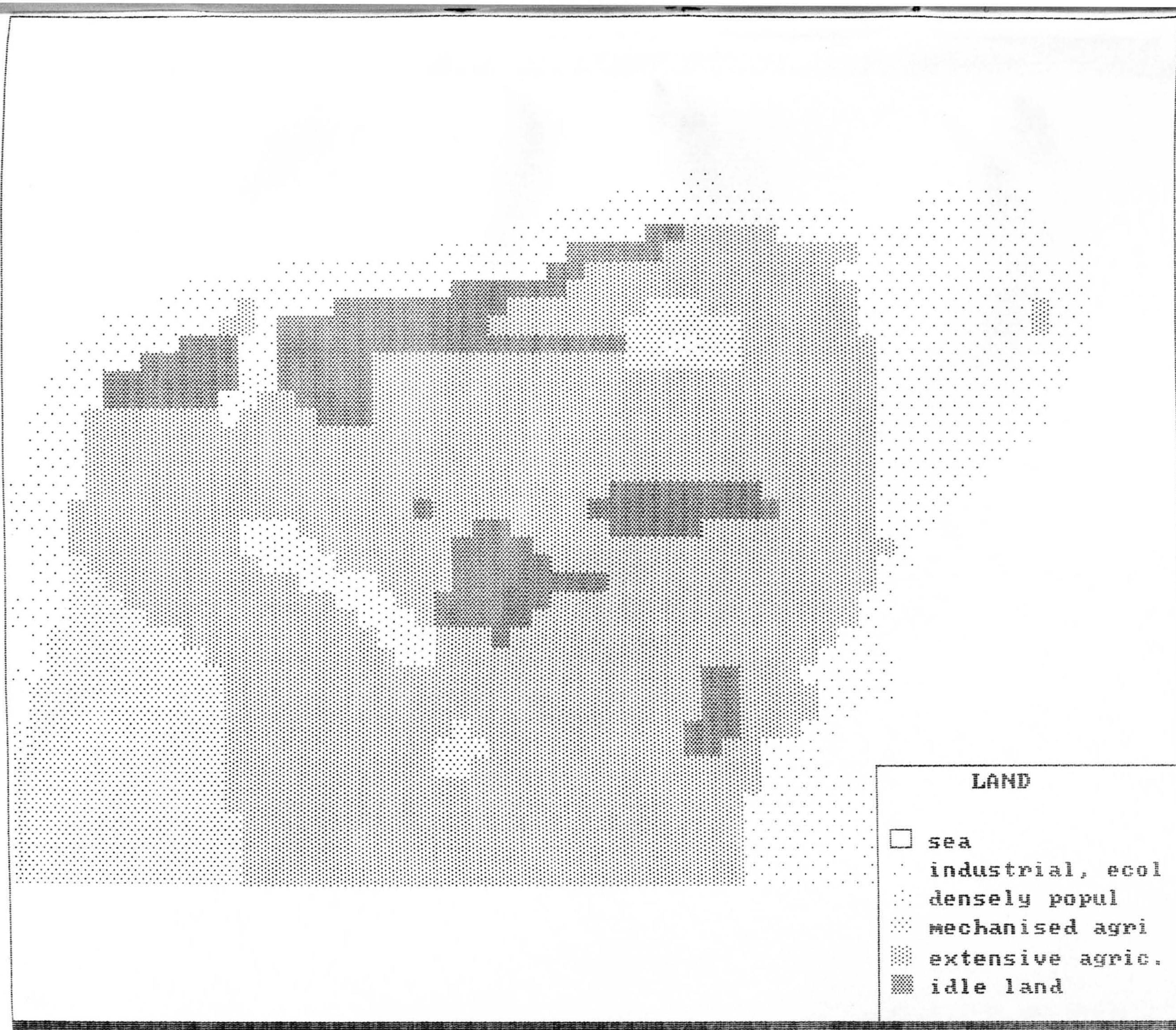

BASE
sea
land

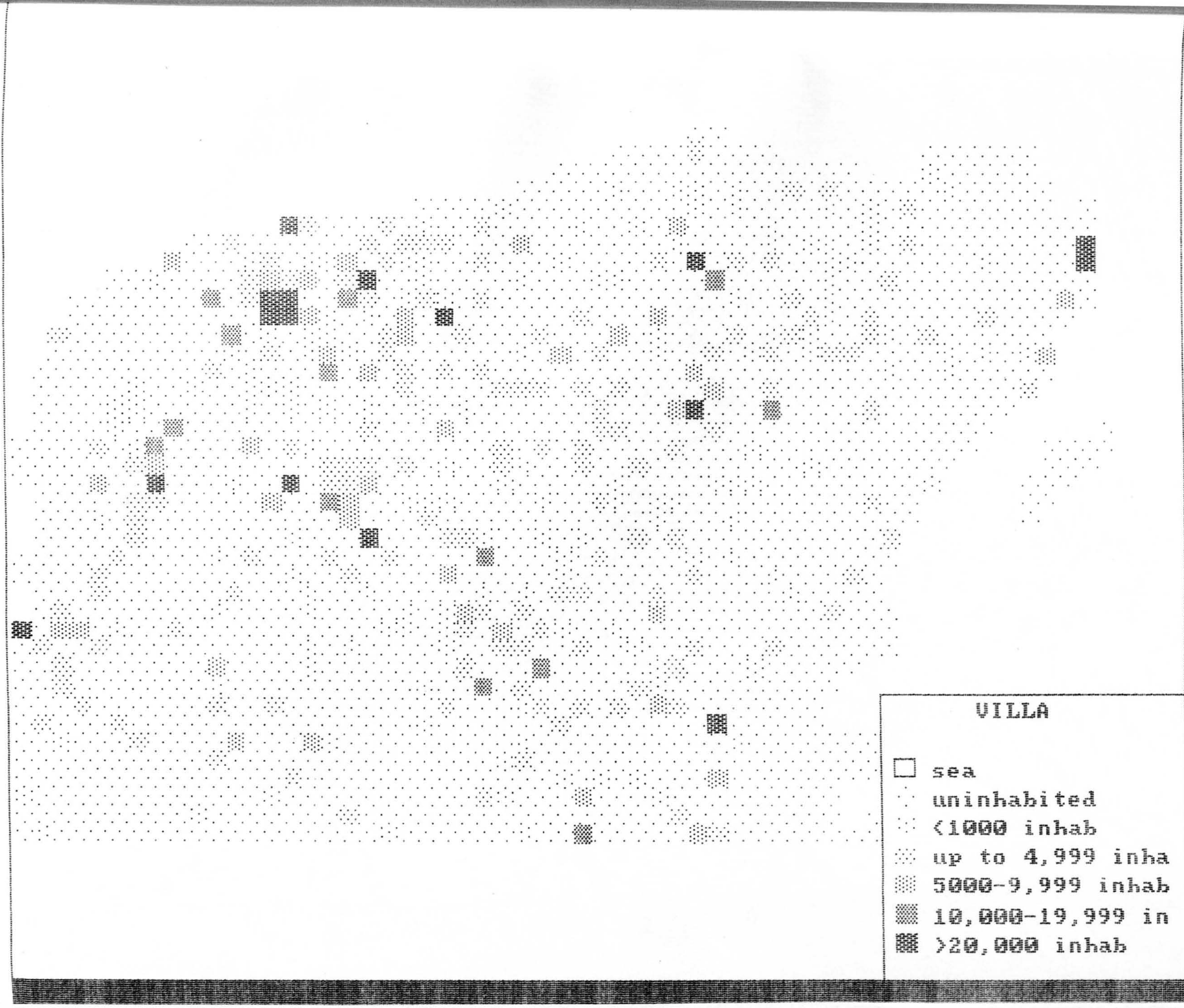

TOPO2
sea
5-30 m ASL
31-50 m ASL
51-70 m ASL
71-90 m ASL
>90 m ASL

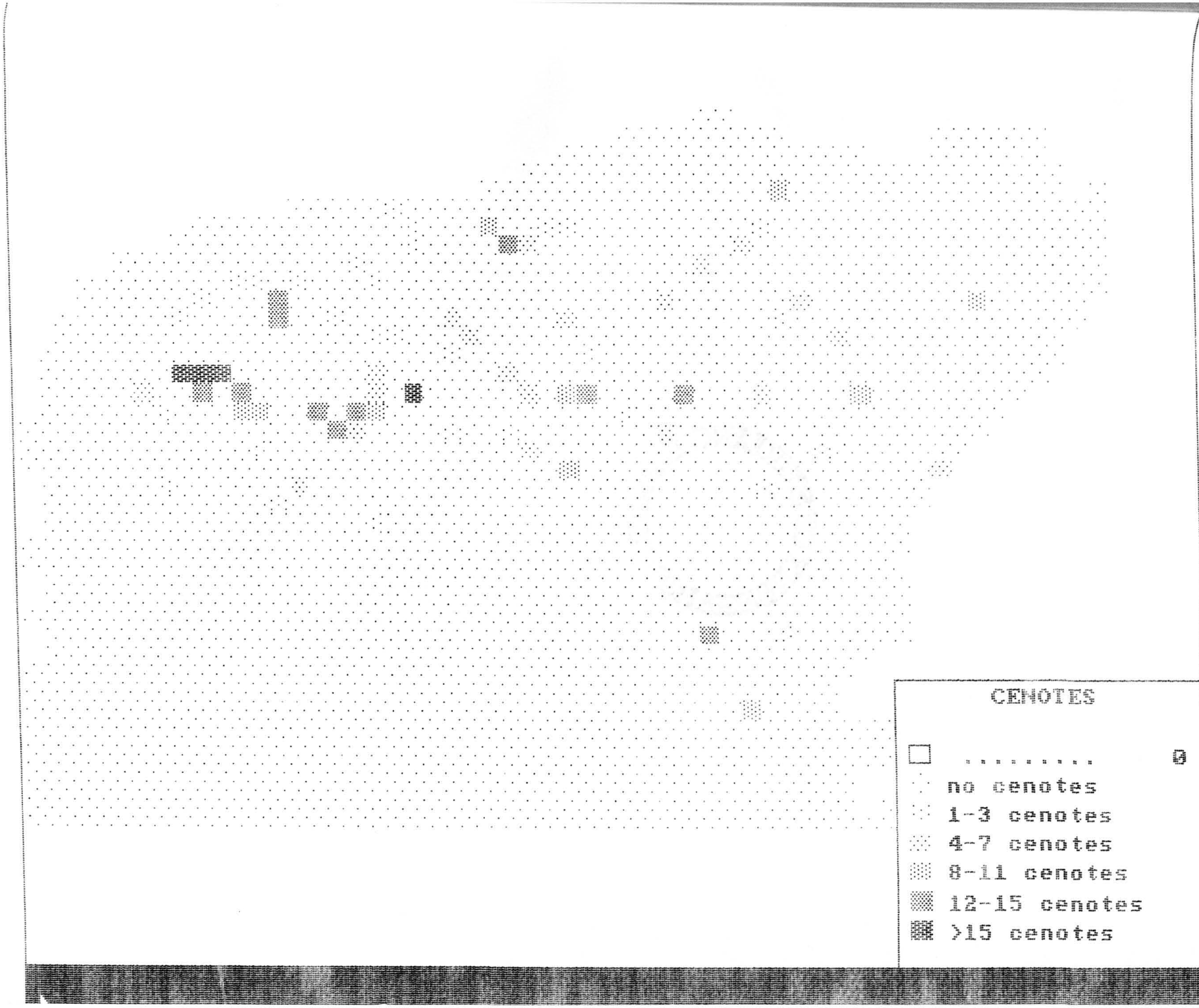

RAIN
sea
<600 mm
601-800 mm
801-1000 mm
1001-1200 mm
>1200 mm


SOILS
sea
others
litosols
cambisols
rendzines
luvisols


ROADS
sea
difficult access
secondary roads
main road 14 km
main road 7 km


LAND
sea
industrial, ecol
densely popul
mechanised agri
extensive agric.
idle land


VILLA
sea
uninhabited
<1000 inhab
up to 4,999 inha
5000-9,999 inhab
10,000-19,999 in
>20,000 inhab


CENOTES
.... 0
no cenotes
1-3 cenotes
4-7 cenotes
8-11 cenotes
12-15 cenotes
>15 cenotes