# DEVELOPMENT AND EVALUATION OF GIS-BASED MODELS FOR PLANNING AND MANAGEMENT OF COASTAL AQUACULTURE: A CASE STUDY IN SINALOA, MEXICO.

A thesis submitted to the University of Stirling
for the degree of Doctor of Philosophy

by

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# DECLARATION

This thesis has been composed in its entirety by the candidate. Except where specifically acknowledged the work described in this thesis has been conducted independently and has not been submitted for any other degree.

Signature of candidate: José Aguilar Manjarrez

Date: 25-March-96

# DEDICATION

*To my mother and father, and to my twin brother and sister*
for all their love and support.

*To Jane E. Bacon*
for all her love, and all her help.

*To the memory of my grandfather's*

# ABSTRACT

This study describes the development and exploration of environmental and socio-economic land-based models, implemented in a Geographical Information System (GIS) for coastal aquaculture development at two planning levels using the State of Sinaloa, Mexico as an example.

At a state-level, a very large database was constructed and models were created which focused on different themes: natural resources, land uses, social impacts, production modifiers and market potential. These models enabled multi-criteria decision-making of land allocation for aquaculture. In assessing final aquaculture site considerations models identified wider management options and resolved conflicts of land allocation and land use between production activities competing for resources through the use of multi-objective land allocation decision-making techniques.

At a site-level, the Huizache-Caimanero lagoon system was identified by the state-level models as being a suitable site for testing the state model's accuracy. Moreover, these smaller more detailed models showed potential to model the wider effects of an activity and clearly had potential for dynamic modelling of environmental impacts.

To evaluate the spatial accuracy and primary data content of the site-levels models and consequently the state-level models a Global Positioning System (GPS) was programmed in Stirling for use in Sinaloa through which it was possible to update and/or modify the database and confirm the general accuracy of the models.

This study objectively showed the extent of opportunities for land-based aquaculture in Sinaloa and further demonstrates the usefulness of GIS as an aquaculture planning tool. Model programming was found to be a very useful tool, enabling regeneration of multiple scenarios very quickly. In general, creating submodels for criteria in natural groupings such as water availability, water quality, etc., allowed the user to evaluate and manipulate these criteria before integrating them into a general model. Thus, spatial modelling provided a more comprehensive and integrated treatment for aquaculture development criteria than is usually possible by manual processing.

Overall, it was found that GIS can be used to assess and direct aquaculture development very comprehensively and has enormous potential in aquaculture and related studies.

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# CHAPTER 1

# GENERAL INTRODUCTION

The rapidly rising world population is creating great pressure on land, water, and food resources. One realistic and practicable way of supplying more food protein is to increase fish production through the extension of aquaculture and inland fisheries (Meaden and Kapetsky, 1991).

Aquaculture interacts with the environment - it utilizes resources and produces wastes which can cause environmental change. Nonetheless, many interactions have beneficial effects. These include: (a) socio-economic benefits such as: provision of food, increased income, employment, foreign exchange earnings, improved nutrition and health (Noriega-Curtis and Vera-Rivas, 1989); (b) compensation of the decreasing growth rate of capture fisheries through stocking and release of hatchery-reared organisms into land and coastal waters; (c) successful species transfers such as the Pacific oyster *Cassostrea gigas*; (d) prevention and control of aquatic pollution, since a sustainable aquaculture development essentially relies on good water quality resources; (e) culture of molluscs and seaweeds may in certain cases counteract processes of nutrient and organic enrichment in eutrophic waters. Conversely, productivity of oligotrophic waters may be enhanced due to the nutrient and organic wastes released from aquaculture farms; (f) aquaculture can contribute to rehabilitation of rural areas through the re-use of degraded land; and (g) in integrated aquaculture the production of aquatic organisms is integrated with the rural or industrial production cycle. Thus, waste products from rural or industrial production systems can be used to produce a crop of high protein food (i.e. fish) whilst sludge from fishponds can be recycled onto the land. Moreover, aquaculture may be integrated with small scale agricultural systems, livestock rearing, vegetable and cereal growing, mixed agriculture and irrigated farming (Schmidt, 1982; Little and Muir, 1987; Larkin, 1991).

On the other hand, with the steady increase in world aquaculture production from 10.5 million MT in 1984 to 22.6 in 1993 (FAO, 1995a) increasing attention has been directed towards the potential environmental hazards associated with this development. Asia leads the world in producing 89% of the total production for 1993 (FAO, 1995a), and consequently many environmental problems have emerged within these countries. Some of the main issues concerning environmental impacts from aquaculture include: (a) environmental problems from conversion of wetlands habitats for aquaculture development (e.g. mangrove clearance or conversion of rice fields for shrimp pond construction); (b) exploitation of wild seed to meet aquaculture stocking demands (e.g. carp, penaeids); (c) removal or alteration of other resources (groundwater, salinization of agricultural soils, freshwater use); (d) release of drugs and chemicals (antibiotics, androgens, insecticides and chemicals); and (e) introduction of exotic species and genetic change to endemic species (e.g. fin fish, molluscs and crustaceans) (Pillay, 1992). Moreover, impacts from aquaculture practices mainly arise from either problems of over-expansion (e.g. shrimp farms in Asia) and/or over-intensification (e.g. Salmonid cage culture in Europe) in which nutrient and organic waste discharges deteriorate water quality. This rapid expansion of intensive monoculture has generated severe environmental as well as socio-economic problems. A major reason is that Western-orientated aquaculture has been managed in isolation from its supporting environment.

The characteristics of monoculture, such as intensive throughput-based salmon-cage farming and shrimp pond farming, are found to be similar to those of stressed ecosystems. Among these characteristics are very inefficient resource use and generation of by-products that are stored or exported. Because of the problems with these monocultures there is a need for Western orientated aquaculture to redirect the industry's behaviour towards a path of synergisms between development and the environment (Folke and Kautsky, 1992).

Aquaculture has progressed fairly rapidly since the 1960's from being a rather restricted and globally insignificant small scale activity to becoming widely recognized as an important industry. It is expected that aquaculture activities will expand significantly in the near future as practices are further improved and diversified (Barg, 1992). However, an uncontrolled expansion of aquaculture could result in a decrease of aquatic biodiversity and could also damage natural resources and contribute to the pollution of waters (Beveridge *et al.*, 1994a). Therefore, it is prudent to take into account the experiences from the past (both positive and negative) in formulating and implementing plans and strategies for future developments (Nash, 1995).

The need for clearly defined policies and plans for aquaculture in both developing and advanced countries has been widely recognized in recent years (e.g. FAO, 1976a; FAO, 1987; Kapetsky *et al.*, 1987; Pillay, 1990; Barg, 1992; Nash, 1995). An aquaculture sector plan is needed for the optimal and orderly growth of aquaculture, and the efficient use of the country's national resources, so that infrastructure and support services are developed harmoniously. A sector plan is also needed so that aquaculture development leads to positive benefits, while adverse (social and economic) effects are kept to a minimum. Failure to plan properly leads to lost development opportunities and wasted resources and effort.

Although there is potential for development in many areas, aquaculture may increasingly be subject to a range of environmental, resource and market constraints. Aquaculture requires land, water resources, and aquatic species and in some cases these needs have resulted in conflicts with other resource users (e.g. urban development, hydrological structures, industrialization, tourism, transportation, agriculture, military, conservation, personal and domestic interests and fishing) (Barg, 1992; Nash, 1995).

Since production sites for aquatic activities need to satisfy fairly complex location criteria it is important that suitable areas are identified and preferably designated in advance (Meaden and Kapetsky, 1991). Statements such as "... site selection is probably the single most important pre-investment decision..." and "many unsuccessful shrimp farming projects were troubled by site-related problems which were difficult or expensive to correct" are common in the literature on brackish-water farming, as in aquaculture in general (Muir and Kapetsky, 1988).

The correct choice of site in any aquatic farming operation is vitally important since it can greatly influence economic viability by determining capital outlay, and by affecting running costs, rates of production and mortality factors (Beveridge, 1987). Even though after many years of painful efforts and of new technology, some farms on poor sites have been turned into productive units, there are many that have been abandoned after considerable investment of money and effort. At the same time it has to be recognized that compromises have often to be made, as ideal sites may not always be available and conflicts of land and water use will have to be solved. In many situations, good irrigated agricultural land may be the best site for pond farms for fish culture, but national priorities in cereal food production may make it unavailable for aquaculture, irrespective of economic or other advantages. On the other hand many countries, particularly in Asia, are now giving higher priority to aquaculture, and farmers are utilizing rice fields increasingly for fish and shrimp culture (Beveridge and Phillips, 1993).

Although many of the factors to be investigated in the selection of suitable sites will depend on the culture system to be adopted, there are some which will affect all systems, such as agroclimatic conditions, access to markets, suitable communications, protection from natural disasters, availability of skilled and unskilled labour, public utilities and security (Lee and Wickins, 1992). However, selection of the optimum site for aquaculture is more complex, taking into consideration variables such as the biological environment for the species to be cultured, availability of adequate supplies of clean water, resource conflict with other users of the site, and accessibility of the technical services associated with the management of the system (Chaston, 1984).

The importance of matching land requirements with needs for food production has long been discussed, e.g. Baker, (1921) and Beek (1978), and many have cited the importance of securing sites specifically for aquaculture or fish production, e.g. Weber (1972), New (1975), Corrie (1979), McAnuff (1979), Henderson (1985), FAO (1989a), FAO (1989b), Petterson (1989), yet little practical work has been done to secure fish production "space". This, plus the intense competition for, and pressure on, the limited "space" available for aquaculture and inland fisheries from competitors highlights both the present importance and the urgency of spatial decision (Meaden and Kapetsky, 1991).

Reliable analytical processes for proper planning have also until now been a major constraint (Ross *et al.,* 1993). Geographical Information Systems (GIS) have an important and increasing role in management and use of natural resources (Burrough, 1986). GIS has a capacity for dynamic modelling of environmental parameters (Grossmann, 1988; Meaden and Kapetsky, 1991; Eastman, 1993) and this feature, in addition to the more cartographic capabilities of GIS, mean that these systems are of enormous potential in aquaculture and related studies.

A Geographical Information System or "GIS" comprises a collection of integrated computer hardware and software which together are used for inputting, storing, manipulating and presenting geographical data. The data may be in any textual, cartographic or numeric form and can be integrated within a single system. GIS exist in a variety of forms and embody the potential for an enormous range of applications. Commercially available GIS programmes vary greatly in sophistication with different aims and abilities, and operating on different computer platforms (Butler, 1988).

Although GIS is only some 30 years old, already the impacts of this new technology are having far-reaching effects. As stated by Chorley (1987): "GIS are as significant as the inventions of the microscope and telescope were to science" and they represent "the biggest step forward in the handling of geographic information since the map".

GIS portray the real world. A view of the world as represented on a map surface reveals that the surface consists of either points, lines or polygons. Thus roads would be lines, houses are usually points, and gardens or fields are polygons (Meaden and Kapetsky, 1991). In a GIS there are two basic organizational modes which the computer may use to display these spatial forms, i.e. vector or raster. In a vector the boundaries or the course of the features are defined by a series of points that, when joined with straight lines, form the geographical representation of that feature. The points themselves are encoded with a pair of numbers giving the X and Y co-ordinates in such systems such as latitude/longitude. A vector can be lined with data files i.e. property parcels might be tied with an attribute database containing the address, and owners name. A raster is a regular grid of cells covering an area in which each cell may be given a numeric value which may then represent a feature identifier, a qualitative attribute code or a qualitative attribute value (Eastman, 1995).

Regardless of the logic used for spatial representation, a geographic database is organized in a fashion similar to a collection of maps. Vector systems may come closest to coverages or map-like collections that contain the geographic definitions of a set of features and their associated attribute tables. However, they differ from maps in two ways. First, each vector will typically contain information on only a single feature, such as a city. Secondly, they may contain a whole series of attributes that pertain to those features such as a census of city blocks. Raster systems also use this map-like logic, but usually allocate data sets into unitary layers. A layer contains all the data for a single attribute. Thus one might have a soil's layer, a road's layer and a land use layer (Burrough, 1986).

The organization of the database into layers is not simply for reasons of clarity. Rather, it is to provide rapid access to the data elements required for geographic analysis. Moreover, because each cell in a layer can only hold one number, different geographical attributes must be represented by separate sets as Cartesian arrays, known as "overlays". In its simplest form, the overlay concept is best realized in raster data structures by stacking layers as shown in **Figure 1.1**.

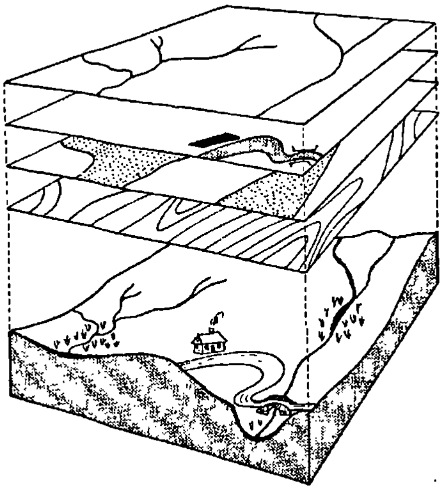


**Figure 1.1. The "overlay" concept: the real world is portrayed by a series of layers in each of which one aspect of reality has been recorded (e.g. topography, soil type, roads, rivers, etc.) (Burrough, 1986).**

Regardless of whether a raster or a vector system is used, the analytical characteristics of a GIS can be looked at in two ways. First, there are the tools that GIS provide which fall into four basic groups: database query, map algebra, distance operators and context operators; and second, the kinds of operations that GIS allow: database query, derivative mapping and process modelling (Eastman, 1995). Clearly a tremendous number of spatial operations can be carried out in a GIS.

The origins of GIS lie roughly in two areas: the map orientated work of people such as geographers, ecologists, cartographers and surveyors, who in the past have used paper maps and transparent overlays and file cards; and the database and graphics side of the computing world. These two streams have come together to form a powerful new means of analysis, interpretation and prediction that can be used in totally disparate areas such as: health care (Hale, 1991), education (Green, 1991), public resource allocation (Braken, 1991), environmental management (Haines *et al.*, 1990), climate studies (Brignall *et al.,* 1991), leisure activities (Aulakh and Koukoulas, 1993), agriculture (Fairbairn and Nkwae, 1991), forestry (Davidson, 1991), urban development (Day, 1992), marine resource management (Friel and Haddad, 1992), hydrology (Finch, 1992), ground modelling (Milne, 1992), remote sensing (Waters, 1991), transport (ambulance services) (Ward, 1994), planning of development in rural areas (Davidson *et al.,* 1993), global positioning (Cross, 1991), retailing, (Ireland, 1994) and telephone services (Page, 1995). GIS can be portable via radio networks, and can benefit lots of areas such as in the faster and more effective control of incidents like criminal activity (Clegg and Robson, 1995), emergency services (Othacéhé, 1995), coastal zone mapping (Harper and Curtis, 1993). GIS is also now used in marine fisheries (Meaden, 1994), and aquaculture planning (Kapetsky, 1994).

The first geographical information systems were developed in the middle 1960's by governmental agencies as a response to a new awareness and urgency in dealing with complex environmental and natural resource issues. The first GIS emphasized the accumulation and use of data sets of local, regional, and occasionally, national scope. A few of these systems, such as the GIS operations initiated in the 1960's by the State of Minnesota and by Environment Canada (CGIS) are still functioning, although the current versions of these systems are very different from the original implementations. Nevertheless, many of the early attempts at GIS failed outright or were short-lived. This was due in part to high performance demands coupled with technical problems encountered in meeting those needs with what was an infant technology. A major factor in system failure, which still plagues the industry, was poor initial system design which often resulted in complete failure to meet user needs, or in meeting these needs in an inefficient fashion  (Peuquet and Marble, 1990). Much of the problem has been the lack of appreciation for administrating and for meeting personal needs (Kapetsky, pers.comm.).

Although there was an awareness of the potential cost-savings of automation, early GIS tended to be very expensive to build as well as to operate. It has only been in the last few years that the true potential and significance of GIS has begun to be realized. This has come about with the initiation of research efforts within universities, government and the private sector, advancements in related technologies, as well as through the accumulation of hands-on knowledge from practical experience. New approaches for analyzing and simply looking at data specifically attuned to the capabilities of the modem computing environment are rapidly being developed. As a result, GIS has now become a viable technology for addressing complex and multi-disciplinary environmental monitoring and management issues on national and even global scales. At the same time, it has been put within the economic reach of local governments and smaller private organizations (Peuquet and Marble, 1990).

The basic principles of geographic information systems for land resource assessment have been explained by Burrough (1986), and many natural resource and environmental applications have been found for this technology. Burrough noted that GIS can serve as a test bed for studying environmental processes and can enable managers to test the consequences of various actions "before the mistakes have been irrevocably made in the landscape itself". Eastman *et al.* (1993) stress that environmental decisions are complex and require the exploration of numerous options, often under conditions involving considerable risk and uncertainty.

The effective management of natural resources is increasingly being recognized as both an important and a complex undertaking. In response to this recognition, the requirement for both accurate and timely information on resources has expanded considerably over the last decade. This emphasis on improved management systems mainly stems from the realization that many resources are diminishing fast. A further important factor is the growing awareness that an environmentally secure future requires that a more integrated and co-ordinated approach is taken towards resource management. These factors create the need for both resource managers and researchers alike, to consider much more carefully the interactions between the different resources when making recommendations on resource management and use. GIS provide an essential technology for considering the interaction between spatially distributed resources (Haines *et al.*, 1990; Trotter, 1991).

Most environmental problems are complex, requiring access to information on a range of ecological aspects. GIS can be used to store large volumes of site-related data in a readily accessible format. They can enhance data-handling capability and speed up access to information for analytical purposes. They also facilitate the integration of information gathered from different surveys and sources. The ability of GIS to store several layers of information for any locational attribute means that detail can be retained. Integration of different data sets can also improve data capture. Digital storage of information makes it possible to carry out calculations using information from different layers, and also to overlay selected maps which are stored in the system. Simple overlaying procedures can be of considerable value in environmental assessment, where it is often necessary to base decisions on complex compromises between conflicting land-use requirements. For example, multi-temporal data sets are often very important. GIS can be used to determine how recorded attributes have changed over certain periods of time, to calculate rates of change, and to project future situations on the basis of current trends. GIS may be of value in combining large data sets with functional models in order to predict possible outcomes (Burrough, 1986; Eastman, 1992; Treweek, 1992).

Ecosystems are dynamic, and cannot be adequately described on the basis of isolated surveys. Most ecological assessments carried out for environmental assessment purposes have therefore been snapshots in space and time, and have not established true baseline conditions. This has made prediction of ecological impacts difficult and unreliable. By considering all relevant sources of information, data capture can be improved and survey information can be cross-referenced with information from other sources. Although there may be problems with compatibility of data from disparate sources, GIS can facilitate handling of such data, by drawing them in a common format for comparative purposes. The ability of GIS to combine information from a number of different sources within a functional environment makes them particularly useful for modelling possible ecological outcomes: both to predict what would have happened in the absence of development, and to predict what might happen if development were to proceed. Linear developments like roads and pipelines may impinge on many habitat types, exerting influences on a number of different scales. Site-by-site assessment does little to address the overall impacts of such developments on the landscape. GIS offer considerable advantages for planning and design of such development types, by helping to identify which impacts are likely to operate at a range of scales (Treweek, 1992).

The rapidly growing use of computers for handling geographic data has been part of a more recent reflection of the overall trend within society towards an increasing reliance on the computer as a data handling and data analysis tool. Extremely large and complex data sets can be both compactly stored and rapidly retrieved with accuracy. The use of automated techniques of necessity imposes uniformity in both storage formats and methods for handling the data; many of the quantitative and analytical techniques developed in the earth sciences, transport and urban planning, and natural resources management, among others, are limited in their practical application without the capacity and very rapid data processing that computers provide to deal with the large volumes of observational data required by these techniques (Peuquet and Marble, 1990). The increasing awareness of the importance of GIS technology has been derived mainly from: (a) improvements in computer hardware and software; (b) improvements in the quality of remotely sensed data available; (c) increasing population competing for resources; (d) decreasing resource availability and environmental quality; (e) recognition of the global nature of problems; (f) increase in the number of public and international problems, (f) creation of large databases to provide information on these matters on various scales, and (g) the growing supply of ready-made digital data has resulted from a parallel revolution in digital data capture techniques, such as those seen in global positioning, attribute measurements and remote sensor imagery (Star *et al.,* 1991).

GIS has only been applied in aquaculture in the last nine years. Nevertheless, a number of useful studies and papers have been published (**Table 1.1**). To date most have covered large geographical areas, dealing with regions or even countries, and have principally been used in the preparation of regional and national-level plans, although many have been little more than demonstrations of the applicability of the technology (Beveridge *et al.*, 1994b).

Most of these GIS studies have been aimed at inland and coastal aquaculture of fish, although shrimp have been considered, and four studies have been applied to molluscs. The largest surface area that has been evaluated at a regional level is Africa (Kapetsky, 1994), whilst at an individual site-level Camas Bruaich Bay in Scotland (Ross *et al.*, 1993) has been the smallest. Moreover, the largest scale or raster size (spatial information is in the form of regular grid cells or pixels) has been 75 km x 75 km whilst the smallest has been 10 m x 10 m. In summary, these studies have been mainly focused on site selection and most of the factors involved in the evaluations have been environmental (i.e. soils, water). The socio-economic aspect of the evaluations is included in some studies, but in general it is considered scant or is only beginning to be fully explored (Gutierrez-García, 1995).

## Table 1.1. GIS studies for aquaculture development (1987 to 1995).

| LOCATION | AREA/ COVERAGE | PIXEL SIZE | SPECIES | SITE/ CULTURE SYSTEM | AUTHOR/ DATE |
|---|---|---|---|---|---|
| **NATIONAL** | | | | | |
| England, U.K. | 244,755 Km$^2$<br>- | 10 Km x 10 Km | Trout (*Oreochromis mykiss*). | Inland/ Earth ponds | Meaden, 1987 |
| Ghana | 238,537 Km$^2$<br>- | - | Tilapia and catfish (*Oreochromis niloticus* & *Clarias gariepinus*). | Coastal/Earth ponds | Kapetsky *et al.*, 1990 |
| Pakistan | 887,750 Km$^2$<br>- | 75 Km x 75 Km | Carp | Inland/Earth ponds | Ali *et al.*, 1991 |
| Norway | 1, 183,167 km$^2$<br>- | - | Salmon and rainbow trout | Coastal/Cages | Ibrekk *et al.*, 1991 |
| Nepal | 147,181 Km$^2$<br>- | 2 Km x 2 Km | Carp | Inland/Earth ponds | Karki, 1992 |
| Africa | 30,300,000 Km$^2$<br>- | 18 Km x 18 Km | Warm water fish | Inland/Earth ponds | Kapetsky, 1994 |
| **REGIONAL** | | | | | |
| Gulf of Nicoya, Costa Rica. | -<br>88.5 km X 72.4 km | - | Oyster, mussel, clam, shrimp and fish. | Coastal/Suspended culture, earth ponds, and cages. | Kapetsky *et al.*, 1987 |
| Franklin parish (county), Lousiana, U.S.A. | 168 Km$^2$<br>- | - | Channel catfish (*Ictalurus punctatus*). | Inland/Earth ponds | Kapetsky *et al.*, 1988 |
| Johor state Malaysia | 23,310 Km$^2$<br>- | - | Shrimp and fish | Coastal/Earth ponds and cages | Kapetsky, 1989 |
| Louisiana state, U.S.A. | 135,900 Km$^2$<br>- | - | Catfish (*Ictalurus punctatus*) & Crawfish (*Procambarus clarkii*). | Inland/Earth ponds | Kapetsky *et al.*, 1990 |
| Yucatan state Mexico | 43,379 Km$^2$<br>60 Km x 40 Km | 49 Km x 49 Km | Fish (Cichlids, *O. niloticus*, *C.punctatus*, *C. idella*). | Inland/Earth pons and cages | Flores-Nava, 1990 |
| Eastern Coast of Prince Edward Island, Canada. | -<br>- | - | Shellfish (oysters, soft-shell clams and mussels). | Coastal/ - | Legault, 1992 |
| Tabasco state Mexico | 24,475 Km$^2$<br>336.5 Km x 209.25 Km | 1 Km x 1 Km | Tilapias, carp. | Inland/Earth ponds and cages | Aguilar-Manjarrez and Ross, 1993 |
| Lingayen Gulf, San Miguel and Calatrava Bay. Phillipins. | -<br>- | - | Milkfish, siganids, seabass and shrimp. | Coastal/Earth ponds | Paw *et al.*, 1994 |
| Sinaloa state Mexico | 58,480 Km$^2$<br>430.4 Km x 557.6 Km | 250 m x 250 m | Tipalia, carp and shrimp. | Coastal/Earth ponds | Aguilar-Manjarrez and Ross, 1995a,b |
| Tabasco state Mexico | 24,475 Km$^2$<br>336.5 Km x 209.25 Km | 1 Km x 1 Km | Tilapias, carp. | Inland/Earth ponds and cages. | Gutierrez-García,1995 |
| **SITE** | | | | | |
| Yaldad Bay, Chile | 5.1 km x 7.8 km<br>- | - | Salmonids and mussels (*Choromytilus chorus*). | Coastal/ Pen cages, bed culture. | Krieger and Mulsow, 1990. |
| Camas Bruaich Bay Scotland | 2 km$^2$<br>800 m x 800 m | 25 m x 25 m & 10 m x 10m | Salmonids | Coastal/Cages | Mendoza, Q-M,1991; Ross *et al.*,1993; Beveridge *et al.*,1994b. |
| Maryland's Chesapeake Bay. | -<br>- | - | Oysters | Coastal/ - | Smith *et al.*,1994. |

Notes: - , data not available. Area = area of study. Coverage is refered to spatial coverage in x, y format.

With the proliferation of GIS in both industry and government, there has been a tremendous increase in demand for remote sensing as a data input source to spatial database development. Products derived from remote sensing are particularly attractive for GIS database development because they can provide cost-effective, large area coverages in a digital format that can be input directly into a GIS. Because remote sensing data are typically collected in a raster format, the data can be cost-effectively converted to a vector or quadtree (a data structure for thematic information in a raster database that seeks to minimise data storage) format for subsequent analysis or modelling applications (Waters, 1991).

Satellite remote sensing applications to aquaculture are more plentiful than those of GIS but even so, are not very numerous. For example Travagalia and Lorenzini (1985) have used Landsat multispectral scanner to inventory commercial algae and monitor their growth in a coastal lagoon. Loubersac (1988) used simulated SPOT (French commercial satellite sensor) data to demonstrate the capabilities of high resolution satellite sensors for aquaculture sitting. CNES-IFREMER (1991) has used remote sensing and GIS for the presentation of sites favourable for tropical fish farming. Kapetsky (1987) used remote sensing to locate and inventory small water bodies for fisheries management and aquaculture development in Zimbabwe. Cordell and Nolte (1988) studied the feasibility of remote sensing to identify aquaculture potential for coastal waters. Johannessen *et al.* (1988) assessed the Norwegian coastal current during an algal bloom. In 1987 Chacon-Torres looked at the limnology of Lake Patzcuaro, Mexico with special reference to the use of remote sensing. Chacon-Torres *et al.* (1988) used remote sensing in water quality investigations for aquaculture and fisheries; Chacon-Torres *et al.* (1992) evaluated chlorophyll and suspended solids observations in Lake Patzcuaro, Mexico using SPOT multispectral imagery. As concluded by Chacon-Torres (1987) "... there is much greater potential of using remotely-sensed data if they can be combined with other spatial sources in a GIS".

The coastal zone is a region of the earth's surface of extreme significance providing sites for a wide range of activities such as agriculture (rice, coco palm, bananas), forestry (mangrove, nypa palm), fisheries and aquaculture, human settlements, manufacturing and extractive industries (e.g. sand mining, oil, minerals), waste disposal, ports and marine transportation, land transportation, infrastructure, water control and supply projects, shore protection works, tourism and recreation.

Some estimates suggest that up to 40% of the earth's human population lives on or near the coast (Carter, 1988); in developed countries, there have been, in recent years, movements of population towards warmer climates and particularly to coastal areas (Nash, 1995). For example, in the United States alone it is anticipated that soon approximately half the population will be living on coastal belts equating to some 5% of the total available land (Salm and Clark, 1984). Given the growing coastal population, there is a consequent development of multiple resource uses or activities in coastal areas, so it is probably inevitable that a variety of changes occur in environmental or socio-economic conditions, which in turn may result in an impact of social concern.

In many coastal areas, pollution and habitat modifications stemming from human activities other than aquaculture are increasingly affecting resources use productivity of aquaculture as well as limiting success and development possibilities of the aquaculture industry (Stickney, 1990; Chua and Tech, 1990; Menasveta, 1987). High organic and microbial loadings in sewage discharged from densely populated urban and resort areas can contaminate cultured shellfish thereby rendering produce unsuitable for humans, particularly if consumed raw or partially cooked. As an example, coliform counts in excess of 1000/100 ml have been recorded in Manila Bay, which is one of the major oyster and mussel culture sites in the Philippines. In 1979, an outbreak of gastro-enteritis was experienced in Singapore, which was traced to oyster meat imported from the Philippines. Heavy organic pollution due to effluents from Malaysian piggeries and Thai sugar mills, characterised by high biochemical oxygen demand, seriously damaged cockle beds and other cultured organisms. Thai shrimp and oyster farms were severely affected by liquid waste from a distillery (Chua and Tech, 1990).

The environmental impacts of, and on, coastal aquaculture may have serious adverse socio-economic and human health implications (Huss, 1988; Bernorth, 1991). There is concern that large-scale mangrove conversion for shrimp and fish farming in Latin America and Asian countries has affected rural communities which traditionally depended on mangrove resources for their livelihood (Mena Millar, 1989; Nath Roy, 1984). According to Bailey (1988), " the expansion of shrimp mariculture into mangrove habitat generally involves the transformation of a multi-use/multi-user resource coastal resource into a privately owned single-purpose resource. Moreover, the costs of a coastal ecosystem disruption for society may include coastal erosion, saltwater intrusion into groundwater and agricultural fields, and a reduction in supply of a wide range of valuable goods and services produced from the resources available in mangrove forests or other coastal wetlands."

Unfortunately, competition for land and water sources also results in use conflicts (Shang, 1992; Stansell, 1992), sometimes with ensuing violence, as seen between rice and shrimp farmers in Thailand (New, 1991). Moreover, several economic disasters due to significant aquaculture production losses have been attributed to self pollution as well as to increased coastal water pollution which fuelled disease outbreaks and harmful phytoplankton blooms (Rosenberry, 1990; New, 1990; Okaichi, 1991).

Given their importance in other areas of natural resource management, it might be anticipated that GIS would be natural tools for assisting planning and decision-making within the coastal environment. Indeed, the potential benefits that might be obtained from using GIS for coastal management was first recognized at least twenty years ago (Ellis, 1972), and has frequently been commented upon since (Fricker and Forbes, 1988; Bartlett, 1990).

Although substantial savings in time, effort, and money could, in theory, be obtained by applying GIS to coastal management, the use of the technology for coastal management purposes has been remarkably slow (Barlett, 1990). Nevertheless, while the applications of GIS to problems in the coastal zone remains one of the major challenges of GIS research, a steadily growing body of literature testifies an increase in interest in coastal zone information systems since the late 1980's (Davis and Davis, 1988; Law, 1991; Townend, 1990, 1991; Bartlett, 1993).

The dynamic nature of the coastal environment is one of its most important characteristics. The coast provides settings for complex flows of matter, energy, organisms and information. These flows move in all directions and on a variety of spatial and temporal levels (Komar, 1983; Shaw, 1985; Carter, 1988; Bartlett and Carter, 1991). The primary forces that power these changes are the short term weather, long term climate changes in sea level, and gravity-driven tides (Beer, 1983; Devoy, 1987; Smith and Piggot, 1987). Partly because of this high degree of mobility the coastal zone provides the setting for many important natural environmental processes (e.g. erosion and deposition). Many important transfers of energy also take place at the shore, particularly in the transmission of heat from the oceans via the atmosphere to the land. Equally important, many marine organisms, and indeed whole ecosystems, depend on the characteristics of the coast for their survival. The waters of the coastal zone, especially in estuarine and in-shore areas, are some of the most biologically productive areas of the earth, and underpin many aquatic and terrestrial trophic chains. For these and other reasons, the coastal scientist or manager requires access to technologies that can take account of the dynamics of the coastal ecosystem.

Simulation of coastal processes by computer opens up important possibilities for clear understanding of the shore, and of the likely impacts of management decisions. The development and testing of dynamic process models and simulations of different abstractions of reality is one of the cornerstones of modern GIS. Traditional simulation modelling of coastal phenomena has tended to focus on specific aspects of the coastal system such as sediment transport (e.g. Komar, 1983), contaminant plume behaviour (e.g. Weyl, 1982), or wave mechanics (Beer, 1983). However, within a GIS context, modelling may also refer to the merging, synthesis and analysis of spatial patterns to obtain answers to specific questions. In recent years, the latter form of spatial modelling has had several notable successes when applied to the coastal zone. Typical applications include: the use of GIS for assessing the threat of sea level rise on the coast of Maine and the likely responses of coastal sand dunes to such rise (Dickson *et al.*, 1988); modelling of oil spills with a view to minimising their environmental impacts (e.g. Kendziorek, 1989; August *et al.*, 1990), modelling possible impacts of dredge spoil dumping (Bokuniewicz *et al.*, 1989, Hansen *et al.*, 1990), and modelling for multiple use of estuarine waters (Clark, 1990; Gardels *et al.*, 1990, Hazelhoff and van Hees, 1991).

GIS can also allow mathematical process models to be used in conjunction with spatial data models. Bartlett (1993), for example, demonstrated that a linear wave energy refraction model written in FORTRAN programming language could successfully be merged with a proprietary vector GIS package (ARC/INFO) allowing digital maps of wave energy distribution to be generated and related to the distribution of sediment size, beach morphology, and other coastal phenomena of interest. Furthermore, by combining rapid data retrieval with analytical functions, GIS has the ability to respond rapidly and flexibly to *ad hoc* "what if" type of questions. A well designed coastal zone information system could, therefore, be a significant technological contribution to development of integrated and sustainable coastal management. Many such systems have either been implemented, or else are currently in various stages of development: Law (1991) and Coleman *et al.* (1991) discuss the benefits that GIS can bring to management of the Canadian Great Lakes shorelines of Ontario; Fairfield (1987) describes the use of GIS to plan marina developments; Townend (1990,1991) describes how a large GIS is being developed to aid management of the East Anglian coast of England, and Crandal (1986) and McGrath (1990) describe how GIS can be used in the management of coastal recreation.

Norway experienced a rapid expansion in coastal aquaculture development during the late 1970s and 1980s which resulted in a range of environmental and managerial problems. As a result, LENKA, a three year project to develop a coastal zone GIS, was established in 1987 to help planners at both a national and local level (Ibrekk *et al.*, 1991). The LENKA GIS incorporated data on environment (e.g. depth, salinity, temperature), existing resource (e.g. settlement, recreation), infrastructure (e.g. roads and electricity) and presence of special areas (e.g. natural reserves and spawning grounds). The final outputs of LENKA included gross national estimates of potential salmonid production and maps and tables detailing specific areas of greatest potential. However, as discussed by Beveridge *et al.* (1994b), a comprehensive account of the usefulness of this approach has yet to be made public. Nevertheless, from what is known, Beveridge *et al.* (1994b) noted some deficiencies to the approach (e.g. the organic loading component was found to be over-simplistic) due to the absence of good predictive models.

There has been a decline in Mexican capture fisheries with sharp decreases in the catch per unit fishing effort (CPUE) from 25 tons/vessel in 1977 to 17 tons/vessel in 1992 (Secretaría de Pesca, 1977 to 1992). There has also been a decrease in more highly valued species, as well as competition among fishermen leading to the economic decline in the fishery industry. Aquaculture offers a practical alternative to overcome the problem of failing fisheries.

Coastal lagoons, estuaries and mangroves are probably the most productive ecosystems (primary production) on earth and have diverse and complex food chains with a high fishing production (90% of the world's fisheries are located in coastal regions) (Whitaker and Likens, 1975; Odum and Heald, 1975; Flores-Verdugo, 1989). México has approximately 10,000 km of coastline and more than 125 coastal lagoons, the most important ecosystems being located in the north-west part of the country in the coastal regions of the states of Sinaloa and Sonora (Lankford, 1977). About 12,000 km$^2$ of inland waters are available for fisheries, of which about 70% are suitable for exploitation. The country has an economic exclusive zone (EEZ) of 3 million km$^2$ and 6,000 km$^2$ of salt and brackish waters. With such vast resources, and a favourable climate, aquaculture seems to have great potential in this country (FIRA, 1986). Moreover, the range of advantages offered by Mexico begins with its people: a highly literate, young, cost efficient work force of 34 million, with plentiful natural resources and a thriving domestic market. The country also has a unique geographic position: a 3,300 kilometre border with the USA; coastlines facing Europe and Asia; the gateway to all of Latin America and the access to the world's largest market: the North America Free Trade Area (NAFTA), with 360 million consumers (Secretaría de Pesca, 1993).

Aquaculture in Mexico is not only important in its own right, but also can be integrated well with cattle and crop farming. It can be complementary to the fishing industry because it can help to maintain a fishing population. It is a source of food and work for many women and children, and a source of income, and for many it represents an alternative production activity when it is difficult to practice livestock rearing or agriculture (FIRA, 1986).

Although aquaculture in Mexico has been developing over the past decades it has not grown as expected, for a number of reasons (**Text Box 1.1**). The industry has suffered from inadequate recognition and support for a long time. However, the government has recently begun to devote attention to this important means of food production. Reduced yields, together with changes in the Fisheries Law have served to focus special attention on aquaculture as a means of meeting fish requirements in many states of the country. The role of aquaculture in integrated rural development has also been recognized, and the development of rural communities dependent on aquaculture as the main economic activity has received important consideration. Moreover, there is a now a national plan for the development of the aquaculture sector, and loans are available.

**Text Box 1.1**
**Factors affecting growth of aquaculture in Mexico.**

1. Environmental:
    - unavailability of suitable land,
    - unavailability of coastal water,
    - problems with water and soil quality,
    - environmental degradation.
2. Biotechnological:
    - problems with natural and artificial postlarvae availability,
    - poor site selection,
    - poor culture system design,
    - poor methodology for pond fertilization and for feeding of aquatic organisms,
    - poor feed quality,
    - poor or no sanitary control or diagnostic service for aquatic organisms,
    - poor technological development,
    - poor or scarce qualified staff,
    - need to establish polyculture and/ or diversify culture into other aquatic species of economic importance such as molluscs and marine and freshwater fishes.
3. Financial and economic:
    - scarce or poor infrastructure for development,
    - marketing problems due to competition for shrimp sales,
    - inaccessible credit facilities.
4. Social and human:
    - common property and common ownership problems,
    - fish consumption habitats and patterns.
5. Administrative and legal:
    - problems with permits and concessions for land use and culture of aquatic species,
    - land use conflicts between production activities,
    - poor research and poor links between the producers and research institutions,
    - lack of investment, financial difficulty and poor support from support from government and institutions mainly due to the inexperience in the field,
    - overall lack of management and poor planning.

Source: Aguilera-Hernandez and Noriega-Curtis (1988); Pares-Sevilla (1988); Cosmocolor (1991); EPAC (1991); Hughes *et al.* (1991); FAO (1995b); Nash (1995); Secretaría de Pesca (1995a).

Four principal species - trout, catfish, tilapia and shrimp are cultivated commercially in many Mexican states. Thus, large scale development of aquaculture is being considered and included in many national development plans. Available information in the Fisheries annual fish capture statistics does not indicate productions from any of these species separately from fish capture data, and gives no indications of production by types of culture systems (i.e. extensive, semi-intensive, intensive), for which reason it is difficult to evaluate Mexico's aquaculture development. One likely solution to this problem proposed by Chavez-Sanchez (1993) is to use indirect indicators such as the number of states in which a species is cultivated, and the number of production units in operation.

Mexico is one of the Latin-American countries with the greatest potential to cultivate shrimp due to its extensive coast line and tropical climate, especially in the central and southern states of the country. Native species are appropriate for culture, and people now have ample experience in the processing and marketing of shrimp. One of Mexico's most important advantages is its proximity to the United States markets. Changes in the

Fishing Law have greatly benefited the activity, and in the last 4 years there has been an explosive expansion, mainly in the state of Sinaloa, where there are 125 registered farms (Chavez-Sanchez, 1993).

Mexico has an enormous potential for shrimp culture, some 5,100 $km^2$ of suitable land for shrimp pond farming having been identified; 4,600 $km^2$ on the Pacific and Gulf of California and 500 $km^2$ in the Gulf of Mexico. Shrimp farming is developing rapidly and according to the statistics, despite the numerous difficulties, there has been an overall increase in the number of ponds and in production, principally in the states of Sinaloa, Nayarit, Sonora and Chiapas (Chavez-Sanchez, 1993).

Shrimp culture began in Mexico in 1970 when the first experimental ponds were built in the Huizache lagoon in Sinaloa, for semi-intensive culture. At the same time, intensive culture of blue shrimp *Penaeus stylirostris* was begun at Sonora University (CICTUS) in Puerto Peñasco, Sonora (Arredondo-Figueroa,1983;1987;1990). Changes in the Fishing Laws, enabled the private sector to invest in the construction of semi-intensive and intensive shrimp farms. In the past 6 years, production units have increased dramatically.

Despite problems, (e.g. technical, financial, market), shrimp culture is considered to be a highly feasible production activity. **Figure 1.2** shows the total shrimp farming units and annual production achieved between 10 states in Mexico which are cultivating shrimp (Baja California Sur, Baja California Norte, Sonora, Sinaloa, Nayarit, Jalisco, Chiapas, Tamaulipas, Veracruz and Campeche). The figure shows a clear increase in the number of shrimp farming units, and also an increase in production (tons/year). The highest production was achieved in 1992 (6,539 tons/year) despite the fact that the number of shrimp farming units was low, although this is probably because information was reported as being incomplete (some states did not report any units).

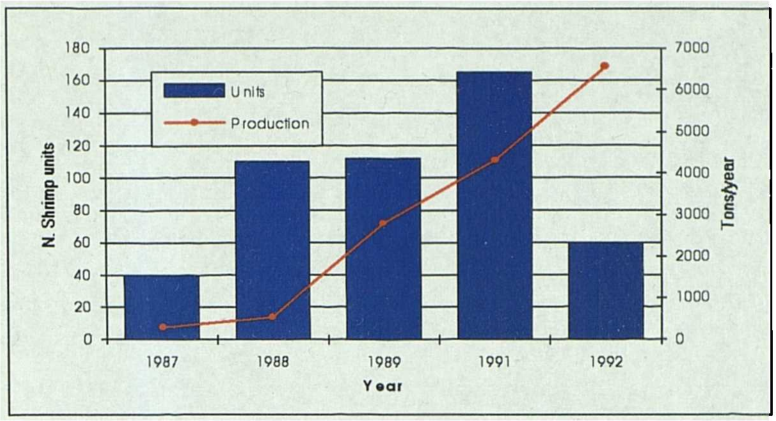


**Figure 1.2. Number of shrimp farms and their production in Mexico (1987-1992)**

Source: Chavez-Sanchez (1993). Note: No data were available for 1990.

The state of Sinaloa is primarily an agricultural area which raises cotton, tobacco, sugarcane, fruits and vegetables. The most important coastal industry is fishing, chiefly for sharks and shrimps, processed locally. Nonetheless, over-exploitation and pollution have resulted in decreases in capture fisheries, and shrimp farming has helped increase local production. **Figure 1.3** shows that the highest number of shrimp farming units is found in the state of Sinaloa.

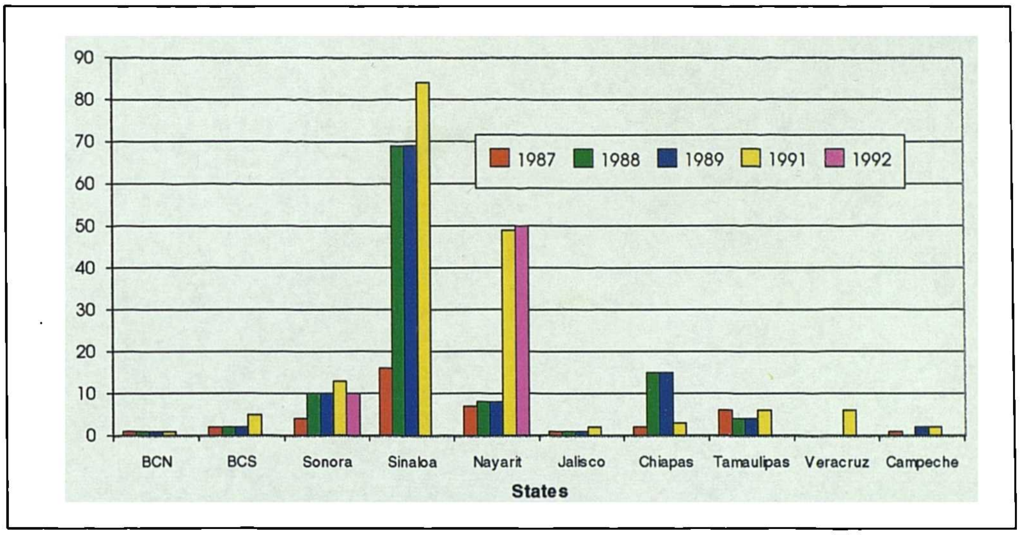


**Figure 1.3 Number of shrimp farming units in Mexico (1987-1991)**

Source: Chavez-Sanchez (1993).

Note: No data were reported for 1990 and only data for Sonora and Nayarit were reported for 1992.

In terms of shrimp production, Sinaloa is by far the biggest producer in Mexico (**Figure 1.4**). Production in this state is increasing, the highest production within this time period (1987-1992) was recorded in 1992 (6,404 tons/year).

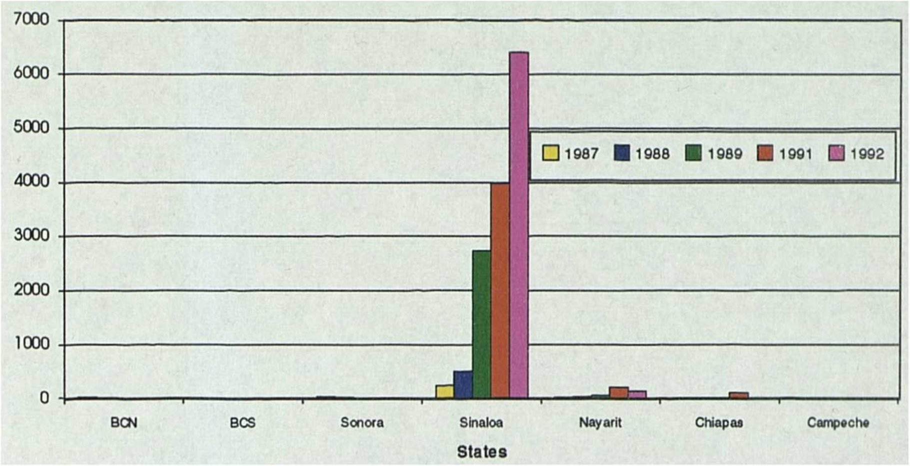


**Figure 1. 4. Production from shrimp farming states in Mexico (1987-1991).**

Source: Chavez-Sanchez (1993). Note: No data for 1990 was reported by the author, data for 1992 was only available for Sinaloa and Nayarit. Moreover, there was no data reported for Jalisco, Tamaulipas and Veracruz.

Most aquatic farms in Sinaloa are dedicated to shrimp farming, growing *Penaeus vannamei* and *Penaeus stylirostris* (Pares-Sevilla, 1988), although a few other species are also cultured, including cichlids, oysters, crayfish, and sea bream. The prevailing shrimp culture system used is semi-intensive ponds, and other types of systems are few. Cage culture for example, has only been carried out on experimental level in the northern region of the state in Topolobampo Bay (Zúñiga-Rodriguez, 1992) for fish such as *Lutjanidae*, *Serranidae* and *Scianidae*.

Even though aquaculture can become an important economic activity, it can also be harmful to the environment (mangroves and water quality in particular), and hence fisheries can be affected as well as shrimp farming itself, without proper planning. Vast land areas are being used for shrimp farming in this state (an average semi-intensive shrimp farm is 5 km$^2$), hence the need for careful resource management. Mangrove destruction can create serious problems in postlarvae availability, water quality and soils. In the Philippines between 1967 and 1977 aquaculture facilities accounted for 80% of the loss of mangrove and in Ecuador, loss of mangrove for ponds was implicated in the crisis in shrimp production in the early 1980's (World Research Institute, 1986). Another example is the conversion of rice fields to shrimp ponds in East Java, Indonesia and Kuhlna, Bangladesh, which resulted in saline water infiltration into agricultural areas (Clark, 1992). In Sinaloa they have already encountered these types of problems where mangroves have been destroyed in Teacapán and Bahía Altata (southern and central region of the state). There is also an increasing concern for the future, and it is becoming clear that major development of the industry may only be possible if healthy (low stress and antibiotic free) culture techniques are adopted (Hopkins and Sandifer, 1993; Pruder *et al.*, 1995).

The coastal zone in Sinaloa, like most coastal regions, is currently under increasing pressure. The coast is a very important biological zone and is also of great importance for the state's economy, for recreation and for settlement. The coastal zone is also extremely vulnerable to pollution and ecological change.

Even though Sinaloa leads other states in Mexico in shrimp farming, lack of planned development and concern for maintaining a productive aquatic environment have been identified as some of the key factors affecting shrimp farming development. Planning studies that locate and quantify aquaculture potential are rare. Consequently, the government, banks and insurance companies have had a difficult task allocating land, time, personnel and finances for aquaculture development. Similarly, environmental impact studies which have only recently become compulsory in Mexico also lack proper planning tools, and therefore, in most cases they have been descriptive and have not fully evaluated the impact of future aquaculture projects. To date, most common planning studies in Mexico still use simple manual map- making technology. Because of the coastal zone's importance for Mexico, government authorities have been investigating which parts of the coastal zones are most suitable for production activities, for recreation and for nature conservation. By request of the Fisheries Secretariat in 1990, Cosmocolor and EPAC (both consulting companies) assessed the potential ecological development in Sinaloa, and also located sites with aquaculture potential using manual map-making technology. Cosmocolor analyzed the southern region of the state, while EPAC analyzed the northern and central regions (Cosmocolor, 1991; EPAC, 1991). Similarly, a year later, FAO and the Fisheries Secretariat made a survey of the shrimp farms in this state (Hughes *et al.*, 1991).

The studies carried out by Cosmocolor and EPAC were developed by a multi-disciplinary team of experts which provided a very thorough description of the state's resources. The primary data sources used were thematic land-use maps (from INEGI), field data and some satellite pictures. The team used qualitative simulation models in their evaluation by means of KSIM language (Kane, 1972; Kane *et al.*, 1973). Such models were used to explicitly discriminate the important variables and processes in the evaluations (Bojorquez-Tapia, 1989). It is thought that the decision-making aspect of the studies was particularly useful because of the use of several brainstorming sessions to fulfil the integrated analysis. However, although potential aquaculture sites were defined, the "spatial" analysis was considered poor due to the obvious disadvantages of using manual techniques - for example, a simple map overlay involving two layers would have been considered to be a gigantic task due to the fact that they were hand drawn and that the paper maps themselves were very large in size and each only covered a portion of the state.

There is no doubt that the former studies could have been greatly enhanced with the aid of a GIS for better decision-making. Mexico is now becoming more GIS aware, and Laser Scan (U.K.) recently equipped Mexico's National Institute of Statistics, Geography and Information (INEGI) (Tarleton, 1994). Mexico's Fisheries Secretariat and FAO (FAO,1995b) developed a methodological guide for the formulation and implementation of local plans for the development of aquaculture in coastal lagoon areas of Mexico; partly based on the outcome of two studies developed for some coastal lagoon systems in the Mexican States of Nayarit and in Veracruz (SMARNyP and FAO, 1995a; SMARNyP and FAO, 1995b). The extent to which GIS was used is not clear, although it appears to have been only cartographic. Aquatic Design and Construction Ltd. has used GIS in the planning and design of shrimp farms in Belize (100 $km^2$) and in Mexico in the State of Nayarit (south of Sinaloa) (Allen, 1994). Although the author does provide a thorough overview of GIS, remote sensing, airborne photography and global positioning system (GPS) technology he does not provide a description of the GIS analytical framework that was used to evaluate shrimp farm locations in Nayarit. Nonetheless, these projects show the beginning of the use of GIS for aquaculture development in Mexico.

## OBJECTIVES

The main objective of this study was to devise analytical strategies that could be used to enhance planning and management of coastal aquaculture development in Sinaloa state, Mexico. This was done by developing GIS-based models based on decision-making techniques. These models aimed to gain better understanding of the interaction among siting criteria required for aquaculture development. The GIS-based models were developed on two planning levels: state-level and individual site-level.

At a state-level, the main objectives were:

- To evaluate the relative importance of aquaculture siting criteria.
- To identify and quantify environmental problems which have appeared as a result of aquaculture development (i.e. mangrove destruction for shrimp farms).
- To identify and solve conflicts of land allocation and land use between production activities.
- To locate and quantify potential areas for aquaculture development.

At an individual site-level, the main objectives were:

- To test the accuracy of the state models.
- To devise higher resolution models to evaluate the effects of the activities on their surroundings.

An important part of the whole procedure of using a GIS in this study was to verify the outcomes of the models produced. To this end, as a final objective, a GPS was used to assist in assessing the accuracy of the database and of the models by comparing field observations with the outcomes shown by the models produced.

Even though the GIS-based models developed in this study have a general application to both fish and shrimp farming, this study concentrates on shrimp due to the prevailing shrimp farming development in Sinaloa. Similarly, the main focus of the evaluation is “land-based” due to the dependency of the study on the data available to it.

It was hoped that reproducible GIS-based models would have general applicability in solving the current problems of planning and management that aquaculture development is facing.

# CHAPTER 2

# THE STUDY AREA : SINALOA, MEXICO.

## 2.1 Geographical location and description

The state of Sinaloa is in north-west México bounded by the coordinates 22° 30' 40"-27° 02' 42" N and 105°23' 20"-109°28'48" W. The area of the state of Sinaloa is about 58,480 $km^2$ which represents 3.0% of the surface of Mexico, and it is the 17th largest state (INEGI, 1995) (**Figure 2.1**).

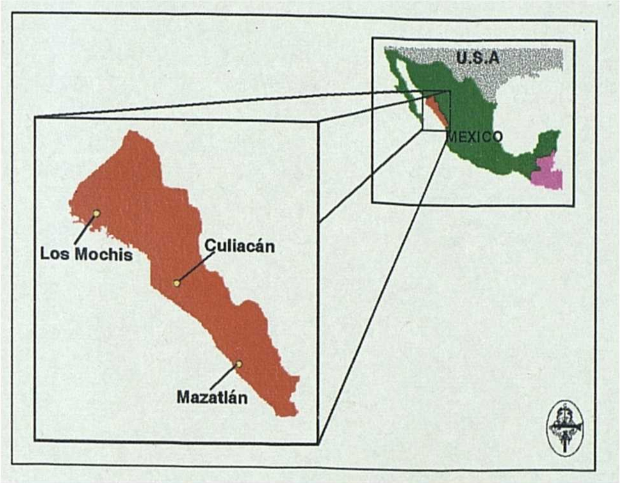


**Figure 2.1. Geographical location of study area.**

The study area of interest for this thesis is shown in **Figure 2.2**, and comprises the zone between 22° 12' - 27° 13' N and 105° 19' - 109° 33' W ensuring coverage of the entire state of Sinaloa as well as areas of neighbouring states (Sonora, Chihuahua, Durango, Nayarit) and the Gulf of California. Long and narrow in shape Sinaloa extends some 560 km along the Gulf of California. The eastern boundary that separates Sinaloa from Chihuahua and Durango lies in the outer ranges of the Sierra Madre Occidental (CEDCP, 1990). Politically Sinaloa is divided into 18 municipalities, and the principal cities are Culiacán, the capital, and Mazatlán, which is a fishing centre and one of Mexico's busiest Pacific ports (ITESM, 1993).

Figure 2.2. Municipalities in Sinaloa.

## 2.2 Environmental factors

### 2.2.1 Water resources

Mexico has 15,673 km$^2$ of coastal lagoons of which 226 km$^2$ (1.4%) are located in Sinaloa. These coastal systems are semi-closed water bodies, in the majority of cases maintaining communication with the ocean. In other cases communication is interrupted by sedimentary effects or by climatological phenomena. Generally, coastal lagoons are surrounded by mangroves which have a tendency to increase from the north to the south of Mexico, and contribute to a great extent to the productivity of these ecosystems. Fishing production from these areas represents 80% of the total national production. Moreover, most aquaculture development is being carried out in, or in proximity to, these lagoons, such as the case of shrimp culture. Lagoon systems in Sinaloa are very important due to the fact that they are homes to many aquatic species of commercial importance. **Figure 2.3.** shows that the largest number and the biggest lagoons are concentrated in the north and, to a lesser extent, in the central part of the state, whilst those in the southern region are smaller and less numerous. Each system has its own characteristics and problems. The main problems are currently being evaluated and are focused on improving the water quality of these lagoons, with the establishment of monitoring programmes to detect and eliminate pollutants, as well as establishing dredging schemes to improve water circulation within these systems (Díaz-Rubín *et al.*, 1992).

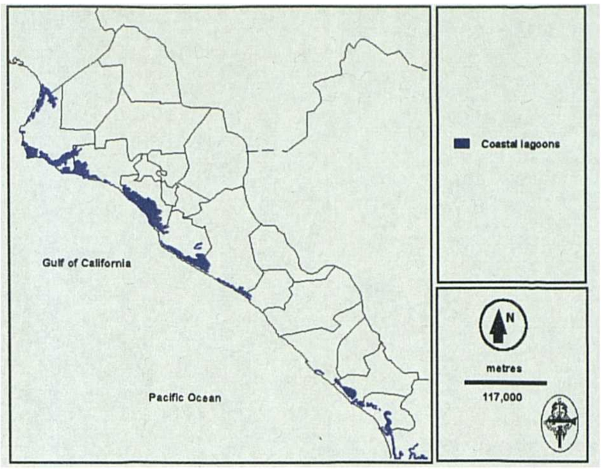


Figure 2.3. Coastal lagoons in Sinaloa.

Sinaloa state contains eleven rivers which flow westwards and all originate in the Sierra Madre and some flowing through portions of Durango or Chihuahua states (**Figure 2.4**). Rivers are influenced by local topography and, in general, they are characterized by maximum discharges towards the end of the summer associated with an increase in rainfall (ITESM, 1993).

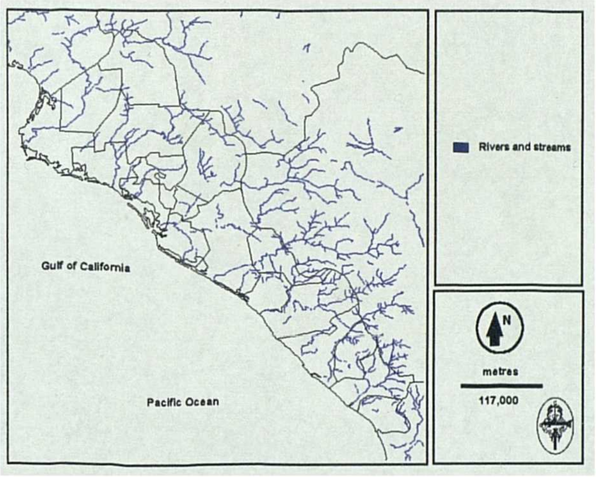


Figure 2.4. Rivers and streams in Sinaloa.

Total annual yield is, on average, 152,200 million m$^3$ which, in addition to the irrigation infrastructure in operation, supports the agricultural activity of the state and the generation of electric energy. Such factors are of extreme importance in the economic development of the region, and Sinaloa is one of the states with the highest hydrological potential in the Pacific region of the country (CEDCP, 1990).

Water from rivers is usually retained and stored in dams for future use in the irrigation of large areas of agricultural land located on the coastal plain. There are 13 dams in Sinaloa, the most important ones being Miguel Hidalgo, Adolfo Lopez Mateos, and Sanalona (**Figure 2.5**). Altogether they are able to irrigate 7,100 km$^2$ for agriculture, and this capacity will increase to 10,248 km$^2$ in the near future (CEDCP, 1990). Despite this development, rivers and streams have not been managed to their full potential because during the rainy season flooding problems still develop in urban and rural areas, causing the loss into the ocean of large volumes of water which could have been exploited. For this reason, the North-west Hydraulic System ("Sistema Hidráulico del Noroeste" or SHINO) project is currently under way in the north-eastern region of Mexico. This will provide irrigation water from the north of the state of Nayarit to the north of Sinaloa. The project comprises dams for storage, irrigation areas and communication links. The estimated increase of area for agricultural crops will be 9,400 km$^2$, 60% destined for Sinaloa, and the approximate volume of water that will be required for this development is 1,200 million m$^3$ (INEGI, 1995).

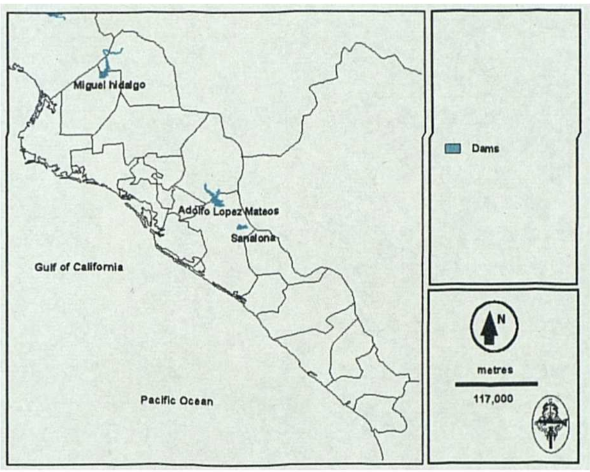


**Figure 2.5. Dams in Sinaloa.**

In order to manage Mexico's surface water resources, researchers in Mexico have divided the country into 37 hydrological regions. Sinaloa occupies two of these regions (numbers 10 and 11). Hydrological region number 10 is the most important in this state and is located in the north-east, and also includes portions of the states of Durango, Chihuahua and Sonora. All the water flows that reach the Pacific Ocean pass through this region and their general direction is from north-east to south-west. Hydrological region number 11 is considered less important because it is smaller in area as well as in its hydrological infrastructure. These regions are in turn divided into 11 river basins, region 10 having 8 river basins (labelled A to H) and region 11 having 3 river basins (labelled B, C and D). **Figure 2.6.** shows these river basins, as well as the quantity of water flow in this state. In general, the amount of water flow increases from north to south, the lowest value (2.7%) being found in river basin H in the municipality of Ahome, and the highest in the municipality of Rosario (INEGI, 1995).

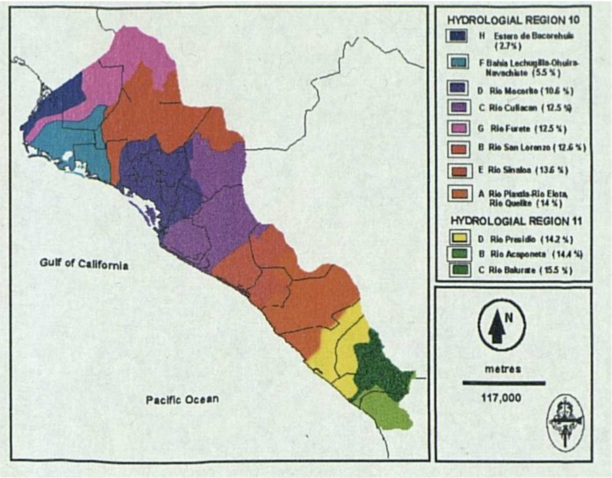


Figure 2.6. Hydrological regions in Sinaloa.

Despite the fact that Sinaloa contains large volumes of superficial water, and that it possesses a solid hydrological infrastructure, it has also been necessary to abstract groundwater. Overall, this resource is under-exploited: **Figure 2.7.** shows that most available groundwater is found in the south (especially in the Culiacán municipality), decreasing towards the north of the state. There are approximately 1044.0 million $m^3$ of water available per year and only 447.1 million have been extracted. Nonetheless, in some cases extraction activities have endangered the existence of this resource. During 1991 Sinaloa state used the 447.1 million $m^3$ of groundwater which was distributed as follows: 62.6% for agricultural activities, 29.9% for urban use, 5.3% for the industries and the remaining 2.2% was used for livestock rearing. In the state there are approximately 2,614 extraction units averaging 40 litres per second but values can reach up to 70 to 80 litres per second. Additionally, there have been some problems with groundwater quality mainly attributed to saline intrusion along the coasts, deficient drainage and geological phenomena (INEGI, 1995).

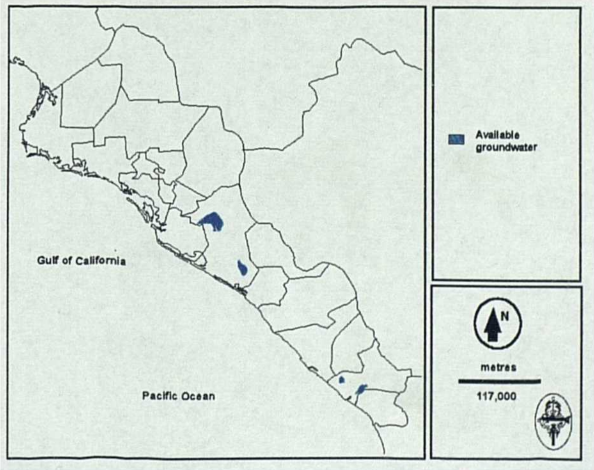


Figure 2.7. Groundwater in Sinaloa.

On a world basis, it is estimated that 6% of freshwater is used for domestic needs, 73% for agriculture and 21% for industrial use. Information provided by the Mexican National Water Commission (CNA) for 1987 gives a rough idea of the amount of freshwater used by each of the major production activities in Sinaloa. **Table 2.1** shows that more than half of the water is used for agriculture and livestock rearing purposes, whilst public, industrial and aquaculture use the lowest percentage.

**Table 2.1. Annual use of freshwater according to main production activities in Sinaloa.**

| WATER USE | $10^6 m^3$ | Percentage |
|---|---|---|
| Public use | 126.1 | 0.87 |
| Agriculture & livestock rearing | 9,058.9 | 62.40 |
| Industrial | 138.6 | 0.96 |
| Hydroelectric | 5,044.0 | 34.74 |
| Aquaculture | 150.0 | 1.03 |

Source: Cosmocolor (1991).

Although Sinaloa is rich in hydrological resources, water conservation and rational use is extremely important because agriculture is the backbone of the state's economy. Moreover, water availability is being affected by the proliferation and dispersion of population centres; whilst the urban population represents 64.08% and is concentrated in 86 localities, the rural population represents 35.92% and is distributed in 5,162 communities (INEGI, 1995).

### 2.2.2 Climate

There is a diverse range of climates in different parts of the state determined by latitude, longitude, altitude, atmospheric conditions and proximity to the Pacific Ocean. The physical barrier formed by the chain of mountains affects rainfall, temperature and evaporation and humid air in the coastal regions and on the mountains edges which surround the Pacific Ocean and the Gulf of California create intense rainfall.

Temperature regimes vary greatly: within the coastal zone in the south-western part of the state the annual mean temperature range is 24 °C to 26 °C whilst low temperatures (18° C to 20 °C) are found in the mountains (**Figure 2.8**).

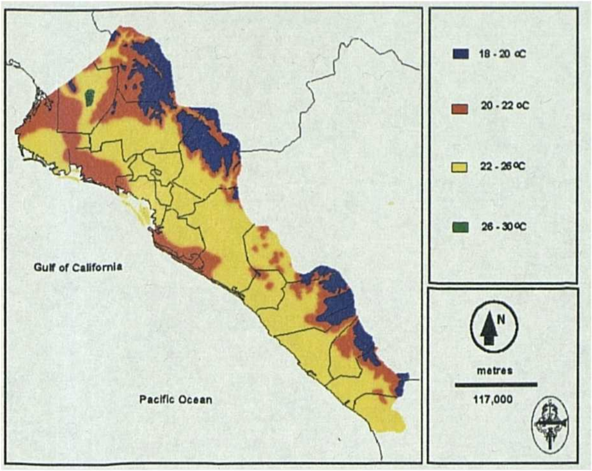


**Figure 2.8. Annual air temperature regimes in Sinaloa.**

In general, coastal rainfall is low with an annual average of 700 mm, increasing considerably in the highest parts of the mountains. Annual averages increase from north to south and towards the mountains. However, rainfall occurs in an irregular manner over the year, mean maximum rainfall occurring during July and October representing 84% of the annual rainfall. The lowest rainfall volumes occur from February to May and represent 3% of the annual rainfall. In the coastal zone rainfall increases parallel to the coast from west to east; in the north-east and centre of this region rainfall varies between 200 and 700 mm, whilst in the southern region values are over 1,000 mm. In the mountain region, rainfall varies between 600 and 1000 mm in the north-east, whilst in the south-east region it varies between 800 and 1,500 mm.

Evaporation changes from the coast to the mountains; annual mean evaporation fluctuates between 1,369 and 2,418 mm. Lowest values are found in the Baridaguato municipality and the highest in the municipality of Choix, both in the north-west region of the state.

A good assessment of the water availability is the balance which results from the relationship between the rainfall and the evaporation (i.e. rainfall - evaporation = water balance). The general trend is for water balance to increase from the coast towards the mountains, the lowest being in the north-western part of the state (**Figure 2.9**).

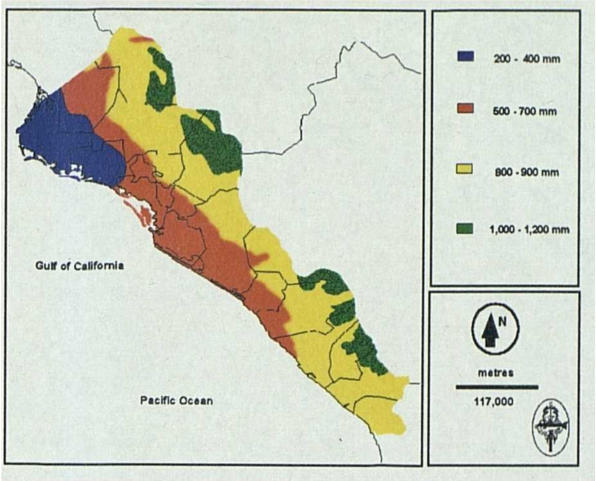


**Figure 2.9. Water balance in Sinaloa.**

Because of Sinaloa's geographical location it is affected by meteorological phenomena such as tropical cyclones and cold fronts, all of which tend to produce intense rainfall. Winds are predominately south-easterly to north-easterly in direction, except in Culiacán where they are predominantly north-easterly. The intensity of the winds fluctuates between 8 and 16 km/h. Hurricanes occur, on average, 1.25 times in a year and 80% of them enter the continent and vanish in the proximity of the Sierra Madre Occidental (INEGI, 1995). **Plate I** shows an image of Hurricane Rosa passing through Sinaloa.

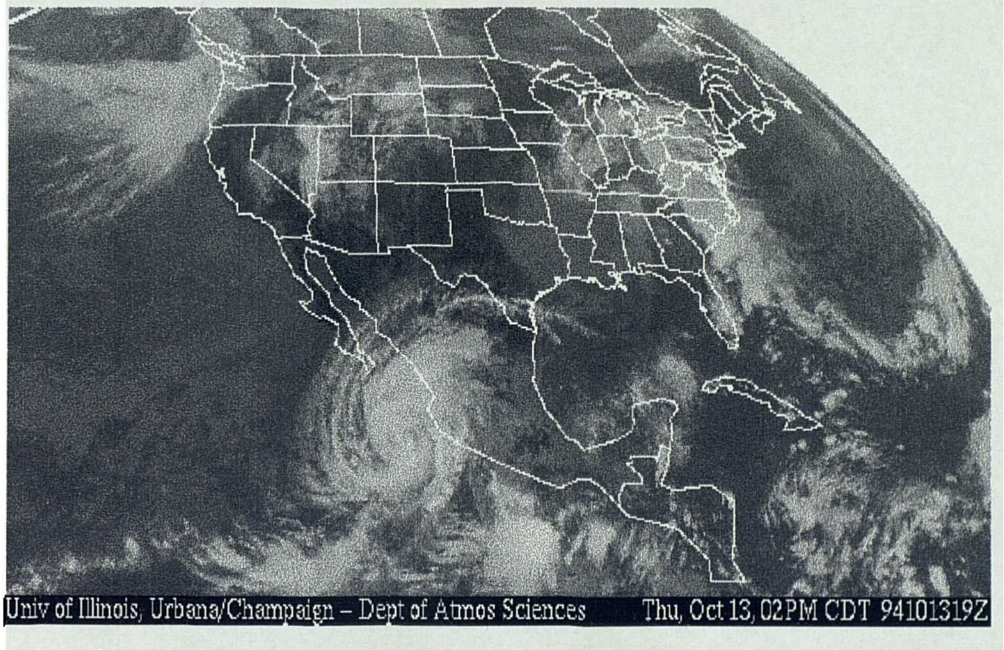


**Plate I. Hurricane Rosa, Sinaloa (2:00 pm, 13 October, 1994).**

Cyclones temporarily stop navigation and cause great flooding problems, they originate in the Gulf of Tehuantepec and commence in May. These phenomena have a parabolic trajectory which is similar to the shape of the Pacific coastline; generally movement is parallel to the coast, and according to statistics their maximum activity occurs in September (De la Lanza, 1991).

### 2.2.3 Soils

Soils are classified according to the FAO-UNESCO (1970) classification modified by one of Mexico's mapping agencies (INEGI) to suit the prevailing conditions of the country. According to this classification there are 25 soil units of which 10 are found in Sinaloa (CEDCP, 1990).

The most common types of soils in Sinaloa are regosols and lithosols which cover about 60% of the state's surface (**Figure 2.10**). Regosols have a medium texture and are located in the north-western part of the state in the mountains, and in the south from the mountains towards the coast. Lithosols have a medium texture and are located mainly in the eastern part of this region, they do not exceed 0.10 m in depth and have a high drainage capacity. Both types of soils are relatively impermeable.

In order of importance, the phaeozems and vertisols cover 25% of the state's soil surface, and are distributed between the coast and the western region of Sierra Madre Occidental. They have a clay texture, are moderately impermeable and are susceptible to erosion. Solonchak soils have a rather reduced but important distribution in the coastal zone. They are alkaline and saline types of soils because they are saturated with brackish waters. Xerosols, which are directly related to vertisols and lithosols are also present in very small proportions. The distribution of these soils is irregular and they have moderate permeability (INEGI, 1995).

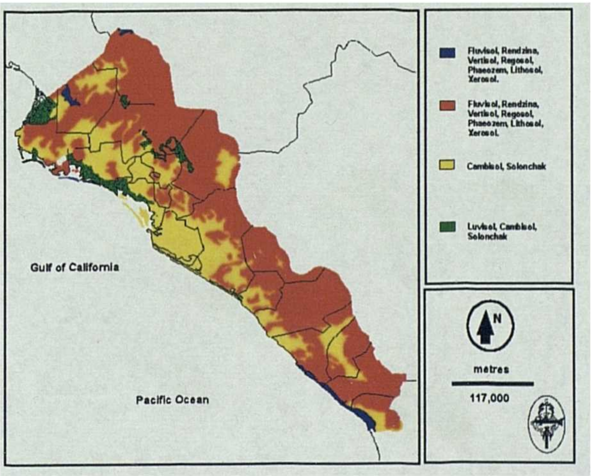


**Figure 2.10. Soils in Sinaloa.**

### 2.2.4 Relief and topography

Topographic data for the entire Sinaloa state was obtained in the form of a Digital Elevation Model (DEM) through INEGI (1994) (**Figure 2.11**) at a 1:250,000 scale (based on topographic chart maps from 1980). Topography in Sinaloa is principally of three types, the mountain zone, the mountain edge and the coastal zone The mountain zone occupies approximately 40% of the state's surface and is located along the eastern edge of the state. It comprises a chain of mountains which can reach up to 2,800 m, and which have slopes in excess of 15%. For this reason, the region is generally inconvenient for the development of agriculture and urban activities. The mountain edge is a transition zone between the mountains and the coast. It is generally located between 150 and 600 m above sea level, and forms a fringe 25 km wide on average to the coastal plain. This region covers approximately 14% of the state's surface, and slopes vary between 5 and 14%. The coastal area is located in the western part of the state and occupies 46% of the state's area. The coastal plain is usually below 150 m above sea level, has slopes of less than 5% and forms a parallel fringe to the coastline with an average width of 55 km, although it is narrower in the south.

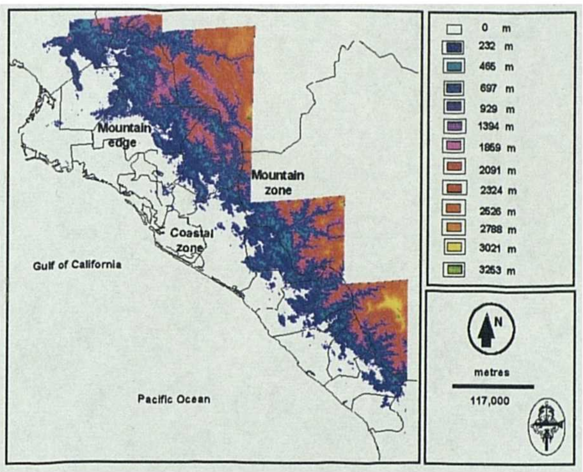


**Figure 2.11. Original DEM image covering the entire state of Sinaloa as well as areas of neighbouring states.**

The mountain region has poorly developed soils and any type of agriculture is seasonal, or for subsistence, due to the limiting factors for its development such as: climate (extreme and uncertain rainfall), topography, soil depth, coarseness and erosion risk. Livestock rearing is practised on a very small scale in these areas. Mining is an important economic activity in this area, but because the access to these resources is very difficult due to the topography, it has had a limited growth and consequently mineral resources are under-exploited. In the areas on the edge of the mountains with gentler slopes, agriculture and livestock rearing are poorly developed and are dependent on the abundance of rainfall. Intensive agriculture is only feasible in some parts of this area. Input requirements are quite high and hence operation costs are considerably increased, and the risk of erosion is also high (CEDCP, 1990). The coastal zone is suitable for agriculture and livestock rearing; benefited by the irrigation infrastructure these lands are used intensively and it is here that population centres are mostly developed.

### 2.2.5 Vegetation

Vegetation coverage constitutes one of the richest natural resources of the state if wisely exploited. Vegetation in Sinaloa has undergone various degrees of alteration. There have been serious erosion problems caused by poor soil management, and to date 2,624 km$^2$ of natural vegetation have been destroyed, mostly in the northern part of the state in the municipalities of El Fuerte, Choix, Sinaloa and Baridaguato. The natural vegetation has been substituted by both long- and short-term agricultural systems (22.94% of the state's surface), and has been destroyed for pasture and for domestic and industrial use.

Sinaloa is populated by a great variety of native, as well as cultivated species of vegetation which have adapted to the climate, morphology, soil and location. This has resulted in a great variety of communities, the low decidious forests, cultivated vegetation and forestry areas being the most widely distributed. Low decidious forests are located in the mountainous region, and occupy approximately 50% of the vegetation land cover. The subhumid climate enables species to grow up to 15m such as *Bursera* spp. (Chupundia), *Lysiloma* spp. (Tepeguajes), *Pseudobombax palmeri* (Amapola), and *Ipomoea* spp. (Morning Glory). Cultivated vegetation makes up approximately 35% of the state's vegetation on the coastal part of the state. Here soils are fertile, agriculture is well-developed and vegetables, fruits, grains and pasture are the main types. Forestry occupies 15% of the vegetation land cover, and consists of pine and oak trees. Cultivated forests are located in the mountainous region surrounded by low decidious forests. Species of this type are from the genus *Pinus* (pine) and *Quercus* (Oak) which grow in the areas from 300 and 1000 to 4200 metres above sea level (CEDCP, 1990).

These three vegetation types occupy approximately 90% of the state's surface. The remaining 10% is composed of limited communities such as thickets and sarcocaule in the north-west in arid areas; mangroves, halophyte, and dune vegetation in the coastal areas and vegetation resistant to saline environments are found in estuaries, marshes and lagoons. There are approximately 963 km$^2$ of mangroves in Sinaloa (land use and vegetation state chart, SPP, 1981) dispersed along the state coastline usually adjacent to coastal lagoons (**Figure 2.12**). Most mangroves are found in the central part of the state, fewer in the north and very few in the south. In general, areas with the least amount of vegetation are found along the coastal strip. Tides, rivers and the dynamic nature of the sand dunes limit the development of vegetation in these areas.

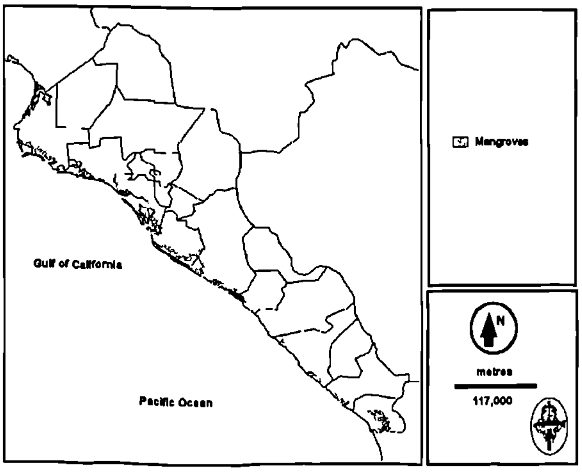


Figure 2.12. Mangroves in Sinaloa.

## 2.3 Land uses

### 2.3.1 Population density and urban development

According to the results of the eleventh Population and Housing census, Sinaloa state has a total population of 2,204,054 inhabitants of which 1,102,433 (50.01%) are women and 1,101,621 (49.99%) are men. There is a general trend towards the expansion of its middle sector (young population) and the older population is small in number. According to the state census of 1990 its total population is 2.72% of the total population of Mexico distributed in an irregular manner as shown in **Figure 2.13**. The mean population density is 38 inhabitants per km$^2$ distributed in 18 municipalities, of which 67.1% are concentrated in Culiacán, Ahome and Guasave. Within these three municipalities there are 5,247 localities of which 5,162 have fewer than 2,500 inhabitants and 85 have a population larger than 2,500 inhabitants, 10 of them have between 20,000 and 50,000 inhabitants and only three have more than 100,000 inhabitants. The urban population is 1,412,447 inhabitants, which represents 64.08% of the total state population (INEGI, 1995).

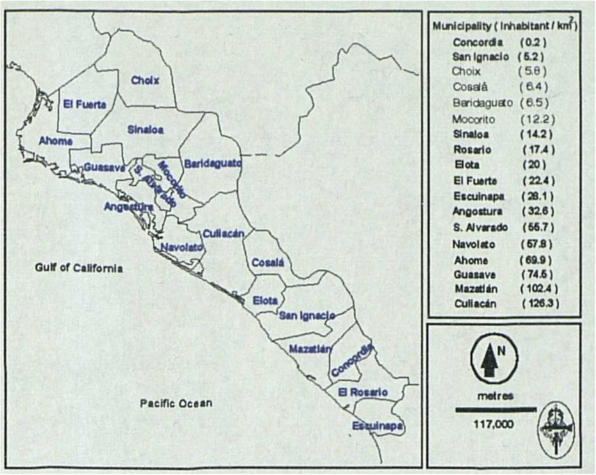


Figure 2.13. Population density in Sinaloa.

**Figure 2.14** shows the relative importance of the 10 main production activities in Sinaloa. Tourism (restaurants and hotels), communication, agriculture and industrial activities are the four most important activities which contribute to the Mexican economy. Construction, livestock rearing and mining come in second place, whilst fishing (including aquaculture), electricity and forestry have a much smaller contribution.

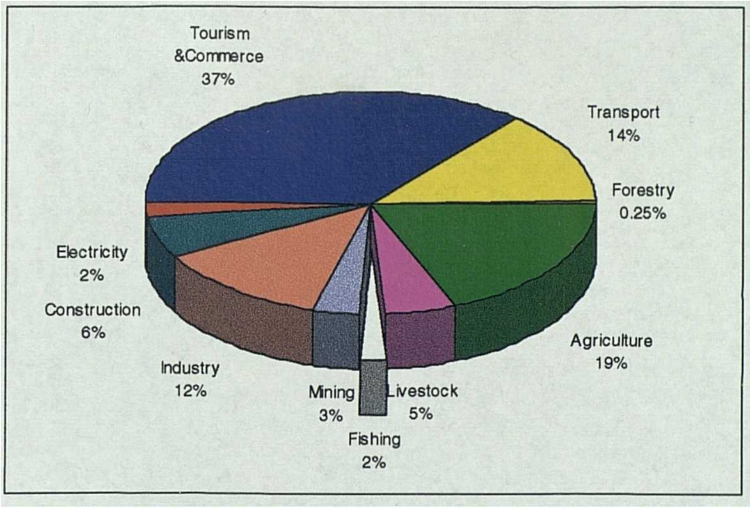


Figure 2.14. Sinaloa state's contribution the Mexican economy according to production activities from 1987 to 1992.

Source: Secretaría de Hacienda y Crédito Público (1992).

### 2.3.2 Tourism and commerce

Tourist activities are an important source of jobs and income and the most efficient earner of foreign exchange. Tourism is mainly concentrated in the southern region of the state, specifically in the port of Mazatlán (74%). This is followed by Culiacán (17%), and Los Mochis (9%) (INEGI, 1995). Seventy percent of the restaurants, hotels and commerce are concentrated in these municipalities. Sinaloa's commercial activities are mainly based on agriculture, livestock and exports of aquatic species (Cosmocolor, 1991).

### 2.3.3 Communication

The state's economic development has considerably benefited from the development of its communication infrastructure. Roads, ports and hydraulic systems were built during the 1950's and 1960's as the economy developed. Road systems have increased to 10,792 km of which 2,633 km are paved, 6,376 km are gravel and 1,783 km are dirt roads. The main highway is the international México-Nogáles highway which is 650 km long enabling communication between the north and the south of the state. Along this important highway there are a considerable number of side-roads which provide communication to the east and western parts of the state. **Figure 2.15** shows that most paved roads are concentrated in the central and northern parts of the state, and to a lesser extent in the south. Gravel and unimproved roads are most abundant in proximity to the coast and decline towards the mountains. There are 895 km of railways which communicate throughout the state in all directions.

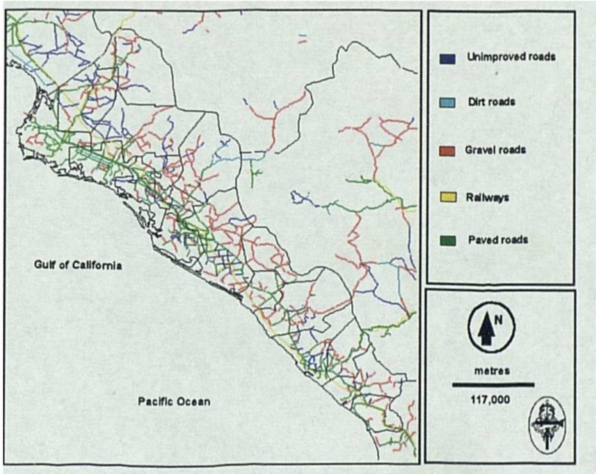


**Figure 2.15. Transportation in Sinaloa.**

Through these means of transport Sinaloa moves an annual average of one million tons of goods such as agricultural products, petrol derivatives, fertilizers and cement. The port infrastructure enhances the fishing sector as well as the industrial, military and tourist sectors. Mazatlán (in the south) and Topolobampo (in the north) are the most important ports. Mazatlán is ranked the 14th most important port on the Pacific, and 6th in terms of its infrastructure. Topolobampo has an area of influence which covers part of the south of Sonora, the state of Chihuahua and more than half of Sinaloa. An international airport is located in Mazatlán, and another two for national flights are located in Culiacán and Los Mochis. Additionally, there are more than 143 sites for small planes for use in fertilizing agricultural fields, material transport or tourism (INEGI, 1995).

Telecommunications and postal services have been modernized in the last decades and telephones, microwaves and communication via satellite operate at state and national level (INEGI, 1995).

### 2.3.4 Industrial activities

The most important industries in the state are orientated towards processing products of agriculture and livestock origin such as sugar, beer, malt, meat and milk products. Large concentrations of industries are located in the municipalities of Mazatlán and Culiacán, making up 73% of the state's production (Cosmocolor, 1991). The rest of the industries are distributed in other municipalities, mainly in proximity to the coast. As shown in **Figure 2.16**, most of the sugar cane industries are concentrated towards the north of the state and decrease in number towards the south.

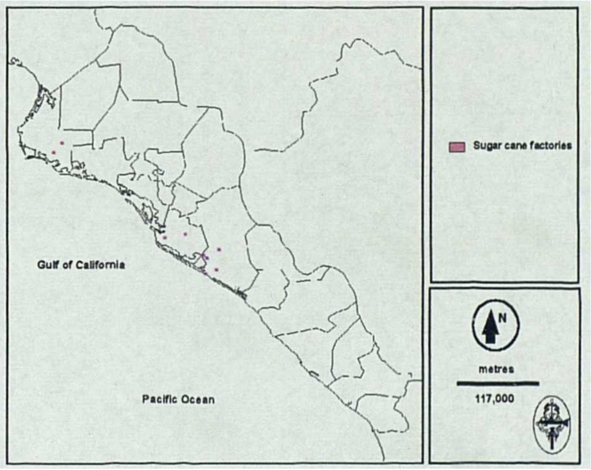


**Figure 2.16. Sugar cane industry distribution in Sinaloa.**

### 2.3.5 Mining

Mining is an activity with great potential in Sinaloa and is located in the mountain regions of the state (**Figure 2.17**). Mining development could enable the state's social and economic growth. One of the most viable possibilities is to consider the exploitation of minerals which could be used as construction materials. Other minerals include silver, nickel and copper. The most important of these minerals is silver, 48,130 tons being extracted in 1986 (Cosmocolor, 1991). However, with the current technology this activity is considered to be under-exploited and new technology needs to be adopted. Even so, the economic contribution from this activity is 5% (CEDCP, 1990).

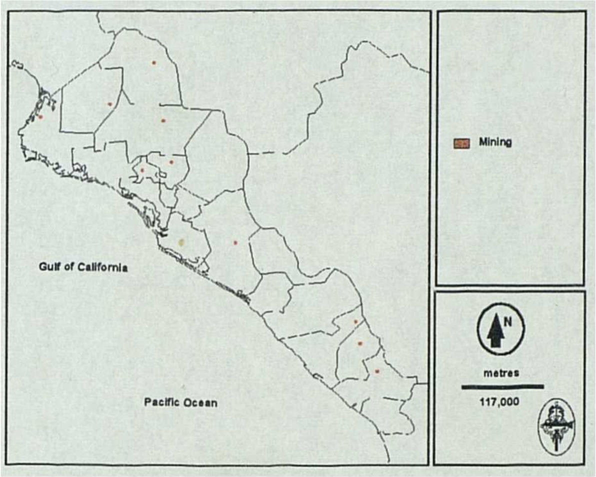


**Figure 2.17. Mining in Sinaloa.**

### 2.3.6 Electricity

The energy generated during 1993 was 4,661,509 megawatts/hour derived mainly from either steam (73%) or hydroelectric plants (27%). The majority of the electrical energy is distributed from the municipalities of Culiacán, Mazatlán, Los Mochis and Guasave (CFE, 1993). Electrical energy can be distributed to 1,125 communities (80% of the state's population) (EPAC, 1991).

### 2.3.7 Agriculture

Agricultural activities are the basis of the state's economy, and their development considerably influences other activities such as commerce and construction. Modern high-technology agriculture has been developed in Sinaloa through the construction of dams, distribution channels and drainage which conduct water by gravity or from wells. Agricultural activities have been developed in proximity to coastal areas especially in the northern and central parts of the state (**Figure 2.18**). Sinaloa has the highest national production of soy beans and vegetables, followed by rice, corn, wheat, and sugar (INEGI, 1995).

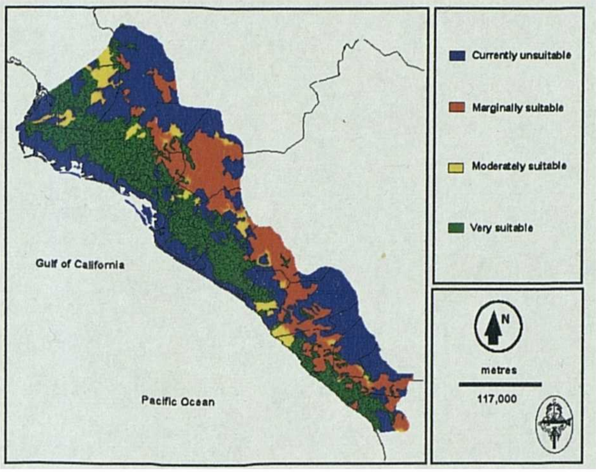


**Figure 2.18. Agriculture in Sinaloa.**

Agriculture is directly influenced by the climate, but scarce rainfall has been partially substituted by irrigation. Since 1948 agriculture has been exploited on a large scale, the development beginning with irrigation in the city of Culiacán. To date irrigation projects have greatly benefited agricultural lands and the wealth of the state, which is considered to be the most prosperous in the country (INEGI, 1995). Most irrigation schemes are in the central and northern parts of the state, and are almost non-existent in the southern region (**Figure 2.19**).

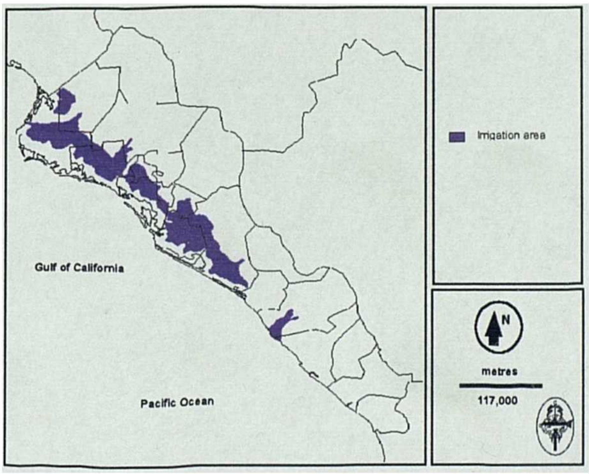


**Figure 2.19. Agricultural irrigation in Sinaloa.**

The agricultural area has been estimated to be 13,335 km$^2$ of which 7,435 km$^2$ are irrigated and 5,900 km$^2$ are seasonal. According to the trends in land use it is expected that the irrigated agriculture activities will increase, and that seasonal agricultural activities will decrease (INEGI, 1995).

### 2.3.8 Livestock rearing

Livestock rearing is also important, even though difficulties are experienced due to the lack of adequate land for pasture (**Figure 2.20**). Summer rainfall is not able to maintain vegetation after November and therefore there is a drought during the following months causing a decrease in livestock. The most suitable sites are found in the northern and central regions of the state, and the most common livestock are cows, pigs, chickens, horses and bees (CEDCP, 1990; CIFSA, 1993; INEGI, 1995).

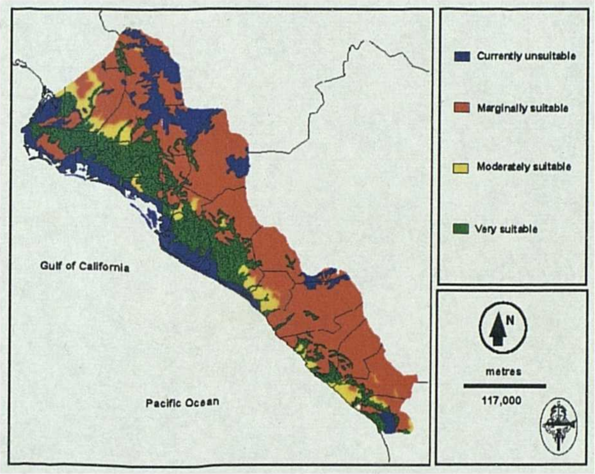


**Figure 2.20. Livestock rearing in Sinaloa.**

### 2.3.9 Forestry

Forests are mainly concentrated in the northern parts of the state in the mountain areas (**Figure 2.21**). Forests in the coastal zones from Ahome to Elota, as well as those in the south of Mazatlán, have been modified by agricultural development. Communities located in areas of low forests extract wood for domestic use. These communities also practice extensive types of low production livestock rearing. Different types of wood are extracted, such as mahogany and red cedar. Poplar is found principally next to the rivers where it is commercially exploited. Even though most of the state's surface is not covered by forests, there are commercial interests in exploiting them locally. There are 2,276 km$^2$ of mixed conifers suitable for commercial exploitation with an annual production of just 48,999 $m^3$, despite having the capacity to exploit 225,000 $m^3$ (CEDCP, 1990).

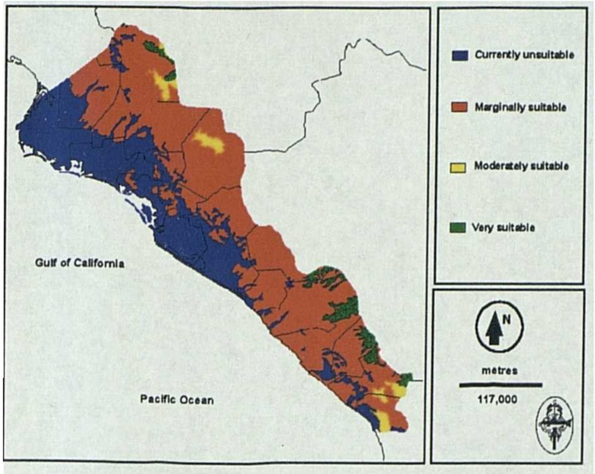


Figure 2.21. Forestry in Sinaloa.

### 2.3.10 Fishing

**Figure 2.22** shows that at a national level Sinaloa is ranked third in capture fisheries production, producing 148,512 tonnes in 1992. **Figure 2.23** shows that Sinaloa generated the highest revenue in 1992 (16% or $N 680 million), followed by Campeche, Veracruz and Tamaulipas.

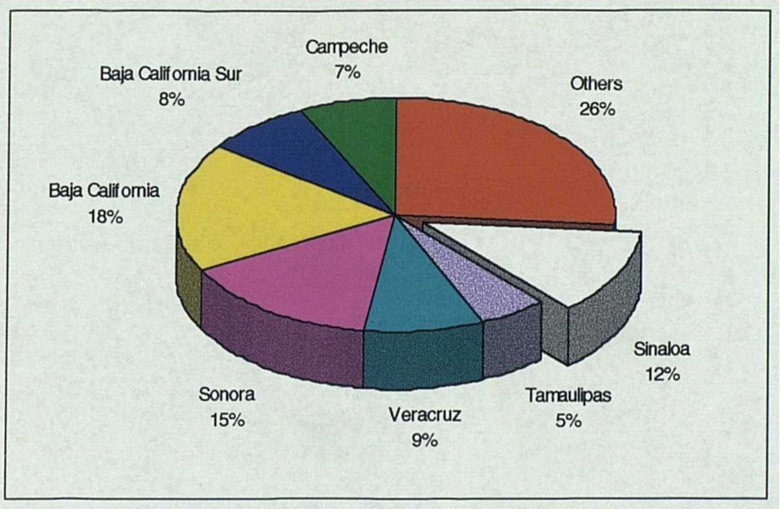


Figure 2.22. States with the highest volume of fish capture.

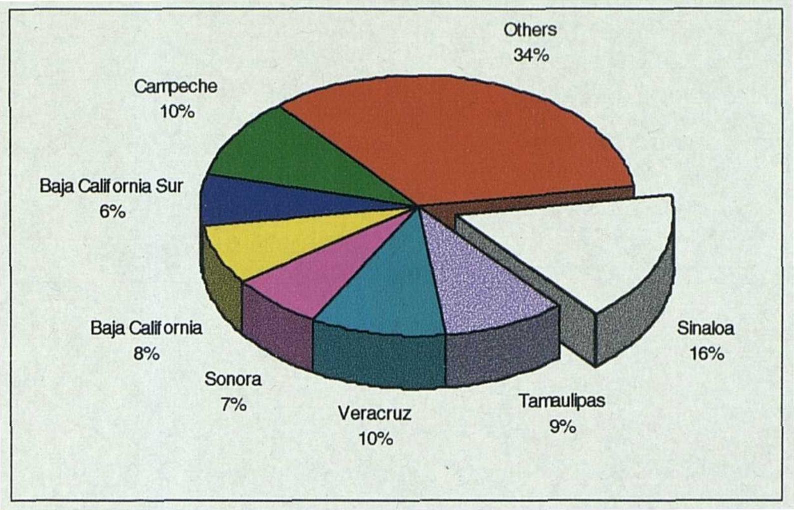


**Figure 2.23. States with the highest economic contribution from fisheries.**

Source: Secretaría de Pesca (1992).

**Figure 2.24.** shows the diversity of species found in Sinaloa and the percentage of the total national fish capture that is derived from the state. Tuna and shrimp capture represent 43 and 34% of the national fish capture, whilst skipjack (also called bonito), mullet and tope represent 16, 14 and 10% respectively. Cichlids, oysters, catfish and abalone also have great potential.

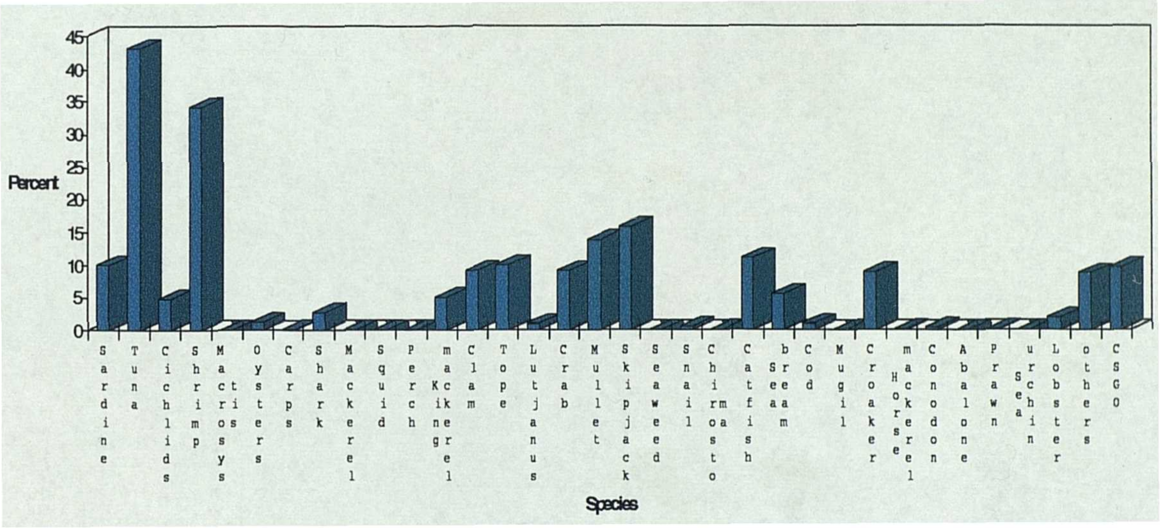


**Figure 2.24. Diversity and quantity of aquatic species derived from fish captures in Sinaloa as compared to National fish captures.**

Source: Secretaría de Pesca (1992). Note: CSGO (captures which were not officially registered)

The fishing sector in Sinaloa has passed through three stages of development. The first was characterized by fishing in coastal waters mainly for shrimp and fish of high value. This was followed by development of tuna and sardine capture, and the last stage has seen the initiation of the culture of aquatic species such as shrimps (INEGI, 1995).

### 2.3.11 Aquaculture

Sinaloa has the highest cultured shrimp production in the country which has developed mainly because of its optimum geographic location and socio-economic characteristics. Moreover, shrimp culture is an activity which can be carried out to different degrees of complexity and by different social classes (i.e. social cooperatives or private sector). **Plate II** shows a typical semi-intensive shrimp farm in Sinaloa.

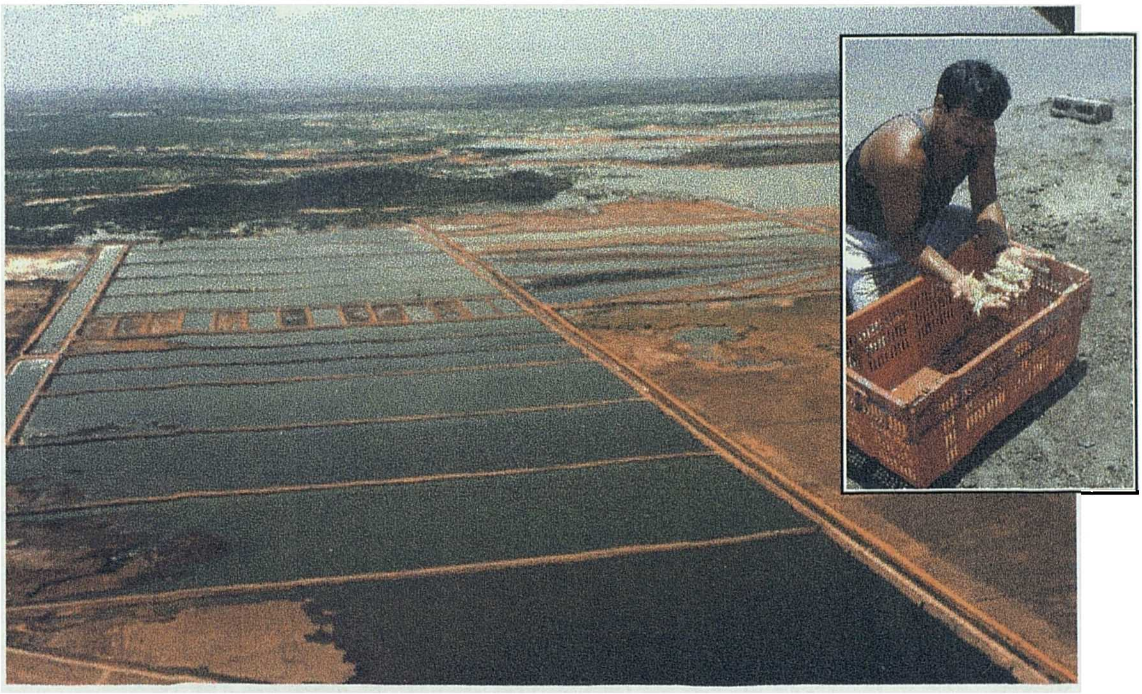


**Plate II. Typical semi-intensive shrimp farm, south Sinaloa. The most common cultured species is *Penaeus vannamei* (inset).**

**Figure 2.25** shows that shrimp farms in Sinaloa are located in 10 of the 18 municipalities and are concentrated in the central and northern regions. There are approximately 125 registered farms of which approximately 84 are in operation; of these 24 are extensive, 54 semi-intensive and 6 intensive. Forty-four of these farms are owned by private investors and 40 are owned by social cooperatives. The largest number of shrimp pond farms is in Navolato (21) in the centre of the state adjacent to the coast, and the municipality with the least is Mazatlán with 3 (Chavez-Sanchez, 1993). Usually, shrimp farms in Sinaloa are located adjacent to coastal lagoons, although there are some exceptions in which intensive shrimp farms have been constructed in proximity to the ocean. Interestingly, in terms of area, the largest shrimp ponds are concentrated in the north.

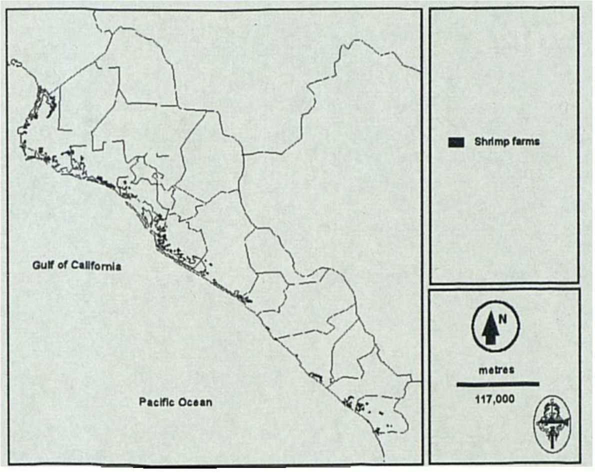
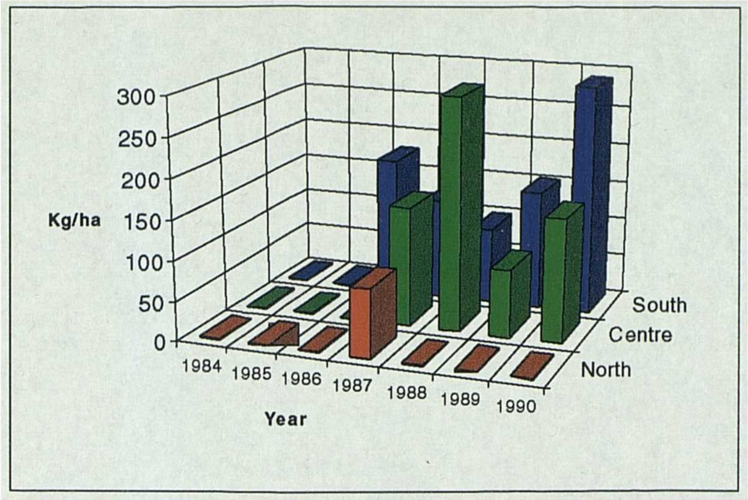
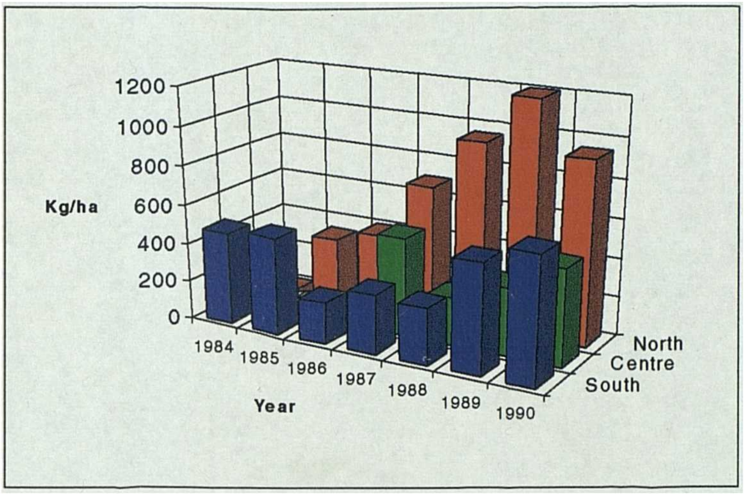


**Figure 2.25. Shrimp farms in Sinaloa.**

**Figure 2.26** shows production yields in kilograms per hectare (kg/ha) for different types of shrimp culture systems within a 7 year period (1984 to 1990). Largest production for extensive farms was in the south of the state, and very low production yields were recorded in the north of the state, except for 1987. Production records for semi-intensive types of culture show that the highest values were found in the north, followed by the south and to a lesser extent in the central region. No data were found for production yields for intensive types of culture systems by region.



**A. Extensive shrimp culture**



**B Semi-intensive culture.**

**Figure 2.26. Production yields for different types of culture systems.**

Source: Delegación Federal de Pesca (1993).

Despite the current state of development, shrimp culture has not reached its full potential and most farms have only one harvest per year. The main problems specific to this activity include: (a) availability of natural postlarvae; (b) social conflicts between farmers and the cooperatives; (c) lack of trained personnel; (d) serious problems in the design, construction and operation of the farm; (e) Mexican approach to shrimp culture has not been systematic; (f) lack of postlarvae produced in laboratories; (g) needs for funding and enhancing foreign investment; and (h) a lack of planning (such as in site selection) and management (Hughes *et al.,* 1991; Vizcarra, pers.comm.).

Aquatic farms which have not been successful are usually abandoned. There are numerous shrimp ponds which have been abandoned such as the "Alvaro Obregón" pond farm adjacent to the Huizache-Caimanero lagoon system, south of Mazatlán (field verification work, April 1995). Aquatic farms for other species have also been abandoned, as in the case of the initially prosperous catfish farm in the municipality of El Rosario, southern Sinaloa, where failure was attributed to water availability and social issues (Cervantes-Castro and Noriega-Curtis, pers.comm.).

## 2.4 Pollution

Currently in Sinaloa, the activities that generate major sources of pollution are: (1) agriculture, (2) tourism, (3) fishing, (4) industrial activities, and (5) increase in population and communications (CEDCP, 1990).

High levels of pollutants have been detected along the coasts of Sinaloa since the 1960's but it was not until the early 1970's that monitoring programmes began. Literature on environmental impacts is limited due to the vast spectrum of pollutants (De la Lanza, 1991; Tovilla-Hernandez, 1991), but discharges from agricultural wastes and especially from sugar factories are the major cause for eutrophication in a great quantity of water bodies.

The state of Sinaloa produces more than 8 million tons of agricultural products. This high production is accompanied by a great quantity of herbicides and pesticides which have been used to increase crop productivity but which have affected soil, water, atmosphere and even food quality in many ways and intensities (CEDCP, 1990). Consequently, local food chains have been considerably altered. There is now a need to establish measures and regulations which can control the use of chemicals in the agricultural areas of the state before they begin to affect public health (INEGI, 1995).

Waste water from sugar-cane factories as well as urban areas, laboratories and industries are mostly found in the northern region of the state where there are usually no treatment plants and wastes are dumped directly into the environment. Consequently, there has been an increase in the levels of toxic waste and organic matter found in rivers, estuaries, coastal lagoons, inlets and bays. This pollution can reach groundwater and consequently affects drinkable water quality because water for human consumption mostly comes from deep wells. It is therefore necessary to establish residual water treatment plants which can restore part of the water quality prior to disposal into the environment. This will also reduce the effects of pollution on agriculture and livestock activities (CEDCP, 1990).

Pollution on the coast of Sinaloa also needs to be considered with respect to its socio-economic development, where there is a rapid expansion of agriculture and an increase in industrialization, marine traffic, fishing boats as well as population. Sinaloa is located in a transition zone between arid and semiarid, and with annual precipitations of 300-800 mm and a high evaporation rate (100-1200 mm/year) there can be a lack of water resources if ecosystems are not managed properly (Flores-Verdugo *et al.*, 1992).

The expansion of agriculture and livestock rearing has altered coastal areas in Sinaloa. Human activities have damaged the environment causing irreversible effects. In some cases alterations in rivers have had many damaging effects such as making serious aquatic alterations and changing sedimentation rates. The indiscriminate use of herbicides and pesticides has had a toxic effect on the processes of primary production. The mismanagement of fertilizers has had negative impacts on the fundamental processes of the lagoon systems. Other similar situations have arisen with urban, industrial and agricultural wastes and those derived by port activities whose discharges affect marine communities. Therefore, there is an urgent need to promote management programmes for the exploitation and adequate restoration of aquatic resources. Although Mexico has an Environmental Secretariat, their records are usually insufficient and such planning is poorly developed (CEDCP, 1990).

## 2.5 Proposed conservation areas

Data from various information sources (Cosmocolor, 1991; EPAC, 1991; Flores-Verdugo *et al.*, 1992) can identify potential conservation areas. These areas contain species which were endangered, in risk of extinction, uncommon or native such as: *Orbignya guacayule* (vegetation in risk of extinction), *Hodomys alleni* (endemic mammal), *Amazilia violiceps* (threatened endemic bird), *Sympholis lippiens* (endemic reptile) and *Rana pustulosa* (endemic frog in risk of extinction) (Cosmocolor, 1991). On the basis of these criteria, researchers have located areas based on the following characteristics: (a) areas which were representative of the species in question, (b) areas which have not suffered from developments (i.e. industrial, urban), (c) areas of historical importance, (d) areas of natural beauty, (e) areas of leisure importance, and (f) areas which are the habitats of migrating native species, in risk of extinction or uncommon for their scientific, ecological or economic vale. Particular attention has been given to the exclusion of mangroves for any development because mangroves give a home to many aquatic species of commercial importance (developments were allowed outside or adjacent to these areas).

Most of the proposed conservation areas are located in the north and decrease towards the south (to Nayarit) along the state's coastline (**Figure 2.27**).

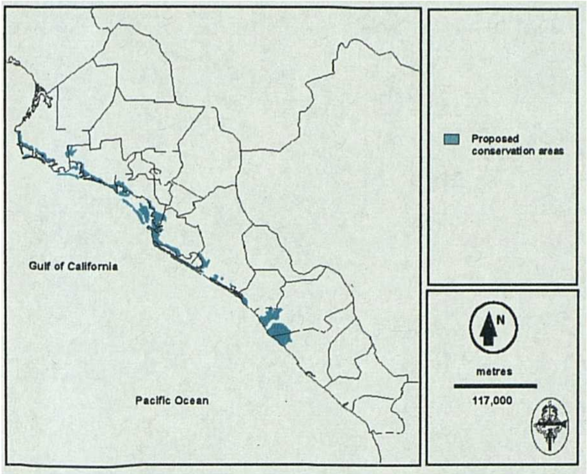


**Figure 2.27. Proposed conservation areas in Sinaloa.**

## CHAPTER 3

# MATERIALS AND METHODOLOGICAL FRAMEWORK FOR DATA COLLECTION AND THE GIS SYSTEM

## 3.1 GIS software

GIS software selection is a crucial component of any GIS evaluation as the user will be semi-dependent upon the software's capabilities. There are many forms of GIS software available (reviewed by Meaden and Kapetsky,1991) but, as with any software in general, it is uncommon to find a single product which will provide all the capabilities required by the user, so often the user has to make a choice based on its main capabilities. Additionally, as more modelling tools become available, it is not uncommon that processes of interest require a capability not built into a GIS system (Eastman, 1995). These cases require the creation of new program modules, but many systems are not well set up for the incorporation of user-defined routines. To alleviate these problems, researchers have had to use more than one software to increase the available tools needed for evaluation (many packages allow easy file import and export). For example, Swindell (1995) used Surfer, AutoCAD and IDRISI, to predict crop yields and to reduce pollution from agricultural chemicals. Ultimately, software selection should be dependent on the research objectives, and should not be entirely dictated by the software's capabilities.

Initially for this study, two packages were available: Arc/Info (PC version) and IDRISI, and so an extensive comparison was carried out between them. Most importantly, Arc/Info is a vector-based GIS software with tremendous cartographic capabilities which provide high quality outputs and very good analytical capabilities and database interfaces. However, Arc/Info is relatively expensive (approximately £5,000) and so it may not be a software that could be implemented for use by a developing country for aquaculture. Moreover, it is not an easy package to use (the manuals themselves take a considerable time to read), and spatial modelling can become very complex due to its vector nature. On the other hand, IDRISI is a low cost (£200) raster-based package which is easily affordable in any country and more importantly, IDRISI's analytical capabilities can produce similar results. Moreover, IDRISI version 1.0 for Windows has increased IDRISI's capabilities (i.e. it is now possible to view a series of images simultaneously, and images can be printed directly without having to export them to another software package). The software is user-friendly and spatial modelling in IDRISI is easier because it is raster-based. Moreover, the system is very compatible with many other GIS packages (i.e. Arc/Info, OSU Map, ERDAS), and recently the use of user-defined routines for the incorporation of programs in any computer language has been enhanced. For the above main reasons IDRISI was selected as the most appropriate software to use.

IDRISI is a low cost, raster-based GIS and was developed at Clark University, Worcester, MA, USA. It is designed to provide a professional-level geographic research tool on a low-cost non-profit basis, and was originally intended as a research and teaching tool that could provide the focus for a collective program of system development and exchange. Since its production in 1987, IDRISI has grown to become the largest raster-based microcomputer GIS and image processing system on the market. It is used in over 120 countries around the world by a wide range of research, government, local planning, resource management and educational institutions. Currently, the IDRISI project employs a permanent staff and has a long term development plan, as well as technical and customer service support (Eastman, 1995).

During its early development, partial financial support was provided by the United Nations Environment Programme Global Resource Information Database (UNEP/GRID), the United Nations Institute for Training and Research (UNITAR), and the United States Agency for International Development (USAID). Currently, all support comes from software sales. However, close relations are maintained with these, and many other international development agencies, in an attempt to provide equitable access to geographic analysis tools.

IDRISI is the technological leader in raster analytical functionality, covering the full spectrum of GIS and Remote Sensing needs from database query to spatial modelling, to image enhancement and classification. Special facilities are included for environmental monitoring and natural resource management, including change and time series analysis, decision-support, uncertainty analysis and simulation modelling. Yet despite the highly sophisticated nature of these capabilities the system is easy to use.

Currently IDRISI is available in versions for both MS-DOS and Windows. Although the two versions are very similar in analytical functionality, IDRISI for Windows offers extended capabilities for display, database query and graphical output.

IDRISI is not a single computer programme, but a collection of over 100 programme modules linked by a unified menu system. These modules fall into one of three broad groups: (1) core modules, providing fundamental utilities for the entry, storage, management and display of raster images; (2) analytical ring modules, providing major tools for the analysis of raster image data; and (3) peripheral modules, associated with data conversion utilities between IDRISI and other programmes and data storage formats. By using independent modules linked by a set of simple data structures, the system allows the user to develop his own modules with minimal regard for the internal working of IDRISI modules in the core set. Furthermore, these modules can be developed in any computer language, and still maintain a simple compatibility (Eastman, 1992).

In this study 3 versions of IDRISI were used as new software was developed and became available. MS-DOS versions 4.0 and 4.1 were used initially, and IDRISI for Windows version 1.0 was used in the final stages of analysis. Advantage was taken of many of the new features as the software developed, to create better image outputs.

### 3.2 Hardware

The GIS software was operated on a 486DX, 66MHz, PC with 8 Mb RAM, 504 Mb Hard disk. Display was via an EIZO Flexscan T660i 52cm colour monitor with a AA51 ultra-high resolution colour graphics controller.

### 3.3 Data storage

The size and number of images in IDRISI is limited by the storage capacity of the computer's hard disk. The only limitation to the image size in IDRISI is the 32,000 integer limit of the PC. That is, in IDRISI an image with up to 32,000 columns by 32,000 rows is possible, but it is uncommon to work with an image this big (Martin, pers. comm.).

The Sinaloa state database comprised of 1,722 columns by 2,230 rows, so the total number of cells for a single image was almost 4 million (3,840,060) which accounted for 10 Mb of hard disk space, and if any distance calculations were carried out these occupied 15 Mb. Even so, these files could be converted into a "packed binary" (file format representing only 5% of the image's original size) using the CONVERT module of IDRISI, thus expanding the storage capacity of the computer. Nonetheless, this was not always possible since it was found that some modules (such as the Multi Criteria-Evaluation (MCE) module) cannot work with these file formats, and therefore the original files (in either real, integer or binary format) had to be used. To alleviate this problem a 2 Gb (Giga bytes) parallel stream DAT backup was used running with ARCSOLO software version 2.2 for DOS, which allowed the storage of large quantities of data to small 2 Gb cartridges. However, even though the data were securely stored, retrieval was still limited by the computer's hard disk storage capacity, so only portions of the database could be retrieved for analysis at a given time. Two solutions were found, but they also proved to have limitations: (1) to allocate space for these images on the network file server, although they were at risk of being damaged or lost; and (2) to create an MS-DOS batch file which could convert these files into packed binary. However, in IDRISI wild cards are not accepted for the conversion of files to packed binary and *vice versa,* so files had to be individually converted, which was very time consuming due to the quantity of images used.

### 3.4 Data capture methods

Paper maps were incorporated into the GIS database by digitizing using an ALTEK DATATAB digitizing table (107 x 152 cm) which can detect locations to within ± 0.25 mm accuracy. The digitizing software used was "TOSCA" which was developed for IDRISI at Clark University. Three versions of the software were used (1, 2 and 2.12). Advantages were taken of some of the new features as new software became available.

In this study setting up the digitizer configuration proved to be a difficult task for two main reasons: (a) there was inaccurate or no on-screen display of raw digitizer output when using "DIAGNOSTICS" (command which initializes the computer's serial port and then sends the reset and stream mode to the digitizer), and (b) a starting node (line end point) appeared instead of an ending node (starting nodes are green empty boxes and end nodes are red boxes) when digitizing in stream mode, so only point digitizing was available. Nonetheless, the correct settings were eventually found (some guidance was provided by the IDRISI project and from Jeffrey F. Jones, creator of TOSCA) and are presented in Appendix 2 in full detail.

### 3.5 Georeferencing and resolution

In IDRISI all geographic files are assumed to be stored according to a grid reference system. Grid referencing systems refer to the systematic way in which the plane (coordinate referring system that uses an arbitrary plane system for which projection parameters are unknown and for which a reference system parameter file is not provided) coordinates of a map sheet relate back to the geographical coordinates of measured earth positions, where grid north is aligned with the edges of the raster image or vector file (Eastman, 1995).

In a GIS it is possible to transfer raster images and vector files from one grid reference system to another. In IDRISI for Windows two programmes are available. In cases where the reference system is plane, RESAMPLE is used. In cases where both the input and the output reference systems are known, and are defined by the reference system parameter (REF) files, PROJECT is used (Eastman, 1995).

In order to transfer images from one grid reference system to another, control points are used. Control points set up the grid reference system for an image file. At least four control points must be entered when digitizing in TOSCA and they do not need to be the corner points of the paper map - they can be any points that have known coordinates and can be entered in any order (Jones, 1995).

Grid cell resolution reflects a relationship between the distance spanned by x and y coordinates and the number of rows and columns in the image. This value is specified by the user. In this study a 250 m resolution was chosen based on the following criteria: (1) the area occupied by the smallest shrimp farm in Sinaloa was 500 x 500 m, (2) the computer's speed and capacity to handle large images, and (3) to allow comparison of the outcome of the GIS results with shrimp farm locations. A 250 m cell resolution meant that one cell in the image covered an area of 250 by 250 metres on the ground.

To determine the number of rows and columns of an image, the length (430,400 m in the x coordinate) and width ( 557,600 m in y) were divided by the 250 m resolution. A single image had 1,722 columns by 2,230 rows, containing 3,840,060 pixels.

The original data obtained for Sinaloa was created in a number of different grid reference systems, so a number of control points had to be determined. Important data sources (such as the location of shrimp farms, and the maps created manually by other studies) were created in a UTM plane reference system. Nonetheless, it was found that large inaccuracies occurred when transferring these specific maps to different reference systems (i.e. lat/long and Lambert Conical Conformal). To make them compatible, all the images for the state analysis were transformed to a UTM plane reference system using the RESAMPLE module in IDRISI. It was found that the state of Sinaloa is located over two UTM zones (12 and 13), so each zone had to be digitized individually and then joined together using the CONCAT V command in IDRISI. The boundary between the two zones is the 108° longitude as shown in **Figure 3.1**. Zone 12 comprises of 156,000 m (624 columns) and 557,600 m (2,230 rows), and zone 13 comprises of 274,400 m (1098 columns) and the same number of metres and rows. Resampling from other grid reference systems to plane references was carried out for images that were not created in a plane reference. Eight control points within each UTM zone gave accurate results when transferring images from one grid reference system to another; the location of these points is shown in **Figure 3.1**.

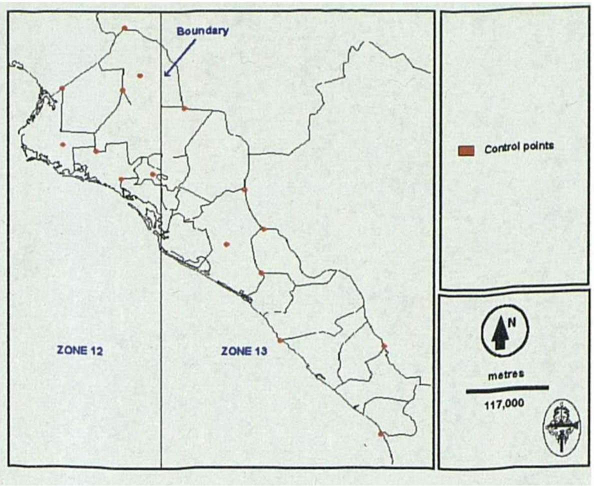


Figure 3.1. Boundary between UTM zones.

### 3.6 Spatial accuracy of paper maps

Uncertainty and error are inevitable in any form of measurement, and digitized map data are no exception. Error issues relate to the accuracy precision, reliability and validity of the measured data. Ideally, assessment of data quality occurs at two stages: before digitizing and after final database editing. Unfortunately the latter is rarely performed. Most digitizing software does, however, provide a simple form of assessment that can provide a rough estimate of the spatial accuracy before digitizing begins. This is the RMS (root-mean-square) error (RMSE) of the control points which establish the relationship between the digitizer and the map, and expresses the degree to which measurements vary from the true value. The RMSE is based on the assumption that errors are random and will thus be normally distributed about the true value. RMSE is therefore equivalent to the standard deviation of that distribution (Jones, 1992).

$$\mathrm{RMSE} = \sqrt{\frac{\sum (x-t)^2}{n-1}}$$

where x = a measurement, and t = true value

Source: Jones (1992).

Approximately 68% of measurements will be found within ±1 RMSE, 95% will be found within ± 2 RMSE, and ± 99.7% within ±3 RMSE (Jones, 1995).

In TOSCA, the RMSE is reported during the "DEFINE FILE" operation, just after digitizing the control points. When digitizing the control point locations on the map, their coordinate positions in the digitizer's grid reference system are also determined. TOSCA computes a best fit linear regression between the digitizer coordinates and the map coordinates.

TOSCA is then able to orientate and scale the map on the digitizing table and transform all digitized coordinates to the map's reference coordinates. As a result of the best-fit procedure for determining the transformation coefficients, TOSCA is able to assess the characteristic error that occurs between the digitized points and their location on the map.

The sources of this RMSE can be numerous, but depend upon the nature of the control points digitized. If control points consist of actual feature locations such as roads and cities, then it is safe to assume that the RMSE reflects a composite of error sources including factors such as eye/hand coordination, source map data quality, and the accuracy of the linear model in describing the relationship between digitizer coordinates and the map's reference coordinates. If, on the other hand, the control points represent only grid intersections used as references for the mapping of features, the RMSE will not reflect errors associated with source map data quality (Jones, 1995).

TOSCA provides a set of procedures for helping to maintain consistency in data quality in accordance with user needs. In general there are four procedures that need to be addressed in the data entry process:

1.- Allowable error is always set in accordance with the intended use of the data. It is dependent on the sources to be used in developing the database. An allowable RMSE may be calculated for any accuracy standard or objective which is required for a given project. The accuracy standard may already be specified for a certain project, or the use to which the data will be put may suggest a logical accuracy objective, or a rule of thumb standard may be adequate in certain situations. Three different starting points can be selected: (a) a stated standard based on the scale of the map referring to the United States National Map Accuracy Standards, but the technique may be applied to any standard based on a map scale; (b) an objective-based profitability of error: for example, a municipality might decide that it needs to record the positions of underground utility lines so that there is no more than one chance in ten thousand that an excavation within 2 metres of a stated position might accidentally intercept a line; and (c) a standard based on expected map products, in cases where there is no well-defined application: for example, a common assumption is that a cartographer can plot positions on a map with a typical error of 0.25 mm.

For purposes of this study an accuracy standard based on scale was used. According to the 1947 revision of the United States National Map Accuracy Standards, maps should have no more than 10 percent of tested points in error by more than 1/30 inch for 1:20,000 scale maps or smaller, and no more than 1/50 inch for maps greater than 1:20,000. Maps used in this Sinaloa study were of four scales (1:1000,000, 1:800,000, 1:250,000 and

1:50,000) so a 1/50 inch error map was the appropriate value to choose.

Conversion of accuracy standards into statistical analysis of the allowable RMSE requires that 90 percent of accidental errors shall be no larger than 1.64 times the RMSE (that is, 1.64 standard deviations, assuming a normal distribution in error) (Eastman, 1992).

Example for a 1:1,000,000 paper map used in this study:

Acceptable error on ground = error on the map x scale conversion x units conversion.
= 1/50 X 1,000,000 X 0.0254
= 508

Allowable RMSE = (Acceptable error on the ground/ Z score probability of occurrence)
= (Acceptable error on the ground/1.64)
= 508 / 1.64
= 310

When the calculated RMSE did not agree with the allowable RMSE, the control points were digitized again and / or a larger number of control points were used to get a more accurate estimate. Should the calculated RMSE have remained high it would have meant that significant error may have existed within the source document (fortunately, this problem did not occur in this study).

2.- Setting the autosnap tolerance. In the process of digitizing it is virtually impossible to digitize exactly the same position twice. However, that is what would be required to join features at nodes, which is an essential requirement when developing a topologically consistent database. The solution to this problem is the "AUTOSNAP" where two nodes are considered to be identical if they are within a certain distance (tolerance) of each other. TOSCA's autosnap feature moves the node currently being digitized to the exact location of the latest node to be digitized in whose tolerance circle the new node is being placed. Points within a distance of each other equal to or less than the allowable RMSE are as likely to be at the same position as they are to being at different positions. Therefore, the snap tolerance, which sets the significant distance between points, was set to express the same position error as the reported RMSE, and was set no larger than the allowable RMSE and no smaller than the calculated RMSE (Jones, 1992). Once the allowable RMSE had been established and the calculated RMSE agreed with that standard, the autosnap parameter helped produce a consistent database.

3.- Setting the point tolerance. The point tolerance refers to the distance which must exist between a point just recorded and the next point to be recorded. If the tolerance is set to

10, for example, TOSCA will not record a new point until it is more than 10 metres from the previous point. The point tolerance was set at half the snap tolerance, as recommended by Jones (1992).

4.- Setting the snap tolerance parameter while editing. To maintain accuracy standards the snap tolerance of the editing session should be set to the same values as the autosnap tolerance when the map was digitized. Snap tolerance while editing was set with the TOLERANCE command in the control box. Nodes which were not snapped while digitizing do not snap during editing. There are three options to solve this problem. First, if it is known which node is misplaced, the incorrectly placed node is moved to within the tolerance circle of the node in the correct location. The second is to digitize a point in the correct location then, while editing, both nodes are moved to the location of that point, and the point is deleted. Third, the snap tolerance is increased and the nodes are snapped (when two points join together).

For the maps used in this study the calculated RMSE was obtained by digitizing the control points. Control points were digitized a number of times for each one of the scales so the final value used represented an average of 20 calculations (this number proved to be sufficient because most values were within the same range). The results of the data quality calculations for these maps are shown in **Table 3.1**. As was expected, both the allowable and calculated RMSE values increased as well as the snap and point tolerances as scale increased, due to the increase in data accuracy and quality of the scale. The highest calculated RMSE was found at a 1:1000,000 scale (100 m). When RMSE is 100 metres (1:1000,000 scale) approximately 68% of all points were digitized within 100 metres of their true position, 95% within 200 m and about 99.7% within 300 m. The calculated RMSE was much smaller than the allowable RMSE and therefore it was an indicator of good spatial accuracy. Moreover, the snap tolerance values (set to the same value as the autosnap tolerance) was set by the difference between the allowable RMSE and the calculated RMSE (e.g. 310 - 100 = 210) instead of choosing a value at random between the RMSE intervals.

**Table 3.1. Results of spatial accuracy calculations based on a 1/50 inch map error and a 0.0254 metre/inch unit conversion.**

| Scale | Acceptable error on ground (m) | Allowable RMSE (m) | Calculated RMSE | Snap tolerance | Point tolerance |
|---|---|---|---|---|---|
| 1:1000,000 | 508 | 310 | 100 | 210 | 105 |
| 1:800,000 | 406 | 248 | 80 | 168 | 84 |
| 1:250,000 | 127 | 77 | 40 | 37 | 18 |

## 3.7 Analysis in GIS

In most GIS systems, the tools provided for analyzing the factors involved in any GIS evaluation fall into four basic groups. The first tool group is called reclassification which creates a new layer of each individual condition of interest. For example, a soil layer which is usually represented by numerous classifications units (e.g. Rendzina and Solonchack in a FAO soil classification) could be reclassified more simply into suitability groups according to their particular characteristics in, for example, a 1 to 4 score range. The second tool group is a mathematical group which contains operations for combining map layers. Three mathematical operations can be carried out. Firstly, creation of a new map layer based on a constant (SCALAR operation), for example, a constant applied to data on altitude may be used to predict mean annual temperature (Eastman, 1992). Second, attribute data value transformation by a standard operation (such as trigonomic functions and log transformations), and thirdly, mathematical combination of different data layers to produce a composite result (OVERLAY operation). The third tool group consists of distance operators. This group provides the tools to construct buffer zones within a specified distance of a feature. Some can evaluate the distance of all locations to the nearest designated features, whilst others can even incorporate frictional effects and barriers into distance calculations. Finally, with the fourth tool group it is possible to create new layers based on the information from an existing map and the context in which it is found, such as the surface analysis where a digital elevation model can be used to produce a slope layer.

## 3.8 Land use classification

Clearly, it is essential that the classification used in a GIS evaluation should enable criteria of land suitability to be assessed in a meaningful and logical way. Classification is crucial for a GIS evaluation at all stages of development. In the initial stages, reclassification is usually carried out (as indicated in the previous section), and as new layers are created these will also need to be classified. GIS final outputs will therefore be strongly dependent on previous classifications, as well as the final classification used (it is common that a final image will contain a large number of factors which are usually reclassified to a smaller number of classes for better understanding).

The problems of class definition, for example the division of soil and landscape into classes, and the assignment of new observations to classes have long exercised the minds of soil scientists and evaluators. Classification is an essential part of the data reduction process, whereby complex data sets of observations are made understandable. Although all classification involves a loss of information, good classification not only aims to reduce information loss to a minimum but, by identifying natural groups of individuals that have common properties, provides a convenient means of information transfer (Burrough, 1989).

Land evaluation is essential in the process of land use planning, because it may guide decisions on land utilization in such a way that the resources of the environment are optimally used, and that a sustained land management is achieved (Tang *et al.*, 1991). The main objective in land evaluation is to classify land in terms of its relative or absolute suitability for a given use (FAO, 1976b). Suitability in this context can be interpreted in two ways. The first concerns the nature of the actual or current physiography of a particular area, without improvement. The second is the potential suitability of an area for given uses through modification of one or more land attributes. In both instances the definition of use-specific land suitability classes is crucial in developing land policy and, moreover, to ensure that land is used in the best possible way. Such considerations are of particular concern in areas where there is evidence of environmental stress through conflicting land uses, and where arable land resources are scarce. In these cases the method of land suitability classification is particularly important (Beek, 1978).

When land needs to be selected to meet specific requirements one commonly used procedure is to define the land requirements in terms of land qualities (FAO, 1976b; Beek, 1978). Land qualities are complex attributes of land such as fertility, or available moisture supply for a given erodibility, that are usually derived from simpler, directly measurable properties. Land qualities are then evaluated in order to decide whether or not a given area is suitable for a particular kind of use (Burrough *et al.*, 1992).

The process of rating land suitability for specific land uses based upon measurable quantitative physiographic characteristics is of considerable importance in developed and developing countries (Vink, 1975). To ensure that scarce land resources are utilized in the most appropriate manner, there are standard methodologies for land use classification: (1) FAO method, (2) limitation method, (3) parametric method, (4) Boolean method, and (5) fuzzy method, all of which have been devised and used extensively for planning and development (Burrough, 1989).

1.- In the FAO method, land suitability for a defined use is classified in terms of limiting land qualities (FAO, 1976b). This classification defines principles for evaluation, but, no specific methodology was suggested to achieve this classification (Tang *et al.*, 1991). Nonetheless, in recent years, a number of methodologies have been developed under this FAO framework such as the following:

2.- In the limitation method each of the land characteristics is evaluated on a relative scale of limitations (Sys *et al.,* 1991). Limitations are imposed when land characteristics deviate form the optimal conditions (Tang *et al.*, 1991).The evaluation consists of the comparison of the characteristics of the land with the requirements of the crop in terms of land characteristics, and the determination of the limitation level for each land characteristic. One single limitation level is attributed to each characteristic, and the final suitability class is determined by the number and intensity of the limitations.

3.- In the parametric method the limitation levels are rated on a scale of 0 to 1 (Sys *et al.*, 1991). When a characteristic of the land is optimal for the intended land utilization type the value 1 is attributed to that characteristic. A lower value is attributed when the characteristic is less favourable. A land index is calculated as the product of the individual rating values of all characteristics multiplied by 100. The suitability classes are determined by the value of the land index (Tang *et al.*, 1991).

4.- In the Boolean method the conceptual basis rests on two fundamental assumptions: first that all questions can be answered exactly because it consists of only 1s and 0s (where 1 signifies true and 0 signifies false) (Eastman, 1992), and secondly, that all important changes occur at the defined class boundary. In almost all cases to date, the process of classifying suitability has conformed to the principles of this theory: crisp or hard partitions of land qualities are utilized to group areas into land-use suitability classes (Wang *et al.*, 1990). However, these assumptions ignore important aspects of gradual variation and measurement error in environmental data (Burrough *et al.*, 1992). Davidson *et al.*(1994) found that there are two main disadvantages when using Boolean logic: (1) the masking of key and positive land properties by less important ones which may depress the overall suitability class; and (2) the inability to take into account the effect of properties which happen to have values near to class boundaries.

5.- In the fuzzy methodology a fuzzy set enables summary, communication and decision-making when spatial information is uncertain (Zadeh *et al.*, 1974; Tang *et al.*, 1991). As its name implies a fuzzy allows gradation from one region to the next. Fuzzy set theory is a generalization of Boolean algebra where zones of gradual transition are used to divide classes, instead of the boundaries. Davidson *et al.* (1994) define fuzzy methodology as a refinement of Boolean logic. Zadeh (1965) proposed that the membership in a set be measured not as a 0 or 1 as in the traditional set theory, but as a value ranging between 0 and 1 (fuzzy set theory). This concept of "the degree of belonging" can be represented in a characteristic function called the "membership function". In this way, the degree of importance of a land characteristic can be expressed by values between 0 and 1; 1 for the most important characteristic and 0 for the least important one.

In summary, the types of classification used in this study were dependent upon the nature of the data used for any evaluation. No single classification was best suited to all of the data used in this study, so trade-offs were established. An FAO classification was required for those factors that needed a limited threshold (such as water bodies), and a Boolean classification was used when a constraint was incorporated in the evaluation (such as protecting existing conservation areas like mangroves). **Table 3.2** provides a summary of the interpretation of these land classification types.

### 3.9 Selection of factors for GIS studies in aquaculture

Land resources are of considerable importance in all countries, especially those in the developing world, and in order to make use of the available land it is of utmost importance to assemble complete and accurate information about this resource (Wang *et al.*, 1990). Aquaculture, like any other economic activity, involves a wide range of interacting factors which between them describe and affect a specific function. These factors are sometimes called production functions (Meaden and Kapetsky, 1991) or criteria (Eastman, 1993). These criteria are of two kinds: factors and constraints (Eastman, 1993). A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. For example, a forestry company may determine that the steeper the slope the more costly it is to transport wood. As a result, better areas for logging would be those on shallow slopes, the shallower the better. The necessary combination of factors will vary in an almost unlimited way; usually more complex activities will involve consideration of more factors. A constraint serves to limit the alternatives under consideration. A good example of a constraint would be the exclusion from development of areas designated as wildlife reserves. In many cases constraints may be expressed in the form of a Boolean (logical) map: areas excluded from consideration being coded with a 0 and those open for consideration with a 1. However, in some instances the constraint will be expressed as some characteristic that the final solution must possess. For example, it may be that the total areas of lands selected for development should be no less than 1,000 $km^2$ . Nonetheless, both forms of constraint have the same ultimate meaning which is to limit the alternatives under consideration (Eastman, 1993).

Table 3.2. Summary of land use classification.

| SUITABILITY ORDER | | FAO | LIMITATION | PARAMETRIC | BOOLEAN | FUZZY |
|---|---|---|---|---|---|---|
| **SUITABLE** | **S1** | Very suitable | Very suitable: land units with no or slight limitations. | Very suitable<br>75 - 100 | Very suitable<br>1 | Very suitable<br>1 |
| | **S2** | Moderately suitable | Moderately suitable: land units with more than 4 slight limitations and/or more than 3 moderate limitations. | Moderately suitable<br>50 - 75 | | |
| | **S3** | Marginally suitable | Marginally suitable: land units with more than 3 moderate limitations and/or more severe limitations. | Marginally suitable<br>25 - 50 | | |
| **UNSUITABLE** | **N1** | Currently unsuitable | Currently unsuitable: land units with very severe limitations that can be corrected. | Currently unsuitable<br>12 - 25 | | |
| | **N2** | Permanently unsuitable | Permanently unsuitable: land units with very severe limitations that cannot be corrected. | Permanently unsuitable<br>0 - 12 | Permanently unsuitable<br>0 | Permanently unsuitable<br>0 |

The selection of factors and constraints involved in a GIS is vitally important since they are the basis of the evaluation. **Table 3.3** shows that aquaculture studies using GIS to date have used from 5 to 32 factors which have varied in nature. This is not surprising because aquaculture is a complex activity (Meaden and Kapetsky, 1991) and the range of relevant factors will therefore be large. Most previous studies have principally incorporated environmental factors although socio-economic aspects were reviewed and incorporated on a simple level as well. Only one study (Gutierrez-García, 1995) is entirely focused on socio-economic factors. Overall, some common factors can be identified such as water resources, water quality, soils, land use and infrastructure. Nonetheless, as noted by Meaden and Kapetsky (1991) "it is difficult to state which functions are of which relative importance since they vary not only objectively, i.e. between types of production units, size of units, types of system, but also subjectively in the view that some fish farmers would be in a better position than others to overcome difficulties". Clearly, any final choice of relevant production functions will depend on the exact circumstances of the study (Meaden and Kapetsky, 1991). The common overall objective must be to exploit the particular advantages of a given site in a sustainable manner, whilst protecting the environment and achieving the most cost-effective stock rearing conditions, taking into account the requirements of both stock and the farmer alike.

## 3.10 Data collection

In order that the potential fish producer can select a site, he must have the necessary information. As discussed by Meaden and Kapetsky (1991), the collection of this information will be one of the most essential activities in the spatial decision-making process. To determine the suitability of locations for aquaculture development in this study, it was necessary to establish which of the factors and constraints found in Sinaloa state, were essential for the activity, and so an extensive review of this information was conducted. Most importantly, it was necessary to investigate which of this data were available. To accomplish this task, a massive data collection was carried out in Mexico (Mexico City, Sinaloa, and Aguascalientes states were visited) during a two month period. The sources of information are presented in **Table 3.4**.

Table 3.3. Criteria selected in GIS studies for aquaculture development (1987 to 1995).

*National planning level studies*

| STUDY AREA | NUMBER of CRITERIA | CRITERIA | AUTHOR | DATE |
|---|---|---|---|---|
| England, U.K. | 14 | Water quality, water temperature, water quantity, groundwater, relief, rainfall, waterway, agglomeration, land costs, road, markets (catering, wholesale, restocking), trout farms. | Meaden, | 1987 |
| Ghana | 15 | Water (annual rainfall, evaporation), land ( water surface of lake Volta and lagoons, soils, forestry reserved areas), inputs (cattle, pig, poultry and rice bran), markets, welfare, extension services, agglomeration and development (roads). | Kapetsky *et al.*, | 1990 |
| Pakistan | 9 | Surface water availability, rainfall, groundwater, air temperature, soil type, slope, fish seed, markets, roads. | Ali, C.Q. *et al.*, | 1991 |
| Norway | 32 | Environment (wave exposure, shallow areas, critical temperatures, icing conditions, salinity, pollution); tidal range; water exchange; current utilization (housing, outdoor recreation, traditional fishing); infrastructure (road, electricity, feed manufacture, slaughtering facilities, waste disposal facilities); special areas (existing fish farms, protection zones for salmonids, nature conservation areas, defence areas, areas earmarked by local authorities); existing loading capacity (sewage, agriculture, industry, precipitation, agriculture, forests, mountains, moorlands); aquaculture permits; open coastal areas and fjords. | Ibrekk *et al.*, | 1991 |
| Nepal | 9 | Annual precipitation, climate, soil, irrigation, relief, agriculture, communications, population density, irrigated land. | Karki, | 1992 |
| Africa | 8 | Water temperature, annual rainfall, streams and rivers, soil texture, slope, market, agricultural by-products and road infrastructure. | Kapetsky, | 1994 |

Note: Ibrekk *et al.* (1991) GIS study was based on a database management system (DMS). To date this study should have been digitized and incorporated into a more spatially orientated GIS.

## *Regional planning level studies*

| STUDY AREA | NUMBER of CRITERIA | CRITERIA | AUTHOR | DATE |
|---|---|---|---|---|
| Gulf of Nicoya<br>Costa Rica | 23 | Fresh and salt water, salinity, soils, infrastructure (villages, roads, ferries, processor, electric service), land uses (water, coniferous forest, decidious forest, range, pasture, marsh, cropland, shrimp ponds, salt work ponds mangroves) bathymetry, shelter and security, shrimp postlarvae. | Kapetsky *et al.*, | 1987 |
| Franklin parish (county), Louisiana, U.S.A | 5 | Soil suitability for ponds and levees, commercial buildings, roads and heavy equipment. | Kapetsky *et al.*, | 1988 |
| Johor State<br>Malaysia | 21 | Water quality (Ammoniacal nitrogen, BOD, pH), annual rainfall, soils (hydrogen ion concentration, texture), infrastructure (primary roads, secondary roads, cities & towns) land use (agriculture, urban, mining, district, drainage basin), shrimp farms, cages, bathymetry (mud-banks, contours), shelter, currents. | Kapetsky, | 1989 |
| Louisiana state, U.S.A | 14 | National and state parks and wild life refuges, urban areas, inland water bodies, parish boundaries, soils distributions and topography, soil suitability, soil characteristics, length of growing season, yields and surface area of catfish, rice and grain sorghum farming. | Kapetsky *et al.*, | 1990 |
| Yucatan state<br>Mexico | 12 | Freshwater lakes, sinkholes, clogged sinkholes, seasonal ponds, gravel querries, precipitation, land elevation ,soils, agriculture, population centres, villages and roads. | Flores-Nava, | 1990 |
| Eastern Coast of Prince Edward Island, Canada. | 13 | Shellfish leases, lease owners, coastline, river systems, roads, county divisions, shellfish closure zones, shellfish approved zones, land-based pollution sources (i.e. waste-water outfalls), agricultural activities, known and potential pollution sources, waste disposal sites. | Legault, | 1992 |
| Tabasco state<br>Mexico | 22 | Lakes, rivers, streams, groundwater, rainfall, evaporation, climate, oil wells, pipe lines, factories and buildings, soils, relief, topography, agriculture, vegetation, livestock rearing, forestry, roads and cities, population density and agglomeration. | Aguilar-Manjarrez and Ross, | 1993 |
| Lingayen Gulf, San Miguel and Calatrava Bay. Philippines | 20 | Soil texture, physiography (tidal flats, beaches, alluvial areas), elevation, land use (grasslands, swamps, coconut plantations, unproductive agricultural land, degraded mangrove areas, national parks, paddy fields, settlements), roads (private, provisional or national), water source (seashore, rivers), eco-zones (buffer zone from rivers & shoreline). | Paw *et al.*, | 1994 |
| Sinaloa state<br>Mexico | 30 | Lagoons, rivers, streams, rainfall, evaporation, groundwater, lakes, dams, temperature, soils, topography, agriculture, irrigation, forestry, livestock rearing, shrimp farms, natural postlarvae, mangroves, population density, industries, sugar factories, domestic pollution, cities, towns, villages, paved roads, gravel roads, railways, dirt roads and conservation areas. | Aguilar-Manjarrez and Ross, | 1995 a,b |
| Tabasco state<br>Mexico | 15 | Potential jobs, entrepreneurial tendencies, fishing traditions, rural cooperation, activity conflicts, road system & transport type, farms, hatcheries, agglomeration, related industry, communications, disposable income, consumption per capita and population density. | Gutierrez-García, | 1995 |

## Site planning level studies

| STUDY AREA | NUMBER of CRITERIA | CRITERIA | AUTHOR | DATE |
|---|---|---|---|---|
| Yaldad Bay, Chile | 7 | Bathymetry, bottom salinity, sediment type, organic content, percent shells in sediment, number of species and density of macroinfauna. | Krieger and Mulsow, | 1990 |
| Camas Bruaich Scotland | 5 | Site, salinity, currents, wave height and bathymetry. | Mendoza, Q-M<br>Ross *et al.*, | 1991<br>1993 |
| Camas Bruaich Scotland | 7 | Site, salinity, currents, wave height, bathymetry, dispersion of dichlorvos from cages and dispersion of solid wastes around cages. | Beveridge *et al.*, | 1994a |
| Maryland's Chesapeake Bay. | 19 | Spatfall, mortality, population size structure, disease prevalence and intensity, locations and extent of all charted oyster bars, bottom characteristics, geographic boundaries and features, bathymetry, salinity, temperature, shell and seed planting, seed movement, harvest, lease boundaries and boundaries of special management areas. | Smith *et al.*, | 1994 |

Note: Smith *et al.* (1994) was only available as an abstract.

Table 3.4. Information sources for data collection in this study.

| SOURCE | TYPE OF DATA | LOCATION |
|---|---|---|
| BIOPESCA | Satellite image (shrimp farm locations). | Ensenada, Baja California, Mexico. |
| CETENAL (Comisión de Estudios del Territorio Nacional). | Paper maps. | Mexico City |
| CIAD (Centro de Investigación en Alimentación y Desarrollo en Acuicultura y Manejo Ambiental). | Aquaculture studies, paper maps. | Mazatlán, Sinaloa. |
| CNA (Comisión Nacional del Agua). | Water resources data, paper maps. | Villa Union, Sinaloa. |
| GEOCENTRO | Paper maps. | Mexico City |
| IMTA (Instituto Mexicano de Tecnología del Agua). | Water resources data on compact disks. | Cuernavaca, Morelos, Mexico |
| INEGI (Instituto Nacional de Estadística, Geografía e Informática). | Paper maps, DEM, socio-economic data & literature. | Aguascalientes and Mexico City. |
| ITESM (Instituto Tecnológico y de Estudios Superiores de Monterrey). | Socio-economic data & literature. | Mazatlán |
| Palacio de Gobierno (Sanchez and Vega). | Land tenancy data. Socio-economic literature. | Culiacán, Sinaloa. |
| PESCA (now called SMARNyP). | Shrimp farms location production data, environment studies. | Mexico City, Mazatlán, Los Mochis and Rosario in Sinaloa. |
| SARH (Secretaría de Agricultura y Recursos Hidráulicos). | Paper maps. | Mexico City |
| SCT (Secretaría de Comunicaciones y Transportes). | Paper maps. | Mexico City |
| SMN (Servicio Metereológico Nacional). | Statistical water resources data. | Mexico City |
| SPP (Secretaría de Programación y Presupuesto). | Paper maps. | Mexico City |
| Stanfords | Paper maps. | London, U.K. |
| UAS (Escuela de Ciencias del Mar, Universidad Autónoma de Sinaloa). | Water quality. | Mazatlán, Sinaloa. |
| UNAM (Universidad Nacional Autónoma de México). | Environment studies. | Mexico City and Mazatlán. |
| University of Illinois (Department of Atmospheric Sciences). | Hurricane image. | Illinois, U.S.A. |
| **CONSULTING COMPANIES** | | |
| Acuipesca Consultores | Aquaculture studies. | Mexico City |
| CIFSA (Consultores en Ingeniería Fluviomarítima, S.A.). | Aquaculture studies paper maps, socio-economic data. | Mexico City |
| CONSULTEC (Consultoría Técnica). | Aquaculture studies, paper maps. | Mexico City |
| Cosmocolor | Aquaculture studies, paper maps. | Mexico City |
| EPAC | Aquaculture studies, paper maps. | Mexico City |

Note: Includes data sources for the entire study (i.e. not only for the state-level assessment).

A range of spatially variable data were obtained which broadly fell into two categories. The first category was primarily concerned with the natural resources (e.g. water availability, soils, relief, climate, temperature, topography and land use), whilst the second category comprised the socio-economic factors (e.g. accessibility to roads and fish markets, inputs and supplies, population density and agglomeration). Constraints were identified which were the same for both categories, i.e. either category would be constrained to areas outside conservation areas (such as mangroves) and potentially polluted areas (urban development, cities, towns, factories and industries). The criteria selected and obtained are shown in two tables. **Tables 3.5** and **3.6** summarize all the data that were used for the Sinaloa state-level assessment. Approximately 90% of the data were derived from paper maps (from national cartography institutions as well as from consulting companies). Other sources included statistical information, questionnaires and data available on computer disks and C.D. (such as population census and digital elevation models).

**Tables 3.5** and **3.6** provide detailed information on the data obtained. Most of these data were obtained from Mexico's National Institute of Geography, Information and Statistics (INEGI), but a great deal of information was also obtained from other sources, such as studies carried out by Mexican consulting companies (e.g. Cosmocolor and EPAC). Most data were generated between 1981 and 1993. A variety of scales were used and most of the map projections were created in a UTM projection. Some data (i.e. roads and urban development and population density) are repeated in the tables because they were used in both the environmental analysis and the socio-economic evaluation.

**Table 3.5. Sources of data for the environmental criteria for aquaculture development in Sinaloa.**

| CRITERIA | NAME | SOURCE | LOCATION | DATE | PROJECTION | SCALE |
|---|---|---|---|---|---|---|
| Surface water | *Hydrology & surface water chart* | *SPP* | Mexico City | 1981 | LCC | 1:1000,000 |
| Surface water | Tactical Pilotage chart<br>Sheets H-22B, H-22D H-22C, and J-24A | DMA | St. Louis Missouri,<br>U.S.A (Stanfords, London, U.K.) | 1984<br>86,87,89 | LCC | 1:500,000 |
| Surface water | Hydrology chart | EPAC | Mexico City | 1991 | UTM | 1:250,000 |
| Surface water | Hydrological units chart | Cosmocolor | Mexico City | 1991 | UTM | 1:250,000 |
| Groundwater | Hydrology & groundwater chart | SPP | Mexico City | 1981 | LCC | 1:1000,000 |
| Evaporation | Evaporation & water deficit chart | SPP | Mexico City | 1983 | LCC | 1:1000,000 |
| Evaporation | Evaporation & water deficit chart | EPAC | Mexico City | 1991 | UTM | 1:250,000 |
| Rainfall | Annual mean rainfall chart | SPP | Mexico City | 1983 | LCC | 1:1000,000 |
| Temperature | Annual mean ambient temperature chart | SPP | Mexico City | 1981 | LCC | 1:1000,000 |
| *Hurricane* | Hurricane Rosa image. | Univ. Illi. | Illinois, U.S.A. | 1994 | - | - |
| Mangroves | Land use and vegetation chart | SPP | Mexico City | 1981 | LCC | 1:1000,000 |
| Mangroves | Vegetation chart | EPAC | Mexico City | 1991 | UTM | 1:250,000 |
| Soils type and texture | Soils chart | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Soils | Soils chart | EPAC | Mexico City | 1991 | UTM | 1:250,000 |
| Topography | *State road chart* | SCT | Mexico City | 1986 | UTM | 1:800,000 |
| Digital elevation model | Digital elevation model. Computer disks. | INEGI | Aguascalientes, Mexico | 1994 | UTM | 1:250,000 |
| Natural postlarvae | Fishing communities chart | Pesca | Mazatlán, México | 1993 | UTM | 1:250,000 |
| Forestry | Potential use of forestry chart | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Livestock rearing | Livestock rearing. *State chart* | CIFSA | Mexico City | 1993 | UTM | 1:800,000 |
| Agriculture | Potential use of agriculture chart | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Agriculture suitability | Agriculture-aquaculture conflicts chart | EPAC | Mexico City | 1991 | UTM | 1:250,000 |
| Livestock rearing | Potential use of livestock rearing chart | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Aquaculture suitability | Capacity *to develop aquaculture chart* | EPAC | Mexico City | 1991 | UTM | 1:250,000 |
| Aquaculture suitability | Environment *landscape classification* | Cosmocolor | Mexico City | 1991 | UTM | 1:250,000 |
| Shrimp farm locations | *Aquatic* farm locations chart | EPAC | Mexico City | 1991 | UTM | 1:250,000 |
| Shrimp farm locations | Shrimp farm location & area chart | Pesca | Mazatlán, Mexico | 1993 | UTM | 1:250,000 |
| Industries | Industries-aquaculture conflicts chart | EPAC | Mexico City | 1991 | UTM | 1:250,000 |
| Industries | Industries, fishing, hotels & markets chart | CIFSA | Mexico City | 1993 | UTM | 1:800,000 |
| Cities, towns, villages | Road state chart | SCT | Mexico City | 1986 | UTM | 1:800,000 |
| Urban development | Population census. Statistical information | INEGI | Mexico City | 1991 | - | Choropleth |
| Urban development | Road state, chart (Municipalities area) | SCT | Mexico City | 1986 | UTM | 1:800,000 |
| Roads | Road state chart | SCT | Mexico City | 1986 | UTM | 1:800,000 |
| Conservation areas | Environmental politics chart | Cosmocolor | Mexico City | 1991 | UTM | 1:250,000 |
| Conservation areas | Environmental problems chart | EPAC | Mexico City | 1991 | UTM | 1:250,000 |

TERMINOLOGY: SPP (Budget and Programming Secretariat), INEGI (National Institute of Statistics, Geography and Information), DMA (Defence Mapping Agency. Aerospace Center) SCT (Communications and Transport Secretariat). CIFSA, Cosmocolor and EPAC are private consultancy companies which were hired to do the studies for the fisheries secretariat (Secretaría de Pesca). Univ. Illi. (University of Illinois. Department of Atmospheric Sciences). Pesca refers to the Fisheries state central office in Mazatlán, Sinaloa. Projections: LCC (Lambert Conformal Conic), UTM (Universal Transverse Mercator). **Note: SPP data is sold by INEGI.**

**Table 3.6. Sources of data for the socio-economic criteria for aquaculture development in Sinaloa.**

| CRITERIA | NAME | SOURCE | LOCATION | DATE | PROJECTION | SCALE |
|---|---|---|---|---|---|---|
| Population density | Population census data. Computer disks. | INEGI | Mexico City | 1993 | UTM | Municipality |
| Staff, technical assistance | Population census data. Sinaloa state. | INEGI | Mexico City | 1991 | - | Choropleth |
| Agglomeration | Aquatic farm locations | EPAC | Mexico City | 1991 | UTM | 1:250,000 |
| Agglomeration | Shrimp farm location & area | Pesca | Mazatlán,Mexico | 1993 | UTM | 1:250,000 |
| Economically active population | Population census data. Sinaloa state | INEGI | Mexico City | 1991 | - | Choropleth |
| Income | Population census data. Sinaloa state | INEGI | Mexico City | 1991 | - | Choropleth |
| Production activities | Population census data. Sinaloa state. | INEGI | Mexico City | 1991 | - | Choropleth |
| Natural postlarvae | Fishing communities areas | Pesca | Mazatlán,México | 1993 | UTM | 1:250,000 |
| Roads | Road state chart | SCT | Mexico City | 1986 | UTM | 1:800,000 |
| Cities, towns, villages | Road state chart | SCT | Mexico City | 1986 | UTM | 1:800,000 |
| Markets | Industries, fishing, hotels & markets chart | CIFSA | Mexico City | 1993 | UTM | 1:800,000 |
| Processing facilities | Industries, fishing, hotels & markets chart | CIFSA | Mexico City | 1993 | UTM | 1:800,000 |
| Fertilizer and lime | Potential use of agriculture chart | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Fertilizer and lime | Potential use of livestock rearing chart | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Energy | Population census data. Sinaloa state. | INEGI | Mexico City | 1991 | UTM | Choropleth |
| Municipalities | Road state chart. (Municipalities areas) | SCT | Mexico City | 1986 | UTM | 1:800,000 |
| Conservation areas | Environmental politics chart | Cosmocolor | Mexico City | 1991 | UTM | 1:250,000 |
| Conservation areas | Environmental problems chart | EPAC | Mexico City | 1991 | UTM | 1:250,000 |

TERMINOLOGY: SPP (Budget and Programming Secretariat), INEGI (National Institute of Statistics, Geography and Information), SCT (Communications and Transport Secretariat). CIFSA and EPAC are private consulting companies which were hired to do the studies for the Fisheries Secretariat (Secretaría de Pesca). Pesca refers to the Fisheries central state office in Mazatlán, Sinaloa.

Note: The Municipality factor served to create chloropleth maps when statistical information was the only source of information available (i.e. population density, staff & technical assistance, economically active population, income, production activities and urban development)

# CHAPTER 4

# SPATIAL MANIPULATION, CLASSIFICATION AND INTEGRATION OF PRIMARY CRITERIA

## 4.1 Background

For clarity, the terms used in this study are defined in Table 4.1.

**Table 4.1. Definition of terms used.**

| CONCEPTS | DESCRIPTION |
|---|---|
| Data | Raw information, statistics, figures, materials. |
| Production function | Those factors controlling economic activities have been called production functions since what is produced is a function of various combinations of the controlling factors (Meaden and Kapetsky, 1991). |
| Criterion | Synonymous to production function. Criteria are of two kinds: factors and constraints (Eastman, 1993). |
| Factor | Criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration (Eastman, 1993). |
| Constraint | Criterion that serves to limit the alternatives under consideration (Eastman, 1993). |
| Primary data | First manipulation and classification of data selected for spatial analysis. |
| Primary criteria | Criteria which have been manipulated and classified for spatial analysis. Integration of some criteria into submodels. Initial stages of the GIS-based models in this study. |
| Secondary criteria | Renamed primary criteria after initial stages of the GIS-based models. Secondary stages of the GIS-based models in this study. |
| Tertiary criteria | Production activities or objectives used for MOLA ( e.g. aquaculture, agriculture ). |
| **IDRISI MODULES** | |
| ASSIGN | Creates new images by linking the geography of features defined in an image file with attributes defined in an attribute values file. By separating attributes from the geography of the features which possess them, this module allows one to use the power of spreadsheet and data base management packages as an integral part of the IDRISI system (Eastman, 1992). |
| CROSSTAB | Performs two operations. The first is image cross-tabulation in which the categories of one image are compared with those of a second image and a tabulation is kept of the number of cells in each combination. The result of this operation is a table output to the printer listing the tabulation totals as well as one and possibly two measures of association between the images. The second operation that CROSSTAB offers is cross-classification which can be linked to a multiple overlay showing all combinations of the logical AND operation. The result is a new image that shows the locations of all combinations of the categories in the original images (Eastman, 1992). |
| DISTANCE | Measures the Euclidean distance between each cell and the nearest set of target features. Distances are output in reference system units (Eastman, 1992). |
| FUZZY | Evaluates the possibility that each pixel belongs to a fuzzy set by evaluating any of a series of fuzzy set membership functions. Functions are controlled by four points ordered from low to high on the measurement scale. The first point marks the location where the membership function begins to rise above 0. The second point indicates where it reaches 1. The third point indicates the location where the membership grade begins to drop again below 1, while the fourth point marks where it returns to zero (Eastman, 1993). |

### Table 4.1 Continuation.

| | |
|---|---|
| HISTO | Produces a frequency histogram of cell values in an IDRISI image. HISTO creates histograms by dividing the data range into classes of a user specified width. The frequency within each class is tabulated. Both graphic and numeric options are available. HISTO also outputs basic statistics about the file (Eastman, 1992). |
| MCE | In Decision theory, multi-criteria evaluation (MCE) is the process by which several criteria are evaluated in order to meet a specific objective (Eastman *et al.,* 1993). Technique used for three purposes: 1) standardization of thresholds of primary criteria; 2) development of GIS-based submodels and models in this study; and 3) used for the MOLA technique for complementary objectives. |
| MOLA | In Decision theory, multi-objective land allocation (MOLA) is the decision process in which several objectives are satisfied simultaneously. These objectives may be complementary, in which case the IDRISI MCE module is used, or conflicting, when the IDRISI MOLA module is used (Eastman *et al.,* 1993). Production activities were used as synonymous to objectives in this study when using MOLA. |
| OVERLAY | Produces a new image from the data on two input images. New values result from any of the following operations on the two input images: add, subtract, multiply, ratio, normalized ratio, exponentiate, cover, minimize and maximize (Eastman, 1992). |
| RANK | Rank orders cells in a byte binary image. Primary application in decision-making where a specified area (or number of cells) is required that contains the best, or worst, cells according to some index (Eastman *et al.*, 1993). Was used for MOLA in this study. |
| RECLASS | Classifies or reclassifies the data stored in images or attributes values files into new integer categories. Classification or reclassification is by equal intervals division of the data range, or by the application of user-defined limits (Eastman, 1992). |
| RESAMPLE | Registers the data in one grid system to a different grid system covering the same area (Eastman, 1992). |
| SAMPLE | Produces a vector file of point locations for use in sampling problems. The points may be selected according to a random, systematic or stratified random sampling scheme (Eastman, 1992). |
| SCALAR | Does scalar arithmetic on images by adding, subtracting, multiplying, dividing or exponentiating the pixels in the input image by a constant value (Eastman, 1992). |
| STRETCH | Rescales image values to fall with a range from 0 to a user-specified upper limit (Eastman, 1992). |
| SURFACE | Calculates slope, aspect and shaded relief images from a digital elevation model, and can create shaded relief images from slope and aspect images (Eastman, 1992). |
| TSA | Used for the analysis of long time series of image data. At present up to 84 images may be analyzed simultaneously. The output from TSA includes both a temporal and spatial analysis, which should be analyzed together (Eastman, 1993). |
| WEIGHT | Used to develop a set of relative weights for a group of factors in a multi-criteria evaluation. The weights are developed by providing a series of pairwise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated. These pairwise comparisons are then analyzed to produce a set of weights that sum to one. The weights can then be used with the factors to produce a weighted linear combination using the MCE module (or the SCALAR and OVERLAY modules). The procedure by which the weights are produced follows the logic developed by Saaty (1977) under the Analytical Hierarchy Process (AHP) (Eastman *et al.*, 1993). |
| **TOSCA MODULES** | |
| Vconcat | Creates a new file by concatenating one or more files. Topological information is retained (Jones, 1995). |
| Vwindow | Extracts a rectangular section of an existing vector file (Jones, 1995). |

A schematic diagram showing the procedures involved in manipulating, classifying and integrating the data in this study is shown in **Figure 4.1**.

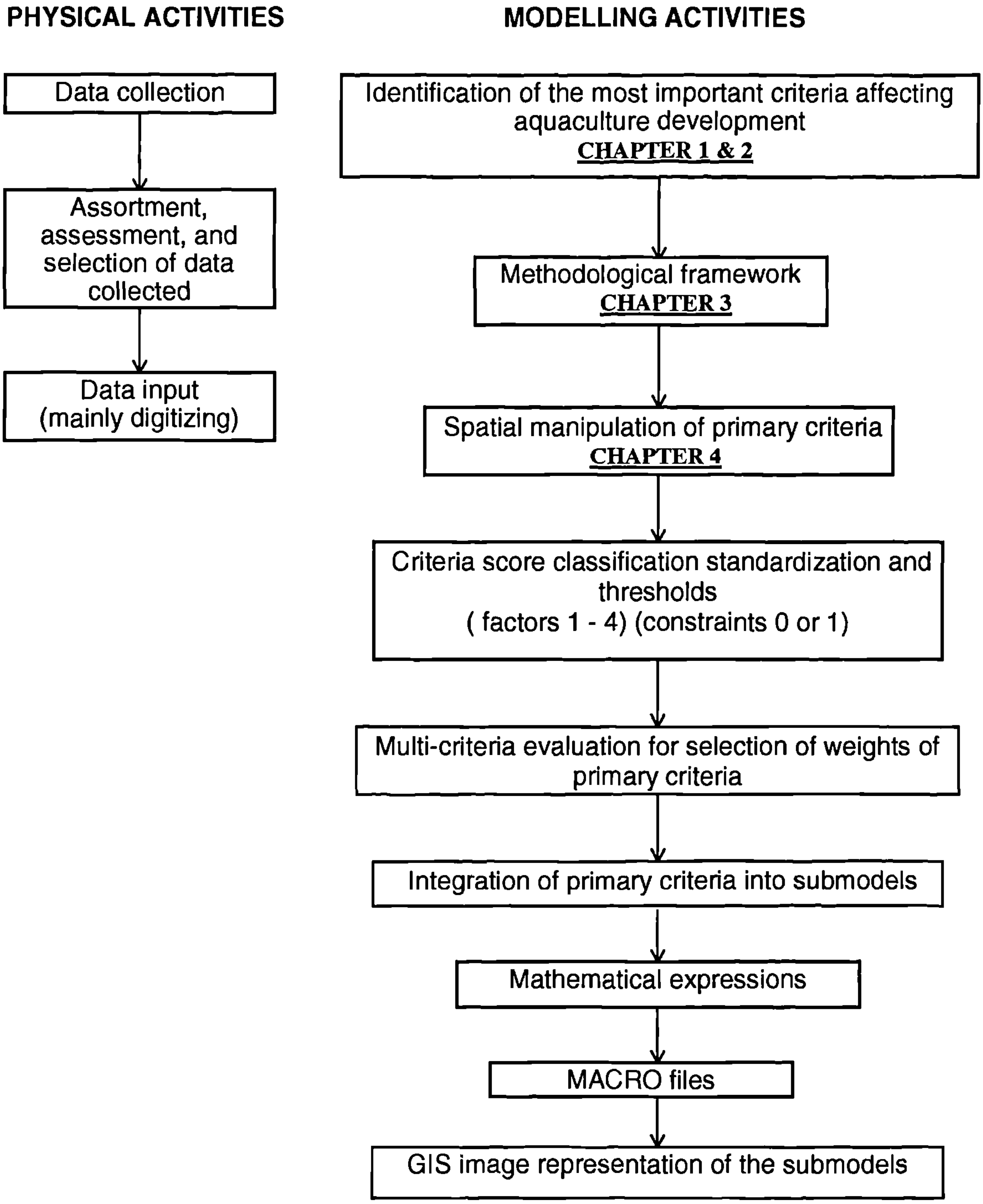


**Figure 4.1. Schematic diagram of procedures that were involved in manipulating, scoring and integrating the primary criteria in this GIS study.**

## *FACTORS*

### *Spatial manipulation*

Depending on the origin of the data, the factors could be spatially manipulated in different ways:

1. To suit the spatial evaluation in IDRISI all factors had to be positive with respect to suitability; as a scale range increases it also has to signify an increase in suitability (Eastman, 1992).

2. Some factors were reclassified using the RECLASS or ASSIGN module according to their previous raw data classifications. For example, the classification already provided in an agricultural paper chart could be reclassified in terms of aquaculture suitability (i.e. a highly intensive type of agriculture would have a low score for aquaculture because these sites would be likely to have pollution problems from pesticides or herbicides).

3. When data were only available in statistical form it was incorporated as a choropleth map (map which depicts average values per unit of area over an administrative region) at a municipal level, since a municipality is the lowest order of organization from which the data is reported.

4. In cases where land areas were small, a distance range was created using the DISTANCE module of IDRISI. This applied to factors such as factories or rivers which are commonly represented spatially as either points or lines (although a distance range could also be used for polygons when small land areas need to be considered). For example, to evaluate water availability from a lagoon, a proximity range (or buffer zone) was created using the DISTANCE module in IDRISI. Therefore, a range of values was created (1 - 4), those closest to the lagoon were given a score of 4 and the furthest away a score of 1. Moreover, the DISTANCE module was also used to represent distances from pollution sources, such as distances from industries or urban developments in order to avoid and/or mitigate possible pollution problems.

5. Certain factors shared two different classifications or interpretations - many factors were used for both the environmental and socio-economic evaluation. For example, the urban development factor was considered as having a positive effect in the socio-economic evaluation and a negative effect in the environmental evaluation. Moreover, factor interpretation was dependent on how this data were assessed on a type of culture system (i.e. extensive, semi-intensive and intensive) and how the factor was integrated with other factors to model a particular query. Because some factors have different classifications for the environmental and socio-economic evaluations, to indicate which one of the factors is being used in the mathematical expressions

and the macro files of the GIS-based models produced in this study, an "(e)" has been added to the names of those factors classified in terms of environment, and an "(se)" has been added to the names of those factors classified from a socio-economic point of view.

### *Standardization and thresholds*

Because of the different scales upon which raw data are measured, it was necessary to adopt a standard classification method (or threshold). The Sinaloa database was revised by giving each factor a physical score from 1 to 4: either very suitable (4), moderately suitable (3), marginally suitable (2), and unsuitable although still with some potential (1). This classification proved to be appropriate because it was found that most thematic maps were classified to a range of four values, and that it matched the FAO classification in terms of suitability of land for defined uses. The majority of thresholds were identified through literature research (e.g. soil textural class) and guidance from expert staff at the Institute of Aquaculture in Stirling and consequently, it was possible, in most cases, to make sound judgements between suitability classes. However, in other cases, it was difficult to establish a borderline. To solve this problem, three techniques were used:

1. *Percentage data*: When assigning scores to percentage data defined thresholds were established as shown in **Text Box 4.1.**

**Text Box 4.1. Percentage threshold.**

80 - 100 = Very suitable
50 - 79.9 = Moderately suitable
20 - 49.9 = Marginally suitable
0 - 19.9 = Unsuitable although with some potential

2. *Frequency distribution*: It was found that an analysis of the frequency distribution of the data could be used in cases where it was most difficult to establish borderlines. Sturges (1926) provides a formula that can serve as a guideline (i.e. the number of thresholds are commonly increased or decreased for convenience): $k = 1 + 3.322\ (\log_{10} n)$.

where k = number of thresholds and n = number of values in the data set under consideration.

Example: For a sample of 275 observations that needed to be grouped (logarithm to the base 10 of 275 is 2.4393): $k = 1 + 3.322\ (2.4393) \approx 9$. In practice, however, other considerations might cause the use of 8 or 10 or more class intervals.

Another criterion that had to be determined was the width of the thresholds. Although sometimes impossible, thresholds generally should be of the same width. Daniel (1987) suggests that this width may be determined by dividing the range by $k$:

$$w = \frac{R}{k}$$

where; w = width of the threshold, and $R$ (the range) is the difference between the smallest and the largest data in the dataset.

For example: If the largest data is 79 and the smallest is 12, then:

$$w = \frac{R}{k} = \frac{79 - 12}{9} \quad \frac{67}{9} \approx 7$$

The result of applying the Sturges (1926) and the Daniel (1987) formulae was only used as guideline. For optimum results, a histogram was created to assess the frequency distribution of the data. Moreover, once the width of the threshold was determined using the Daniel formula, the same class width was used for each one of the suitability classes. For example, for a sample of 10 numbers, the largest number of data remains in the moderate and marginal classifications while the smallest remain in the very suitable and unsuitable classifications as shown in **Text Box 4.2**. This technique proved to be useful throughout this GIS study, but should be applied with common sense (i.e. careful analysis of the data in hand).

**Text Box 4.2. Frequency distribution threshold.**

Number of thresholds: ( Sturges, 1926 )
$k = 1 + 3.322 ( \log_{10} n )$

Threshold width: ( Daniel, 1987 )
$w = R/k$

Example:
1,2 = Very suitable
3,4,5 = Moderately suitable
6,7,8 = Marginally suitable
9,10 = Unsuitable although with some potential.

3. *Weights.* After standardizing all of the data sources to a common scoring system it was necessary to establish the relative importance between the factors by developing weights. Relative importance is usually judged according to several criteria, and each criterion may be shared by some or all of the activities. Although a variety of techniques exist for the development of weights, one of the most promising is that of a pairwise comparison developed by Saaty (1977) known as the Analytical Hierarchy Process (AHP). The first introduction of this technique to a GIS was that of Rao *et al.* (1991), although the procedure was developed outside the GIS software using a variety of analytical resources. In IDRISI a module called Multi-Criteria Evaluation (MCE), is based on the AHP to facilitate the decision-making process (Eastman, 1993). The primary issue of this technique relates to the standardization of criteria scores and weights.

Using MCE the factors being used in the GIS were rated in terms of their relative importance in achieving the stated objective. Ratings were systematically scored on a 17-point continuous scale according to Saaty (1977) from 1/9 (least important) to 9 (most important). For example, if it was considered that proximity to roads was much more important than slope in determining the suitability for pond aquaculture, one would enter a 5 on this scale. In the inverse case where slope was much more important than proximity to roads one would enter 1/5. A more detailed description of this continuous rating scale is presented in **Table 4.2.**

**Table 4.2. The continuous rating scale and its description.**

| INTENSITY OF IMPORTANCE | DEFINITION | EXPLANATION |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective. |
| 3 | Weak importance of one over another | Experience and judgement slightly favour one activity over another. |
| 5 | Essential or strong importance | Experience and judgement strongly favour one activity over another. |
| 7 | Demonstrated importance | An activity is strongly favoured and its dominance is demonstrated in practice. |
| 9 | Absolute importance | The evidence favouring one activity over another is of the highest possible order of affirmation. |
| 2,4,6,8 | Intermediate values between the two adjacent judgements | When compromise is needed. |

Source: Saaty (1977).

To illustrate the approach, five factors were chosen to infer the relative quality of the water for aquaculture: suitable temperature (a very important limiting factor since it regulates factors such as species behaviour, feeding and growth), suitable soils (to avoid acidic soils harmful to aquatic life), distance from forests (indicators of good water quality but far enough to minimize construction costs), low input agriculture (small risk of pesticide and herbicide pollution), distance from irrigation (to minimize risk of pollution such as pesticides). The procedure developed by Eastman (1993) then required that the matrix be computed to produce a best fit set of weightings. Since the weightings sum to one, a resulting suitability map would have a range of values that matched those of the standardized factor maps (1 - 4). In developing the weights, the decision-maker compares every possible pairing and enters the ratings into a pairwise comparison matrix. As the matrix is symmetrical only the lower half actually needs to be completed **(Table 4.3)**. The procedure then required that the pairwise comparison matrix be computed to a best fit of weights. A good approximation to this result can be achieved by calculating the weights with each column and then averaging over all columns. For example, if we take the first column of figures from Table 1, they sum to 1.96. Dividing each of the entries in the first column by 1.96 yields weights of 0.51, 0.13, 0.06, 0.17 and 0.18 (compare to the values in Table 4.3). Repeating this for each column and averaging the weights over the column gives a good approximation. However, IDRISI has a module named WEIGHT which can do this directly.

**Table 4.3. The weightings derived by the pairwise comparison matrix for assessing five water quality factors for land-based aquaculture development in Sinaloa.**

| FACTOR MAPS | Temp.* | Soils | Forests | Agriculture | Irrigation | Weightings |
|---|---|---|---|---|---|---|
| Temperature | 1 | | | | | 0.49 |
| Soils | 1/4 | 1 | | | | 0.12 |
| Forests | 1/8 | 1/3 | 1 | | | 0.06 |
| Agriculture | 1/3 | 3 | 2 | 1 | | 0.16 |
| Irrigation | 1/4 | 1 | 3 | 2 | 1 | 0.17 |
| **SUM** | | | | | | 1.00 |

Numbers show the rating of the row factor relative to the column.

Temp.* = Temperature was assigned the highest weight signifying that it was the most important factor.

Because the pairwise comparison matrix contains multiple paths by which the relative importance of criteria can be assessed, it was necessary to determine the degree of consistency that had been used in developing the ratings (1/9 to 9). Saaty (1977) provides a procedure by which an index of consistency known as consistency ratio (CR) can be produced. The CR indicates the probability that the matrix ratings are randomly generated. **Table 4.3** has a consistency ratio of 0.07, well within the ratio recommended by Saaty (1977) of equal to or less than 0.10, signifying a small probability that the weightings were developed by chance. In addition to the overall consistency ratio, it was also possible to analyze where the inconsistencies arose within the matrix. Both the consistency ratio and the inconsistency analyses were calculated as part of the WEIGHT module in IDRISI.

### *Constraints*

Constraints were developed as a Boolean map (image containing either a zero or a one) to prevent or minimize possible pollution problems and to protect environmentally sensitive areas. The constraints for this study were incorporated in three ways:

1.- In terms of the physical space available there are many areas which are already being used (i.e. it would not be possible to construct ponds in urban development or in water bodies), and therefore they were considered to be a constraint. Moreover, to reduce and/or mitigate negative influences from pollution sources proximity or distance constraints were created by using the DISTANCE module and reclassified using the RECLASS or ASSIGN module to values of zero. For example, a 0 to 2 km distance range was allocated to cities, so any development within that area had a value of zero because of vulnerability to pollution or further urban development.

2.- Due to the environmental importance of mangroves these were evaluated separately to prevent or mitigate any damage in these areas.

3.- Conservation areas comprising of species susceptible to extinction, or other conservation areas with high pollution problems, were also incorporated as a Boolean map.

Whether a factor or a constraint, the results obtained from reclassifying an image after using DISTANCE were strongly dependent on the pixel size of the study area, (see Chapter 3) so the minimum proximity (or distance) that could be spatially represented on this scale was 250 m. This did not prove to be a limitation in this study (except when wanting to develop smaller more detailed analysis) due to the large land area being assessed. Most of the distance ranges were chosen semi-subjectively (i.e. they are not exact measures but are based on literature, maps, field visits, as well as personal communications with Mexican researchers).

In this study a "(c)" was added to the names of those criteria which were used as constraints.

### *Submodels*

To develop a decision-making model, the selected and scored criteria can be developed into a series of submodels which can logically group certain factors together within a general model. For example, some factors were grouped to form submodels naturally (e.g. in a FAO soil classification, soil texture and soil type factors are grouped into a submodel called soils), whilst some other factors were grouped into submodels to enable a better understanding (e.g. hotels, fish processing plants and markets were grouped to form a sales/market submodel). The fundamental approach (Aguilar-Manjarrez, 1992) and the models presented in this study were considerably developed from the work of Aguilar-Manjarrez and Ross (1995a, b). Ross and Aguilar-Manjarrez (1993) noted that the creation of submodels may be divided into stages within the general model (i.e. primary, secondary, tertiary, etc.). The number of stages will vary according to the application, but the overall approach is the same and contains the following steps:

1. The primary stage of the model constitutes its foundation and is represented by the collection of original data (i.e. thematic maps, statistical data and data available in computer format);
2. In the secondary stage factors are grouped together naturally (i.e. lakes, rivers would all be associated to a water resource group) and as non-specifically as possible;
3. As the model develops more sub-models are created in a more specifically orientated way so as to develop specific responses required by the user (e.g. construction constraints for pond construction);
4. Only at the very end of the model do the groupings become application-specific in order to solve a particular problem.

To illustrate the approach used **Figure 4.2** below is a schematic diagram of the decision-making process based on the work of Aguilar-Manjarrez and Ross (1992).

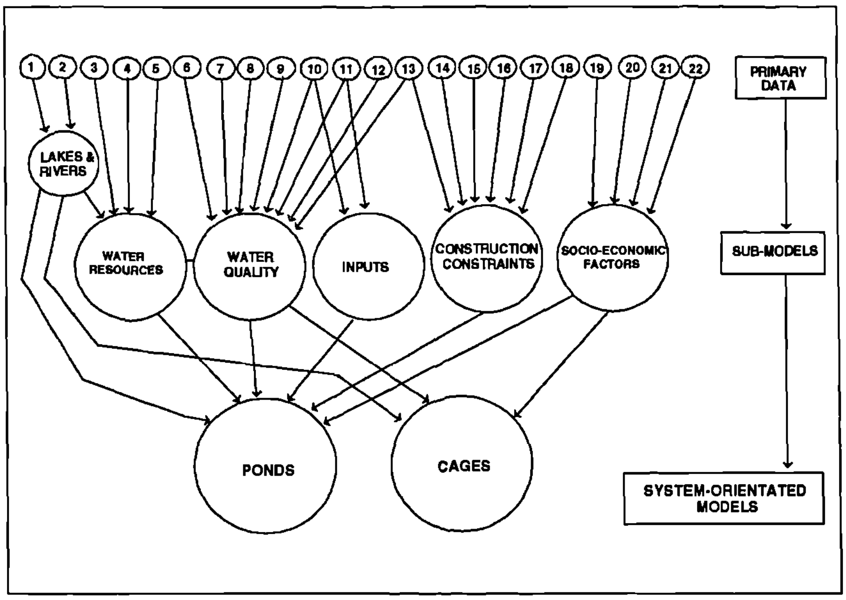


**Figure 4.2. Schematic representation of a decision-making process for pond and cage fish culture in Tabasco State, Mexico (Ross and Aguilar-Manjarrez, 1993).** Primary data: 1, lakes; 2, rivers; 3, groundwater; 4, rainfall; 5, evaporation; 6, oil wells; 7, factories; 8, buildings; 9, vegetation; 10, agriculture, 11, livestock rearing; 12, pipelines; 13, soil type; 14, soil texture; 15, forestry; 16, flood area; 17, relief; 18, topography; 19, agglomeration; 20, population density; 21, cities and towns; 22, roads.

The advantages of constructing the model in this way are that, firstly, if the model is kept as general as possible through the early stages it will enable the user to evaluate a broader range of scenarios. As shown in **Figure 4.2** the model enabled the evaluation of fish culture in a system-orientated way without having to recreate a whole new model for each of the culture options (ponds and cages). Secondly, and most importantly, grouping factors together in stages enables the user to evaluate each grouping so as to have a better understanding of the role of that submodel within the overall model. Moreover, if any of the data at any stage of the model (primary data or submodels) appears to be misleading, or needs to be updated or replaced, this can easily be done without having to reconstruct the entire model.

### *Model programming*

1. *Mathematical expression:* Once the flowchart diagrams of the models had been developed it was possible to arrange them into a mathematical expression. For example, in **Figure 4.2**, the inputs submodel was created by two primary data (numbers 10 and 11). Two lines symbolizing these primary data are incorporated into the input's submodel. The mathematical expression of this schematic representation can be expressed as: **MI = ( 0.70 x L) + ( A X 0. 30 )**, where **MI** is the submodel for inputs, **L** are the livestock rearing areas and **A** are the agricultural areas. Moreover, because each factor was classified on a 1 - 4 range it could then be multiplied by the weights (i.e. 0.70 and 0.30) derived from the MCE pairwise comparison matrices to indicate the relative importance between these factors. In this case, livestock rearing is given a higher weighting because it was considered to be a better source of inputs. Consequently, a consistent 1 to 4 range classification could be maintained. This technique enabled a more objective approach in establishing weights in the formulae used to create the submodels.

2. *Command line mode:* An IDRISI module normally operates interactively and asks the user for the information needed to run. However, this data can be specified in a single command line for fully automative operation.

For example using the mathematical expression for inputs:

```
c:\idrisi> mce x 0 2 inputs 0  lives 0.70 agri 0.30
```

would cause the MCE module to immediately use 0 constraints and 2 factors to create an image called "inputs" with no constraints using the image for livestock called "lives" with a weight of 0.70 and the image for agriculture called "agri" with a weight of 0.30 (the "x" indicates that batch mode is being used and any name can be assigned to the images, the only restriction of IDRISI is that the name is limited to a maximum of eight characters).

3. *Creating macros:* MACRO files, written as a batch file, can make use of the operating system commands and calls to IDRISI modules running in command line mode. MACRO files are used to execute repetitive sequences such as averaging or summing a set of images, or perhaps to create a mathematical model for simulation or prediction. IDRISI for Windows, has a macro-processor capable of interpreting all MS-DOS batch calls of IDRISI modules and translating them into the appropriate call to the IDRISI for Windows module equivalents. Instructions for a MACRO can be placed into an ASCII file with an ".IML" (acronym for IDRISI Macro Language) extension. Typically this will be done in the "EDIT" module. Then to run the MACRO the user selects "Run MACRO" option in the File menu.

## 4.2 ENVIRONMENTAL FACTORS

The environmental factors in this database were grouped into two sets. The first was primarily concerned with the physical and environmental resources involved in aquaculture development, and the second group reviewed the impact of the land uses and infrastructure on the natural environment. The factors are presented in **Table 4.4.**

**Table 4.4. Factors for environmental assessment for aquaculture development in Sinaloa.**

| PHYSICAL and ENVIRONMENTAL RESOURCES | LAND USES and INFRASTRUCTURE |
|---|---|
| Lagoons | Population density |
| Coast-line | Capital city |
| Rivers and streams | Other cities |
| Dams | Towns |
| Groundwater | Villages |
| Annual water balance | Paved roads |
| Monthly water balance | Railway |
| Ambient temperature | Gravel roads |
| Soil texture | Dirt roads |
| Soil type | Unimproved roads |
| Topography | Industries |
| | Agriculture |
| | Irrigation |
| | Livestock rearing |
| | Forestry |
| | Aquaculture |

## 4.2.1 PHYSICAL AND ENVIRONMENTAL RESOURCES

### 4.2.1.1 Water resources submodel

Water is essential for all forms of aquaculture and is a key factor in determining where aquaculture may be developed. However, growing demands for water from an expanding aquaculture industry are resulting in increasing competition with other water users for this limited resource (Muir and Beveridge, 1987; Phillips *et al.,* 1991; Nash, 1995).

The presence and availability of water can be defined in overall terms by the hydrological cycle in which water is evaporated from land and sea surfaces. However, water quality may vary throughout the cycle modified by the solution of various ions and by physical uptake and deposition of particular materials. The other feature of variability is the seasonal and climatic change affecting distribution of water within the cycle. At the macro-scale these variations mostly correspond with areas where the timing of seasonal rainfall may be unreliable, inland areas in the mid-latitudes where precipitation totals are unpredictable, warm areas which occasionally experience freak frost, or areas having tropical cyclones or hurricanes. Micro-climate variations, on the other hand, seldom cause problems to aquaculturists (Aguilar-Manjarrez, 1992).

The availability of water of appropriate quality is important for all systems in aquaculture, but the quantity is of particular importance for land based systems (Pillay, 1992). In spite of this, many farms are still sited at locations where resources are inadequate. Inadequacies can include not only volume and costs to develop source waters, but also water constituents. When selecting a farm site it is necessary to investigate, as thoroughly as possible, seasonal and yearly fluctuations in water quality and availability (Wang and Fast, 1992). Considerable difficulties can arise if aquaculture systems are designed and built requiring more water than is usually available. Not only may water supply vary seasonally, but there may also be regulatory frameworks which affect the quantities of water which can be made available to an aquaculture facility.

Water can come from a number of sources: the water which enters and moves through or over the upper soil surface constitutes the major resource for freshwater aquaculture. Of this, the water freely flowing in rivers and streams provides an easily accessible resource, and one which is most often the subject of man-made interventions. Lakes are of considerable importance in aquaculture, particularly for cage culture, aquaculture-based fisheries and water supply and storage. Sea-water may be used in aquaculture in one of three ways: firstly by placing the culture system directly into a suitable sheltered or protected area of the sea (e.g. a coastal lagoon); secondly, sea-water may be channelled into ponds, such as in shrimp farming; and thirdly sea-water may be pumped ashore for more intensive systems. Another source of water is groundwater which can provide an extremely valuable resource depending on its depth and residence time in lower soil and rock zones (Aguilar-Manjarrez, 1992). Finally, dams may be used for restocking fish. This is a common practice found in Sinaloa; for example, a tilapia fish farm in El Varejonal cultures fish for restocking into the Adolfo Lopez Mateos dam (Chavez-Sanchez, 1993; Field surveys in Sinaloa).

To evaluate overall water availability, three different factors were identified: (1) proximity ranges to sources of water; (2) annual water balance; and (3) monthly water availability.

1. Kapetsky *et al.* (1987) noted that the maximum economically practical distance for the transport of saltwater or freshwater to ponds can be assumed to be 1 km and that saltwater can be available land-ward as far as the inner extension of mangroves. A 1 km band should thus be established land-ward from the margin of mangrove to portray the maximum economical distance for the transport of saltwater. Likewise a 1 km band can be generated at either side of a river to represent the area in which freshwater could be moved either by gravity or pumping. With the above in mind, a 1 km range was considered most suitable for this study.

Using the DISTANCE module in IDRISI, proximity ranges of various sizes were created in accordance with the importance of that factor as a water source as shown in **Text Box 4.3**. For example, proximity to the coast-line, the lagoons, and the rivers and streams were considered to be the most important factors mainly because of the potential to develop further shrimp farming culture practices in Sinaloa. Dams were considered less important due to the likelihood that these water sources would be near pollution sources (i.e. irrigation schemes). Similarly, groundwater was also considered less important because abstraction of large quantities of water from groundwater sources in Sinaloa has been found to cause environmental problems, salinization of agricultural land and land subsidence (Cosmocolor, 1991). Furthermore, those sites closest to the water source were considered

**Text Box 4.3. Proximity to water resources submodel.**

| INTERPRETATION | | SCORE |
|---|---|---|
| Very suitable, low costs, low damage to environment (i.e. small inlet canals for ponds). | | 4 |
| Lagoons | 250 m - 2 km | |
| Coast-line | 250 m - 2 km | |
| Rivers & streams | 250 m - 2 km | |
| Dams | 250 m - 1 km | |
| Groundwater | 0 m - 1 km | |
| Moderate, suitability, costs and damage to the environment. | | 3 |
| Lagoons | 2 - 3 km | |
| Coast-line | 2 - 3 km | |
| Rivers & streams | 2 - 3 km | |
| Dams | 1 - 2 km | |
| Groundwater | 1 - 2 km | |
| Marginal proximity , high costs, damage to the environment. | | 2 |
| Lagoons | 3 - 4 km | |
| Coast-line | 3 - 4 km | |
| Rivers & streams | 3 - 4 km | |
| Dams | 2 - 3 km | |
| Groundwater | 2 - 3 km | |
| Distant sites, high costs, high damage to the environment. | | 1 |
| Lagoons | > 4 km | |
| Coast-line | > 4 km | |
| Rivers & streams | > 4 km | |
| Dams | > 3 km | |
| Groundwater | > 3 km | |

optimum because costs would be low (e.g. pumping), and inlet water channels (e.g. to a shrimp pond farm) would be shorter and therefore cause less damage to the environment.

Water resource factors were developed into a submodel shown in **Figure 4.3** which was developed by using the MCE technique.

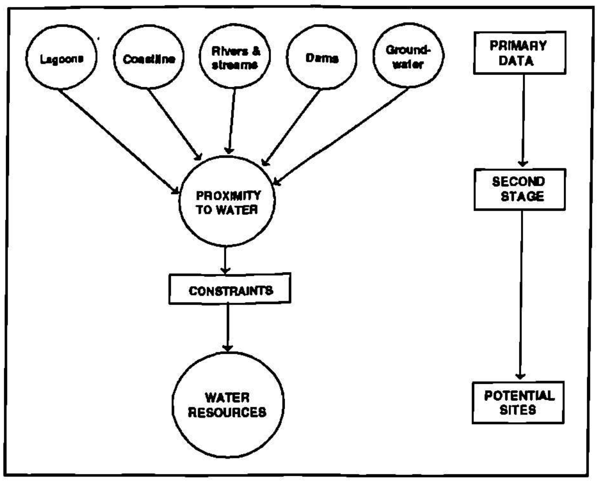


**Figure 4.3. Proximity to water resource submodel.** PW = ( LA X 0.34 ) + ( COA X 0.27 ) + ( RS X 0.22 ) + ( D X 0.10 ) + ( G X 0.07 ) X CONWA. Where; LA = lagoons; COA = coastline; RS = rivers and streams; D = dams; G = groundwater; CONWA = area constraints for water bodies. (Note: Lagoons were given the highest weight due to the advantages of providing shelter for aquatic culture (e.g. shrimp farming)).

**Figure 4.4** shows the allocation of land found in this GIS submodel. Very suitable sites were found in the central and northern parts of the state adjacent to the ocean and to the coastal lagoons. Municipalities with the highest scores were found to be Ahome, Guasave, Angostura, Navolato and Culiacán. Areas with close proximity to rivers appear to be evenly distributed at first glance but, the southern region of the state does have a slightly larger concentration, especially towards the mountains. Proximity to dams and groundwater have been merged into a single score (i.e. 1) as a result of their low weights.

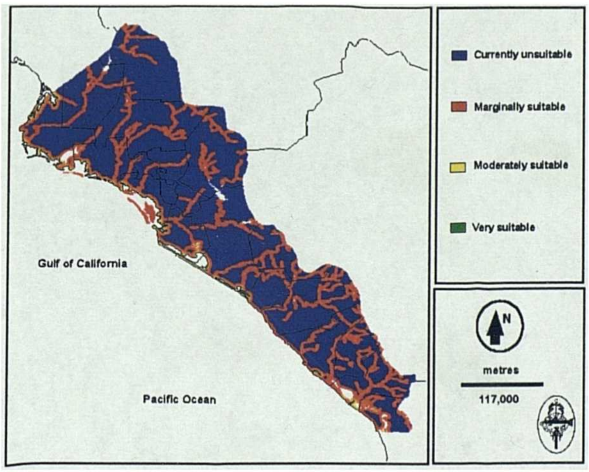


**Figure 4.4. Proximity to water resource submodel image in Sinaloa.**

2.- The distribution of water in Sinaloa represented a major determinant factor in the spatial analysis, and so classification of the overall water resources was important. Rainfall was considered to be a problem, as it is variable through the year, so it was important to consider the water balance of rainfall and evaporation to identify critical areas, or periods of the year, in which there would be a water deficit.

In Sinaloa there is a tendency for a high water deficit - annual rainfall ranges being between 300-800 mm and evaporation rate between 200 - 1,200 mm/year (Flores-Verdugo *et al.,* 1992). A water balance resulting from the difference in rainfall and evaporation is thus an important factor, and an annual water balance map provided by SPP (1983) was used to evaluate areas in which positive water balance was highest. The score interpretation for the annual water balance is shown in **Text Box 4.4** and the resulting image using this classification is presented in **Figure 4.5**. The general pattern is that annual water balance increases towards the mountains and towards the south of the state. Municipalities with the highest water balance in this southern region are Mazatlán and Concordia. Lack of water is located in the north, especially in the municipalities of Ahome and Guasave.

**Text Box 4.4. Annual water balance.**

| INTERPRETATION | SCORE |
|---|---|
| 1,000 - 1,200 mm. Very suitable as a water source for ponds. | 4 |
| 800 - 900 mm moderately suitable for ponds. | 3 |
| 500 - 700 mm . Very likely to encounter water availability problems. | 2 |
| 200 - 400 mm. Unsuitable, many problems to fill ponds. | 1 |

Note: Threshold based on frequency distribution.

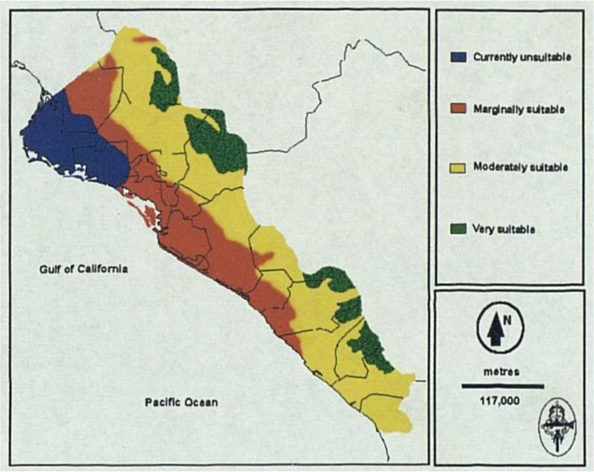


Figure 4.5. Reclassified annual water balance image for aquaculture development in Sinaloa.

3.- Although the above information proved to be useful it was, in most cases, only available as yearly averages, so it was difficult to know which areas would not have sufficient water available during the dry months of the year. To assess the seasonal fluctuation in water availability, monthly rainfall and evaporation data were obtained in numerical form from Mexico's National Meteorological Institution (SMN, 1993). A choropleth map was produced based on the data recorded in meteorological stations within the river basins. The main objective was to locate and evaluate areas where the water balance was going to be ample, and/or more importantly, where water was going to be scarce. To estimate the water balance the numerical values of rainfall were subtracted from evaporation and are presented in **Appendix 1**. The scoring interpretation of this data is shown in **Text Box 4.5.** The resulting image using this classification is presented in **Figure 4.6.** A more detailed analysis of the water balance clearly reveals that the southern regions of the state has a suitable water balance because rainfall is sufficient during many months of the year. By contrast, rainfall is insufficient in the north - 6,036 Km$^2$ of land were found to have a lack of water during many months of the year, most notably in the municipality of Ahome.

**Text Box 4.5. Monthly water balance.**

| INTERPRETATION | SCORE |
|---|---|
| > 4 consecutive months with positive water balance. | 4 |
| 3 - 4 consecutive months with moderate water balance. | 3 |
| 1 -2 consecutive months with marginal water balance. | 2 |
| Months with no positive water balance. Unsuitable. Very scarce supply of water. | 1 |

Note: Threshold based on frequency distribution.

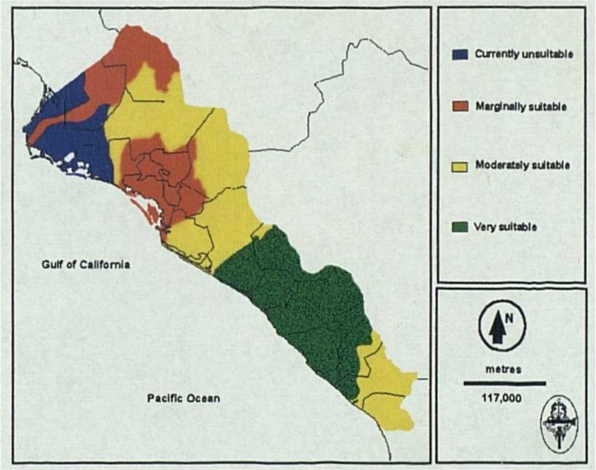


**Figure 4.6. Monthly water balance image for aquaculture development in Sinaloa.**

The water resources factors were developed into submodels (**Figure 4.7**) which were focused into two different themes (i.e. proximity to water and water balance). Both submodels were developed by using the MCE decision-making technique and the choice of weights in these formulae was based on the description given to these factors earlier. The integration of this submodel involved three stages:

(1) selection, reclassification and manipulation of water resources factors (primary data) according to aquaculture suitability on a scale of 1-4, 4 being the most suitable; (2) development of secondary factors for proximity to water and water balance using the MCE decision-making techniques; (3) integration of proximity to water and water balance.

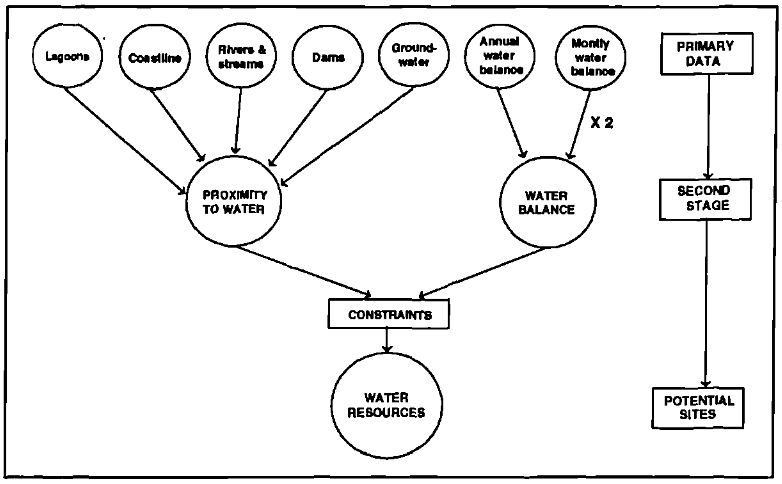


**Figure 4.7. Water resources submodel for aquaculture development in Sinaloa.**

WRS = PW + ( AWABA + ( MWABA X 2 ) ). Where, WRS = water resources submodel; PW = proximity to water submodel; AWABA = annual water balance and MWABA = monthly water balance. Note: In this submodel, monthly water balance was multiplied by a factor of 2 because it gave a better indication of water availability.

**Macro file**
**Water resources submodel**
overlay x 3 la(c) rs(c) lars
overlay x 3 lars lk(c) larslk
overlay x 3 larslk d(c) conwa
mce x 1 6 water conwa la 0.34 coa 0.27 rs 0.22 d 0.10 g 0.07
overlay x 3 awaba mwaba waba
overlay x 1 water waba wrs

The resulting values for the water resources submodel were reclassified according to the frequency distribution threshold to maintain a 1 to 4 score range. **Figure 4.8** shows the allocation of land found by the GIS water resources submodel for land-based aquaculture development. Results of the water resources submodel provided a general idea of were water is most abundant. Overall, very suitable sites covering 42% of the state land were identified in the southern region. Unsuitable sites are clearly located in the north and account for 6% of the area.

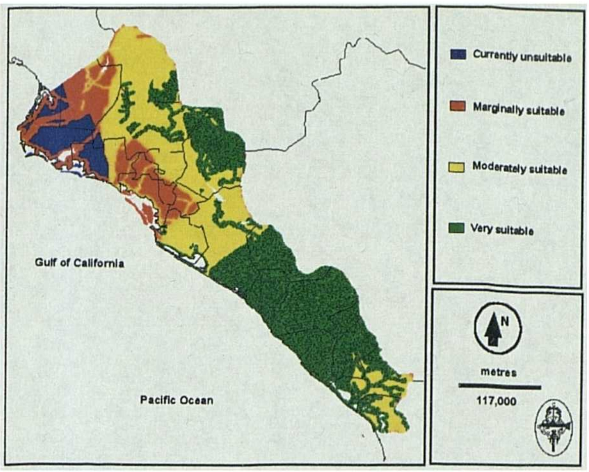


**Figure 4.8. Water resources submodel image for aquaculture development in Sinaloa.**

### 4.2.1.2 Annual air temperature

Water temperature is one of the most important variables for all aquatic organisms. It influences the oxygen content of the water, primary production, and the reproduction and growth of all species. Temperature is both a limiting factor, setting high and low temperature lethal limits, and a determinant of growth rate through its impact on molecular activity. Poor growth and survival at low temperatures can cause significant problems, as well as at high temperatures. In order to choose an appropriate aquaculture site it is necessary to know what the temperature conditions are, and whether they are highly variable or not (Fast and Lannan, 1992; Lester and Pante, 1992). Air temperature is the dominant factor in controlling water temperature and the agreement between air and water values is sufficiently close to enable air temperature to be used as a reliable predictor of water temperatures (Kapetsky, 1994).

Water temperature is one of the principal factors limiting shrimp culture world-wide; temperate regime has been perhaps the largest impediment to the development of a shrimp culture industry in the United States, where normally only one summer crop is achieved each year. Two crops are possible with greenhouse nursery start-up and/or two phase grow-out, but the economics of this are questionable. Even in Taiwan and Japan, winter water temperatures are unsuitable, or are marginally suitable from two to four months each winter. Although growth responses to temperature have not yet been clearly defined for commonly cultured shrimp species, the consensus is that most cultured shrimp grow best in a temperature range of 24 to 32 °C. A notable exception is *P. chinensis* which can survive prolonged temperatures as low as 10 °C, and can grow well below the optimum for most of the cultured shrimp (Lester and Pante, 1992). Countries such as Thailand, the Philippines, Indonesia and Ecuador have some of the best water temperatures for shrimp culture, combined with excellent broodstock sourcing and availability (Fast and Lannan, 1992).

An annual air temperature chart created by SPP (1981) was reclassified for both warm water fish farming and shrimp culture based on criteria established from Menz (1976); Lee and Wickins (1992); and Kapetsky (1994) and is presented in **Text Box 4.6.**

**Text Box 4.6. Annual air temperature.**

| INTERPRETATION | SCORE |
|---|---|
| 26 - 30 °C . Very suitable for warm water fish and shrimp. | 4 |
| 22 - 26 °C. Moderately suitable because salinity could affect growth and survival in high temperatures. | 3 |
| 20 - 22 °C. Low for both aquatic species. High 30 -32 °C. | 2 |
| 18 - 20 °C. Too low and hence unsuitable for these species.<br>32 - 34 °C too high hence unsuitable. | 1 |

The reclassified annual air temperature image is presented in **Figure 4.9.** Very suitable temperatures are found in the northern region; moderately suitable temperatures are found in 60% of the state's land, and lowest temperatures are found towards the mountains but only account for 15% of the land. In general, temperature does not seem to be a constraint providing suitable conditions for a variety of species. However, temperature could be considered as unsuitable in some places during some periods of the year. For example, during summer time, high temperatures can contribute to the lack of water.

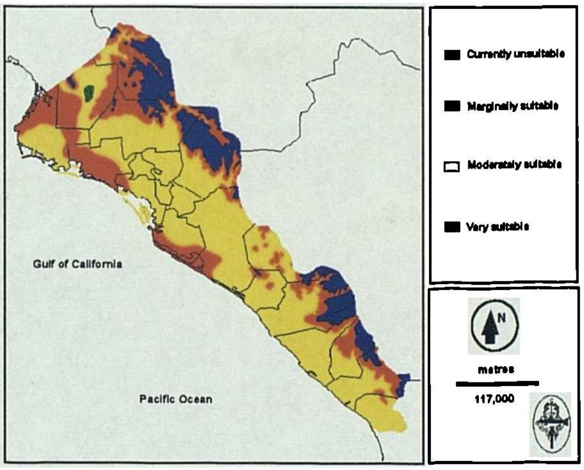


**Figure 4.9. Reclassified annual air temperature image for aquaculture development in Sinaloa.**

### 4.2.1.3 Soils submodel

The assessment and use of soils is a very important aspect of aquaculture site selection, development and management. This is particularly the case in pond farms, where soil quality has a great influence on construction and maintenance costs, and on pond productivity. It is also important in selecting sites and developing designs for ancillary components such as water supply channels, building foundations and river or coastal protection structures. Excessive seepage often results from improper site selection, therefore, soil properties should be clearly investigated and identified during site selection. Situations may arise where no satisfactory site is available and, in those cases, poor soils must be enhanced. Soil treatments such as compaction, clay blankets, bentonite, chemical additives or waterproof linings are used (Coche and Laughlin, 1985; Wang and Fast, 1992; Chanratchakool *et al.*, 1994).

The main soil properties important for aquaculture are summarized in **Table 4.5**.

**Table 4.5. Soil properties important for aquaculture.**

| PHYSICAL PROPERTIES | PHYSICO-CHEMICAL PROPERTIES | BIOLOGICAL PROPERTIES |
|---|---|---|
| Strength, ability to hold water. | Ion exchange. | Presence of organic material. |
| Suitability of soils structure for physical needs. | Capacity of soil elements. | Presence of assimilative nutrient transforming biomass. |
| Biological substrate. | Acid/alkaline reaction. | |
| | Presence and possible leaching of ions and chemical compounds. | |
| | Adsorptive, binding capacity of soil structure. | |

Source: Coche and Laughlin (1985).

One of the most important soil characteristics is its ability to hold water. Good soil should contain impermeable material thick enough to prevent excessive seepage. Clays and silts are usually satisfactory. Pond soil should be carefully examined for peat and other organic materials. Should excessive amounts of these materials be found, they must be removed before construction starts. When constructing a shrimp pond, the levee or dike foundation should be strong enough to support the structure and provide resistance against water passage. Good foundation materials are a mixture of coarse and fine-textured soils such as gravel-sand-clay, gravel-sand-silt, sand-clay and sand-silt (Wang and Fast, 1992). Soils should be non-acidic, they should have good texture, low slope and low permeability for pond construction and these can also be ranked according to various civil engineering criteria (Coche and Laughlin,1985; Pillay, 1992).

Soils are commonly classified according to horizons and a range of classifications systems is used. A soil horizon may be defined as a layer of soil approximately parallel to the soil surface, with characteristics produced by soil forming processes. A soil horizon is commonly differentiated from the one adjacent by characteristics that can be seen or measured in the field such as colour, texture, structure, consistency and sometimes in laboratory tests (FAO-UNESCO, 1974; 1975).

In this study, the thematic maps used for the soils of Sinaloa were based on a horizon classification corresponding to the FAO/UNESCO (1970) unified soil classification system, modified by INEGI (1990). In Sinaloa, there are 10 major soil groups and 40 soil types in total within these groups (**Table 4.6**).

Nonetheless, in a GIS study for assessing aquaculture development in Tabasco State, Mexico, Aguilar-Manjarrez (1992) noted that horizons are defined in broad qualitative terms and do not provide a clear and complete description of the morphological characteristics of each soil. Additionally, the soil descriptions are principally focused on agriculture. Even though the Mexican classification used by INEGI (1990) corresponds to the unified classification system it did not contain the same characteristics when compared with the soil map of the world (FAO-UNESCO, 1975). The FAO system gives information about texture, slope and permeability at 1 : 5,000,000 scale, whereas INEGI had information on texture, and dominant and secondary soils at 1 :1,000,000 scale. Aguilar-Manjarrez (1992) noted that the FAO classification could give some useful information but the scale was too broad to be effective.

The intention was to extract relevant information with which the soils could be classified according to their aquaculture suitability. This was found to be a difficult task and it was finally considered that the best information given by this classification system was soil texture which was extracted and re-mapped as the main characteristic; those soils considered to have fine texture being considered to be most suitable as shown in **Text Box 4.7.**

**Text Box 4.7. Soil texture.**

| INTERPRETATION | SCORE |
|---|---|
| Fine texture very useful for pond construction. | 4 |
| Medium texture useful for ponds | 3 |
| Coarse soils difficult for constructing ponds. | 2 |
| No data | 1 |

In addition to the above information, Aguilar-Manjarrez (1992) established a scoring system according to the major soil groups based on data from INEGI (1990) and Secretaría del Estado de Tabasco (1987). Other relevant information for soils specific to Sinaloa was obtained but overall, the scores established by Aguilar-Manjarrez (1992) were used in establishing the scores in this study. A summary of the major soil group characteristics in Sinaloa is presented in **Table 4.7.**

Table 4.6. Soil types according to their soil group based on the FAO/UNESCO (1970) unified soil classification system, modified by INEGI (1990) for Sinaloa.

TEN MAJOR SOIL GROUPS

| Cambisol | | Fluvisol | | Lithosol | Luvisol | | Phaeozem | | Regosol | | Rendzina | Solonchak | | Vertisol | | Xerosol | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | | J | | I | L | | H | | R | | E | Z | | V | | X | |
| calcic | Bk | calcaric | Jc | | albic | La | calcaric | Hc | calcaric | Rc | | gleyic | Zg | cromic | Vc | calcic | Xk |
| cromic | Bc | distric | Jd | | calcic | Lk | gleyic | Hg | distric | Rd | | molic | Zm | pelic | Vp | gypsic | Xg |
| distric | Bd | eutric | Je | | cromic | Lc | haplic | Hh | eutric | Re | | ortic | Zo | | | haplic | Xh |
| eutric | Be | gleyic | Jg | | ferric | Lf | luvic | Hi | gelic | Rx | | takiric | Zt | | | luvic | Xi |
| ferralic | Bf | tionic | Jt | | gleyic | Lg | | | | | | | | | | | |
| gelic | Bx | | | | ortic | Lo | | | | | | | | | | | |
| gleyic | Bg | | | | plintic | Lp | | | | | | | | | | | |
| humic | Bh | | | | vertic | Lv | | | | | | | | | | | |
| vertic | Bv | | | | | | | | | | | | | | | | |

TERMINOLOGY: Group and soil type letter symbols were used in the original thematic paper maps (SPP, 1982), for which reason they are included in this table. For example, **B** is the Cambisol major soil group and **Bk** is the calcic soil type.

Note: Lithosols and Rendzinas are not classified into soil types.

Table 4.7. Summary of soil types main characteristics according to the FAO/UNESCO (1970) classification, modified by INEGI (1990) for Sinaloa.

| SOIL GROUP | CHARACTERISTICS | SCORE |
|---|---|---|
| **Luvisol** | Present in any climate except in arid areas, they can have any type of vegetation. Thick, organically rich and clayish soils. Low draining and high water-logging capacity (low permeability). | 4 |
| **Cambisol** | New soils, with accumulation of calcium and some clay. Moderate draining capacity. | 3 |
| **Solonchak** | Thick soils with a high content of salts. Mainly found in coastal areas. Not suitable for agriculture except for crops resistant to high salinities. | 3 |
| **Fluvisol** | River soils. Characterized by being formed by materials from rivers. Usually found in any type of climate adjacent to water bodies. They can be clayish or sandy, shallow or deep depending on the material from which they are formed. | 2 |
| **Rendzina** | Calcareous extremely shallow and sticky. Usually clayish soils. High draining capacity (high permeability). | 2 |
| **Vertisol** | Usually found in areas of climate extremes (very dry or very wet periods), clayish soils, sticky when wet but very hard when dry. Sometimes saline soils. | 1 |
| **Regosol** | Present in various climates, located in sandy soils such as beaches and dunes. They can also be found adjacent to the edge of mountains. | 1 |
| **Phaeozem** | Can be found in various climatic conditions as well as in different types of relief (flat or hilly), they can have any type of vegetation. Mainly characterised by a rich superficial layer of organic material and nutrients. Use of these soils is dependent on the topography. | 1 |
| **Lithosol** | Calcified soils with depths not exceeding 0.10 m. High draining capacity. | 1 |
| **Xerosol** | Located in arid or semi-arid areas. Not suitable for agriculture but suitable for livestock rearing. | 1 |

Source: Flores-Nava (1990); INEGI (1990).
Note: Scoring was based primarily by a detailed analysis developed by Aguilar-Manjarrez (1992).

Aguilar-Manjarrez (1992) noted that Gleysols (although not present in Sinaloa) and Luvisols are the most suitable for aquaculture purposes. Cambisols and Solonchaks have a fair rating, Fluvisols and Rendzinas are poor soils and all others were found to be unsuitable. To prepare the soil map for digitizing, the thematic paper map was reclassified manually according to the major soil group suitability classes, but most importantly according to their textural class on a suitable to unsuitable basis (**Appendix 3**).The soils factors were developed into a submodel by integrating the soil texture and soil type factors as shown in **Figure 4.10.**

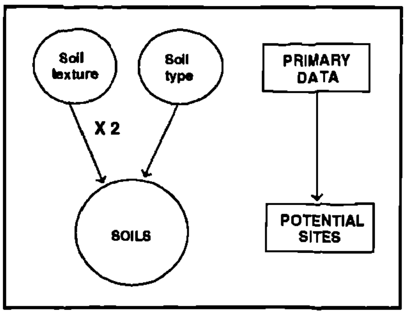


**Figure 4.10. Soils submodel for aquaculture development in Sinaloa.**

SS = ( SOILTX X 2 ) + SOILT. Where; SS = soils submodel; SOILTX= soil texture and SOILT = soil type

**Macro file**
**Soils submodel**
scalar x soiltx soiltx2 3 2
overlay x soiltx2 soilt ss

Texture was given greater importance by multiplying by a factor of two (**Appendix 3**), and the resulting classification was then used to create a soil map image which was re-classified using the frequency distribution threshold so a consistent 1 to 4 score range was maintained (**Text Box 4.8**).

**Text Box 4.8. Soils submodel.**

| INTERPRETATION | SCORE |
|---|---|
| > 8. Fine texture very useful for pond construction. Clayish soils, low permeability. | 4 |
| 7 - 8. Fine and medium texture useful for pond construction. Moderate draining capacity. | 3 |
| 5 - 6. Medium and coarse soils some difficulty in constructing ponds. River soils, sticky soils. | 2 |
| < 5. Coarse texture, high permeability. Very difficult to construct ponds. | 1 |

Note: For more detailed information on soil type interpretation see Table 4.7. above.

**Figure 4.11** shows the allocation of land found by the GIS soils submodel for aquaculture development in Sinaloa. Very suitable soils are located in the north-eastern region of the state but only account for 4% of the area. Nonetheless, moderately suitable soils account for 19,295 km$^2$ (34%) and are located in proximity to the coast along the entire state. Unsuitable soils are very few (1.5%) and are located in the south and north-western part of the state.

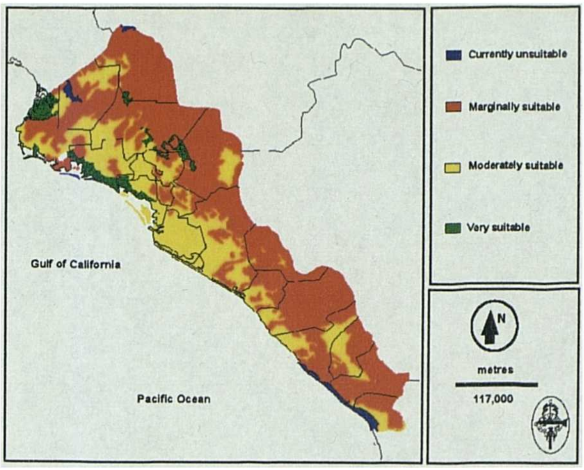


Figure 4.11. Soils submodel image for aquaculture development in Sinaloa.

#### 4.2.1.4 Topography

The principal objective was to identify areas suitable for the construction of ponds, the primary consideration being elevation, and the way in which the land slopes. A gentle slope of less than 2% is highly desirable. Such a slope allows for gravity water conveyance to and from the ponds, and provides efficient drainage. Coastal areas where marine aquaculture is practised often have a slope far less than 1%, and potential problems with flood drainage must be carefully investigated. Land elevation (above mean sea level), topography, and tidal conditions are all important, whether the culture area is supplied by tidal water exchange or by mechanical pumps. Pond elevations and distances must be carefully considered since these can affect capital construction costs, as well as operating costs (e.g. over the life of the farm pumping costs can be substantial) (Coche *et al.*, 1992; Wang and Fast, 1992).

Wherever possible pond layouts should take into account the existing site topography, firstly to minimize pond construction costs and secondly to make use of gravity drainage and possibly gravity water supply. To convert the DEM into a slope image the SURFACE module (slope option) was used in IDRISI. The image was then reclassified based on the thresholds and scores determined by Kapetsky, (1994) presented in **Text Box 4.9**.

**Text Box 4.9. Topography.**

| DOMINANT SLOPE (%) | INTERPRETATION | SCORE |
|---|---|---|
| 0 - 2 | Suitable for larger 1 - 5 ha ponds, If slope is 1 - 2 % | 4 |
| 2 - 5 | 0.01 -0.05 ha ponds (ICLARM and GTZ, 1991). | 3 |
| 5 - 8 | generally suitable | 2 |
| 8 - 30 | Mainly too steep for ponds, except in valley bottoms. | 1 |

The reclassified topography image is presented in **Figure 4.12**. Flat land covers almost the entire state; 60% of the state comprises of areas having slopes between 0 and 8%. Slopes increase away from the coast towards the mountains; slopes which are greater than 30% account for 14, 911 km$^2$.

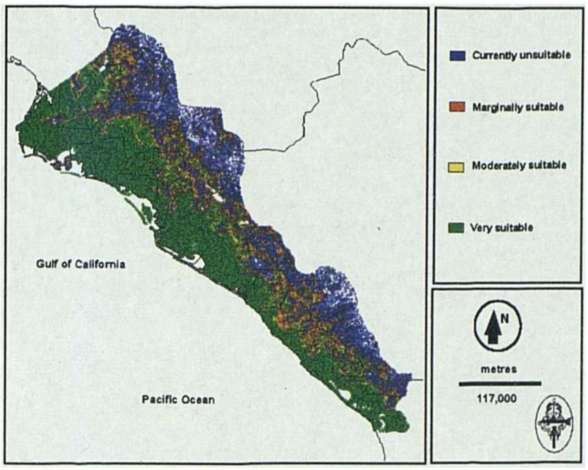


Figure 4.12. Reclassified topography image for aquaculture development in Sinaloa.

### 4.2.2 LAND USES AND INFRASTRUCTURE

Land use was assessed in three ways: as indicative of water quality, in terms of site acquisition costs and as indicative of site development costs.

Water quality requirements for productive aquaculture can seldom be maintained economically in commercial farms if the natural water resources are polluted, and the environmental integrity of the area is disregarded (Pillay, 1992). Although information to assess water quality constraints on aquaculture development is scarce, Kapetsky *et al.* (1987) noted that proportional land use can help infer the relative quality of water. For example, range-land could be a positive influence on water quality if it is not overgrazed. Other activities can have negative effects on water quality for aquaculture such as intensive crop production caused by sub-lethal or lethal concentrations of pesticides, turbidity through soil erosion, and fluctuating quantities of run-off because of the absorptive capacity of cultivated crops compared with that of natural vegetation.

Site development costs are considered to be relatively low on cropland because there would be no trees to clear, but somewhat higher on range-land because trees and shrubs are interspersed with less substantial growth. Forest land is the most expensive to clear because of the need to remove the many trunks, roots and underbrush (Kapetsky *et al.*, 1987). Furthermore, assessment of land use is important in order to establish where aquaculture activities are likely to be compatible with other uses.

Studies have shown (e.g. EPAC, 1991; De la Lanza, 1991; Flores-Verdugo *et al.,* 1992) that water pollution is the biggest problem of environmental degradation in Sinaloa. Rivers in this state are greatly affected by agrochemical and urban discharges causing over-fertilization of coastal waters with consequent eutrophication problems. Agricultural water discharges, in particular sugar cane factories, are the principal causes of eutrophication of various lagoons in Sinaloa, such as Topolobampo-Ohuira and Ensenada de Pabellón.

### 4.2.2.1 Population density

Population density is a measure of the concentration of people in a given region. Waste discharges generated from human population represent serious ecological impacts in coastal areas, principally when they are discharged in shallow and closed water bodies with little water exchange (De la Lanza, 1991). A large population is also indicative of industrial pollution (Kapetsky, pers.comm.). Hence, simply stated, a smaller population is likely to be a smaller pollution source.

Data for population density (**Table 4.8**) was obtained from computer disks for 1990 as choropleth maps at a municipal level (INEGI, 1993). This population density choropleth data were imported into IDRISI and re-scored as shown in **Text Box 4.10.**

**Figure 4.13** shows that 11 out of the 18 municipalities have population densities lower than 31 inhabitants/km$^2$ and, except for Mazatlán, the southern region has the lowest population density and hence pollution sources are minimum when compared to the rest of the state. Municipalities with the highest population density are Culiacán and Mazatlán.

**Text Box 4.10. Population density.**

| INTERPRETATION | SCORE |
|---|---|
| Municipalities with a population density < 31 habitants / km$^2$ Minimum risk of pollution. | 4 |
| Municipalities with a population density 31-62 habitants / km$^2$ Moderate risks of pollution. | 3 |
| Municipalities with a population density 63 - 94 habitants / km$^2$ Likely pollution. | 2 |
| Municipalities with a population density > 95 habitants / km$^2$ Highest pollution. | 1 |

Note: Threshold based on frequency distribution.

Table 4.8. Population density in Sinaloa for 1990.

| MUNICIPALITY | ( Inhabitants / km$^2$ ) | SCORE |
|---|---|---|
| **NORTH** | | |
| Ahome | 69.9 | 2 |
| Choix | 5.8 | 4 |
| El Fuerte | 22.4 | 4 |
| Guasave | 74.5 | 2 |
| Sinaloa | 14.2 | 4 |
| **CENTRE** | | |
| Angostura | 32.6 | 3 |
| Baridaguato | 6.5 | 4 |
| Culiacán | 126.3 | 1 |
| Mocorito | 12.2 | 4 |
| Salvador Alvarado | 55.7 | 3 |
| Navolato | 57.8 | 3 |
| **SOUTH** | | |
| Concordia | 0.2 | 4 |
| Cosalá | 6.4 | 4 |
| Elota | 20.0 | 4 |
| Escuinapa | 28.1 | 4 |
| Mazatlán | 102.4 | 1 |
| El Rosario | 17.4 | 4 |
| San Ignacio | 5.2 | 4 |

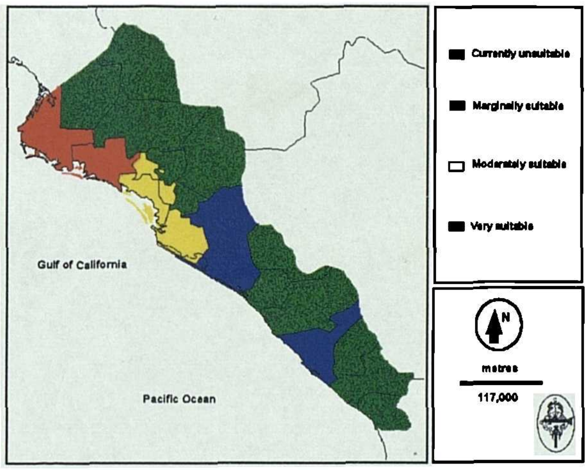


Figure 4.13. Population density for aquaculture development in Sinaloa.

### 4.2.2.2 Urban development submodel

As in any other region under development, Sinaloa has pollution problems from urban waste waters and municipal wastes, which have increased in the last decades. Furthermore, basic services such as drinking water, drainage and waste collection have not been sufficient.

Insufficient and deficient systems of waste collection have caused the proliferation of waste disposal in isolated land areas, and most importantly directly into the water bodies without any treatment (CEDCP, 1990; ITESM, 1989;1993).

In cities various sources of pollution, from domestic wastes to commercial and industrial discharges, can be found. Thus, the further away an activity is from a city the less likely it is to encounter such pollution problems. To avoid and/or minimize the risks from urban pollution four different distance ranges were created, according to the level of pollution derived from each activity (**Text Box 4.11**). Culiacán is the capital city, and the major polluting city, and so the greatest distance range (i.e. up to 15 km) was given to this location; other cities (Mazatlán, Los Mochis, Guasave, and Guamuchil) although not as large, are also important pollution producers. Towns are also sources of pollution, and villages, although to a much lesser extent, may also damage the environment. Similarly, because pollution is found within and adjacent to these urban developments, distance constraints were created to minimise risks of pollution which also varied according to the intensity of pollution. The urban development factors were integrated into a submodel (**Figure 4.14**) created by using the MCE decision-making technique.

**Text Box 4.11. Urban development submodel.**

| INTERPRETATION | | SCORE |
|---|---|---|
| Low risks of pollution | | 4 |
| Capital city | > 20 km | |
| Other cities | > 8 km | |
| Towns | > 4 km | |
| Villages | > 2 km | |
| Moderate risk of pollution | | 3 |
| Capital city | 15 - 20 km | |
| Other cities | 6 - 8 km | |
| Towns | 3 - 4 km | |
| Villages | 1 - 2 km | |
| Possible risk of pollution | | 2 |
| Capital city | 10 - 15 km | |
| Other cities | 4 - 6 km | |
| Towns | 2 - 3 km | |
| Villages | 500 m -1 km | |
| High risk of pollution. | | 1 |
| Capital city | 5 - 10 km | |
| Other cities | 2 - 4 km | |
| Towns | 1 - 2 km | |
| Villages | 0 - 500 m | None |

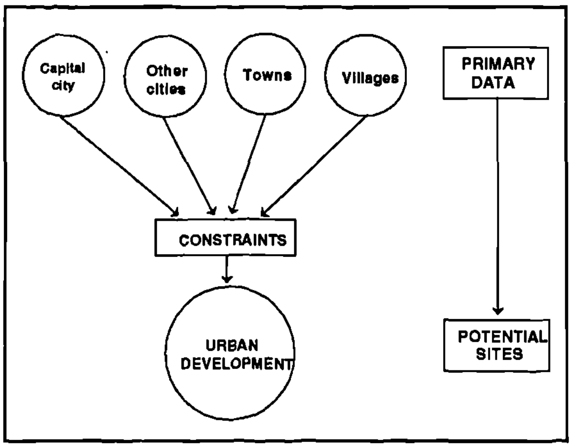


**Figure 4.14. Urban development submodel for aquaculture development in Sinaloa.** URBS(e) = ( CC X 0.50 ) + ( OC X 0.30 ) + ( TW X 0.15 ) + ( VI X 0.05 ) X CONUR. Where; URBS(e) = urban development submodel; CC = capital city; OC = other cities; TW = towns; VI = villages; CONUR = area constraints for urban development.

The interpretation described for the distance ranges was used to establish the weights obtained for the mathematical expression using the MCE decision-making technique. **Figure 4.15** shows the allocation of land found by the GIS urban development submodel for land-based aquaculture development in Sinaloa. Minimum impact from urban development occurs away from the coastline. Lowest score and therefore highest pollution is clearly identified as being in Culiacán in the centre of the state. Other important pollution sources are found in other cities in other municipalities except for Elota, where only towns and villages are present, and hence where there appears to be the least amount of pollution.

**Command line mode file**
**Urban development submodel**

```
overlay x 3 cc(c) oc(c) ccoc
overlay x 3 ccoc tw(c) ccoctw
overlay x 3 ccoctw vi(c) conur
mce x 1 4 urbs(e) conur cc 0.50 oc 0.30 tw 0.15 vi 0.05
```

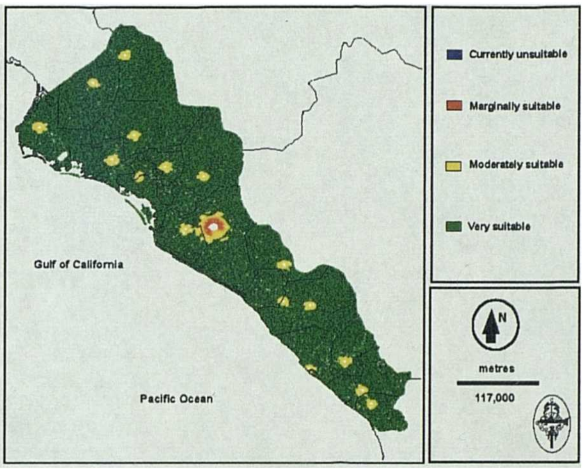


**Figure 4.15. GIS derived allocation of land found by the GIS urban development submodel for land-based aquaculture development in Sinaloa.**

### 4.2.2.3 Roads submodel

Access to roads can in some cases have a great effect on the hydrological pattern. A road can interrupt tidal flow to a mangrove area and hence have a similar damaging effect to that seen with the construction of embankments (Flores-Verdugo *et al.*, 1992). For this study, the spatial analysis of the roads submodel was based on setting two different distance ranges to avoid any possible impacts (**Text Box 4.12**). Due to the pixel size used in this study (250 m) smaller distances could not be used, so only two scores were assigned. The roads factors were integrated into a submodel (**Figure 4.16**) created by using the MCE decision-making technique.

**Text Box 4.12. Roads submodel.**

| INTERPRETATION | | SCORE |
|---|---|---|
| No impact | | 4 |
| Paved roads | > 500 m | |
| Railways | > 500 m | |
| High risks of impacts | | 1 |
| Paved roads | 250 - 500 m | |
| Railways | 250 - 500 m | |

Note: No impact derived from gravel roads, dirt roads and unimproved roads

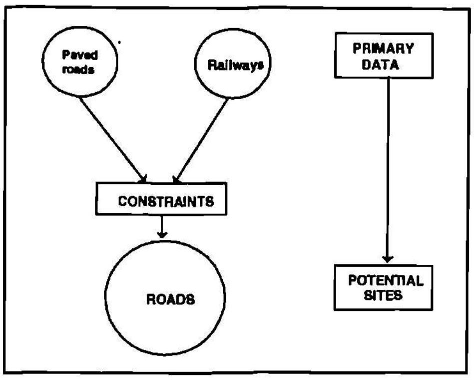


**Figure 4.16. Roads submodel for aquaculture development in Sinaloa.**
ROS(e) = ( PR X 0.60 ) + ( RW X 0.40 ) X CONRO. Where; ROS(e) = roads submodel; PR = paved roads; RW = railways; CONRO = area constraints for roads.

**Command line mode file**
**Roads submodel**

```
overlay x 3 pr(c) rw(c) prrw
overlay x 3 prrw gr(c) conro
mce x 1 3 ros(e) conro pr 0.60 rw 0.40
```

It was considered that paved roads were the only road types which could cause greatest damage to the environment (e.g. a major change in the natural flow of a river) and pollution problems, such as water runoff from its surface during periods of rainfall so it was given the highest weight (0.60). Railways may also cause many environmental damages (e.g. modifying natural flow of water bodies) and therefore were also considered important but to a lesser extent (0.40). Impacts from gravel roads, dirt roads and unimproved roads were assumed to be insignificant, so their area constraints were only considered. **Figure 4.17** shows the allocation of land found by the GIS roads submodel for land-based aquaculture development in Sinaloa. Clearly, the largest environmental damage from roads development is located along the state's coastline, especially in the central and northern region. Highest road concentration is located in the municipalities of Ahome, Guasave, Angostura and Culiacán. In general, road impact decreases considerably towards mountains and to the south of the state.

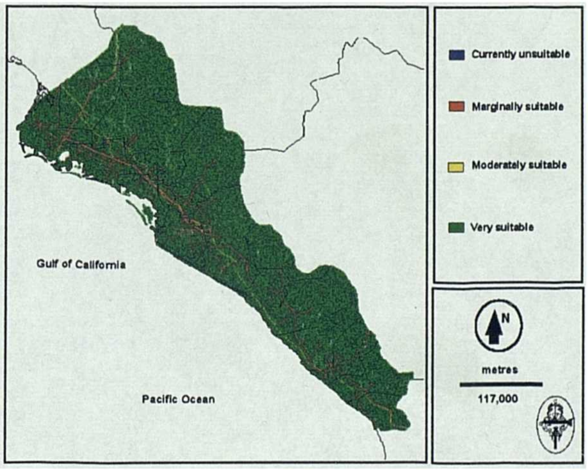


**Figure 4.17. Roads submodel image for aquaculture development in Sinaloa.**

#### 4.2.2.4 Industries

Industries in Sinaloa are principally associated with food processing. Due to the magnitude and characteristics of the existing industries in Sinaloa, effects from their wastes in soils are not of great concern, but they are significant in the water (CEDCP, 1990). Flores-Verdugo *et al.* (1992) identified sugar cane factories as the highest water pollution problem in the state; each sugar cane factory has the capacity to contaminate with organic waste the water supply equivalent of a population of approximately 170,000 inhabitants in terms of BOD (Biological Oxygen Demand). For this reason, any aquaculture site would have to be distant from such pollution sources as indicated in **Text Box 4.13** and presented in **Figure 4.18.** The most important discharges from this activity are located in the central and northern region of the state. The municipality of Culiacán has 6 sugar factories and Navolato and Ahome two (Cosmocolor, 1991; EPAC, 1991).

**Text Box 4.13. Industries.**

| INTERPRETATION | SCORE |
|---|---|
| Low risk of pollution.<br>> 4 km. | 4 |
| Moderate risk of pollution<br>3 - 4 km. | 3 |
| Likely pollution<br>2 - 3 km. | 2 |
| High risks of pollution<br>250 m - 2 km. | 1 |

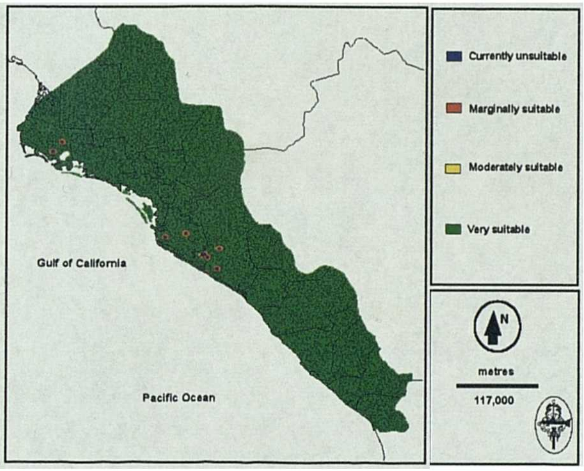


**Figure 4.18. Distance from industries for aquaculture development in Sinaloa.**

#### 4.2.2.5 Agriculture

Aquaculture is particularly vulnerable to the effects of pollutants (e.g. herbicides, pesticides) entering the water from agricultural processes. These can cause reduced performance or sudden mortalities and can degrade the product. Many pollutants remove oxygen from the water, the resulting BOD may leave insufficient dissolved oxygen to sustain the biomass of aquatic species present in a farm causing suffocation (Flores-Verdugo *et al.*, 1992; Galindo-Reyes, 1985; Galindo-Reyes *et al.*,1992).

To avoid and/or mitigate the negative impact of agricultural pollutants from intensive agriculture in Sinaloa, a classification system was established in which those sites in which agriculture was carried out intensively were given the lowest score as shown in **Text Box 4.14**, and the resulting image is presented in **Figure 4.19.** Very suitable sites were found adjacent to the coast and towards the mountains accounting for 41% of the state's area. Likely sources of pollution for aquaculture, derived from very suitable sites for agriculture, cover 30 % of the area (17,777 km$^2$) along the state's coastline, especially in the central and northern regions.

**Text Box 4.14. Agriculture.**

| INTERPRETATION | SCORE |
|---|---|
| Not suitable for agriculture. | 4 |
| Manual cultivation moderate risk of pollution. | 3 |
| Seasonal cultivation, likely risks of pollution. | 2 |
| Intensive cultivation throughout the year. High risk of pollution. | 1 |

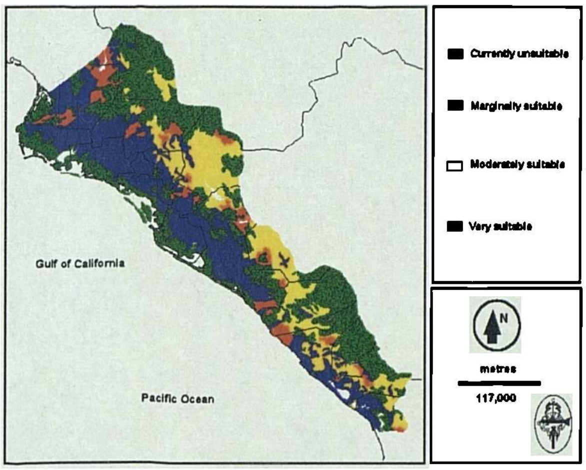


Figure 4.19. Reclassified agriculture image for aquaculture development in Sinaloa.

However, not all aspects of agriculture have negative effects - aquaculture ventures frequently fail because they are not integrated into local farming systems. Agricultural activities are likely to provide inputs for pond culture, particularly smaller-scale activities. Potential for useful farming by-products, for example foodstuff inputs from crop growth, can be judged by assessing the length of the growing period (LGP) and the variety of crops grown (Kapetsky, 1994).

Conditions encouraging agricultural production generally favour aquaculture production and *vice versa*, and agriculture can be used as a good indicator of areas where aquaculture might flourish (Little and Muir, 1987). In this way, the agriculture classification could be re-interpreted, and hence reclassified, if it was considered that agricultural land production is a source of inputs, although there is still a likely pollution problem.

### 4.2.2.6 Irrigation

Thirty per cent of Sinaloa's state surface has well-developed irrigation systems supporting highly mechanized agriculture. Use of great quantities of fertilizers and pesticides has generated soil and water degradation, affecting coastal water bodies in the central and northern parts of the state (Flores-Verdugo *et al.*, 1992). To mitigate the negative effect, irrigation buffer zones were created with the DISTANCE command of IDRISI. The score interpretation for these distances is presented in **Text Box 4.15** and the resulting image from this classification is presented in **Figure 4.20.** An area distance constraint was not applied in this case because of the extensive land area occupied by this activity. Conversely, irrigation could serve as a water supply mechanism so this factor could be re-interpreted as having a positive influence. However, due to the pollution problems reported in many studies (e.g. Cosmocolor, 1991; De la Lanza, 1991; EPAC, 1991; Flores-Verdugo *et al.*, 1992), this factor was considered as having a negative influence in this study. The central and northern regions of the state are areas in which irrigation has developed considerably and, therefore, these areas were assigned low scores. By contrast, with the exception of the irrigation scheme in the municipality of San Ignacio, the southern region of the state does not present pollution problems derived form this activity.

**Text Box 4.15. Irrigation.**

| INTERPRETATION | SCORE |
|---|---|
| Low risk of pollution.<br>> 3 km. | 4 |
| Moderate risk of pollution<br>2 - 3 km. | 3 |
| Likely pollution<br>1 - 2 km. | 2 |
| High risks of pollution<br>0 - 1 km. | 1 |

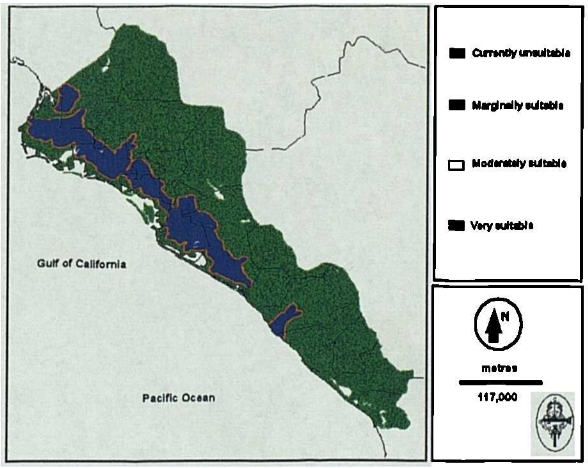


**Figure 4.20. Irrigation influence on aquaculture development in Sinaloa.**

### 4.2.2.7 Livestock rearing

Animal manure wastes are used as inputs to pond aquaculture in the form of feeds and fertilizer in many countries of the world, and are considered superior to inorganic fertilizers in producing and maintaining desirable species of planktonic and benthic food organisms in fresh and brackish-water ponds (Little and Muir, 1987; Pillay, 1992). To this end, livestock rearing for this study was considered to have a positive influence (**Text Box 4.16**). In terms of subsistence fish farming and extensive shrimp culture, manure is particularly important and will increase the pond's natural productivity. Nonetheless, in more intensive types of culture systems, manure is undesirable due to risks of pollution (i.e. herbicides). For example, for shrimp culture in Sinaloa, use of manure is minimal and so a trade-off could be established by re-classifying this factor according to the type of culture being assessed. **Figure 4.21** shows that very suitable sites are primarily found in the central and northern region of the state comprising 14,036 km$^2$ of land. Land not suitable for livestock rearing is found adjacent to the coast, especially in the central and northern regions, and in the mountains.

**Text Box 4.16. Livestock rearing.**

| INTERPRETATION | SCORE |
|---|---|
| Suitable land for all types of livestock can provide good quantities of manure for pond fertilization. | 4 |
| Suitable land for livestock feeding on pasture, also considered a source of fertilization. | 3 |
| Land with vegetation exploitation other than pasture. | 2 |
| Land not suitable for livestock and hence no source of fertilization. | 1 |

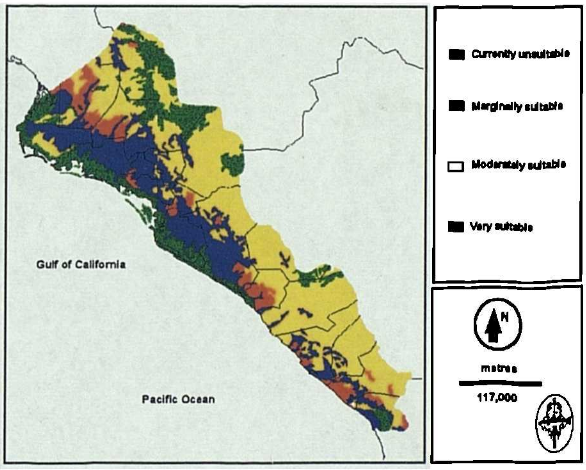


Figure 4.21. Reclassified livestock rearing image for aquaculture development in Sinaloa.

### 4.2.2.8 Forestry

Kapetsky *et al.* (1987) noted that forests can be associated with non-polluted waters, and that it can be assumed that good quality water drains from these lands. However, in terms of site development costs forest land would be the most expensive to clear because of the need to remove the many trunks, roots and underbrush.

Forestry can have a substantial impact on water quality and quantity. The forests most likely to have significant effects on the water environment are those on headwater catchments, particularly on acid-sensitive soils and geology. Forestry activities can cause soil erosion and deposition, effects on water yield, acidification, pollution by fertilizers and pesticides and changes to riparian and aquatic habitats. Forestry activities can also affect the ability of existing users to abstract water, by causing pollution of surface and groundwater or an increase in acidification (Flores-Verdugo *et al.,* 1992). For the purposes of this study, the score interpretation of this factor is shown in **Text Box 4.17.** **Figure 4.22** shows that land not suitable for forestry is found in proximity to the coastline.

**Text Box 4.17. Forestry.**

| INTERPRETATION | SCORE |
|---|---|
| Land not suitable for forestry exploitation. No trees, low costs and ease of pond construction. | 4 |
| Non-wood land could be suitable as a source of other inputs for fish feed formulation. | 3 |
| Land with wood products will be difficult for construction. Forestry activities likely to cause pollution. | 2 |
| Land with wood and non-wood products will be difficult for construction and will involve high costs. Forestry activities will cause pollution. | 1 |

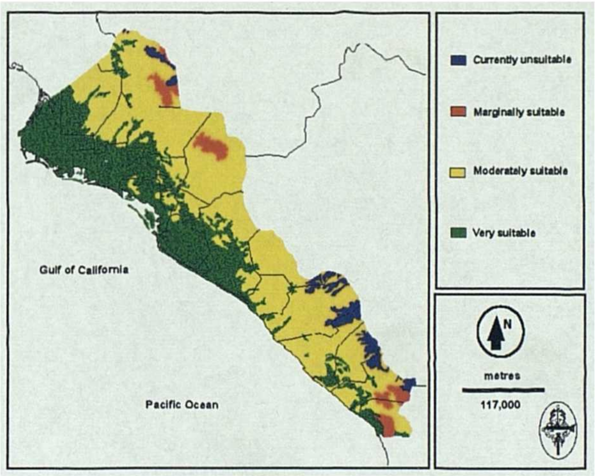


Figure 4.22. Reclassified forestry image for aquaculture development in Sinaloa.

#### 4.2.2.9 Aquaculture impacts

To assess the environmental impact of aquaculture it is necessary to know the background concentration of nutrients in the receiving waters, as well as the emission of nutrients from the farm per unit of time, and the retention time of water in a given area. For example, in land based farms, especially pond farms, chemicals and other toxic substances are used commonly to control predators, pests and weeds, usually as part of pond preparation before stocking with larvae and fingerlings. Though the types of wastes produced in aquaculture farms are basically similar, there are differences in the quality and quantity of the components depending on the species and the culture practices adopted. Much of the information relates to intensive systems of salmonid culture and, to a large extent, to pens and cages in temperate climates. Even though the processes involved may not differ significantly, the applicability of such information to other forms of aquaculture in different climate areas cannot be taken for granted. However, it could provide the background to future investigations and the basis for assessments (Beveridge *et al.,* 1991; Phillips *et al.,*1991; Pillay, 1992).

Small scale aquaculture, which is unlikely to have any significant impact on the environment, is generally exempt from the need for such assessment, except in especially sensitive areas. Usually the scale is determined on the basis of annual production. However, decisions on this have to be based on local conditions, bearing in mind that a large number of small-scale farms located together along a watercourse can have as much or even greater impact than a single large-scale farm. Nonetheless, it is often difficult to determine the impact of aquaculture on the environment in isolation, as the observed consequences are in many cases the cumulative effect of several factors that disturb its natural state. Available data seems to indicate that the pollutant effects of aquaculture are comparatively small and highly localized (Pillay, 1992; Phillips *et al.,* 1993).

Coastlines are affected by the pumping operations carried out in a shrimp farm, for example, temporary flood zones (marshes) are converted into a semi-permanent flooding zone. Changes in the hydrological pattern cause saline intrusions to adjacent areas (both to the agricultural areas as well as the mangroves) increasing soil salinity. Increase in salinity in mangroves which already have high salinities, particularly in arid and semi-arid areas, can cause a major structural loss in this ecosystem including mortalities. Inlet channels in a shrimp farm change the water level in the lagoons, and hence shallow areas are dried and the phreatic layer increases in salinity (Beveridge and Phillips, 1993; Phillips *et al.*, 1993).

Pond farms situated along a common watercourse, which serves both as a source of water inflows and also for drainage of waste water, can easily become infected through discharges from an infected farm upstream. The environmental impacts of aquaculture, such as eutrophication, can create conditions favourable for disease outbreak (Pillay, 1992). In Sinaloa eutrophication problems already exist in some lagoons in Santa María, Ohuira, San Ignacio-Navachiste and Bahía Altata-Ensenada del Pabellón (De la Lanza *et al.*, 1993).

The recommended distance between farms can be limited by the level of production. Distances depend on the type of species being cultured, as well as the hydrological conditions of the site - size and production capacity of the farms. For example, the Crown Estate determines a distance of 5 miles between salmon farms in Scotland (Crown Estate, 1987). Some other countries have declared the maximum admissible production in salmonid farms that can be allowed in the environment based on water discharges. Some countries stipulate the areas where farming can be undertaken, based on site characteristics including depth and exchange rate of water (Nash, 1995).

The spatial analysis of shrimp farms was based on setting distance ranges to mitigate its possible negative influence. The interpretation of these distance ranges is presented in **Text Box 4.18** and the resulting image is shown in **Figure 4.23**. Impacts from aquaculture are found along the entire coastline, the largest being in the central and northern regions, in the municipalities of Ahome and Navolato. The southern area has very few farms, and therefore few impacts are derived form this activity. However, not all environmental consequences of aquaculture are negative, so shrimp farms could be reclassified by treating this factor as a positive proximity factor instead of a negative distance factor. Many aquaculture activities are highly beneficial to effective environmental management when the land use is regenerative rather than merely exploitative. For example, dumping of domestic and industrial wastes near farms sites is more easily prevented, and the multiplication of dangerous diseases, that thrive in many marshy areas, can at least be reduced, if not eliminated. If domestic and farm wastes are used for fertilizing or feeding, not only would it be an inexpensive means of waste disposal but it would be effective recycling to produce food and fodder. Moreover, aquaculture can often utilize water that is unsuitable for drinking and irrigation, such as saline waters occurring in semi-arid areas (Little and Muir, 1987; Pillay, 1992; Beveridge and Phillips, 1993).

**Text Box 4.18. Aquaculture impacts.**

| INTERPRETATION | SCORE |
|---|---|
| Low risks of pollution<br>> 3 km. | 4 |
| Moderate risk of pollution<br>2 - 3 km | 3 |
| Likely risk of pollution<br>1 - 2 km | 2 |
| High risk of pollution.<br>500 - I km | 1 |

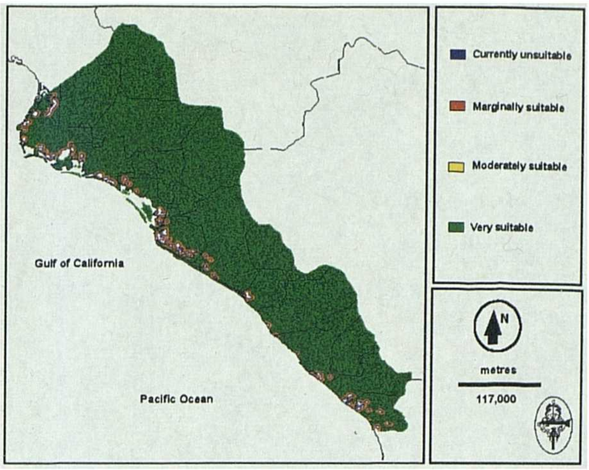


Figure 4.23. Aquaculture impacts image for aquaculture development in Sinaloa.

## 4.3 SOCIO-ECONOMIC FACTORS

In addition to factors of the natural environment which may influence the development of an aquaculture industry, there are a number of factors which are described collectively as socio-economic. To date, much of the research on aquaculture development has concentrated on technical and managerial aspects, whilst social and economic factors including the environmental impacts of aquaculture development on society, have been neglected (Harrison *et al.*, 1994; Pillay, 1994).

Dutrieux and Guelorget (1988) stress the importance of an ecological approach to the planning of aquaculture, and note that very few sites on the French Mediterranean coast have been chosen simply for their productivity potential. Among 15 studied, nine were chosen for socio-economic reasons such as the availability of the plot or planning permission from the authorities. The need for food, employment or foreign exchange has often influenced decision-makers to opt for short-term economic benefits despite socio-economic and environmental losses in the long run (Bernorth, 1991; Chua, 1993). Large-scale mangrove conversion into fish and shrimp pond farms (e.g. Thailand) has displaced rural communities which traditionally depend on mangrove resources for their livelihood (Chua, 1993). The economic disaster of the shrimp farming industry in Taiwan in 1988 and 1989, in which shrimp production plunged from 90,000 tons in 1987 to 50,000 tons in 1988 and then to 20,000 tons in 1989, shows the magnitude and severity of the social and economic implications of self-pollution from shrimp farming operations. Likewise, according to Bailey (1988), "the expansion of shrimp mariculture into mangrove habitat generally involves the transformation of a multi-use/multi-user coastal resource into a privately owned single purpose resource. Moreover, the costs of coastal ecosystem disruption for society may include coastal erosion, saltwater intrusion into groundwater and agricultural fields, and a reduction in supply of a wide range of valuable goods and services produced from the resources available in the mangrove forests or other wetlands".

Socio-economic and environmental factors for aquaculture development (i.e. the impact of aquaculture to the environment and the impact of other activities to aquaculture) must be assessed from the early planning stages of all projects. Good site selection can help to minimise the negative impacts of aquatic farming whilst maximising the potential benefits. Bearing this in mind, and in order to make a comprehensive analysis, it was decided to logically group the factors selected for the socio-economic evaluation into three categories (**Table 4.9**).

**Table 4.9. Factors for socio-economic assessment for aquaculture development in Sinaloa.**

| SOCIAL IMPACTS | PRODUCTION MODIFIERS | MARKET POTENTIAL |
|---|---|---|
| Age-group | Energy | Population density |
| Primary sector | Natural postlarvae | Salary/wage structure |
| Secondary sector | Agriculture | Preferred species |
| Tertiary sector | Livestock rearing | Fishing activity |
| Job creation | Capital city | Hotels |
| Agriculture | Other cities | Fish processing plants |
| Livestock rearing | Towns | Markets |
| Agglomeration | Villages | |
| | Agglomeration | |
| | Paved roads | |
| | Railway | |
| | Gravel roads | |
| | Dirt roads | |
| | Unimproved roads | |
| | Road types | |
| | Communications | |
| | Support centres | |

### 4.3.1 SOCIAL IMPACTS

Aquaculture projects have many sociological impacts, either in a beneficial way, such as the stimulation of development, improvement in the standard of living, employment opportunities, or as negative social impacts, such as modification of traditional social values, privatization of common property, use of natural resources, activity conflicts and unsuccessful technologies.

Employment opportunities generated through aquaculture development, including processing, transport and marketing, can be expected to affect, to some extent, the drift of rural people to urban areas. Large-scale development of aquaculture can also eventually lead to better communications in rural areas, as they are needed also for proper management of aquaculture production and distribution (Avault, 1989; Ruddle, 1993).

Whether a project is intended to meet the socio-economic needs of a community fully or partly, it is necessary to design it carefully to provide the expected outputs. On the assumption that the potential for aquaculture development in the area is established, priority has to be given to the study of the community. It should aim to identify the basic needs to be fulfilled, and those that can be met through an aquaculture programme. A knowledge of the level of human, economic and social infrastructure development, and the cultural and political context in which the programme has to be implemented, is necessary for appropriate project design (Pillay, 1990). As Ruddle (1993) puts it, "... aquaculture must be adapted to society; the converse is not worthy of consideration".

#### 4.3.1.1 Human resources submodel

Along with the developing philosophy of strategic management has come the recognition that the company's personnel are probably the most important resource. Therefore, the existence of appropriate human resources should form part of any aquaculture development plan. The primary importance of hands-on experience in successful farming has been shown all over the world (Chaston, 1984; Pillay, 1994; Nash, 1995).

Suitably qualified technical staff can usually be obtained more easily in regions where aquaculture has been established. People with suitable hands-on experience, but with some technical background and an education in science, can be found in most developed, and some developing countries, and can be trained accordingly. Requirements for well-trained and experienced technical staff are most important in more intensive projects, whereas those on a small-scale can be supported by extension agencies (Pillay, 1994; Nash, 1995).

In addition, there may be a need for professional and engineering services, legal assistance, specialist plumbing, pond clearing and harvesting services. Obviously the requirement for, and availability of, each of these will vary from one location to the next. Especially difficult to obtain in some countries is technical support, which can be very important when problems arise during production. Technical support is often provided by extension services, disease specialists and laboratory services which can perform water quality and nutritional analysis, albeit at a cost. Some feed companies take on the role of extension agents in return for purchase of their feeds (Chaston, 1984; Balayut, 1989; Fast, 1992; Nash, 1995).

The availability of a casual and seasonal labour force should be investigated if it will be needed for construction work, or for harvesting and processing operations. The availability of professional services, for example for quantity surveying, site engineering and contracting, well drilling and electrical installation, will need to be checked.

Assessment of the human resource submodel was based on a factor and a submodel within the human resource submodel: (1) the age-group was used as a factor, and (2) skills of the economically active population were used as the other submodel. The objective was to locate and score the available work-force.

1.- Age-group data were extracted from a computer database for a population census created by INEGI (1993). Inhabitants above 15 years of age and below 55 years were considered to have potential to carry out aquaculture activities as suggested by the United Nations Development Programme and FAO (1982). Data provided by INEGI consisted of inhabitants which are over 15 years of age, selected because they are reported to have had post-primary school education - a great number of inhabitants have not passed this level of education or have not had any education at all. Raw age-group data (**Table 4.10**) was scored according to the interpretation in **Text Box 4.19** and the resulting image using this classification is presented in **Figure 4.24**. High work-force potential is located in 4 out of the 18 municipalities, of which Culiacán and Mazatlán have the highest potential. Lowest work-force is found in the south of the state, with the exception of the municipality of Mazatlán.

**Text Box 4.19. Age-group.**

| INTERPRETATION (number of inhabitants) | SCORE |
|---|---|
| > 60,000 High potential work-force | 4 |
| 11,000 - 60,000 Work-force with moderate potential. | 3 |
| 4,000 - 10,000 Potential work-force but to a much lesser extent. | 2 |
| < 3,000 Few personnel available | 1 |

*Note: Threshold based on frequency distribution.*

**Table 4.10. Labour force according to age-group and education level in Sinaloa for 1990.**

| MUNICIPALITY | AGE-GROUP OVER 15 YEARS WITH POST-PRIMARY EDUCATION (number of inhabitants) | SCORE |
|---|---|---|
| **NORTH** | | |
| Ahome | 98,989 | 4 |
| Choix | 2,724 | 1 |
| El Fuerte | 16,950 | 3 |
| Guasave | 62,163 | 4 |
| Sinaloa | 12,661 | 3 |
| **CENTRE** | | |
| Angostura | 10,750 | 3 |
| Baridaguato | 2,882 | 1 |
| Culiacán | 186,923 | 4 |
| Mocorito | 7,687 | 2 |
| Salvador Alvarado | 19,384 | 3 |
| Navolato | 24,381 | 3 |
| **SOUTH** | | |
| Concordia | 4,131 | 2 |
| Cosalá | 1,757 | 1 |
| Elota | 4,824 | 2 |
| Escuinapa | 10,936 | 3 |
| Mazatlán | 106,751 | 4 |
| El Rosario | 9,390 | 2 |
| San Ignacio | 2,918 | 1 |

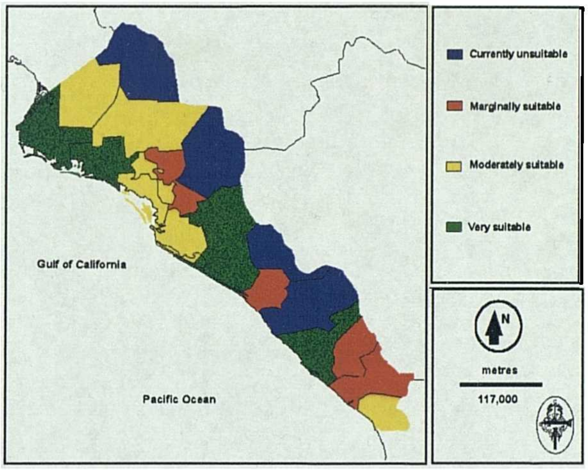


**Figure 4.24. Age-group image for aquaculture development in Sinaloa.**

2.- The skills of the economically active population have been classified by the Mexican government into three sectors. The primary sector comprises people involved in agriculture, livestock rearing, poultry, hunting and fishing; the secondary sector involves mining, petroleum, gas extraction, manufacturing industries and generation of electricity; and the tertiary sector involves those people involved in commerce and services. These factors were developed into a submodel as shown in **Figure 4.25.**

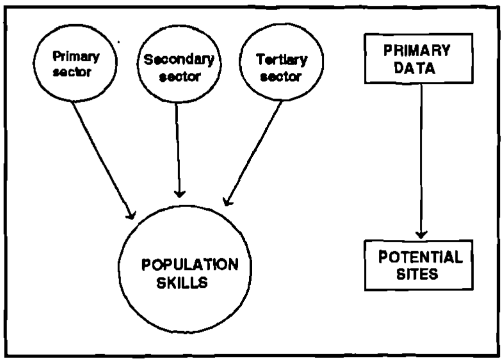


**Figure 4.25. Skills submodel for aquaculture development in Sinaloa.**

**PSS** = ( PRIM X 0.57 ) + ( SEC X 0.07 ) + ( TERT X 0.36 ). Where; **PSS** = population skills submodel; **PRIM** = PRIMARY ( number of inhabitants involved in the primary sector: agriculture, livestock rearing, poultry, hunting and fishing); **SEC** = SECONDARY (number of inhabitants involved in the secondary sector: mining, petroleum extraction, gas, manufacturing industries, generation of electricity and construction); and **TERT** = TERTIARY (number of inhabitants involved in the tertiary sector: commerce and services).

**Command line mode file**
**Population skills submodel**
mce x 0 3 pss 0 prim 0.57 sec 0.07 tert 0.36

Scores for **PRIM**, **SEC** and **TERT** were defined using the percentage threshold. The MCE technique was used to obtain the weights used in the mathematical expression for obtaining the values of **PSS** (**Table 4.11**). Since the inhabitants from the primary sector would be well-suited to an aquaculture development it was given the highest weight (0.57). Inhabitants involved in secondary activities were considered least important because their skills would not be as beneficial, and therefore it was given the lowest weight (0.07). Tertiary activities, although necessary to a lesser extent in comparison to primary activities, were also considered as likely sources of labour because they could be involved in aquaculture to some degree, so a weight of 0.36 was assigned. The interpretation of the final score PSS is presented in **Text Box 4.20** and the resulting submodel image is shown in **Figure 4.26.** Very suitable and unsuitable sites were not identified by the general model. Half the number of municipalities were identified as having a moderate suitability whilst the other half was identified as being marginal, most sites classified as moderately suitable were found in the north.

**Text Box 4.20. Population skills submodel.**

| INTERPRETATION | SCORE |
|---|---|
| Mainly primary activities. | 4 |
| Primary & secondary activities important. | 3 |
| Secondary & tertiary activities important. | 2 |
| Mainly dominated by tertiary activities. | 1 |

## Table 4.11. Population skills according to production sectors in Sinaloa for 1990.

| MUNICIPALITY | OCCUPIED POPULATION | PRIMARY | % | SCORE PRIM | SECONDARY | % | SCORE SEC | TERTIARY | % | SCORE TERT | PSS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **NORTH** | | | | | | | | | | | |
| *Ahome* | 92,134 | 27,242 | 29.6 | 2 | 17,293 | 18.8 | 1 | 44,794 | 48.6 | 2 | 2 |
| Choix | 5,913 | 3,613 | 61.1 | 3 | 790 | 13.4 | 1 | 1,234 | 20.9 | 2 | 3 |
| El Fuerte | 24,932 | 14,549 | 58.4 | 3 | 3,547 | 14.2 | 1 | 6,172 | 24.8 | 2 | 3 |
| Guasave | 75,765 | 40,087 | 52.9 | 3 | 10,580 | 14.0 | 1 | 22,820 | 30.1 | 2 | 3 |
| Sinaloa | 22,926 | 16,006 | 69.8 | 3 | 2,198 | 9.6 | 1 | 3,390 | 14.8 | 1 | 2 |
| **CENTRE** | | | | | | | | | | | |
| *Angostura* | *12,877* | *8,126* | *63.1* | 3 | 442 | 3.4 | 1 | 2,851 | 22.1 | 2 | 3 |
| Baridaguato | 7,129 | 5,257 | 73.7 | 3 | 529 | 7.4 | 1 | 864 | 12.1 | 1 | 2 |
| *Culiacán* | 187,968 | 45,795 | 24.4 | 2 | 37,306 | 19.8 | 1 | 97,295 | 51.8 | 3 | 2 |
| Mocorito | 12,617 | 7,835 | 62.1 | 3 | 1,406 | 11.1 | 1 | 2,709 | 21.5 | 2 | 3 |
| Salvador Alvarado | 18,019 | 4,270 | 23.7 | 2 | 3,205 | 17.8 | 1 | 10,006 | 55.5 | 3 | 2 |
| Navolato | 47,107 | 30,309 | 64.3 | 3 | 6,423 | 13.6 | 1 | 8,489 | 18.0 | 1 | 2 |
| **SOUTH** | | | | | | | | | | | |
| Concordia | 7,323 | 3,036 | 41.5 | 2 | 1,834 | 25.0 | 2 | 2,173 | 29.7 | 2 | 2 |
| Cosalá | 3,527 | 1,983 | 56.2 | 3 | 589 | 16.7 | 1 | 816 | 23.1 | 2 | 3 |
| Elota | 7,573 | 4,183 | 55.2 | 3 | 1,104 | 14.6 | 1 | 1,935 | 25.6 | 2 | 3 |
| Escuinapa | 12,982 | 6,450 | 49.7 | 2 | 1,482 | 11.4 | 1 | 4,623 | 35.6 | 2 | 2 |
| Mazatlán | 103,168 | 12,621 | 12.2 | 1 | 21,778 | 21.1 | 2 | 65,197 | 63.2 | 3 | 2 |
| El Rosario | 12,700 | 7,140 | 56.2 | 3 | 1,471 | 11.6 | 1 | 3,516 | 27.7 | 2 | 3 |
| San Ignacio | 6,245 | 4,198 | 67.2 | 3 | 519 | 8.3 | 1 | 1,255 | 20.1 | 2 | 3 |

Source: INEGI (1991).

TERMINOLOGY:

**PR** = PRIMARY ( number of inhabitants involved in the primary sector: agriculture, livestock rearing, poultry, hunting and fishing)

**SEC** = SECONDARY ( number of inhabitants involved in the secondary sector: mining, petroleum extraction, gas, manufacturing industries, generation of electricity and construction)

**TERT** = TERTIARY (number of inhabitants involved in the tertiary sector: commerce and services)

Note: Scores for **PRIM**, **SEC** and **TERT** were defined using the percentage threshold. The MCE technique was used to obtain the values of **PSS**.

**PSS** = Population skills submodel.

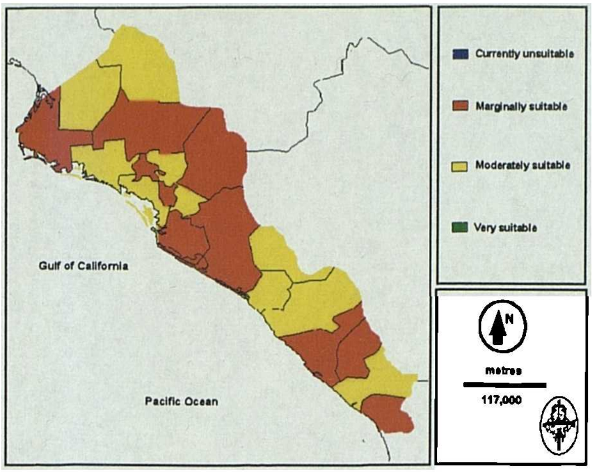


Figure 4.26. Population skills submodel image.

To integrate the age-group factor and the skills of the population, a human resources submodel was developed as shown in **Figure 4.27**.

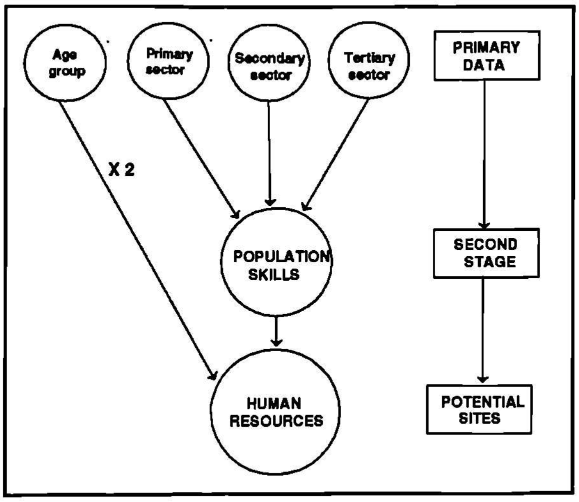


Figure 4.27. Human resources submodel for aquaculture development in Sinaloa.

HRS = ( AGE X 2 ) + PSS. Where, HRS = human resources submodel; AGE = age-group factor and PSS = population skills.

**MACRO FILE**
**Human resources submodel**
mce x 0 3 pss 0 prim 0.57 sec 0.07 tert 0.36
scalar x agea ageb 3 2
overlay x 3 ageb pss hrs

The age-group factor was given a higher weight primarily because it represents the potential work-force that is available. The resulting values from this mathematical expression were classified according to the frequency distribution threshold.

A shown by the human resources submodel image (**Figure 4.28**) a fairly even distribution of scores was found in Sinaloa. Very suitable sites were found in the municipalities of Ahome, Guasave, Culiacán and Mazatlán.

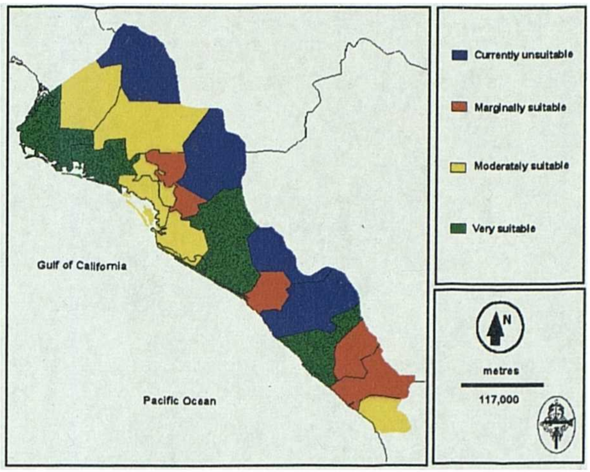


**Figure 4.28. Human resources submodel image for aquaculture development in Sinaloa.**

### 4.3.1.2 Job opportunities created by aquaculture

Employment generation represents one of the most evident economic benefits that aquaculture can provide. The assumption made was that the unemployed section of the population is potentially available in rural areas and therefore suitable for aquaculture labour. Percentages for the number of inhabitants in each municipality were estimated (**Table 4.12**) and then these percentages were assigned a score according to the interpretation shown in **Text Box 4.20** and the resulting image is presented in **Figure 4.29**. Between 31 and 41% of unemployed inhabitants were reported in each municipality and therefore, according to the percentage threshold established, all municipalities were classified as being marginal for the creation of new jobs.

**Text Box 4.21. Job opportunities created by aquaculture**

| INTERPRETATION | SCORE |
|---|---|
| 80 - 100 % New jobs vital | 4 |
| 50 - 79.9 % New jobs significant | 3 |
| 20 - 49.9 % New jobs valuable | 2 |
| 0 - 19.9 % New jobs useful | 1 |

Table 4.12. Possible potential labour for aquaculture in Sinaloa for 1990.

| MUNICIPALITY | NUMBER of INHABITANTS | UNEMPLOYED POPULATION (number of inhabitants) | %Total | SCORE |
|---|---|---|---|---|
| **NORTH** | | | | |
| Ahome | 303,558 | 117,008 | 38.6 | 2 |
| Choix | 26,167 | 10,462 | 39.9 | 2 |
| El Fuerte | 86,074 | 33,304 | 38.7 | 2 |
| Guasave | 258,130 | 99,279 | 38.5 | 2 |
| Sinaloa | 88,002 | 32,303 | 36.7 | 2 |
| **CENTRE** | | | | |
| Angostura | 47,324 | 19,599 | 41.4 | 2 |
| Baridaguato | 37,988 | 15,486 | 40.8 | 2 |
| Culiacán | 601,123 | 211,589 | 35.2 | 2 |
| Mocorito | 51,674 | 20,580 | 39.8 | 2 |
| Salvador Alvarado | 66,659 | 26,479 | 39.7 | 2 |
| Navolato | 131,973 | 41,617 | 31.5 | 2 |
| **SOUTH** | | | | |
| Concordia | 26,314 | 10,465 | 39.8 | 2 |
| Cosalá | 16,975 | 6,827 | 40.2 | 2 |
| Elota | 30,319 | 11,589 | 38.2 | 2 |
| Escuinapa | 45,928 | 17,168 | 37.4 | 2 |
| Mazatlán | 314,345 | 113,357 | 36.1 | 2 |
| El Rosario | 47,416 | 18,753 | 39.6 | 2 |
| San Ignacio | 24,085 | 9,497 | 39.4 | 2 |

Source: INEGI (1991).

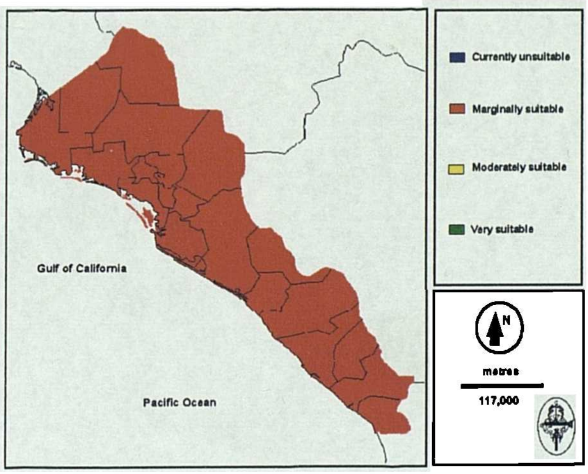


Figure 4.29. Job opportunities created by aquaculture development in Sinaloa.

#### 4.1.3.3 Activity conflicts submodel

Some of the major constraints in the development of aquaculture are the conflicts that may arise in terms of use of land and water for various activities (Pollnac, 1992). Aquaculture has been involved in land-use conflict issues in several parts of the tropics, particularly in highly urbanized or overcrowded areas (Beveridge and Phillips, 1993). In Singapore and Hong Kong, shortages of land have adversely affected production of fish for the aquarium trade (Tan and Siow, 1989) and unfortunately, in some cases, competition for land has resulted in violence, as seen between rice and shrimp farmers in Thailand (New, 1991). Nonetheless, in some cases, aquaculture could be integrated with other production activities whereby it can complement and improve the overall efficiency of many types of farm, for instance, in the more efficient use of water and labour, as well as waste recycling with fish. Conversely, livestock and arable crop production may be the only source of feeds and fertilizers available at low enough cost to make fish culture possible (Little and Muir, 1987). Whichever the case (conflict or complementary activities), it is necessary to identify these areas and this usage of land and water. It is important to plan and design the feasibility of aquaculture by the optimization of resource use, and to identify and establish when possible, an integration with other specific activities like agriculture and livestock rearing (Chua, 1993). The ultimate goal is to develop natural resources in a manner that ensures a sustainable increase in the level of societal and individual welfare (Dixon, and Fallon, 1989).

Activities in Sinaloa which demand large areas of land and water, both essential for aquaculture (Nash, 1995), are tourism, recreational facilities, and conservation areas. Other land uses competing for resources are industries (e.g. the energy industry is particularly demanding of land and water), urban development, agriculture, fisheries, livestock rearing and forestry. The social and/or political problems perceived for aquaculture mainly involve water and land use; environmental, aesthetics and navigation.

For this study, agriculture, livestock rearing and existing shrimp farms were found to be in conflict in terms of land space because many areas could be suitable for these activities (see Chapter 2). These three activities were integrated into an activity conflict submodel as shown in **Figure 4.30**. The agriculture and livestock rearing factors used for this activity conflict submodel are shown **Figure 2.18** and **Figure 2.20**. The aquaculture factor used was the agglomeration image shown in **Figure 4.37**.

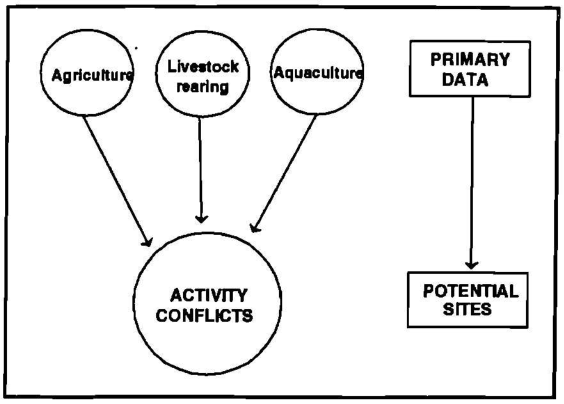


**Figure 4.30. Activity conflicts submodel for aquaculture development in Sinaloa.**

ACTS= AGR(se) + LI(se) + AQ(se). Where, ACTS = Activity conflicts submodel; AGR (se)= agriculture; LI(se) = livestock rearing, and AQ(se) = existing shrimp farms. Note: Classification of these activities within the socio-economic model results in the "(se)" appended to their names.

**Macro file**
**Activity conflicts submodel**
overlay x 1 agr(se) li(se) agrli
overlay x 1 agrli aq(se) acts

The higher the score obtained from this additional model, the higher the amount of conflicts encountered. The layer was then reclassified according to **Text Box 4.22** and the resulting submodel image is presented in **Figure 4.31**. Activity conflicts increase towards the coast where most of the production activities take place. Minimum conflicts were found in the mountains and in a few regions in the north of the state adjacent to the coast. Lowest scores were found in close proximity to many shrimp farms along the coastline where most of the activities take place.

**Text Box 4.22. Activity conflicts submodel.**

| INTERPRETATION | SCORE |
|---|---|
| No activity, no conflict. | 4 |
| Two activities,<br>moderate conflicts. | 3 |
| Three activities.<br>Many conflicts. | 2 |
| More than 3 activities.<br>Highest number of conflicts. | 1 |

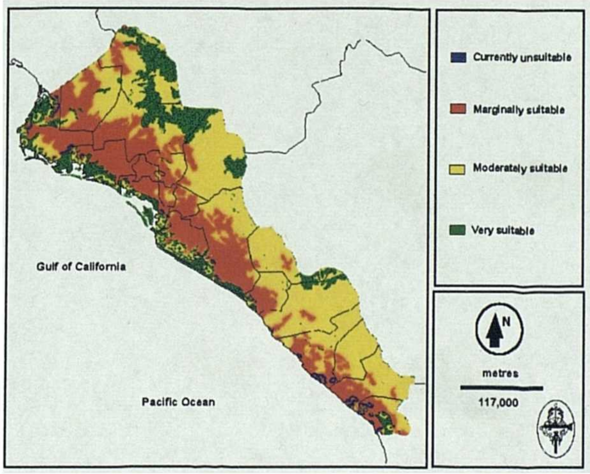


**Figure 4.31. Activity conflicts submodel image for aquaculture development in Sinaloa.**

### 4.3.2 PRODUCTION MODIFIERS

In the development of aquaculture projects it is important to identify and locate the cost and availability of production inputs to make the activity profitable. The factors selected are directly related to growing the selected species and also include the logistics of providing the necessary inputs for the farm. These factors are defined as production modifiers because they may enhance or detract from the aquaculture activity, although none will prevent the activity from taking place.

#### 4.3.2.1 Energy

Energy use is one of the most important operating costs in an aquaculture activity and is dependent upon the intensity of the culture system. Many important factors relating to energy supply are dependant on the locality chosen. At the level of a country or region it may be important to investigate the overall national policy. Sometimes electricity prices for industry are subsidised to promote regional development. Countries with a well-developed electrical network can provide a more reliable supply (Pillay, 1994; Nash, 1995). The quality of the supply with regard to interruptions, overall capacity, voltage consistency and the number of phases available is also relevant. Inadequate or non-existent supplies at many sites necessitate the use of diesel-powered generators either as a back-up or to provide for all electrical needs. The energy factor was evaluated in terms of the number of houses with electricity, based on the assumption that these areas could provide the required energy needed for aquaculture operations.

The percentage of houses with electricity in each municipality was calculated from data provided by INEGI (1991) (**Table 4.13**) and then scored as shown in **Text Box 4.23.** As shown in **Figure 4.32**, ten out of the eighteen municipalities were classified as very suitable, the highest being located in the central and southern region of the state. Only the municipality of Baridaguato was classified as marginal.

**Text Box 4.23. Energy.**

| INTERPRETATION | SCORE |
|---|---|
| 80 - 100 % Municipalities with the highest number of houses with electricity Best location in terms of electric energy. | 4 |
| 50 - 79.9 % Municipalities with moderate quantities of houses with electricity. Also very good potential. | 3 |
| 20- 49.9% Municipalities with a moderate amount of houses with electricity. Some farms will have difficulty reaching power-lines. | 2 |
| 0 - 19.9% Municipalities with very few houses with electricity. Difficulty in obtaining energy. Generators are very likely to be used instead. | 1 |

Table 4.13. Energy (number of houses provided with electricity in Sinaloa) for 1990.

| MUNICIPALITY | NUMBER of HOUSES | NUMBER of HOUSES WITH ELECTRICITY | HOUSES (%) | SCORE |
|---|---|---|---|---|
| **NORTH** | | | | |
| Ahome | 58,754 | 56,201 | 95.7 | 4 |
| Choix | 5,173 | 2,783 | 53.8 | 3 |
| El Fuerte | 15,931 | 12,688 | 79.6 | 3 |
| Guasave | 46,423 | 43,536 | 93.8 | 4 |
| Sinaloa | 15,508 | 11,705 | 75.5 | 3 |
| **CENTRE** | | | | |
| Angostura | 9,114 | 8,722 | 95.7 | 4 |
| Baridaguato | 6,674 | 2,390 | 35.8 | 2 |
| Culiacán | 115,662 | 108,132 | 93.5 | 4 |
| Mocorito | 10,080 | 7,889 | 78.3 | 3 |
| Salvador Alvarado | 13,055 | 12,267 | 94 | 4 |
| Navolato | 24,735 | 23,316 | 94.3 | 4 |
| **SOUTH** | | | | |
| Concordia | 5,486 | 4,362 | 79.5 | 3 |
| Cosalá | 2,895 | 1,634 | 56.4 | 3 |
| Elota | 5,620 | 4,987 | 88.7 | 4 |
| Escuinapa | 9,111 | 8,256 | 90.6 | 4 |
| Mazatlán | 66,967 | 63,123 | 94.3 | 4 |
| El Rosario | 9,757 | 8,328 | 85.4 | 4 |
| San Ignacio | 4,810 | 3,360 | 69.9 | 3 |

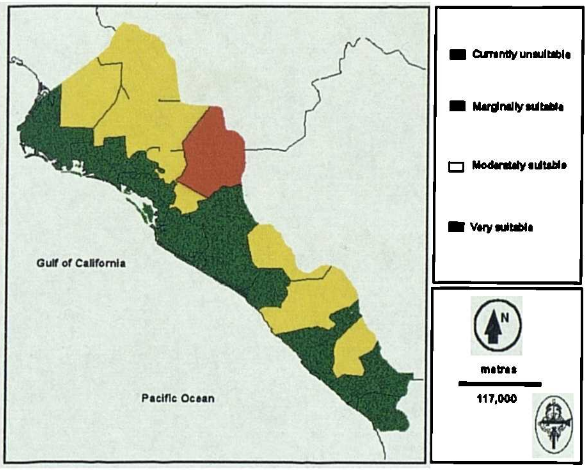


Figure 4.32. Energy for aquaculture development in Sinaloa.

#### 4.3.2.2 Availability of natural postlarvae

Despite the many differences between the shrimp farming industries of different countries, the establishment of a reliable supply of seed has always been vital to expansion. Hence, broodstock and/or seedstock are essential to aquaculture and great attention should be given to locating reliable resources. A conveniently well-located wild stock can support a culture industry at more than one level of operation by providing both wild-caught juveniles for farms, and broodstock for hatcheries. Moreover, because the cost of postlarvae can amount to about 30% of total operating and harvesting costs in semi-intensive shrimp farming (Dugger, 1990; Lobato-Gonzales, 1990; Fast, 1992), any means which increases availability or improves survival can increase profitability. In this regard, proximity to high densities of seed-stock could be an important siting factor in two ways. The first is that losses due to transport could be minimized, and shrimp would be in better condition when stocked than if carried long distances. The second is that if a farm is located in an area of high density of post-larvae there would be more postlarvae to be entrained into the water supply canals during daily pumping for water exchange, thereby lessening stocking needs (Lee and Wickins, 1992).

A map showing possible locations of natural shrimp postlarvae was not available so the location of the fishing communities was used as "surrogate" data source (Meaden and Kapetsky, 1991). A map locating the fishing communities where postlarvae capture is being carried out was provided by the fisheries department in Mazatlán (Delegación Federal de Pesca, 1993) and from this, a proximity range was created to represent the positive influence of this factor. The score interpretation for these proximity ranges is presented in **Text Box 4.24** and the resulting image is presented in **Figure 4.33**. The largest quantity of fishing communities was located in the central and northern parts of the state, particularly in Ahome and Angostura. The lowest number of fishing communities was found in the southern region of the state, but this was also considered as a potential region to obtain postlarvae.

**Text Box 4.24. Natural postlarvae availability.**

| INTERPRETATION | SCORE |
|---|---|
| Closest proximity ( 0 - 1 km ) minimum costs, likely to entrain postlarvae in water supply canals. | 4 |
| Good proximity ( 1 - 2 km ), minimum transport costs | 3 |
| Moderate proximity ( 2 - 3 km ). There will be costs involved in transportation. | 2 |
| Marginal proximity ( > 3 km ). Higher possibility of loss of postlarvae during transport. High costs. | 1 |

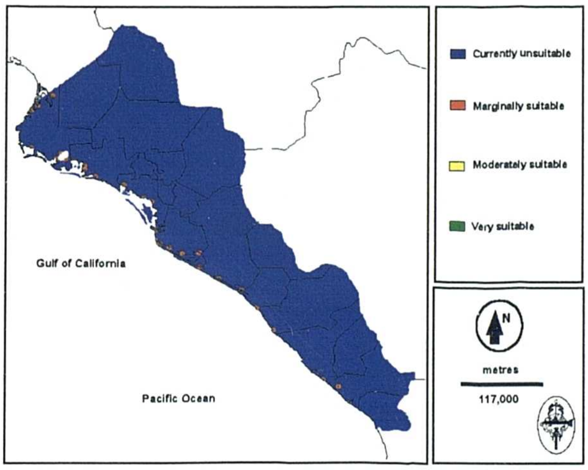


**Figure 4.33. Natural postlarvae availability for aquaculture development in Sinaloa.**

### 4.3.2.3 Availability of input by-products submodel

Supplies and prices of inorganic fertilizers should be easy to find because these products are widely used in agriculture. Organic fertilizers, which are mostly by-products of poultry and livestock production, are bulky, and if sources are distant transport costs may be prohibitive. Liming materials are often widely available because of their use in farming, and in the manufacture of cement.

As animal manure (especially poultry manure) is good for pond culture the distance from farms having livestock is obviously of importance to the spatial availability of fertilizer. There will be large cost variations in acquiring fertilizers because of variations in quality, the amounts available seasonally and transport costs ( Little and Muir, 1987; ICLARM and GTZ, 1991).

The type of production system will influence the demand for fertilizer - where water exchange rates are high then fertilizer inputs will be less effective. The farmer might consider the viability of polycultural systems as a means of supplying fertilizers. If natural fertilizers are unavailable the producer might need to consider the economic viability and availability of inorganic fertilizers or supplementary feeds (Meaden and Kapetsky, 1991).

The livestock rearing classification used in the environmental evaluation remained the same, but the agricultural classification was reversed in the sense that a very suitable land for agriculture would be most suitable as a source of input by-products (**Text Box 4.25**). The inputs factors were developed into a submodel by integrating the livestock rearing and the agriculture factors as shown in **Figure 4.34**.

**Text Box 4.25. Inputs**

| INTERPRETATION | SCORE |
|---|---|
| Highest quantities of agricultural by-products Land very suitable for livestock rearing | 4 |
| Large quantities of inputs from livestock rearing and agriculture | 3 |
| Marginal quantities of inputs from livestock rearing and agriculture. | 2 |
| Minimum agricultural and livestock rearing activities very few by-products. | 1 |

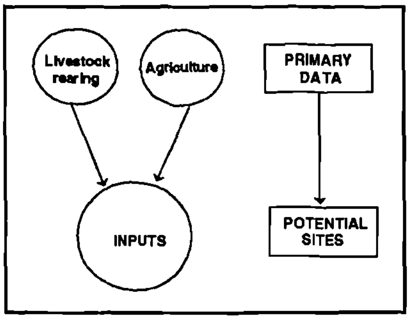


**Figure 4.34. Inputs submodel for aquaculture development in Sinaloa.**

**Command line mode file**
**Inputs submodel**

```
mce x 0 2 ins 0 li 0.70 agr(se) 0.30
```

INS = ( LI X 0.70 ) + ( AGR(se) X 0.30 ). Where, INS = inputs submodel; LI = Livestock rearing and AGR(se) = agriculture.

A higher weight was assigned to livestock rearing because it was considered a more reliable source of inputs. **Figure 4.35** shows the image from the inputs submodel. Largest source of inputs was found in the central and northern parts of the state. Overall, very suitable sites account for 23% of the land. Unsuitable sites are found adjacent to the coastline in the centre and north of the state, as well as in the mountains.

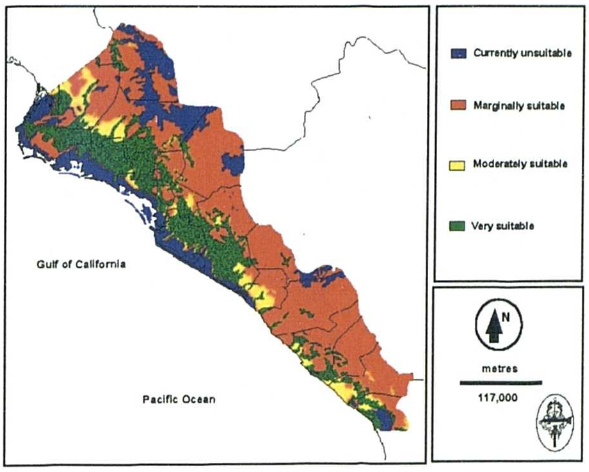


**Figure 4.35. Inputs submodel image for aquaculture development in Sinaloa.**

#### 4.3.2.4 Urban development submodel

Many supplies are needed for semi-intensive and intensive culture operations, and they represent a major production expense. For example, the availability of essential supplies (e.g. pumps, diesel generators, cement, steel) should be investigated and unit costs calculated to include allowances for delivery; feed of suitable quality must be readily available at a price which does not significantly narrow profit margins (e.g. the poor quality of shrimp feed produced in some Latin American countries is a major reason for the lack of success of shrimp culture in Mexico (Asian Shrimp Culture Council, 1992).

The costs and availability of essential inputs will have a direct bearing on the economics and ease of operating an aquatic farm. Although it is possible to transport men and materials almost anywhere in the world, it makes economic sense to set up operations where essential resources are readily available and inexpensive, or at least competitively priced. It is important to locate and quantify the infrastructure required for aquaculture development. Proximity to towns and district centres can mean a considerable reduction on the expenditure of transport or the construction of housing for employees; proximity to communities and facilities such as schools and health centres are also advantages. Additionally, villages and district centres are indicative sources of labour, electrical services and supplies (Pillay, 1994; Nash, 1995).

For the purpose of this evaluation the urban development factor used in the environmental evaluation was re-interpreted using a proximity range instead of a distance range, and therefore the most suitable sites were located in proximity to the capital cities (e.g. Culiacán) and other cities as shown in **Text Box 4.26**. **Figure 4.36** shows that it is the central (i.e. Culiacán) and the northern regions of the state where most of the main cities and towns are concentrated.

**Text Box 4.26. Urban development submodel.**

| INTERPRETATION | | SCORE |
|---|---|---|
| Closest proximity, highest economic benefit, very low costs. | | 4 |
| Capital city | 5 - 10 km | |
| Other cities | 2 - 4 km | |
| Towns | 1 - 2 km | |
| Villages | 500 m - 1 km | |
| Moderate proximity, also with many economic benefits, low costs. | | 3 |
| Capital city | 10 - 15 km | |
| Other cities | 4 - 6 km | |
| Towns | 2 - 3 km | |
| Villages | 1 - 2 km | |
| Marginal proximity, high costs, low benefits. | | 2 |
| Capital city | 15 - 20 km | |
| Other cities | 6 - 8 km | |
| Towns | 3 - 4 km | |
| Villages | 2 - 3 km | |
| Most distant sites, high costs. | | 1 |
| Capital city | >20 km | |
| Other cities | > 8 km | |
| Towns | > 4 km | |
| Villages | > 3 km | |

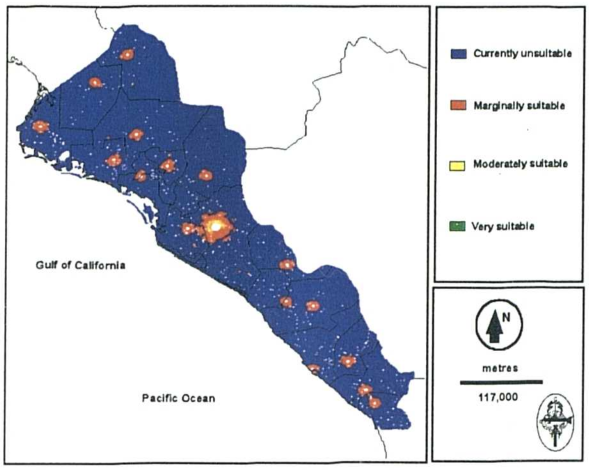


**Figure 4.36. Urban development submodel image for aquaculture development in Sinaloa.**

### 4.3.2.5 Agglomeration

Meaden and Kapetsky (1991) defined agglomeration as a means for measuring the synergistic influence of existing aquatic farms on the development of new farms. Agglomeration implicitly takes into account such factors as already developed farming skills, availability of broodstock , fingerlings, transportation, equipment, facilities and markets. Nonetheless, as noted by Meaden and Kapetsky (1991), it is necessary to ascertain whether agglomeration advantages will function positively. In some cases it might be better to site at a distance from another producer in order to have less competition for land, water and markets. Whichever the case, for the purpose of the present study agglomeration was considered to have a positive influence by reclassifying the aquaculture impact factor as shown in **Text Box 4.27** and is presented in **Figure 4.37**. Highest benefit from agglomeration is found in Navolato (in the centre) and in Ahome ( in the north).

**Text Box 4.27. Agglomeration.**

| INTERPRETATION | SCORE |
|---|---|
| Closest proximity, highest benefits ( 500 - l km ). | 4 |
| Moderate proximity, still with many benefits. ( 1 - 2 km ) | 3 |
| Marginal benefits ( 2 - 3 km ). | 2 |
| Most distant sites, although still with some benefits ( > 3 km). | 1 |

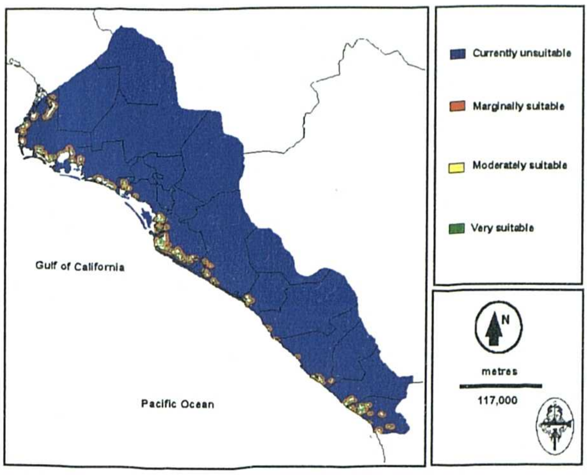


Figure 4.37. Agglomeration in Sinaloa.

### 4.3.2.6 Transportation submodel

The existence of a suitable transport infrastructure is important to ensure that fish products will not suffer unnecessary spoilage or deterioration in quality (Eddie, 1983; Shaw, 1990). Siting production a way from the market will bring severe technical and financial penalties in transportation of fish and in availability of materials and services. Costs and reliability of transportation must be considered, although consumers may be prepared to travel to a local market to make small purchases. Transport accessibility might very well control aquatic production. Studies have shown that the lack of transport routes presents a huge impediment to fish production development (FAO, 1975; Eddie, 1983; Muir and Kapetsky, 1988).

For the purposes of this study, the scores developed for the roads factor in the environmental analysis were re-interpreted by using a proximity instead of a distance range. The highest value in this case would comprise of those areas in proximity to a high density of roads as shown in **Text Box 4.28**. As a complementary approach to the socio-economic evaluation of transport, the range of transport types was evaluated (**Table 4.14** and **Text Box 4.29**).

**Text Box 4.28. Roads submodel**

| INTERPRETATION | | SCORE |
|---|---|---|
| Closest proximity, best access.<br>Low costs of transport | | 4 |
| Paved roads | 250 m - 2 km | |
| Railways | 250 m - 1 km | |
| Gravel roads | 250 m - 1 km | |
| Dirt roads | 0 m - 500 m | |
| Unimproved roads | 0 m - 500 m | |
| Moderate proximity ,<br>good access, low costs. | | 3 |
| Paved roads | 2 - 3 km | |
| Railways | 1 - 2 km | |
| Gravel roads | 1 - 2 km | |
| Dirt roads | 500 m - 1 km | |
| Unimproved roads | 500 m - 1 km | |
| Marginal proximity, some<br>access difficulty, high costs. | | 2 |
| Paved roads | 3 - 4 km | |
| Railways | 2 - 3 km | |
| Gravel roads | 2 - 3 km | |
| Dirt roads | 1 - 1.5 km | |
| Unimproved roads | 1 - 1.5 km | |
| Most distant sites,<br>poor accessibility, high costs. | | 1 |
| Paved roads | > 4 km | |
| Railways | > 3 km | |
| Gravel roads | > 3 km | |
| Dirt roads | > 1.5 km | |
| Unimproved roads | > 1.5 km | |

Those municipalities with a larger variety and quantity of transport types were scored higher than those with poor transport availability.

**Text Box 4.29. Transport type.**

| INTERPRETATION | SCORE |
|---|---|
| > 4 transport types, best communication. | 4 |
| 4 transport types, good transport access | 3 |
| 3 transport types, some problems with transport access. | 2 |
| 2 transport types, difficult for new developments may impose costs and constraints. | 1 |

**Table 4.14. Transport types in Sinaloa for 1988.**

| MUNICIPALITY | TRANSPORT TYPE | SCORE |
|---|---|---|
| **NORTH** | | |
| Ahome | Rd / Rw / Lp / Pt / Pu | 4 |
| Choix | Rd / Rw / Sp / Pu | 3 |
| El Fuerte | Rd / Rw / Sp / Pu | 3 |
| Guasave | Rd / Rw / Lp / Pu | 4 * |
| Sinaloa | Rd / Rw / Sp / Pu | 3 |
| **CENTRE** | | |
| Angostura | Rd / Rw / Pu | 2 |
| Baridaguato | Rd / Lp / Pu | 3 * |
| Culiacán | Rd / Rw / Lp / Pu | 4 * |
| Mocorito | Rd / Rw / Sp / Pu | 3 |
| Salvador Alvarado | Rd / Rw / Sp / Pu | 3 |
| Navolato | Rd / Rw / Sp / Pu | 3 |
| **SOUTH** | | |
| Concordia | Rd / Pu | 1 |
| Cosalá | Rd / Sp / Pu | 2 |
| Elota | Rd / Rw / Sp /Pu | 3 |
| Escuinapa | Rd / Rw / Sp / Pu | 3 |
| Mazatlán | Rd / Rw / Lp / Pt / Pu | 4 |
| El Rosario | Rd / Rw / Sp / Pu | 3 |
| San Ignacio | Rd / Rw / Sp / Pu | 3 |

Source: Centros Estatales de Estudios Municipales (1988).

TERMINOLOGY: Rd = Roads; Rw = Railway; Lp = Large planes; Sm= Small planes (e.g. one or two passengers); Pt = Port; Pu = Public transport such as buses and taxies. Note: * Cases in which the score was increased due to the availability of large planes.

The transportation types factor was integrated into the roads submodel as shown in **Figure 4.38.**

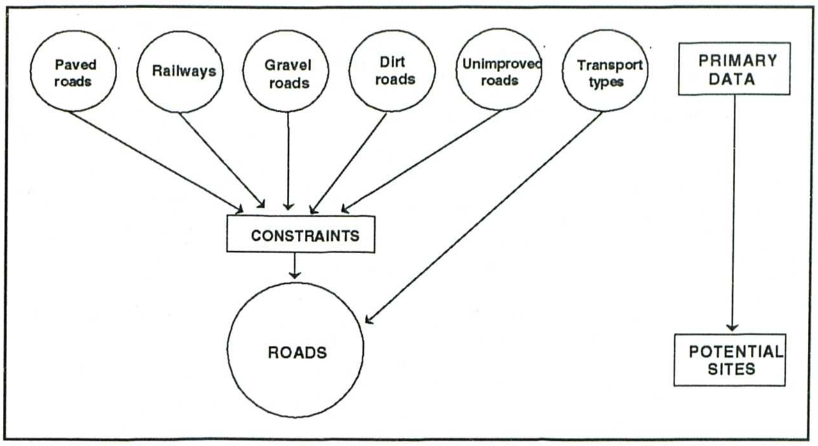


**Figure 4.38. Transportation submodel for aquaculture development in Sinaloa.**

TRS = ( PR X 0.50 ) + ( RW X 0.23 ) + ( GR X 0.15 ) + ( DR X 0.10 ) + ( UR X 0.02 ) X CONRO + TT. Where, TRS = transport submodel; PR = paved roads; RW = railways; GR = gravel roads; DR= dirt roads; UR= unimproved roads; TT = transport types; CONRO = area constraint for roads.

**Macro file**
**Transport submodel**

```
overlay x 3 pr(c) rw(c) prrw
overlay x 3 prrw gr(c) conro
mce x 1 3 ros(e) conro pr 0.50 rw 0.23 gr 0.15 dr 0.10 ur 0.02
overlay x 1 ros(se) transt trs
```

The resulting values from the mathematical expression above were re-classified according to the frequency distribution threshold, the outcome of this reclassification is presented in **Figure 4.39**. Very suitable sites were clearly identified by the submodel in the municipalities of Ahome, Guasave, Culiacán and Mazatlán. Conversely, the municipality of Concordia is an area of poor transport availability.

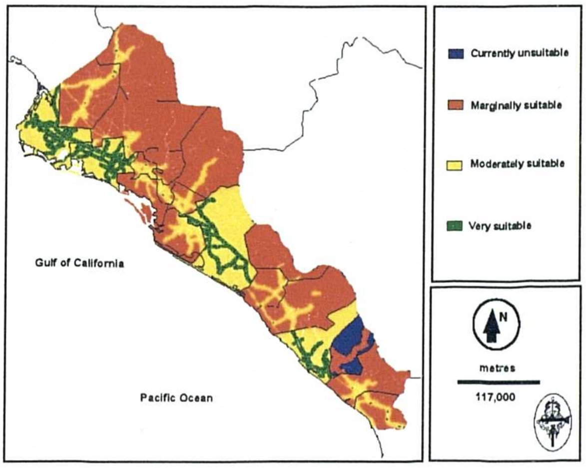


**Figure 4.39. Transportation submodel image for aquaculture development in Sinaloa.**

### 4.3.2.7 Communications

Communication is not essential for the development of aquaculture, but as suggested by Gutierrez-García (1995), good communication could be considered as an enhancement factor that may assist the performance of aquaculture projects. The interpretation was based on the variety and availability of the systems. Those municipalities with the best communication were scored highest (**Table 4.15**), their interpretation is found in **Text Box 4.30**.

**Text Box 4.30. Communication**

| INTERPRETATION | SCORE |
|---|---|
| More than five communication types will enhance new developments. | 4 |
| Five communication types will be beneficial to new developments. | 3 |
| Four communication types will not be very beneficial to new developments. | 2 |
| Some difficulty will arise with three or less communication types. | 1 |

**Figure 4.40** shows that very suitable communication can be found in four out of the eight municipalities which are Ahome, Guasave, Culiacán and Mazatlán. However, 11 municipalities were scored with a value of one, and most of them are found in the central region, meaning that some difficulty may arise for new developments.

**Table 4.15. Communication types in Sinaloa for 1988.**

| MUNICIPALITY | COMMUNICATION TYPE | SCORE |
|---|---|---|
| **NORTH** | | |
| Ahome | Post / Tel / Tx / Ra / Telv / C | 4 |
| Choix | Post / Tel | 1 |
| El Fuerte | Post / Tel / Tex/ Ra / Telv | 3 |
| Guasave | Post / Tel / Tex / Ra / Telv / C | 4 |
| Sinaloa | Post / Tel / Tex | 1 |
| **CENTRE** | | |
| Angostura | Post / Tel | 1 |
| Baridaguato | Post / Tel | 1 |
| Culiacán | Post / Tel / Tx / Ra / Telv / C | 4 |
| Mocorito | Post / Tel | 1 |
| Salvador Alvarado | Post / Tel | 1 |
| Navolato | Post / Tel | 1 |
| **SOUTH** | | |
| Concordia | Post / Tel | 1 |
| Cosalá | Post / Tel | 1 |
| Elota | Post / Tel | 1 |
| Escuinapa | Post / Tel / Ra / Telv | 2 |
| Mazatlán | Post / Tel / Tx / Ra / Telv / C | 4 |
| El Rosario | Post / Tel / Ra / Telv | 2 |
| San Ignacio | Post / Tel | 1 |

Source: Centros Estatales de Estudios Municipales (1988). TERMINOLOGY: Post = Postal services; Tel = Telephone; Tx = Telex; Ra = Radio stations; Telv = Television and C = Cellular Note: Although cellular communication was not found in the literature, it is likely this that this type of communication is available in the main municipalities (i.e. where main cities are located). Hence, a score increase was assigned to those municipalities with cellular communication as shown in **Table 4.15.** above.

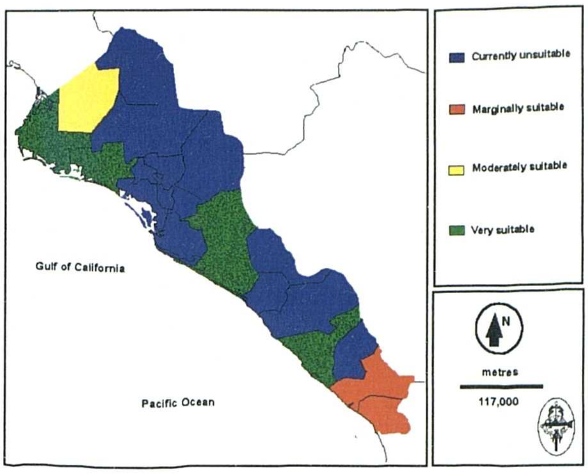


Figure 4.40. Communication types in Sinaloa.

### 4.3.2.8 Support centres

The existence of tested technologies, or the ability to develop or adapt existing technologies to suit local conditions, is an important aspect to be taken into account in aquaculture planning. As problems of aquaculture are very often site-specific, even well-established technologies have to be adapted or modified for local application, and tested to determine their economic viability. This would require at least minimum research capability and facilities. Large-scale development often needs a regular health inspection and disease diagnostic programme and this could from part of a the research establishment or of an extension service attached to it (Balayut, 1989; Pillay, 1994; Nash, 1995).

The development of appropriate human resources should form part of any national aquaculture development plan. Organized institutions for training are increasingly needed for farm managers and technicians. Since aquaculture is interdisciplinary by nature, specialized training programmes will be required for major categories of personnel. Universities and specialized research centres are the major sources of research personnel. Depending on the organization of aquaculture in the country (small scale, large scale or industrial scale) a suitable extension programme with the appropriate number of adequately trained and experienced extension personnel will have to be built (Pillay, 1990; Gutierrez-García, 1995; Nash, 1995).

For this study, the support centres factor was referred to the research, training and extension centres available in Sinaloa to support aquaculture development. **Table 4.16** shows that almost all the support available is found in Mazatlán and, except for Ahome and Rosario, the rest of the municipalities do not have support centres. Clearly, any aquaculture development in Sinaloa is greatly dependent on the support from Mazatlán. Moreover, in Mazatlán a newly-formed unit for aquaculture and environmental management (CIAD) with Stirling Aquaculture graduates is having a big impact on aquaculture research in Mexico (Ross, 1995). The score interpretation of the support centre data is presented in **Text Box 4.31** and the resulting image is presented in **Figure 4.41**. Without doubt, greatest support from a research, training and extension point of view is found in the south, in Mazatlán for which reason a score of 5 was assigned. Very good support centres are found in El Rosario, and in Ahome. The rest of the municipalities do not have support centres but are benefited by the radius of influence of the existing centres. Areas of influence from support centres were assumed due to lack of data.

**Text Box 4.31. Support centres.**

| INTERPRETATION | SCORE |
|---|---|
| Well established support centres | 4 |
| Benefited by the influence of > 5 support centres. | 3 |
| Benefited by the influence of 4 - 5 support centres. | 2 |
| Benefited by the influence of < 4 support centres. | 1 |

Note: Threshold based on frequency distribution

**Table 4.16. Support centres for aquaculture in Sinaloa for 1995.**

| MUNICIPALITY | RESEARCH | TRAINING | EXTENSION | SCORE |
|---|---|---|---|---|
| **NORTH** | | | | |
| Ahome | CI/U//C/**CT** | CI/U/**S**/C/**CT** | CI/U/**S**/C/**CT** | **4** |
| Choix | CI/U//C/CT | CI/U/S/C/CT | CI/U/S/C/CT | 2 |
| El Fuerte | CI/U//C/CT | CI/U/S/C/CT | CI/U/S/C/ CT | 2 |
| Guasave | CI/U//C/CT | CI/U/S/C/CT | CI/U/S/C/CT | 2 |
| Sinaloa | CI/U//C/CT | CI/U/S/C/CT | CI/U/S/C/CT | 2 |
| **CENTRE** | | | | |
| Angostura | CI/U/C | CI/U/S/C | CI/U/S/C | 1 |
| Baridaguato | CI/U/C | CI/U/S/C | CI/U/S/C | 1 |
| Culiacán | CI/U/C | CI/U/S/C | CI/U/S/C | 1 |
| Mocorito | CI/U/C | CI/U/S/C | CI/U/S/C | 1 |
| Salvador Alvarado | CI/U/C | CI/U/S/C | CI/U/S/C | 1 |
| Navolato | CI/U/C | CI/U/S/C | CI/U/S/C | 1 |
| **SOUTH** | | | | |
| Concordia | CI/U/C/US/I | CI/U/S/C/US/I | CI/U/S/C/US/I | 3 |
| Cosalá | CI/U/C/US/I | CI/U/S/C/US/I | CI/U/S/C/US/I | 3 |
| Elota | CI/U/C/US/I | CI/U/S/C/US/I | CI/U/S/C/US/I | 3 |
| Escuinapa | CI/U/C/US/I | CI/U/S/C/US/I | CI/U/S/C/US/I | 3 |
| Mazatlán | **CI/U/C/US/I** | **CI/U/S/C/US/I** | **CI/U/S/C/US/I** | **5** |
| El Rosario | CI/U/C/US/I | CI/U/**S**/C/US/I | CI/U/**S**/C/US/I | **4** |
| San Ignacio | CI/U/C/US/I | CI/U/S/C/US/I | CI/U/S/C/US/I | 3 |

TERMINOLOGY: **Wide influence**: CI = (CIAD) Centro de Investigación en Alimentación y Desarrollo en Acuicultura y Manejo Ambiental; U = (UNAM) Universidad Nacional Autónoma de México; S = (SMARNyP) Secretaría del Medio Ambiente Recursos Naturales y Pesca; C = (CRIP) Centro Regional de Investigaciones Pesqueras. **Limited Influence**: US = (UAS) Escuela de Ciencias del Mar, Universidad Autónoma de Sinaloa; I = (ITMAR) Instituto Tecnológico del Mar; CT = (CETMAR) Centro de Educación Técnica del Mar.

Note: letters in "bold" represent well established support centres.

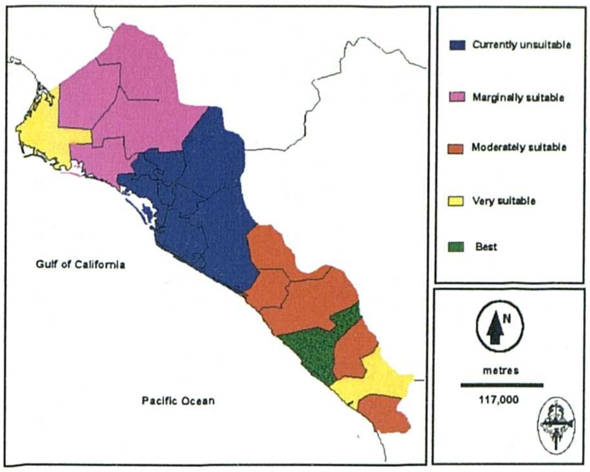


Figure 4.41. Support centres for aquaculture development in Sinaloa.

### 4.3.3 MARKET POTENTIAL

Identification of consumer preferences is the most important factor in marketing (Shaw, 1986; 1990). Moreover, before any development takes place, it is important to consider the existing distribution system, as well as the market outlets and the infrastructure available. Demand is the primary indicator of any industry, since its analysis reveals the conditions of consumption and dictates future strategies. For aquaculture this is particularly important when comparing the nature of fish products against those alternative food industries such as meat and poultry (Shaw, 1990).

#### 4.3.3.1 Population density

Data on population density has long been used to generate various indicators to help make judgements about a wide range of social and economic conditions. The capacity of each district to absorb aquatic production as well as sources of labour, supplies and electrical services to power aquaculture operations can be estimated within this criterion (Meaden and Kapetsky, 1991). Kapetsky (1994) has shown that population density can be used as surrogate data for market demand based on the general logic that there will be a higher availability of consumers in areas of high human concentration.

For this evaluation, the population density data used in the environmental evaluation was re-interpreted so that a high population density with a high growth rate was indicative of potential areas of fish consumption, as well as sources of inputs and labour (**Text Box 4.31**).The resulting image is presented in **Figure 4.42**. Clearly, largest population density is found in Mazatlán and Culiacán.

**Text Box 4.32. Population density.**

| INTERPRETATION | SCORE |
|---|---|
| Municipalities with a population density > 95 habitants / km$^2$ very good sources of labour & supplies. Maximum fish consumption achievable. | 4 |
| Municipalities with a population density 63-94 habitants / km$^2$ Likely to find labour and supplies, also with high potential. Good consumption of fish. | 3 |
| Municipalities with a population density 31-62 habitants / km$^2$ will encounter some minor problems with supplies & labour. Moderate fish consumption. | 2 |
| Municipalities with a population density < 31habitants / km$^2$ still with potential although there will be difficulties with supply and labour. Low fish consumption but still with reasonable potential. | 1 |

Note: Threshold based on frequency distribution.

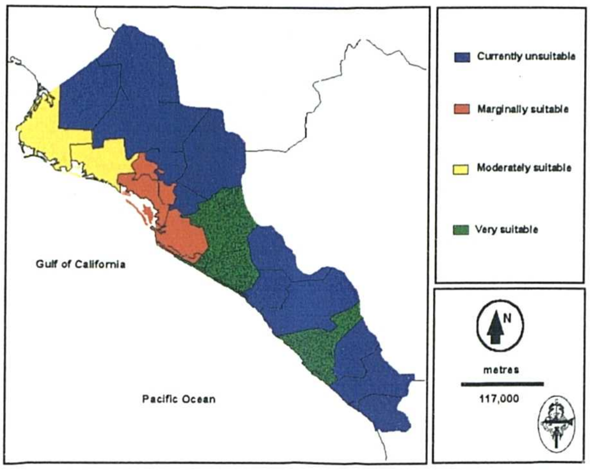


Figure 4.42. Reclassified population density factor in Sinaloa.

### 4.3.3.2 Disposable income submodel

Disposable income was considered to be beneficial in terms of purchasing aquaculture products. For this study, disposable income was evaluated by locating the largest number of inhabitants earning an income above the minimum wage as shown in **Table 4.17**. Four levels of wages were used (1.5, 2.4, 4 and 7.5 times the minimum wage), and the scores were defined using the percentage threshold. These wages (i.e. factors) were developed into a submodel as shown in **Figure 4.43**.

## Table 4.17. Number of inhabitants according to the levels of disposable income in Sinaloa for 1990.

| MUNICIPALITY | OCCUPIED INHABITANTS | 1.5 Mw | % | SCORE 1.5 mw | 2.5 Mw | % | SCORE 2.5 mw | 4 Mw | % | SCORE 4 mw | 7.5 Mw | % | SCORE 7.5 mw | DIS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NORTH** | | | | | | | | | | | | | | |
| Ahome | 92,134 | 36,755 | 39.9 | 2 | 17,513 | 19.0 | 1 | 12,686 | 13.8 | 1 | 6,993 | 7.6 | 1 | 1 |
| Choix | 5,913 | 1,795 | 30.4 | 2 | 484 | 8.2 | 1 | 288 | 4.9 | 1 | 105 | 1.8 | 1 | 1 |
| El Fuerte | 24,932 | 13,632 | 54.7 | 3 | 3,755 | 15.1 | 1 | 2,027 | 8.1 | 1 | 725 | 2.9 | 1 | 1 |
| Guasave | 75,765 | 36,875 | 48.7 | 2 | 12,743 | 16.8 | 1 | 8,036 | 10.6 | 1 | 3,558 | 4.7 | 1 | 1 |
| Sinaloa | 22,926 | 9,861 | 43.0 | 2 | 2,821 | 12.3 | 1 | 1,648 | 7.2 | 1 | 617 | 2.7 | 1 | 1 |
| **CENTRE** | | | | | | | | | | | | | | |
| Angostura | 12,877 | 5,212 | 40.5 | 2 | 2,235 | 17.4 | 1 | 1,639 | 12.7 | 1 | 677 | 5.3 | 1 | 1 |
| *Baridaguato* | *7,129* | *941* | 13.2 | 1 | 460 | 6.5 | 1 | *226* | 3.2 | 1 | 131 | 1.8 | 1 | 1 |
| Culiacán | 187,968 | 72,699 | 38.7 | 2 | 35,982 | 19.1 | 1 | 25,642 | 13.6 | 1 | 13,715 | 7.3 | 1 | 1 |
| Mocorito | 12,617 | 5,099 | 40.4 | 2 | 1,592 | 12.6 | 1 | 861 | 6.8 | 1 | 404 | 3.2 | 1 | 1 |
| Salvador Alvarado | 18,019 | 6,984 | 38.8 | 2 | 3,106 | 17.2 | 1 | 2,378 | 13.2 | 1 | 1,171 | 6.5 | 1 | 1 |
| Navolato | 47,107 | 24,879 | 52.8 | 3 | 7,716 | 16.4 | 1 | 3,287 | 7.0 | 1 | 1,377 | 2.9 | 1 | 1 |
| **SOUTH** | | | | | | | | | | | | | | |
| Concordia | 7,323 | 1,926 | 26.3 | 2 | 1,611 | 22.0 | 2 | 760 | 10.4 | 1 | 278 | 3.8 | 1 | 1 |
| Cosalá | 3,527 | 791 | 22.4 | 2 | 430 | 12.2 | 1 | 202 | 5.7 | 1 | 141 | 4.0 | 1 | 1 |
| Elota | 7,573 | 3,011 | 39.8 | 2 | 968 | 12.8 | 1 | 511 | 6.7 | 1 | 220 | 2.9 | 1 | 1 |
| Escuinapa | 12,982 | 4,226 | 32.6 | 2 | 3,212 | 24.7 | 2 | 1,412 | 10.9 | 1 | 528 | 4.1 | 1 | 1 |
| Mazatlán | 103,168 | 33,965 | 32.9 | 2 | 23,930 | 23.2 | 2 | 16,333 | 15.8 | 1 | 8,417 | 8.2 | 1 | 1 |
| El Rosario | 12,700 | 4,661 | 36.7 | 2 | 3,147 | 24.8 | 2 | 1,014 | 8.0 | 1 | 370 | 2.9 | 1 | 1 |
| San Ignacio | 6,245 | 1,947 | 31.2 | 2 | 717 | 11.5 | 1 | 337 | 5.4 | 1 | 122 | 2.0 | 1 | 1 |

Source: INEGI (1991).

SCORES TERMINOLOGY:

**Mw** = Minimum wage
**DIS** = Disposable income
**1.5 mw** = Number of inhabitants receiving 1.5 times the minimum wage
**2.5 mw** = Number of inhabitants receiving 2.5 time the minimum wage
**4 mw** = Number of inhabitants receiving 4 times the minimum wage
**7.5 mw** = Number of inhabitants receiving 7.5 times the minimum wage

Note: Scores for **1.5 mw, 2.5 mw, 4 mw** and **7.5 mw** were defined using the percentage threshold. The MCE technique was used to obtain the values of **DIS**.

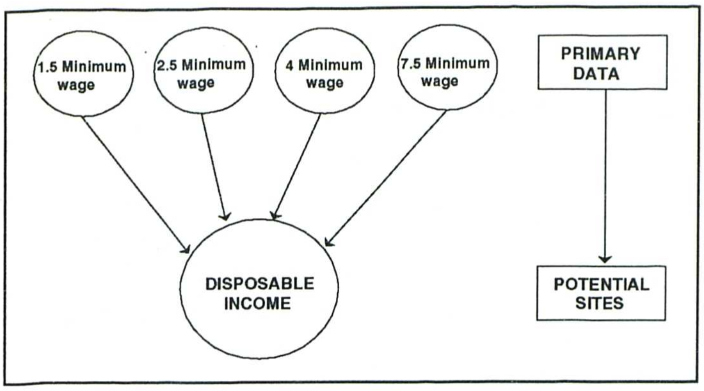


**Figure 4.43. Disposable income submodel for aquaculture development in Sinaloa.**

**DIS** = ( 1.5mw X 0.1 ) + ( 2.5mw X 0.16 ) + ( 4mw X 0.26 ) + ( 7.5mw X 0.48 ). Where; **DIS** = Disposable income submodel; **1.5 mw** = Number of inhabitants receiving 1.5 times the minimum wage; **2.5 mw** = Number of inhabitants receiving 2.5 time the minimum wage; **4 mw** = Number of inhabitants receiving 4 times the minimum wage; **7.5mw** = Number of inhabitants receiving 7.5 times the minimum wage.

**Command line mode file**
**Disposable income submodel**

```
mce x 0 4 dis 1.5mw 0.1 2.5mw 0.16 4mw 0.26 7.5mw 0.48
```

The mathematical expression was based on the MCE technique and weights varied according to the increase in minimum wage. For example, the highest wage (i.e. 7.5 times) received the highest weight ( 0.48).

The final score produced by this mathematical expression was reclassified according to **Text Box 4.33** and the resulting image is presented in **Figure 4.44.** The submodel showed the entire state as having a low purchasing power which was strongly attributed to the low number of inhabitants earning 2.5, 4 and 7.5 times the minimum wage.

**Text Box 4.33. Disposable income submodel.**

| INTERPRETATION | SCORE |
|---|---|
| Highest income, high purchasing power. | 4 |
| Good income, high purchasing power. | 3 |
| Marginal purchasing power | 2 |
| Low purchasing power | 1 |

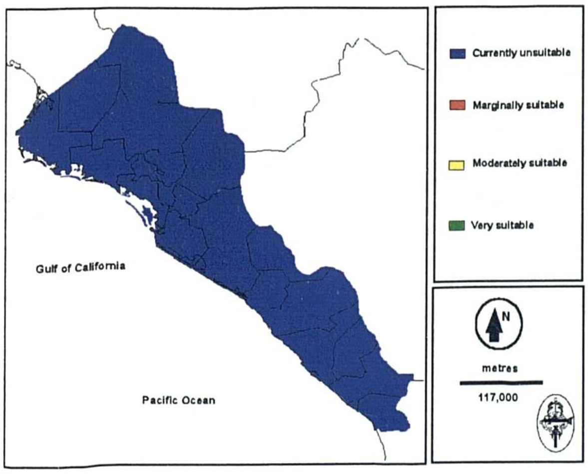


**Figure 4.44. Disposable income submodel image for aquaculture development in Sinaloa.**

### 4.3.3.3 Fish consumption submodel

Good marketing is far more than just finding customers for a product. It starts with customers, both the final end user and trade customers. From an analysis of their needs decisions can be made about what should be produced, when it should be produced and what the consumer should be offered (Shaw, 1985; 1986; 1990). For this study an indicator of fish consumption was based on a knowledge of the preferred types of aquatic species for consumption in Sinaloa. A reclassification was based on qualitative data provided by Centros Estatales de Estudios Municipales (1988). In addition, it was assumed that there was potential for consumption in those areas in which fishing activities were taking place, and in water bodies where fishing activities had most potential (e.g. coastal areas were given priority). Hence a fishing activity factor was taken into consideration as an enhancement factor for fish consumption (**Table 4.18**).

The fish consumption submodel was developed by integrating the preferred fish for consumption, and the fishing activity, as shown in **Figure 4.45**.

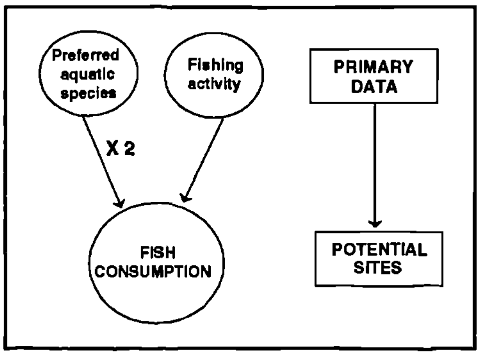


**Figure 4.45. Fish consumption submodel for aquaculture development in Sinaloa.**

**FIS** = ( PFISH X 2 ) + FACT. Where; **FIS** = fish consumption submodel; **PFISH** = preferred aquatic species for consumption and **FACT** = fishing activity.

**Command line mode file**
**Fish consumption**
overlay x 3 pfish fact fis

Table 4.18. Fish consumption in Sinaloa for 1990.

| MUNICIPALITY | PREFERRED FISH FOR CONSUMPTION | SCORE PFISH | FISHING ACTIVITY | SCORE FACT | Z | FIS |
|---|---|---|---|---|---|---|
| **NORTH** | | | | | | |
| Ahome | Shrimp and shellfish | 3 | Economically important, bays and sheltered waters | 4 | 10 | 4 |
| Choix | Not reported | 1 | Mountain area, no fishing | 1 | 3 | 1 |
| El Fuerte | Mojarra, lobina and catfish | 2 | Dams | 2 | 6 | 2 |
| Guasave | Shrimp, lisa, sardine and shellfish | 3 | 50 km coastline, bays | 3 | 9 | 3 |
| Sinaloa | Not reported | 1 | Distant from water, no fishing | 1 | 3 | 1 |
| **CENTRE** | | | | | | |
| Angostura | Shrimp, shellfish, and pargo | 3 | Important 80 km coastline | 4 | 10 | 4 |
| Baridaguato | Not reported | 1 | Distant from water, no fishing | 1 | 3 | 1 |
| Culiacán | Shrimp and shellfish (e.g. clams and oysters) | 3 | 256 km coastline and dams | 3 | 9 | 3 |
| Mocorito | Not reported | 1 | Distant from water, no fishing | 1 | 3 | 1 |
| Salvador Alvarado | Note reported | 1 | Fishing in inland waters, dams | 2 | 4 | 2 |
| Navolato | Shrimp, fish and shellfish | 3 | Coastline, abundance and variety of aquatic species | 3 | 9 | 3 |
| **SOUTH** | | | | | | |
| Concordia | Not reported | 1 | Distant from water, no fishing | 1 | 3 | 1 |
| Cosalá | Not reported | 1 | Mountain area no fishing | 1 | 3 | 1 |
| Elota | Shrimp, lisa and shellfish (oysters) | 3 | 45 km coastline and 2500 km$^2$ inland waters | 3 | 9 | 3 |
| Escuinapa | Shrimp and lisa | 3 | Very economic important activity. Coastline, bays and inland waters | 4 | 10 | 4 |
| Mazatlán | Largest variety (e.g. shrimp, fish, shellfish) | 4 | 80 km coastline, inland waters | 4 | 12 | 4 |
| El Rosario | Shrimp and shellfish | 3 | Very important economic activity, coastal and inland | 4 | 10 | 4 |
| San Ignacio | Shrimp, fish and shellfish | 3 | Activity is not economically important despite having coastline | 3 | 9 | 3 |

Source: Centros Estatales de Estudios Municipales (1988).

TERMINOLOGY: **PFISH** = preferred fish for consumption and **FACT** = fishing activity

Note: Scores for **PFISH**, and **FACT** were entirely based on the description provided on *this table*. **Z** = *Value found by the mathematical expression*. The final score **(FIS)** was defined using the frequency distribution threshold on **Z** values.

**Preferred fish**

| INTERPRETATION | SCORE |
|---|---|
| Largest variety of species | 4 |
| Shrimp, fish, shellfish | 3 |
| Only Fish | 2 |
| Not reported, still some potential. | 1 |

**Fishing activity**

| INTERPRETATION | SCORE |
|---|---|
| Very important activity | 4 |
| Good, close proximity to water sources. | 3 |
| Few water bodies | 2 |
| Distant from water bodies, still some potential. | 1 |

Scores for **PFISH**, and **ACTF** were entirely based on the description provided in this table and their score interpretation is presented in **Table 4.18** above.

**Text Box 4.34. Fish consumption submodel.**

| INTERPRETATION | SCORE |
|---|---|
| > 10. Largest number of aquatic species being consumed, fishing activity very important, proximity to water sources. | 4 |
| 7 - 9. Large consumption, high fishing activity nearby water sources. | 3 |
| 4 - 6 Consumption to a much lesser extent, some proximity to water sources and some fishing. | 2 |
| < 4 Very small consumption, very distant from water sources, no fishing. | 1 |

Note: Threshold based on frequency distribution.

Clearly the preferred aquatic species being consumed was the most important factor, so a multiplying factor of two was used in order to establish a proper weight between the two factors. The final score was defined using the frequency distribution threshold and the interpretation for these scores is presented in **Text Box 4.34**, and the resulting image is shown in **Figure 4.46**. Very suitable sites were found in five municipalities, of which three of them are located in the south of the state (Mazatlán, El Rosario and Escuinapa). Not surprisingly, municipalities located in the mountain regions of the state were identified as having a low score due to their low fish consumption and distance from the coastline.

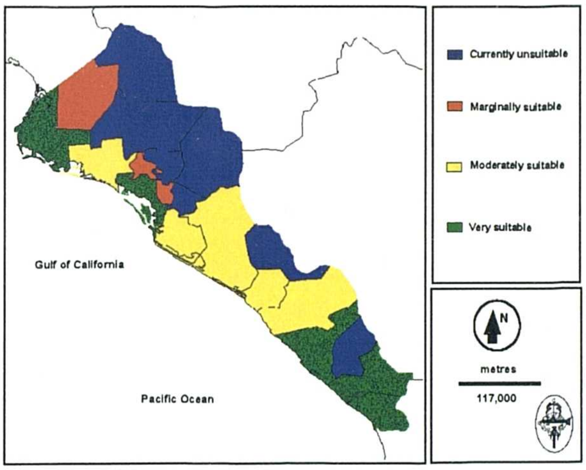


**Figure 4.46. Fish consumption submodel image for aquaculture development in Sinaloa.**

#### 4.3.3.4 Sales / Markets submodel

In tropical areas fish may need to be disposed of quickly (usually locally) unless smoking, sun-drying or ice facilities are available to allow more distant markets to be served. Most fish handled would be fresh and purchase would be on a day-to-day basis, this especially being the case when selling via the farm-gate or at the dock-side, directly to the public, when the highest returns can be achieved (Meaden and Kapetsky, 1991). Other wholesale outlets include fish processors, who would buy fish for freezing, canning or smoking, but in general, to achieve higher returns, many fish producers would endeavour to dispose of a high proportion of their product directly to markets which are closest to the final purchaser.

Processing requirements may be minimal if live or fresh products are sold on local markets, but processing facilities for washing, beheading, freezing, packing or canning will usually be required for bulk and export markets. Processing plants often exist to handle wild-caught products and they can easily deal with additional yields from aquaculture. Farming operations should be located so that only short journeys are required for their perishable products to reach the processor, and the availability of processors and the quality of their installations should be investigated to ensure they meet acceptable standards of hygiene and quality control. Reputations of quality vary between plants and countries and will influence the prices that can be obtained (Shaw, 1990; Lee and Wickins, 1992; Shang, 1992).

Lewis (1984) has shown that trade can be obtained, often with considerable success, if there is a busy route passing by the production site (having appropriate parking). Dock-side sales are only really possible where regular markets can be guaranteed at sites having public access. The next best return might be achieved by operating a fish delivery round or by selling to local hotels, restaurants, caterers or peddlers. Some larger producers have contracts to supply supermarkets direct, and sometimes direct to fishmongers and retailers. Proximity to the market, or at least very efficient transport links, are essential. When limited small and local markets are targeted either at the farm gate or direct to the catering trade, attention should be given to finding sites within reach of population centres or tourist areas.

Three factors were used to define the sales / market submodel in order to locate potential areas in which aquaculture products could be sold (i.e. hotels, fish processing plants and markets). These factors were developed into a submodel as shown in **Figure 4.47**.

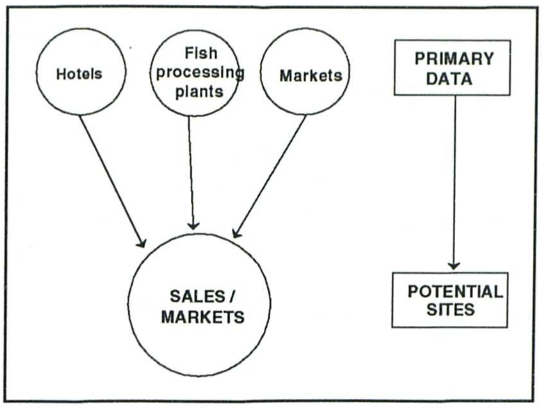


**Figure 4.47. Sales / Markets submodel for aquaculture development in Sinaloa.**

SALES = ( HOT X 0.2 ) + ( FISHP X 0. 3 ) + ( MARK X 0.5 ) where, SALES = sales / markets submodel; HOT = HOTELS (number of hotels in each municipality); FISHP = FISH PROC. (number of fishing processing plants in each municipality); MARK = MARKETS (number of markets in each municipality).

**Command line mode file**
**Sales / Markets submodel**
mce x 0 3 sales hot 0.2 fishp 0.3 mark 0.5

Scores HOT, FISHP and MARK were defined using the frequency distribution threshold (**Table 4.19**). From the available literature, and from field verification studies, existing fish markets were considered the most important and so were assigned the highest weight (0.5), followed by fish processors and finally hotels. The interpretation of the final score **SALES** is presented in **Text Box 4.35** and the resulting image is shown in **Figure 4.48**. The municipalities of Mazatlán, Culiacán and Ahome had high scores and it is here that the largest number of hotels, fish processing plants and markets are found. Six municipalities were identified as unsuitable and this was because they are located away from the coast in the mountain region, where very few activities take place.

**Text Box 4.35. Sales / Markets submodel.**

| INTERPRETATION | SCORE |
|---|---|
| Municipalities with abundance of markets, fish processing plants and hotels. Most likely selling location. | 4 |
| Large number of markets and processing plants. Also considered with very good potential for sales. | 3 |
| Municipalities with small number of markets, processing plants & hotels. Very few sales, although still with some potential. | 2 |
| Municipalities with small number of markets, processing plants and hotels. Very few sales, although still with some potential. | 1 |

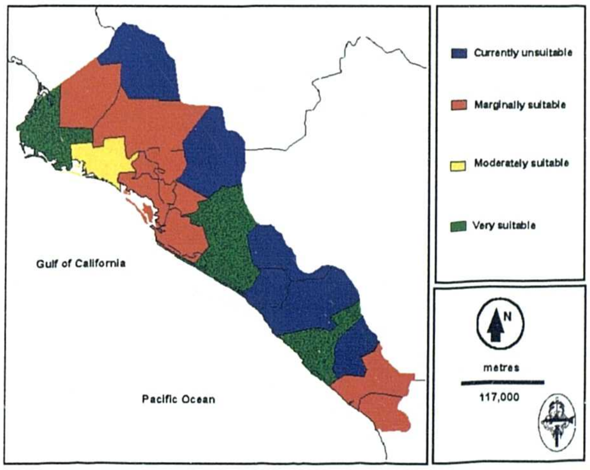


**Figure 4.48. Sales / Markets submodel image for aquaculture development in Sinaloa.**

Table 4.19. Potential sales / market infrastructure for aquaculture development in Sinaloa for 1990.

| MUNICIPALITY | HOTELS | SCORE HOT | FISHP | SCORE FISHP | MARKETS | SCORE MARK | SALES |
|---|---|---|---|---|---|---|---|
| **NORTH** | | | | | | | |
| Ahome | 23 | 3 | 22 | 3 | 10,305 | 4 | 4 |
| Choix | 3 | 2 | 0 | 1 | 244 | 1 | 1 |
| El Fuerte | 6 | 3 | 1 | 1 | 1,066 | 3 | 2 |
| Guasave | 9 | 3 | 7 | 3 | 4,921 | 3 | 3 |
| Sinaloa | 0 | 1 | 0 | 1 | 664 | 2 | 2 |
| **CENTRE** | | | | | | | |
| Angostura | 0 | 1 | 3 | 2 | 683 | 2 | 2 |
| Baridaguato | 0 | 1 | 0 | 1 | 130 | 1 | 1 |
| Culiacán | 41 | 3 | 15 | 3 | 17,723 | 4 | 4 |
| Mocorito | 1 | 1 | 0 | 1 | 525 | 2 | 2 |
| Salvador Alvarado | 8 | 3 | 0 | 1 | 2,228 | 3 | 2 |
| Navolato | 1 | 1 | 2 | 2 | 1,913 | 3 | 2 |
| **SOUTH** | | | | | | | |
| Concordia | 2 | 2 | 0 | 1 | 234 | 1 | 1 |
| Cosalá | 2 | 2 | 0 | 1 | 126 | 1 | 1 |
| Elota | 5 | 2 | 0 | 1 | 477 | 1 | 1 |
| Escuinapa | 8 | 3 | 3 | 2 | 661 | 2 | 2 |
| Mazatlán | 144 | 4 | 48 | 4 | 12,470 | 4 | 4 |
| El Rosario | 4 | 2 | 3 | 2 | 752 | 2 | 2 |
| San Ignacio | 5 | 2 | 0 | 1 | 354 | 1 | 1 |

Source: CIFSA (1993).

TERMINOLOGY: **HOT** = HOTELS (number of hotels in each municipality); **FISHP** = Fish processing plants (number of fishing processing plants in each municipality); **MARK** = MARKETS (number of markets in each municipality).

Note: Scores **HOT**, **FISHP**, and **MARK** were defined using the frequency distribution threshold. The MCE technique was used to obtain the values of **SALES**.

| HOT | FISHP | MARK | SCORE |
|---|---|---|---|
| > 41 | >22 | > 6,000 | 4 |
| 6 - 41 | 4 - 22 | 1001- 6,000 | 3 |
| 2 - 5 | 2 - 3 | 501 - 1,000 | 2 |
| <2 | <2 | < 500 | 1 |

## 4.4 CONSTRAINTS

**Table 4.20** shows a summary of the distance and proximity constraints used in the environmental and socio-economic evaluation. Areas which were considered permanently unsuitable for any aquaculture development had a score of zero or one (i.e. the lowest value). The general constraints interpretation was described earlier and some constraints have already been applied (i.e. water bodies, urban development and roads submodels). Overall, the objective was to prevent or minimize possible pollution problems and to protect environmentally sensitive areas, and the proximity or distance constraint varied according to the importance of that factor. For example, only small distance constraints were required for areas in proximity to the water sources to protect environmentally sensitive areas (e.g. to avoid making drastic changes to the natural flow of rivers), whereas large distance constraints were assigned to cities, towns and industries to prevent or minimize possible pollution problems.

**Table 4.20. Factor constraints, summary of criteria and thresholds.**

| FACTORS | PROXIMITY or DISTANCE CONSTRAINT |
|---|---|
| **NATURAL RESOURCES** | |
| Lagoons | 0 - 250 m |
| Coastline | 0 - 250 m |
| Rivers and streams | 0 - 250 m |
| Dams | 0 - 250 m |
| Slopes | > 30 % (too steep) |
| Mangroves | 0 - 250 m |
| Proposed conservation areas | 0 - 250 m |
| **LAND USE** | |
| Capital city | 0 - 5 km |
| Other cities | 0 - 2 km |
| Towns | 0 - 1 km |
| Villages | 0 - 500 m |
| Paved roads | 0 - 250 m |
| Railways | 0 - 250 m |
| Gravel roads | 0 - 250 m |
| Industries | 0 - 500 m |
| Shrimp farms | 0 - 500 m |

Note: Highest distance constraint was assigned to the capital city (i.e. 5 km ) because this is the largest source of pollution.

Due to the important role that mangroves and conservation areas play in this study's evaluation a more detailed description of these factors follows.

### 4.4.1 Mangroves

Mangrove environments have often been favoured sites for human settlements because of their sheltered coastal locations. The mangrove forests have provided populations with a seemingly endless variety of derived products such as charcoal, tanning agents, resins, dyes, oils, medication, fodder, fish poisons (de la Cruz, 1979; Watson, 1982). The mangrove environment has also yielded an abundant supply of food: fish and prawns from its waterways, shellfish such as oysters and crabs from the shore zone, and bird's eggs, honey and edible fruits from the forest. Aquaculture activities in mangrove swamps date back about 500 years to the development of coastal milkfish culture in Indonesia during the fifteenth century (de la Cruz, 1979). Even today, inestimable quantities of food are collected from mangrove areas by hand, and by means of simple nets and traps.

The scale of mangrove destruction for pond aquaculture has been alarming, even in countries such as Malaysia and Thailand where management systems of rotation and regeneration or replanting are practised. Approximately 15 - 20% of Thailand's mangrove forests have disappeared over the past decade (Beveridge and Phillips, 1993). Complete reclamation of mangrove environment for paddy cultivation and other forms of agriculture, and for solar salt production has occurred traditionally (de la Cruz, 1979), and now, increasingly, mangrove reclamation is made to accommodate urban and industrial development as human pressures on the coastal zone escalate. Moreover, no single solution to proper mangrove management can be applied to all mangrove areas; both the problems and the solutions are quite diverse. Failure to find and implement an appropriate management strategy can lead to substantial economic losses, ecological degradation and, where mangroves support important traditional livelihoods, increased social and political instability. Typically each component of the mangrove ecosystem (forestry, fisheries, traditional uses) is exploited independently, without regard for the impacts which such exploitation has on other components. For example, clear cutting for wood-chip production threatens fish and shrimp breeding grounds (Ruitenbeek, 1991).

Experience has shown that the development of shrimp ponds in mangroves can result in acidic conditions which, in turn, lower shrimp growth and survival. Shrimp culture in mangroves can also be self-defeating from the point of view of replacing shrimp nursery areas with shrimp ponds, as well as the nursery, feeding, and breeding areas of other fished species. Furthermore, pond construction costs are less outside of the mangrove habitat than inside. Moreover, there is considerable pressure from environmentalists to conserve mangrove areas in Mexico (Flores-Verdugo, 1989; Cosmocolor, 1991; EPAC, 1991).

The basic location constraint for shrimp farming is that it should be outside mangrove areas. Flores-Verdugo *et al.* (1992) suggest that shrimp ponds should be sited at least 50 metres away from mangrove areas, and that for every area of mangrove affected the estimated conservation area should be two-fold. Turner (1991) states that 30% of the area occupied by a shrimp farm should be unmodified, and there should be untouched spaces between farms, mangroves, and agriculture areas, which could enable tidal flows and avoid salinization problems. From another point of view, a proximity rather than a distance range should also be considered because proximity to a mangrove forest may have many positive effects, such as postlarvae availability and good water quality (Kapetsky *et al.*, 1987), and could also serve as a filter for preventing eutrophication problems from shrimp pond waste discharges (Robertson and Phillips, 1995; Flores-Verdugo, In press).

Bearing the above suggestions in mind, a trade-off was established in this study by considering that a distance constraint with a value of zero would prevent any impact from new farm developments directly inside the mangrove forests, whilst the distance range with a score of one would also serve as a buffer zone to minimize or mitigate impacts **(Text Box 4.36)**. Furthermore, any development directly adjacent to the buffer zone scored with a one would be considered to have potential since it would be in proximity to the benefits of these areas but also at a safe distance to mitigate possible impacts, thus a compromise was established. A 50 m buffer area as suggested by Flores-Verdugo *et al.* (1992) could not be created because the smallest pixel in this study is 250 m. However, a 250 m distance was, in fact, considered more appropriate in minimizing potential impacts.

**Text Box 4.36. Mangroves.**

| INTERPRETATION | SCORE |
|---|---|
| 0 - 250 m was used as a distance constraint. | 0 |
| 250 - 500 m was considered suitable on the basis that there should be untouched spaces between farms-mangroves-and agricultural areas which could enable tide flows and avoid salinization problems. | 1 |

### 4.4.2 Proposed conservation areas

Through data collection from various information sources (Cosmocolor, 1991; EPAC, 1991; Flores-Verdugo *et al.*, 1992) it was possible to locate and to propose areas which are in need of conservation due either to extinction of species or to pollution. A value of one was applied to a 250 to 500 m buffer zone outside these areas to avoid and/or minimize any negative impacts such as pollution as shown in **Text Box 4.37.**

**Text Box 4.37. Proposed conservation areas.**

| INTERPRETATION | SCORE |
|---|---|
| 0 - 250 m was used as a distance constraint. | 0 |
| A 250 - 500 m buffer zone was also considered suitable to protect endangered species and to avoid and/or mitigate likely pollution problems. Conservation areas should be untouched and carefully assessed as they are sensitive for any development. | 1 |

Source: Cosmocolor, (1991); EPAC, (1991); Flores-Verdugo *et al.* (1992).

Constraints were developed into a submodel by integrating all the constraints involved in this study as shown in **Figure 4.49.** Model integration involved three stages; (1) selection, reclassification and manipulation of constraints according to the distance constraints established; (2) integration of the constraints submodels (water, urban development and roads); (3) integration of mangroves, proposed conservation areas, industries, shrimp farms and slopes. The incorporation of a constraints submodel within a general model (Chapter 5) was particularly important in order to make sure that such areas remained as constraint areas once the final suitability image was produced.

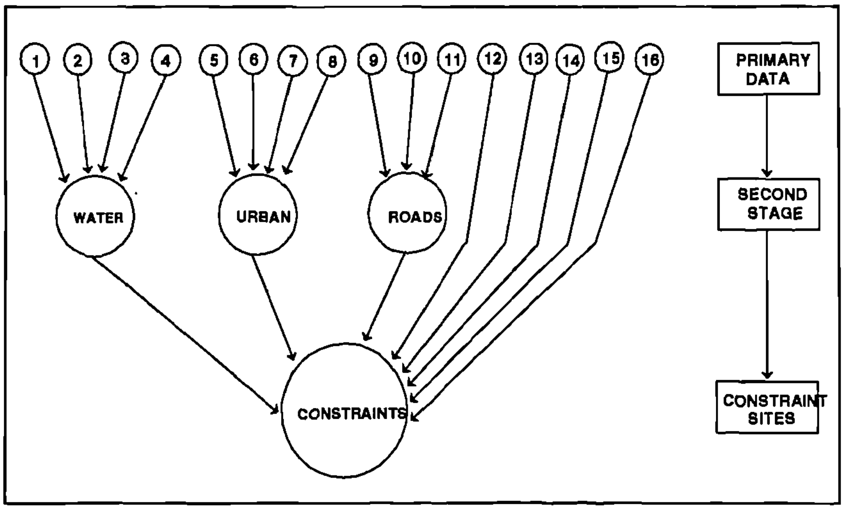


**Figure 4.49. Constraints submodel for aquaculture development in Sinaloa.**

Primary data: 1, lagoons; 2, coastline; 3, rivers and streams; 4, dams; 5, capital city; 6, other cities; 7, towns; 8, villages; 9, paved roads; 10, railways; 11, gravel roads; 12, mangroves; 13, proposed conservation areas; 14, sugar industries; 15, shrimp farms; 16, slopes. CONS = ( LA(c) X COA(c) X RS(c) X D(c) ) X ( CC(c) X OC(c) X TW(c) X VI(c) ) X ( PR(c) X RW(c) X GR(c) ) X M(c) X PC(c) X IN(c) X SH(c) X SLP(c). Where; CONS = constraints submodel; LA = lagoons; RS = rivers and streams; D = dams; CC = capital city; OC = other cities; TW = towns; VI = villages; PR = paved roads; RW= railways; GR = gravel roads; M = mangroves; PC = proposed conservation areas; IN = industries; SH = shrimp farms; SLP = slopes. Note: A "(c)" was added to each name to indicate that it is a constraint.

Each of the constraints images was created as a Boolean image and so multiplying images together meant that the final image remained Boolean in nature. Moreover by multiplying submodels by groups this meant that each constraint submodel within the general submodel could be incorporated in any stage of the model (i.e. some constraints were used to create submodels such as water bodies, urban development and roads submodels), leaving the general submodel as general as possible.

**Macro File**
**Constraints submodel**

```
overlay x 3 la(c) coa(c) lacoa
overlay x 3 lacoa rs(c) lacoars
overlay x 3 lacoars d(c) conwa
overlay x 3 cc(c) oc(c) ccoc
overlay x 3 ccoc tw(c) ccoctw
overlay x 3 ccoctw vi(c) conur
overlay x 3 pr(c) rw(c) prrw
overlay x 3 prrw gr(c) conro
overlay x 3 m(c) pc(c) mpc
overlay x 3 mpc in(c) mpcin
overlay x 3 mpcin sh(c) mpcinsh
overlay x 3 mpcinsh slp(c) con
overlay x 3 conwa conur waur
overlay x 3 waur conro waurro
overlay x 3 waurro con cons
```

To incorporate the mangroves and the proposed conservation areas buffer zones for the final images in this study two separate images were created for these constraints; one image was used to mask out the 0 - 250 m distance range whilst the other image was used to incorporate the buffer zone with a value of one (i.e. from 250 to 500 m).

## 4.5 SUMMARY

All factors and constraints in this study were reclassified to positive values mainly focused on locating the most suitable sites by choosing optimum environmental and socio-economic factors. Spatial manipulations for factors were created either by reclassifying original data source classifications or by reclassifying proximity ranges. Moreover, to mitigate and/or reduce the negative effects from the land uses, distance ranges were created.

Certain factors may share two different classifications or interpretations, and many factors were used for both environmental and socio-economic evaluations either by reclassifying (i.e. agriculture) or by re-interpreting the scores. Overall, and most importantly, factor classifications are dependant on how the data will be further integrated to model a particular query (e.g. where are the most suitable sites in terms of soil texture) and therefore, reclassifications and trade-offs will vary. Constraints were used either because a land space was already being used (i.e. a proximity or distance constraint) or to avoid and/or mitigate any pollution problems in environmentally sensitive areas such as mangroves and proposed conservation areas.

Although scoring and classification of criteria were based on sound decisions which were primarily based on literature, they will tend to vary between decision-makers. The primary goal of this study was the development of analytical procedures and assumptions for scoring, classifying and integrating the criteria.

## CHAPTER 5

# GIS-BASED MODELS FOR AQUACULTURE DEVELOPMENT IN SINALOA STATE, MEXICO.

### 5.1 Background

Formal analyses for decision-making began with the development of operations research in response to demands for rational and analytical decision-making during the second world war (Moore, 1975). Today decisions analyses are used in a wide range of disciplines, each with its own techniques and focus of study. Generally, studies in decision-making fall into two areas: descriptive and prescriptive decision analysis (Eastman *et al.*, 1993).

Descriptive studies in decision-making have their roots in psychology and sociology and concentrate on the search for reasons why decisions are made in the manner in which they are. For example, we might be interested in why customers buy a certain product. On the other hand, as defined by Moore (1975), "the prescriptive analysis of decisions emphasize the development, evaluation and application of techniques to facilitate decision-making". These studies rely upon mathematics and statistics and utilize the concepts of utility and probability to analyze decision problems. The concept of utility relates to the expression of preferences among relative options, whilst probability serves to evaluate the likelihood of these preferences being realized (Eastman *et al.*, 1993).

Traditionally, prescriptive analysis has taken the form of either an objective or subjective evaluation of decision criteria. In objective analysis attempts are made to provide a financial appraisal of decision-making, whilst subjective analysis, on the other hand, comprises various approaches which help decision-makers arrange their thoughts, express consistent judgement and choose rationally (e.g. Cochrane and Zeleny, 1973; Coleman, 1971; Keeney and Raiffa, 1976; Voogd, 1983). Current GIS largely fall into the latter category.

Decisions may be characterized as single- or multi-objective in nature, based on either single or multiple criteria. While one is occasionally concerned with single criterion problems, most problems approached within a GIS are multi-criteria in nature - for example, identifying areas for pond construction on the basis of slope, soil texture and land uses. In these instances, the problem is how to combine these criteria to arrive at a composite decision. Most commonly decision problems are dealt with from a single perspective. However, in many instances, the problem is actually multi-objective in nature (Diamond and Wright, 1988). Yet despite the prevalence of multi-objective problems, current GIS software is severely lacking in techniques to deal with this kind of decision. To date, most examples of multi-objective decision procedures in the literature have dealt with the problem through the use of linear programming optimization (e.g. Janssen and Rietveld 1990; Carver, 1991; Campbell *et al.*, 1992; Wright *et al.*, 1983). However, terminology and procedures of linear programming are unknown to most decision-makers and have a complexity that is not easy to understand.

Decision theory is concerned with the logic by which one arrives at a choice between alternatives. The nature of those alternatives can vary. There might be alternative actions, alternative hypotheses about a phenomenon, alternative objects to include in a set, and so on. However, in the context of GIS, it is useful to distinguish between policy decisions and resource allocation decisions. The latter involve decisions that directly affect the utilization of resources (e.g. land), whilst the former is only intended to influence the decision behaviour of others who will, in turn, make resource commitments. GIS has considerable potential for both arenas (Eastman, 1993). Land evaluation and allocation is one of the most fundamental activities of resource development (FAO, 1976b), and resource allocation decisions are prime candidates for analysis with a GIS.

Even though GIS applications in aquaculture implicitly deal with decision-making, very few citations have been made in the literature to date which are specific to GIS and decision-making concerning site selection and location (Eastman *et al.*, 1993). Site selection factors for aquaculture have usually been dealt with by listing and explaining their significance. A common approach has been that of ranking systems. For example, Jamandre and Rabanal (1975) developed siting criteria in a 6-country evaluation, by using a weighting and a ranking system for aquaculture development; Anon (1982) provides criteria for coastal aquaculture by assigning weights and FAO (1984) assessed factors affecting aquaculture development on a country basis by using a rating scale.

In the context of policy decisions, GIS is most commonly used to inform the decision-maker. However, it also has potential as a process-modelling tool, in which the spatial effects of decisions might be simulated. Simulation modelling, particularly of the spatial nature of socio-economic issues and their relation to nature, is still in its infancy. However, it is to be expected that GIS will play an increasingly sophisticated role in this area in the future.

An important methodological GIS development initiated in the 1980's has been the increasing application of modelling techniques. The term "modelling" is open to a wide range of interpretations but, in essence, a model can be considered as some form of abstraction or simplification of the real world. Thus, spatial patterns and processes can be investigated in order to quantify relationships between component variables. Such relationships can then be used as the basis for predicting change under a variety of management, planning policy or environmental scenarios (Davidson, 1992).

The capacity of GIS for dynamic modelling and cartographic capabilities make these systems of enormous potential in aquaculture and related studies. At a country level Kapetsky *et al.* (1990) designed GIS models to assess the capability of districts in Ghana to provide opportunities for fish farming in ponds. At a state-level, a GIS study of aquaculture in Tabasco State, Mexico by Aguilar-Manjarrez and Ross (1993) showed how system-related models could be developed. Aguilar-Manjarrez and Ross (1994; 1995a, b) assessed the usefulness of constructing GIS-based environmental models for aquaculture development in Sinaloa State, Mexico. At site-level, Beveridge *et al.* (1994b) found that there is great potential to develop GIS-based models focused on the dispersion of therapeutants and solid wastes from fish cage culture practices in Camas Bruaich Bay, Scotland. More importantly, the authors noted that GIS could incorporate models developed by Gowen *et al.*(1989) which can predict dispersion and sediment loadings, thereby ensuring, for example, that no other cage farm or development be sited within the zone of influence of the farm. Similarly, Muir and Bostock (1994) noted that GIS could be integrated with modelling techniques constructed by Anon (1993) which have been recently applied to the aquaculture industry as a tool for planning and control. Hence, modelling potential in GIS is just beginning to be fully explored for aquaculture.

The initial stages of the GIS-based models have already been developed in **Chapter 4** by creating submodels for some of the primary criteria. As a continuation, these primary criteria were integrated together to create the final GIS-based models. For this, the same logic established to create the submodels in Chapter 4 was used (i.e. use of MCE), although some adjustments had to be made (e.g. MCE and score adjustments).

The overall objective of the study was to construct general models to evaluate aquaculture development from which more specific models could be developed (e.g. models based on extensive, semi-intensive and intensive shrimp culture systems). A schematic diagram of the procedures involved in creating the GIS-based models is presented in **Figure 5.1**.

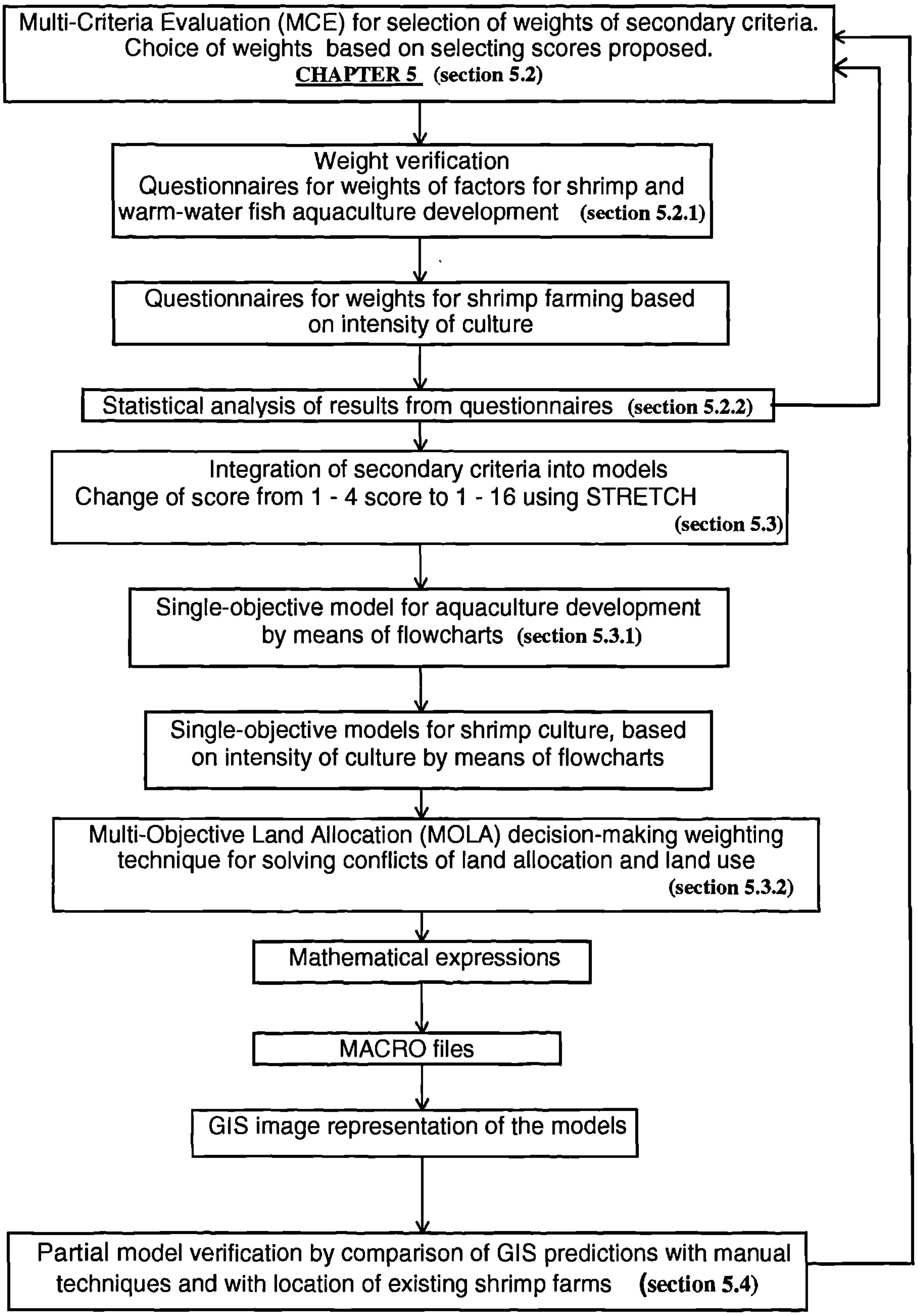


**Figure 5.1. Schematic diagram of procedures that were involved in integrating the secondary criteria in this study. The feedback parts and dynamic nature of the process are indicated by the arrows.**

## 5.2 Multi-criteria evaluation (MCE) adjustments.

As described in **Chapter 4**, the MCE pairwise comparison matrix was very effective in establishing weights between factors, and good results were achieved when dealing with a small number of factors. **Table 5.1** shows a pairwise comparison matrix for obtaining weights between 13 environmental factors. This matrix has a consistency ratio (0.09) again well within the ratio recommended by Saaty (1977), and according to the weights obtained, water resources, temperature, and soils consistently emerge as the most important factors in the evaluation. However, even though logical results were obtained from this table it was found that when dealing with larger numbers of factors in a single matrix, the matrix was difficult to complete and lost accuracy (e.g. the consistency ratios were not within the ratio recommended by Saaty (1977)). Moreover, even though a consistency ratio suggested that the weights were appropriate, the wrong weights could be chosen even if the CR was very low. Similarly, improving the consistency did not mean getting an answer closer to the "real life" solution, only that the ratio estimates in the matrix were closer to being consistently related rather than randomly chosen. To solve this problem, it was found that optimum results were achieved when the relative ranking of the factors was made before completing the pairwise comparison matrix. **Tables 5.2** and **5.3** show that scores were assigned in rank order from 1 to 13 without repetition to the 13 factors involved in the environmental and socio-economic pairwise comparison evaluation (e.g. **Tables 5.1**). Scores presented in these tables should not be confused with the later scores assigned in the MCE. The 1-13 score range assisted in the questionnaire to assign appropriate weights to each of the factors involved.

The scores were ranked to simulate the assignment of weights in a matrix, and each factor was accompanied by a summary description of its importance to make the evaluation more comprehensive. From this, the pairwise comparison matrices were completed to obtain the weights required for the MCE decision-making technique in IDRISI.

Table 5.1. **Pairwise comparison matrix for assessing the comparative importance of 13 factors for Aquaculture development in Sinaloa (numbers show the rating of the row factor relative to the column).**

| **FACTORS** | Water | Temperature | Soils | Topography | Population | Urban | Roads | Industries | Agriculture | Irrigation | Livestock | Forestry | Shrimp farms | WEIGHTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water | 1 | | | | | | | | | | | | | 0.19 |
| Temperature | 1 | 1 | | | | | | | | | | | | 0.14 |
| Soils | 1/2 | 1 | 1 | | | | | | | | | | | 0.12 |
| Topography | 1/3 | 1/3 | 1/3 | 1 | | | | | | | | | | 0.08 |
| Population density | 1/5 | 1/5 | 1/5 | 1/4 | 1 | | | | | | | | | 0.04 |
| Urban development | 1/4 | 1/4 | 1/4 | 1/3 | 4 | 1 | | | | | | | | 0.06 |
| Roads | 1/8 | 1/8 | 1/8 | 1/7 | 1/6 | 1/7 | 1 | | | | | | | 0.01 |
| Industries | 1/3 | 1/3 | 1/2 | 2 | 4 | 3 | 7 | 1 | | | | | | 0.09 |
| Agriculture | 1/4 | 1/4 | 1/4 | 1/2 | 4 | 3 | 7 | 1/3 | 1 | | | | | 0.07 |
| Irrigation | 1/2 | 1/2 | 1 | 3 | 5 | 4 | 7 | 1 | 4 | 1 | | | | 0.10 |
| Livestock rearing | 1/6 | 1/6 | 1/5 | 1/5 | 1/4 | 1/4 | 3 | 1/5 | 1/5 | 1/5 | 1 | | | 0.02 |
| Forestry | 1/6 | 1/6 | 1/6 | 1/5 | 1/5 | 1/5 | 4 | 1/5 | 1/5 | 1/6 | 4 | 1 | | 0.03 |
| Shrimp farms | 1/5 | 1/5 | 1/5 | 1/3 | 1 | 1/3 | 7 | 1/4 | 1/3 | 1/5 | 5 | 5 | 1 | 0.05 |
| **SUM** | | | | | | | | | | | | | | **1.00** |

| 1/9 | 1/8 | 1/7 | 1/6 | 1/5 | 1/4 | 1/3 | 1/2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| extremely | | very strongly | | strongly | | moderately | | equally | | moderately | | strongly | | very strongly | | extremely |

**LESS IMPORTANT** **MORE IMPORTANT**

17 POINT CONTINUOUS RATING SCALE (Source: Eastman *et al.*, 1993).

## Table 5.2. Environmental factors, interpretation and score for aquaculture development in Sinaloa.

| FACTORS | CRITERIA FOR SCORE | SCORE 1-13 |
|---|---|---|
| Water availability /10 /15 | Availability of water is important for all systems in aquaculture. Quantity is particularly of importance for land based systems. An estimation of the dry and rainy seasons should be as accurate as possible so that all phases (construction, operation, maintenance) are properly planned. Seasonal and yearly fluctuations and availability need to be carefully considered. | 13 |
| Suitable temperature /2 /8 /11 /14 | Temperature is both a limiting factor, setting high and low lethal limits, and a determinant for growth and survival rate through its impact on molecular activity. | 12 |
| Suitable soils /3 /4 /15 | Non-acidic, impermeable and compactible. Clay or loam based soils are preferable. Very important for pond culture. | 11 |
| Suitable topography /4 /10 | A gentle slope of less than 2% is highly desirable for gravity water, conveyance to and from the ponds, provides efficient drainage. | 8 |
| Low population density /9 /10 /12 | A smaller population density is likely to be a lesser pollution source. | 4 |
| Distance from urban development /9 /10 /12 | The further away from a city the less likely it is to have pollution problems such as domestic wastes and commercial and industrial discharges. | 6 |
| Distance from roads /1 /6 /7 | Paved roads in particular can have a negative influence in the environment such as modifying the natural flow of a river and/or interrupting the tidal flow to a mangrove area. | 1 |
| Distance from industries /9 /10 /11 | Industrial wastes have been a serious pollution problem, particularly in the water. Sugar cane factories are the biggest problem causing pollution in the form of organic wastes. | 9 |
| Low production agriculture /9 /10 | Small risk of pesticide and herbicide pollution. | 7 |
| Distance from irrigation /5 /7 /9 | Highest pollution source in the state by using large quantities of fertilizers and pesticides. Damaging effects in coastal areas. | 10 |
| Presence of livestock (pigs & poultry) /10 | Availability of manure to fertilize ponds, however, to a moderate extent since too much manure could generate eutrophication problems (i.e. depending on density of livestock and land runoff). | 2 |
| Small distance from forests | Proximity should ensure good water quality but a certain distance should be kept to minimize construction costs. Extraction of forests products can have substantial impact on water quality and quantity by causing soil erosion and deposition. | 3 |
| Distance from shrimp farms. /6 /10 /13 | Little documented information on the effect of discharges. Apparently pollution is small and highly localized. Pollution comprises of farm effluents and saltwater contamination. | 5 |

Source: 1/Aguilar-Manjarrez and Ross (1992); 2/ Beveridge (1987); 3/ Chanratchakool *et al.* (1994); 4/Coche and Laughlin(1985); 5/CEDCP (1990); 6/Crown Estate (1987); 7/De la Lanza (1991); 8/Fast and Lanna (1992); 9/Flores-Verdugo *et al.* (1992); 10/ Kapetsky *et al.* (1987); 11/ Lester and Pante (1992); 12/ Pillay (1992); 13/ Secretaría de Pesca (1991); 14/ Stirling (1985); 15/Wang and Fast (1992).

**Table 5.3. Socio-economic factors, interpretation and score for aquaculture development in Sinaloa.**

| FACTORS | CRITERIA FOR SCORE | SCORE (1-13) |
|---|---|---|
| Human resources /7 | People with good managerial skills, biological knowledge and experience are of primary importance to run an aquaculture operation. Need for professional and engineering services as well technical support which can be very important when problems occur during production. Identification of potential labour by production activities suitable for aquaculture and by age group (over 15 years of age). | 13 |
| Job creation /12 | Areas with unemployment inhabitants were considered optimum for providing labour intensive work for aquaculture. | 10 |
| Activity conflicts /3 /5 | Areas in which there was minimum conflict between activities was considered very suitable for aquaculture. In Sinaloa most of the state land is occupied by Agriculture and hence there have been many conflicts between activities competing for land. Moreover, polluted agricultural lands are likely to be unsuitable for aquaculture. | 12 |
| Sufficient energy /6 | Electricity network is essential for all electrical needs. Mostly needed for water pumping and aeration. | 6 |
| Proximity to natural postlarvae /6 /9 /10 | The costs and availability of essential input will have a direct bearing on the economics and ease of operating an aquatic farm. Great attention should be given to locating reliable sources of postlarvae as they are significant components of the operating budget. During certain times of the year and during certain years seed is scarce. | 9 |
| Good sources of input by-products /4 /13 | Used in extensive shrimp culture and small scale fish culture systems to promote the growth of shrimp food organisms. Good sources of inputs are derived from agriculture and livestock rearing activities. | 2 |
| Proximity to urban developments /1 /2 /11 | Likely existence of labour, inputs (feeds and raw material for semi-intensive and intensive operations), and supplies. Quality feeds are essential for clean pond bottoms, good water quality and healthy shrimp. | 5 |
| High agglomeration /13 | Availability of farming skills, broodstock, markets, sources of feed. Excellent indicator of site suitability, since it is likely to occur in areas which show outstanding factor mixes (i.e. climate and roads). | 7 |
| Good transportation and communications /9 /13 | Permanent accessibility to the potential areas for development is considered to be of paramount importance. Transport can be seen in terms of accessibility and might very well control aquatic production. | 8 |
| Adequate population density /1 /13 | Capacity to absorb aquatic production, sources of labour, supplies and electrical services to power aquaculture operations. | 4 |
| Good disposable income /8 /15 | Amount of money that individuals have remaining after the payment of income personal taxes. Amount of money available for consumption of aquatic organisms. The higher the better. | 1 |
| Fish consumption /14 | A knowledge of the preferred aquatic species for consumption was found to be essential for deciding what the consumer should be offered. | 11 |
| High quantity of markets /9 /13/14 | Knowledge of local market conditions (i.e. hotels, fish processing plants and markets), can be significant to the site selection process. | 3 |

Source: 1/ Aguilar-Manjarrez and Ross (1992);2/ Asian Shrimp Culture Council (1992); 3/Beveridge and Phillips (1993); 4/Chavez-Sanchez (1993); 5/ Dugger (1990); 6/Fast (1992); 7/Flores-Tom and Garmendia-García (1991); 8/ITESM (1993);9/Lee and Wickins (1992); 10/Lobato-Gonzalez (1990); 11/Lovell (1989); 12/ Main and Nash (1987); 13/Meaden and Kapetsky (1991); 14/Shaw (1990); 15/The Encyclopedia Americana (1988).

### 5.2.1 Weight verification

Although factor scores were objectively based upon real data, the assignment of weights during MCE was considered partly subjective because it was entirely dependent upon decisions made by the author. It was decided that the use of questionnaires could help reduce some of this subjectivity. A group of 5 aquaculture staff members were chosen for the questionnaire based upon two major factors: 1) similar aquaculture experience, and 2) physically available in order to provide feedback through interviews during and after the questionnaires had taken place.

The main objective was to evaluate whether the ranking of the factor scores assigned previously matched the rank order of the factor scores by the decision-makers. During initial testing two decision-makers (M.Sc. students in Aquaculture), not included in the subsequent statistical analysis, served to adjust or amend the questionnaire prior to its application.

Both questionnaires involved asking the five staff members to score and assign a weight to each of the factors involved in the evaluation. The questionnaires were in two parts. The first questionnaire involved environmental and socio-economic factors based on their perceived influence on shrimp and warm water fish farming, whilst the second questionnaire assessed the influence of the same environmental and socio-economic factors on different intensities of culture systems.

#### 5.2.1.1 Questionnaire findings for shrimp and warm-water fish aquaculture development.

In the first questionnaire, decision-makers were provided with a summary description of the study area and the tables presented previously (**Tables 5.2** and **5.3** ). They were asked to analyze **Tables 5. 2** and **5.3**, and to give a score from 1-13 without repetition to each of the 13 factors involved in the analysis. After they had become familiar with the factors and had scored them, they were asked to complete the pairwise comparison matrices for the environmental evaluation shown previously in **Tables 5.1** and for the socio-economic evaluation. Additionally, spaces were provided for their comments after completing the questionnaire. One week was given as a deadline to complete the questionnaire.

**Table 5.4** summarizes the scores and the weights from the environmental evaluation, whilst **Table 5.5** shows the results for the socio-economic evaluation. In summary, it can be seen that there was a general agreement between decision-makers since most of the most important factors were assigned high scores. For example, temperature in the environmental evaluation and activity conflicts in the socio-economic evaluation were assigned similar scores.

Table 5.4. Relative scoring and weighting of 13 environmental factors for aquaculture development in Sinaloa, according to 6 decision-makers.

| DECISION-MAKER | A | B | C | D | E | F | MEAN | A | B | C | D | E | F | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCORES | | | | | | | WEIGHTS | | | | | | |
| Water | 13 | 13 | 13 | 12 | 13 | 12 | 12.7 | 0.19 | 0.22 | 0.18 | 0.13 | 0.19 | 0.14 | 0.175 |
| Temperature | 12 | 12 | 12 | 13 | 4 | 13 | 11.0 | 0.14 | 0.12 | 0.16 | 0.18 | 0.04 | 0.17 | 0.135 |
| Soils | 11 | 7 | 8 | 11 | 8 | 9 | 9.0 | 0.12 | 0.07 | 0.08 | 0.12 | 0.08 | 0.10 | 0.095 |
| Topography | 8 | 3 | 10 | 8 | 12 | 5 | 7.7 | 0.08 | 0.03 | 0.10 | 0.08 | 0.14 | 0.05 | 0.080 |
| Population density | 4 | 5 | 6 | 4 | 5 | 7 | 5.2 | 0.04 | 0.05 | 0.06 | 0.04 | 0.05 | 0.07 | 0.052 |
| Urban development | 6 | 6 | 4 | 7 | 7 | 10 | 6.7 | 0.06 | 0.06 | 0.04 | 0.07 | 0.07 | 0.11 | 0.068 |
| Roads | 1 | 4 | 3 | 1 | 1 | 1 | 1.8 | 0.01 | 0.04 | 0.03 | 0.01 | 0.01 | 0.01 | 0.018 |
| Industries | 9 | 9 | 9 | 10 | 10 | 11 | 9.7 | 0.09 | 0.09 | 0.09 | 0.11 | 0.10 | 0.12 | 0.100 |
| Agriculture | 7 | 8 | 5 | 9 | 11 | 4 | 7.3 | 0.07 | 0.08 | 0.05 | 0.10 | 0.12 | 0.04 | 0.077 |
| Irrigation | 10 | 10 | 11 | 5 | 9 | 6 | 8.5 | 0.10 | 0.10 | 0.11 | 0.05 | 0.09 | 0.06 | 0.085 |
| Livestock | 2 | 2 | 2 | 2 | 3 | 2 | 2.2 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.022 |
| Forests | 3 | 11 | 1 | 3 | 2 | 3 | 3.8 | 0.03 | 0.11 | 0.01 | 0.03 | 0.02 | 0.03 | 0.038 |
| Shrimp farms | 5 | 1 | 7 | 6 | 6 | 8 | 5.5 | 0.05 | 0.01 | 0.07 | 0.06 | 0.06 | 0.08 | 0.055 |
| Sum | | | | | | | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| CR | | | | | | | | 0.09 | 0.08 | 0.09 | 0.08 | 0.07 | 0.08 | 0.082 |

TERMINOLOGY:
A = Author
B,C,D,E,F = Staff
CR = Consistency ratio

Table 5.5. Relative scoring and weighting of 13 socio-economic factors for aquaculture development in Sinaloa, according to 6 decision-makers.

| DECISION-MAKER | A | B | C | D | E | F | MEAN | A | B | C | D | E | F | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCORES | | | | | | | WEIGHTS | | | | | | |
| Human resources | 13 | 13 | 10 | 11 | 7 | 13 | 11.2 | 0.16 | 0.22 | 0.11 | 0.12 | 0.07 | 0.14 | 0.137 |
| Job creation | 10 | 6 | 7 | 8 | 6 | 11 | 8.0 | 0.11 | 0.06 | 0.07 | 0.08 | 0.06 | 0.12 | 0.083 |
| Activity conflicts | 12 | 12 | 11 | 10 | 13 | 8 | 11.0 | 0.14 | 0.12 | 0.12 | 0.11 | 0.22 | 0.09 | 0.133 |
| Energy | 6 | 5 | 13 | 2 | 2 | 12 | 6.7 | 0.06 | 0.05 | 0.18 | 0.02 | 0.02 | 0.13 | 0.077 |
| Natural postlarve | 9 | 11 | 9 | 13 | 12 | 10 | 10.7 | 0.10 | 0.11 | 0.09 | 0.17 | 0.12 | 0.11 | 0.117 |
| Inputs | 2 | 3 | 3 | 4 | 4 | 1 | 2.8 | 0.02 | 0.03 | 0.03 | 0.04 | 0.04 | 0.01 | 0.028 |
| Urban development | 5 | 9 | 4 | 9 | 5 | 3 | 5.8 | 0.05 | 0.09 | 0.04 | 0.10 | 0.05 | 0.03 | 0.060 |
| Agglomeration | 7 | 7 | 12 | 12 | 9 | 6 | 8.8 | 0.07 | 0.07 | 0.14 | 0.14 | 0.09 | 0.07 | 0.097 |
| Transportation | 8 | 10 | 8 | 6 | 11 | 7 | 8.3 | 0.08 | 0.10 | 0.08 | 0.06 | 0.11 | 0.08 | 0.085 |
| Population density | 4 | 2 | 6 | 3 | 3 | 4 | 3.7 | 0.04 | 0.02 | 0.06 | 0.03 | 0.03 | 0.04 | 0.037 |
| Income | 1 | 1 | 5 | 1 | 1 | 5 | 2.3 | 0.01 | 0.01 | 0.05 | 0.01 | 0.01 | 0.06 | 0.025 |
| Fish consumption | 11 | 8 | 2 | 7 | 8 | 9 | 7.5 | 0.13 | 0.08 | 0.02 | 0.07 | 0.08 | 0.10 | 0.080 |
| Markets | 3 | 4 | 1 | 5 | 10 | 2 | 4.2 | 0.03 | 0.04 | 0.01 | 0.05 | 0.10 | 0.02 | 0.042 |
| Sum | | | | | | | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| CR | | | | | | | | 0.08 | 0.09 | 0.09 | 0.09 | 0.08 | 0.09 | 0.086 |

TERMINOLOGY:
A = Author
B,C,D,E,F = Staff
CR = Consistency ratio

Although there was good agreement between the scoring of factors which affected aquaculture development, in some cases it was considered difficult to establish scores since the particular type of culture system, particularly its intensity, was unknown. For example, a semi-intensive shrimp farm requiring wild-caught seed for local marketing would need a very different score interpretation for site selection from that of an intensive farm with a hatchery for export marketing.

There was general agreement that the factors chosen for the evaluation were relevant. Most importantly, none of the factors was considered to be unsuitable, or was rejected from the evaluation. Contrary to expectations, many of the staff wanted to include some other factors which would enhance the evaluation. For example, a salinity factor could be added since access to freshwater may improve growth rates. By contrast, evaporation during dry seasons may cause sites to be unsuitable for farming.

Even though the expert advice from the staff members was very useful in the evaluation, and although the questionnaire did provide a summary description of the study area and a description of the factors involved, it was not possible for them to become fully aware of the study area they were assessing in a short period of time - some of them had not been to Mexico and so their comments were based upon their knowledge and experience in other countries. For example, one of the major problems in Ecuador now is pesticide pollution from banana plantations - hence, some staff members considered the "low production agriculture" score of considerable importance. However, this particular problem has not yet been encountered in Sinaloa. Even so, this was not considered to be a strong limitation because it did give an accurate score, by emphasizing the negative effect from agricultural activities.

Even though the decision-makers were greatly benefited by assigning scores prior to completing the pairwise comparison matrix, none of the resulting matrices met the consistency ratio desired. Although many changes were made to the matrices, all the adjustments that needed to be made to meet the CR required were based entirely upon the scores assigned by the decision-makers.

#### 5.2.1.2 Questionnaire findings for culture systems.

Since this questionnaire involved scoring three types of culture systems, and therefore involved more time to complete, a period of three weeks was given as a deadline. The decision-makers were provided with descriptive tables providing information on the factors assigned by the author (**Tables 5.6** and **5.7**) and pairwise comparison tables for the weights.

## Table 5.6. Environmental factors, interpretation and score according to intensity of culture system.

| FACTORS | EXTENSIVE CRITERION | EXTENSIVE SCORE | SEMI-INTENSIVE CRITERION | SEMI-INTENSIVE SCORE | INTENSIVE CRITERION | INTENSIVE SCORE |
|---|---|---|---|---|---|---|
| Water availability | Relies largely on tidal flow (some pumping), adequate inflowing water, ponds are drainable during low tide Seldom problems with toxic metabolites. /2 /3 /4 /6. | 13 | Relies on both tidal flow and pumping. Regular management scheme. Feeding and toxic metabolites can increase over time /2 /3 /6 /10. | 13 | Highest control over water. Relies on pumping. Largest demand of water because of the need to remove more waste metabolites and oxygen supply. /2 /3 /5 /6. | 13 |
| Suitable temperature | Greatly benefited for suitable growth conditions and survival. /8 | 11 | Greatly benefited for suitable growth conditions and survival. /8 | 12 | Greatly benefited for suitable growth conditions and survival. /8 | 12 |
| Suitable soils | No soil treatment, highest dependency on natural state of soil. /3 | 12 | High dependence but soil treatment by compaction, clay blankets, bentonite or chemical additives can be used to minimize negative effects of soils /3 | 11 | Moderate to low dependence on natural soil. Sediment conditions can be improved by compaction, clay blankets, bentonite, chemical additives, waterproof lining. /3 | 5 |
| Suitable topography | Ponds are constructed in low lying impoundment's along bays and tidal rivers. /1 | 10 | Conducted above the high tide coastal line. /1 | 10 | Not necessarily in low-lying impoundment's. /1 | 7 |
| Low population density | Commonly developed in rural areas and hence a lower population will have lower pollution. Minimal impacts on water quality. /10 | 4 | In Sinaloa these farms are usually developed in areas of low population density. /9 | 4 | Located in low population areas but highly vulnerable since lower quantities of pollutants are desired to ensure optimum water quality. /9 | 4 |
| Distance from urban development | Distance should mitigate adverse effect on natural pond environment. | 5 | Important to make production safe. | 5 | Very important. Should protect farm from variety of pollution sources from cities. | 8 |
| Proximity to roads | Roads are commonly unimproved or dirt, Low density roads so minor modifications on environment. | 2 | Dirt roads, medium effects on environment (i.e. river flow) | 1 | Farms are located in close proximity to highways, high density roads. High effect on environment (river flow). | 2 |

## Table 5.6. Continuation

| | | | | | | |
|---|---|---|---|---|---|---|
| Distance from industries | Pollution can have serious effects, although due to a large area of production impact should be minimized. | 7 | Distance should defend farm from negative impacts. Production should be made safe from these pollutants. | 7 | Vulnerable to a serious production loss if contaminated. Distance should help mitigate impact. | 9 |
| Low production agriculture | Even though considered important, densities are low and culture areas are big, hence a water dilution can help minimize negative effects. /2 /9 | 6 | Farms are vulnerable to pollution, hence low agricultural production is like to minimize impact. /9 | 8 | Important, there should be a minimum risk of pesticide and herbicide pollution to secure production. /9 | 6 |
| Distance from irrigation | Negative pollution effects are minimized by distance. Pollution is moderate. | 8 | Distance secures farms from unwanted pollution. Pollution can have serious effects. | 9 | Distance will defend the farm against unsuitable pollution sources which could have a negative effect on production. | 11 |
| Presence of livestock (pigs & poultry) | No inputs are purposely added. However, manure could greatly increase ponds productivity /2 /7 /9 | 9 | Rarely used, however, some manure may increase ponds productivity. /9 | 2 | Almost no natural food production and therefore minimum requirement of manure. /1 /2 /9 | 1 |
| Small distance from forests | Although benefited from good quality water from forests it is not of primary importance. | 1 | Benefited from good quality waters and far enough to minimize construction costs. | 3 | Water runoff from forests have a positive influence. Although construction costs are very high. | 3 |
| Distance from shrimp farms | Unlikely to provide any significant loading of nutrients or organic matter to the coastal system. /8 | 3 | Increase of inputs (fertilizers and feed) Likely to provide significant loading problems. If high stocking density are practiced in neighbouring farms. /8 | 6 | Potential nutrient and organic loads will be the highest due to higher stocking densities and more frequent effluents. /8 | 10 |

Source: 1/ Aquaculture Digest (1993); 2/ Arredondo-Figueroa (1990); 3/Fast (1992); 4/ Fast and Boyd (1992); 5/ Fast and Lannan (1992); 6/Kungvankij (1984); 7/ Nash (1995); 8/Phillips *et al.* (1993); 9/ Secretaría de Pesca (1993); 10//Wang and Fast (1992).

### Table 5.7. Socio-economic factors, interpretation and score according to intensity of culture system.

| FACTOR | EXTENSIVE CRITERION | EXTENSIVE | SEMI-INTENSIVE CRITERION | SEMI-INTENSIVE | INTENSIVE CRITERION | INTENSIVE |
|---|---|---|---|---|---|---|
| Human resources | Low training skills and costs. No dependence on technical assistance.<0.15 persons/ha Minimal management. Least amount of labour mostly fishermen. /2 /3 | 8 | Moderate to high training skills. Labour intensive although minimised by mechanization. Dependence on technical assistance. 0.10-0.25 persons/ha. Continuous skilled management. Fishermen, technicians, administrators & salesmen. | 11 | Very high and varied training skills, costs are high. Labour minimized by mechanization. Highly dependant on continuous technical assistance. 0.5-1.0 persons/ha. Qualified technicians, administrators, salesmen. /3 | 13 |
| Job creation | Few labour except for some stages of culture (i.e. harvest). /5 | 9 | Moderate provision of jobs for labour intensive work. /5 | 12 | Lowest provision of jobs for labour intensive work. /5 | 2 |
| Activity conflicts | Most demanding on space and less on water. /6 | 13 | Most demanding on water and less on space /6. | 13 | Least demanding on space but highest on good quality water. | 6 |
| Sufficient energy | No dependence, no pumping is required. Usually no facilities that use electricity. 0-2 hp/ha. Energy use may be zero. /2 | 1 | Dependence for water pumping and facilities. 2 - 5 hp/ha /2 | 5 | High dependence for water pumping, aeration. High costs 15 - 20 hp/ha. /2 | 12 |
| Proximity to natural postlarvae | Highest dependence on natural supply. Supply is seasonally dependant. Moderate law restrictions. Difficult to stock at desired densities. Lowest stocking densities /1 /2 /4 | 12 | High dependence on catches from wild postlarvae. Seasonally dependant. Serious law restrictions due to closed seasons for capture (although some illegal off season catches are obtained). Seed may enter the pond with influent water but commonly stocked at moderate densities. /1 /2 /4 | 10 | Dependant on artificial breeding often by induced spawning. Hence, moderate dependence on natural postlarvae. Depend on a large supply of known age seed on a timely basis. Highest stocking densities /1 /2 /4 | 5 |
| Good sources of inputs (organic fertilizers) | Shrimp production relies largely on natural pond fertility. Usually there is no application of fertilizers despite the fact that manure could greatly increase ponds productivity. /6 | 2 | Considerable amounts of inorganic fertilizers are required. Organic fertilizers are used to a minimum. /6 | 2 | Almost all shrimp's nutrition comes from costly formulated diets. No organic fertilizers are used. /2 | 1 |

## Table 5.7 Continuation

| | | | | | | |
|---|---|---|---|---|---|---|
| Proximity to urban developments | No dependence on equipment. Feed is dependant on natural pond fertility. No supplement feed (only on rare occasions). Characterized by low feed input. /2 /4 /7 | 6 | Reliance on equipment. Large quantities of materials are needed. Rely on natural pond productivity but typically require supplemental formulated diets. Feed of suitable quality must be available( biggest operating cost). Greater inputs of feed. /2 /4 /7 | 7 | High reliance on imported equipment. Large quantities of materials are needed. Shrimp depend on commercial feed, low consumption of natural food production. Feed of the best quality must be available. /2 /3 /7 | 8 |
| High agglomeration | Suitable as a source of food, but few jobs for the community, very few skills to share. | 3 | Advantage of already developed farming skills, postlarvae and markets. | 8 | Highest benefit from farming skills, postlarvae, and already established markets. | 11 |
| Good transportation and communications | Dirt and unimproved roads. Infrastructure should be maintained for access especially during harvest times /8 | 5 | Dirt roads. Not easily accessible during rainy season, repairs are sometimes necessary. Very important to maintain access at all stages of shrimp culture /8 | 9 | Gravel and dirt roads. Good quality roads, easy access. Highest importance of road access. /8 | 10 |
| Adequate Population density | Low to moderate capacity to absorb aquatic production. | 7 | Moderate to high capacity to absorb aquatic production. | 3 | Greatest capacity to absorb aquatic production. | 7 |
| Good Income | Often low to moderate. Purchase of low price aquatic products. /1 /3 | 4 | Moderate to high amount of money for purchase of aquatic products. /4 | 1 | Very high, amount of money. Aquatic products of high value . /4 | 3 |
| Fish consumption | Knowledge of high protein species at low costs within reach of rural population. | 10 | Knowledge of the preferred species at low to moderate cost for local sales and exports. | 6 | Knowledge of the preferred species of highest value mainly for exports. | 9 |
| High quantify of markets | Production sold directly to the public, small local markets. /9 | 11 | Relies on distant bulk. Mostly sold within the country and some exports. /9 | 4 | Relies on distant bulk. Mainly for exports and also sold within the country. /9 | 4 |

Source: 1/Dugger (1990); 2/Fast (1992); 3/Kungvankij (1984); 4/ Lobato-Gonzales(1990); 5/Main and Nash (1987); 6/ Nash (1995); 7/ Phillips *et al.* (1993); 8/ SCT (1986); 9/ Shaw (1990).

**Tables 5.8, 5.9** and **5.10** summarize the scores and the weights for the environmental evaluation, whilst **Tables 5.11, 5.12** and **5.13** show the results for the socio-economic evaluation. In overview, it can again be seen that there was agreement between decision-makers, since nearly all of the most important factors were assigned high scores.

It was strongly agreed that scoring and weighting was made easier once it was specific to a species and a culture system.

Due to the amount of time involved in completing this questionnaire, the decision-makers did not add as many comments as in the first questionnaire. Nonetheless, general comments included suggestions to include other factors and/or to expand on the interpretation of some factors. More importantly, as with the first questionnaire, none of the factors was considered unsuitable or was excluded from the evaluation.

Table 5.8. Relative scoring and weighting of 13 environmental factors for extensive shrimp culture in Sinaloa, according to 6 decision-makers.

| DECISION-MAKER | A | B | C | D | E | F | MEAN | A | B | C | D | E | F | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCORES | | | | | | | WEIGHTS | | | | | | |
| Water | 13 | 12 | 12 | 13 | 13 | 12 | 12.5 | 0.17 | 0.14 | 0.13 | 0.19 | 0.16 | 0.13 | 0.153 |
| Temperature | 11 | 11 | 13 | 12 | 9 | 9 | 10.8 | 0.12 | 0.12 | 0.16 | 0.15 | 0.09 | 0.10 | 0.123 |
| Soils | 12 | 10 | 11 | 11 | 12 | 13 | 11.5 | 0.14 | 0.10 | 0.12 | 0.11 | 0.15 | 0.14 | 0.127 |
| Topography | 10 | 8 | 10 | 9 | 10 | 11 | 9.7 | 0.11 | 0.08 | 0.11 | 0.09 | 0.10 | 0.12 | 0.102 |
| Population | 4 | 6 | 5 | 4 | 4 | 3 | 4.3 | 0.04 | 0.06 | 0.05 | 0.04 | 0.04 | 0.03 | 0.043 |
| Urban development | 5 | 4 | 4 | 7 | 6 | 5 | 5.2 | 0.05 | 0.04 | 0.04 | 0.07 | 0.06 | 0.06 | 0.053 |
| Roads | 2 | 1 | 1 | 2 | 1 | 2 | 1.5 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 | 0.02 | 0.015 |
| Industries | 7 | 5 | 8 | 6 | 5 | 8 | 6.5 | 0.07 | 0.05 | 0.09 | 0.06 | 0.05 | 0.09 | 0.068 |
| Agriculture | 6 | 7 | 6 | 5 | 7 | 6 | 6.2 | 0.06 | 0.07 | 0.06 | 0.05 | 0.07 | 0.07 | 0.063 |
| Irrigation | 8 | 9 | 7 | 8 | 8 | 7 | 7.8 | 0.08 | 0.09 | 0.08 | 0.08 | 0.08 | 0.08 | 0.082 |
| Livestock rearing | 9 | 13 | 9 | 10 | 11 | 10 | 10.3 | 0.10 | 0.19 | 0.10 | 0.10 | 0.14 | 0.11 | 0.123 |
| Forests | 1 | 3 | 3 | 3 | 2 | 1 | 2.2 | 0.01 | 0.03 | 0.03 | 0.03 | 0.02 | 0.01 | 0.022 |
| Shrimp farms | 3 | 2 | 2 | 1 | 3 | 4 | 2.5 | 0.03 | 0.02 | 0.02 | 0.01 | 0.03 | 0.04 | 0.025 |
| Sum | | | | | | | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| CR | | | | | | | | 0.08 | 0.08 | 0.08 | 0.09 | 0.08 | 0.09 | 0.083 |

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**A** = Author
**B,C,D,E,F** = Staff
CR = Consistency ratio

Table 5.9. Relative scoring and weighting of 13 environmental factors for semi-intensive shrimp culture in Sinaloa, according to 6 decision-makers.

| DECISION-MAKER | A | B | C | D | E | F | MEAN | A | B | C | D | E | F | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCORES | | | | | | | WEIGHTS | | | | | | |
| Water | 13 | 13 | 13 | 13 | 12 | 13 | 12.8 | 0.17 | 0.17 | 0.15 | 0.16 | 0.14 | 0.15 | 0.157 |
| Temperature | 12 | 11 | 12 | 12 | 13 | 10 | 11.7 | 0.13 | 0.13 | 0.13 | 0.14 | 0.2 | 0.11 | 0.140 |
| Soils | 11 | 10 | 11 | 11 | 9 | 12 | 10.7 | 0.12 | 0.11 | 0.12 | 0.13 | 0.09 | 0.13 | 0.117 |
| Topography | 10 | 12 | 10 | 10 | 10 | 11 | 10.5 | 0.11 | 0.14 | 0.11 | 0.11 | 0.1 | 0.12 | 0.115 |
| Population | 4 | 3 | 3 | 2 | 3 | 3 | 3.0 | 0.04 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | 0.030 |
| Urban development | 5 | 6 | 8 | 7 | 6 | 6 | 6.3 | 0.05 | 0.06 | 0.09 | 0.07 | 0.06 | 0.07 | 0.067 |
| Roads | 1 | 1 | 2 | 1 | 1 | 2 | 1.3 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | 0.013 |
| Industries | 7 | 8 | 6 | 6 | 7 | 8 | 7.0 | 0.07 | 0.08 | 0.07 | 0.06 | 0.07 | 0.09 | 0.073 |
| Agriculture | 8 | 7 | 7 | 8 | 8 | 7 | 7.5 | 0.09 | 0.07 | 0.08 | 0.08 | 0.08 | 0.08 | 0.080 |
| Irrigation | 9 | 9 | 9 | 9 | 11 | 9 | 9.3 | 0.1 | 0.09 | 0.1 | 0.1 | 0.11 | 0.1 | 0.100 |
| Livestock rearing | 2 | 2 | 1 | 3 | 2 | 1 | 1.8 | 0.02 | 0.02 | 0.01 | 0.03 | 0.02 | 0.01 | 0.018 |
| Forests | 3 | 5 | 4 | 4 | 5 | 4 | 4.2 | 0.03 | 0.05 | 0.04 | 0.04 | 0.05 | 0.04 | 0.042 |
| Shrimp farms | 6 | 4 | 5 | 5 | 4 | 5 | 4.8 | 0.06 | 0.04 | 0.05 | 0.05 | 0.04 | 0.05 | 0.048 |
| Sum | | | | | | | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| CR | | | | | | | | 0.07 | 0.08 | 0.08 | 0.09 | 0.08 | 0.08 | 0.080 |

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**A** = Author
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CR = Consistency ratio

Table 5.10. Relative scoring and weighting of 13 environmental factors for intensive shrimp culture in Sinaloa, according to 6 decision-makers

| DECISION-MAKER | A | B | C | D | E | F | MEAN | A | B | C | D | E | F | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCORES | | | | | | | WEIGHTS | | | | | | |
| Water | 13 | 13 | 13 | 13 | 13 | 13 | 13.0 | 0.19 | 0.17 | 0.14 | 0.15 | 0.18 | 0.19 | 0.170 |
| Temperature | 12 | 11 | 11 | 12 | 10 | 12 | 11.3 | 0.14 | 0.13 | 0.12 | 0.14 | 0.11 | 0.14 | 0.130 |
| Soils | 5 | 3 | 3 | 4 | 3 | 3 | 3.5 | 0.05 | 0.03 | 0.03 | 0.04 | 0.03 | 0.03 | 0.035 |
| Topography | 7 | 5 | 4 | 5 | 5 | 5 | 5.2 | 0.07 | 0.05 | 0.04 | 0.05 | 0.05 | 0.05 | 0.052 |
| Population | 4 | 6 | 7 | 6 | 6 | 6 | 5.8 | 0.04 | 0.06 | 0.08 | 0.06 | 0.06 | 0.06 | 0.060 |
| Urban development | 8 | 9 | 6 | 9 | 8 | 8 | 8.0 | 0.08 | 0.09 | 0.07 | 0.10 | 0.08 | 0.08 | 0.083 |
| Roads | 2 | 4 | 5 | 3 | 4 | 4 | 3.7 | 0.02 | 0.04 | 0.06 | 0.03 | 0.04 | 0.04 | 0.038 |
| Industries | 9 | 7 | 10 | 8 | 9 | 9 | 8.7 | 0.09 | 0.07 | 0.11 | 0.09 | 0.10 | 0.09 | 0.092 |
| Agriculture | 6 | 8 | 8 | 7 | 7 | 7 | 7.2 | 0.06 | 0.08 | 0.09 | 0.08 | 0.07 | 0.07 | 0.075 |
| Irrigation | 11 | 10 | 9 | 10 | 11 | 11 | 10.3 | 0.12 | 0.11 | 0.10 | 0.11 | 0.12 | 0.12 | 0.113 |
| Livestock rearing | 1 | 1 | 1 | 1 | 2 | 1 | 1.2 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.012 |
| Forests | 3 | 2 | 2 | 2 | 1 | 2 | 2.0 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.020 |
| Shrimp farms | 10 | 12 | 12 | 11 | 12 | 10 | 11.2 | 0.10 | 0.14 | 0.13 | 0.12 | 0.13 | 0.10 | 0.120 |
| Sum | | | | | | | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| CR | | | | | | | | 0.07 | 0.08 | 0.07 | 0.09 | 0.08 | 0.08 | 0.078 |

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CR = Consistency ratio

Table 5.11. Relative scoring and weighting of 13 socio-economic factors for extensive shrimp culture in Sinaloa, according to 6 decision-makers.

| DECISION-MAKER | A | B | C | D | E | F | MEAN | A | B | C | D | E | F | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCORES | | | | | | | WEIGHTS | | | | | | |
| Human resources | 8 | 7 | 9 | 9 | 7 | 7 | 7.8 | 0.08 | 0.08 | 0.09 | 0.09 | 0.07 | 0.07 | 0.080 |
| Job creation | 9 | 8 | 6 | 7 | 8 | 8 | 7.7 | 0.09 | 0.09 | 0.06 | 0.07 | 0.08 | 0.08 | 0.078 |
| Activity conflicts | 13 | 13 | 13 | 13 | 13 | 13 | 13.0 | 0.19 | 0.15 | 0.19 | 0.19 | 0.21 | 0.17 | 0.183 |
| Energy | 1 | 1 | 1 | 4 | 1 | 1 | 1.5 | 0.01 | 0.01 | 0.01 | 0.04 | 0.01 | 0.01 | 0.015 |
| Natural postlarvae | 12 | 12 | 12 | 12 | 12 | 12 | 12.0 | 0.15 | 0.13 | 0.15 | 0.15 | 0.13 | 0.15 | 0.143 |
| Inputs | 2 | 2 | 4 | 1 | 3 | 6 | 3.0 | 0.02 | 0.02 | 0.04 | 0.01 | 0.03 | 0.06 | 0.030 |
| Urban development | 6 | 6 | 7 | 6 | 6 | 5 | 6.0 | 0.06 | 0.07 | 0.07 | 0.06 | 0.06 | 0.05 | 0.062 |
| Agglomeration | 3 | 3 | 5 | 3 | 4 | 4 | 3.7 | 0.03 | 0.03 | 0.05 | 0.03 | 0.04 | 0.04 | 0.037 |
| Transportation | 5 | 4 | 3 | 5 | 5 | 3 | 4.2 | 0.05 | 0.04 | 0.03 | 0.05 | 0.05 | 0.03 | 0.042 |
| Population density | 7 | 10 | 8 | 8 | 9 | 11 | 8.8 | 0.07 | 0.11 | 0.08 | 0.08 | 0.09 | 0.13 | 0.093 |
| Income | 4 | 5 | 2 | 2 | 2 | 2 | 2.8 | 0.04 | 0.05 | 0.02 | 0.02 | 0.02 | 0.02 | 0.028 |
| Fish consumption | 10 | 9 | 10 | 10 | 11 | 10 | 10.0 | 0.10 | 0.10 | 0.10 | 0.10 | 0.11 | 0.10 | 0.102 |
| Markets | 11 | 11 | 11 | 11 | 10 | 9 | 10.5 | 0.11 | 0.12 | 0.11 | 0.11 | 0.10 | 0.09 | 0.107 |
| Sum | | | | | | | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| CR | | | | | | | | 0.08 | 0.09 | 0.09 | 0.08 | 0.08 | 0.09 | 0.085 |

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CR = Consistency ratio

Table 5.12. Relative scoring and weighting of 13 socio-economic factors for semi-intensive shrimp culture in Sinaloa, according to 6 decision-makers.

| DECISION-MAKER | A | B | C | D | E | F | MEAN | A | B | C | D | E | F | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCORES | | | | | | | WEIGHTS | | | | | | |
| Human resources | 11 | 9 | 10 | 10 | 12 | 11 | 10.5 | 0.12 | 0.09 | 0.11 | 0.10 | 0.13 | 0.12 | 0.112 |
| Job creation | 12 | 13 | 12 | 11 | 11 | 12 | 11.8 | 0.14 | 0.22 | 0.13 | 0.13 | 0.11 | 0.13 | 0.143 |
| Activity conflicts | 13 | 12 | 13 | 13 | 13 | 13 | 12.8 | 0.17 | 0.12 | 0.18 | 0.17 | 0.21 | 0.20 | 0.175 |
| Energy | 5 | 8 | 8 | 7 | 4 | 5 | 6.2 | 0.05 | 0.08 | 0.08 | 0.07 | 0.04 | 0.05 | 0.062 |
| Natural postlarvae | 10 | 11 | 11 | 12 | 10 | 10 | 10.7 | 0.11 | 0.11 | 0.12 | 0.15 | 0.10 | 0.10 | 0.115 |
| Inputs | 2 | 3 | 2 | 2 | 5 | 4 | 3.0 | 0.02 | 0.03 | 0.02 | 0.02 | 0.05 | 0.04 | 0.030 |
| Urban development | 7 | 2 | 6 | 9 | 2 | 7 | 5.5 | 0.07 | 0.02 | 0.06 | 0.09 | 0.02 | 0.07 | 0.055 |
| Agglomeration | 8 | 7 | 7 | 6 | 9 | 8 | 7.5 | 0.08 | 0.07 | 0.07 | 0.06 | 0.09 | 0.08 | 0.075 |
| Transportation | 9 | 6 | 9 | 8 | 8 | 9 | 8.2 | 0.10 | 0.06 | 0.10 | 0.08 | 0.08 | 0.09 | 0.085 |
| Population density | 3 | 5 | 5 | 4 | 3 | 3 | 3.8 | 0.03 | 0.05 | 0.05 | 0.04 | 0.03 | 0.03 | 0.038 |
| Income | 1 | 1 | 1 | 1 | 1 | 2 | 1.2 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.012 |
| Fish consumption | 6 | 10 | 4 | 5 | 7 | 6 | 6.3 | 0.06 | 0.10 | 0.04 | 0.05 | 0.07 | 0.06 | 0.063 |
| Markets | 4 | 4 | 3 | 3 | 6 | 1 | 3.5 | 0.04 | 0.04 | 0.03 | 0.03 | 0.06 | 0.01 | 0.035 |
| Sum | | | | | | | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| CR | | | | | | | | 0.07 | 0.08 | 0.08 | 0.08 | 0.08 | 0.07 | 0.077 |

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CR = Consistency ratio

### Table 5.13. Relative scoring and weighting of 13 socio-economic factors for intensive shrimp culture in Sinaloa, according to 6 decision-makers

| DECISION-MAKER | A | B | C | D | E | F | MEAN | A | B | C | D | E | F | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCORES | | | | | | | WEIGHTS | | | | | | |
| Human resources | 13 | 13 | 13 | 13 | 13 | 8 | 12.2 | 0.17 | 0.17 | 0.17 | 0.18 | 0.19 | 0.09 | 0.162 |
| Job creation | 2 | 5 | 3 | 6 | 8 | 3 | 4.5 | 0.02 | 0.05 | 0.03 | 0.06 | 0.08 | 0.03 | 0.045 |
| Activity conflicts | 6 | 9 | 8 | 4 | 5 | 6 | 6.3 | 0.06 | 0.09 | 0.08 | 0.04 | 0.05 | 0.07 | 0.065 |
| Energy | 12 | 11 | 11 | 9 | 12 | 13 | 11.3 | 0.15 | 0.13 | 0.12 | 0.09 | 0.14 | 0.15 | 0.130 |
| Natural postlarvae | 5 | 3 | 9 | 3 | 7 | 4 | 5.2 | 0.05 | 0.03 | 0.10 | 0.03 | 0.07 | 0.04 | 0.053 |
| Inputs | 1 | 1 | 1 | 2 | 1 | 2 | 1.3 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.02 | 0.013 |
| Urban development | 8 | 6 | 6 | 8 | 6 | 7 | 6.8 | 0.08 | 0.06 | 0.06 | 0.08 | 0.06 | 0.08 | 0.070 |
| Agglomeration | 11 | 10 | 12 | 12 | 10 | 12 | 11.2 | 0.12 | 0.11 | 0.14 | 0.15 | 0.10 | 0.13 | 0.125 |
| Transportation | 10 | 12 | 10 | 11 | 9 | 10 | 10.3 | 0.11 | 0.14 | 0.11 | 0.12 | 0.09 | 0.11 | 0.113 |
| Population density | 7 | 8 | 2 | 10 | 2 | 5 | 5.7 | 0.07 | 0.08 | 0.02 | 0.10 | 0.02 | 0.05 | 0.057 |
| Income | 3 | 2 | 4 | 1 | 4 | 1 | 2.5 | 0.03 | 0.02 | 0.04 | 0.01 | 0.04 | 0.01 | 0.025 |
| Fish consumption | 9 | 7 | 7 | 5 | 11 | 11 | 8.3 | 0.09 | 0.07 | 0.07 | 0.05 | 0.12 | 0.12 | 0.087 |
| Markets | 4 | 4 | 5 | 7 | 3 | 9 | 5.3 | 0.04 | 0.04 | 0.05 | 0.07 | 0.03 | 0.10 | 0.055 |
| Sum | | | | | | | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| CR | | | | | | | | 0.07 | 0.07 | 0.08 | 0.09 | 0.09 | 0.08 | 0.080 |

TERMINOLOGY:
**A** = Author
**B,C,D,E,F** = Staff
CR = Consistency ratio

### 5.2.2 Statistical analysis of questionnaires

To assess questionnaire results, it was crucial to determine whether the rank scores of the author matched the position of the rank score of the decision-makers. Non-parametric analysis was used as: 1) data were not collected at random, because the questionnaires had to be assessed by experienced personnel, and 2) data sample had to be very small since the MCE technique had to be carefully evaluated by each of the decision-makers involved in the questionnaire, and it was preferable to have a few very well analyzed questionnaires rather than a large number of questionnaires which were likely to be inaccurate.

The Kendal coefficient of concordance (**W**) measures the extent of association among several sets of rankings, or m entities. It is useful in determining the agreement among several decision-makers of the associations between several factors and has special applications in providing a standard method of ordering entities according to consensus (Siegel, 1965). It is based upon the hypothesis:

HO: The m sets of rankings are not associated; H1: The m sets of rankings are associated and is derived using the following formula:

$$\mathbf{W} = \frac{\sum_{j=1}^{n=1} Rj^2 - 3m^2n(n+1)}{m^2n(n^2-1)}$$

where, **W** = Kendall coefficient of concordance; Rj = sum of the ranks assigned; m = number of sets of rankings; n = number of individuals.

When the observed sets of rankings were in close agreement W was large (close to one); when the agreement was poor W was close to zero. Therefore large values of W rejected HO (Kendall, 1984a, b). Furthermore, it was possible to compute: $X^2 = m(n-1)W$, and compare it with the value of chi $\chi^2 = (n-1)$. If the $X^2$ was larger than chi, rankings were associated and therefore there was an agreement.

High or significant values of W were interpreted as meaning that the decision-makers were applying essentially the same standard in ranking the factors under study. However, it should be emphasized that a high or significant value of W did not necessarily mean that the orderings observed were “correct”. In fact, they may all be incorrect with respect to some external criterion (Siegel, 1965). It is possible that a variety of decision-makers can agree in ordering objects because they all employ the "wrong" criterion. In this case a high or significant W would simply show that all more or less agree in their use of a "wrong" criterion. To solve this problem Kendall (1984a) suggests that the best estimate of the "true" ranking is provided when W is significant, by the order of the various sums of ranks, Rj. If one accepts the interpretation which the various decision-makers agreed upon (as evidenced by the magnitude and significance of W) in ranking the m entities, then the best estimate of the "true" ranking of those entities according to that interpretation is provided by the order of the sums of ranks (Rj).

A comparison of the results was achieved by rank ordering the scores and weights established initially by the author and comparing them against the rank position of the scores and weights found by the decision-makers (both ranks were ordered in descending order). Since the weights had to match the scores exactly to make a logical assessment (e.g. water resources were assigned the highest score and hence the highest weight), the rank position of the weights was exactly the same as the rank position of the scores, and hence the result of the Kendall coefficient of concordance test was exactly the same.

#### 5.2.2.1 Analysis of the questionnaire findings for shrimp and warm-water fish aquaculture development.

***a) Environmental analysis***

For the environmental analysis **Table 5.14** shows that the author's results were very similar to the rest of the group. The value of the Kendall coefficient of concordance (W) was 0.70 and therefore the m sets of rankings were associated; $X^2$ (50.57) was considerably larger than chi at a 5% significance level (21.03). In other words, the ranks established by the author agreed with those established by the decision-makers. As shown in this table, only 3 (industries, soils, and irrigation) out of the 13 factors did not match the exact rank order when compared to the author. Clearly, both the author and the decision-makers agreed that water resources and temperature were the most important site factors in this list.

***b) Socio-economic analysis***

For the socio-economic evaluation, **Table 5.15** shows that the value of W was 0.62 and therefore the m sets of rankings were associated (hypothesis H0 was rejected); $X^2$ (44.68) was considerably larger than chi at a 5% significance level (21.03), hence most of the ranks established by the author in conjunction with the ranks established by the decision-makers were in agreement. Overall, 6 factors out of the 13 factors matched the exact rank position when compared to the author. Conversely, some factors such as natural postlarvae and agglomeration were not in agreement between decision-makers.

### Table 5.14. Environmental factors for aquaculture development in Sinaloa.

### Kendall's coefficient of concordance W. Test statistics between 6 decision-makers.

| | SCORES | | | | | | | | RANK ORDER GROUP | | | RANK ORDER AUTHOR | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | MEAN | | FACTORS | | | FACTORS |
| FACTORS | A | B | C | D | E | F | Rj | $Rj^2$ | Rj | WEIGHT | | SCORE | WEIGHT | |
| Water | 13 | 13 | 13 | 12 | 13 | 12 | 76 | 5776 | 12.7 | 0.175 | Water | 13 | 0.19 | Water |
| Temperature | 12 | 12 | 12 | 13 | 4 | 13 | 66 | 4356 | 11.0 | 0.135 | Temperature | 12 | 0.14 | Temperature |
| Soils | 11 | 7 | 8 | 11 | 8 | 9 | 54 | 2916 | 9.7 | 0.100 | Industries | 11 | 0.12 | Soils |
| Topography | 8 | 3 | 10 | 8 | 12 | 5 | 46 | 2116 | 9.0 | 0.095 | Soils | 10 | 0.10 | Irrigation |
| Population density | 4 | 5 | 6 | 4 | 5 | 7 | 31 | 961 | 8.5 | 0.085 | Irrigation | 9 | 0.09 | Industries |
| Urban development | 6 | 6 | 4 | 7 | 7 | 10 | 40 | 1600 | 7.7 | 0.080 | Topography | 8 | 0.08 | Topography |
| Roads | 1 | 4 | 3 | 1 | 1 | 1 | 11 | 121 | 7.3 | 0.077 | Agriculture | 7 | 0.07 | Agriculture |
| Industries | 9 | 9 | 9 | 10 | 10 | 11 | 58 | 3364 | 6.7 | 0.068 | Urban development | 6 | 0.06 | Urban development |
| Agriculture | 7 | 8 | 5 | 9 | 11 | 4 | 44 | 1936 | 5.5 | 0.055 | Shrimp farms | 5 | 0.05 | Shrimp farms |
| Irrigation | 10 | 10 | 11 | 5 | 9 | 6 | 51 | 2601 | 5.2 | 0.052 | Population density | 4 | 0.04 | Population density |
| Livestock rearing | 2 | 2 | 2 | 2 | 3 | 2 | 13 | 169 | 3.8 | 0.038 | Forests | 3 | 0.03 | Forests |
| Forests | 3 | 11 | 1 | 3 | 2 | 3 | 23 | 529 | 2.2 | 0.022 | Livestock rearing | 2 | 0.02 | Livestock |
| Shrimp farms | 5 | 1 | 7 | 6 | 6 | 8 | 33 | 1089 | 1.8 | 0.018 | Roads | 1 | 0.01 | Roads |

**W** = 0.70; $X^2$ = 50.57; **chi 12.** = 21.03

TERMINOLOGY:
**A** = Author
**B,C,D,E,F** = Staff

## Table 5.15. Socio-economic factors for aquaculture development in Sinaloa.

## Kendall's coefficient of concordance W. Test statistics between 6 decision-makers.

| | SCORES | | | | | | | | RANK ORDER GROUP | | | RANK ORDER AUTHOR | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | MEAN | | FACTORS | | | FACTORS |
| FACTORS | A | B | C | D | E | F | Rj | Rj2 | Rj | WEIGHT | | SCORE | WEIGHT | |
| Human resources | 13 | 13 | 10 | 11 | 7 | 13 | 67 | 4489 | 11.2 | 0.137 | Human resources | 13 | 0.16 | Human resources |
| Job creation | 10 | 6 | 7 | 8 | 6 | 11 | 48 | 2304 | 11.0 | 0.133 | Activity conflicts | 12 | 0.14 | Activity conflicts |
| Activity conflicts | 12 | 12 | 11 | 10 | 13 | 8 | 66 | 4356 | 10.7 | 0.117 | Natural postlarve | 11 | 0.13 | Fish consumption |
| Energy | 6 | 5 | 13 | 2 | 2 | 12 | 40 | 1600 | 8.8 | 0.097 | Agglomeration | 10 | 0.11 | Job creation |
| Natural postlarve | 9 | 11 | 9 | 13 | 12 | 10 | 64 | 4096 | 8.3 | 0.085 | Transportation | 9 | 0.10 | Natural postlarve |
| Inputs | 2 | 3 | 3 | 4 | 4 | 1 | 17 | 289 | 8.0 | 0.083 | Job creation | 8 | 0.08 | Transportation |
| Urban development | 5 | 9 | 4 | 9 | 5 | 3 | 35 | 1225 | 7.5 | 0.08 | Fish consumption | 7 | 0.07 | Agglomeration |
| Agglomeration | 7 | 7 | 12 | 12 | 9 | 6 | 53 | 2809 | 6.7 | 0.077 | Energy | 6 | 0.06 | Energy |
| Transportation | 8 | 10 | 8 | 6 | 11 | 7 | 50 | 2500 | 5.8 | 0.06 | Urban development | 5 | 0.05 | Urban development |
| Population density | 4 | 2 | 6 | 3 | 3 | 4 | 22 | 484 | 4.2 | 0.042 | Markets | 4 | 0.04 | Population density |
| Income | 1 | 1 | 5 | 1 | 1 | 5 | 14 | 196 | 3.7 | 0.037 | Population density | 3 | 0.03 | Markets |
| Fish consumption | 11 | 8 | 2 | 7 | 8 | 9 | 45 | 2025 | 2.8 | 0.028 | Inputs | 2 | 0.02 | Inputs |
| Markets | 3 | 4 | 1 | 5 | 10 | 2 | 25 | 625 | 2.3 | 0.025 | Income | 1 | 0.01 | Income |

**W** = 0.62; **$X^2$** =44.68 ; **chi 12.** = 21.03

TERMINOLOGY:
**A** = Author
**B,C,D,E,F** = Staff

### 5.2.2.2 Analysis of the questionnaire findings for culture systems.

#### *a) Environmental analysis*

**Table 5.16** shows that a high value of 0.96 for W was found in the semi-intensive and intensive evaluation, whilst in the extensive evaluation a value of 0.93 was found. Interestingly, however, the coincidence of the rank order of the factors between Rj and the scores assigned by the author was highest in the extensive and semi-intensive systems (9 out of 13 matched exactly), and least in the intensive (only 5 matched exactly). Despite this, as shown in these tables, the rank position of the factors was usually only missed by one rank order and hence the overall comparison was found to be in strong agreement. Moreover, all values of $X^2$ were much larger than chi.

#### *b) Socio-economic analysis*

**Table 5.17** shows that the highest W value was found in the extensive systems (0.94), followed by the semi-intensive (0.88) and the intensive (0.78). The strongest agreement between the values of Rj found by the decision-making group and the author were found in the extensive system (8 matched exactly out of 13), followed by the intensive system (7 out of 13) and finally the extensive systems (6 matched exactly). All values of $X^2$ were larger than chi, as found in the environmental evaluation. Although some of the factors did not match the rank position exactly, the overall evaluation also proved to be in strong agreement.

**Table 5.16. Environmental factors for shrimp culture based on intensity of culture in Sinaloa. Kendall's coefficient of concordance W Test statistics.**

1)

| EXTENSIVE | | | | | |
|---|---|---|---|---|---|
| RANK ORDER GROUP | | | RANK ORDER AUTHOR | | |
| MEAN | | FACTORS | | | FACTORS |
| Rj | WEIGHT | | SCORE | WEIGHT | |
| 12.5 | 0.153 | Water | 13 | 0.17 | Water |
| 11.5 | 0.127 | Soils | 12 | 0.14 | Soils |
| 10.8 | 0.123 | Temperature | 11 | 0.12 | Temperature |
| 10.3 | 0.123 | Livestock rearing | 10 | 0.11 | Topography |
| 9.7 | 0.102 | Topography | 9 | 0.10 | Livestock rearing |
| 7.8 | 0.082 | Irrigation | 8 | 0.08 | Irrigation |
| 6.5 | 0.068 | Industries | 7 | 0.07 | Industries |
| 6.2 | 0.063 | Agriculture | 6 | 0.06 | Agriculture |
| 5.2 | 0.053 | Urban development | 5 | 0.05 | Urban development |
| 4.3 | 0.043 | Population | 4 | 0.04 | Population |
| 2.5 | 0.025 | Shrimp farms | 3 | 0.03 | Shrimp farms |
| 2.2 | 0.022 | Forests | 2 | 0.02 | Roads |
| 1.5 | 0.015 | Roads | 1 | 0.01 | Forests |

**W** = 0.93; **$X^2$** = 67.01; **chi 12.** = 21.03

2)

| SEMI-INTENSIVE | | | | | |
|---|---|---|---|---|---|
| RANK ORDER GROUP | | | RANK ORDER AUTHOR | | |
| MEAN | | FACTORS | | | FACTORS |
| Rj | WEIGHT | | SCORE | WEIGHT | |
| 12.8 | 0.157 | Water | 13 | 0.17 | Water |
| 11.7 | 0.140 | Temperature | 12 | 0.13 | Temperature |
| 10.7 | 0.117 | Soils | 11 | 0.12 | Soils |
| 10.5 | 0.115 | Topography | 10 | 0.11 | Topography |
| 7.5 | 0.100 | Irrigation | 9 | 0.10 | Irrigation |
| 9.3 | 0.080 | Agriculture | 8 | 0.09 | Agriculture |
| 7.0 | 0.073 | Industries | 7 | 0.07 | Industries |
| 6.3 | 0.067 | Urban development | 6 | 0.06 | Shrimp farms |
| 3.0 | 0.048 | Shrimp farms | 5 | 0.05 | Urban development |
| 4.8 | 0.042 | Forests | 4 | 0.04 | Population |
| 1.8 | 0.030 | Population | 3 | 0.03 | Forests |
| 4.2 | 0.018 | Livestock rearing | 2 | 0.02 | Livestock rearing |
| 1.3 | 0.013 | Roads | 1 | 0.01 | Roads |

**W** = 0.96; **$X^2$** = 69.30; **chi 12.** = 21.03

3)

| INTENSIVE | | | | | |
|---|---|---|---|---|---|
| RANK ORDER GROUP | | | RANK ORDER AUTHOR | | |
| MEAN | | FACTORS | | | FACTORS |
| Rj | WEIGHT | | SCORE | WEIGHT | |
| 13.0 | 0.170 | Water | 13 | 0.19 | Water |
| 11.3 | 0.130 | Temperature | 12 | 0.14 | Temperature |
| 11.2 | 0.120 | Shrimp farms | 11 | 0.12 | Irrigation |
| 10.3 | 0.113 | Irrigation | 10 | 0.10 | Shrimp farms |
| 8.7 | 0.092 | Industries | 9 | 0.09 | Industries |
| 8.0 | 0.083 | Urban development | 8 | 0.08 | Urban development |
| 7.2 | 0.075 | Agriculture | 7 | 0.07 | Topography |
| 5.8 | 0.060 | Population | 6 | 0.06 | Agriculture |
| 5.2 | 0.052 | Topography | 5 | 0.05 | Soils |
| 3.7 | 0.038 | Roads | 4 | 0.04 | Population |
| 3.5 | 0.035 | Soils | 3 | 0.03 | Forests |
| 2.0 | 0.020 | Forests | 2 | 0.02 | Roads |
| 1.2 | 0.012 | Livestock rearing | 1 | 0.01 | Livestock rearing |

**W** = 0.96; **$X^2$** = 68.90; **chi 12.** = 21.03

**Table 5.17. Socio-economic factors for shrimp culture based on intensity of culture in Sinaloa. Kendall's coefficient of concordance W. Test statistics.**

1)

| EXTENSIVE | | | | | |
|---|---|---|---|---|---|
| RANK ORDER GROUP | | | RANK ORDER AUTHOR | | |
| MEAN | | FACTORS | | | FACTORS |
| Rj | WEIGHT | | SCORE | WEIGHT | |
| 13.0 | 0.183 | Activity conflicts | 13 | 0.19 | Activity conflicts |
| 12.0 | 0.143 | Natural postlarvae | 12 | 0.15 | Natural postlarvae |
| 10.5 | 0.107 | Markets | 11 | 0.11 | Markets |
| 10.0 | 0.102 | Fish consumption | 10 | 0.10 | Fish consumption |
| 8.8 | 0.093 | Population density | 9 | 0.09 | Job creation |
| 7.8 | 0.080 | Human resources | 8 | 0.08 | Human resources |
| 7.7 | 0.078 | Job creation | 7 | 0.07 | Population density |
| 6.0 | 0.062 | Urban development | 6 | 0.06 | Urban development |
| 4.2 | 0.042 | Transportation | 5 | 0.05 | Transportation |
| 3.7 | 0.037 | Agglomeration | 4 | 0.04 | Income |
| 3.0 | 0.030 | Inputs | 3 | 0.03 | Agglomeration |
| 2.8 | 0.028 | Income | 2 | 0.02 | Inputs |
| 1.5 | 0.015 | Energy | 1 | 0.01 | Energy |

W = 0.94; $X^2$ =67.45 ; **chi 12.** = 21.03

2)

| SEMI-INTENSIVE | | | | | |
|---|---|---|---|---|---|
| RANK ORDER GROUP | | | RANK ORDER AUTHOR | | |
| MEAN | | FACTORS | | | FACTORS |
| Rj | WEIGHT | | SCORE | WEIGHT | |
| 12.8 | 0.175 | Activity conflicts | 13 | 0.17 | Activity conflicts |
| 11.8 | 0.143 | Job creation | 12 | 0.14 | Job creation |
| 10.7 | 0.115 | Natural postlarvae | 11 | 0.12 | Human resources |
| 10.5 | 0.112 | Human resources | 10 | 0.11 | Natural postlarvae |
| 8.2 | 0.085 | Transportation | 9 | 0.10 | Transportation |
| 7.5 | 0.075 | Agglomeration | 8 | 0.08 | Agglomeration |
| 6.3 | 0.063 | Fish consumption | 7 | 0.07 | Urban development |
| 6.2 | 0.062 | Energy | 6 | 0.06 | Fish consumption |
| 5.5 | 0.055 | Urban development | 5 | 0.05 | Energy |
| 3.8 | 0.038 | Population density | 4 | 0.04 | Markets |
| 3.5 | 0.035 | Markets | 3 | 0.03 | Population density |
| 3.0 | 0.030 | Inputs | 2 | 0.02 | Inputs |
| 1.2 | 0.012 | Income | 1 | 0.01 | Income |

W = 0.88; $X^2$ = 63.45; **chi 12.** = 21.03

3)

| INTENSIVE | | | | | |
|---|---|---|---|---|---|
| RANK ORDER GROUP | | | RANK ORDER AUTHOR | | |
| MEAN | | FACTORS | | | FACTORS |
| Rj | WEIGHT | | SCORE | WEIGHT | |
| 12.2 | 0.162 | Human resources | 13 | 0.17 | Human resources |
| 11.3 | 0.130 | Energy | 12 | 0.15 | Energy |
| 11.2 | 0.125 | Agglomeration | 11 | 0.12 | Agglomeration |
| 10.3 | 0.113 | Transportation | 10 | 0.11 | Transportation |
| 8.3 | 0.087 | Fish consumption | 9 | 0.09 | Fish consumption |
| 6.8 | 0.070 | Urban development | 8 | 0.08 | Urban development |
| 6.3 | 0.065 | Activity conflicts | 7 | 0.07 | Population density |
| 5.7 | 0.057 | Population density | 6 | 0.06 | Activity conflicts |
| 5.3 | 0.055 | Markets | 5 | 0.05 | Natural postlarvae |
| 5.2 | 0.053 | Natural postlarvae | 4 | 0.04 | Markets |
| 4.5 | 0.045 | Job creation | 3 | 0.03 | Income |
| 2.5 | 0.025 | Income | 2 | 0.02 | Job creation |
| 1.3 | 0.013 | Inputs | 1 | 0.01 | Inputs |

W = 0.78; $X^2$ = 56.46; **chi 12.** = 21.03

## 5.3 Integration of secondary criteria for modelling.

### *Change of score*

Although the original score range (1 to 4) was maintained and was most suitable at the initial stages of classification for primary criteria, the maximum number of factors involved in an MCE evaluation at that stage was only 5 (i.e. proximity to water) (**Chapter 4**). Conversely, the number of factors involved for the development of the secondary criteria was much larger (maximum of 13 criteria) meaning that if a 1 - 4 range was used with 13 factors in an MCE evaluation the final image would maintain a 1 - 4 score range, but this would mean that valuable information would be lost (i.e. the final image would be too simple). Consequently, it was necessary to standardize the original 1-4 score range to values of 1-16 so that the final model image had a larger range of values (i.e. a maximum of 16). A 1 to 16 range was chosen mainly for three main reasons; (1) the data range had to be a multiple of 4 to fit the land use classification suitability orders (e.g. very suitable, moderately suitable, *etc.*); (2) the range selected suited the range of colours displayed by an IDRISI image; and (3) the range had to be small enough to enable interpretation of suitability orders, whilst at the same time large enough to reveal enough details from the model outputs.

Using the STRETCH module in IDRISI allowed the factor scores (1-4) to be expressed according to a consistent numeric range of 1-16 (16 being the most suitable).

### *Integration of weights found in the questionnaires with the GIS-based models*

The main objective was to integrate the secondary criteria to create the GIS-based models. For this, the weights found by the author and verified by the questionnaires were used to create these models, and were developed using the MCE decision-making technique. Moreover, because it was clear that the author had a wider knowledge of the study area and of the decision-making spatial technique being used it was logical to expect that the author's weights would be more reliable than the weights assigned by the decision-makers. Nevertheless, the general environmental and socio-economic models were run twice by using the author's weights and the mean weights found by the decision-makers involved in the questionnaire in order to carry out a spatial comparison between the different weights assigned.

## 5.3.1 Environmental models

### 5.3.1.1 General model

Based on the source data, criteria in the GIS were developed into submodels which were focused into different themes (i.e. general environmental issues, water resources, urban development and roads). Due to the nature of the criteria involved, and so as to make a comprehensive analysis, it was reasoned that submodels should be created differently. Some models were created by MCE whilst others, such as the water resources submodel, were created by a mathematical approach. Model integration (**Figure 5.2**) involved five stages:

(1) selection, reclassification and manipulation of environmental factors (primary data) according to aquaculture suitability on a scale of 1 - 16; (2) development of secondary criteria for proximity to water, water balance, urban development and roads through the MCE techniques; (3) mathematical manipulations for water resources; (4) addition of the physical and environmental resources and land use and infrastructure factors; (5) incorporation of a map of all constraints (proximity and distance ranges, mangroves and conservation areas).

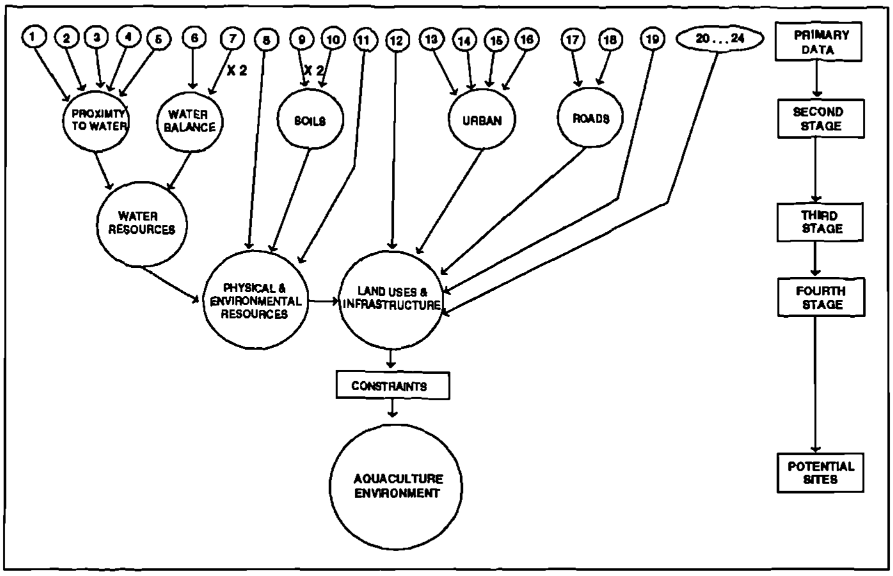


**Figure 5.2. Overall hybrid model integrating environmental factors for assessing site considerations for aquaculture development in Sinaloa.** Primary data: 1, lagoons; 2, coastline; 3, rivers and streams; 4, dams; 5, groundwater; 6, annual water balance; 7, monthly water balance; 8, temperature; 9, soil texture; 10, soil type; 11, topography; 12, population density; 13, capital city; 14, other cities; 15, towns; 16, villages; 17, paved roads; 18, railways; 19, industries; 20, agriculture; 21, irrigation; 22, livestock rearing; 23, forestry; 24, shrimp farms. Note: Only one line is used from values 20 - 24 to avoid confusion between lines.

**RES** = ( WRS X 0.19 ) + ( T X 0.14) + ( SS X 0.12 ) + ( TOP X 0.08 ); **LAUSE** = ( PO X 0.04 ) + ( URBS(e) X 0.06) + ( ROS(e) X 0.01) + ( IND X 0.09 ) + ( AGR(e) X 0.07 ) + ( IRR X 0.10 ) + ( LI X 0.02 ) + ( FO X 0.03 ) + ( SH(e) X 0.05 ); **GEM** = ( RES + LAUSE ) X CONS X BCONS(m) + BCONS(a)

Note: As some factors share two different classifications for the environmental and socio-economic evaluations, an "(e)" has been added to the names of those factors classified in terms of environment and an "(se)" has been added to the names of those factors classified from a socio-economic point of view (see introduction of **Chapter 4**). Where, RES = physical and environmental resources; LAUSE = land use and infrastructure factors; WRS = water resources submodel; T = annual ambient temperature; SS = soils submodel; TOP = topography; PO = population density; URBS(e) = urban development submodel; ROS(e) = roads submodel; IND = industries; AGR(e) = agriculture; IRR = irrigation; LI = livestock rearing; FO = forestry; SH(e) = shrimp farms;. GEM = general environmental model; CONS = constraints used to mask out conservation areas; BCONS = buffer zone for conservation areas (see end of **Chapter 4**), BCONS(m) in the mathematical expression masks out the conservation buffer zone whilst BCONS(a) adds the masked buffer zone with a value of one.

The macro file for this model shows that the integration of the model did not rely on MCE evaluations alone because the submodels had to be treated differently. As noted by Aguilar-Manjarrez and Ross (1994), the model must be a hybrid because some variation in mathematical procedures had to be included (e.g. use of MCE, OVERLAY and SCALAR).

**MACRO FILE**
**ENVIRONMENT**
**GENERAL MODEL**

*PRIMARY CRITERIA*

```
overlay x 3 la(c) coa(c) lacoa
overlay x 3 lacoa rs(c) lacoars
overlay x 3 lacoars d(c) conwa
mce x 1 6 water conwa la 0.34 coa 0.27 rs 0.22 d 0.10 g 0.07
overlay x 3 awaba mwaba waba
overlay x 1 water waba wrs
scalar x soiltx soiltx2 3 2
overlay x soiltx2 soilt ss
overlay x 3 cc(c) oc(c) ccoc
overlay x 3 ccoc tw(c) ccoctw
overlay x 3 ccoctw vi(c) conur
mce x 1 4 urbs(e) conur cc 0.50 oc 0.30 tw 0.15 vi 0.05
overlay x 3  pr(c) rw(c) prrw
overaly x 3  prrw gr(c) conro
mce x 1 3 ros(e) conro pr 0.60 rw 0.40
```

*SECONDARY CRITERIA*

```
mce x 0 4 res wrs 0.19 t 0.14 ss 0.12 top 0.08
mce x 0 9 lause po 0.04 urbs(e) 0.06 ros(e) 0.01 ind 0.09
agr(e) 0.07 irr 0.10  li 0.02 fo 0.03  sh(e)  0.05
overlay  x  1  res lause nala
overlay  x  3  conwa conur waur
overlay  x  3  waur conro waurro
overlay  x  3  m(c) pc(c) mpc
overlay  x  3  mpc in(c) mpcin
overlay  x  3  mpcin sh(c) mpcinsh
overlay  x  3  mpcinsh slp(c) con
overlay  x  3  waurro con cons
overlay  x  3  cons nala em1
overlay  x  3  bcons(m) em1 em2
overlay  x  1  bcons(a) em2 gem
```

Note: The words primary and secondary criteria are just used for clarity and are not part of the macro file.

**Figure 5.3** below shows the allocation of land for aquaculture development determined using this general model. Overall, 19% (11,198 km$^2$) of the state land was identified by the general model as very suitable, most of this land was located in the south of the state. Here, there are no irrigation schemes, agricultural activities are seasonal, there are no sugar factories, and there is a small concentration of urban development and roads in comparison to the rest of the state. The model did find very suitable sites near the coastal lagoons in the central part of the state in Angostura, Navolato and Culiacán. However, because this area is vulnerable to pollution from the capital city and from a high agricultural development many sites above these very suitable sites were also classified from moderate to marginal. Additionally, very suitable sites were also found in the northern part of the state in Ahome. However, development in this area could be affected by a number of pollutants like irrigation, urban development and roads, and therefore the majority of the sites above these very suitable sites were also classified by the model as having moderate to marginal suitability.

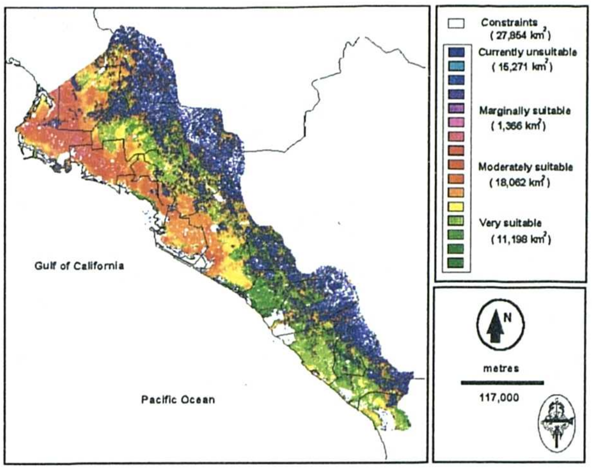


**Figure 5.3. Allocation of land for aquaculture development found by the GIS general model.**

### 5.3.1.2 General model using scores and weight determined by decision-makers.

As a comparison the GIS-model was re-run based on using the weights developed from the opinions of the decision-makers (i.e. the mean and rank order of the weight found in statistical analysis). **Figure 5.4** shows the allocation of land for aquaculture found by the GIS-model by the decision-making group. Due to the strong agreement between the weights assigned by the author and the decision-making group, very similar sites were found for all land classifications. Nonetheless, there were an additional 1,010 km$^2$ of land classified as very suitable by the decision-making group which was primarily attributed to the differences in weights assigned to the soils, irrigation and industries factors. These additional sites were found in the municipality of Navolato.

**MACRO FILE**
**ENVIRONMENT**
**GENERAL MODEL (using weights of decision-makers)**

*PRIMARY CRITERIA*

*SECONDARY CRITERIA*
mce x 0 4 res wrs 0.175 t 0.135 ss 0.095 top 0.080
mce x 0 9 lause po 0.052 urbs(e) 0.068 ros(e) 0.018
ind 0.100 agr(e) 0.077 irr 0.085 li 0.022 fo 0.038
sh(e) 0.055
overlay x 1 res lause nala

Note: Only the new adjustments are presented in this macro file. The Primary criteria macro file is identical to the macro previously presented in section 5.3.1.1., similarly, the constraints used in the secondary criteria are exactly the same.

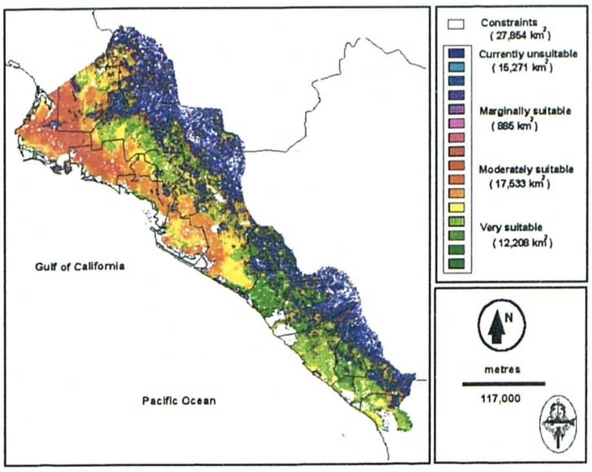


Figure 5.4. GIS-derived allocation of land for aquaculture development based on environmental factors based on decisions from questionnaire.

### 5.3.1.3 Culture system orientated models.

Based on the weights found by the author and on the structure of the general model, culture system orientated models were developed (**Figure 5.5**).

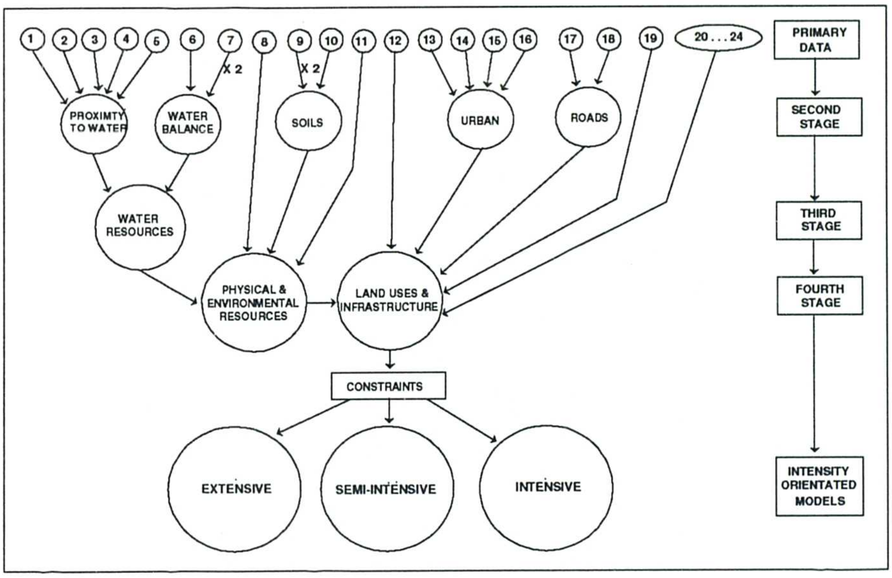


Figure 5.5. General model for assessing potential sites for shrimp culture for different types of culture systems.

Since the weights were different for each culture system model, then obviously the outcome of the models was also different. This is shown clearly in **Figures 5.6.** A comparison of the results between the three culture systems reveals that it is strongly agreed that land in the southern region of the state is the most environmentally suitable for new aquaculture developments at all levels of intensity. Notably, because more intensive culture systems are more affected by pollution sources, the number of very suitable sites identified by the models increased by an increase of culture intensity towards the south of the state, away from potential pollution sources identified in the central and northern region. Additionally, in the case of the intensive culture model, increase in suitability (16,462 km$^2$) was found to be strongly attributed to the lower weight assigned to the slopes, and therefore a number of very suitable sites was located towards the mountains. An evaluation of the coastline reveals that very suitable sites are found in the central (Navolato) and southern (Elota) part of the state, and only a few in the northern region (Guasave).

**MACRO FILE**
**ENVIRONMENT**
**CULTURE SYSTEMS**

*PRIMARY CRITERIA*

*SECONDARY CRITERIA*

EXTENSIVE

```
mce x 0 4 resext wrs 0.17 t 0.12 ss 0.14 top 0.11
mce x 0 9  laext po 0.04 urbs(e) 0.05 ros(e) 0.02 ind 0.07
agr (e) 0.06 irr 0.08  li 0.10 fo 0.01  sh (e) 0.03
overlay x 1 resext laext relaext
```

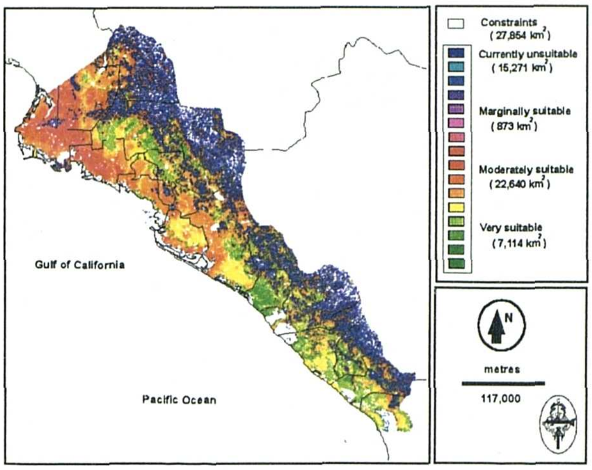
SEMI-INTENSIVE

```
mce x 0 4 ressin wrs 0.17 t 0.13 ss 0.12 top 0.11
mce x 0 9 lasin po 0.04 urbs(e) 0.05 ros(e) 0.01 ind 0.07
agr(e) 0.09 irr 0.10  li (r) 0.02 fo 0.03 sh(e) 0.06
overlay x 1 ressin lasin  relasin
```

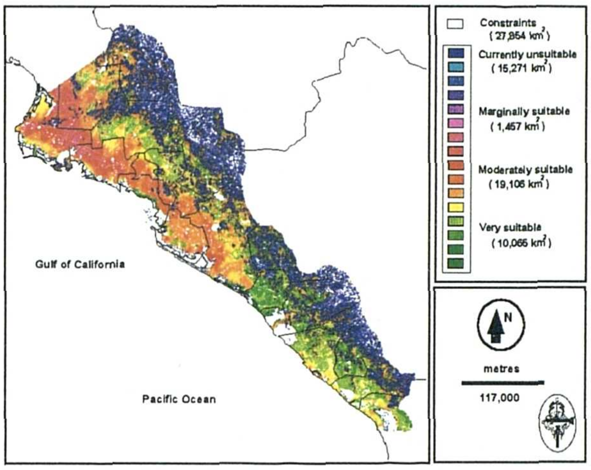
INTENSIVE

```
mce x 0 4 resint wrs 0.19 t 0.14 ss 0.05 top 0.07
mce x 0 9 laint po 0.04 urbs(e) 0.08 ros(e) 0.02 ind 0.09
agr(e) 0.06 irr 0.12 li (r) 0.01 fo 0.03  sh(e) 0.10.
overlay x 1 resint laint  relaint
```

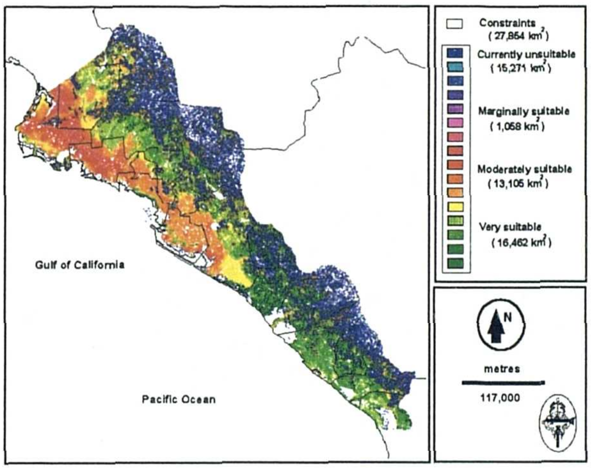
Note: Only the new adjustments are presented in these macro files. The Primary criteria macro file *is identical to the macro* previously presented in section 5.3.1.1., similarly, the constraints used in the secondary criteria are exactly the same.
Livestock classification was reversed for semi-intensive and intensive culture models, this is indicated by an "(r)" symbol (see Chapter 4 for explanation).



1.- Extensive.



2.- Semi-intensive



3.- Intensive

**Figure 5.6. GIS-derived allocation of land for shrimp farming for different types of culture systems based on environmental criteria.**

### 5.3.2 Socio-economic models

#### 5.3.2.1 General model

**Figure 5.7** illustrates the development of the socio-economic model, which involved four stages: (1) selection of primary data, in which source layers were classified on a scale of 1-4, 4 being the most suitable, and then stretched to a 1-16 range. Proximity constraints were also incorporated to avoid using a value within an area that is considered permanently unsuitable; (2) creation of secondary criteria for inputs, urban development and roads through MCE evaluations; (3) development of tertiary criteria for social, production and marketing submodels based on MCE evaluations; (4) incorporation of a map of constraints (proximity and distance ranges, mangroves and conservation areas).

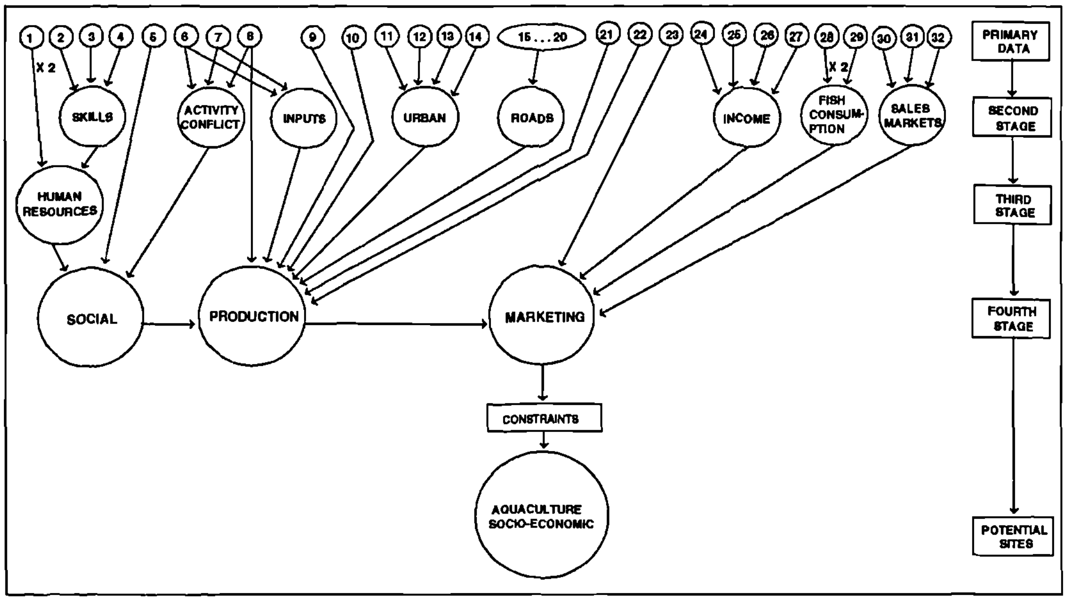


**Figure 5.7. Overall hybrid model integrating socio-economic factors for assessing site considerations for aquaculture development in Sinaloa.** Primary data: 1, age group; 2, primary sector; 3, secondary sector; 4, tertiary sector; 5, job creation; 6, agriculture; 7, livestock rearing; 8, agglomeration; 9, energy; 10, natural postlarvae; 11, capital city; 12, other cities; 13, towns; 14, villages; 15, paved roads, 16, railways, 17, gravel roads, 18, dirt roads; 19, unimproved roads; 20, transport types, 21, communications; 22, support centres; 23, population density; 24, number of inhabitants earning 1.5 the minimum wage; 25, number of inhabitants earning 2.5 times the minimum wage; 26, number of inhabitants earning 4 times the minimum wage; 27, number of inhabitants earning 7.5 times the minimum wage; 28, preferred aquatic specie for consumption; 29, fishing activity; 30, hotels; 31, fish processing plants; 32, markets. Note: Only one line is used from values 15 - 20 to avoid confusion between lines.

**SOCIAL** = ( HRS X 0.16 ) + ( JC X 0.11 ) + ( ACTS X 0.14 ); **PROD** = ( ( E X 0.06 ) + ( POS X 0.10 ) + ( INS X 0.02 ) + ( URBS(se) X 0.05 ) + ( AG X 0.07 );+ ( TRS X 0.08 ) ) + C + SC; **MARKET** = ( PO X 0.04 ) + ( DIS X 0.01 ) + ( FIS X 0.13 ) + ( SALES X 0.03 ); **GSM** = ( SOCIAL + PROD + MARKET ) X CONS X BCONS(m) + BCONS(a)

where, SOCIAL = Social factor submodel; HRS = human resources submodel; JC = job creation factor; ACTS = activity conflict submodel; PROD = production modifiers submodel; E = energy factor;

POS = natural postlarvae availability; INS = inputs submodel; URBS(se) = urban development submodel; AG = agglomeration; TRS = transport submodel; C = communications constant; SC = support centres constant; MARKET = market potential submodel; PO = population density; DIS = disposable income submodel; FIS = fish consumption submodel; SALES = sales/market submodel; GSM = general socio-economic model; CONS = constraints used to mask out conservation areas; BCONS = buffer zone for conservation areas.

**Figure 5.8** shows the allocation of land found by the GIS general model for aquaculture development based on socio-economic factors. The model identified an increase in suitability towards the coast. There are 1,028 km$^2$ of land identified as very suitable, most of which are located in Mazatlán. Here, human resources, fish consumption, transportation and energy are particularly suitable when compared to the rest of the state. Nonetheless, the rest of the municipalities in the southern region were found to be marginal or unsuitable. Hence, with the exception of Mazatlán, it was found that at a state- level the northern and central parts of the state are most suitable for aquaculture development.

**MACRO FILE**
**SOCIO-ECONOMIC**
**GENERAL MODEL**

*PRIMARY CRITERIA*

```
mce x 0 3 pss 0 prim 0.57 sec 0.07 tert 0.36
scalar x agea ageb 3 2
overlay x 3 ageb pss hrs
overlay x 1 agr(se) li agrli
overlay x 1 agrli aq(se) acts
mce x 0 2 ins li 0.7 agr(se) 0.35
overlay x 3 cc(c) oc(c) ccoc
overlay x 3 ccoc tw(c) ccoctw
overlay x 3 ccoctw vi(c) conur
mce x 1 4 urbs(se) conur cc 0.50 oc 0.30 tw 0.15 vi 0.05
overlay x 3  pr(c) rw(c) prrw
overaly x 3  prrw gr(c) conro
mce x 1 3 ros(e) conro pr 0.50 rw 0.23 gr 0.15 dr 0.10  ur 0.02
overlay x 1 ros(se) transt trs
mce x 0 4 dis 1.5mw 0.1 2.5mw 0.16 4mw 0.26  7.5mw 0.48
overlay x 3 pfish fact fis
mce x 0 3 sales hot 0.2 fishp 0.3 mark 0.5
```

*SECONDARY CRITERIA*

```
mce x 0 3 social hrs 0.16 jc 0.11 acts 0.14
mce x 0 6 prod e 0.06 pos 0.10 in 0.02 urbs(se) 0.05
ag 0.07 trs 0.08
overlay x 1  c prod cprod
overlay x 1  sc cprod scprod
mce x 0 4 market po 0.04 dis 0.01 fis 0.13 sales 0.03
overlay x 1 social scprod sopro
overlay x 1 market sopro socioec
overlay x 3 la(c) coa(c) lacoa
overlay x 3 lacoa rs(c) lacoars
overlay x 3 lacoars d(c) conwa
overlay  x  3  conwa conur waur
overlay  x  3  waur conro waurro
overlay  x  3  m(c) pc(c) mpc
overlay  x  3  mpc in(c) mpcin
overlay  x  3  mpcin sh(c) mpcinsh
overlay  x  3  mpcinsh slp(c) con
overlay  x  3  waurro con cons
overlay  x  3  cons socioec em1
overlay  x  3  bcons(m) em1 em2
overlay  x  1  bcons(a) em2 gsm
```

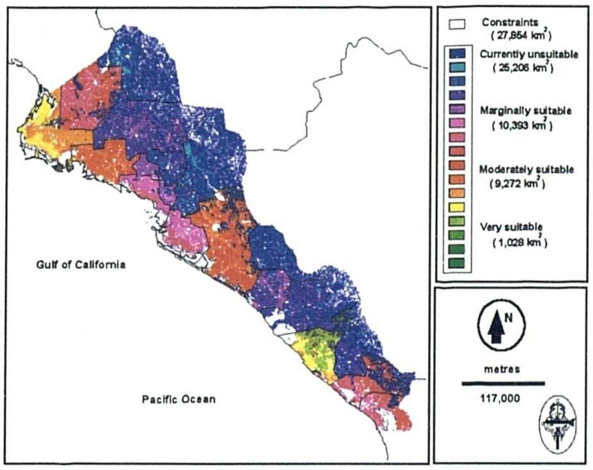


Figure 5.8. GIS-derived allocation of land for aquaculture development based on socio-economic factors in Sinaloa.

### 5.3.2.2 General model using scores and weight determined by decision-makers.

As a comparison the GIS-model was re-run based on using the weights developed from the opinions of the decision-makers (i.e. the mean and rank order of the weight found in statistical analysis). **Figure 5.9** shows that very similar results were found by the decision-making group when compared to the results of the author. Nonetheless, there was a slight decrease (15 km$^2$) in the amount of very suitable sites using the weights assigned by the experts, which was primarily attributed to the differences in weights assigned to the natural postlarvae and agglomeration factors. The difference in suitability was found for some sites in the municipalities of Navolato, Angostura and Ahome.

**MACRO FILE**
**SOCIO-ECONOMIC**
**GENERAL MODEL (using weights of decision-makers)**

*PRIMARY CRITERIA*

*SECONDARY CRITERIA*

```
mce x 0 3 social hrs 0.137 jc 0.083 acts 0.133
mce x 0 6 prod e 0.077 pos 0.117 ins 0.028 urbs(se) 0.06
ag 0.097 trs 0.085
overlay x 1 c prod cprod
overlay x 1 sc cprod scprod
mce x 0 4 market po 0.037 dis 0.025 fis 0.08 sales 0.042
overlay x 1 social scprod sopro
overlay x 1 market sopro socioec
```

Note: Only the new adjustments are presented in this macro file. The Primary criteria macro file is identical to the macro previously presented in section 5.3.2.1., similarly, the constraints used in the secondary criteria are exactly the same.

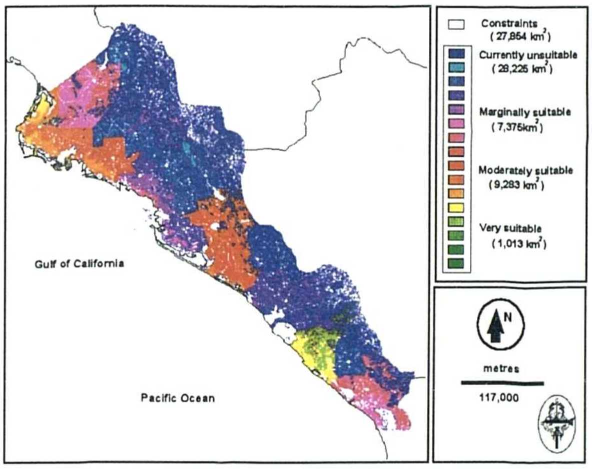


**Figure 5.9. GIS-derived allocation of land for aquaculture development based on socio-economic factors based on decisions from questionnaire.**

### 5.3.2.3 Culture system orientated models

Based on the weights previously established in the questionnaires, and on the structure of the general model, culture system orientated models were also developed (**Figure 5.10**). The outcome of these models is shown in **Figure 5.11**.

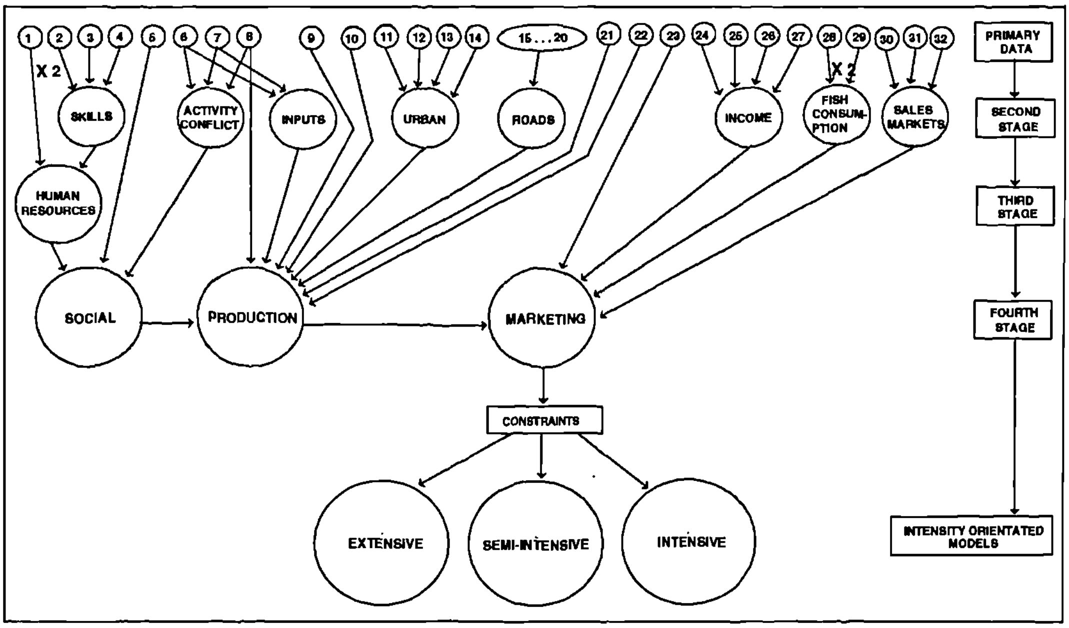
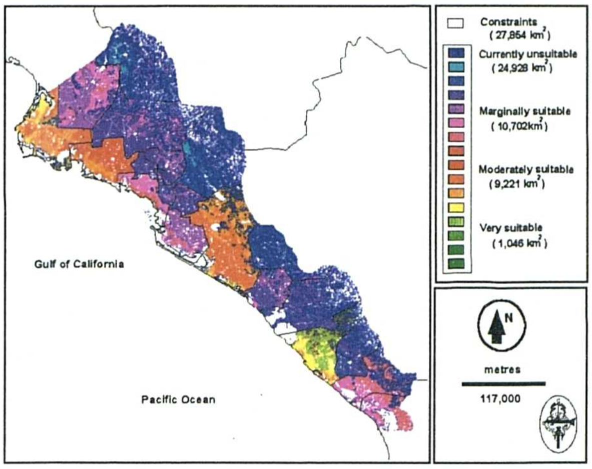


Figure 5.10. General socio-economic model for assessing potential sites for shrimp culture for different types of culture systems.

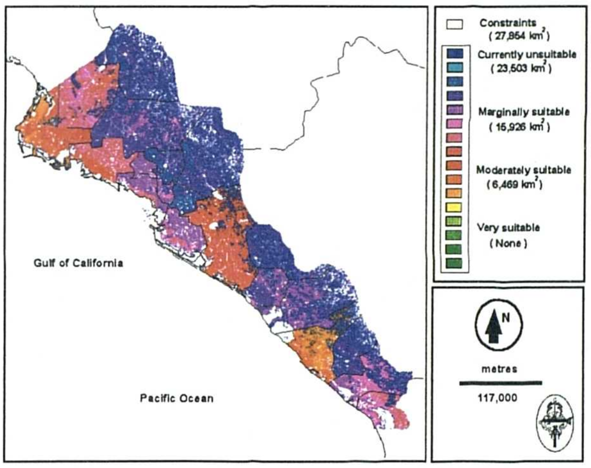
Using the different weights found by the author and verified by the questionnaires, different outcomes of the general model were produced for each type of culture system. **Figure 5.11.** shows the GIS-derived allocation of land identifying potential sites for shrimp farming based on socio-economic factors. The municipalities of Ahome, Guasave, Culiacán and Mazatlán were found to be the most suitable for all culture systems of which Mazatlán was always found to be the most suitable. Interestingly, considerable changes in scores occurred in these four municipalities when comparing the results found by the three models. The highest scores were found in the intensive model, moderate in the extensive and low in the semi-intensive. The reason for this was strongly influenced by the fact that most of the choropleth factors used in the semi-intensive model were assigned low weights, whereas many choropleth factors were assigned high weights in the extensive and intensive model. No sites classified as very suitable were found in the semi-intensive model, whereas for the extensive and intensive models there

```
MACRO FILE
SOCIO-ECONOMIC. CULTURE SYSTEMS

PRIMARY CRITERIA

SECONDARY CRITERIA
EXTENSIVE
mce x 0 3 social hrs 0.08 jc 0.09 acts 0.19
mce x 0 6 prod e 0.01 pos 0.15 ins 0.02 urbs(se) 0.06
ag 0.03 trs 0.05
overlay x 1 c prod cprod
overlay x 1 sc cprod scprod
mce x 0 4 market po 0.07 dis 0.04 fis 0.10 sales 0.11
overlay x 1 social scprod sopro
overlay x 1 market sopro socioec

SEMI-INTENSIVE
mce x 0 3 social hrs 0.12 jc 0.14 acts 0.17
mce x 0 6 prod e 0.05 pos 0.11 ins 0.02 urbs(se) 0.07
ag 0.08 trs 0.10
overlay x 1 c prod cprod
overlay x 1 sc cprod scprod
mce x 0 4 market po 0.03 dis 0.01 fis 0.06 sales 0.04
overlay x 1 social scprod sopro
overlay x 1 market sopro socioec

INTENSIVE
mce x 0 3 social hrs 0.17 jc 0.02 acts 0.06
mce x 0 6 prod e 0.15 pos 0.05 ins 0.01 urbs(se) 0.08
ag 0.12 trs 0.11
overlay x 1 c prod cprod
overlay x 1 sc cprod scprod
mce x 0 4 market po 0.07 dis 0.03 fis 0.09 sales 0.04
overlay x 1 social scprod sopro
overlay x 1 market sopro socioec
```

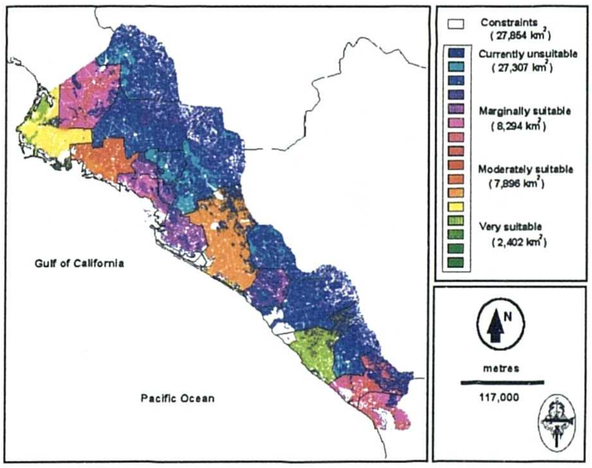
are 1,046 km$^2$ and 2,402 km$^2$ of land. Overall, the three culture system models identified unsuitable sites in similar areas towards the mountains, and in many municipalities in the south of the state.



1.- Extensive.



2.- Semi-intensive



3.- Intensive

**Figure 5.11. GIS-derived allocation of land for shrimp farming for different types of culture systems based on socio-economic criteria.**

MULTI-OBJECTIVE MODELS

Five production activities were selected for this analysis: agriculture, livestock rearing, aquaculture, forestry and urban development; the objective being to quantify the relationship between activities. The first consideration with these objectives (or activities) was whether or not they were in conflict with each other. As a preliminary assessment, so as to determine the kind of relationship (complementary or conflicting), a cross-tabulation was carried out using the module "CROSSTAB" in IDRISI, which calculated the correlation coefficient between these factors. Using CROSSTAB it was found that agriculture had the highest correlation value with all other activities, which meant that it was competing for space with most of the activities. Moreover, because agriculture had a very high correlation with aquaculture it meant that large amounts of land were suitable for both activities.

### 5.3.3 Aquaculture environmental models compared with socio-economic models

Both the environmental and socio-economic general models identified potential sites for aquaculture development. Nonetheless, potential sites in terms of environment are not always potential sites in socio-economic terms, as discussed in **Chapter 4**. For example, a low population density is a priority in an environmental evaluation but in socio-economic terms it is the opposite. One solution to this problem was to evaluate the two images by means of creating a cross-classification image. This option allows the user to evaluate the correlation between the scores found by the two images, and can allow the decision-maker to evaluate and establish trade-offs between these objectives by selecting the most appropriate combination (e.g. a high environmental score with a moderate socio-economic score). **Figure 5.12.** shows an example of a cross-classification image in which the high scores obtained by each model were compared. Most sites classified as very suitable were found in Mazatlán (in the south) and Ahome (in the north), and account for 6% (3,219 km$^2$) of the state land. Moderately suitable sites were found in Guasave and Culiacán (14%). Both models agreed that unsuitable sites are found towards the mountains.

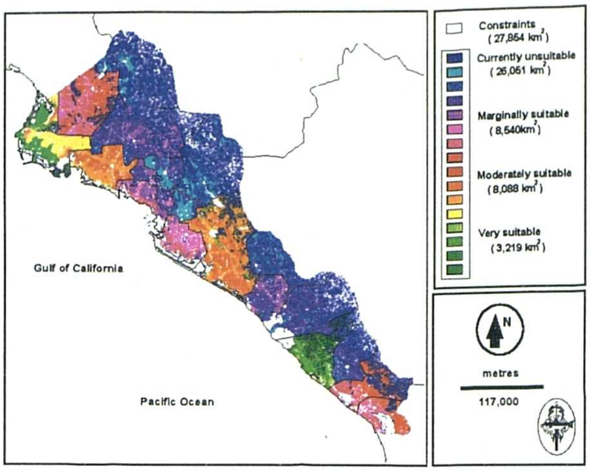


**Figure 5.12. Cross-classification image between two different objectives.**

### 5.3.4 Aquaculture compared with agriculture

Because aquaculture could be integrated well with agriculture it was initially thought that a complementary approach between activities would be most suitable. However, this procedure would combine both activities together, and it was very likely that there could be problems such as pollution from pesticides and herbicides. Therefore, both activities were considered as areas of conflict because in many cases they were competing for the same area of land. A multi-objective land allocation (MOLA) technique available in IDRISI was used. MOLA uses the set of ranked suitability maps, one for each activity, the relative weights assigned to each (the relative weight of that objective in resolving conflicting claims for land), the total area to be assigned to each (the amount of land desired) and an areal tolerance (the point at which MOLA decides that it has come close enough to satisfying the area needs of the objectives for it to stop with the iterations). From this, a compromise solution was determined which maximized the availability of suitable land for each objective.

To find an exact solution, weights for each activity were set to be the same (0.50 for each). With the MOLA, a trade-off was achieved between both production alternatives on the basis of the weights and area goals established. Similar area goals to those found by the manual survey carried out by two Mexican consulting companies (Cosmocolor (1991) and EPAC (1991) ) for aquaculture were used (see end of **Chapter 1**), enabling comparisons between the GIS in this study and the manual techniques. An area tolerance of zero was set for both activities. The ranked map for aquaculture and agriculture (derived from the MCE suitability maps which were ranked by the module RANK) were evaluated using the IDRISI MOLA module in order to resolve conflicts based on the weighted logic. Taking this and the source data into account, criteria in the GIS were developed into the model based on the work of Aguilar-Manjarrez and Ross (1995b), with some adjustments and enhancements (**Figure 5.13**). Aquaculture in this model refers to the general environmental aquaculture image model presented earlier. However, different versions of this model can be run by changing the aquaculture model to deal with the different types of culture systems. Moreover, if less optimum sites were used for agriculture, it could be assumed that this would minimize the risks of pollution and therefore instead of treating these activities as conflicting they could be complementary by considering agriculture as a source of inputs for aquaculture.

Because availability of water of appropriate quality is important in all systems in aquaculture a submodel specific for water quality was created based on the assumption that land use can be indicative of water quality (**see Chapter 4**).

The model involved a series of stages:

(1) selection, reclassification and manipulation of environmental factors (primary data according to aquaculture and agriculture suitability); (2) creation of secondary criteria through the MCE techniques and mathematical manipulations for water resources; (3) incorporation of the physical and environmental resources and land use and infrastructure factors for water quality and environmental factors from MCE evaluations for aquacultural and agricultural developments; (4) incorporation of constraints; up to this point, data were handled separately for both production alternatives; (5) integration of both data together using the MOLA technique so as to determine the areas of conflict, and allocation of appropriate areas for each activity.

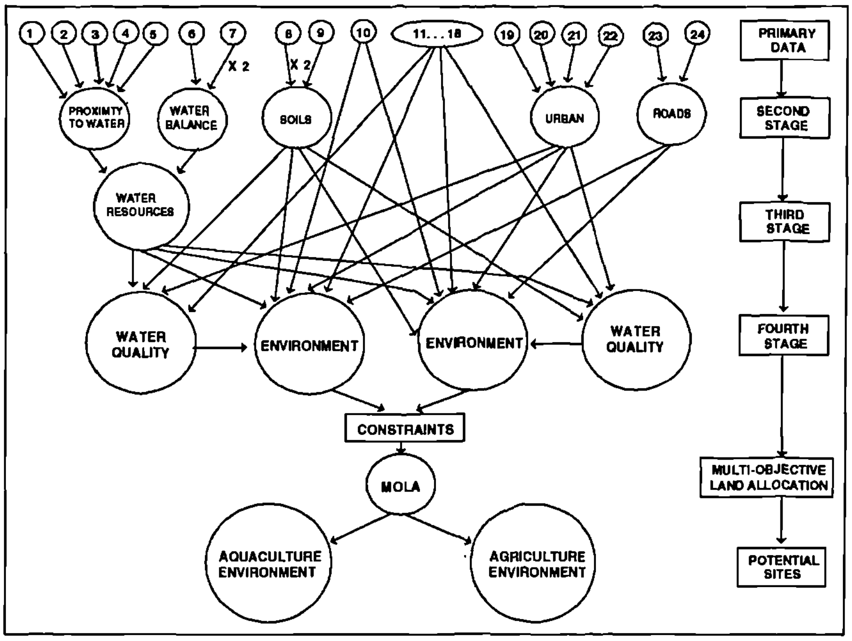


**Figure 5.13. Overall hybrid model integrating submodels for assessing site considerations for aquaculture development in Sinaloa (based on Aguilar-Manjarrez and Ross, 1995b).** Primary data: 1, lagoons; 2, coastline; 3, rivers and streams; 4, dams; 5, groundwater; 6, annual water balance; 7, monthly water balance; 8, soil texture; 9, soil type; 10, topography; 11, temperature; 12, population density; 13, industries; 14, agriculture; 15, irrigation; 16, livestock rearing; 17, forestry; 18, shrimp farms; 19, capital city; 20, other cities; 21, towns; 22, villages; 23, paved roads; 24, railways. Data were integrated for both activities in this hybrid model and therefore lines derived from the secondary data submodels in this figure were duplicated (although classification of primary data for aquaculture and agriculture were different). Additionally, only two lines are duplicated from values 11 to 18 in order to avoid confusion between lines.

Although the initial model proposed by Aguilar-Manjarrez and Ross (1995b) can evaluate the negative effects of some of the factors, during that stage of model development the questionnaires had not been developed to take advantage of these new data. In order to make this new model more comparable with others in this study it was necessary to adjust the old model by not using subtractions, and this was done by reversing the classification used. For example, when evaluating pollution, the highest score was assigned to those sites closest to a city, whilst in this new evaluation, highest scores were assigned to those sites furthest away. Clearly because two different manipulations (i.e. subtraction and addition) were used then spatial score classifications had to be different.

The mathematical expressions for the secondary criteria of the aquaculture model were:

*ENVIRONMENT*

**RES** = ( WRS X 0.19 ) + ( T X 0.14) + ( SS X 0.12 ) + ( TOP X 0.08 ); **LAUSE** = ( PO X 0.04 ) + ( URBS(e) X 0.06) + ( ROS(e) X 0.01) + ( IND X 0.09 ) + ( AGR(e) X 0.07) + ( IRR X 0.10 ) + ( LI X 0.02 ) + ( FO X 0.03 ) + ( SH(e) X 0.05 ); **GEM** = RES + LAUSE

*WATER QUALITY*

**RESWQ** = ( WRS X 0.18 ) + ( T X 0.16 ) + ( SS X 0.14 ); **LAWQ** = ( PO X 0.05 )+ ( URBS(e) X 0.07) + ( IND X 0.09 ) + ( AGR(e) X 0.08 )+ ( IRR X 0.12) + ( LI X 0.02 ) + ( FO X 0.03 ) + ( SH(e) X 0.06 ); **GWQM** = RESWQ + LAWQ

where, RESWQ = physical and environmental resources for water quality environmental criteria; LAWQ = land use and infrastructure for water quality environmental criteria; GWQM = general water quality model.

As shown by the mathematical expression for the general environmental model, new weights were developed for the water quality submodel. Such weights were obtained using the MCE technique. Here, water availability, temperature and soils were assigned the highest values as they were considered to be the factors which had the largest influence on the quality of the water.

Model integration

AQUA(e) = (GEM + GWQM) X CONS X BCONS(m) + BCONS(a). Where, AQUA(e) = final model; CONS = constraints; BCONS = buffer zone for conservation areas.

The mathematical expressions for the secondary criteria of the agriculture model were:

Water resources submodel

PW(ag) = ( RS X 0.48 ) + ( D X 0.29 ) + ( G X 0.23 ) X CONWA; WRS(ag) = PW + WB. Where, PW (ag) = proximity to water submodel; RS = rivers and streams; LK = Lakes; D = Dams; G = groundwater; WRS(ag) = water resources submodel; WB = water balance submodel.

*ENVIRONMENT*

**RESAGM** = ( WRS(ag) X 0.18 ) + ( T X 0.12 ) + ( SS X 0.11 ) + ( TOP X 0.10 ); LAAGM = ( PO X 0.02 ) + ( URBS(e) X 0.05 ) + ( ROS (e) X 0.01 ) + ( IND X 0.06) + ( IRR(ag) X 0.16 ) + ( LI X 0.07 ) + ( FO X 0.09 ) + ( SH(e) X 0.03 ); **GAGM** = RESAGM + LAAGM

*WATER QUALITY*

**RESAGWQ** = ( WRS(ag) X 0.20 ) + ( T X 0.14 ) + ( SS X 0.13 ); **LAGWQ** = ( PO X 0.03 ) + ( URBS(e) X 0.07 ) + ( IND X 0.08 ) + ( IRR(ag) X 0.19 )+ ( FO X 0.11 ); + ( SH(e) X 0.05 ); **GAGWQM** = RESAGWQ + LAAGWQ

(the letters “ag” were added to the general models so as to indicate they are specific to agriculture (e.g. WRS(ag) = water resources submodel for agriculture)).

Model integration:

AGRI(e) = (GAGM + GAGWQM) X CONS X BCONS(m) + BCONS(a).

Since many factors are common to both aquaculture and agriculture the general environmental mathematical expression was used as the basis to develop the agriculture expression.

Development of the agriculture model in general included the reduction in the numbers of factors used in the aquaculture environmental model and obvious change of weights (i.e. the weights were obtained by using the MCE technique). The primary criteria remained the same except for the water resources submodel. Here it was found that proximity to rivers and streams as well as to lakes, dams and groundwater was most important, whereas proximity to the coastline and to the lagoons was not used (because they are saltwater sources). Similarly, the livestock rearing factor was re-classified in the sense that a very suitable livestock area would be very suitable for agriculture in terms of manure inputs. New weights were also developed for the water quality agriculture submodel and such weights were also obtained using the MCE technique.

**MACRO FILE**
**MULTI-OBJECTIVE MODELS**
**ENVIRONMENT**
**AQUACULTURE - AGRICULTURE**

AQUACULTURE

*PRIMARY CRITERIA*

*SECONDARY CRITERIA*

```
mce x 0 4 res wrs 0.19 t 0.14 ss 0.12 top 0.08
mce x 9 lause po 0.04 urbs(e) 0.06 ros(e) 0.01 ind 0.09
agr(e) 0.07 irr 0.10 li 0.02 fo 0.03 sh(e) 0.05
overlay x 1 res lause gem
mce x 0 3 reswq wrs 0.18 t 0.16 ss 0.14
mce x 0 8 lawq  po 0.05 urbs(e) 0.07 ind 0.09 agr(e) 0.08
irr 0.12  li 0.02 fo 0.03  sh(e) 0.06
overlay x 1 reswq lawq gwqm
overlay x 1 gem gwqm envwq
overlay  x  3  conwa conur waur
overlay  x  3  waur conro waurro
overlay  x  3  m(c) pc(c) mpc
overlay  x  3  mpc in(c) mpcin
overlay  x  3  mpcin sh(c) mpcinsh
overlay  x  3  waurro mpcinsh cons
overlay  x  3  cons envwq em1
overlay  x  3  bcons(m) em1 em2
overlay  x  1  bcons(a) em2 aqua
```

AGRICULTURE

*PRIMARY CRITERIA*

```
mce x 1 4 water conwa  rs 0.48 d 0.29 g 0.23
overlay x 3 awaba mwaba waba
overlay x 1 water waba wrs(ag)
```

*SECONDARY CRITERIA*

```
mce x 0 4 resagm wrs(ag) 0.18 t 0.12 ss 0.11 top 0.10
mce x 0 7 laagm po 0.02 urbs(e) 0.05 ros (e) 0.01 ind 0.06
irr 0.16 li 0.07 fo 0.09  sh(e) 0.03
overlay x 1 resagm laagm gagm
mce x 0 3 resagwq wrs(ag) 0.20 t 0.14 ss 0.13
mce x 0 6 laagwq po 0.03 urbs(e) 0.07 ind 0.08
irr 0.19 fo 0.11 sh(e) 0.05
overlay x 1 resagwq  laagwq gagwqm
overlay x 1 gagm gagwqm envwqag
overlay  x  3  conwa conur waur
overlay  x  3  waur conro waurro
overlay  x  3  m(c) pc(c) mpc
overlay  x  3  mpc in(c) mpcin
overlay  x  3  mpcin sh(c) mpcinsh
overlay  x  3  waurro mpcinsh cons
overlay  x  3  cons envwqag em1
overlay  x  3  bcons(m) em1 em2
overlay  x  1  bcons(a) em2 agri
```

*TERTIARY CRITERIA*

```
rank x aqua(e) none raqua d
rank x agri(e) none ragri d
mola x 2 aqag 0 aqua(e) 0.50 agri(e) 0.50 raqua(e) 33,422
ragri(e) 239,873
```

Note: The words primary and secondary criteria, as well as aquaculture and agriculture are just used for clarity and are not part of the macro file. The macro for the primary criteria in the agriculture model is identical to the aquaculture macro except for the water resources model as indicated above.

**Figure 5.14** illustrates the outcome of the model produced. The area targets set for each objective were clearly met - most suitable sites for agriculture were clearly identified in the northern and central parts of the state, while for aquaculture very suitable sites were mostly identified in the south and towards the mountains as a result of the incorporation of the water quality submodel. Along the coast, Angostura, Culiacán and Elota were identified as very suitable sites for aquaculture.

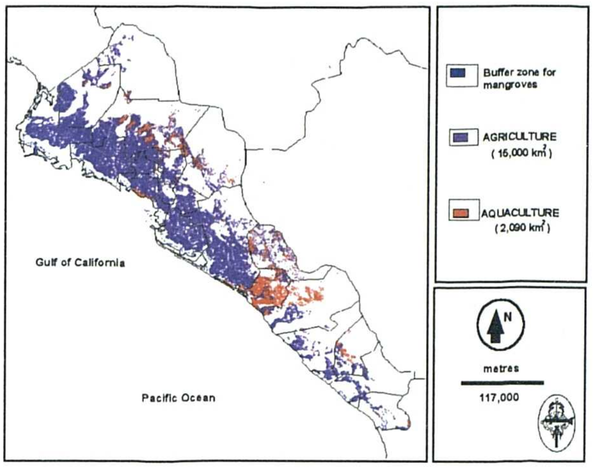


**Figure 5.14. GIS-based derived allocation of land for aquaculture and agriculture in Sinaloa.**

### 5.3.5 Integrating aquaculture with other production activities.

Major conflicts in the development of aquaculture are the conflicts that may arise in terms of the available land and water. For this study agriculture, livestock rearing and aquaculture were found to be in conflict because many areas were suitable for all three activities. Conversely, urban development and forestry presented no or minimum conflict with aquaculture. Furthermore, to prioritize the importance between these factors, weights were assigned to each activity according to its economic importance within the state, and area goals were established on the basis of the amount of land area classified as very suitable for each objective (see **Chapter 2** and **4**) **Text Box 5.1.**

**Text Box 5.1. Production activity weights and assigned areas.**

| INTERPRETATION | WEIGHT | AREA ($km^2$) |
|---|---|---|
| Complementary objectives No conflict with aquaculture in terms of land area being used. Rank order in terms of economic importance. | | |
| Urban development | 0.70 | |
| Forestry | 0.30 | |
| Sum | 1.00 | 5,000 |
| Conflicting objectives with aquaculture in terms of land area used. Rank order in terms of economic importance. | | |
| Agriculture | 0.45 | 12,000 |
| Livestock rearing | 0.35 | 9,000 |
| Aquaculture | 0.20 | 2,090 |
| Sum | 1.00 | |

The MCE technique was used for those activities which were not in conflict (complementary objectives). The GIS urban development image (socio-economic urban development submodel) and the forestry image (obtained from a primary data source) were used as input images for the MCE evaluation. Here, urban development was given priority over forestry due to the inevitable increase in population (**Text Box 5.1**).

For conflicting activities, suitability images derived from the GIS models in this study were used (i.e. aquaculture and agriculture), except for livestock rearing which suitability image was derived from the primary data source. These images were ranked using the IDRISI RANK module and were evaluated using the IDRISI MOLA module to resolve the conflicts of land allocation based on the weighted logic (**Text Box 5.1**). The area targets set for these activities were set to the amount of land area that was found to be maximally suitable for each activity (i.e. very suitable classification area) and the areal tolerance was set to zero to find an exact solution.

**Figure 5.15** illustrates the integration of the production activities into an overall hybrid model.

The model involved a series of stages:

(1) Potential areas from each production activity were treated as primary data; (2) creation of complementary and conflicting submodels; (3) a map of constraints was incorporated; (4) the multi-objective land allocation decision-making technique was used for the conflicting activities submodel based on the weights assigned for each activity; (5) addition of submodels.

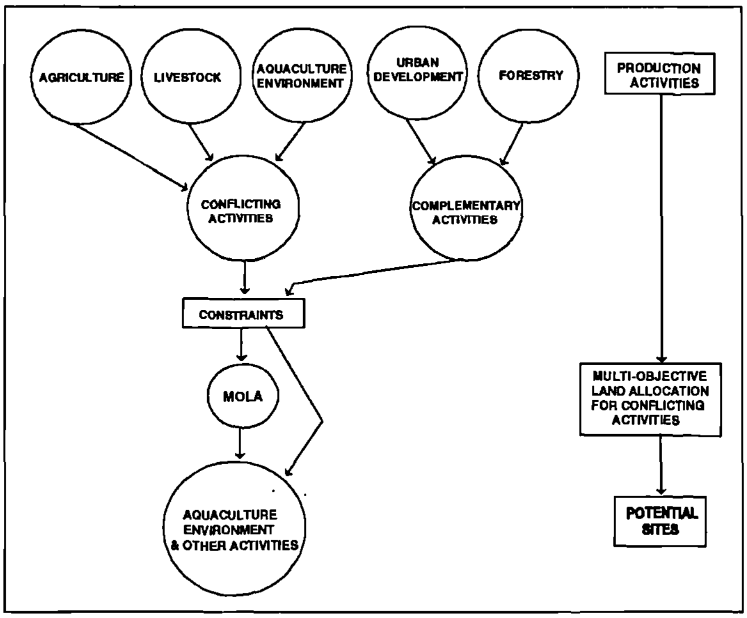


**Figure 5.15. Integration of the production activities into an overall model.**

COMACT = ( URBS(se) X 0.70 ) + ( FO(r) X 0.30) X CONS. Where, COMACT = complementary activities; URBS = urban development submodel image derived from the general aquaculture socio-economic model and FO(r) = forestry primary criteria (forestry classification was reversed to indicate maximum suitability of activity, indicated by an "(r)" symbol); CONS = constraints used to mask out conservation areas.

CONACT = (( AGRI(se) X 0.45 ) + ( LI X 0.35 ) + ( GEM(e) X 0.20 )) X CONS. Where, CONACT = conflicting activities; AGRI = agriculture image based on classification from data source; LI = livestock rearing image based on classification from data source; GEM = aquaculture general environmental model image; CONS = constraints used to mask out conservation areas.

Model integration between activities = ( COMACT+CONACT ) X CONS X BCONS(m) + BCONS(a). Note: CONS = constraints used to mask out conservation areas; BCONS = buffer zone for conservation areas.

```
                         MACRO FILE
                   MULTI-OBJECTIVE MODELS
            AQUACULTURE & OTHER ACTIVITIES
TERTIARY CRITERIA
mce x 1 2 com cons urbs(se) 0.70 fo(r) 0.30
rank x com none com2 d
reclass x i com2 comact 2 4 1 79,959 0 79,959 999999999
overlay x cons agri(e) cagri
overlay x cons li cli
overlay x cons gem caqua
rank x cagri none ragri d
rank x cli none rli d
rank x caqua none raqua d
mola x 3 conact cons 0 cagri 0.45 cli 0.35 caqua 0.20 ragri 191,899 rli 143,924 raqua  33,422
overlay x 1 comact conact comconc
overlay  x  3  cons comconc em1
overlay  x  3  bcons(m) em1 em2
overlay  x  1  bcons(a) em2 finaqua

       Note: Although not presented in this macro file, the constraints used
          are exactly the same as the ones used throughout  this study.
```

**Figure 5.16** illustrates the integration of aquaculture with other production activities. Complementary activities for urban development were mainly located in Culiacán and in terms of forestry, the mountain region in the south in Cosalá, San Ignacio and Mazatlán was most suitable. Best sites for agriculture were found primarily in the central region of the state, whilst for livestock rearing the northern part of the state was most suitable. Aquaculture sites in proximity to the coast were found in Angostura, Culiacán and Elota, whilst potential sites away from the coast were found in Sinaloa and Cosalá.

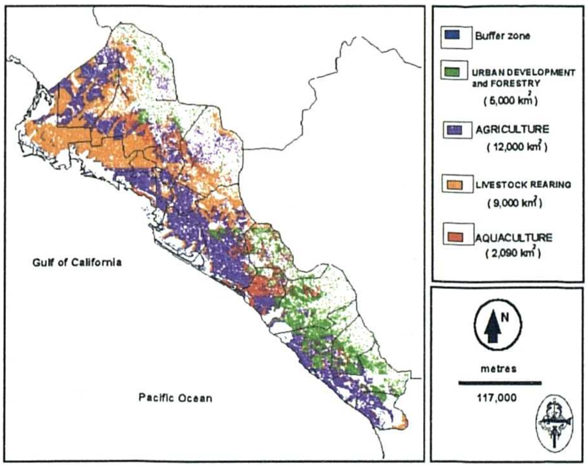


**Figure 5.16. GIS-derived allocation of land to aquaculture and other production activities in Sinaloa (using an environmental aquaculture suitability image).** Note: The aquaculture submodel could be developed by treating it in three ways: as either a purely environmental model (in this study), as a socio-economic model or as a combination of both by means of producing a cross-classification image.

A further version of the model was developed, taking into account shrimp culture based on intensity of farming (**Figure 5.17**).

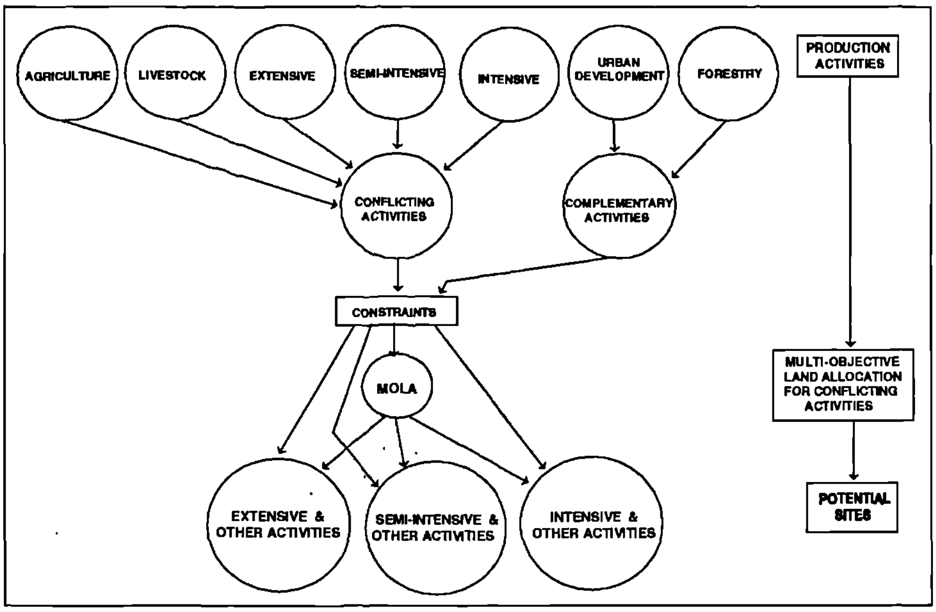
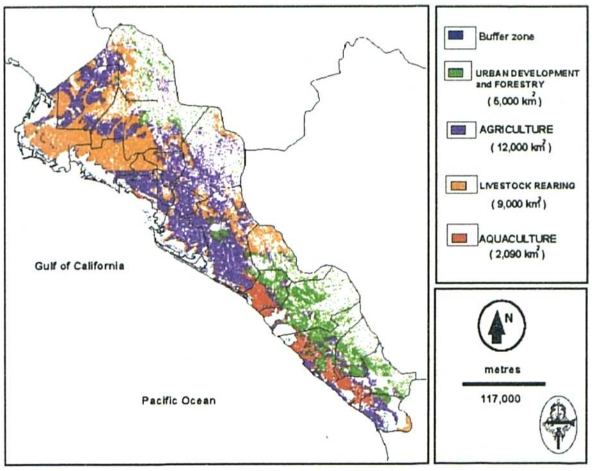
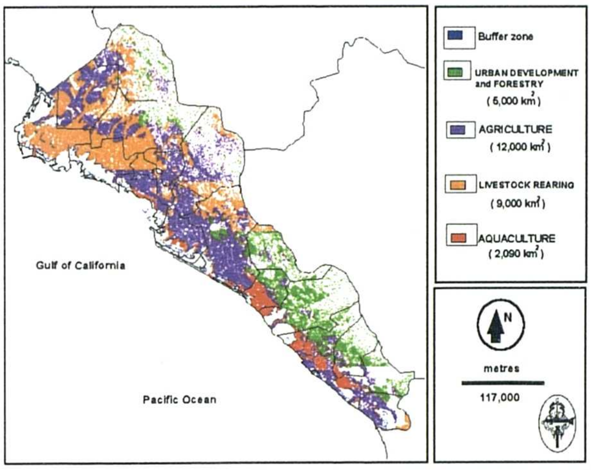


**Figure 5.17. Integration of activities into an overall model.**

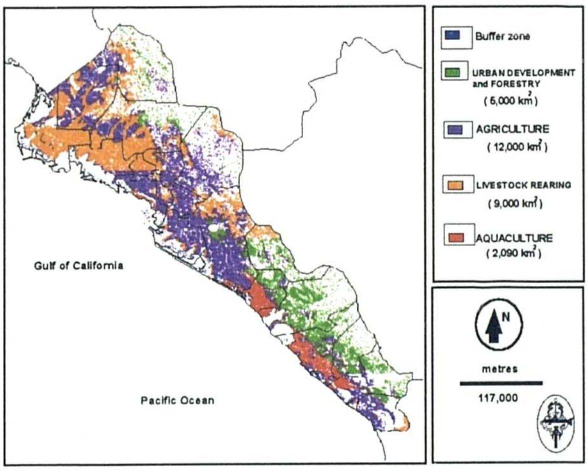
**Figure 5.18** shows the GIS-derived allocation of land to aquaculture (according to intensity of culture) and other production activities in Sinaloa. Similar sites were found for agriculture and livestock rearing between the three types of culture systems and the general environmental model. Interestingly, despite the clear differences between the three culture model predictions, when these predictions were evaluated using the MOLA technique using the same area goals for each activity (agriculture, livestock, aquaculture) it was found that, in general, they all gave similar results. The three models identified potential aquaculture sites in the central region in Angostura, a few potential sites were identified in the northern region in Guasave, and towards the south many sites were identified in the municipality of Elota.



1. Using extensive shrimp culture as the aquaculture input image.



2. Using semi-intensive shrimp culture as the aquaculture input image.



3. Using intensive shrimp culture as the aquaculture input image.

Figure 5.18. GIS-derived allocation of land to aquaculture according to intensity of culture and other production activities in Sinaloa.

## 5.4 SUMMARY AND DISCUSSION

### *Summary*

GIS was used as a decision-making tool for aquaculture development in Sinaloa State, Mexico. A multi-criteria evaluation (MCE) decision-making technique was used to assess the relationship between site factors involved in the GIS evaluation by using weights. It was found that the use of weights derived from a MCE pairwise comparison matrix using the MCE module in IDRISI (Eastman, 1993) was very useful for spatial manipulation. However, the choice of weights was found to be difficult, time-consuming and became less accurate as the number of factors in the matrix increased. An alternative solution to this problem was proposed by assigning scores in a rank order (i.e. 1 to 13 without repetition) to the factors involved in the matrix evaluation, and therefore the choice of weights was entirely based on the choice of scores initially established.

Even when the choice of weights was greatly improved by the use of these scores, and was based on soundly published principles, the weights were still considered to be semi-subjective. This is because the final weight selection was initially entirely dependent upon the weight assigned by the author. Results based on the author's weighting were greatly strengthened by comparing them with the results of the questionnaire responses from a group of experts. Using a Kendall coefficient of concordance ranking test it was possible to examine rank order of the factors chosen between all decision-makers. The overall results from this test demonstrated that the rank position of the scores, and therefore the weights established by the author, were in close agreement with the other decision-makers.

Once the factors and constraints scores, and the factor weights, had been established, models were created by integrating this data into submodels which developed in a series of stages or hierarchies to create an overall model. Thus, the foundation of the GIS-based models in this study relied upon a large number of decisions.

A general GIS-based model was constructed for environmental and socio-economic factors based on the general site factors. Based on this general model, shrimp culture models were developed by intensity of culture. To assess final aquaculture developments, the interactions with other production activities competing for resources were considered using the Multi-Objective Land Allocation (MOLA) decision-making technique developed by Eastman (1993). These models were also based on weights derived by establishing the relative strength or priority of each activity with respect to aquaculture development. These models identified wider management options and helped resolve conflicts of land allocation and land use between activities.

### *Discussion*

It was found that the smaller the number of factors involved in a MCE pairwise comparison matrix, the more consistent results were obtained. Moreover, as the number of factors involved in a pairwise comparison matrix increased, the perturbations (i.e. adding or omitting a factor) in the matrix became less significant because the values of all weights decreased. Conversely, when dealing with a small number of factors, any perturbation in the matrix was very large, and the value of the weights remained large. In this study 13 factors were used. This proved to be adequate because it enabled the evaluation of all possible interactions between factors, and therefore provided an overall picture of the objective in question (i.e. environmental or socio-economic). However, results from the matrices could be enhanced if the number of factors involved in the matrix was smaller. A maximum range of approximately 9 to 10 factors was found in this study to be most adequate. Miller (1956) found that any scale used should be able to represent people's differences in judgements when comparisons are made. It should represent, as much as possible, all distinct shades of judgement that people have. He advised that a suitable scale range should be from 1 to 9. Moreover, consistency was a necessary but not a sufficient condition for judging how good a set of factors were. For example, the consistency may be good, but the correspondence of the judgements to reality may be poor.

Although the general model approach proved to have many advantages in terms of model adjustments and development, it was found that it was difficult to assign weights objectively unless the type of culture system was known. This was especially the case with the socio-economic evaluation. A low coincidence between the rank order of the Rj mean and the rank order of the scores found by the author in the socio-economic general evaluation were attributed to the fact that, in a socio-economic evaluation, the scores between the culture systems were more pronounced. For example, job creation, energy, and agglomeration had very different scores. By contrast, in the environmental evaluation most of the scores were closer to each other (except for the distance from shrimp farms).

Although decision-makers generally agreed in choosing the appropriate weights, further field studies need to be carried out to further reduce the subjectivity of weights. Despite this, greatest benefit from the MCE in this study was gained by the feedback obtained from the decision-makers through their comments and during some of the interviews. It is probable that, in future studies, greatest benefit from this technique could be achieved if the decision-makers could be brought together and the results could be discussed as a group so as to make final weight adjustments. Additionally, it was noted that the MCE technique could be greatly enriched by developing the questionnaires prior to the group discussion, thus enabling the subjects to be more familiar with the technique.

Although the various explanatory models presented in this study were different from each other, they were all developed on the basis of integrating data into submodels (i.e. by similarity or proximity with respect to a function) or natural groupings rather than treating all the data together. This general approach of establishing submodels within an overall model proved to be a meaningful way to integrate data and to accomplish specific tasks. General information occurred in the first stages of the model, whilst greater depth in understanding its purpose occurred lower down the stages of the model. Moreover, the models are flexible and perturbation does not disturb the entire model. The overall purpose of the model is divided into levels whereby each solves a partial problem and the totality meets the overall purpose. The initial stages are not concerned with the overall purpose, but are selected to meet with the specific goals of that system. The models should be interpreted not in terms of the overall goal, but in terms of specific goals at each level, for which reason the stages differed both in structure and function. The proper functioning of the lower levels depended on the proper functioning of the higher levels (or primary stages). Hence, the understanding of the final stages was based upon the understanding and selection of relevant data at the initial stages.

Many factors were particularly difficult to allocate to a single submodel. For example a transportation factor is important in both a production and a market submodel. Because of the structure of the models created in this study, primary data could be easily incorporated into any number of submodels. Additionally, constructing a model by establishing submodels minimized the use of large MCE pairwise comparison matrices and therefore it arguably allowed a more accurate evaluation. Submodels enabled greater capacity to understand and to manipulate data - they provided great flexibility because data could be modified, updated, adjusted and/or excluded without having to re-assemble the entire model. Moreover, the task of managing large and complex data sets was considerably simplified when it was broken into submodels which were individually easier to understand.

No single result was produced from the creation of these models. Models should be thought of as being dynamic in the sense that they can be modified to solve many queries. Some possible questions for aquaculture development were solved and presented in this study, but the scope for further evaluation is unlimited. However, this could be considered to be a disadvantage to the user and therefore, it is crucial to determine the appropriate "what if?" type of question in order to benefit in full from the use of GIS. It is therefore very important that the decision-makers become GIS-aware so that they can understand the output derived from these models in order to formulate their own questions.

The construction of the environmental models was enhanced by the fact that most of the information was not in a choropleth form and, therefore, it was possible to evaluate the effects of factors with greater detail (i.e. from the exact location of the shrimp farms it was possible to create proximity or distance ranges). Conversely, the socio-economic model proved to be somewhat simplistic because many of the factors involved in the evaluation were in choropleth form. Similarly, the environmental model dealt with negative factors and the socio-economic model did not, so the environmental model in this study was found to be more complex, mainly due to the availability and nature of the data. Moreover, during the assessment and selection of data collected at the initial stages of the model development it was noted that a number of socio-economic factors were simplistic, and were difficult to spatially represent in comparison to the environmental factors (e.g. support centres socio-economic factor). Despite this, a solution was found by treating these types of data as enhancement factors. These types of data were treated as primary criteria in the model flowcharts, and as constant factors in the mathematical expression.

The MOLA technique proved to be useful for discussion of the identified objectives and their relative strengths and weaknesses. The model also enabled isolation of the problems of deciding between competing objectives by allocating the areas that were least damaging and most profitable, and thus proved to be very useful.

Questionnaires were used to verify the selection of weights. Moreover, to verify the final outcome of the GIS model predictions, partial verification was achieved by comparing the results of the GIS models in two ways:

1. The first approach was to compare the GIS-predicted aquaculture sites found in this study, with the predicted aquaculture sites found from the combined work of two Mexican consulting companies using manual techniques ((Cosmocolor (1991); (EPAC (1991)) (see end of **Chapter 1**). To understand the outcome of such a comparison a summary description of this GIS study and of the manual study is presented in **Table 5.18**. Clearly when comparing these two tables, GIS show far more potential in all aspects of assessment.

## Table 5.18. Summary of comparison between this GIS study and the Manual study for assessing aquaculture development in Sinaloa.

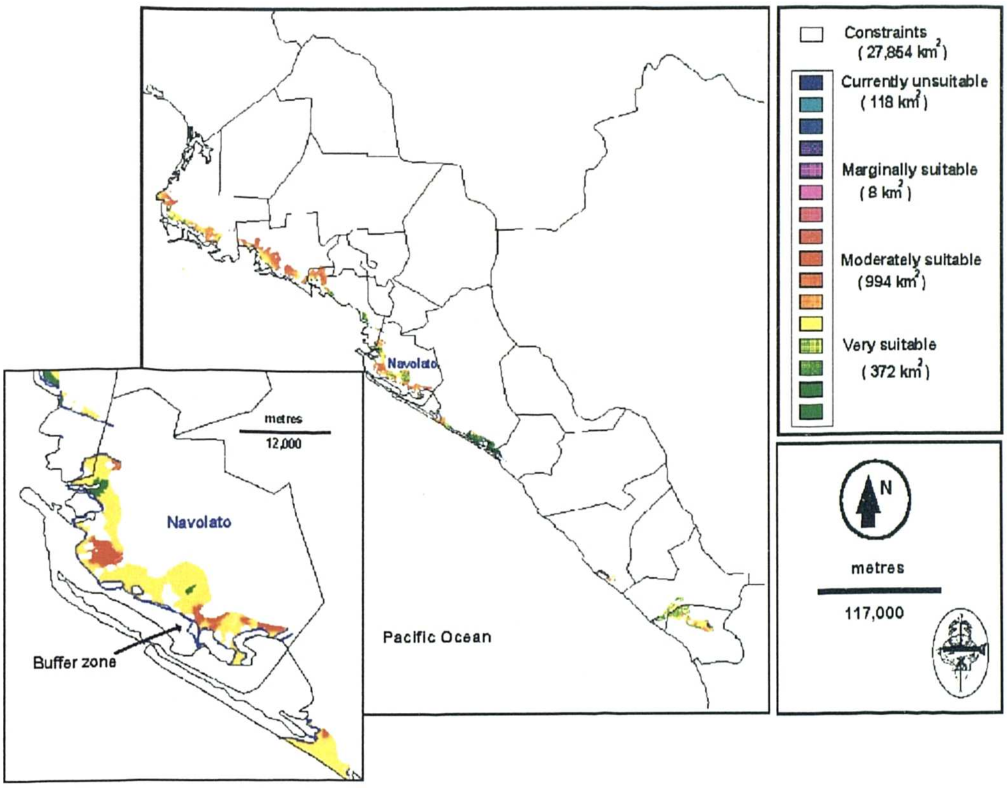
| CRITERION | GIS | MANUAL |
|---|---|---|
| **MAP CREATION**<br>Map making technology | Digitizing, computer based cartographic package. Not constrained to specific guidelines for research development. 1/ | Hand drawn on paper. A standard methodology was developed by the environmental Secretariat (SEDUE), guidelines must be followed in carrying out assessment. /4 /10 |
| Level of map accuracy | Although it is still hand drawn, there is a much higher level of accuracy by using georeferences and on screen editing which minimize inaccuracies. /4 | Low, dependant on drawing skills, maps were drawn by various people and companies. Some level of inaccuracy was reported. |
| Size and scale of study area | Entire state as well as neighbouring states and part of the Gulf of California. Source layers can be seen using "zoom" Furthermore, it is capable of transforming data into a variety of scales, "No need to re-digitize" allowing user to analyse and manipulate areas of interest at different scales. /1 /2 /4 | Most of the state of Sinaloa except the mountain regions in the north-east. Limited to a single scale. Difficult to carry out visual analysis, due to the size and quantities of paper maps produced to cover the study area. Constrained to a single scale, not able to use other scales, unless created separately. |
| Editing | Time consuming but, good editing capabilities and only limited by computer storage capacity. /4 | Very time consuming, limited to physical space on the paper map as well as quantify of data. |
| **DATA**<br>Data source | Paper maps from INEGI at *various scales, information* available in computer media from INEGI, statistical data and literature. /1 | Paper maps from INEGI, field data collection, satellite colour photographs (not digital) and statistical references from various sources. |
| Data storage | Very high. Limited by the specific computer storage capacity, however, use of a 2Gb parallel stream DAT backup increased data storage tremendously. /1 /3 | Low, limited to size of paper maps. |
| Spatial analysis | Very high, variety of analytical methods were applied (i.e. MCE, MOLA, overlay, scalar, distance, and area calculations). /1 /5 | Very low, limited by simple hand drawn overlays. Overlays limited to "cover" other *land* use areas, no mathematical manipulation (i.e. addition, subtraction, division and multiplication,). /4 /10 |
| Data output | Cartographic and numerical. Variety of output forms such as in computer media (i.e. floppy disks), paper of any size ( only dependent on printer used) and slides. Variety of calculations are provided (areas, histograms, regressions, crosstabulations and multiple overlays), most of which are compatible with many different computer software. Colour outputs easy to asses. Entire study area is contained in a single image. /1 /2 /3 /4 | Mainly cartographic, few simple area estimates, minor calculation, estimates, predictions. Variations due to paper shrinking when making copies from original paper from which is was drawn Black and white outputs very difficult to assess because study area is comprised of three large paper maps (i.e. three maps for a single factor or layer), moreover, each of these maps is 133 X 81 cm in size. /4 /10 |
| Results and verification | High flexibility in spatial manipulation with very little effort once database was created. An unlimited number of queries can be solved. Not based on a single GIS model output. GIS predicted locations were compared with the results from the manual survey and the existing shrimp farm locations. /1 | Very low flexibility of results limited to a final output unless most of the spatial process is re-done manually again. Very time consuming.<br>No verification of study results to date. |
| **METHODOLOGY**<br>Method of assessing data | Decision-making of scores and weights were determined by author and most of the results were verified by a group of experts through questionnaires and interviews. *Assessment of factor and* constraints by assigning scores. Selection of factor weights by multi-criteria evaluations (MCE) through pairwise comparison matrices. Multi-objective land allocation (MOLA) decision-making weighting technique was used for solving conflicts of land allocation and land use between production activities. Model creation based on scores and weights of MCE and MOLA . /1 2/ /3 /5 | Decision-making by direct group participation.<br>A Diagnosis phase was proposed comprised of a weighting/scaling technique to assess suitability of land, which in turn was a modification of the suitability analysis proposed by Betters and Rubin (1978). Modification consisted in the use of divisive polythetic techniques and a principal components biplot ordination to determine where overlapping land uses were likely to occur. Qualitative simulation models by means of the KSIM language were used to discriminate the important variables and processes under examination. /1 /2 /3 /5 /6 /7 /8 /9 |
| Ecological regions | Study area was NOT divided into land systems. No baseline information. Study area was considered as a whole. /1 | The procedure follows SEDUE (1990) in which the study area was divided into land systems (associations that are grouped for practical purposes) *Baseline* information for regions includes topography, geology and soils. /10 |
| Factors classification | Priorities and interests were classified for each factor. /1 | Priorities and interests were classified for each area, then the experts ranked the environmental criteria for each land use . /2 |
| Number of persons involved. | One | Twenty eight |
| Types of personnel | PhD student | Interdisciplinary team of local and non-local experts. |
| Time involved | First results were completed within 1 year. Entire study completed in three years ( included state-level and site-level assessment for Huizache-Caimanero ) | 6 months for final output ( only a state-level assessment.). |
| **FACTORS**<br>Number of factors | 60 Environmental and socio-economic factors. | 15 Environmental and socio-economic factors |

**GIS SOURCE:** 1/ Aguilar-Manjarrez and Ross (1994, 1995a, b); 2/ Eastman (1992, 1993); 3/ Eastman *et al.* (1993); 4/ Jones (1992,1993,1995); 5/ Saaty (1977).

**MANUAL SOURCE:** 1/ Betters and Rubin (1978); 2/ Bojorquez-Tapia (1989, 1993); 3/ Bojorquez-Tapia and Ongay-Delhumeau (1992, In press); 4/Cendrero (1982); 5/ Digby and Kempton (1987); 6/ Kane (1972); 7/ Kane *et al.*(1973); 8/ Kessler (1992); 9/ Steiner (1983);10 / SEDUE (1989).

To make spatial comparisons between the two techniques, the semi-intensive GIS model image (**Figure 5.6**) was used, because both studies gave particular attention to this type of existing culture system in Sinaloa. In comparison to the earlier study carried out by Aguilar-Manjarrez and Ross (1995a, b), rather than simplifying the land suitability GIS predictions into a 1 - 4 score range for comparison, it was decided to evaluate the GIS land suitability predictions based on the final 1 to 16 score range (**Figure 5.6**) within the area predicted by the manual technique.

Within the proposed areas identified by the manual technique (**Figure 5.19**) the GIS found 372 km$^2$ (18%) of land classified as very suitable, highest score (15) was found in Culiacán. Moderately suitable sites were found in 994 km$^2$ (48%) of the area and were distributed amongst all manual sites and only 0.4 % of the land was classified as marginal. Additionally, there were 598 km$^2$ (29%) of land classified as a constraint (value of zero) and 118 km$^2$ (5%) classified as a constraint buffer zone (value of one) adjacent to the ocean and/or mangrove areas (i.e. 250 m buffer).

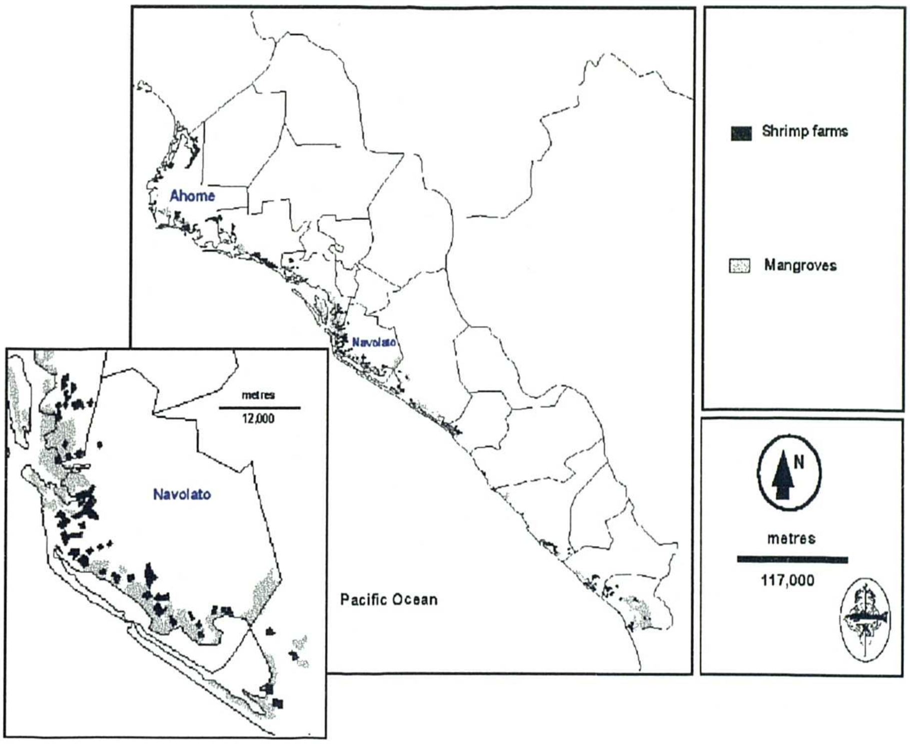


**B. A zoomed section in Navolato shows the comparison.**

**A. State-level comparison.**

**Figure 5.19. Comparative results between the predictions found by the manual techniques and the GIS predictions.**

2. Due to the important role that mangroves play in this study, the location of the existing mangroves was assessed in relation to both the existing shrimp farms and the predicted aquaculture sites (**Figure 5.20**). Moreover, because existing shrimp farm locations were likely to occur in suitable areas, the second approach was to compare the GIS-predicted locations that have shrimp farming potential with the actual locations of the existing shrimp farms. Additionally, because the GIS-predictions were based upon the integration of optimum factors for either an environmental or socio-economic objective, any shrimp farming activity in proximity of those areas was considered to be in a suitable location. As suggested by Kapetsky (1994), GIS predictions were analyzed in areas where aquaculture is practised, but where farming potential had not been forecasted for threshold re-evaluation. Hence, it was also considered very important to evaluate the existing shrimp farm locations in those sites found to be less optimum or unsuitable by the GIS. **Figure 5.20 A** shows that most shrimp farms in Sinaloa have been constructed in proximity to mangrove areas but, more importantly, some shrimp farms have been constructed within some mangrove areas; such farms are located in the central and northern regions. **Figure 5.20 B** shows an expanded area in Navolato revealing those farms which are located well within mangrove areas. The only location in which there is a large concentration of farms and no mangroves was identified in Ahome, in close proximity to the state of Sonora.

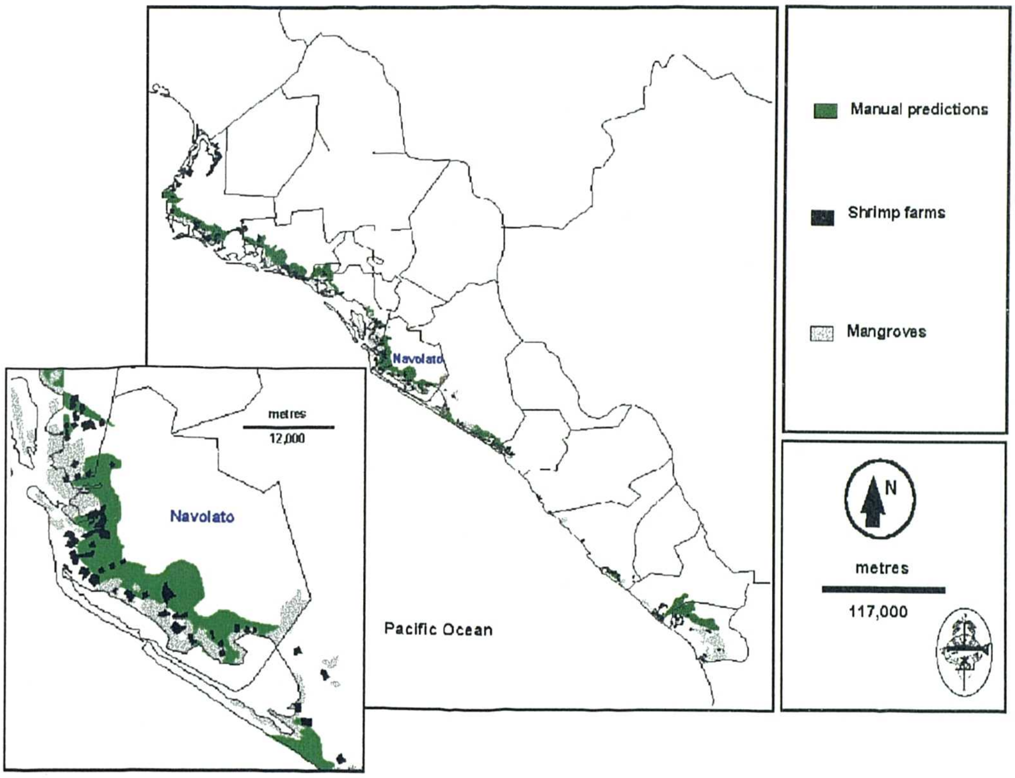


**B. A zoomed section in Navolato shows the comparison.**

**A. State-level comparison.**

**Figure 5.20. Comparison between the existing location of shrimp farms and the mangroves areas.**

**Figure 5.21 A** shows that there is a very strong coincidence between the general location of the existing shrimp farms, mangrove areas and the aquaculture sites proposed by the manual technique in the northern and central regions of the state. Highest coincidence was found in Navolato. **Figure 5.21 B** shows an expanded area in Navolato revealing this comparison. By contrast, few sites coincided in the southern region of the state: there are no sites proposed in San Ignacio where there are two farms and no mangroves, and only a small area is proposed in Mazatlán where there are 11 farms and no mangroves. Further south, a large area is proposed within the municipalities of Rosario and Escuinapa, but only 1 out of 25 farms lies within the proposed area. Even though proposed sites are in proximity to mangroves, only about 1% of the total areas proposed was identified to be inside a mangrove area.

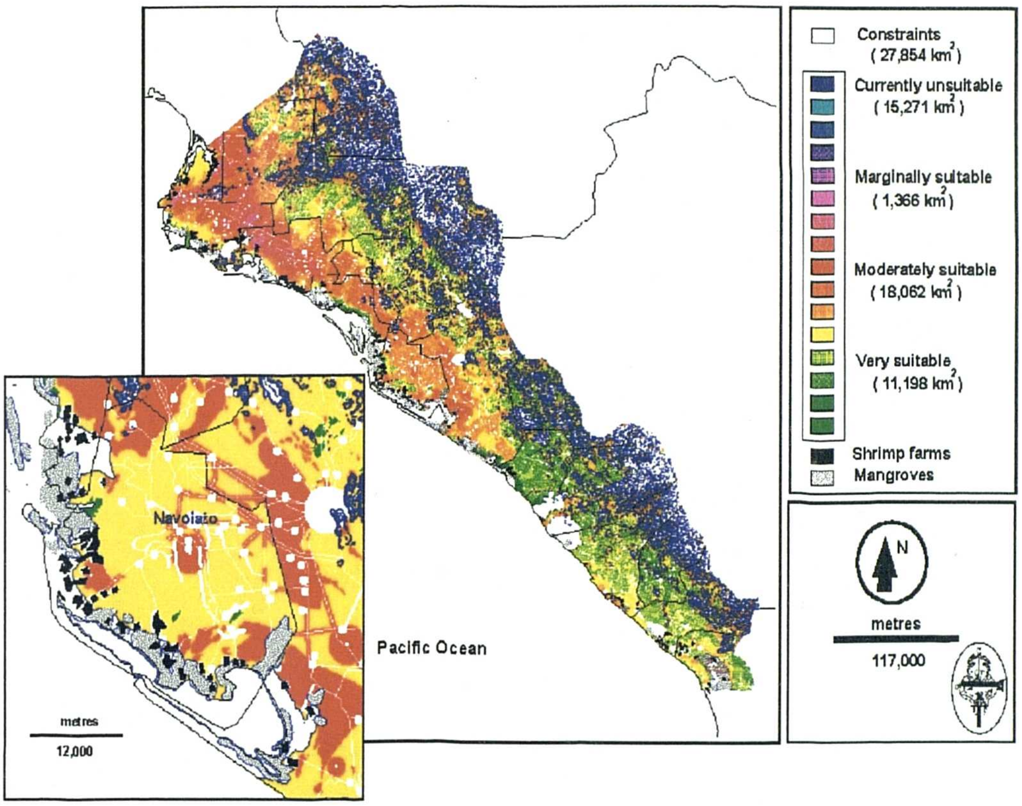


**B. A zoomed section in Navolato shows the comparison.**

**A. State-level comparison.**

**Figure 5.21. Comparative results between the existing location of shrimp farms, mangroves and the predictions found by the manual technique.**

In general, results from the GIS environmental models also coincide to some degree with the location of the existing shrimp farms along the entire state coastline. As was expected, the highest coincidence between the existing shrimp farm location and the GIS predictions was found by the semi-intensive model (**Figure 5.22 A**). However, in comparison to the manual study, there were fewer sites identified in the northern region (e.g. Guasave) and more sites in the south. **Figure 5.22 B** shows an expanded area in Navolato revealing this comparison. In strong agreement with the manual technique, and as a result of the constraints applied by the GIS models, many potential sites are in the vicinity of a mangrove area but none of them lie within that area. All of the existing shrimp farms were located within or in the vicinity of an area predicted by the GIS (except those shrimp farms located inside mangrove areas).



**B. A zoomed section in Navolato shows the comparison.**

**A. State-level comparison.**

**Figure 5.22. Comparative results between the existing location of shrimp farms, mangroves and the predictions found by this GIS study.**

From the above analysis, it can be concluded that there is potential for aquaculture development in many parts of the state of Sinaloa. Major exceptions are those areas reserved for conservation, as well as the areas of high slopes in the mountains. Nonetheless, even in these unsuitable areas there could still be sites available.

The results of the socio-economic models identified the central and northern region as the most suitable, and similar conclusions were obtained by comparing the results of the semi-intensive environmental model image with the manual technique and with the location of existing shrimp farms. However, future expansion in these areas must be carefully evaluated due to the vast number of shrimp farms already existing, as well as urban development and intensive agriculture, and this was shown by the lower scores found by the GIS environmental models in the central and northern regions of the state above these very suitable sites. Moreover, the environmental models strongly agreed that in general (i.e. away from the coast) Sinaloa's southern region is the most environmentally suitable for further aquaculture development. However, it is vital that the Mexican government becomes fully aware of the benefits and impacts of current aquaculture before further aquaculture development takes place. For instance, it was revealed in this study that some shrimp farms are located within mangrove areas, so it is important to stop this type of development. Furthermore, it is important to prevent a vast and uncontrolled shrimp farm expansion. In India, an uncontrolled shrimp farm expansion (1,000 $km^2$ of land) has caused the government to prohibit further shrimp pond construction in the states of Tamil Nadu, Andhra Pradesh and Pondicherry. Problems derived from this regulation have general applicability, and have been mainly attributed to: (a) mangrove destruction; (b) salinization of land (e.g. agriculture) and water; (c) water pollution and use; (d) availability of postlarvae; and (e) activity conflicts created by use of vast areas of land (Khor, 1995; Shiva, 1995).

# CHAPTER 6

# AQUACULTURE DEVELOPMENT IN THE HUIZACHE-CAIMANERO LAGOON SYSTEM: COMPILING THE DATABASE.

## 6.1 Background and justification

### *Background*

Lagoon systems in Mexico are commonly semi-closed water bodies which, in the majority of cases, maintain communication with the sea. Usually, coastal lagoons are surrounded by mangroves which provide ideal nursery and growth grounds for penaeid shrimp, and support important seasonal fisheries (Edwards and Bowers, 1974; Edwards, 1978a). Capture fisheries from these areas provide approximately 80% of capture fisheries in Mexico, and most aquaculture such as shrimp culture is being developed in the vicinity of these areas (Díaz-Rubín *et al.*, 1992).

The Huizache-Caimanero lagoon system of north-west Mexico has great social and economic importance because it supports a large commercial fishery. Moreover, because the lagoon system is shallow, and is of the enclosed type with narrow exits to the ocean, it has had siltation problems which have decreased fish capture. Consequently, the lagoon system has been the subject of much research and many papers have been published in the last 29 years (**Appendix 4**). Interestingly, all studies have been based on environmental issues and only 4 authors (CONSULTEC, 1990; De la Lanza and García-Calderón, 1991; Díaz-Rubín *et al.,* 1992; Acuipesca Consultores, 1993) have included a very brief socio-economic evaluation (e.g. population density, cooperatives), despite the social and economic importance of this lagoon system in the region.

Aquaculture potential in the lagoon system was first described in 1970 by Cabrera. In more recent studies CONSULTEC (1990) developed a detailed study for the construction of a large shrimp farm (5 km$^2$ ) inside the Caimanero lagoon. The emphasis of this study was on the engineering aspects of the construction of shrimp ponds. Cosmocolor (1991) assessed aquaculture potential at a state-level (see previous chapters), and most recently, Flores-Verdugo (In press) provides a site-level environmental assessment of the lagoon system by proposing potential areas for aquaculture on the basis of minimizing and/or avoiding any damage to the environment. To date however, the only GIS study covering this area was carried out at a state-level by Aguilar-Manjarrez and Ross (1995a, b), although these authors did not specifically describe potential sites for aquaculture in the Huizache-Caimanero lagoon.

Shrimp culture was first started in Mexico in 1970 at an experimental level in the Huizache lagoon. Since then many shrimp farms have been constructed (De la Lanza *et al.,* 1993). Culture methods in this lagoon system are extensive and semi-intensive (CONSULTEC, 1990) and are based on *Penaeus vannamei.* This is the most appropriate species for culture because there is an abundance of this species in the region, as well as in the Huizache-Caimanero lagoon system (*Penaeus vannamei* represents 90 % of the shrimp capture in the Huizache-Caimanero lagoon system (Chapa and Soto-Lopez, 1969); large quantities of postlarvae are available in the natural environment, as well as from hatcheries (Díaz-Rubín *et al.*, 1992). *P. vannamei* is also best adapted to the environmental conditions ( Lee and Wickins, 1992). Moreover, under cultivation, this species grows quickly to a large size (Edwards, 1978a); there is information and experience available for culture (CONSULTEC, 1990), and it is a commercially important species (Tseng, 1988).

**Figure 6.1** shows that annual shrimp farm production has had only a few increases from 1989 to 1991 and 1993. However, there has been a considerable increase in production for 1994.

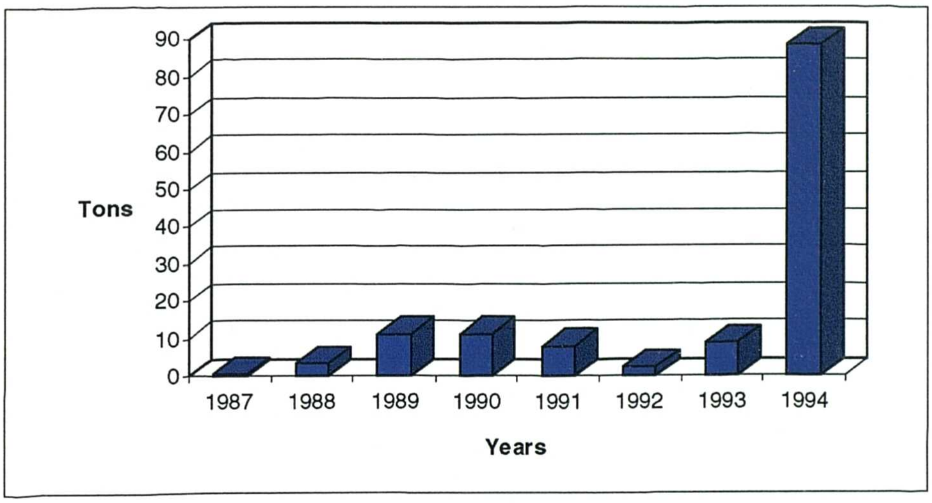


**Figure 6.1 Shrimp culture production from the Huizache-Caimanero lagoon system (1987-1994).** Source: Secretaría de Pesca (1995b).

Despite an increase in production in recent years, not all of the shrimp farms continue to operate due to the instability of the environmental factors in the lagoon, such as lack of water during the dry season (De la Lanza *et al.,* 1993). The fishing effort has also increased creating serious conflicts between the lagoon users, particularly between shrimp farmers and subsistence fishermen (Díaz-Rubín *et al.*, 1992). Moreover, because some shrimp farms have already been abandoned, it is evident that expansion should not be carried out without a proper assessment of the current position. The use of GIS could prove beneficial by integrating much of which is already available (**Appendix 4**) for present and future planning and development.

### *Justification of study*

The GIS assessment at the state-level showed potential sites for shrimp and fish farming development, which would be worthy of more detailed evaluation. The Huizache-Caimanero lagoon area was selected from the state-level assessment for more detailed studies of environmental and socio-economic issues.

Because of the quantity of data available, and the proximity of the lagoon system to technical support and research facilities in Mazatlán, this area of Sinaloa was particularly suitable for GIS analysis. Appropriate data were compiled and assessed and GIS-based models were created to estimate the area of land which is suitable for semi-intensive shrimp farming adjacent to the Huizache-Caimanero lagoon system.

To determine the suitability of locations for aquaculture development, it was necessary to establish which of the factors and constraints found in the Huizache-Caimanero lagoon system are required, and so extensive review of this information was conducted. Most importantly, it was necessary to investigate which data were available, and a substantial data location and collection exercise was conducted in Mexico City and in Mazatlán.

## 6.2 The Huizache-Caimanero database

### *Geographical location and description*

The Huizache-Caimanero lagoons lie in southern Sinaloa, 25-60 km south-east of Mazatlán (**Figure 6.2**).

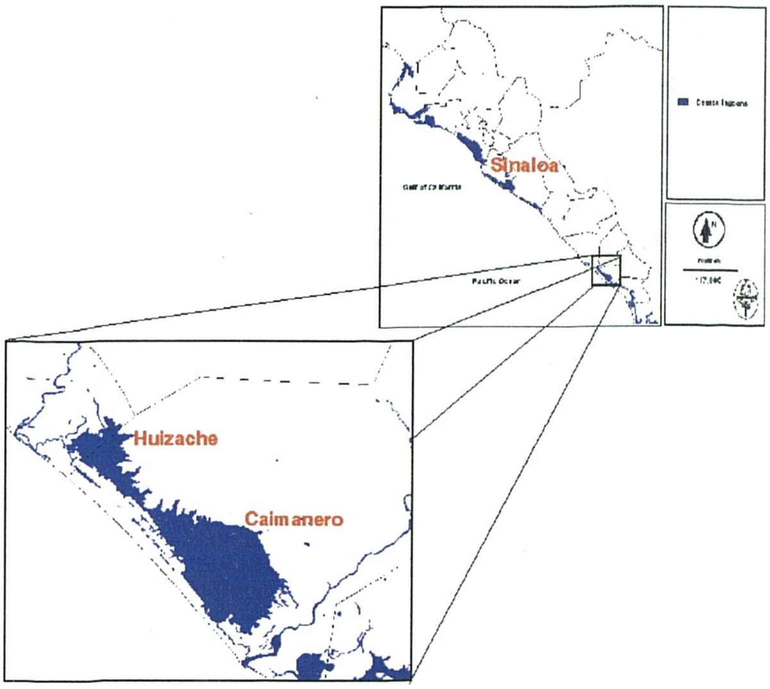


**Figure 6.2. Location of the Huizache-Caimanero lagoon system in Sinaloa, Mexico.**

The study area of interest for this thesis is shown in **Figure 6.2**, and comprises the zone between 22° 48' - 23° 11' N and 105° 50' - 106° 18' W ensuring coverage of the Huizache-Caimanero lagoons as well as areas of neighbouring municipalities (Mazatlán, Concordia, Escuinapa) and the Pacific Ocean.

The lagoon system is approximately 32 km long and 10 km wide at its widest point (Menz, 1976). It is a double lagoon which occupies the area between rivers Presidio to the north and Baluarte to the south, and is connected to them by the esteros[6.1] (**Figure 6.3**). Both esteros are approximately 10 km long, 30 m wide and rarely deeper than 1.5 m (Mair, 1979a).

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[6.1] The "esteros" are not real estuaries, they are long tortuous narrow waterways or canals (Blake *et al.*, 1981).

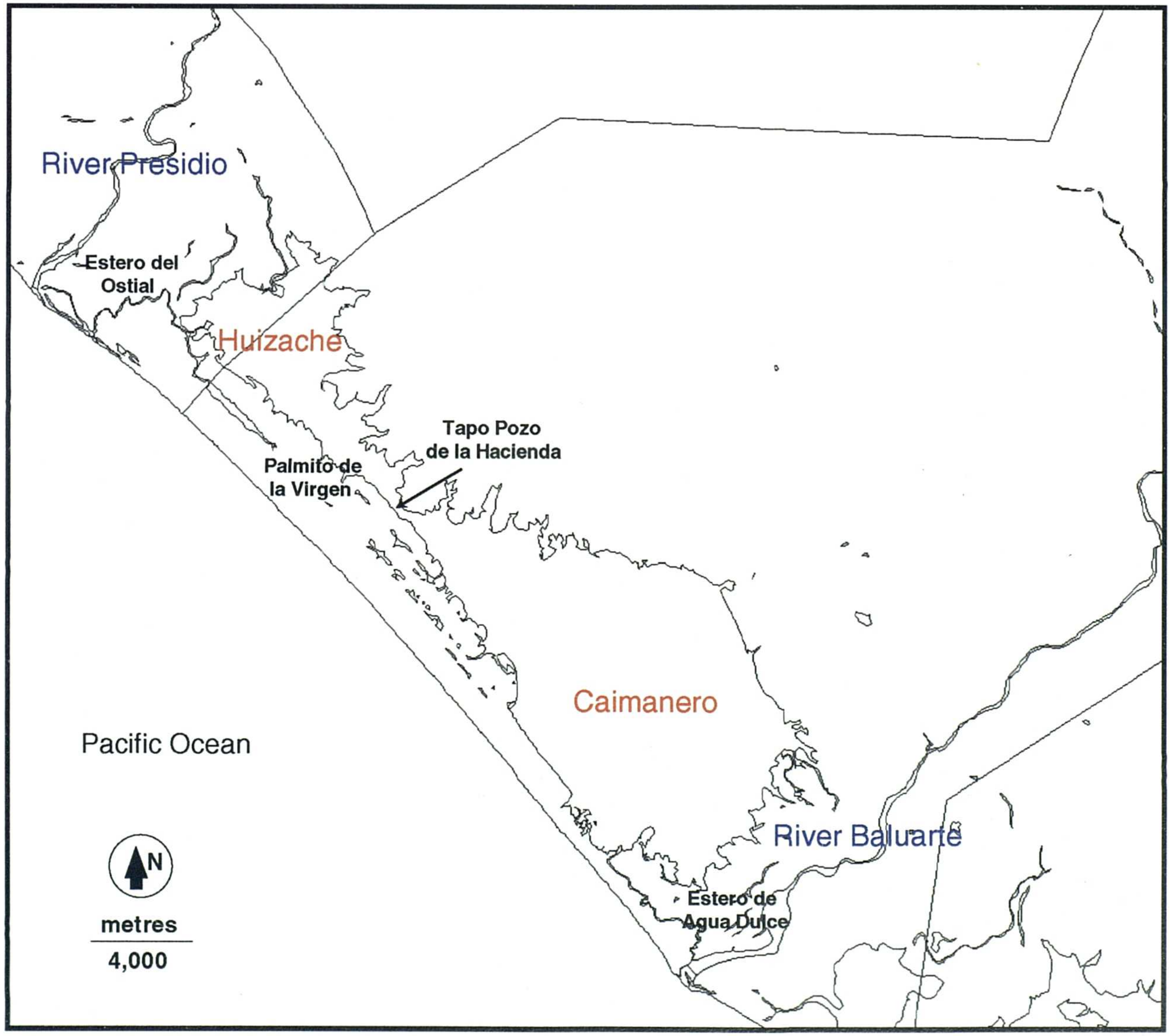


Figure 6.3. The Huizache-Caimanero lagoon system.

Both rivers Presidio and Baluarte have small catchment areas extending across a coastal plain 10-25 km wide, and part way up the western side of the Sierra Madre Occidental. A number of well-defined streams flow into the lagoon system, but they are only activated during the rainy season. (CONSULTEC, 1990).

The maximum total surface of the lagoon system is 175 $km^2$ (Soto-Lopez, 1969), of which 134.3 $km^2$ (77%) correspond to the Caimanero lagoon and 40.7 $km^2$ (22.3%) to Huizache (Díaz-Gonzales and Soto-Lopez, 1988). The lagoons vary considerably in their form but are generally very shallow, with an average depth of half a metre (Menz, 1976). During the dry season the lagoon is considerably reduced from 175 $km^2$ to 65 $km^2$; Caimanero is reduced from 134 to 51 $km^2$ and Huizache from 41 to 14 $km^2$ (**Plate III**) (De la Lanza and García-Calderón, 1991).

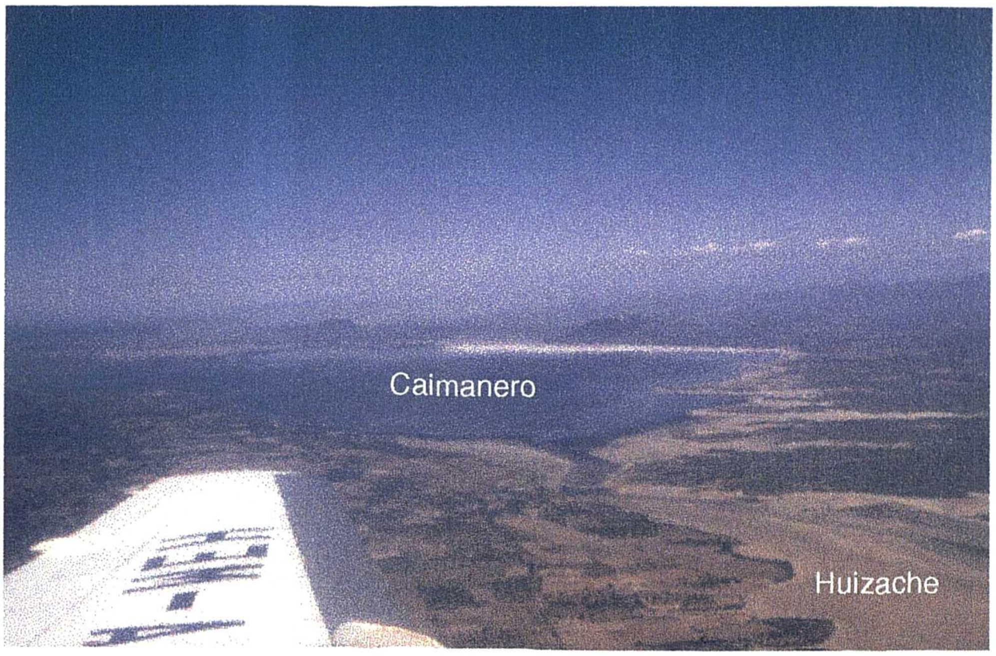


**Plate III. Aerial view of the Huicahe- Caimanero lagoon system during the dry period (March, 1995).**

The lagoons do not have direct communication to the ocean or to the rivers; communication is made through the esteros (CONSULTEC, 1990). Both lagoons are separated from the ocean by a long, narrow sand barrier known as Palmito de la Virgen (Curry *et al.*, 1969) which varies from 1.5 km to 3.5 km wide and extends for 35 km between the two rivers (Menz, 1976).

The main physical differences between the two lagoons are size, the fact that most of Huizache dries out during the dry season, and that salinity is lower overall in Huizache lagoon than in Caimanero (Menz, 1976). The lagoon conditions vary between the extremes of the wet and dry seasons, and this in turn influences population size, density, species composition, growth and probably mortality rates of juvenile shrimp (Edwards, 1978b). Menz (1976) points out that because of these differences, growth of *P.vanamei* is lower in Huizache than in Caimanero.

The lagoon system has had siltation problems which have caused decreases in fish and shrimp capture (Díaz-Rubín *et al.*, 1992). Siltation (**Figure 6.4**) is mainly attributed to seven important factors: 1, suspended solids carried by rivers and streams into the lagoon system; 2, rainfall which carries materials from the surrounding land into the lagoons; 3, land materials transported by wind from the adjacent land (especially during the dry period); 4, materials carried into the system by the tides; 5, increased agricultural activity in the area including clearing of hill-sides has increased the sediment load of the run-off; 6, artificial barriers (or tapos) reduce tidal force and increase sedimentation rate; and finally 7, deforestation is also a cause for an increase of siltation. Ramirez (1988) has estimated in the Philippines that silt loads of 2 to 8 tons/ha/year is present in a forested area, whilst in a deforested area silt exports increases to 200 tons/ha/year. For the Huizache-Caimanero lagoon system Flores-Verdugo (In press) estimated siltation at a rate of 1 cm per year.

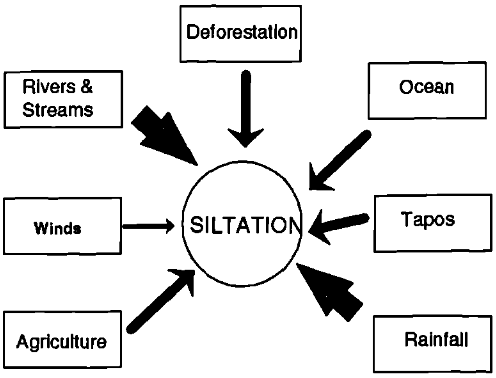


**Figure 6.4. Schematic diagram of the interaction between the factors involved in the siltation process in the Huizache-Caimanero lagoon system.**

Note: directions and sizes of the arrows indicate the type and intensity of the relationship.

Mexican scientists have been aware for some time of the dangers to the fisheries of sedimentation in lagoons, hence large-scale dredging operations have been carried out for the construction of channels in Huizache-Caimanero to combat sedimentation, particularly in the esteros and their conjunction with the lagoon. Initially, the projects started in Huizache and only later in Caimanero (Dirección General de Obras Marítimas, 1974; CONSULTEC, 1990). The Huizache-Caimanero lagoon is one of the first lagoons in Mexico in which such management and maintenance operations have been conducted (see **Appendix** 4). These are designed to maintain water exchange, and also serve to assist entry of postlarvae shrimp, while at the same time concentrating juveniles as they leave the lagoon, thus making them easier to capture (Edwards, 1978a). Diversion of river waters through canalization has been used to maintain a larger lagoon surface area for a longer duration to benefit survival and growth of shrimp (Kapetsky, 1981).

Canalization has been carried out from the lagoon to the sea, and within the lagoon system, in order to increase fish capture and shrimp culture in the lagoon which would otherwise become almost completely dry (Huizache lagoon), or periodically become so extremely hypersaline that almost no aquatic life could be supported. Furthermore, channels have proved beneficial in allowing earlier arrival, increased survival and longer growing periods for shrimp (Kapetsky, 1981). Canals also promote water circulation to carry away domestic, industrial, and agricultural pollutants (Cervantes-Castro, 1980).

Despite the benefits of canal construction a problem with the canals is that they tend to silt up after a number of years, and therefore continuous dredging is necessary. Moreover, it is now widely accepted in Mexico that lagoons of the semi-closed type should remain semi-closed, and that attempts to increase contact with the sea by constructing canals through the barrier island may be disadvantageous unless controlled through the use of sluice-gates. The majority of the fauna in semi-closed lagoons requires brackish water for its proliferation, so that disturbances in salinity, temperature, or nutrient levels may not be advantageous from a fisheries point of view (Edwards, 1978a; Flores-Verdugo, In press).

The lagoon fisheries are based on preventing penaeid juveniles from leaving the lagoons by using weirs, called tapos, from which they are caught in cast nets (Menz, 1976). Typically on the west coast of Mexico the emigration of juvenile shrimp is impeded by the construction of these barriers in exit channels and esteros, and across narrow stretches between the lagoons. This method of fishing has been described by Lindner (1957), Mercado (1961) and Chapa (1966), and Edwards and Bowers (1974) for the Huizache-Caimanero lagoon system. The Huizache-Caimanero lagoons contain 6 tapos which are of two types. The first is the traditional type made entirely from mangrove poles, palm tree trunks and rocks (**Plate IV**), and the second type is modern, constructed of reinforced concrete with screens of galvanized steel mesh (**Plate V**) (Edwards, 1978a). Traditional tapos in the Huizache-Caimanero system are tapo Agua Dulce, tapo Caimanero and tapo Ostial. Modern tapos are represented by tapo Pozo de la Hacienda, tapo Pozo del Caiman and tapo Botadero (Menz, 1976). Even though the main function of tapos is to capture shrimp, they also have an important influence on other aspects of the lagoon system. Firstly, Gomez (1981) noted that these structures have a strong influence on the tidal water circulation discharges and velocities within the lagoon system. Secondly, tapos increase the water level in the lagoon system from 0.39 to 0.97 m and prevent tidal water flow making it difficult for shrimp farms to operate (CONSULTEC, 1990).

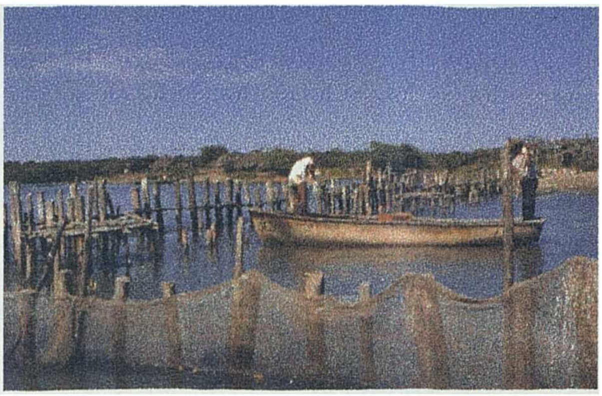


**Plate IV. Tapo Caimanero - a traditional type of tapo (March,1995).**

**Plate V. Aerial view of tapo de la Hacienda - a modern type of tapo (March,1995).**

### 6.2.1 Environmental factors

### 6.2.1.1 Water availability

The Huizache-Caimanero lagoons system is an ecological frontier where the marine and freshwater environments meet. Air, sea and land in this lagoon system comprise an extraordinarily dynamic ecosystem due to the flows of energy (Acuipesca Consultores, 1993). The hydrological process within the Huizache-Caimanero lagoon system is complex since it involves a series of interactions between four major factors - rivers Presidio and Baluarte as well as streams, local and regional rainfall, adjacent oceanic environment, and air as a transference of heat through evaporation. As shown in **Figures 6.5** and **6.6**, the lagoon system receives water from three sources (rivers and streams, rainfall and ocean) and two of the factors receive water from the lagoon (air and ocean). The oceanic water flow is positive or negative depending on the prevailing conditions dictated by the other components. Water level, water quantity and quality is dependent on the prevalence of one or the other of these components.

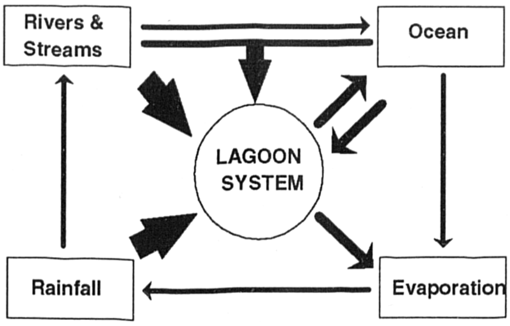


**Figure 6.5. Hydrological process during the wet season.**

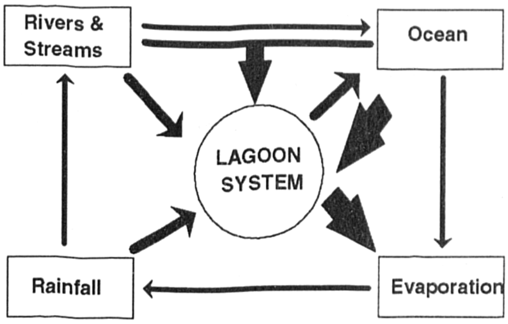


**Figure 6.6. Hydrological process during the dry season.**

Note: Directions and sizes of arrows indicate the type and intensity of the relationship.

The hydrological process within the Huizache-Caimanero lagoon system is further complicated by the integration of both lagoons, the channels and the tapos. Water movements within the lagoon system are complex and vary seasonally and diurnally (Menz, 1976), and the hydrological process can be further complicated by variations in rainfall in different years, which cause earlier or later drying out (Edwards, 1977).

### *a) Rivers Presidio and Baluarte*

The rivers, Rio Presidio and Rio Baluarte, have an indirect communication with the lagoon system through the esteros as well as artificial canals. River flow is modified and interrupted during the dry season (Acuipesca Consultores, 1993). Rivers provide nutrients and transport materials; in the former they contribute to increase production, whilst in the latter they play an important role in the siltation process (Hernandez-Carballo, 1991). The Rio Presidio arises in the Sierra Madre Occidental, approximately 40 km to the west in the state of Durango. It is 215 km long covering a superficial area of 7,368 km². The river basin is located 20 km south-east of Mazatlán and is connected indirectly to Huizache through the channel Pozo del Caiman and reaches the sea through Boca Barrón. Data recorded over a 19 year period (**Figure 6.7**) shows that maximum water flow occurs from July to October, and minimum water flow occurs in April and May; average annual water flow for this period is 87 million $m^3$/ yr.

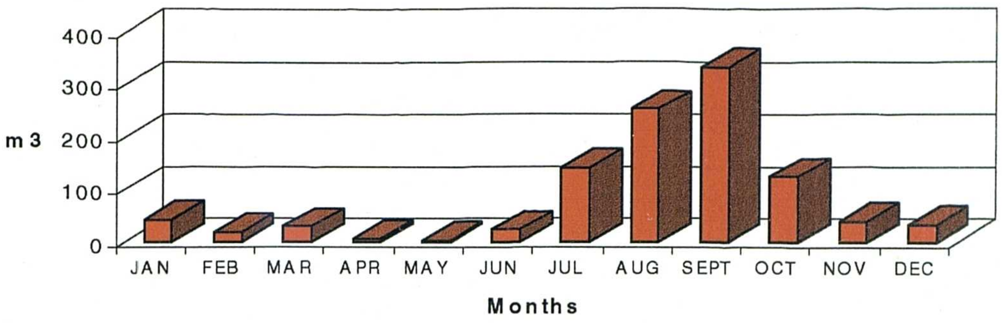


**Figure 6.7. Water flow in River Presidio over a 19 year period (1955 to 1973).**
Source: CNA (1995).

Rio Baluarte arises in a valley next to La Peña and travels 26 km covering an area of 5,047 $km^2$. It is linked to Caimanero through an artificial channel called Las Anonas and through El Estero de Agua Dulce, it reaches the sea through Boca de Chametla (Secretaría de Pesca, 1980; De la Lanza and García-Calderón, 1991). Data recorded over a 47 year period (**Figure 6.8**) shows that maximum water flow also occurs from July to October, and minimum water flow occurs in April and May. In contrast to the river Presidio, the average annual water flow for Baluarte is 340 million $m^3$. Moreover, Baluarte river can be considered permanent because even during the dry season it is able to maintain a water flow (Rogelio-Poli and Calderón-Perez, 1985).

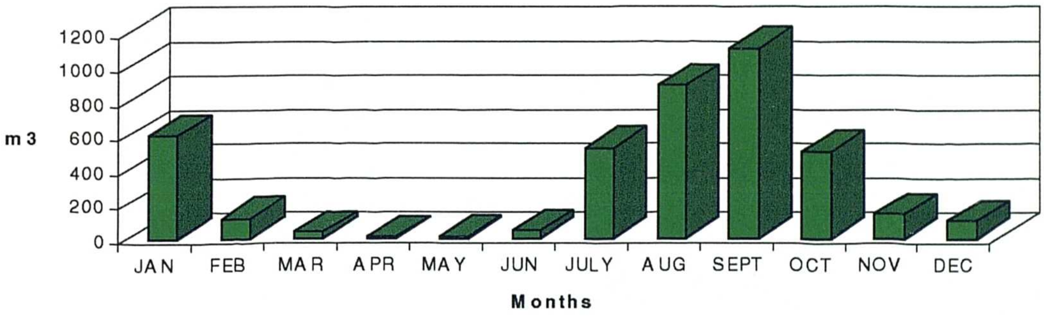


**Figure 6.8. Water flow in river Baluarte for a 47 year period ( 1948 - 1994).**
Source: CNA (1995). Note: A high average value was recorded for January, but this was due to a very high value recorded in 1992 ( 1274.4 million $m^3$) which was far greater than the rest of the 46 years. Hence, this abnormality should be verified with the National Water Commission (CNA in Villa Union, Sinaloa). Unfortunately, rainfall data were only obtained until 1990 and it was therefore not possible to determine if this abnormality was due to a very high period of rainfall.

In addition to these rivers there are 36 seasonal streams, covering an area of 300 km$^2$ ; a total of 45 million m$^3$ was recorded in 1969 (Soto-Lopez, 1969). These streams cause floods during the rainy season, but during the dry season their water flow is either insignificant or non-existent.

### *b) Rainfall*

Rainfall is the only environmental factor in the lagoon system which shows similar patterns between years; it has been natural therefore that most fishermen have sought a correlation between rainfall and fish capture (Soto-Lopez, 1969; Llunch, 1974; Menz, 1976). Catches are generally higher during years of high rainfall, and this may be explained by the fact that the abundant rain, particularly if it starts early in the season, provides a greater forage area more rapidly and for a longer time than if the rains are sparse and late. Furthermore, high rain results in high nutrient input into the lagoon from outside sources (Menz, 1976). **Figure 6.9** shows the seasonal pattern of monthly rainfall for a 20 year period (1964-1979 and 1985-1990) and clear maximum occurs between July and September, with a minimum in April and May.

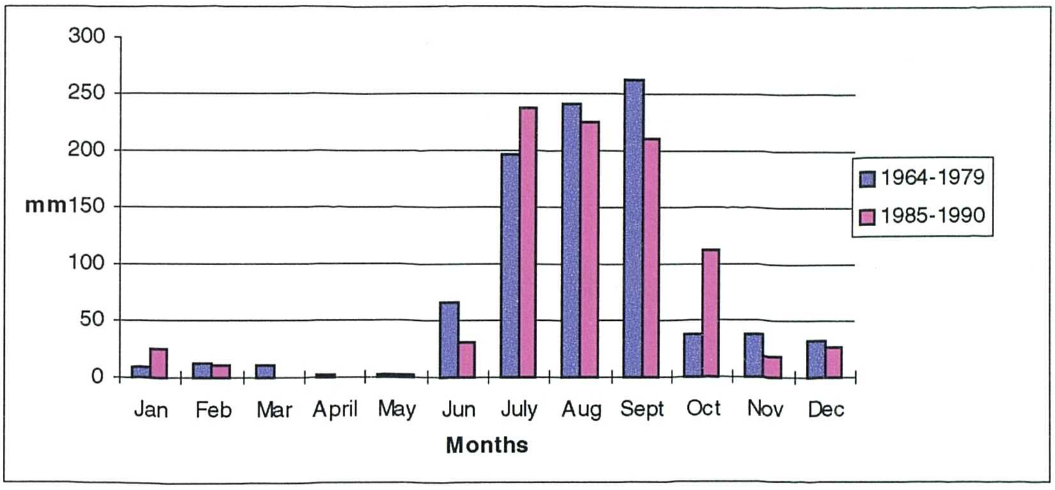


**Figure 6.9. Monthly mean (1964-1979) and total rainfall (1985-1990) in El Rosario Sinaloa.**

Note: No data recorded in February 1989 and December 1990. Source: SARH (1993).

### *c) Evaporation*

The Huizache-Caimanero lagoon system is an evaporation basin, especially during the summer time. During the night, temperature decreases and water from the lagoons evaporates to give the locality a tropical humid climate (Acuipesca Consultores, 1993). **Figure 6.10** shows the seasonal pattern of monthly evaporation for a 20 year period (1964-1979 and 1985-1990) at El Rosario Sinaloa. As shown below maximum values occur from April to June and minimum from January to February.

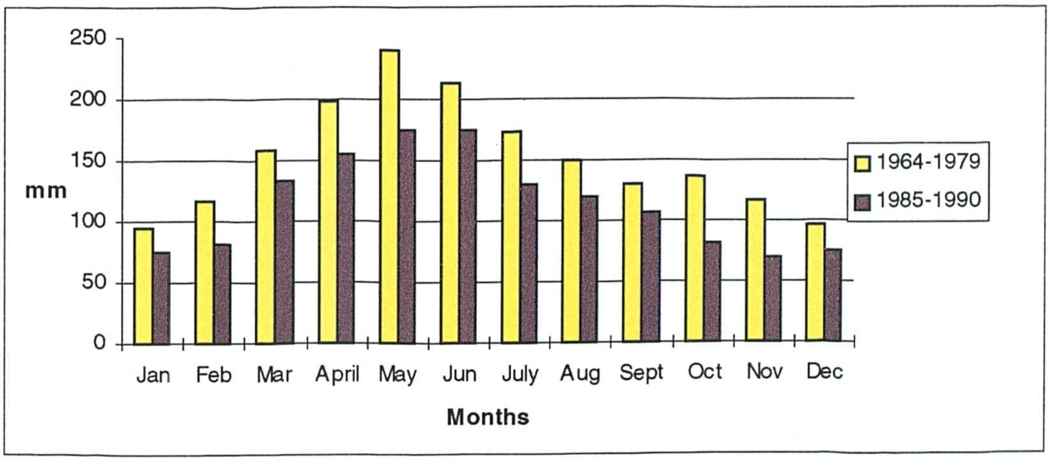


**Figure 6.10. Monthly mean (1964-1979) and total evaporation (1985-1990) in El Rosario Sinaloa.**

Note: * No data recorded in February 1989 and December 1989 and 1990. Source: SARH (1993).

Maximum and minimum values for evaporation and rainfall are similar for the two time periods and differing datasets. Annual average for monthly mean values was 152 mm, and annual average for total evaporation was 115 mm.

### *d) Groundwater*

Even though abstraction of groundwater has been restricted due to environmental problems in some areas of Sinaloa (see **Chapter 4** for water resources), in the Huizache-Caimanero region there are two large areas which have been classified as suitable for exploitation by SPP (1981). The first area is located adjacent to the lagoon in proximity to the communication between the two lagoons - close to tapo de la Hacienda, whilst the second is located along river Baluarte adjacent to Caimanero lagoon (**Figure 6.11**).

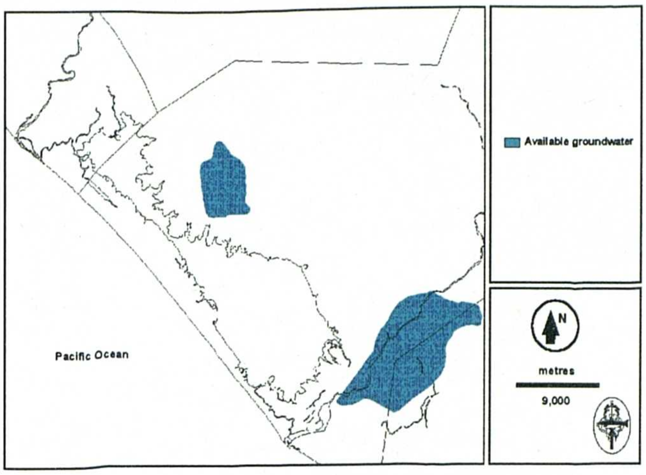


Figure 6.11. Groundwater in the Huizache-Caimanero region.

### 6.2.1.2 Air temperature

Over a 5 year period (1985-1990), as shown in **Figure 6.12**, maximum temperatures are found from June to August and minimum temperatures are found from December to February. There is a maximum temperature of 39 ° C during the month of June and a minimum value of 9 ° C in January (SARH, 1993).

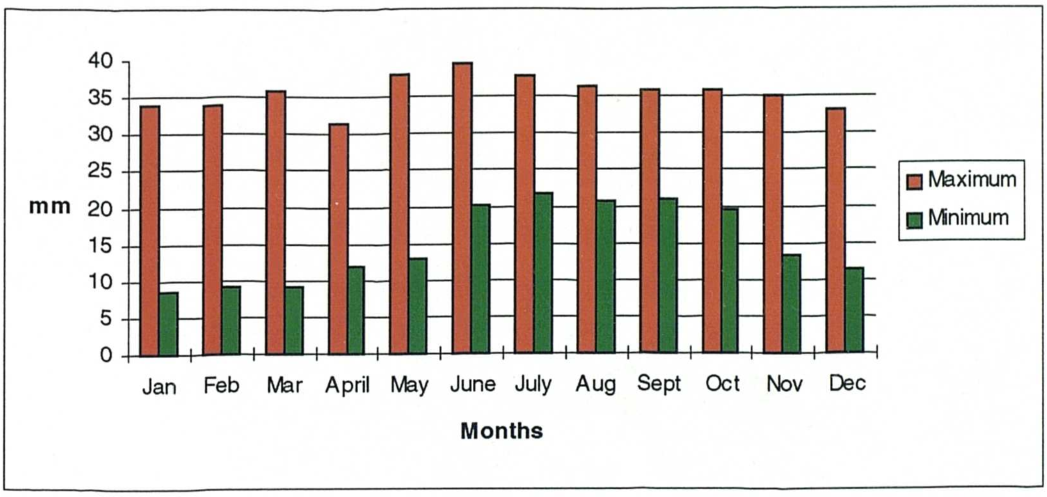


Figure 6.12. Maximum, and minimum air temperature in El Rosario Sinaloa during a 5 year period (1985-1990).

Source: SARH (1993).Note: * No data recorded In February 1989 or December 1990. Winter fog is present in this region and is related to low temperatures. Moreover, the cold California current also has an important effect on temperature (De la Lanza and García-Calderón, 1991).

### 6.2.1.3 Water balance

Rainfall and evaporation play a key role in the availability of water, and therefore their relationship plays an important part in evaluating a water balance. **Figure 6.13** shows the availability of water from 1964-1979 for monthly mean values of rainfall and evaporation, whilst **Figure 6.14** shows total values from 1985 - 1990. Clearly, positive water balance occurs between July and September. Conversely, April and May are critical months with serious lack of water, when there is maximum evaporation and almost no rainfall.

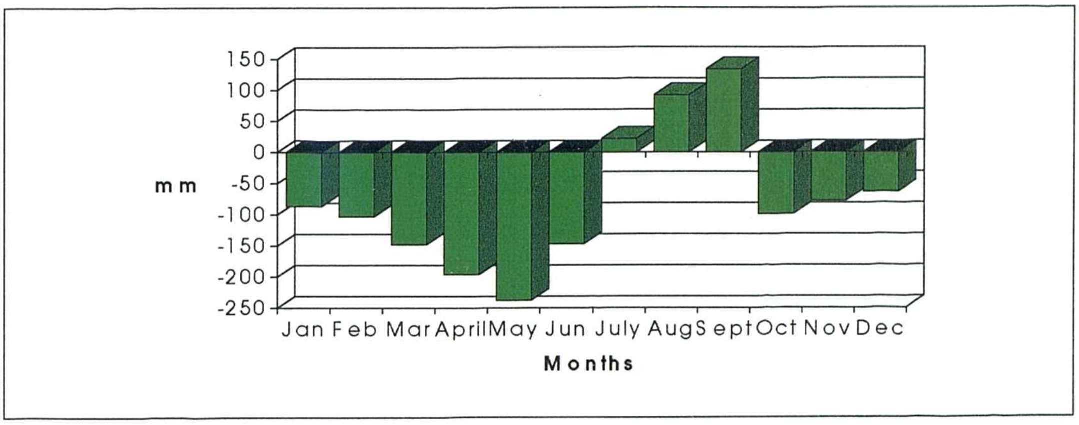


**Figure 6.13. Water balance 1964 - 1979 based on monthly mean values.** Note: Figure created using data provided by SARH (1993). Figures produced by the subtraction of the evaporation from the rainfall.

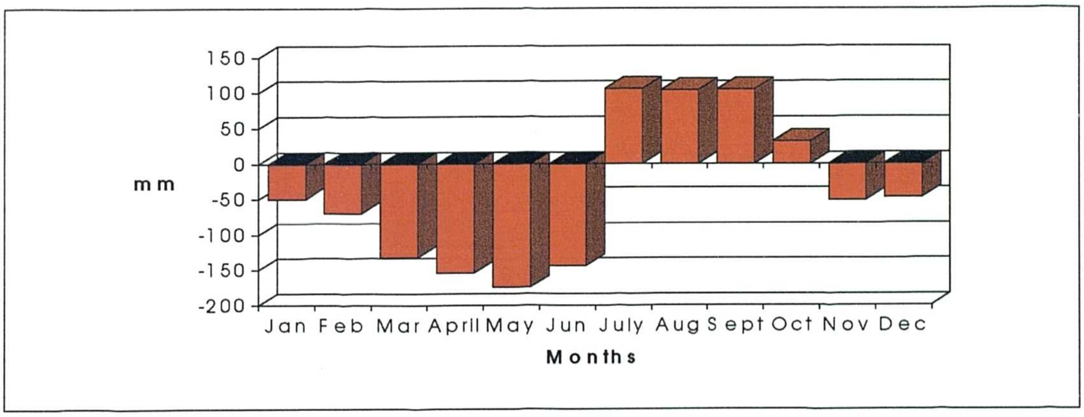


**Figure 6.14 Water balance 1985 - 1990 based on total values.** Note: Figure created using data provided by SARH (1993). Figures produced by the subtraction of the evaporation from the rainfall.

Despite the above, water balance is much more complex since many other factors are involved. **Table 6.1** shows a water balance estimation by Soto-Lopez (1969), who found that there is an overall annual positive water balance (128 million m$^3$). The esteros provide the greatest amount of annual water (288 million m$^3$), followed by rainfall (113 million m$^3$), whilst evaporation is by far the most important output factor (287 million m$^3$). In terms of monthly water availability July, August and September are the only months of the year in which the water balance is positive - additional data for October, November and December of 1966 confirm part of the results for 1967.

## Table 6.1. Water balance in the Huizache-Caimanero lagoon system (Soto-Lopez, 1969).

( million $m^3$ )

| DATE | INPUTS | | | | | OUTPUTS | | | | BALANCE | VOLUME |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1966** | RAIN | CHANNELS | STREAMS | ESTEROS | TOTAL | EVAPORATION | ESTEROS | SUBSOIL | TOTAL | | |
| O | 0.2 | 0 | 0 | 0 | 0.2 | 30 | 15.9 | 0 | 45.9 | -45.7 | 101.3 |
| N | 0 | 0 | 0 | 0 | 0 | 19.9 | 3.3 | 0 | 23.2 | -23.2 | 78.1 |
| D | 0.2 | 0 | 0 | 0 | 0.2 | 15.6 | 1.2 | 0 | 16.8 | -16.6 | 61.5 |
| **TOTAL** | 0.4 | 0 | 0 | 0 | 0.4 | 65.5 | 20.4 | 0 | 85.9 | -85.5 | 240.9 |
| **1967** | | | | | | | | | | | |
| J | 3 | 0 | 1.7 | 0 | 4.7 | 15.4 | 0.7 | 0 | 16.1 | -11.4 | 50.1 |
| F | 0 | 0 | 0 | 4 | 4 | 14.4 | 0 | 0 | 14.4 | -10.4 | 39.7 |
| M | 0 | 0 | 0 | 10.1 | 10.1 | 16.6 | 0 | 0 | 16.6 | -6.5 | 33.2 |
| A | 0 | 0 | 0 | 11.9 | 11.9 | 17.6 | 0 | 0 | 17.6 | -5.7 | 27.5 |
| M | 0 | 0 | 0 | 10 | 10 | 23.7 | 0 | 0 | 23.7 | -13.7 | 13.8 |
| J | 1.7 | 0 | 1 | 19.3 | 22 | 25.8 | 0 | 0 | 25.8 | -3.8 | 10 |
| J | 11.3 | 3.5 | 4.6 | 66.2 | 85.6 | 33.6 | 0 | 9.6 | 43.2 | **42.4** | 52.4 |
| A | 51.5 | 10.4 | 20 | 104.4 | 186.3 | 34.1 | 0 | 24.9 | 59 | **127.3** | 179.7 |
| S | 33.7 | 10.4 | 12.9 | 61.8 | 118.8 | 30.3 | 0 | 6.3 | 36.6 | **82.2** | 261.9 |
| O | 0 | 8.6 | 0 | 0 | 8.6 | 30.6 | 2.6 | 0 | 33.2 | -24.6 | 237.3 |
| N | 0 | 7.5 | 0 | 0 | 7.5 | 24.3 | 21.3 | 0 | 45.6 | -38.1 | 199.2 |
| D | 11.5 | 10.3 | 4.8 | 0 | 26.6 | 20.5 | 15.8 | 0 | 36.3 | -9.7 | 189.5 |
| **TOTAL** | **112.7** | **50.7** | **45** | **287.7** | **496.1** | **286.9** | **40.4** | **40.8** | **368.1** | **128** | |
| % | 22.72 | 10.22 | 9.07 | 57.99 | 100.00 | 77.94 | 10.98 | 11.08 | 100.00 | | |

### 6.2.1.4 Water quality

The Huizache-Caimanero lagoon system has a small communication with the ocean, and water quality is mainly governed by the effect of the materials that enter the system from the surrounding land during the rainy season (Arenas, 1970). Some of the most important factors which alter the quality of the water bodies are:

- Water level from the adjacent ocean as well as the lagoon; tide level.
- Temperature: daily, seasonal and inter-annual; distribution, extreme limits
- Salinity: daily, seasonal and inter-annual variations; extreme limits.
- Oxygen: daily variations, anoxia, DOB.
- Pollution.

Source: Acuipesca Consultores (1993).

#### *a) Water level*

The exact mechanism by which the lagoons fill and empty has not, as yet, been thoroughly investigated, but the general features are clear. The main influx of water occurs from July to September as a result of maximum precipitation, runoff from the surrounding land and through the esteros due to an increase in the water levels of the rivers Presidio and Baluarte. Although a number of factors are involved (i.e. evaporation, rainfall, subsoil) the main difference between the lagoon system's water level and the adjacent ocean is determined by the direction and intensity of the water flows shown in **Figure 6.15** and **6.16**. The water level within the lagoon is an indicator of the quantity of nutrients being transferred, organic matter and suspended solids. The variation is a very good indicator of the system's water circulation and recycling process. As shown in the figures there are 5 major factors which determine the lagoon's water level. It is also evident from these figures that there is a repetitive process of gaining and losing water between the ocean and the lagoon system.

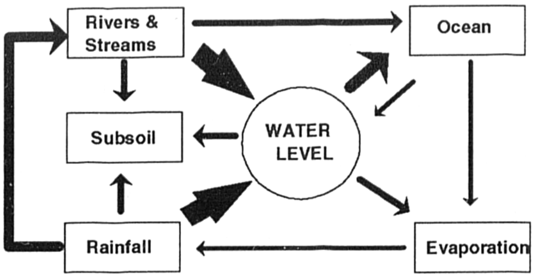


Figure 6.15 Water level during the wet season.

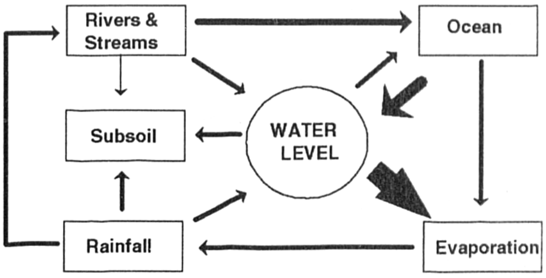


Figure 6.16. Water level during the dry season.

Note: Direction sand sizes of the arrows indicate the type and intensity of the relationship.

The water level is even further complicated when taking into consideration the influence of the canals and tapos.

Tidal changes cause the lagoons to fill during the summer and empty in the autumn. However, there is a considerable damping effect on tides caused by long narrow esteros. From July to September there seems to be a net flow of water from the Huizache basin through Pozo la Hacienda to the Caimanero basin; also during this time the lagoons shed water almost continuously via the esteros. From October onwards the lagoon level falls steadily, and continues to do so until the following June. The fall in level is due mainly to the cessation of rains and rapid evaporation. Greatly assisting the process of evaporation is the daily cycle of sea-breeze which can reach speeds of up to four knots, and are north-westerly during the day and southerly during the night and early morning (Menz, 1976).

During the dry season an oxidation process occurs, and during the rainy season there is a transport of nutrients and materials. This process is extremely important in determining the level of production of the lagoon (Hernandez-Carballo, 1991). Moreover, there is a considerable influence of marine water entering the lagoon system. Tides are important in controlling the migrating movement of shrimp (Menz, 1976). However, tides can sometimes have an insignificant effect or no effect at all during the dry period (CONSULTEC, 1990). Currents in the esteros in Huizache-Caimanero are affected by marine tidal cycles, lagoon level changes in relation to annual mean sea level changes, and varying river discharge rates (Mair, 1979a).

### *Bathymetry*

Huizache-Caimanero is a shallow water body whose depth fluctuates according to the water level as previously described. In Huizache, maximum depth is just above a metre, and mean depth is usually about 0.8 m. Caimanero on the other hand can reach a maximum depth of just over 2 metres, and mean depth is about 1.2 metres (Soto-Lopez, 1969) (**Figure 6.17**). From the deeper areas the slope varies gently towards the ocean (Menz, 1976). Depth in the lagoon system has varied over the years due to human intervention through the construction of artificial barriers and canals, as well as dredging activities (CONSULTEC, 1990).

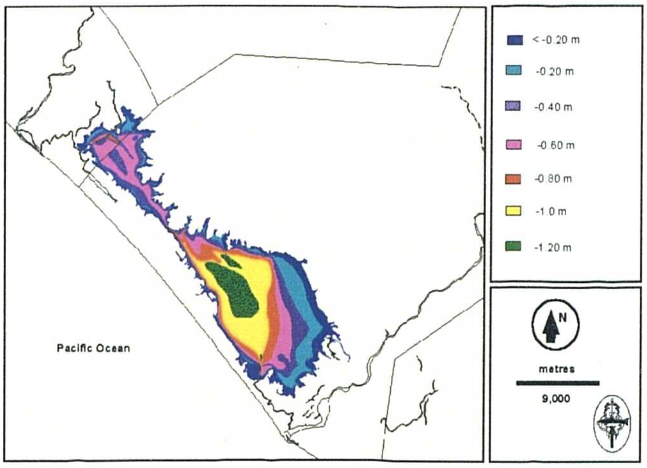


**Figure 6.17. Bathymetry in the Huizache-Caimanero lagoon system. (Wet season, 1969).**

Source: Soto-Lopez (1969).

### b) pH

pH in the Huizache-Caimanero lagoon varies between 7.5 and 8.9 (CONSULTEC, 1990). pH is an important characteristic of water to an aquaculturist as extreme values can cause stress to shrimp, and pH also affects the degree of ionisation of toxic substances such as ammonia (Stirling, 1985).

### *c) Water Temperature*

Because the lagoon system is very shallow water temperature constitutes an important limiting growth and survival factor of many aquatic species. Water temperature can vary from day to day, seasonally and spatially. Minimum temperature is 21 °C registered in January and February, and maximum is 32 °C in August and September (Acuipesca Consultores, 1993).

**Figure 6.18** illustrates the interaction occurring between the factors involved in determining the water temperature. From this figure it is clear to see that water temperature follows the same pattern as the ambient temperature.

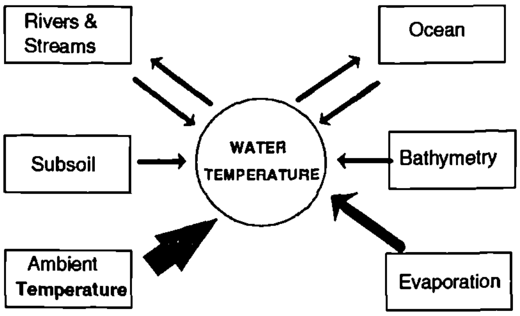


**Figure 6.18. Schematic diagram showing the factors in determining the water temperature.**
Note: directions and sizes of the arrows indicate the type and intensity of the relationship.

### *d) Salinity*

Salinity within the lagoon system varies greatly both temporally and spatially (Menz, 1976) due to variations in flow of the rivers, sea water, evaporation, and depth (**Figure 6.19**). Salinity is considered to be the main environmental variable in the Huizache-Caimanero lagoon system, with large fluctuations in the wet and dry seasons ranging from 1 to 60 ppt (parts per thousand) (Edwards, 1977). When the lagoons are full, from about July to December, a salinity gradient exists across the lagoon from about 2 ppt in Huizache where most of the fresh water enters the system, to 5 ppt at Pozo de la Hacienda, and 12-15 ppt at the southern end of Caimanero (Menz, 1976). From evidence of salinity distributions, Ayala-Castañares and Phleger (1971) deduced that most of the sea water enters the system into Caimanero lagoon, and most of the fresh water enters during the rainy season into Huizache.

There are distinct salinity gradients across the length and breadth of the lagoon system. The general picture is one of increasing salinity as one moves away from tapo La Hacienda and the western shore towards the south-eastern part of the Caimanero lagoon. The magnitude of the salinity varies with location, month and year. Gradients were found to vary from 0 ppt to a maximum of 145 ppt across the lagoon, being most distinct in September, and then gradually diminishing as the freshwater influx into the lagoon ceases (Menz, 1976).

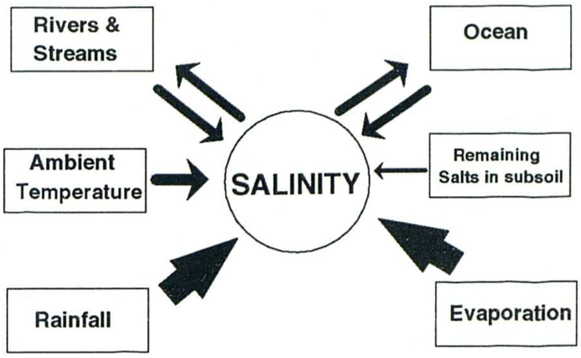


**Figure 6.19. Schematic diagram showing the factors involved in determining salinity in the Huizache-Caimanero lagoon system.**

Soto-Lopez (1969) found three different salinity zones in the water column. The first is located in the esteros Agua Dulce and El Ostial, which comprise an area of mixture between the sea water and river water, where values range from 3 to 30 ppt. The second zone is located in the transition zone between the two lagoons; values range from 3 to 25 ppt. Finally, the third zone, with a salinity between 15 and 60 ppt, is located in the water bodies created by the tidal cycle. In El Ostial salinity as low as 1 ppt has been detected. Estero Las Anonas and del Caiman have river water, and hence they are freshwater. When water flows into the lagoon from rivers Baluarte and Presidio are insignificant during the dry season, parts of the lagoons are transformed into large salt flats (**Plate VI**) which have been industrially exploited (Soto-Lopez, 1969). Salt flats plus residual salt left in the sediment seem likely to add to the overall salinity during the wet season, when only limited amounts of salt water enter the lagoons (Menz, 1976).

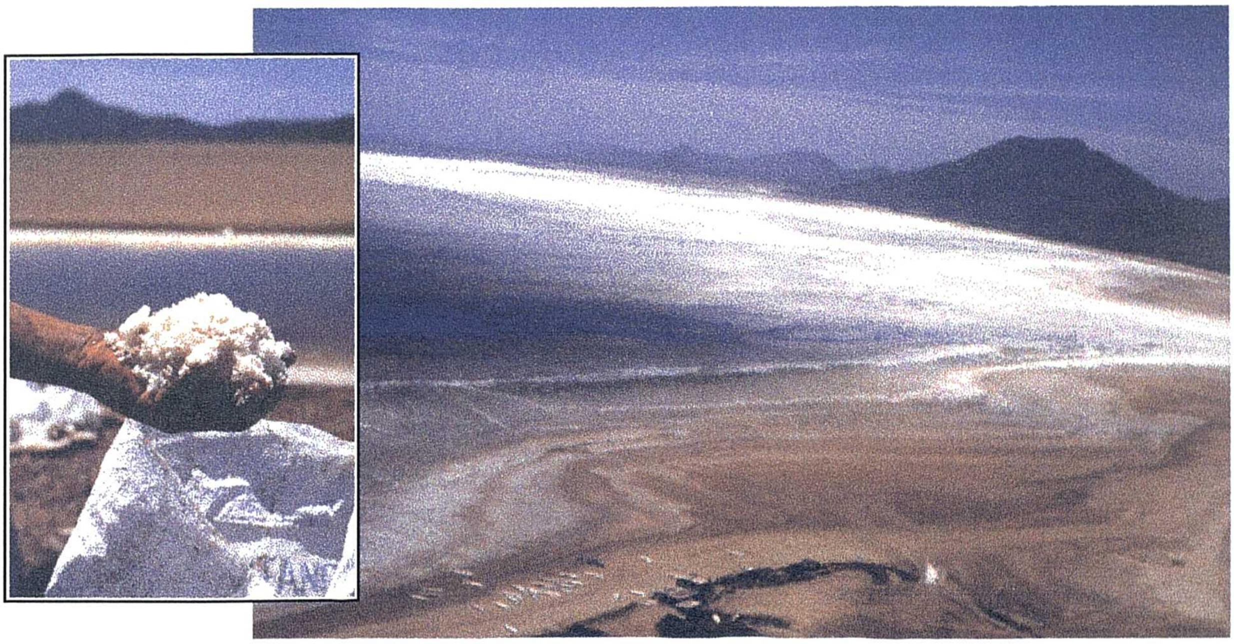


**Plate VI. Aerial view of salt flats in the Caimanero lagoon. Collection of salt in the Caimanero lagoon (inset) (March, 1995).**

### *e) Dissolved Oxygen*

Dissolved oxygen (DO) varies with temperature and salinity and ranges from 1 to 7 ml / l. The daily variation (day to night) is an expression of the biological processes which occur in the lagoon system (Acuipesca Consultores, 1993). Annual DO concentrations reach super-saturated values of 7.0 ml / l during winter time in tapo Pozo de la Hacienda (Arenas, 1979). Lowest values are found in tapo Caimanero, during the dry season.

As with temperature and salinity, the quantity of oxygen is an important limiting factor for many organisms which would colonize this environment. Oxygen is incorporated into the system through tidal flows, by advection to the air at night time and by photosynthesis. Oxygen is lost from the system by denitrification, aerobically or anaerobically (Acuipesca Consultores, 1993).

### *f) Interaction between water temperature, salinity and dissolved oxygen in the Huizache-Caimanero lagoon system.*

**Figures 6.20** and **6.21** show the spatial and seasonal variation of temperature, salinity and dissolved oxygen created from data provided by Galindo-Reyes for 1990 and 1994 (1990; In press). **Figure 6.20** shows the distribution of these factors at 4 water sample stations for 1990. The general pattem is that highest salinity and lowest dissolved oxygen were found from April to July. Highest dissolved oxygen values were recorded from September to March. Critical vales were obtained in tapo Caimanero and tapo Los Pozos where dissolved oxygen was lowest from April to July. **Figure 6.21** shows the distribution of water quality factors in 15 stations for 1994; decreases in salinity occurred towards each end of the lagoon, which seems to be logical due to the proximity to the rivers. Conversely, in water samples towards the communication between the two lagoons, salinity increased (i.e. stations 6 to 10) and consequently dissolved oxygen concentrations decreased. In summary, even though dissolved oxygen is low in July and September, it appears that lagoon locations in stations 6, 9 and 10 would provide optimum growth for shrimp because temperature and salinity are highest when compared to other stations. Best values for stations 6 , 9 and 10 appear to be in September when dissolved oxygen is highest. From these three station locations in the lagoon, number 9 appears to have the best combination of factors.

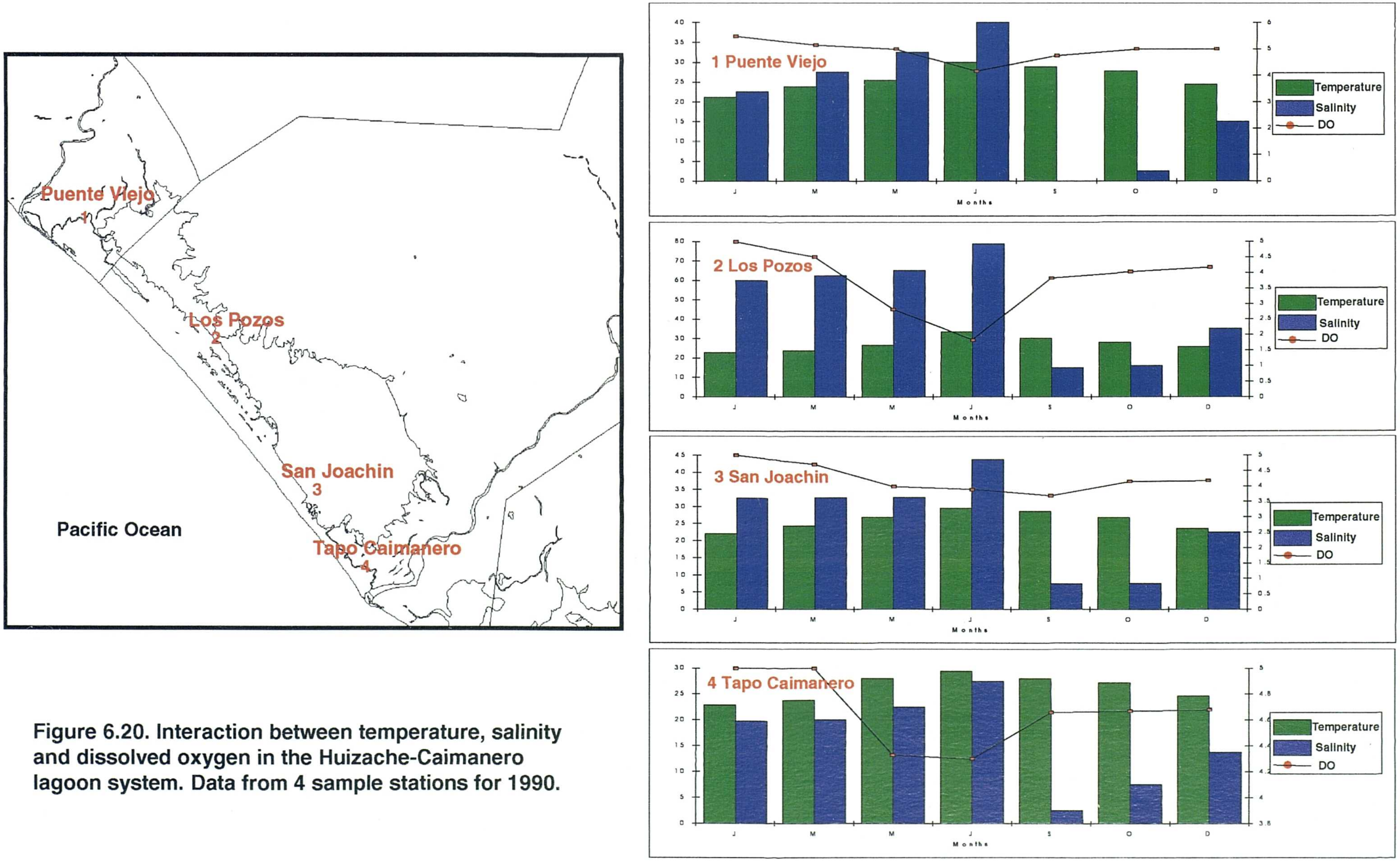
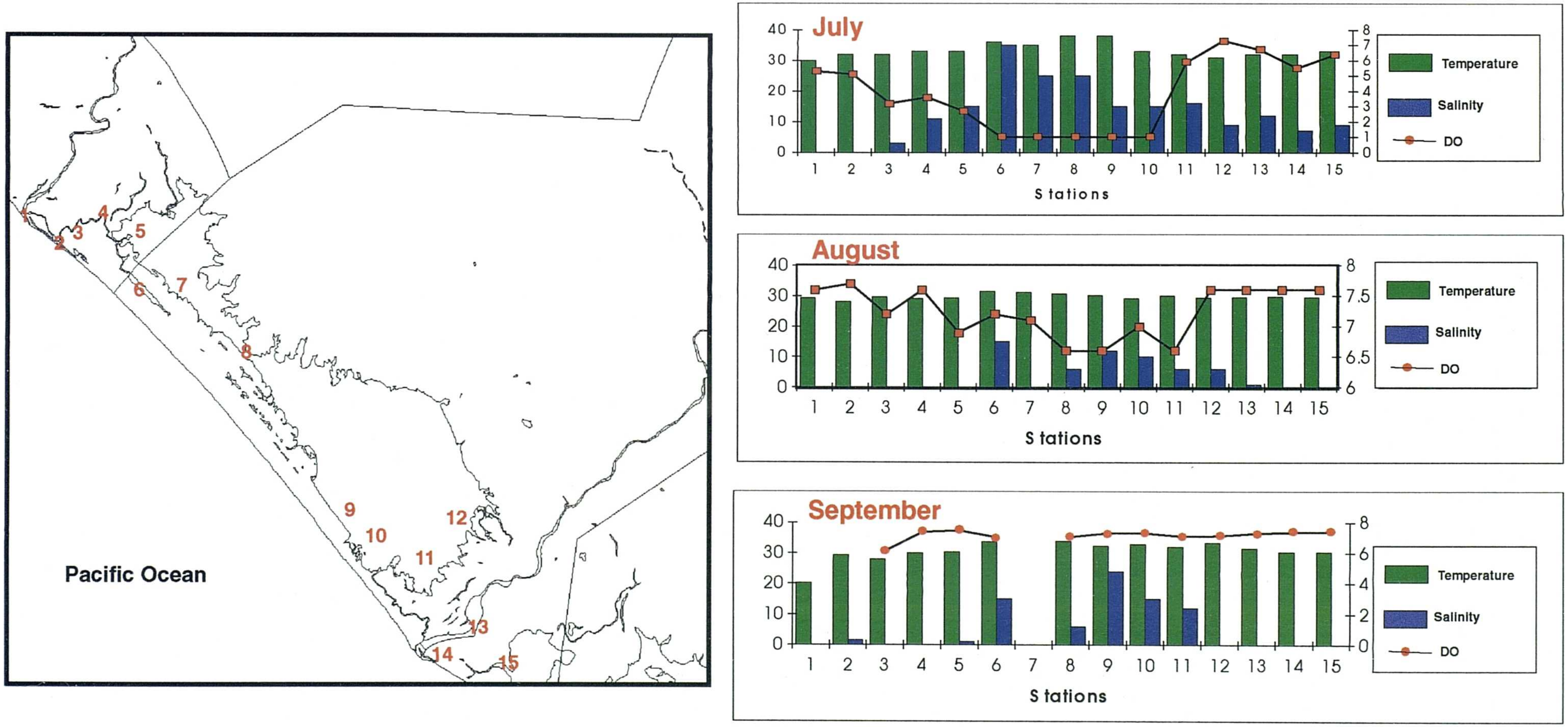


Figure 6.20. Interaction between temperature, salinity and dissolved oxygen in the Huizache-Caimanero lagoon system. Data from 4 sample stations for 1990.



Note: No data for station 7

Figure 6.21. Interaction between temperature, salinity and dissolved oxygen in the Huizache-Caimanero lagoon system. Data from 15 sample stations for 1994.

### 6.2.1.5 Summary of seasonal environmental factor changes in the lagoon system.

**Figure 6.22** provides a summary of the seasonal factor changes in the lagoon system. It can be seen that from July to September water quantity in the lagoon is at its peak. Furthermore, water quality is assumed to be the best or it is improved during this period. The impact of water discharges from shrimp farms, for example, is minimized because communication to the ocean and to the rivers is greatly improved thereby causing an increase in water movement within the lagoon. By contrast, during the dry season, from February to May, rainfall is lowest, and consequently depth in the lagoon is minimum (i.e. Huizache dries up and parts of the lagoon system are converted into large salt flats). Water input from the ocean and from the rivers is low or insignificant, consequently water circulation is minimum and thus it is a critical time period for fisheries production as well as for shrimp culture within the lagoon system. Moreover, April and May seem to be the worst months because dissolved oxygen is at a minimum, and evaporation and salinity are maximum.

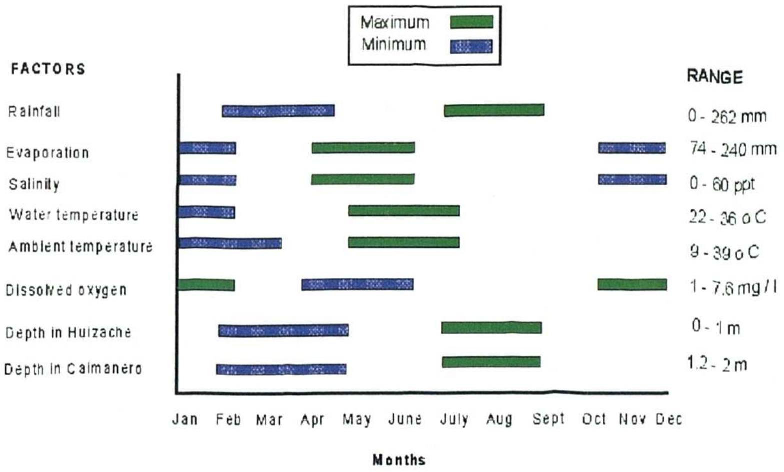


**Figure 6.22. Seasonal maximum and minimum environmental factor changes in the Huizache-Caimanero lagoon system.**

### 6.2.1.6 Pollution

Even though the Huizache-Caimanero lagoon system is located in a rural area, it is inevitable that population growth, food and fibre production, industrialization and urbanization all demand increased use of synthetic materials such as pesticides and fertilizers, release of industrial by-products, as well as use of air, land, and water resources. The fate of agricultural chemicals, namely pesticides, in aquatic environments is also a subject of international concern (e.g. Khan, 1977, Galindo-Reyes, 1985; Galindo-Reyes *et al.*, 1992; Jones, J.G.1993; Ramirez *et al.*, In press).

The primary concern with pesticide pollution is derived from their damage to the environment and to human health. In the former, it is likely that pesticides decrease the number of commercially important aquatic species such as shrimp, oysters and fish, whilst in the latter pesticides can cause intoxications, tumours or even brain damage (Galindo-Reyes *et al.*, 1992). In fish, reproduction can be affected, mortality increased and toxins can accumulate in their flesh making them toxic to humans (Castillo-Alarcón and Ortega-Romero, 1985).

In water samples taken by Galindo-Reyes (1990) in the Huizache-Caimanero lagoon there were critical concentrations of agricultural pesticides. **Table 6.2** shows that 5 types of pesticides were found, of which lindane was present in all the samples collected. The largest diversity of pesticides was found on the 30 th of August, 1990, and the highest concentration of lindane was reported on the 12 th of October in Puente Viejo sample station (see **Figure 6.20** for location of sample station).

Data obtained from water samples by Galindo-Reyes (1990) gave an indication of existing pollution. However, data on residues in water tend to vary markedly with season, the degree of turbulence of the water, and amount of suspended particulate matter, so fish are often considered to be a much better indicator of water pollution by pesticides than analysis of water samples. Residues in fish tissues are several orders of magnitude higher than in water and much easier to analyze. Fish, and shellfish prove to be excellent species for indicating the presence of pesticides in the environment. Fish especially pelagic fish, travel great distances, thus indicating the occurrence of pesticides somewhere within the range. Conversely shellfish are sedentary and can be used to specifically locate the source of the residue (Khan, 1977).

## Table 6.2. Types and monthly concentrations of pesticides ( μg / l ) found in water samples in the Huizache-Caimanero lagoon system in 1990.

| STATION | JANUARY 11 th | | APRIL 13 th | | JUNE 24 th | | AUGUST 30 th | | OCTOBER 12 th | | DECEMBER 9 th | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Puente Viejo | Lindane | 0.12 | Lindane | 0.39 | | | Lindane | 0.89 | Lindane | 2.60 | Lindane | 0.62 |
| | | | Isodrin | 0.07 | | | Methylparathion | 0.22 | | | Methylparathion | 0.06 |
| 2 Los Pozos | | | Lindane | 0.58 | | | Lindane | 0.33 | Lindane | 1.01 | | |
| | Aldrin | 0.42 | Isodrin | 0.15 | | | Aldrin | 1.20 | Aldrin | 1.02 | Aldrin | 0.61 |
| | | | | | | | Methylparathion | 0.09 | | | | |
| 3 San Joachin | | | Lindane | 0.92 | Lindane | 0.15 | Lindane | 0.49 | | | | |
| | | | Isodrin | 0.14 | Aldrin | 0.08 | | | | | | |
| | | | | | Isodrin | 0.02 | | | | | | |
| 4 Caimanero | | | | | Lindane | 1.04 | Lindane | 0.24 | | | Lindane | 0.06 |
| | | | | | Isodrin | 0.08 | Isodrin | 0.04 | | | Isodrin | 0.03 |

Source: Table created using data from Galindo-Reyes (1990).

*Penaues aztecus, P. duodarum* and *P. setiferus* have been used in experimental work with polluting substances or environmental surveys (Verschueren, 1983). However, there is no information on the level of damage that the pesticides found by Galindo-Reyes (1990) can cause specifically to *P. vannamei.* Nonetheless, the sample data obtained by Galindo-Reyes may be high - methylparathion has been found to be the most damaging pesticide (Baird, pers.comm.). Galindo-Reyes has found, in unpublished work, that physiological and biochemical changes in *Penaeus* spp. larvae occurred when intoxicated by organochloride pesticides such as lindane. Such intoxication caused an increase in the larva's respiration rate, and also caused drastic alterations in their metabolism.

Data obtained from sediment samples by Galindo-Reyes (1990) also gave an indication of existing pollution (**Table 6.3**). From these samples, 6 types of pesticides were found, of which lindane was also present in every sample (except for December).

Although different pesticides were found in the sediments when compared to the water samples, the diversity and quantity of pesticides was also greatest in August, but the highest concentration of lindane was found in the Caimanero sample station.

Table 6.3. Types and monthly concentrations of pesticides ( µg / g ) found in sediment samples in the Huizache-Caimanero lagoon system in 1990.

| STATION | JANUARY 11 th | | APRIL 13 th | | JUNE 24 th | | AUGUST 30 th | | OCTOBER 12 th | | DECEMBER 9 th | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Puente Viejo | Dieldrin | 0.0004 | Lindane | 0.0019 | Lindane | 0.0003 | Lindane | 0.0027 | Lindane | 0.0007 | DDT | 0.022 |
| | DDT | 0.0008 | Dieldrin | 0.0016 | DDT | 0.0017 | DDT | 0.0047 | DDT | 0.0022 | Aldrin | 0.02 |
| 2 Los Pozos | DDT | 0.0004 | Dieldrin | 0.0007 | Lindane | 0.0001 | Heptachlorine | 0.0001 | Heptachlorine | 0.0003 | | |
| | | | Aldrin | 0.0002 | | | DDT | 0.0007 | Lindane | 0.0013 | | |
| | | | DDT | 0.0003 | | | Lindane | 0.0003 | DDT | 0.0012 | | |
| | | | | | | | Aldrin | 0.0001 | | | | |
| 3 San Joachin | DDT | 0.0009 | Lindane | 0.0014 | | | Lindane | 0.0017 | Lindane | 0.0009 | | |
| | | | Dieldrin | 0.0004 | | | DDT | 0.0012 | | | | |
| | | | DDT | 0.0011 | | | | | | | | |
| 4 Caimanero | Lindane | 0.0016 | Dieldrin | 0.0003 | Lindane | 0.0012 | Lindane | 0.004 | Lindane | 0.0009 | Epox. Heptachlorine | 0.0002 |
| | DDT | 0.0011 | | | | | DDT | 0.0035 | | | Heptachlorine | 0.002 |
| | | | | | | | Aldrin | 0.002 | | | | |
| | | | | | | | Heptachlorine | 0.0027 | | | | |

Source: Table created using data from Galindo-Reyes (1990).

The largest amount of pesticides found in the month of August is mainly caused by the fact that it coincides with the time in which agricultural land is being prepared (i.e. application of fertilizers) and to an increase in evaporation (Galindo-Reyes *et al.*, 1992). **Table 6.4** shows a comparison of the safe water limits established by the Federal Water Pollution Control Administration (FWPA) from the U.S. Department of the Interior with the values found by Galindo-Reyes (1990). Clearly, the values found in the lagoon system for aldrin and lindane were found to exceed the permissible levels established for aquatic life. Nonetheless, although it was beyond the scope of this study to consider the evaluation of these pesticides in great detail, this comparison does give a clear indication that these pesticides may be damaging lagoon species (i.e. persistence of lindane in sediments samples) and could also have a negative impact on shrimp culture. However, as previously discussed a means of evaluating the negative impact from these chemicals would be to establish a monitoring programme.

**Table 6.4. Interpretation for water quality.**

**( permissible levels in μg / l )**

| Organochloride | Drinking water (desirable level) | Agriculture & livestock | Aquatic life | Lagoon range water samples |
|---|---|---|---|---|
| Aldrin | 0.0 | 17.0 | 0.01 | 0.08 - 1.20 |
| Clordine | 0.0 | 3.0 | 0.04 | |
| DDT | 0.0 | 42.0 | 0.002 | |
| Dieldrin | 0.0 | 17.0 | 0.005 | |
| Endrin | 0.0 | 1.0 | 0.002 | |
| Heptachlorine | 0.0 | 18.0 | 0.01 | |
| Epox. Heptachlorine | 0.0 | 18.0 | * | |
| Lindane | 0.0 | 56.0 | 0.02 | 0.06 - 1.04 |
| Metoxchlorine | 0.0 | 35.0 | 0.01 | |

Note: * No data. Source: FWPA (1992).

Field studies revealed that most of the shrimp farms in the Huizache-Caimanero lagoon carry out most of their water supply and discharge within the lagoon which already has poor water circulation. Some authors (e.g. CONSULTEC, 1990) have thought that water quality could benefit from the establishment of new shrimp farms in the sense that water pumping operations could increase or improve the water circulation within the lagoon, which is sometimes small or non-existent, especially during the dry period. However, this approach is probably unacceptable since although water circulation may improve, water quality is likely to deteriorate due to the semi-closed nature of the lagoon (i.e. poor communication with the ocean).

### 6.2.1.7 Soils

Soils are classified according to the FAO/UNESCO (1970) classification modified by one of Mexico's mapping agencies (INEGI) to suit the prevailing conditions of the country (see **Chapter 3**). Most common types of soils in this lagoon region are phaeozems located on the continental portion of the lagoon system, whilst the second most common type of soils are the regosols which are found along the sand barrier adjacent to the ocean, and on some mountains alongside the lagoons (**Figure 6.23**) ( SPP, 1982). Sediments inside the Huizache-Caimanero lagoons are mostly clay-loam soils, the distribution of which has been attributed to the siltation process (De la Lanza and García-Calderón, 1991).

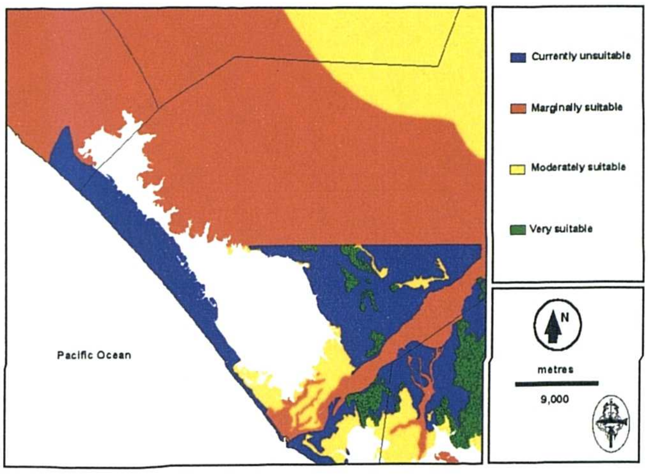


**Figure 6.23. Soils in the Huizache-Caimanero region.**

### 6.2.1.8 Topography

According to Tamayo (1962) the lagoon basin has a mean elevation of 100 m, its general orientation is NNW-SSE and it is located on a large plain which slopes gently towards the ocean only interrupted by small hills and low mountains of up to 400 m high, which are adjacent to the eastern shore of the lagoon (**Figure 6.24**).

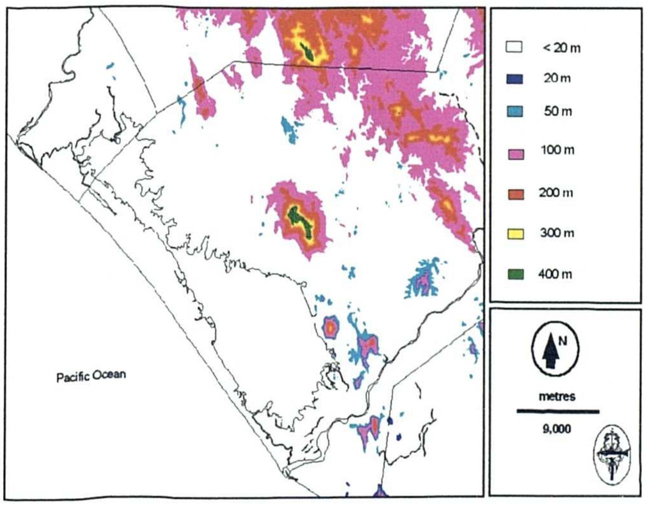


**Figure 6.24. Topography in the Huizache-Caimanero lagoon region.**

### 6.2.2 Land uses

#### 6.2.2.1 Population density and urban development.

The Huizache-Caimanero lagoon system is located in two municipalities. The Huizache lagoon and its tributaries are found in the municipality of Mazatlán, and the Caimanero lagoon together with its surrounding esteros are located in the municipality of Rosario (Acuipesca Consultores, 1993) (**Figure 6.25**). In terms of population, according to the last census (1990) there are 314, 345 and 47,416 inhabitants in these municipalities, respectively, which correspond to 14.3% and 2.2% of the whole state (De la Lanza and García-Calderón,1991; Acuipesca Consultores, 1993).

The principal consuming centres in proximity to the Huizache-Caimanero region are located in Rosario, Villa Union, Escuinapa and Mazatlán (Acuipesca Consultores, 1993 ). At a local level, there are two shrimp processing plants and two ice factories in Rosario, whilst in the neighbouring municipalities of Escuinapa and Mazatlán there are also suitable storage places (CONSULTEC, 1990).

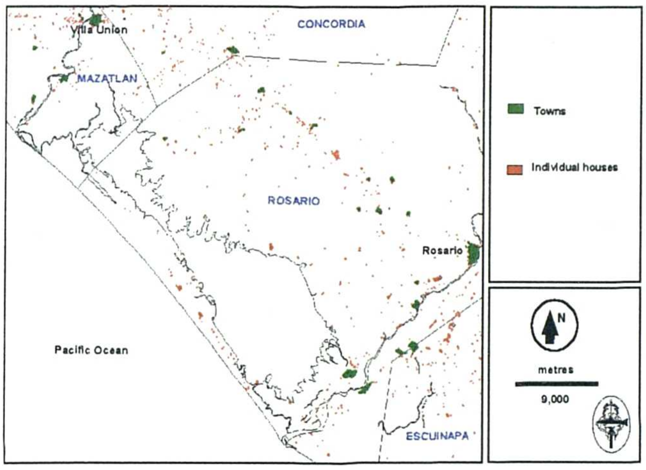


**Figure 6.25. Population density in the Huizache-Caimanero lagoon region.**

#### 6.2.2.2 Transportation and communication

A railway runs adjacent to both the Huizache and Caimanero lagoons leading to Mexico City. Moreover, there is an important highway that leads to Mexico City located on the north of the Huizache-Caimanero lagoon system connecting the town of Villa Union (north of Huizache) and the town of Rosario (north of Caimanero) (**Figure 6.26**). A series of gravel roads originate from this important highway which mostly lead to Caimanero, in particular its southern portion. Conversely, there are very few roads that lead to the Huizache lagoon and most of these are unimproved. The Huizache lagoon is therefore not accessible throughout the year.

During the driest part of the year, from March to June, desiccated areas inside the lagoon systems are utilized as optional roads (**Plate VII**). These activities are damaging to the environment since they isolate important parts of the system, and impede the development of natural communities which could contribute to increase primary production (Arenas, 1979).

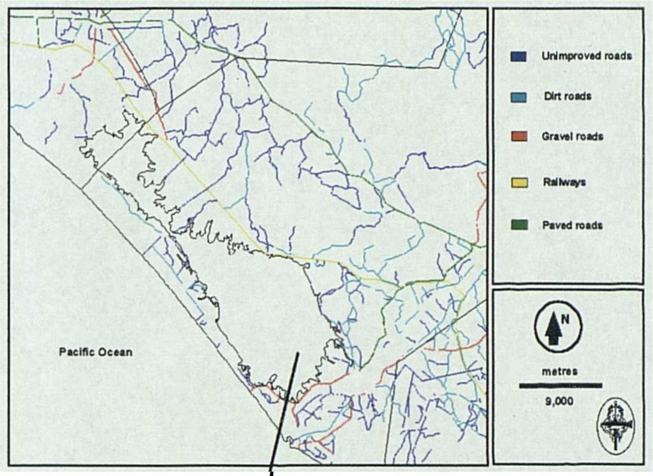


**Figure 6.26. Roads in the Huizache-Caimanero region.**

**Plate VII. Optional circulation routes inside the Caimanero lagoon (April, 1995).**

### 6.2.2.3 Energy

Power lines run parallel to both the main highway and the railway adjacent to the Huizache-Caimanero lagoon system (**Figure 6.27**). Offshoots of these power lines lead to Villa Union running close to the Huizache lagoon, and from Rosario adjacent to the Caimanero lagoon.

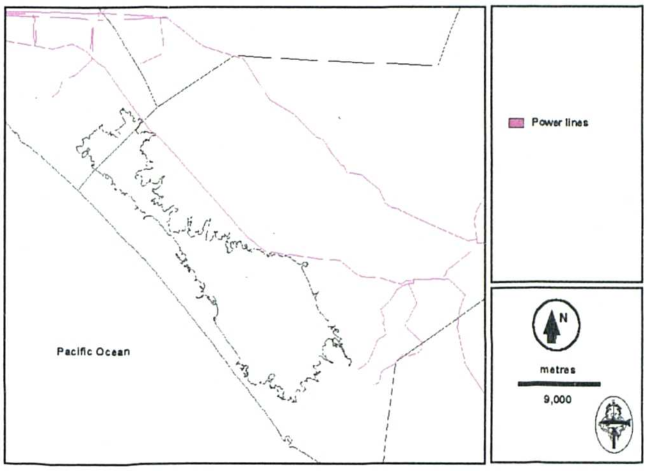


Figure 6.27. Energy in the Huizache-Caimanero region.

### 6.2.2.4 Land tenancy

In the early 1960's land began to be distributed in the Huizache-Caimanero lagoon region in an excessive fashion, without organization. This initiated the establishment of population centres very near the lagoons, as well as an accelerated deforestation which, in turn, has increased the siltation problems in the lagoon system (Díaz-Rubín *et al.*, 1992). The land is either communal or privately owned (**Figure 6.28**). Aquatic resources are the preserve of cooperatives, and concessions to businessmen and small ownership are scarce, except in urban and suburban areas (Acuipesca Consultores, 1993; Sanchez and Vega, 1995). Potential areas for fishing and aquaculture are in the majority of cases communal (i.e. very suitable classification) and are given by concession only by specific authorisation of the Fisheries Secretariat (Acuipesca Consultores, 1993). Aquaculture is less likely to develop on privately owned land since ownership in this region is mostly located in urban areas (i.e. unsuitable classification).

Land cost in the region is very variable depending on the land quality as well as its use. For example, agricultural land varies considerably in price depending on the soil quality, and whether the activity is seasonal or irrigated (Acuipesca Consultores, 1993 ).

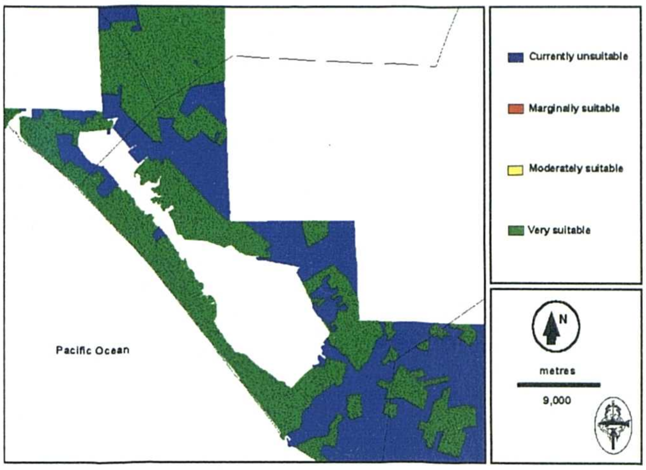


**Figure 6.28. Land tenancy in the Huizache-Caimanero region.**

Source: Sanchez and Vega (1995).

### 6.4.2.5 Agriculture

Large areas of vegetation have been cleared for agriculture (CONSULTEC, 1990). Most of the coastal strip, including the sand barrier, is used for agriculture (**Figure 6.29**), the major crops being maize, tomatoes, beans, chillies and mangoes (Menz, 1976).

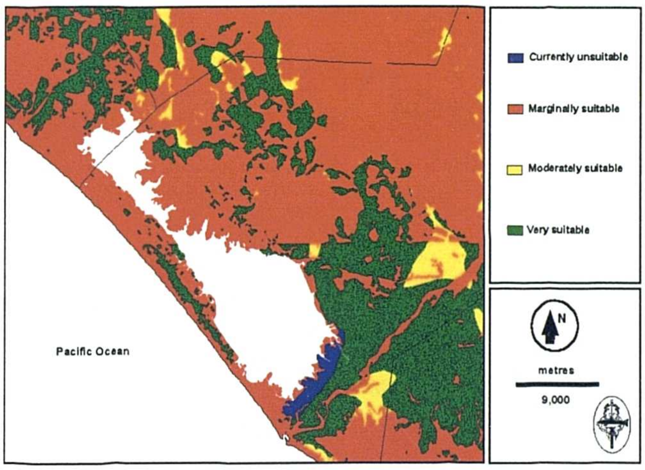


**Figure 6.29. Agriculture in the Huizache-Caimanero region.**

### 6.2.2.6 Livestock rearing

Livestock rearing is also an important production activity, most of which is carried out on the low hills (**Figure 6.30**). The most common livestock is cattle (Díaz-Rubín *et al.*, 1992).

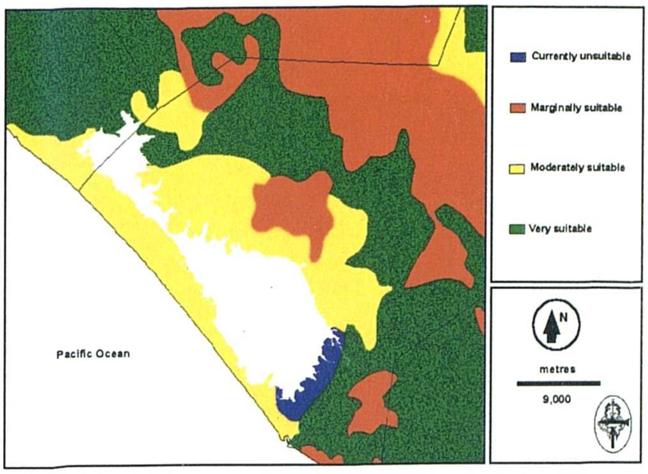


**Figure 6.30. Livestock rearing in the Huizache-Caimanero region.**

### 6.2.2.7 Forestry

Terrestrial vegetation is dominated by deciduous forests. In the highlands, oak forests and pine and oak associations predominate, whilst the coastal zone is characterized by mangroves and halophytic vegetation (**Figure 6.31**). The hills close to the lagoon are densely covered with xerophytic associations of spiny leguminous trees up to 10 m high, interspersed with various shrubs, vines and cacti. The municipality has a wood mill which mainly specialises in processing pine, oak and ash (Menz, 1976).

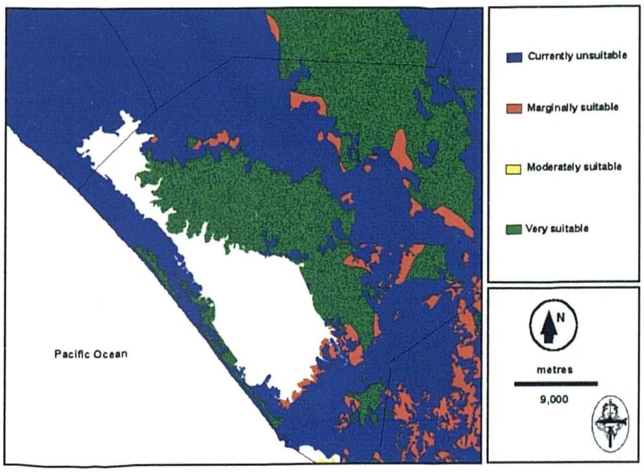


**Figure 6.31. Forestry in the Huizache-Caimanero region.**

### 6.2.2.8 Fishing

The ichthyofauna of the Huizache-Caimanero coastal lagoon system is very diverse comprising 27 families, 46 genera and 60 species; 15% of the species are freshwater, a further 15% typically estuarine fishes which visit the estuary as adults looking for food, 40% are marine fishes which use the estuary as a natural breeding area, and 30% are marine fishes which are occasional visitors. The species which are most representative in terms of number of individuals and biomass during the year are: *Dipterus pruvianus, Pomadasys macracanthus, Mugil curema* and *Galeichthys caerulescens.* The last two are the most important species from the point of view of the biological and fishing aspects of the lagoon system (Amezcua, 1977).

The most important commercial aquatic species in this lagoon system are the shrimp; mainly *Penaues vannamei, P. stylirostris, P.californiensis* and *P.brevirostris* (Díaz-Rubín *et al.*, 1992). The most important is the white shrimp (*Penaeus vannamei*) which constitutes about 90% of the total capture, followed by *P. stylirostris.* These two species depend on these lagoons for their reproduction, although the second is not well adapted to the low salinity conditions which prevail at certain times of the year.

Since the 1960's the number of fishing co-operatives, as well as the fishing effort, the quantity of ships, number of motors and also fishing gear, have increased considerably. Fishery resources in the lagoon system have been governed by cooperatives since the 1920's, and there are currently 19 Social Cooperatives with 1,441 members which have 1,041 small boats or "pangas", and 387 motors (Díaz-Rubín *et al.*, 1992).

Shrimp production has varied considerably over the last 32 years. As shown in **Figure 6.32** dramatic fluctuations in production have occurred due to natural and human intervention (e.g. siltation and creation of artificial barriers and channels) (Díaz-Rubín *et al.*, 1992).

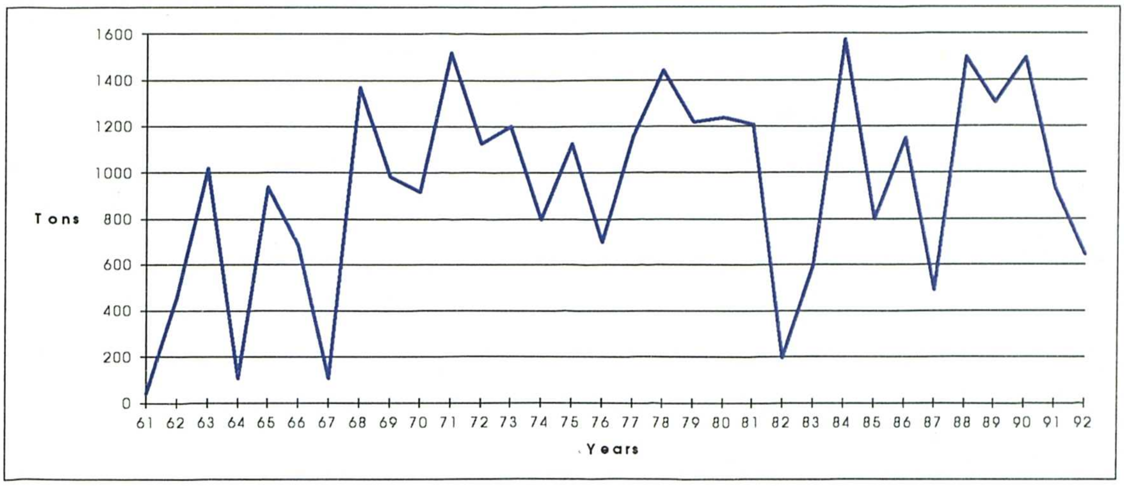
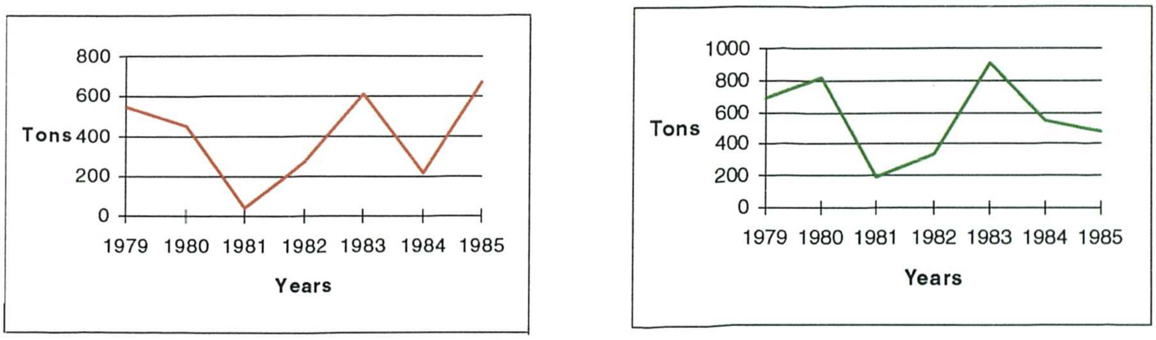


**Figure 6.32. Shrimp (heads on) production (tons) in the Huizache-Caimanero lagoon system during a 32 year period (1960-1992).**

Source: Hernandez-Carballo (1991). Note: Years are expressed as double figures (e.g. 61 for 1961).

**Figure 6.33A** shows shrimp production figures for the Huizache lagoon and **Figure 6.33B** for Caimanero. Clearly production figures are higher for the 1979 to 1985 period in Caimanero than in Huizache (except in 1985). Annual average fish capture for Huizache is 398 tons and for Caimanero 565 tons. According to Flores-Verdugo (In press) differences in production are probably attributed to the high salinities found in Caimanero, and to the differences in size between the two lagoons.



**A** **B**

**Figure 6.33A. Shrimp capture Huizache. B. Shrimp capture Caimanero.**

Source: Hernandez-Carballo (1991).

Although penaeids support the most valuable fishery in the lagoons of Mexico's west coast, a number of finfish species are also exploited (Warburton, 1979).These species are mainly puffer fish, croaker, catfish and mullets (**Table 6.5**).

**Table 6.5. Most locally important fish species captured in the Huizache-Caimanero Lagoon (other than shrimp).**

| | 1989 | | 1990 | | 1991 | |
|---|---|---|---|---|---|---|
| **Species** | **Ton** | **%** | **Ton** | **%** | **Ton** | **%** |
| Puffer fish | 5.1 | 0.36 | 0.7 | 0.05 | 7.2 | 0.91 |
| Croaker | 17.5 | 1.23 | 7.9 | 0.58 | 36.1 | 4.54 |
| Catfish | 52.1 | 3.65 | 270.7 | 19.93 | 29.8 | 3.75 |
| Mullet | 135.5 | 9.5 | 146 | 10.75 | 45.2 | 5.68 |

Source: Díaz-Rubín *et al.* (1992).

Due to a considerable decrease in shrimp capture (see **Chapter 1**), the Mexican government has established a closed season during which period it is illegal to capture any shrimp. For coastal fishing, the season starts on September 16th and ends on July 16th. In the coastal lagoons the season is longer than in the sea. Tapos in the Huizache-Caimanero lagoon system are removed on April 16th and replaced on August 12th. This covers the second half of the dry season and the first two months of the wet season. Although the tapos are sealed on August 12th the fishery does not start until early September because the fishermen allow the juvenile shrimp to grow larger before fishing begins (i.e. date is decided by the Fisheries Delegate and is also attributed to political pressures). As may be expected the tapos are sealed when populations of shrimp in the lagoons are highest (in the wet season) and they are opened when populations are lowest (in the dry season) when the commercial fishery is poor (Edwards, 1978a).

### 6.2.2.9 Agglomeration

#### *Shrimp culture*

In the Huizache-Caimanero region shrimp farms have been constructed since 1970 (see **Chapter 1**) but did not remain in operation, mainly due to the environmental and social problems mentioned. Moreover, it is of great concern that some of the most recent shrimp farms have been constructed in sub-optimal areas. For example, a large shrimp farm was constructed "inside" the lagoon system as clearly shown in **Plate VIII**, which has consequently caused much environmental and socio-economic damage, particularly as the area used for fishing has been greatly reduced.

**Plate VIII. LANDSAT view of a shrimp farm constructed "inside" the Huizache-Caimanero lagoon system (Summer, 1992).**

**Figure 6.34** shows the location of the existing shrimp farms which account for 26 $km^2$ of land, as well as the location of the proposed shrimp farms (16 $km^2$).

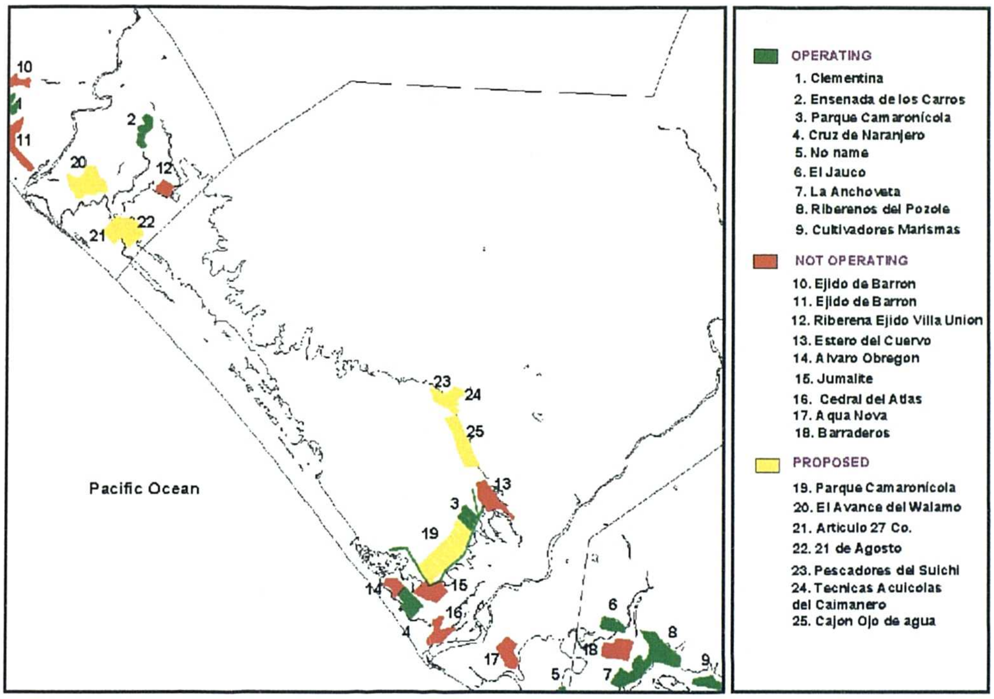


**Figure 6.34. State of development of shrimp farms in the Huizache-Caimanero lagoon.**

In the northern portion of the Huizache lagoon only one shrimp farm has been operating, named Ribereña Ejido Villa Union. Interestingly, as shown in **Figure 6.35**, production was recorded for 1987 and 1988, but, for some unknown reason production stopped between 1989 and 1993 and started again in 1994.

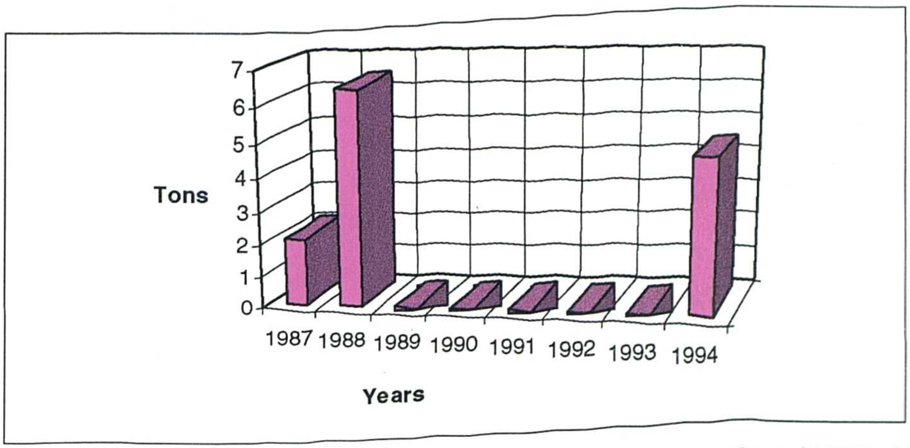


**Figure 6.35. Shrimp culture production in the Huizache lagoon system (1987- 1994).**
Source: Secretaría de Pesca (1995b).

In the Caimanero lagoon, 4 shrimp farms have been in operation since 1987. **Figure 6.36** shows that very low production was recorded between 1987 and 1993. However, for 1994 there was a considerable boost in production, probably due to the maintenance and construction of new channels.

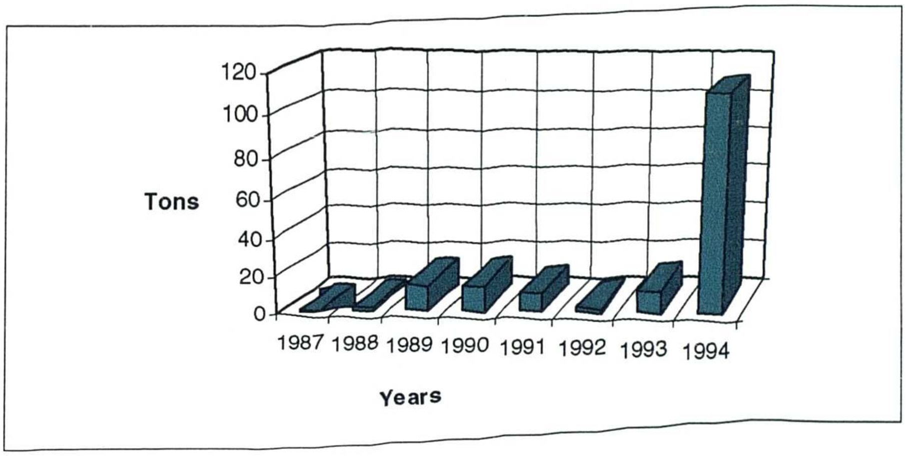


**Figure 6.36. Shrimp culture production in the Caimanero lagoon system (1987- 1994).**
Source: Secretaría de Pesca (1995b).

### 6.2.2.10 Sources of postlarvae

Postlarvae for shrimp culture are normally obtained from the wild, most commonly on the river mouths of Baluarte and Presidio, or close to the municipality of Escuinapa (Díaz-Rubín *et al.*, 1992). Even though proximity to natural postlarvae may be a major advantage, shrimp culture cannot be sustained by relying only on collection of seed from the wild. For example, some countries in South America, such as Ecuador, which lack a sufficient supply of seed, have seen the development of their shrimp farming industry failing expectations (Lee, 1989). Hence, resistance to fishing for both postlarvae and broodstock may come from established fishing interests concerned about real or perceived detrimental impacts on wild stock and competition from aquaculture. This has occurred in Mexico following the capture of increasing number of shrimp postlarvae, for which reason a closed season has already been established.

The problem of natural postlarvae availability can be solved by hatcheries. There are only three hatcheries in Sinaloa, located in the south of the state. Despite this, most of them have not been successful mainly due to a lack of experience, and therefore the majority of the shrimp farms still rely on natural postlarvae. Of the three existing hatcheries, two of them are in the Huizache-Caimanero region (**Figure 6.37**). Both of them are located along the sand barrier adjacent to the ocean; one of them is operating (confirmed by field survey in April, 1995), adjacent to the Huizache lagoon and the other is under construction and is adjacent to the Caimanero lagoon. It is hoped that these hatcheries will become successful and that they will have a positive agglomeration effect.

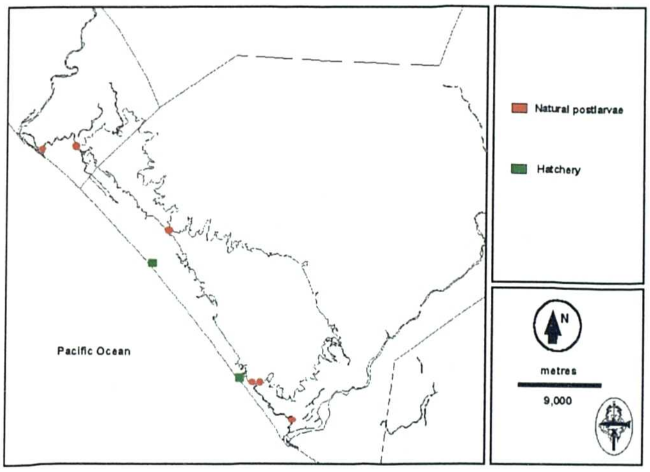


**Figure 6.37. Sources of postlarvae in the Huizache-Caimanero region.**

### 6.2.11 Proposed conservation areas

There are three mangrove species in this area: *Rhizophora mangle, Laguncularia racemosa* and *Avicenia nitida* (Edwards,1977), and according to Flores-Verdugo (1989) these mangrove forests are the least exploited in the region. River mouths (Boca de Barron and Boca Chametla), estuary channels and marshes are areas in which mangroves are most abundant (**Figure 6.38**). A large number of migrating birds such as *Ardea herodias*, *Egreta* spp, *Ajajai ajaja* occur here, together with a great diversity of birds commonly found on beaches, such as *Pelecanus occidentalis*. These areas are also important for conservation because they allow access of marine and brackish water into the lagoon system, as well as access of shrimp postlarvae and other aquatic animals (Flores-Verdugo, In press). Beaches which are adjacent to the Presidio and Baluarte river mouths were identified as nesting areas for marine turtles such as *Lepidochelis olivacea* (golfina), and to a lesser extent for *Eretmochelis imbricata*.

From his bird census carried out in 1994 along the coasts of Sonora, Sinaloa and Nayarit Flores-Verdugo (In press) estimated that there are approximately 1,600,000 birds, 10% of which are found in Huizache-Caimanero. Most birds are found in the continental part of the lagoon system, but the largest number are concentrated in the south-east area of the Caimanero lagoon.

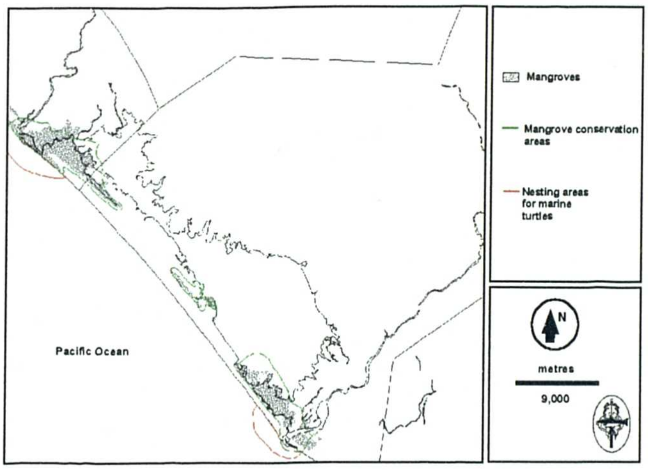


**Figure 6.38. Proposed conservation areas in the Huizache-Caimanero region according to Flores-Verdugo (In press).**

## 6.3 SUMMARY

Developing from the state-level assessment, the important Huizache-Caimanero lagoon was selected for more detailed studies on environmental and socio-economic issues. The lagoon was found to be an excellent candidate for GIS evaluation due to the quantity of data available.

Due to the complexity and dynamic nature of the factors influencing the Huizache-Caimanero lagoon system, an extensive review of the main site factors for semi-intensive shrimp farming was conducted. Clearly, the most significant of these factors was water availability due to the natural cycle in the lagoon, as well as prevailing environmental problems, such as lack of water due to siltation. A detailed assessment was carried out to evaluate how site factors influenced water availability on an annual and seasonal basis, in order to determine the quantity and quality of water available in the lagoon system for shrimp farming.

For this more detailed evaluation a 20 x 20 m pixel size was chosen. Spatial variations of the factors involved at the state and individual site-level showed that differing functions dominated between two scales. Although most of the paper maps obtained were on a scale of 1:50,000, and therefore at a much more detailed level when compared to the state-level assessment, some other data were not found on this scale and so the state-level data had to be used. Moreover, because some of the data (e.g. social factors) were only available in choropleth form, both the interpretations and the state-level classifications of some of these factor data, which were already assessed and presented in **Chapter 4**, are included in the Huizache-Caimanero evaluation and only the new factors (i.e. water quality) and the new adjustments have been presented in this chapter.

# CHAPTER 7

# GIS-BASED MODELS FOR SEMI-INTENSIVE SHRIMP CULTURE IN THE HUIZACHE-CAIMANERO LAGOON SYSTEM

## 7.1 Background

The procedures involved in creating the models for the Huizache-Caimanero lagoon system were very similar to those used for the state-level models, although there were some important differences (**Figure 7.1**). Firstly, the Huizache-Caimanero model creation procedures did not involve the use of questionnaires - mainly because the experts who completed the questionnaires in the state-level assessment would need too much time to become familiar with the lagoon system's special characteristics (e.g. siltation, water level). Consequently, the results presented in this chapter were mostly dependent upon decisions taken by the author which, in turn, were based upon the literature available (see **Appendix 4**). Secondly, a time-series analysis procedure, which was not included in the state-level assessment due to lack of data, was included in the assessment of the lagoon system.

## 7.2 Materials and methodological framework

### 7.2.1 Spatial coverage of the analysis

A great advantage of a GIS is that the system can operate on any physical scale specified by the user, and this suggests its use in more detailed site selection work. However, when using raster-based GIS software, a single pixel size must be chosen by the user in order to carry out spatial analysis. By contrast, vector graphics are not restricted to one size and can be used to cover a particular raster image (e.g. it is common to overlay accurate vector boundaries of administrative districts of a study area on a thematic raster image of that area).

The 250 X 250 m pixel size selected as optimum for the state-level assessment was too coarse for more detailed analysis, and for field verification work. Ross *et al.* (1993) noted that the selection of scale is a trade-off between effort in digitizing the data and the spatial objectives of the GIS. They found that in selecting a site for salmonid cage culture in a 800 m x 800 m bay, a 25 m resolution was too coarse and did not allow satisfactory processing, whereas a 10 m resolution proved to be optimum.

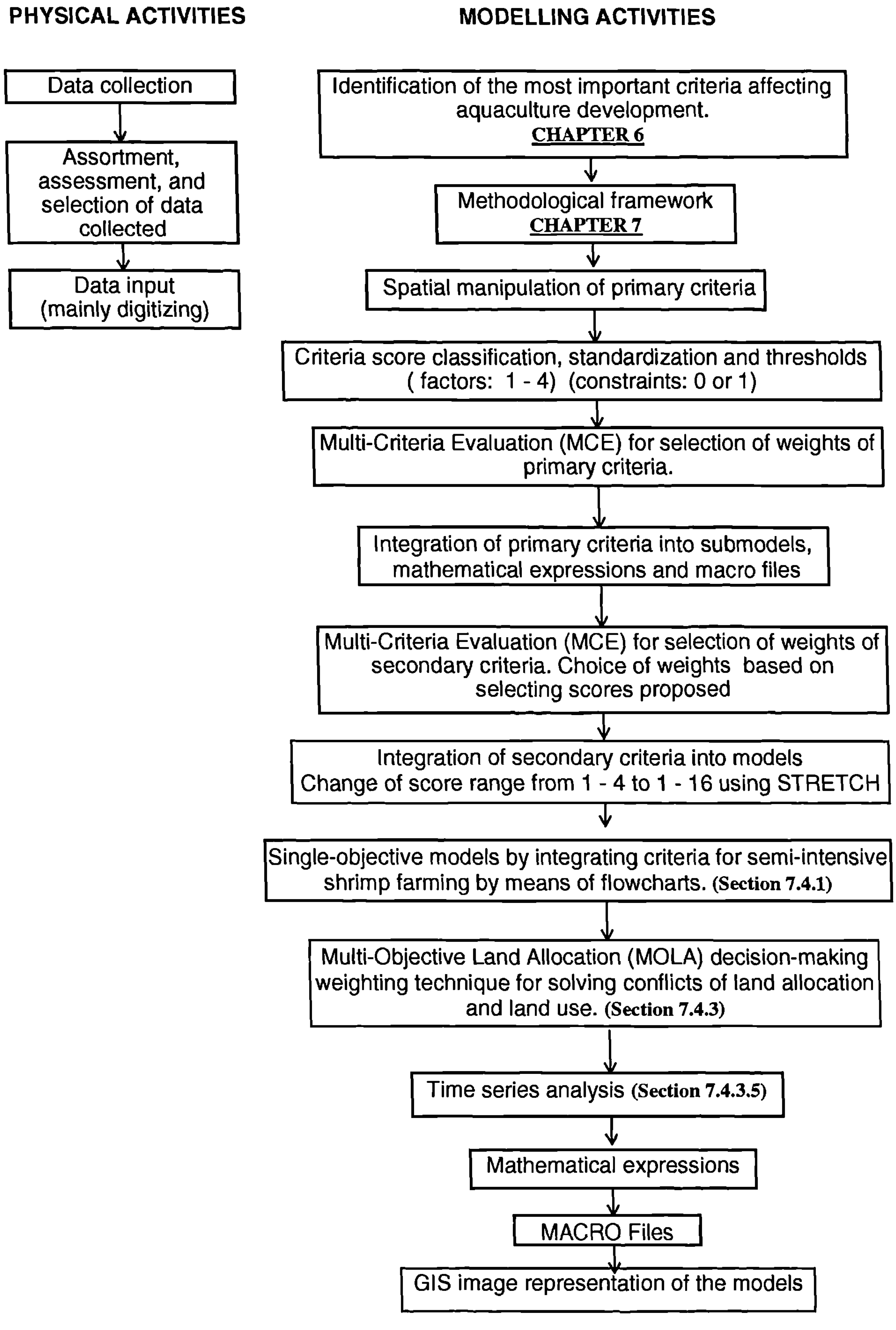


**Figure 7.1. Schematic diagram of procedures that were involved in creating the GIS-based models for shrimp farming in the Huizache-Caimanero lagoon system.**

For this study, pixel size needed to allow the identification of all the major components of the lagoon system (i.e. communication with the ocean and between lagoons, rivers, towns, roads). It was also necessary to be able to visualize and analyze as many of the shrimp farm components as possible (i.e. inlets, outlets). The final size of the image created is a limiting factor. A very small pixel size, for example 10 meters, would probably be very good for the water quality interpolation function as noted by Ross *et al.* (1993). However, if 10 m were to be chosen then the final image size for this study would have consisted of 14,400,000 pixels and hence it would be very large and less manageable when carrying out some GIS functions (see **Chapter 3** for data storage). It was found during the preliminary state-level assessment that even at a 250 x 250 m resolution (3,840,060 pixels) the processing of some functions proved to be extremely slow. For example, when carrying out distance analysis a single distance image took an average of 1.5 hours to process. Finally, a 20 m scale was selected in which the study area was composed of 2,357 columns by 2,156 rows, and each individual image or database layer therefore consisted of 5,081,692 pixels without compression (see **Chapter 3** for image size and compression). Any image size limitation was related to the computer's storage and processing capacity, but this should not be considered as an important limitation in future studies since Windows 95, more RAM and a 150 Mhz Pentium will cut processing time dramatically.

### 7.2.2 Spatial accuracy of paper maps

Based on the methodology presented in **Chapter 3**, a 1/50 inch map error and a 0.0254 metre/inch unit conversion were used for calculating the spatial accuracy of the paper maps for the 1:50,000 maps that were used for Huizache-Caimanero (**Table 7.1**).

**Table 7.1. Data quality values for 1:50,000 scale maps used for the Huizache-Caimanero lagoon evaluation.**

| Scale | Acceptable error on ground (m) | Allowable RMSE (m) | Calculated RMSE | Snap tolerance | Point tolerance |
|---|---|---|---|---|---|
| 1:50,000 | 25 | 16 | 0.0005 | 1 | 0.5 |

### 7.2.3 Selection of factors for GIS analysis

The factors and constraints selected for this GIS are shown in two tables (**Table 7.2** and **7.3**). Overall, as in the state-level assessment, approximately 90% of the data compiled was in the form of paper maps and statistical information. Other sources not included in the state-level assessment included field data collection (see **Chapter 8**).

As expected, tables **7.2** and **7.3** show that most of the data for this lagoon system was much more detailed in comparison to the state-level data - for this lagoon the majority of the data were obtained at a 1:50,000 scale. Most data were obtained from INEGI in Mexico City, although a great deal of information was also obtained from other places, such as Mazatlán and the United Kingdom (see **Appendix 4**). Most data were produced between 1966 and 1994. The oldest paper map data source is dated 1969 (a bathymetry chart of the Huizache-Caimanero lagoon system), and the most recent are the land ownership charts for Huizache-Caimanero lagoon system and the studies carried out by Mexican researchers for this lagoon system (e.g. Flores-Verdugo, In press). A variety of scales was used, and most of the map projections were created in a UTM projection.

Table 7.2. Sources of data for the environmental criteria for the Huizache-Caimanero lagoon system.

| CRITERIA | NAME | SOURCE | LOCATION | DATE | PROJECTION | SCALE |
|---|---|---|---|---|---|---|
| Surface water | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Future dam construction | Baluarte-Presidio project.Construction location | SARH | Sinaloa,Mexico | 1994 | UTM | 1:100,000 |
| Groundwater | Hydrology and groundwater chart | SPP | Mexico City | 1981 | LCC | 1:1000,000 |
| Evaporation | Evaporation and water deficit chart | SPP | Mexico City | 1983 | LCC | 1:1000,000 |
| Evaporation | Monthly & annual evaporation in mm data | SARH | Mexico City | 1995 | - | Choropleth |
| Rainfall | Annual mean rainfall in mm data | SPP | Mexico City | 1983 | LCC | 1:1000,000 |
| Rainfall | Monthly and annual rainfall in mm data | SARH | Mexico City | 1995 | - | Choropleth |
| Temperature | Annual mean temperature chart | SPP | Mexico City | 1983 | LCC | 1:1000,000 |
| Temperature | Monthly & annual temperature in mm data | SARH | Mexico City | 1995 | - | Choropleth |
| Bathymetry | Batimetría de Huizache-Caimanero | Soto-Lopez | Ensenada, Mexico | 1969 | Plane | - |
| Mangroves | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Mangroves | Land use chart | CETENAL | Mexico City | 1974 | UTM | 1:50,000 |
| Soils type and texture | Soils chart | CETENAL | Mexico City | 1974 | UTM | 1:50,000 |
| Soils | Soils chart | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Topography | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Digital elevation model | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Natural postlarvae | Fishing communities | Pesca | Sinaloa, Mexico | 1993-95 | UTM | 1:250,000 |
| Forestry | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Forestry | Potential use of forestry | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Forestry | Land use chart | CETENAL | Mexico City | 1974 | UTM | 1:50,000 |
| Agriculture | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Agriculture | Potential use of agriculture | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Agriculture | Land use chart | CETENAL | Mexico City | 1974 | UTM | 1:50,000 |
| Agriculture suitability | Baluarte-Presidio project.Construction location | SARH | Sinaloa,Mexico | 1994 | UTM | 1:100,000 |
| Livestock rearing | Potential use of livestock rearing | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Livestock rearing | Land use chart | CETENAL | Mexico City | 1974 | UTM | 1:50,000 |
| Aquaculture suitability | Aquatic farms & level of impact | Flores-Verdugo | Sinaloa, Mexico | In press | Plane | - |
| Shrimp farm locations | Aquatic farm locations | CONSULTEC, EPAC | Mexico City | 1990; 91 | UTM | 1:250,000 |
| Shrimp farm locations | Shrimp farm location and area | Pesca | Sinaloa, Mexico | 1993 | UTM | 1:250,000 |
| Shrimp farm locations | LANDSAT TM image | BIOPESCA | Ensenada, Mexico | 1992 | UTM | 1:100,000 |
| Cities, towns, villages | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Urban development | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Urban development | Road state, chart (municipality areas) | SCT | Mexico City | 1986 | UTM | 1:800,000 |
| Roads | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Conservation areas | Areas of restauration and conservation | Flores-Verdugo | Sinaloa, Mexico | In press | Plane | - |
| Conservation areas | Landscape units | Flores-Verdugo | Sinaloa, Mexico | In press | Plane | - |

TERMINOLOGY: SPP (Budget and Programming Secretariat), INEGI (National Institute of Statistics, Geography and Information), SCT (Communications and Transport Secretariat). SARH (Secretaría de Agricultura y Recursos Hidráulicos). CETENAL (Comisión de Estudios del Territorio Nacional). EPAC is a private consulting company which was hired to do a state study for the Fisheries Secretariat (Secretaría de Pesca). Pesca refers to the Fisheries state central office in Mazatlán. Projections: LCC (Lambert Conformal Conic), UTM (Universal Transverse Mercator).

Table 7.3. Sources of data for the socio-economic criteria for the Huizache-Caimanero lagoon system.

| CRITERIA | NAME | SOURCE | LOCATION | DATE | PROJECTION | SCALE |
|---|---|---|---|---|---|---|
| Population density | Population census data. Sinaloa state | INEGI | Mexico City | 1991 | - | Choropleth |
| Staff, technical assistance | Population census data. Sinaloa state | INEGI | Mexico City | 1991 | - | Choropleth |
| Agglomeration | Aquatic farm locations | CONSULTEC, EPAC | Mexico City | 1990; 91 | UTM | 1:250,000 |
| Agglomeration | Shrimp farm location and area | Pesca | Sinaloa, Mexico | 1993 | UTM | 1:250,000 |
| Economically active population | Population census data. Sinaloa state | INEGI | Mexico City | 1991 | - | Chroropleth |
| Income | Population census data. Sinaloa state | INEGI | Mexico City | 1991 | - | Choropleth |
| Production activities | Population census data. Sinaloa state | INEGI | Mexico City | 1991 | - | Choropleth |
| Natural postlarvae | Fishing communities | Pesca | Sinaloa, Mexico | 1993 | UTM | 1:250,000 |
| Roads | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Urban development | Road state, chart (municipality areas) | SCT | Mexico City | 1986 | UTM | 1:800,000 |
| Urban development | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Markets | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Inputs | Potential use of agriculture chart | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Inputs | Potential use of livestock rearing chart | SPP | Mexico City | 1982 | LCC | 1:1000,000 |
| Energy | Topography chart | INEGI | Mexico City | 1980-93 | UTM | 1:50,000 |
| Land tenancy | Plano Mosaico Fotogramétrico | Sanchez and Vega | Sinaloa, Mexico | 1995 | UTM | 1:20,000 |
| Municipalities | Road state chart (municipality areas) | SCT | Mexico City | 1986 | UTM | 1:800,000 |

TERMINOLOGY: SPP (Budget and Programming Secretariat), INEGI (National Institute of Statistics, Geography and Information), SCT (Communications and Transport Secretariat). SARH (Secretariat of Agriculture and Hydrological Resources). Palacio de Gobierno (Central state government office of Sinaloa located in Culiacán). EPAC is a private consulting company which was hired to do a state study for the fisheries secretariat (Secretaría de Pesca). Pesca refers to the Fisheries state central office in Mazatlán. Projections: LCC (Lambert Conformal Conic), UTM (Universal Transverse Mercator).

Note: The Municipality factor served to create chloropleth maps when statistical data was the only source of information available (i.e. population density, staff & technical assistance, economically active population, income, production activities and urban development).

### 7.2.4 Assessment and classification of the factors and constraints compiled for semi-intensive shrimp culture in the Huizache-Caimanero lagoon system.

As in the state-level assessment factors were grouped naturally, and submodels were also used. The factors used in this study are presented in **Table 7.4** for the environmental factors and **Table 7.5** for the socio-economic factors.

**Table 7.4. Factors for environmental assessment for semi-intensive shrimp culture.**

| PHYSICAL and ENVIRONMENTAL RESOURCES | WATER QUALITY | LAND USES and INFRASTRUCTURE |
|---|---|---|
| Lagoons | Bathymetry | Population density |
| Coast-line | Water temperature | Towns |
| Rivers and streams | Dissolved oxygen | Villages |
| Groundwater | Salinity | Houses |
| Annual water balance | | Paved roads |
| Monthly water balance | | Railways |
| Air temperature | | Gravel roads |
| Soil texture | | Dirt roads |
| Soil type | | Unimproved roads |
| Topography | | Agriculture |
| | | Livestock rearing |
| | | Forestry |
| | | Aquaculture |

**Table 7.5. Factors for socio-economic assessment for semi-intensive shrimp culture.**

| SOCIAL IMPACTS | PRODUCTION MODIFIERS | MARKET POTENTIAL |
|---|---|---|
| Age-group | Energy | Population density |
| Primary sector | Natural postlarvae | Salary/wage structure |
| Secondary sector | Agriculture | Fish consumption |
| Tertiary sector | Livestock rearing | Preferred species |
| Job creation | Towns | Fishing activity |
| Land tenancy | Villages | Hotels |
| | Houses | Fish processing plants |
| | Shrimp farms | Markets |
| | Hatcheries | |
| | Paved roads | |
| | Railway | |
| | Gravel roads | |
| | Dirt roads | |
| | Unimproved roads | |
| | Road types | |
| | Communications | |
| | Support centres | |

Meaden and Kapetsky (1991) noted that when spatial variations of the factors involved in a GIS analysis are examined at very different spatial scales then differing functions may dominate. This is clearly the case for the present study. During the initial state-level assessment distance functions were particularly important when evaluating proximities of shrimp farms to water resources, main cities, markets and pollution sources. However, for the Huizache-Caimanero lagoon study area distances to main cities and markets were of less relevance, and other considerations such as water quality factors were of great relevance.

The classification of most of the spatial factors involved in the spatial analysis was described earlier (**Chapter 4**). Most classifications remain the same for the Huizache-Caimanero lagoon evaluation and **Table 7.6** shows only the new criteria (e.g. water quality factors) and criteria which were re-classified. Proximity ranges to water resources were smaller when compared to the state-level assessment and dams were no longer part of the evaluation. Moreover, because of the lack of water in Huizache-Caimanero lagoon system during many months of the year it was sensible to establish smaller proximity ranges so that potential sites for aquaculture would be closer to the lagoon and therefore had a better chance of obtaining water. Annual and monthly water balance classifications remained the same but are of minor relevance when compared to the state-level assessment since they involve the assessment of larger areas (e.g. hydrological regions). New water quality factors were incorporated which were not included in the state-level assessment, and the only changes made for land use were to urban development in the sense that cities were no longer part of the evaluation and were substituted by main towns (i.e. Villa Union and Escuinapa).

With reference to the socio-economic factors, for the production modifier factors, energy data were available in the form of power lines and individual houses were incorporated in the urban development submodel. In terms of postlarvae availability and agglomeration, hatcheries were included as an additional factor.

Table 7.6. Environmental and socio-economic factors, summary interpretation and thresholds for semi-intensive shrimp culture in the Huizache-Caimanero lagoon system.

| FACTORS | CLASS 4<br>VERY SUITABLE | CLASS 3<br>MODERATE | CLASS 2<br>MARGINAL | CLASS 1<br>UNSUITABLE |
|---|---|---|---|---|
| **ENVIRONMENT** | | | | |
| **A. Physical and environmental resources** | | | | |
| Proximity to water resources | | | | |
| Lagoons | 240 - 1 km | 1 - 2 km | 2 - 3 km | > 3 km |
| Coast-line | 240 - 1 km | 1 - 2 km | 2 - 3 km | > 3 km |
| Rivers and streams | 240 - 1 km | 1 - 2 km | 2 - 3 km | > 3 km |
| Groundwater | 0 - 500 m | 500 - 1 km | 1- 1.5 km | > 1.5 km |
| **B. Water quality** | | | | |
| Bathymetry | Greatest depth in lagoon system ( > 1.5 m). Promotes water circulation, good water quality. | Moderate depth in lagoon system (1 - 1.5 m ). Moderate water quality and circulation. | Marginal depth in lagoon ( 0.5 - 1 m). Marginal water quality and circulation. | Lowest depths in lagoon ( < 0.5 m). Very likely to have poor water quality and circulation. High salinities. |
| Water temperature | 26 - 30 ° C | 22 - 26 ° C | 20 - 22 ° C<br>30 - 32 ° C | 18 - 20 °C<br>32 -34 °C |
| Salinity | 25 - 30 ppt | 20 - 25 ppt<br>30 - 35 ppt | 15 - 20 ppt<br>35 - 40 ppt | 10 - 15 ppt<br>> 40 ppt |
| Dissolved oxygen | 6 - 8 mg /l | 4 - 6 mg / l | 2 - 4 mg / l | < 2 mg / l |
| **SOCIO-ECONOMIC** | | | | |
| **A. Production modifiers** | | | | |
| Energy | Closest proximity to a power line ( 0 - I km). Best location in terms of energy supply. | Close proximity to a power line (1 - 2 km). Also with very good potential. | Far from a power line, but still with potential (2 -3 km). Will have difficulty reaching power lines. | Far from a power line (> 3 km) high costs. Difficulty reaching power lines. Generators are likely to be used instead.. |
| Houses | 20 - 240 m | 240 - 500 m | 500 m - 1 km | > 1 km |
| Hatcheries | 240 m - 2 km | 2 - 4 km | 4 - 6 km | > 6 km |

Notes: **Environment:** Scores of zero were allocated to temperatures < 18 ° C and > 34° C , to salinity ranges < 10 ppt and > 45 ppt, and to dissolved oxygen below 1 mg/l (all thresholds were based on threshold ranges presented in **Chapter 6** ( Figures 6.20, 6.21 and 6.22 ).

**Socio-economic**: Hatcheries are both an agglomeration and a source of postlarvae factor. However, to avoid repetition, the hatchery thresholds are only presented in the production modifiers section of this table.

In terms of constraints, all classifications and spatial manipulations remained the same, except for the buffer zones for conservation areas which distance was changed from 250 to 240 m to adjust to the new pixel size (i.e. 20 m). Moreover, proposed conservation areas by Cosmocolor (1991) and EPAC (1991) were not within the Huizache-Caimanero spatial study area, and the conservation areas proposed by Flores-Verdugo were not included in the GIS models because these were based on a single and old geomorphological map manually created by Ortiz (1970), and therefore only provided rough guidelines.

## 7.3 Multi-criteria evaluation

The scores assigned to the spatial factors chosen for the multi-criteria evaluation are presented with their summary interpretations in three tables: **Table 7.7** provides the scores for the water quality factors, **Table 7.8** deals with the scores assigned for the environmental factors, and **Table 7.9** shows the scores for the socio-economic factors.

**Table 7.7. Water quality factors interpretation and score for semi-intensive shrimp culture in the Huizache-Caimanero lagoon system.**

| FACTORS | CRITERION | SCORE |
|---|---|---|
| Bathymetry | Water level is very variable. Increases in water depth promotes water circulation and consequently good water quality. | 5 |
| Water temperature | Very important. Affected by water depth. | 2 |
| Salinity | Most variable factor. Salinity seems to have a lesser effect than temperature on survival and growth of shrimp. However, extreme salinities can increase mortality (e.g. moulting). | 4 |
| Dissolved oxygen | Suitable DO promotes increases in aquatic production and is an important limiting factor for many organisms. Oxygen concentrations can be lethal depending upon exposure time. DO decreases according to increases in salinity. | 3 |

Table 7.8. Environmental factors interpretation and score for semi-intensive shrimp culture in the Huizache-Caimanero lagoon system.

| FACTORS | CRITERION | SCORE |
|---|---|---|
| Water availability | Very variable, seasonally dependent. Relies on both tidal flow and pumping. Regular management scheme due to siltation. | 11 |
| Suitable ambient temperature | Variable, seasonally dependent, influences water temperature directly. Important for growth and survival. | 10 |
| Suitable soils | High dependence but soil treatment by compaction, clay blankets, bentonite or chemical additives can be used to minimize negative effects of soils. | 9 |
| Suitable topography | Lagoon is located on a large flat surface area with a gentle slope towards the ocean only interrupted by small hills and low mountains. A gentle slope of less than 2% is highly desirable for drainage from ponds. | 8 |
| Low population density | Most of the lagoon system is located in the municipality of Rosario which is an area of low population density in comparison to the rest of the state. | 4 |
| Distance from urban development | The lagoon is located in a rural area where there is an absence of industries and large urban concentrations. However, some level of pollution is still present. | 5 |
| Proximity to roads | Paved roads and railways have a damaging effect on the environment (i.e. river flow). | 1 |
| Low production agriculture | Seasonal agriculture is being developed adjacent to the lagoon system, including the sand barrier, so farms are vulnerable to pollution. Some level of pesticide pollution has already been found. | 7 |
| Presence of livestock (pigs & poultry) | Manure is not commonly used as a source of input but if added as fertilizer it could increase ponds' productivity. | 2 |
| Small distance from forests | Benefited from good quality waters and far enough to minimize construction costs. | 3 |
| Distance from shrimp farms | Most shrimp farm inlet and outlet channels lead into the lagoon system which is already lacking appropriate water circulation. Significant loading problems if high stocking density is practised. | 6 |

Table 7.9. Socio-economic factors interpretation and score for semi-intensive shrimp culture in the Huizache-Caimanero lagoon system.

| FACTOR | CRITERION | SCORE |
|---|---|---|
| Human resources | Moderate to high training skills. Labour intensive although minimised by mechanization. Dependence on technical assistance. 0.10-0.25 persons/ha. Continuous skilled management. Fishermen, technicians, administrators and salesmen. | 11 |
| Job creation | Moderate provision of jobs for labour intensive work. | 12 |
| Activity conflicts | Most demanding on water and less on space. Due to the large amount of land used for agriculture adjacent to the lagoon most conflicts will be found with this activity. | 13 |
| Sufficient energy | Dependence for water pumping and facilities. 2 -5 hp/ha. | 5 |
| Sources of postlarvae | High dependence on wild postlarvae which are caught in the river basins (Presidio or Baluarte) or close to Escuinapa. Seasonally dependant. Serious law restrictions due to closed seasons for capture (although some illegal off-season catches are obtained). Seed may enter the pond with influent water but commonly stocked at moderate densities.<br>The problems of natural postlarvae availability can be solved by the existing hatcheries in this region. | 10 |
| Good sources of inputs (Fertilizer and lime) | Considerable amounts of inorganic and organic fertilizers are required. | 2 |
| Proximity to urban developments | Reliance on equipment. Large quantities of materials are needed. Rely on natural pond productivity but typically require supplemental formulated diets. Feed of suitable quality must be available( biggest operating cost). Greater inputs of feed. | 7 |
| High agglomeration | Advantage of already developed farming skills, postlarvae and markets (includes shrimp farms and hatcheries). | 8 |
| Good transportation and communications | Dirt roads. Not easily accessible during rainy season, repairs are sometimes necessary. Very important to maintain access at all stages of shrimp culture. | 9 |
| Adequate population density | Moderate to high capacity to absorb aquatic production. | 3 |
| Good Income | Moderate to high amount of money for purchase of aquatic products. | 1 |
| Fish consumption | Knowledge of the preferred species at low to moderate cost for local sales and exports. | 6 |
| High quantity of markets | Relies on distant bulk. Mostly sold within the country and some exports | 4 |

## 7.4 Integration of criteria for modelling

Although some primary data were either omitted or added for the lagoon system GIS-based models, the structures of most of them were quite similar to the state models. The new models are presented here, but to avoid repetition reference can be made to the earlier descriptions.

## SINGLE OBJECTIVE MODELS

### 7.4.1 Environmental models

The schematic model is shown in **Figure 7.2** and the allocation of land found by the GIS environmental model is presented in **Figure 7.3.**

#### 7.4.1.1 Environmental model for semi-intensive shrimp culture.

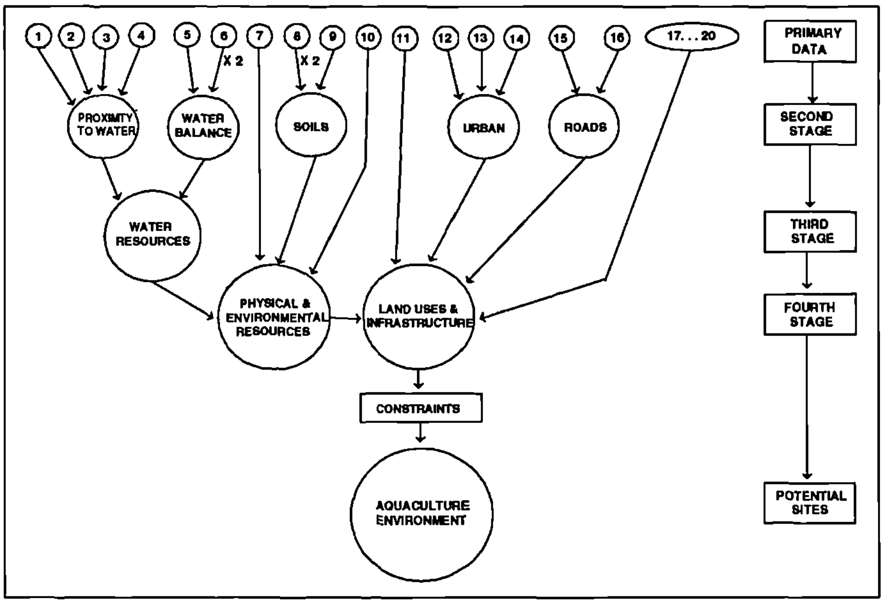


**Figure 7.2. Overall hybrid model integrating environmental factors for assessing site considerations for semi-intensive shrimp farming in the Huizache-Caimanero lagoon system.** Primary data: 1, lagoons; 2, coastline; 3, rivers and streams; 4, groundwater; 5, annual water balance; 6, monthly water balance; 7, temperature; 8, soil texture; 9, soil type; 10, topography; 11, population density; 12, main towns; 13, other towns; 14, villages; 15, paved roads; 16, railways; 17, agriculture; 18, livestock rearing; 19, forestry; 20, shrimp farms. Note: Only one line is used from values 17 - 20 to avoid confusion between lines.

In comparison to the semi-intensive environmental state-level model, a number of changes had to be made (e.g. change of weights) at all stages of the model (i.e. except for soils and water balance submodels), because there was a reduction in the number of factors involved (i.e. from 24 to 20), and there were also new factors involved. For the primary criteria, a new water resources submodel was developed because there were no dams within the study area; and a new urban development submodel was created because the study area does not contain the capital city or other cities. For the secondary criteria, new weights were developed because there are no irrigation schemes or sugar industries within the Huizache-Caimanero study area. Finally, constraints were also adjusted accordingly (i.e. no dams and a new urban development submodel).

The mathematical expression for the modified primary criteria was:

Water resources submodel:

$$PW = ( LA \times 0.37 ) + ( COA \times 0.30 ) + ( RS \times 0.25 ) + ( G \times 0.08 ) \times CONWA.$$

$$WRS = PW + (AWABA + ( MWABA \times 2).$$

where; PW = proximity to water submodel; LA = lagoons; COA = coastline; RS = rivers and streams; LK = lakes; G = groundwater; CONWA = area constraints for water bodies; WRS= water resources submodel; AWABA = annual water balance; MWABA = monthly water balance.

Urban development submodel:

$$URBS(e) = (MTW \times 0.52) + ( TW \times 0.32) + ( VI \times 16) .$$

where; URBS(e) = urban development submodel; MTW= main towns; TW = other towns; VI = villages.

The mathematical expression for the secondary level of this model was:

$$\mathbf{RES} = ( WRS \times 0.19 ) + ( T \times 0.14 ) + ( SS \times 0.13 ) + ( TOP \times 0.12); \mathbf{LAUSE} = ( PO \times 0.06 ) + ( URBS(e) \times 0.07 ) + ( ROS(e) \times 0.02 ) + ( AGR(e) \times 0.10) + ( LI (e) \times 0.04 ) + ( FO \times 0.05 ) + ( SH(e) \times 0.08 ); \mathbf{GEM} = ( RES + LAUSE ) \times CONS \times BCONS(m) + BCONS(a)$$

where, RES = physical and environmental resources; LAUSE = land uses and infrastructure; WRS = water resources submodel; T = annual ambient temperature; SS = soils submodel; TOP = topography; PO = population density; URBS(e) = urban development submodel; ROS(e) = roads submodel; AGR(e) = agriculture; LI(e) = livestock rearing; FO = forestry; SH(e) = shrimp farms; GEM = general environmental model; CONS = constraints used to mask out conservation areas; BCONS = buffer zone for conservation areas.

The new weights assigned, which are shown in the mathematical expression and in the macro file, were developed using the MCE technique but were based upon the weights assigned in the previous chapters (e.g. roads submodel).

**MACRO FILE**
**ENVIRONMENT**
**GENERAL MODEL**

```
PRIMARY CRITERIA
overlay x 3 la(c) coa(c) lacoa
overlay x 3 lacoa rs(c) conwa
mce x 1 5 water conwa la 0.37 coa 0.30 rs 0.25 g 0.08
overlay x 3 awaba mwaba waba
overlay x 1 water waba wrs
scalar x soilt soiltx2 3 2
overlay x soiltx2 soilt ss
overlay x 3 mtw(c) tw(c) mtwtw
overlay x 3 mtwtw vi (c) mtwtwvi
overlay x 3 mtwtwvi ho(c) conur
mce x 1 3 urbs(e) conur mtw 0.52 tw 0.32 vi 0.16
overlay x 3 pr(c) rw(c) prrw
overaly x 3 prrw gr(c) conro
mce x 1 3 ros(e) conro pr 0.60 rw 0.40

SECONDARY CRITERIA
mce x 0 4 res wrs 0.19 t 0.14 ss 0.13 top 0.12
mce x 0 7 lause po 0.06 urbs(e) 0.07 ros(e) 0.02
agr(e) 0.10 li(e) 0.04 fo 0.05 sh(e) 0.08
overlay x 1 res lause nala
overlay x 3 conwa conur waur
overlay x 3 waur conro waurro
overlay x 3 m(c) sh(c) msh
overlay x 3 msh slp(c) con
overlay x 3 waurro con cons
overlay x 3 cons nala em1
overlay x 3 bcons(m) em1 em2
overlay x 3 bcons(a) em2 gem
```

**Figure 7.3** shows the allocation of land for aquaculture development determined using this environmental model. Overall, the model identified 3 km$^2$ of land south-east of the Caimanero lagoon where water is abundant, land is not suitable for livestock rearing and agriculture activities are minimum or seasonal. Moderately suitable sites account for 56% (753 km$^2$) of the area and were identified along the sand barrier and north-east of the Huizache lagoon. Marginal sites only accounted for 1% (13 km$^2$) of the land area and no sites were classified as unsuitable. Constraints (blank spaces) and buffer zones for mangroves (i.e. 250 m) are clearly shown.

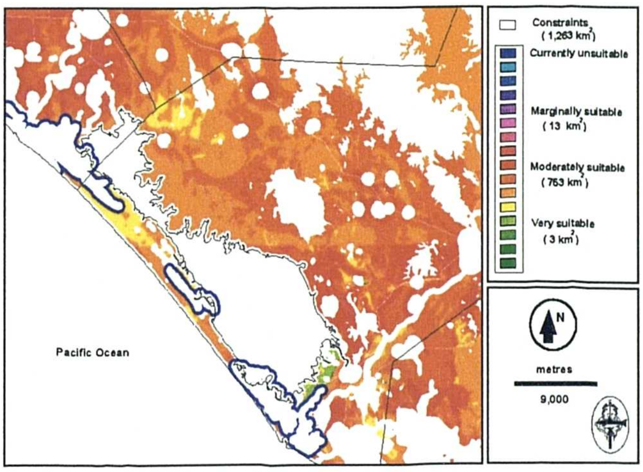


**Figure 7.3. Allocation of land found by the GIS general model for semi-intensive shrimp farming in the Huizache-Caimanero lagoon.**

### 7.4.1.2 Water quality models based on water samples

Water quality factors of interest were mainly bathymetry, water temperature, salinity, and dissolved oxygen. To carry out the spatial analysis, data provided by Galindo-Reyes (1990) were used (see **Chapter 6**). In order to increase spatial coverage, water quality point data were interpolated (using the IDRISI DISTANCE module) from the water sample stations in this study, based on assumptions developed from Ross *et al.* (1993). The different interpolation radii (**Text Box 7.1**) selected were selected according to the spatial variability of each factor (see **Chapter 6**). For example, because salinity was the most variable factor it required a smaller radius in comparison to those which were considered more stable (i.e. temperature).

**Text Box 7.1. Water quality based on water samples submodel.**

| FACTOR | INTERPRETATION | RADIUS |
|---|---|---|
| Salinity | *Very high variability* | *100 m* |
| D. Oxygen | Moderately variable | *200 m* |
| Water temp. | Most stable factor | 300 m |

Note: Bathymetry did not require an interpolation because point data were not used.

The integration of these factors into a model is shown in **Figure 7.4**. In this particular model, primary data were divided into two stages:

1. Manipulation of water quality factors (primary data) by creating distance bands in accordance to their spatial variability (see Text Box 7.1 for factor variability). Reclassification according to aquaculture suitability (Table 7.6) on a scale from 1 - 4, 4 being the most suitable (**Table 7.10**).

**Table 7. 10. Water quality in the Huizache-Caimanero lagoon system. (Wet season data from July to September, 1990)**

| STATION No. | Temp (°C) | | Salinity (ppt) | | D. oxygen (mg/l) | |
|---|---|---|---|---|---|---|
| | MEAN | SCORE | MEAN | SCORE | MEAN | SCORE |
| 5 | 31 | 2 | 8 | 0 | 6 | 3 |
| 7 | 22 | 3 | 8 | 0 | 9 | 4 |
| 8 | 34 | 1 | 12 | 1 | 8 | 4 |
| 9 | 33 | 1 | 17 | 2 | 8 | 4 |
| 10 | 32 | 1 | 13 | 1 | 8 | 4 |
| 11 | 31 | 2 | 11 | 1 | 7 | 4 |
| 12 | 31 | 2 | 5 | 0 | 7 | 4 |

Note: Data created from data provided by Galindo-Reyes (1990).

2. Reclassification of the bathymetry data to a 1 - 4 scale according to aquaculture suitability (Table 7.6).

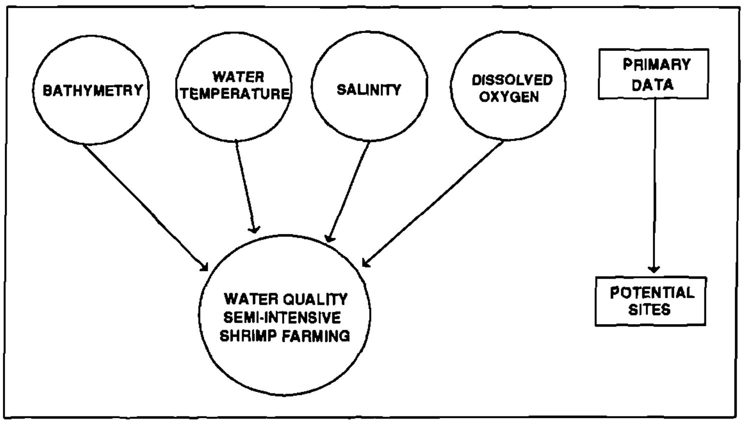


**Figure 7.4. Integration of water quality factors during the wet season for semi-intensive shrimp farming in the Huizache-Caimanero lagoon.** WQ = ( BA X 0.27 ) + ( WT X 0.34 ) + ( SAL X 0.16 ) + ( DO X 0.23 ). Where; WQ = water quality model; BA = bathymetry; WT= water temperature; SAL = salinity; DO = dissolved oxygen.

**Command line mode file**
**Water quality model**

```
mce x 0 5 wq ba 0.35 wt 0.15 sal 0.25 do 0.18 pol 0.07
```

Because water is abundant, both bathymetry and salinity were given low weights. Conversely, for the dry season, the weights would change considerably because the major constraint during this time would be lack of water and very high salinities. The weights would then be changed to: WQ = ( BA X 0.34 ) + ( WT X 0.16 ) + ( SAL X 0.27 ) + (DO X 0.23 )

**Figure 7.5** shows the derived image from the wet season model. Based on water quality data provided by Galindo-Reyes (1990) (see Chapter 6), only 7 sample points fell within the lagoon system for spatial analysis. Nonetheless, even with these few sample points the model was able to identify sample station number 9 as the area with best water quality, and this coincided with the water quality analysis presented in Chapter 6 (**section 6.2.1.4 f**). The other 6 sample stations were identified as marginal. Blank spaces within the lagoon represent areas which were classified as being too shallow, making these sites unsuitable, although sample stations 11 and 12 had a similar score to the rest because of the good salinity and temperature values.

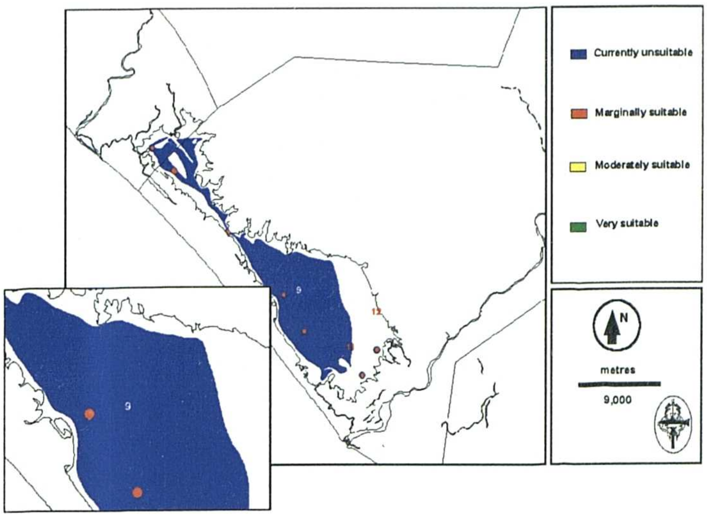


Figure 7.5. GIS-derived allocation of land during the wet season. (from July to September)

### 7.4.2 Socio-economic models

### 7.4.2.1 Socio-economic model for semi-intensive shrimp culture

**Figure 7.6** illustrates the structure of the socio-economic model. An important change in the secondary stage of the state-level model was carried out when postlarvae and agglomeration submodels were created, including a hatchery factor.

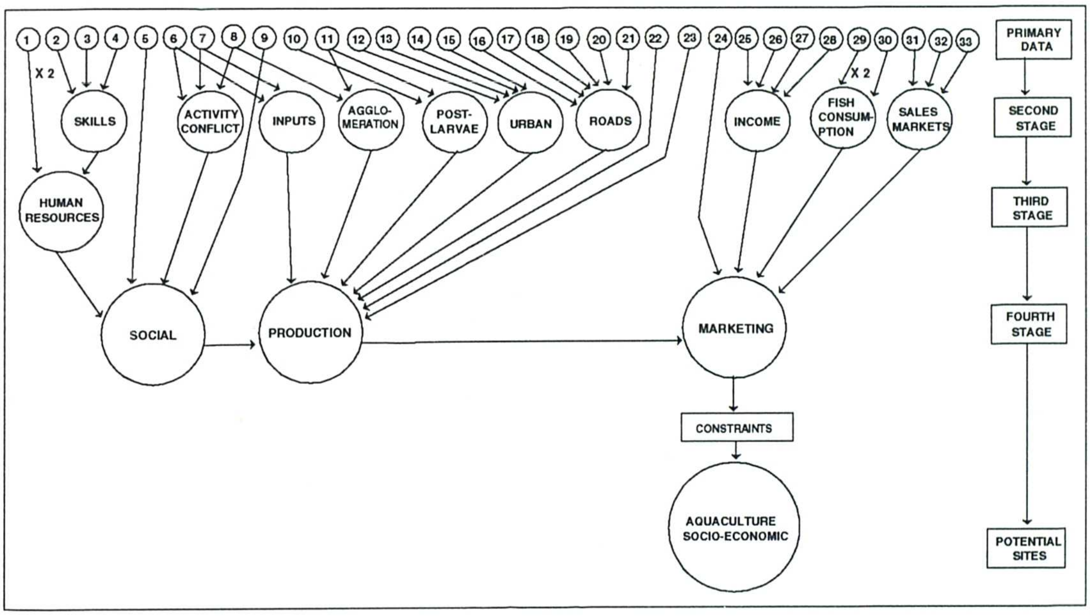


**Figure 7.6. Overall hybrid model integrating socio-economic factors for assessing site considerations for semi-intensive shrimp farming in the Huizache-Caimanero lagoon system.** Primary data: 1, age-group; 2, primary sector; 3, secondary sector; 4, tertiary sector; 5, job creation;

6, agriculture; 7, livestock rearing; 8, shrimp farms; 9, energy; 10, natural postlarvae; 11, hatcheries; 12, main towns; 13, towns; 14, villages; 15, houses; 16, paved roads; 17, railways; 18, gravel roads; 19, dirt roads; 20, unimproved roads; 21, transport types; 22, communications; 23, support centres; 24, population density; 25, number of inhabitants earning 1.5 times the minimum wage; 26, number of inhabitants earning 2.5 times the minimum wage; 27, number of inhabitants earning 4 times the minimum wage; 28; number of inhabitants earning 7.5 time the minimum wage; 29, preferred aquatic specie for consumption; 30, fishing activity; 31, hotels; 32, fish processing plants; 33, markets.

The mathematical expression for the secondary criteria of this model was:

**SOCIAL** = ( HRS X 0.12 ) + ( JC X 0.13) + ( ACTS X 0.14 ); **PROD** = ( ( E X 0.06 ) + ( POSS X 0.11 ) + ( INS X 0.02 ) + ( URBS(se) X 0.08) + ( AGS X 0.09 ) + ( ( TRS X 0.10 ) ) + C + SC; **MARKET** = ( PO X 0.03 ) + ( DIS X 0.01 ) + ( FIS X 0.07 ) + ( SALES X 0.04 ); **GSM** = ( SOCIAL + PROD + MARKET) X CONS X BCONS(m) + BCONS(a).

Where; SOCIAL = Social factor submodel; HRS = human resources submodel; JC = job creation factor; ACTS = activity conflict submodel; LT = land tenancy factor; PROD = production modifiers submodel; E = energy factor; POSS = sources of postlarvae submodel; INS = inputs submodel; URBS(se) = urban development submodel; AGS = agglomeration submodel; TRS = transport submodel; C = communications constant; SC = support centres constant; MARKET = market potential submodel; PO = population density; DIS = disposable income submodel; FIS = fish consumption submodel; SALES = sales/market submodel; GSM = general socio-economic model; CONS = constraints used to mask out conservation areas; BCONS = buffer zone for conservation areas.

**MACRO FILE**
**SOCIO-ECONOMIC**
**GENERAL MODEL**

*PRIMARY CRITERIA*

```
mce x 0 3 pss 0 prim 0.57 sec 0.07 tert 0.36
scalar x age a ageb 3 2
overlay x 3 ageb pss hrs
overlay x 1 agr(se) li(se) agrli
overlay x 1 agrli aq(se) acts
mce x 0 2 poss npos 0.30 hpos 0.70
mce x 0 2 insli 0.7 agr 0.35
mce x 0 2 ags  nsh 0.30 hatch 0.70
overlay x 3 mtw(c) tw(c) mtwtw
overlay x 3 mtwtw vi(c) mtwtwvi
overlay x 3 mtwtwvi ho(c) conur
mce x 1 3 urbs(se) conur mtw 0.50 tw 0.30 vi 0.15 ho 0.05
overlay x 3 pr(c) rw(c) prrrw
overlay x 3 prrw gr(c) conro
mce x 1 3 ros(se) conro pr 0.50 rw 0.23 gr 0.15 dr 0.10 ur 0.02
overlay x 1 ros(se) transt trs
mce x 0 4 dis 1.5mw 0.1 2.5mw 0.16 4mw 0.26 7.5mw 0.48
overlay x 3 pfish fact fis
mce x 0 3 sales hot 0.2 fishp 0.3 mark 0.5
```

*SECONDARY CRITERIA*

```
mce x 0 4 social hrs 0.11 jc 0.12 acts 0.13 lt 0.14
mce x 0 6 prod e 0.05 poss 0.10 ins 0.02 urbs(se) 0.07
ags 0.08 trs  0.09
overlay x 1  c prod cprod
overlay x 1 sc cprod scprod
mce x  0 4 market po 0.03 dis 0.01 fis 0.6 sales 0.04
overlay x 1 social scprod sopro
overlay x 1 market sopro socioec
overlay x 3 la(c) rs(c) conwa
overlay x 3 conwa conur waur
overlay x 3 waur conro waurro
overlay x 3 m(c) sh(c) msh
overlay x 3 msh slp(c) con
overlay x 3 waurro con cons
overlay x 3 cons socioec em1
overlay x 3 bcons(m) em1 em2
overlay x 3 bcons(a) em2 gsm
```

In comparison to the semi-intensive socio-economic state-level model, two additional factors were added to the evaluation: hatcheries and land tenancy. By adding a hatcheries factor two new primary criteria submodels were created. The first of these submodels was sources of postlarvae (incorporated in the natural postlarvae availability factor), whilst the second submodel was agglomeration (incorporated in the shrimp farms factor). The creation of these submodels was based on the MCE technique and the resulting weights are shown in the macro file for this model (due to the reliability of postlarvae from the hatcheries, this factor was given a higher weight of

0.70 in both submodels). The urban development was adjusted according to the environmental model described earlier in this chapter (the new submodel is presented in this macro file). Finally, the same constraints that were modified for the environmental model previously described in this chapter were used for this socio-economic model.

**Figure 7.7** shows the allocation of land found by the GIS model for semi-intensive shrimp farming in the Huizache-Caimanero lagoon based on socio-economic factors. The model did not find sites classified as very suitable. Moderately suitable sites account for 5% (73 km$^2$) of the area in the municipality of Mazatlán. Here, human resources, transportation, urban development, fish consumption and support centres are some of the factors which make these sites areas particularly suitable. Marginal sites account for 47% (624 km$^2$) and are mostly located in Rosario, and to a lesser extent in Escuinapa. Unsuitable sites were clearly identified in Concordia, but, these sites have the advantage of being in proximity to Mazatlán.

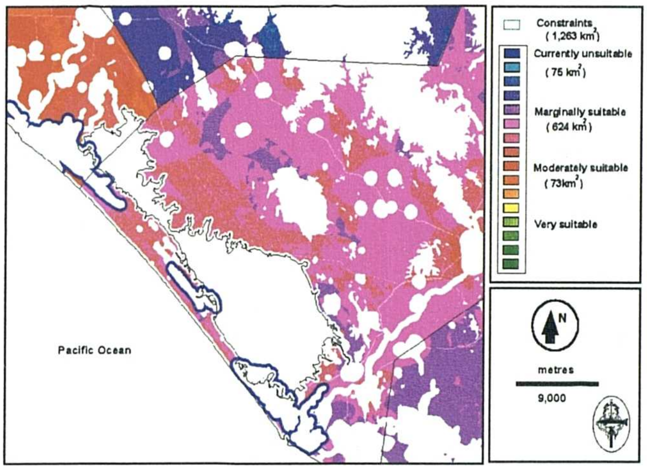


**Figure 7.7. GIS-derived allocation of land for semi-intensive shrimp farming in the Huizache-Caimanero lagoon system based on socio-economic factors.**

### 7.4.3 Multi-objective models

The same five activities used in the state-level model were selected for MOLA analysis: agriculture, livestock rearing, aquaculture, forestry and urban development. As before, agriculture had the highest correlation with other activities which meant that it was competing for space with most of the activities. To determine the kind of relationship that aquaculture has with other objectives and/or activities a further series of models was created:

#### 7.4.3.1 Aquaculture environmental models compared with socio-economic models

Both environmental and socio-economic general models identified potential sites for semi-intensive shrimp farming. The two images produced by these models were merged together as discussed in the state-level assessment by creating a cross-classification image as shown in **Figure 7.8**. Clearly, very suitable sites for both models (73 km$^2$) were found in Mazatlán. Moderately suitable sites account for 8% of the area (113 km$^2$) and were identified in Rosario and Mazatlán. The majority of the marginal sites were identified in Rosario, and to a much lesser extent in Escuinapa. Unsuitable sites only account for 15% (194 km$^2$) and occurred in Concordia and Escuinapa.

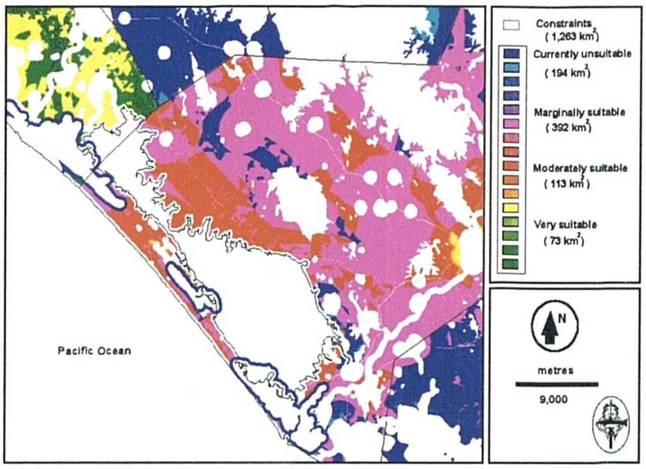


**Figure 7.8. Cross-classification image between environmental and socio-economic images produced by the models.**

#### 7.4.3.2 Aquaculture compared with agriculture

Area goals from the manual study were not available at this level of model development. These were established during a field verification mission to Mexico. Instead, the area goals were defined by using the "very suitable and moderate" classifications of both activities shown in **Figure 6.30** for agriculture (400 km$^2$) and **Figure 7.3** for aquaculture (16 km$^2$). The aquaculture factor in this model was based on the environmental aquaculture model, but different versions of this model could also be run by using the socio-economic model, or the cross-classification image previously created. Additionally, if less optimum sites were used for agriculture, it could be assumed that this would minimize the risks of pollution, and therefore, instead of treating these activities as conflicting, they could be complementary by considering agriculture as a source of inputs for aquaculture. The structure of this model is shown in **Figure 7.9.**

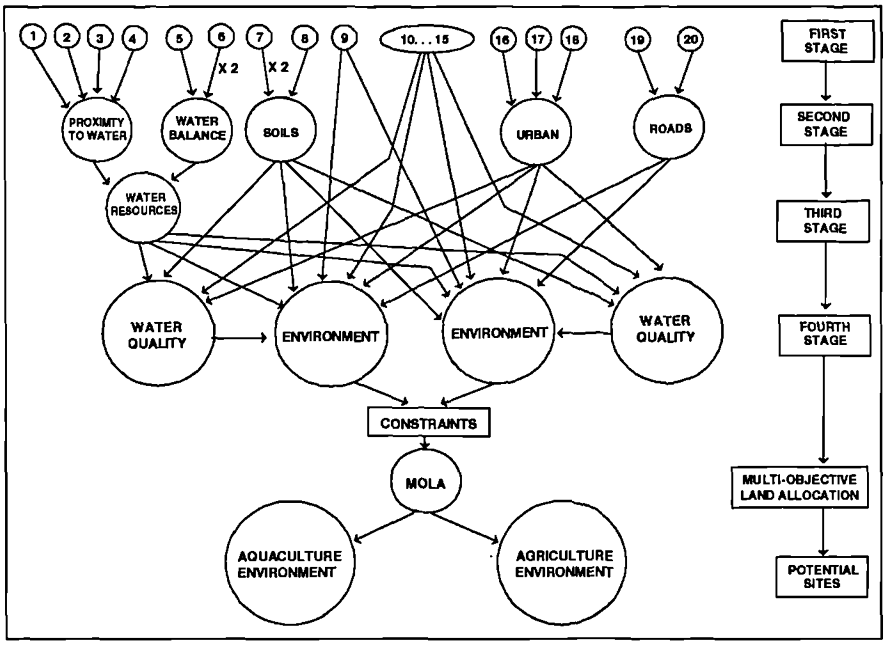


**Figure 7.9. Overall hybrid model integrating submodels for assessing site considerations for semi-intensive shrimp farming in the Huizache-Caimanero lagoon system (using the aquaculture environmental image).** Primary data: 1, lagoons; 2, coastline; 3, rivers and streams; 4, groundwater; 5, annual water balance; 6, monthly water balance; 7, soil texture; 8, soil type; 9, topography; 10, temperature; 11, population density; 12, agriculture; 13, livestock rearing; 14, forestry; 15, shrimp farms; 16, main towns; 17, towns; 18, villages; 19, paved roads; 20, railways. Note: Only two lines are duplicated from values 10 - 15 to avoid confusion between lines.

The mathematical expressions for the secondary criteria of the aquaculture model were:

*ENVIRONMENT*

**RES** = ( WRS X 0.19 ) + ( T X 0.14) + ( SS X 0.13 ) + ( TOP X 0.12 ); **LAUSE** = ( PO X 0.06 ) + ( URBS(e) X 0.07) + ( ROS(e) X 0.02) + (AG (e) X 0.10) + ( LI(e) X 0.04 ) + ( FO X 0.05 ) + ( SH(e) X 0.08 ); **GEM** = RES + LAUSE.

*WATER QUALITY*

**RESWQ** = ( WRS X 0.20 ) + ( T X 0.16 ) + ( SS X 0.15 ); **LAWQ** = ( PO X 0.08 ) + ( URBS(e) X 0.09) + ( AGR (e) X 0.12) + ( LI(e) X 0.03 )+ ( FO X 0.07 )+( SH(e) X 0.10 ); **GWQM** = RESWQ + LAWQ.

Where; RESWQ = physical and environmental resources for water quality environmental criteria; LAWQ = land uses and infrastructure for water quality environmental criteria; GWQM = general water quality model.

**AQUA(e)** = (GEM + GWQM) X CONS X BCONS(m) + BCONS(a).

Where, AQUA(e) = final model; CONS = constraints; BCONS = buffer zone for conservation areas.

The mathematical expressions for the secondary criteria of the agriculture model were:

Water resources submodel

PW(ag) = ( RS X 0.62 ) + ( G X 0.38 ) X CONWA

WRS(ag) = PW + (AWABA + MWABA X 2).

Where; PW (ag) = proximity to water submodel; RS = rivers and streams; LK = lakes; G = groundwater; CONWA(ag) = area constraints for water bodies; WRS(ag) = water resources submodel; WB = water balance submodel.

*ENVIRONMENT*

**RESAGM** = ( WRS(ag) X 0.19 ) + ( T X 0.16 ) + ( SS X 0.15) + ( TOPX 0.12 ); **LAAGM** = ( PO X 0.04 ) + ( URBS(e) X 0.08 ) + ( ROS(e) X 0.01) + ( LI(se) X 0.09 ) + ( FO X 0.10 ) + ( SH(e) X 0.06 ); **GAGM** = RESAGM + LAAGM.

*WATER QUALITY*

**RESAGWQ** = ( WRS(ag) X 0.22 ) + ( T X 0.19 ) + ( SS X 0.18 ); **LAAGWQ** = ( PO X 0.07 ) + ( URBS(e) X 0.12 ) + ( FO X 0.13 ) + ( SH(e) X 0.09 ); **GAGWQM** = RESAGWQ + LAAGWQ

**AGRI(e)** = (GAGM + GAGWQM) X CONS X BCONS(m) + BCONS(a).

**Figure 7.10** shows the derived image for this model. Common sites for both agriculture and aquaculture were found to be primarily south-east of the Caimanero lagoon, and to a lesser extent north-east of the Huizache lagoon. By using MOLA, most aquaculture sites were allocated south-east of Caimanero and along the sand barrier adjacent to Huizache, whereas for agriculture most sites were allocated north-east of the Huizache lagoon. Despite this, the south-east of the Caimanero lagoon was still considered as an area of conflict because many sites found by the model for both activities were adjacent to each other.

```
MACRO FILE
MULTI-OBJECTIVE MODELS
ENVIRONMENT
AQUACULTURE - AGRICULTURE

AQUACULTURE
PRIMARY CRITERIA

SECONDARY CRITERIA
mce x 0 4 res wrs 0.19 t 0.14 ss 0.13 top 0.12
mce x 0 7 lause po 0.06 urbs(e) 0.07 ros(e) 0.02
agr(e) 0.10  li(e) 0.04 fo 0.05 sh(e) 0.08
overlay x 1 res lause gem
mce x 0 3 reswq wrs 0.20 t 0.16 ss 0.15
mce x 0  6 lawq po 0.08 urbs(e) 0.09 agr(e) 0.12
li(e)  0.03
fo 0.07 sh(e) 0.10
overlay x 1 reswq lawq gwqm
overlay x 1 gem gwqm envwqm
overlay x 3 conwa conur waur
overlay x 3 waur conro waurro
overlay x 3 m(c) sh(c) msh
overlay x 3 msh slp(c) con
overlay x 3 waurro con cons
overlay x 3 cons envwqm em1
overlay x 3 bcons(m) em1 em2
overlay x 3 bcons(a) em2 aqua(e)

AGRICULTURE
  PRIMARY CRITERIA
mce x 1 3  water conwa rs 0.62 g 0.38
overlay x 3 awaba mwaba waba
overlay x 1 water waba wrs(ag)

SECONDARY CRITERIA
mce x 0 4 resagm wrs((ag) 0.19 t 0.16  ss 0.15 top 0.12
mce x 0 5  laagm po 0.04 urbs(se) 0.08 ros(e) 0.01
li(e) 0.09  fo 0.10  sh(e) 0.06
overlay x 1 resagm laagm gagm
mce x 0 3 resagwq  wrs(ag) 0.23  t 0.19 ss 0.18
mce x 0 4 laagwq po 0.07 urbs(e) 0.12 fo 0.13 sh(e) 0.09
overlay x 1 resagwq lagwq gagwqm
overlay x 1 geagm gagwqm envwqagm
overlay x 3 conwa conur waur
overlay x 3 waur conro waurro
overlay x 3 m(c) sh(c) msh
overlay x 3 msh slp(c) con
overlay x 3 waurro con cons
overlay x 3 cons envwqagm em1
overlay x 3 bcons(m) em1 em2
overlay x 3 bcons(a) em2 agri(e)

TERTIARY CRITERIA
mola x 2 aqag 0 aqua(e) 0.50 agri(e) 0.50 raqua 40,181
ragri 1,004,520.
```

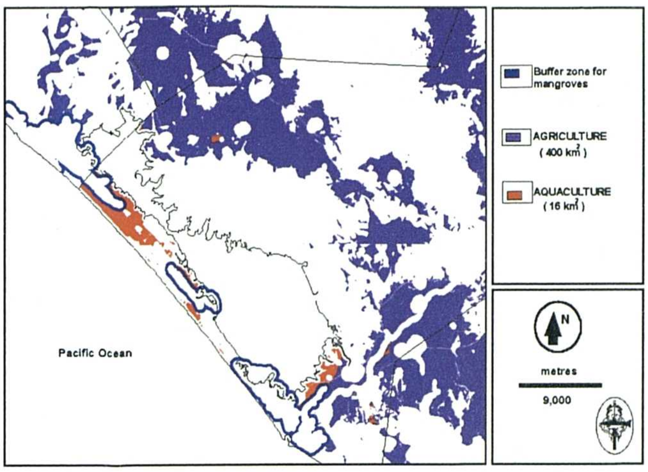


**Figure 7.10. GIS-based derived allocation of land for semi-intensive shrimp farming and agriculture in the Huizache-Caimanero lagoon system.**

### 7.4.3.3 Integrating aquaculture with other production activities

To establish the area targets it was decided to use the area found as maximally suitable for each objective, and the MCE technique to assign weights for each production activity according to its importance within the state. The production activities (i.e. urban development and forestry, agriculture, livestock rearing and aquaculture), as well as the methodology and the weights assigned, follow the description presented in Chapter 5. However, the area goals were changed to 100 km$^2$, 400 km$^2$, 200 km$^2$ and 16 km$^2$ accordingly. **Figure 7.11** shows the structure of the overall model.

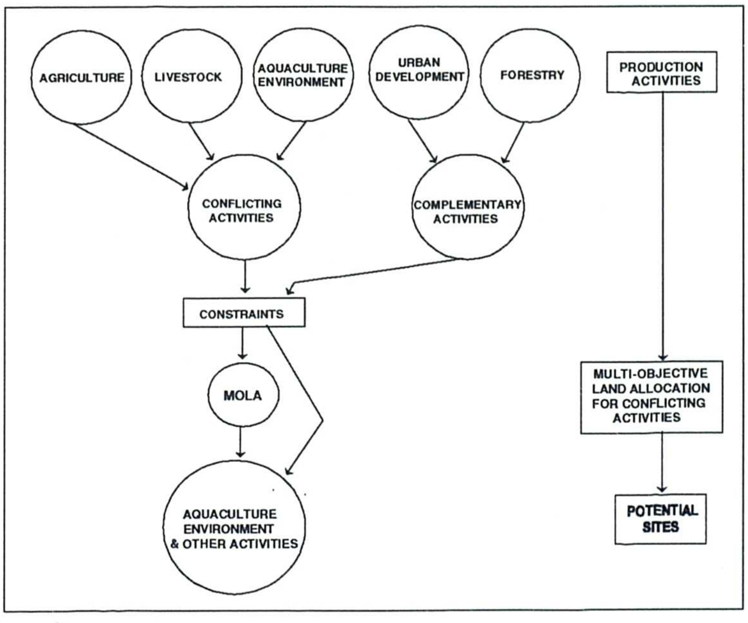


**Figure 7.11. Integration of the different activities into an overall model.**

COMACT = ( URBS(se) X 0.70 ) + ( FO(r) X 0.30) X CONS. Where, COMACT = complementary activities; URBS = urban development submodel image derived from the aquaculture socio-economic model and FO(r) = forestry primary criteria (forestry classification was reversed to indicate maximum suitability of activity, this is indicated by an "(r)" symbol).

CONACT = (( AGRI(se) X 0.45 ) + ( LI X 0.35 ) + ( GEM(e) X 0.20 )) X CONS. Where, CONACT = conflicting activities; AGRI = agriculture image based on classification from data source; LI = livestock rearing image based on classification from data source; GEM = aquaculture environmental model image.

( COMACT+CONACT ) X CONS X BCONS(m) + BCONS(a).

**MACRO FILE**
**MULTI-OBJECTIVE MODELS**
**AQUACULTURE & OTHER ACTIVITIES**

*TERTIARY CRITERIA*

```
mce x 1 2 com cons urbs(se) 0.70 fo(r) 0.30
rank x com none com2 d
reclass x i com2 comact 2 4 1 251,130 0 251,130 999999999
overlay x cons agri(e) cagri
overlay x cons li cli
overlay x cons gem caqua
rank x cagri none ragri d
rank x cli none rli d
rank x caqua none raqua d
mola x 3 conact cons 0 cagri 0.45 cli 0.35 caqua 0.20 ragri 1,004,520 rli 502,260 raqua 40,181
overlay x 1 comact conact comconc
overlay  x  3  cons comconc em1
overlay  x  3  bcons(m) em1 em2
overlay  x  1  bcons(a) em2 finaqua
```

Note: Although not presented in this macro file, the constraints used in this macro file are exactly the same as the ones used throughout this study.

**Figure 7.12** shows the derived image from this model. Overall, complementary activities were found away from the coast. Most suitable sites in terms of urban development were located in the main towns of Villa Union and Rosario, whereas forestry potential was identified in the mountain region. Agriculture activities comprise 30% (400 km$^2$) of the land area and were well dispersed in the area. Conversely, livestock rearing sites were mostly concentrated in Rosario in proximity to Villa Union. Aquaculture sites were clearly identified south-east of the Caimanero lagoon and along the sand barrier.

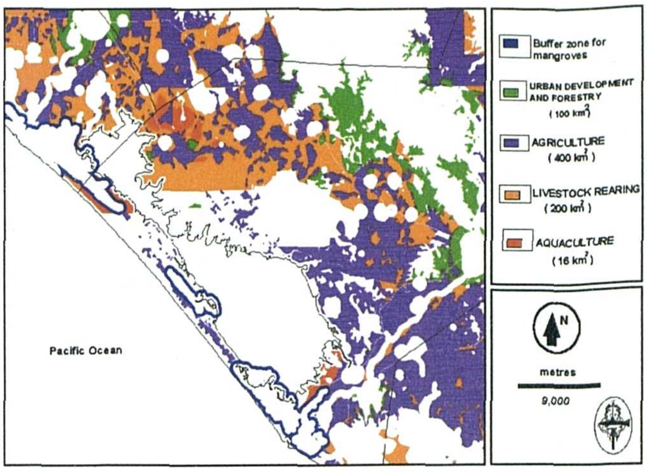


**Figure 7.12. GIS-derived allocation of land for aquaculture and other production activities in the Huizache-Caimanero lagoon system using the environmental suitability image.**

### 7.4.3.4 Time series analysis

A time series analysis is one of the greatest advantages of using a GIS for planning and management. Broadly defined by Jones (1995) "a times series analysis (TSA) in a GIS involves the examination of the differences between two or more states of the environment at different times". In this study, the potential of using a TSA has already been demonstrated by evaluating present aquaculture scenarios and comparing them with the GIS predictions. Additionally, it was possible to obtain "real" development data for proposed future aquaculture and agricultural developments in the Huizache-Caimanero lagoon region. New shrimp farm locations and sizes were obtained from the Fisheries Secretariat (Secretaría de Pesca, 1995b) and from CONSULTEC (1990), and data concerned with the development of agriculture were obtained from the National Water Commission (CNA) for 1995 in Villa Union. Finally, as an enhancement to this analysis, land tenancy data were obtained from Sanchez and Vega (1995). All these data were available as paper maps of different sizes (see **Appendix 4**) and were digitized manually for this study.

#### *a) Future shrimp farms*

To make an assessment of the location of the future shrimp farms, these "new" farms were draped over **Figure 7.3** presented previously to create a new image (**Figure 7.13**). Here it can clearly be seen that many of the new shrimp farms, represented in black, are located in the unsuitable areas predicted by the GIS. Three of these new farms are clearly located within a mangrove area north-west of the Huizache lagoon, and the farm inside the Caimanero lagoon, which is clearly an unsuitable location, will be expanded to an additional 9 ponds (3 km$^2$ of land).

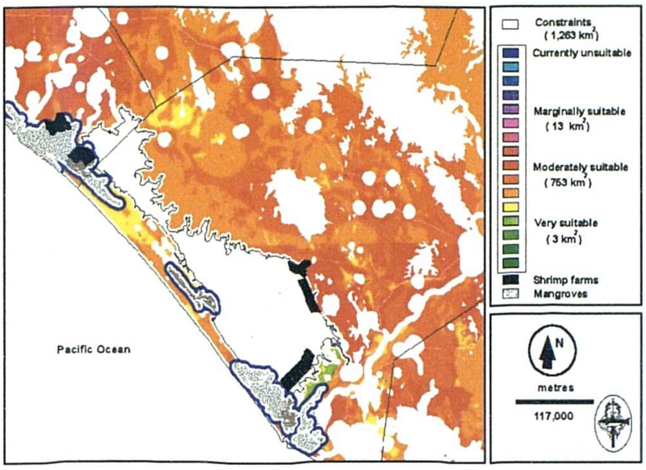


Figure 7.13. **Assessment of the location of the new shrimp farms.**

***b) Future agriculture development***

A very large-scale agriculture development plan has been designed by the CNA (1995) involving the construction of dams for irrigation. Since the area involved in such a development is larger than the present study area for the Huizache-Caimaneo region it was necessary to view this new development on two different scales. At a municipality level, **Figure 7.14** shows that major agricultural development will be carried out from Mazatlán to Teacapán. The total agricultural area will cover 660 km$^2$ and many dams and canals for irrigation will be constructed parallel to the lagoon system. To have constant water supply from the rivers throughout the year there will be two large dams, one of which will be constructed north of Huizache, directly connected to the river Presidio, and another one is already being constructed north of Caimanero, directly connected to river Baluarte. Furthermore, in addition to this agricultural development, new urban areas are also being proposed by the CNA and will occupy a total land area of 257 km$^2$.

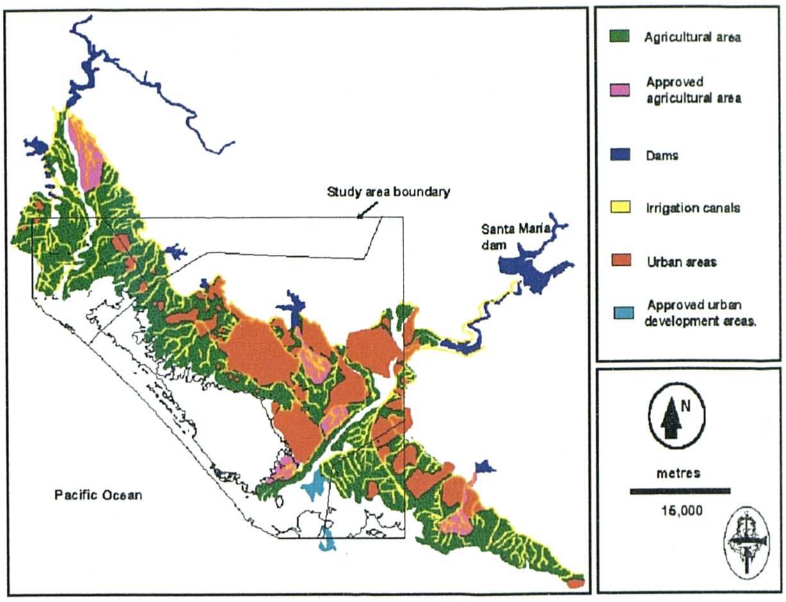


Figure 7.14. Future agriculture development in the Huizache-Caimanero region at a regional level.

For the area selected in this study **Figure 7.15** shows that agriculture development will be carried out in close proximity to the entire length of the lagoon system and will occupy 32% (435 km$^2$) of the land area. Clearly, this new development is of major concern since it is very likely that it will increase the level of pesticide pollution already detected in the lagoon (see **Chapter 6**). The new urban areas are also of environmental concern, they will occupy 16% (209 km$^2$) of the land area.

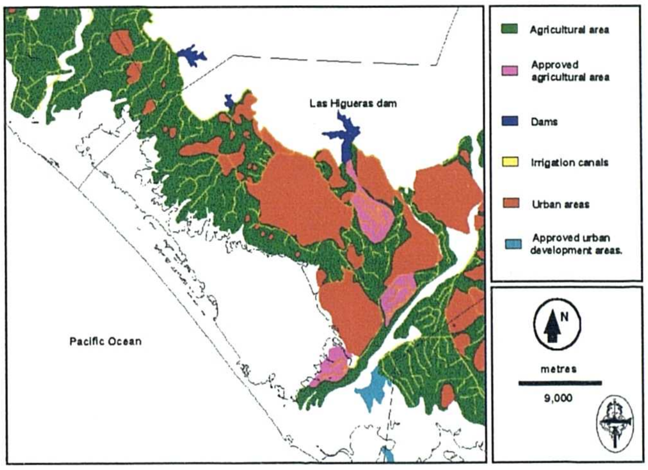


Figure 7.15. Future agriculture development in the Huizache-Caimanero region at a site-level.

To carry out the time series analysis, the environmental model in **Figure 7.3** was modified by replacing the old agriculture primary data by the new agriculture land proposed by the CNA (1995). The resulting image is shown in **Figure 7.16** and shows how the incorporation of the new agriculture factor considerably decreases the number of very suitable sites identified by the previous model (**Figure 7.3**) in the south-east of the Caimanero lagoon. Not surprisingly, due to the vast land area that would be occupied by this agriculture development, the model was only able to locate very suitable and moderately suitable sites for aquaculture away from this development towards the coast along the sand barrier, and in the south adjacent to Los Cerritos Lagoon. Interestingly, the number of very suitable sites increased from 3 km$^2$ in the previous model (Figure 7,4) to 6 km$^2$; however many of these new sites were not located in close proximity to the Huizache-Caimanero lagoon, but were mainly located in the municipality of Escuinapa. Of major concern is that from the vast land area that is being proposed for agriculture, the south-east of Caimanero has been already approved for development, and this area coincides with the aquaculture location predicted by the GIS. More importantly, the largest existing shrimp farm and its future expansion is adjacent to this new agricultural development. This south-east area is also being proposed for new urban areas.

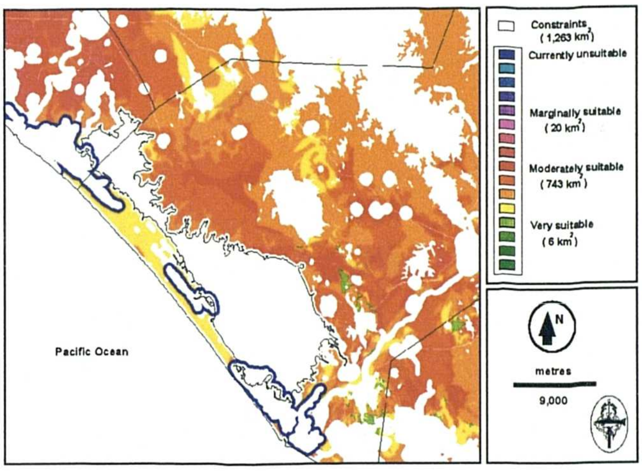
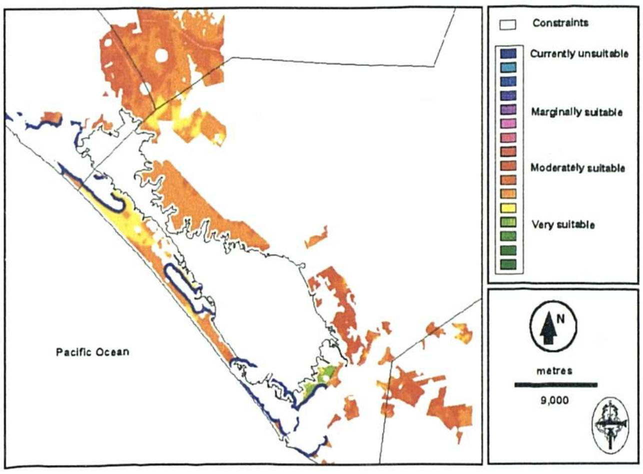


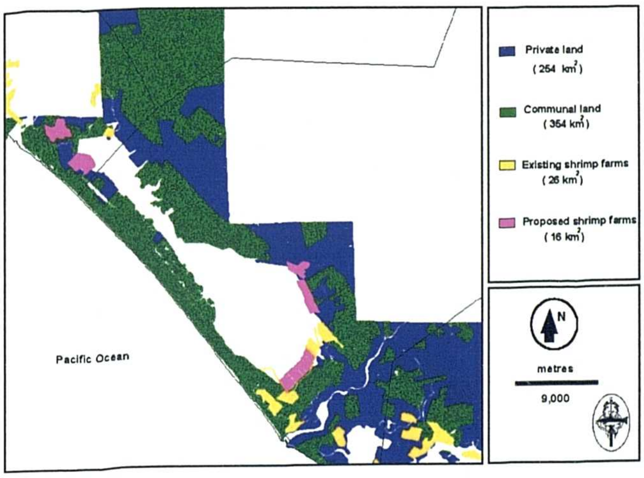
**Figure 7.16. Resulting allocation of land found by the GIS model using the new agriculture factor.**

### c) Land tenancy

Land tenancy could be a major restriction to the establishment and expansion of any activity and, therefore, it could have played a very important role in the socio-economic model presented in this study. However, the data available only accounted for 45% of the study land area and, therefore, it was not sensible to incorporate this factor into the model. Nonetheless, from the data available, it was found that communal land accounts for 26% (354 km$^2$) of the area, ownership in this region accounts for 19% and is located in urban areas where aquaculture is not likely to develop. Nevertheless, there might still be some potential if permits can be obtained. Adjacent to the Huizache-Caimanero lagoon system, private land is only located north-east and north-west of Huizache, and south-east of Caimanero. GIS environmental predictions (**Figure 7.17A**) lie well within communal land, and therefore concessions could be obtained (despite difficulty with permits and transactions). The majority of the existing shrimp farms are located inside communal areas (**Figure 7.17B**). Distinctively, however, the farm constructed inside the Caimanero lagoon is located in government land meaning the use of this land required a specific authorization given by the Fisheries Secretariat (Lopez-Peiro, pers.comm.). Two of the proposed farms are located well inside private land, north-west of the Huizache lagoon.



**A. GIS predictions within communal areas.**



**B. Shrimp farms within communal areas.**

**Figure 7.17. Land tenancy in the Huizache-Caimanero region.**

## 7.5 SUMMARY AND DISCUSSION

### *Summary*

Site-level models for the Huizache-Caimanero lagoon system were developed for environmental, water quality and socio-economic factors. The aquaculture environmental model was used in the multi-objective evaluations for solving conflicts of land allocation and land use with agriculture and other production activities. Finally, a time series analysis was evaluated for the "real" (as opposed to predicted) shrimp farm locations, agriculture developments and land tenancy data.

### *Discussion*

Most of the procedures involved in creating the GIS-based models were very similar to the state-level models. Even though the site-level models for the Huizache-Caimanero lagoon system did not involve the use of questionnaires, the results of the state-level questionnaires for semi-intensive shrimp farming were found to be of great use when developing the site-level models, since they also involved scores for semi-intensive shrimp farming.

It was clearly shown that, in a site-level assessment, factors such as water quality from water samples were particularly relevant, whereas this analysis would have been of lesser relevance on a state-level (i.e. water quality assessment is always relevant, the difference in importance is attributed to the scales used). A complete analysis of the water quality in the lagoon system was initially prepared by Soto-Lopez (1969) and has been used as a guideline by many authors over the years. Unfortunately, there has been no continuation of Soto-Lopez's water quality study which could have benefited the water quality evaluation in this study enormously. Unpublished information provided by Galindo-Reyes for 1990 and 1994 was used in this study.

The water sampling stations used by Soto-Lopez were sufficient to describe the overall water quality fluctuations in the lagoon system (i.e. salinity distribution), and the same locations were used by Galindo-Reyes. However, for spatial analysis in a GIS, the number of sample stations would need to be increased by establishing a spatially uniform grid, since the number of sample stations used by Soto-Lopez and Galindo-Reyes were very few and only covered a small portion of the lagoon's surface area. Although the water sample stations used by Menz (1976) covered a larger surface area, Menz's data were not used, firstly because the data were not spatially uniform (some sample stations were concentrated within a small area) and secondly, water samples were only taken for a 4 month period from September to December of 1974 and 1975. It would not, therefore, be possible to carry out an annual water quality evaluation (of most concern was the evaluation of the dry period from February to March which was not considered by Menz). Furthermore, the interpolation of the water quality point data from the water sample stations in this study used certain assumptions, and care needs to be taken in selecting the appropriate interpolation distance due to the dynamic nature of the lagoon system. The different interpolation radii selected should be adjusted according to the spatial variability of each factor. The most variable factor (e.g. salinity) would require a smaller radius in comparison to those which were considered more stable (e.g. temperature).

Pollution is likely to be high during the wet season due to the fact that it is the time of the year in which agricultural land is being prepared, and it is also the time during which most of the shrimp farms operate. It could therefore become an important factor in the water quality model presented in this study. However, this factor was not used because only two sample stations were located inside the lagoon system (see Chapter 6, Tables 6.3 and 6.4)

By comparison with the state-level models, the environmental models were found to be much more detailed and accurate in identifying potential sites for aquaculture development than the socio-economic models. As was discussed in Chapter 5, the reason for this was that most socio-economic data were only available in choropleth form, whereas the use of choropleth images at a state-level did not have an important effect on the results; at a more local level choropleth images will significantly affect the socio-economic results. For example, since the Huizache-Caimanero lagoon is located in two municipalities (Mazatlán and Rosario), and most of the socio-economic data were only available in choropleth form, it was not surprising to find that most suitable sites for semi-intensive shrimp farming were in the municipality of Mazatlán. Conversely, most of the best sites in the environmental image models were found in Rosario. If more detailed data replaced the choropleth data layers used in this study then a more accurate and complete socio-economic model could have been developed.

Real data obtained for future aquaculture and agriculture developments were evaluated by using a times series analysis (TSA), thus enhancing the evaluation of the GIS predictions. The TSA used in this study only involved the comparison between pairs of images. However, by integrating a series of data over time it would be possible to analyze trends or anomalies in multiple images. In IDRISI for Windows a TSA can produce an analysis of up to 84 input images. Examples of using this technique are provided by Eastman (1993) and Eastman and Fulk (1993). Satellite imagery is perfectly suited for a TSA, and this is an area that could be further investigated for aquaculture planning and development. For example, the bathymetry factor used in this study was digitized manually from a paper map which was created during the wet season. Since the lagoon's surface area varies considerably during the dry period it would be important to have a time series analysis in which the water levels within the lagoon system could be monitored, in order to have a more realistic approximation of the quantity and quality of water available in the lagoon system.

Due to the vast areas of mangroves that have been damaged for shrimp pond construction world-wide (e.g. Ecuador), and most importantly for this study in Sinaloa, TSA evaluation could have been used to give a realistic assessment of the level of impact that shrimp pond construction has had on mangroves over the years. This may help decision-makers to mimimize and/or avoid the future impacts of shrimp pond construction. Some researchers have already used satellite imagery to assess the distribution patterns of mangroves (e.g. Long and Skewes (1994)) and the evaluation of the impact of shrimp culture on the coastal zone (e.g. CNES-IFREMER (1991); Ly *et al.* (1994)). Such data could be incorporated into a GIS form and used in a TSA.

As in the state-level assessment, results of the GIS evaluation were entirely dependent upon the quality of the data that was available. For example, a problem with the data obtained for the Huizache-Caimanero lagoon system was that the soils information available was found for Caimanero and not for Huizache; in other words half of the image was missing. To solve this problem it was necessary to use the Vwindow command in TOSCA to extract a rectangular section of the state-level vector file, and then use Vconcat to paste this section into the Caimanero section. Since both sections were uniform and were parallel to each other the concatenation of the files was not difficult. Similarly, the livestock rearing paper map was not available on a 1:50,000 scale and so the state-level data were used. Finally, since the 1:50,000 scale agriculture and livestock rearing paper maps did not have a classification in terms of suitability it was again necessary to use the state-level classifications.

# CHAPTER 8

# MODEL AND DATABASE FIELD VERIFICATION

## 8.1 Background and justification

An important aspect of using a GIS is the need to verify the outcomes of the models produced. Partial verifications have already been made in this study in three ways. Firstly, by using questionnaires to establish the relationship between site factors, secondly, by comparing the area predicted by the GIS with that proposed by studies carried out using manual techniques, and thirdly, by comparing the location of the shrimp farms with the area predicted by the GIS.

It was considered essential to conduct verification studies to enhance the dynamic nature of the models produced (**Figure 8.1**). The models were dependent upon a large variety of data sources at different scales - which themselves were likely to have some level of inaccuracy. It was also very important to verify the results of the models and of the database in the field. **Figure 8.1** illustrates how the field verification work was incorporated in the present study, and it can be seen that field verification is an important procedure in developing and verifying the models produced for the different planning levels.

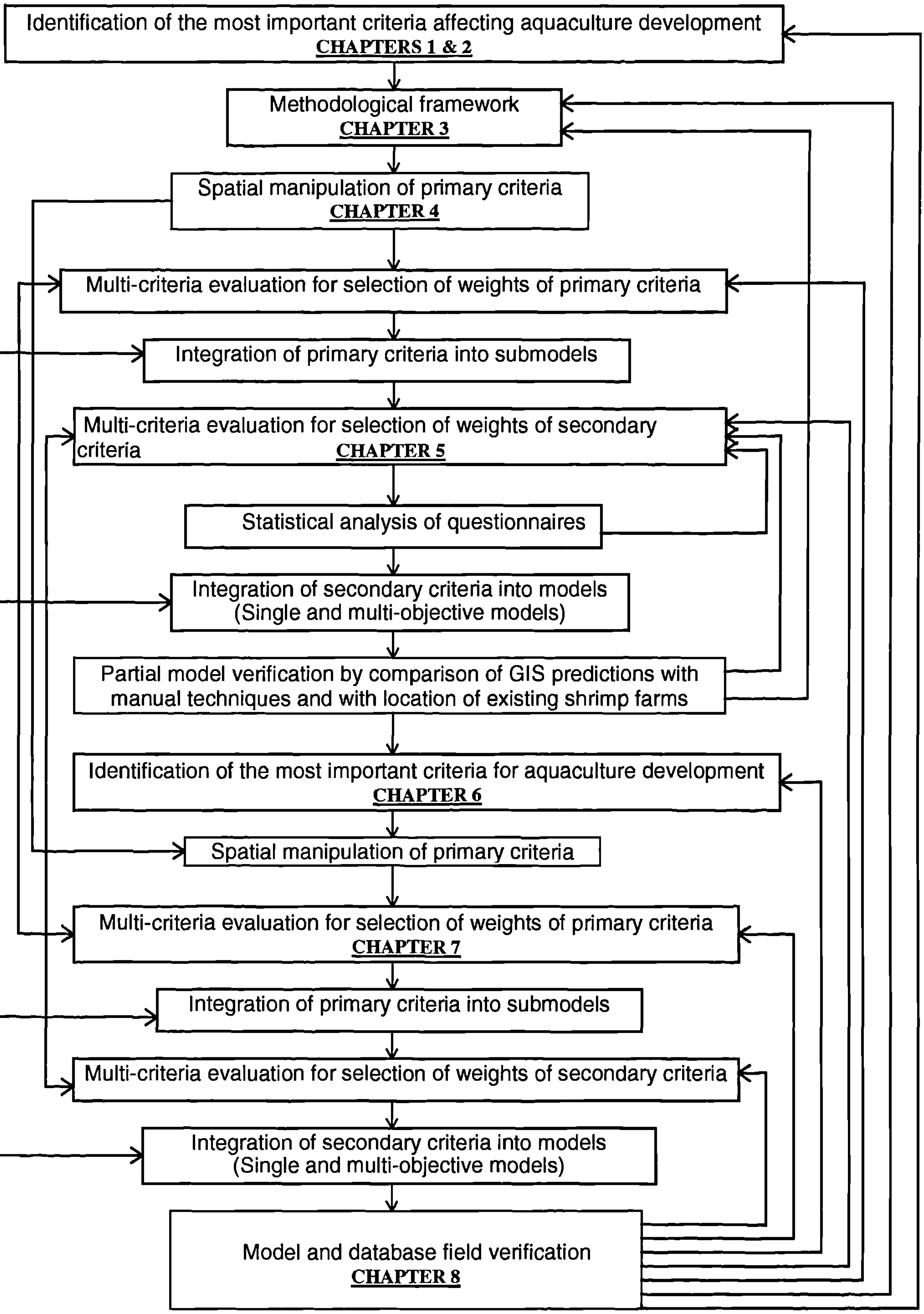


**Figure 8.1. Schematic diagram resulting from model and database field verification for the entire GIS study. The feedback parts and dynamic nature of the processes are indicated by the arrows.**

GIS verification work has been substantially assisted in recent years by the development of GPS, a sophisticated navigation system based on a series of satellites known as NAVSTAR, located at an altitude of 17,699 km and operated by the Defence Secretariat of the United States. The system allows the user to obtain position information (latitude, longitude and elevation) almost instantaneously and can be operated in a static or dynamic mode. The flexibility of the system, and the variety of operational capabilities, enable the user to obtain information at different levels of precision from hundreds of metres to only a few metres (or less) (Allen, 1994).

Because a GPS is based on a series of satellites, a position can be recorded anywhere on the planet on the basis of its distance from the satellites which serve as extremely precise reference points. The great advantage of a GPS over conventional methods is that there is no need to be able to see two points in order to measure the distance between them. Each satellite transmits a position signal to the GPS from which latitude, longitude and elevation can be obtained when at least 4 satellites are available. Additionally, GPS software enables the user to record data captured in the field in a x, y, z format which can be directly downloaded into a GIS.

GPS is rapidly becoming an important tool to the GIS and remote sensing industries. The use of hand-held GPS receivers to collect detailed attribute information, and to verify ground truth data collected by remote sensing, is increasing at a dramatic rate (Gilbert, 1994). GPS have been used to record data in seismology, marine geophysics, forestry and practical camping (Gilbert, 1994). GPS, GIS and a combined harvester have been used to improve crop yields and reduce pollution from agricultural chemicals (Swindell, 1995); and Royal navy warships in the U.K. use GIS and GPS tools for better practical plots (Anticliff, 1995). In the U.K., government agencies are by far the greatest users of GPS mapping equipment, and it has been used in forestry and land management, surveying and environmental protection. U.K. local authorities use GPS to map city-owned assets such as traffic signals and street lighting (Gilbert, 1994). In overview, most of the applications use GPS to catalogue, validate or collect details for databases or GIS. Occasionally, GPS are used to collect and store only position data. Usually, however, GPS are used to simultaneously collect a wide range of attribute information associated with each position.

GPS technology is also starting to be used in Mexico. Aquatic Design and Construction (an American company) and IFREMER (the French Institute of Oceanographic and Coastal Studies) have already used GPS to help design shrimp pond farms in the state of Nayarit in Mexico (Allen, 1994). During the present study, it was found that a shrimp farm in Caimanero lagoon named “Parque Camaronícola” was also using GPS for land topography to help design future expansion of their shrimp pond farm.

## 8.2 Materials

### 8.2.1 The GPS used in this study

A high precision GARMIN Global Positioning System (GPS 100 SRVY II personal surveyor) was used which can receive information from up to 8 satellites. If four or more satellites with good geometry are available, then latitude, longitude and altitude are computed. If only three satellites are available the unit automatically operates in 2D mode in which only latitude and longitude are computed (GARMIN, 1993a). The main functions provided by this GPS are data collection, real-time differential GPS and navigation.

1. Data collection refers to the unit’s extensive data recording capability based on user-supplied attribute and description information which greatly simplifies the data collection task in the field. More than 18 hours of differential GPS information (or 200,000 positions) computed by the receiver can be stored internally, as well as optional user-supplied attribute and description information (differential GPS refers to the use of two units to differentially correct data for post-processing). This eliminates the need for using a data logger or PC in the field, greatly simplifying the data-collection task. Additionally, up to 250 waypoints (point data which contain a name, location, attribute and a description) and 10 routes (each route contains up to 9 waypoints), and 100 attributes can be stored. The stored data can be transferred to a PC and processed, manipulated, analyzed, plotted, printed or converted to a GIS format using the post-processing software. Waypoints, routes and attributes can also be edited using the GPS software and uploaded to a unit or even cross-loaded between units.

2. Real-time differential GPS operation refers to the SRVY II’s transmitting or receiving RTCM SC-104 (Radio Technical Commission for Maritime Services, Special Committee No. 104, such as a U.S. Coast Guard Marine radio beacon) for satellite data corrections in real-time, improving accuracy of field position data.

3. Navigation refers to using the computed position to navigate to the point locations whose coordinates have been previously entered. Navigation can be used in conjunction with real-time differential GPS, and is useful for field verification of site changes and speedy updating

of data, as well as for initial location of a site that has not been visited before (GARMIN, 1993a).

Autonomous, non-differential, dynamic operation accuracy is typically 15 metres with Selective Availability (S/A) off (S/A is a U.S. government capability to degrade the GPS satellite signals); with S/A on the accuracy can be degraded to 100 metres. Static, uncorrected survey accuracy, used in conjunction with averaging, is typically 5 metres with S/A off. The SRVY II, used in conjunction with differential post-processing, will achieve accuracies of 1 to 5 metres in static mode (at least 3 to 5 minutes of data collection) and 3 to 10 metres in dynamic mode. Collecting data for a longer period (e.g. 20 to 30 minutes) can improve accuracy to better than a metre.

### 8.2.2 Global Positioning System (GPS) software

The PC100S2 GPS software provides numerous capabilities for processing, analyzing, displaying and outputting the data collected by the GPS and this is well suited to GIS, mapping and processing applications.

Running on an IBM compatible PC, the PC100S2 software can be used to: (a) download route, waypoint and position data for analysis plotting and processing; (b) display digital maps in real time for GIS mapping and navigation guidance; (c) geographically plot data files with zooming, panning and distance calculation capabilities; (d) edit and upload attributes to SVRY II for converting tagging of position data in the field; (e) edit and upload routes and waypoints to SRVY II for navigation or surveying sessions; in addition to a number of other functions (GARMIN, 1993b).

### 8.2.3 Computer used for GPS software

Data collected in this study with the GPS 100 SRVY II was downloaded to a 386, 25 MHz, notebook PC with 4 Mb RAM, 80 Mb hard disk with a VGA graphics adapter and a LCD monochrome display running under MS DOS version 5.0. Following each field session, data downloading was carried out at CIAD Acuicultura y Manejo Ambiental (aquaculture research centre) in Mazatlán and was subsequently transferred to the 486 DX computer used for GIS evaluation in Stirling.

### 8.2.4 Configuration and accuracy of GPS in this study

The GPS SRVY II can be configured according to the user's needs. The configuration used for this study is provided in detail in **Table 8.1**. The single GPS unit was used in 3D mode because more than 3 satellites were available at all times during field work. For navigation the autonomous, non-differential, dynamic operation was used with an accuracy of 15 metres with S/A off. For position recording in static, uncorrected operation in conjunction with averaging, a 5 metres accuracy was obtained with S/A off.

**Table 8.1. Selected technical requirements for using GARMIN GPS 100 SVRY II in Scotland and in Sinaloa.**

| OPERATIONS | FIELDS | CONFIGURATION |
|---|---|---|
| **SURVEY** | Configuration | Performed as a FIELD unit (can provide positions and or record data for both DGPS and non-DGPS applications). |
| | Application | STATIC mode (unless necessary). |
| | Recordings | RECORD POSITIONS (records position data either differentially corrected or uncorrected). |
| | Receive and apply differential corrections | INPUT RTCM DATA 4800 Baud. |
| **NAVIGATION AND PLANNING** | Course Deviation Indicator (CDI) | Scale 10 m (10 m left and right of cross track error)<br>Orientation: "CENTER" (towards the center to eliminate cross track error).<br>Alarm ON. |
| | Mode selection | Normal (defaulted mode for survey applications, offers continuos survey updates, operates 8 hours on a single pack of alkaline batteries or 5 hours using the rechargeable battery pack). |
| **UNIT CUSTOMIZATION** | Map projection | **SCOTLAND**<br>DATUM: WGS 84<br>POSN>BRITISH GRID.<br>**SINALOA**<br>DATUM: NAD 27<br>POSN>UTM/UPS |
| | Display units | Distance, speed and altitude in metric units<br>Heading Mode option: GRID heading (all information was relative to the GRID north, corrected with the grid convergence angle computed by the GPS). |
| | Output formats | PLOTTING (for interface with PC for real-time plotting or monitoring). |

Source: GARMIN (1993a ).
Note: GPS was programmed to be tested in the U.K prior to field verification.

## 8.3 Methodological framework

### 8.3.1 Model and database environmental verification

The first step was to construct a spatial sample. The sampling plan was based in the environmental GIS data which was more accurate than the choropleth data. Moreover, because the environmental image model (**Figure 7.4**) was the basis from which the rest of the environmental models were developed it was reasoned that this image was the most suitable for the evaluation.

In addition to the "land-based" environmental evaluation water quality was also considered as part of the field verification. The pre-selected sites for water quality were not based on GIS predictions since the water quality data (Chapter 6) was not obtained until the second visit to Mexico.

#### *Sample assessment*

To decide which factors were going to be assessed at each sample location to enable a valid verification of the database and of the models, factors had to be selected on the basis of: (a) the relative importance of that factor in relation to the other factors, (b) the need to verify the database of that factor (e.g. spatial variability), and (c) time and effort required. For the land-based environmental evaluation soils, topography and land use were selected, and in the water quality survey, salinity, dissolved oxygen, temperature and depth were assessed.

Since a smaller number of factors were involved in the evaluation, the land-based environmental image (**Figure 7.4**) had to be simplified and re-evaluated for the purposes of sample point selection. The mathematical expression for the secondary criteria of this new model was:

**NARES** = ( S X 0.28) + (TOP X 0.27); **LAUSE** = (AGR X 0.25) + ( FO X 0.20); **GEM** = (NARES + LAUSE) X CONS X BCONS(m) + BCONS(a). Where, NARES = natural resources; S = soils submodel; TOP = topography; LAUSE = land use; AGR(e) = agriculture; FO = forestry; GEM = general environmental model; CONS = constraints used to mask out conservation areas; BCONS = buffer zone for conservation areas.

### Water-based verification

The water-based image was not based on a GIS prediction. Nonetheless, since the field visit was going to be carried out during the dry season, the bathymetry factor used in the water-quality model was re-classified (**Figure 8.2**) by excluding those sites with less than 0.80 metres in depth, to avoid the chances of locating sampling points in dry areas.

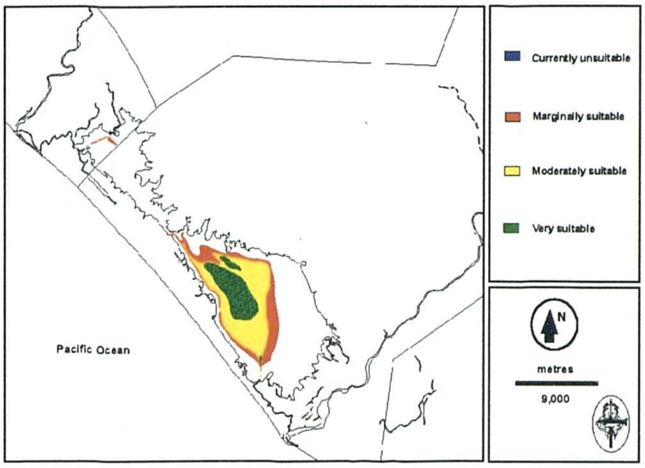


**Figure 8.2. Reclassified bathymetry image for estimating number of sample points.**

From these evaluations, the number of sample points was set at 60 for both "land-based" (i.e. 20 for each classification) and "water-based" (i.e. for those sites located in depths greater than 0.80 m) evaluations.

### *Sample locations*

Both the land-based and water-based images were classified into Boolean images then, to determine the location of the sample points selected, the SAMPLE module in IDRISI was used to produce a vector file of point locations. The stratified random sample option was used in which the study area was divided into a regular matrix of large cells (one cell per point). The exact positions of points within the cells were then determined by choosing random coordinates. This procedure had good geographical coverage (because of the regular structure of the spatial image) and was reasonably unbiased because of the random selection of point coordinates.

SAMPLE assumes that the spatial area selected by the user matches the total rectangular dimensions of the raster grid. Thus, when SAMPLE was used a number of sample points fell within areas that were not included in the evaluation. This problem was overcome by increasing the sample number to ensure that the total number of points did fall within each one of the selected areas. To this end, it was necessary to estimate the area that was occupied by each land-based and water-based image relative to the total area of the raster image. Knowing the proportional area[8.1] of each image the new sample size was calculated to ensure that an adequate number of points did fall within the study region.

By using the SAMPLE module it was possible to create four point vector files from the four images selected (i.e. three land-based images and one water-based image) within the desired areas. These vector files, containing the location of each point (latitude and longitude) as well as a random ID number, were downloaded directly into the memory of the GPS unit.

### *Coding system*

To make the sample assessment as thorough as possible, and to reduce the amount of time spent on each pre-selected site location, while at the same time increasing the number of factors which could be evaluated at each pre-selected site, a coding system was designed whereby each factor was scored from 1 to 4 so as to match the re-classification previously described for the environmental images (**Table 8.2**). At each pre-selected site the factors were evaluated using this coding system and were keyed directly into the GPS. (**Figure 8.3**).

| | | | |
|---|---|---|---|
| 36 Vs | N 22° 52' 55" W 106° 0' 36" | P3T4A4F4 | Wild vegetation |
| Name (ID number) | Location | Attribute | Description |

**Figure 8.3. Summary information for each pre-selected site after field evaluation.**

Note: Vs = Very suitable (class 4).

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[8.1] The proportional area of the background value (0) was calculated using HISTO, so the remaining area corresponded to the area of interest.

## Table 8.2. Classification and coding system for land-based field verification factors.

|  | Class 4<br>Very suitable | CODE | Class 3<br>Moderately suitable | CODE | Class 2<br>Marginally suitable | CODE | Class 1<br>Currently unsuitable | CODE |
|---|---|---|---|---|---|---|---|---|
| **PHYSICAL AND ENVIRONMENTAL RESOURCES** |  |  |  |  |  |  |  |  |
| *Textural soil class /2 | Clay, Silty clay, Sandy clay, Silty clay loam, Sandy clay loam, Clay loam. |  | Silt, Silty loam, Loam |  | Sandy loam, Loamy sand, Sand. |  | No data. |  |
| pH /2 | 6.5 - 8.5 | P4 | 5.5 - 6.5 or 8.5 - 9.5 | P3 | 4 - 5.5 or 9.5 - 11 | P2 | < 4 or > 11 | P1 |
| Topography /3 | Gentle slope | T4 | Rolling | T3 | Steep | T2 | Very steep | T1 |
| **LAND USES AND INFRASTRUCTURE** |  |  |  |  |  |  |  |  |
| Agriculture /1 | Not suitable for agriculture. | A4 | Manual cultivation, moderate risk of pollution. | A3 | Seasonal cultivation, likely risks of pollution. | A2 | Intensive cultivation through the year. High risk of pollution. | A1 |
| Forestry /1 | Land not suitable for forestry, no trees very easy to prepare for pond construction. | F4 | Non-wood product land suitable for pond construction. Easy to prepare for pond construction. | F3 | Land with wood products will be difficult for construction. Forestry activities likely to cause pollution. | F2 | Land with wood and non-wood products will be difficult for construction. Forestry activities will cause pollution. | F1 |

Note: * Textural class defined after laboratory analysis.

Thresholds defined by: 1/ Aguilar-Manjarrez and Ross (1993); 2/ Coche and Laughlin (1985); 3/ FAO (1977).

## 8.4 Field assessment

### 8.4.1 Reconnaissance survey

Prior to the assessment of the pre-selected sites, the lagoon system and some of the shrimp farms were visited in order to become familiar with the area. Additionally, time was also spent on visiting institutions (e.g. Fisheries Secretariat) and contacting researchers, farmers and fishermen who provided very useful information about the lagoon system. Since the GPS navigation function was going to be mainly used to locate the pre-selected sites, a series of tests were carried out in the field by navigating in dynamic and in uncorrected modes to some known locations so as to become familiar with the GPS unit.

From the preliminary visits a series of routes was created by programming the GPS unit prior to field assessment. This meant that soon after a pre-selected site was visited the GPS began navigating for the next pre-selected site, so there was no need to spend time programming the GPS unit whilst in the field.

Due to the large area of the lagoon (175 km$^2$) and of the shrimp pond farms in this region (largest shrimp farm is 2 km$^2$) it would be difficult to have a clear picture of the significance of the field evaluation whilst on the ground. Therefore, as a further aid to the preliminary visits to the study region, aerial photographs and a video were taken from a helicopter.

### 8.4.2 Evaluation and coding of sample points.

An off-road vehicle (4 x 4) was used to get as close as possible to the pre-selected locations. However, many of the sites were located far from roads, and had to be visited on foot.

When assessing a sample point on the ground, it was important that the size of the area being assessed was the same at each sample location. Taking into consideration that the accuracy of the GPS[8.2] could be limited to 15 metres (worst case in this study) and that the pixel size of the spatial image was 20 x 20 m, it was considered unnecessary to evaluate an area larger than the pixel size.

At each location the pre-determined factors were evaluated, coded and keyed directly into the memory of the GPS unit. In this way, most factors were coded after a simple field

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[8.2] The accuracy of the GPS used in autonomous, non-differential, dynamic operation is 15 metres.

observation. However, since soils were found to be one of the most important site factors for shrimp pond farm development, the soil pH test was chosen as suggested by Coche and Laughlin (1985) because of its influence on pond productivity, and because it was quick to carry out in the field. To obtain a general indication of the soil pH, papers from a soil pH testing kit were dipped into soil suspensions made by mixing one part of the soils being sampled with one part of distilled water. The resultant change in colour was compared to the chart supplied.

### 8.4.3 Laboratory analysis

A more detailed definition of soil texture was carried out by taking a single soil sample at each pre-selected site. Each soil sample weighed a maximum of 1 kg except in gravel soils where samples had to be large enough to contain at least 100 grams of fine earth as suggested by Coche and Laughlin (1985). A hole digger was used to obtain the disturbed soil sample from a depth of about 30 cm. These samples were placed in pre-labelled plastic bags and were then taken to CIFSA (consulting company) in Mexico City at the end of the field analysis for quantitative determination of the particle sizes[8.3]. The procedure used was the mechanical soil analysis described by Coche and Laughlin (1985) using the particle-size classification used by the U.S. Department of Agriculture (USDA) which defines silt from 0.05 to 0.0002 mm. The results of the mechanical soil analysis made in the laboratory were expressed as a percentage of the total initial dry weight of earth. Then, a textural class was assigned to each sample using the textural triangle method according to USDA particle sizes. The results from the soil analysis are presented in three tables (**Tables 8.3** to **8.5**) for the very suitable, moderately suitable and marginal pre-selected sites.

### 8.4.4 Coding assessment

Land-based

At the end of each field verification day the data were transferred to a 386 notebook PC. To incorporate this data into the GIS analysis. The soils sub-factors (i.e. soil pH field analysis[8.4] and textural classes) were scored from 1 to 4, as shown in **Table 8.2**, then an overall score, **S**, was produced by assigning weights.

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[8.3] Soils were assigned to textural classes depending on the proportions of sand, silt and clay-size particles.

[8.4] The soil pH value was re-measured as part of the laboratory analysis in order to cross-check the results of the field measurements. Most importantly pH was re-measured to account for very low pH values.

The mathematical expression for this model was:

**S** = ( LS X 0.70 ) + ( PS X 0.3 )

Where, S = soil submodel score; LS = laboratory soil score; PS = soil pH score during field verification (cross-checked in laboratory).

The laboratory textural class soil score was given the highest weight (0.70) due to its importance for pond construction and to the reliability of the quantitative results. Once the value of **S** was obtained, it was then incorporated with the rest of the factors scores for topography, agriculture and forestry by using the simplified GIS environmental image previously described:

**NARES** = ( S X 0.28) + (TOP X 0.27); **LAUSE** = (AGR X 0.25) + ( FO X 0.20); **GEM** = (NARES + LAUSE). Then, a final score **M** was produced.

The results presented in **Tables 8.3** to **8.5** show that the value of **M** clearly distinguished the three suitability classes (i.e. very suitable, moderately suitable, and marginally suitable). Best results were achieved for the moderately suitable classification where an accuracy of 90% was achieved, only 2 sites were not classified as 3. Good results were also obtained with the very suitable sites with 80% accuracy, only 4 sites were not classified as 4. Finally, 65% was achieved for the marginal sites. Overall, the largest potential appears to be on the south of Caimanero and along the sand barrier.

## Table 8.3. Very suitable (class 4) coding assessment of field and laboratory data.

| | POSITION | | FIELD SCORES | | | | | | LABORATORY SOIL SCORE | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Longitude | Latitude | pH | | T | AGRI | | F | Sand | Silt | Clay | Text. class | LS | S | M |
| | | | Value | PS | | Type | AS | | % | % | % | | | | |
| 66 | -106° 1' 19" | 22° 51' 53" | 5.8 | 3 | 4 | Wild veg. | 4 | 4 | 8.0 | 78.8 | 13.2 | Silty loam | 3 | 3 | 4 |
| 62 | -106° 1' 6" | 22° 52' 3" | 5.8 | 3 | 4 | Ploughed | 2 | 4 | 7.8 | 84.2 | 8.0 | Silt | 3 | 3 | 3 |
| 33 | -106° 0' 51" | 22° 52' 16" | 5.8 | 3 | 4 | Wild veg. | 4 | 4 | 7.7 | 77.6 | 14.7 | Silty loam | 3 | 3 | 4 |
| 63 | -106° 0' 35" | 22° 52' 30" | 5.8 | 3 | 4 | Wild veg. | 4 | 4 | 6.0 | 72.9 | 21.1 | Silty loam | 3 | 3 | 4 |
| 8 | -106° 0' 42" | 22° 52' 42" | 5.8 | 3 | 4 | Pasture | 3 | 4 | 14.9 | 74.2 | 11.0 | Silty loam | 3 | 3 | 3 |
| 36 | -106° 0' 36" | 22° 52' 55" | 5.5 | 3 | 4 | Wild veg. | 4 | 4 | 12.3 | 55.7 | 32.0 | Silty clay loam | 4 | 4 | 4 |
| 32 | -106° 0' 16" | 22° 52' 53" | 6.1 | 3 | 4 | Wild veg. | 4 | 2 | 17.4 | 46.0 | 36.6 | Silty clay loam | 4 | 4 | 4 |
| 41 | -106° 0' 53" | 22° 52' 55" | 6.1 | 3 | 4 | Wild veg. | 4 | 2 | 26.3 | 32.5 | 41.2 | Clay | 4 | 4 | 4 |
| 76 | -105° 59' 39" | 22 ° 53' 2" | 5.3 | 2 | 4 | Wild veg. | 4 | 4 | 7.1 | 78.1 | 14.8 | Silty loam | 3 | 3 | 4 |
| 77 | -105° 59' 53" | 22 ° 53' 16" | 5.5 | 3 | 4 | Wild veg. | 4 | 4 | 10.3 | 64.8 | 24.8 | Silty loam | 3 | 3 | 4 |
| 19 | -105° 59' 47" | 22 ° 53' 27" | 5.8 | 3 | 4 | Wild veg. | 4 | 4 | 12.2 | 76.0 | 11.8 | Silty loam | 3 | 3 | 4 |
| 35 | -105° 59' 54" | 22 ° 53' 53" | 5.8 | 3 | 4 | Wild veg. | 4 | 4 | 11.6 | 84.2 | 4.2 | Silt | 3 | 3 | 4 |
| 55 | -105° 59' 27" | 22 ° 53' 50" | 5.5 | 3 | 4 | Wild veg. | 4 | 4 | 27.0 | 54.2 | 18.8 | Silty loam | 3 | 3 | 4 |
| 54 | -105° 59' 12" | 22 ° 53' 49" | 5.3 | 2 | 4 | Corn | 2 | 4 | 2.0 | 40.9 | 57.1 | Silty clay | 4 | 3 | 3 |
| 74 | -105° 59' 57" | 22 ° 53' 43" | 5.5 | 3 | 4 | Wild veg. | 4 | 4 | 2.3 | 62.7 | 35.1 | Silty clay loam | 4 | 4 | 4 |
| 2 | -105° 58' 57" | 22 ° 54' 13" | 5.8 | 3 | 4 | Wild veg. | 4 | 4 | 5.5 | 85.5 | 9.0 | Silt | 3 | 3 | 4 |
| 73 | -105° 58' 47" | 22 ° 54' 13" | 5.5 | 3 | 4 | Wild veg. | 4 | 4 | 10.1 | 66.8 | 23.1 | Silty loam | 3 | 3 | 4 |
| 60 | -105° 59' 17" | 22 ° 54' 39" | 5.3 | 2 | 4 | Wild veg. | 4 | 4 | 15.8 | 41.9 | 42.4 | Silty clay | 4 | 3 | 4 |
| 27 | -105° 59' 37" | 22 ° 49' 48" | 5.8 | 3 | 4 | Wild veg. | 4 | 4 | 15.4 | 81.2 | 3.4 | Silt | 3 | 3 | 4 |
| 53 | -105° 58' 52" | 22 ° 55' 36" | 5.5 | 3 | 4 | Ploughed | 2 | 4 | 29.5 | 66.4 | 4.1 | Silty loam | 3 | 3 | 3 |

TERMINOLOGY: **PS** = Soil pH score during field verification (cross-checked in laboratory); **T** = Topography score during field verification; **AS** = agriculture score during field verification; **F** = Forestry score during field verification; **LS** = laboratory soil score; **S** = Soil submodel score; **M** = model final score.

Note: Ploughed = Ploughed land for unknown agriculture crop; Wild veg. = Wild vegetation no agriculture. Text. Class = Soil textural classes.

Table 8.4. Moderately suitable (class 3) coding assessment of field and laboratory data.

| | POSITION | | FIELD SCORES | | | | | | LABORATORY SOIL SCORE | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Longitude | Latitude | pH | | T | AGRI | | F | Sand | Silt | Clay | Text. class | LS | S | M |
| | | | Value | PS | | Type | AS | | % | % | % | | | | |
| 68 | -106° 12' 23" | 23° 6' 15" | 5.8 | 3 | 4 | Corn | 2 | 3 | 4.0 | 88.9 | 7.2 | Silt | 3 | 3 | 3 |
| 59 | -106° 10' 60" | 23° 7' 19" | 5.8 | 3 | 4 | Ploughed | 2 | 4 | 11.4 | 65.5 | 23.0 | Silty loam | 3 | 3 | 3 |
| 1 | -106° 10' 15" | 23° 6' 23" | 5.5 | 3 | 4 | Ploughed | 2 | 4 | 12.4 | 72.8 | 14.8 | Silt loam | 3 | 3 | 3 |
| 34 | -106° 13' 10" | 23° 6' 4" | 5.5 | 3 | 4 | Corn | 2 | 3 | 7.2 | 78.9 | 13.9 | Silty loam | 3 | 3 | 3 |
| 9 | -106° 13' 48" | 23° 6' 6" | 5.5 | 3 | 4 | Ploughed | 2 | 4 | 7.2 | 85.9 | 7.0 | Silt | 3 | 3 | 3 |
| 39 | -106° 13' 44" | 23° 2' 48" | 5.5 | 3 | 4 | Corn | 2 | 3 | 8.9 | 80.9 | 10.2 | Silt | 3 | 3 | 3 |
| 7 | -106° 12' 19" | 23° 1' 38" | 5.5 | 3 | 3 | Wild veg. | 4 | 4 | 26.0 | 69.0 | 5.0 | Silty loam | 3 | 3 | 3 |
| 44 | -106° 10' 24" | 23° 0' 16" | 5.3 | 2 | 4 | Ploughed | 2 | 4 | 4.4 | 88.2 | 7.3 | Silt | 3 | 3 | 3 |
| 58 | -106° 10' 56" | 23° 1' 21" | 5.5 | 3 | 4 | Corn | 2 | 3 | 14.3 | 75.3 | 10.3 | Silty loam | 3 | 3 | 3 |
| 31 | -106° 7' 42" | 22° 56' 46" | 5.5 | 3 | 4 | Corn | 2 | 3 | 31.1 | 46.5 | 22.4 | Loam | 3 | 3 | 3 |
| 65 | -106° 9' 43" | 23° 4' 24" | 5.8 | 3 | 3 | Wild veg. | 4 | 2 | 8.4 | 76.6 | 15.0 | Silty loam | 3 | 3 | 3 |
| 6 | -105° 59' 25" | 22° 52' 45" | 5.5 | 3 | 3 | Wild veg. | 4 | 2 | 14.9 | 58.5 | 26.6 | Silty loam | 3 | 3 | 3 |
| 43 | -105° 59' 1" | 22° 53' 7" | 5.5 | 3 | 2 | Wild veg. | 4 | 1 | 2.7 | 82.5 | 14.8 | Silty loam | 3 | 3 | 3 |
| 23 | -105° 58' 59" | 22° 53' 41" | 5.8 | 3 | 2 | Wild veg. | 4 | 1 | 39.3 | 37.0 | 23.7 | Loam | 3 | 3 | 3 |
| 10 | -105° 58' 42" | 22° 55' 35" | 5.8 | 3 | 2 | Wild veg. | 4 | 2 | 87.2 | 9.7 | 3.1 | Sand | 2 | 2 | 3 |
| 16 | -105° 59' 42" | 22° 52' 20" | 5.3 | 2 | 2 | Wild veg. | 4 | 1 | 52.3 | 26.5 | 21.2 | Sandy clay loam | 4 | 3 | 3 |
| 4 | -106° 3' 2" | 23° 0' 8" | 5.3 | 2 | 4 | Ploughed | 2 | 4 | 47.2 | 24.8 | 28.0 | Sandy clay loam | 4 | 3 | 3 |
| 17 | -106° 2' 32" | 23° 0' 2" | 5.5 | 3 | 4 | Wild veg. | 4 | 1 | 88.4 | 7.7 | 3.9 | Sand | 2 | 2 | 3 |
| 38 | -106° 11' 28" | 23° 1' 6" | 5.3 | 2 | 4 | Coconut | 1 | 1 | 97.9 | 0.3 | 1.8 | Sand | 2 | 2 | 2 |
| 51 | -106° 9' 50" | 23° 5' 58" | 6.1 | 3 | 4 | Coconut | 1 | 1 | 92.7 | 7.1 | 0.2 | Sand | 2 | 2 | 2 |

TERMINOLOGY: **PS** = Soil pH score during field verification (cross-checked in laboratory); **T** = Topography score during field verification; **AS** = agriculture score during field verification; **F** = Forestry score during field verification; **LS** = laboratory soil score; **S** = Soil submodel score; **M** = model final score.

Note: Ploughed = Ploughed land for unknown agriculture crop; Wild veg. = Wild vegetation no agriculture. Text. Class = Soil textural classes.

## Table 8.5. Marginally suitable (class 2) coding assessment of field and laboratory data.

|  | POSITION |  | FIELD SCORES |  |  |  |  |  | LABORATORY SOIL SCORE |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Longitude | Latitude | pH |  | T | AGRI |  | F | Sand | Silt | Clay | Text. class | LS | S | M |
|  |  |  | Value | PS |  | Type | AS |  | % | % | % |  |  |  |  |
| 49 | -106° 7' 39" | 23° 1' 42" | 5.3 | 2 | 2 | Wild veg. | 4 | 1 | 85.8 | 7.8 | 6.4 | Loamy sand | 2 | 2 | 2 |
| 71 | -106° 3' 13" | 22° 59' 51" | 5.3 | 2 | 2 | Wild veg. | 4 | 1 | 8.2 | 70.8 | 21.1 | Silty loam | 3 | 3 | 2 |
| 11 | -106° 0' 31" | 22° 58' 11" | 5.8 | 3 | 2 | Conout | 1 | 1 | 75.2 | 17.7 | 7.1 | Loamy sand | 2 | 2 | 2 |
| 18 | -106° 0' 1" | 22° 57' 19" | 5.3 | 2 | 4 | Mango | 1 | 1 | 6.6 | 80.1 | 13.3 | Silty loam | 3 | 3 | 2 |
| 12 | -105° 59' 10" | 22° 56' 13" | 5.5 | 3 | 4 | Mango | 1 | 1 | 19.5 | 71.1 | 9.5 | Silty loam | 3 | 3 | 2 |
| 24 | -105° 58' 10" | 22° 55' 2" | 5.8 | 3 | 4 | Mango | 1 | 1 | 6.5 | 87.1 | 6.5 | Silt | 3 | 3 | 2 |
| 57 | -106° 1' 22" | 22° 59' 33" | 5.3 | 2 | 3 | Corn | 2 | 3 | 59.2 | 34.7 | 6.1 | Sandy loam | 2 | 2 | 2 |
| 56 | -106° 6' 6" | 23° 0' 58" | *4.7 | 2 | 2 | Wild veg. | 4 | 1 | 64.2 | 24.8 | 11.0 | Sandy loam | 2 | 2 | 2 |
| 50 | -106° 9' 26" | 22° 59' 10" | 5.3 | 2 | 2 | Wild veg. | 4 | 1 | 72.3 | 23.4 | 4.3 | Sandy loam | 2 | 2 | 2 |
| 46 | -106° 5' 17" | 22° 54' 23" | 5.3 | 2 | 4 | Coconut | 1 | 1 | 79.6 | 19.2 | 1.2 | Loamy sand | 2 | 2 | 2 |
| 61 | -106° 0' 39" | 22° 58' 39" | 5.3 | 2 | 4 | Coconut | 1 | 1 | 74.3 | 22.8 | 2.9 | Loamy sand | 2 | 2 | 2 |
| 45 | -106° 2' 15" | 22° 59' 49" | 5 | 3 | 3 | Pasture | 3 | 4 | 80.1 | 16.1 | 3.9 | Loamy sand | 2 | 2 | 3 |
| 40 | -105° 59' 16" | 22° 57' 44" | 5.8 | 3 | 3 | Pasture | 3 | 1 | 88.8 | 8.1 | 3.2 | Sand | 2 | 2 | 2 |
| 48 | -105° 58' 12" | 22° 56' 21" | 4.7 | 3 | 3 | Pasture | 3 | 3 | 72.5 | 22.3 | 5.2 | Sandy loam | 2 | 2 | 3 |
| 37 | -106° 9' 11" | 22° 58' 36" | 5.8 | 3 | 4 | Corn | 2 | 3 | 20.8 | 74.4 | 4.8 | Silty loam | 3 | 3 | 3 |
| 30 | -105° 58' 57" | 22° 58' 26" | 5.5 | 3 | 4 | Corn | 2 | 3 | 31.8 | 62.0 | 6.2 | Silty loam | 3 | 3 | 3 |
| 13 | -106° 4' 6" | 23° 0' 0" | 5.8 | 3 | 3 | Chilli | 2 | 3 | 11.5 | 74.8 | 13.7 | Silty loam | 3 | 3 | 3 |
| 25 | -105° 59' 6" | 22° 59' 26" | 5.8 | 3 | 3 | Chilli | 2 | 3 | 10.1 | 76.4 | 13.5 | Silty loam | 3 | 3 | 3 |
| 70 | -106° 0' 39" | 22° 59' 41" | 5.5 | 3 | 3 | Pasture | 3 | 1 | 79.0 | 19.6 | 1.5 | Loamy sand | 2 | 2 | 2 |
| 69 | -106° 9' 3" | 23° 2' 17" | 5.5 | 3 | 2 | Wild veg. | 4 | 1 | 33.6 | 44.2 | 22.2 | Loam | 3 | 3 | 3 |

TERMINOLOGY: **PS** = Soil pH score during field verification (cross-checked in laboratory); **T** = Topography score during field verification; **AS** = agriculture score during field verification; **F** = Forestry score during field verification; **LS** = laboratory soil score; **S** = Soil submodel score; **M** = model final score.

Note: Ploughed = Ploughed land for unknown agriculture crop; Wild veg. = Wild vegetation no agriculture. Text. Class = Soil textural classes.

* = Soil pH during field verification was 5.4 and then changed to 4.7 when cross-checking pH values in the lab. Decrease in pH indicates likely acidity problems in site.

### Water-based

In the water-based evaluation, 10 out of the 60 sample sites were new sites chosen at random while in the field because water depth prevented access to all of the pre-selected sites by boat. Sampling on foot was considered but this would have taken too long because of the muddy bottom. Since water quality was not based on GIS predictions, the measurements were keyed directly into the memory of the GPS unit. These data were later coded according to **Table 7.6** and were then integrated into the model presented previously (section 7.4.1.2) for the dry season (i.e. **WQ** = (BA X 0.34) + (WT X 0.16) + ( (SAL X 0.27) + ( DO X 0.23)).

**Table 8.6** shows the results from 10 sample stations in the Huizache lagoon. Here, it was found that all samples had a value of 2, meaning that the values found were marginal. Mean depth was low (21 cm) and temperature was suitable (27 °C) and stable. Dissolved oxygen was found to be moderate (4 mg/l) and mean salinity was high (38 ppt). Conversely, out of 50 samples in Caimanero (**Table 8.7** ) 43 of them had a value of 1 because mean depth was extremely low (29 cm), salinity values were higher than 90 ppt, and dissolved oxygen values were very low ( mean of 2 mg/l ). The remaining 7 sites were classified as moderate, and these were located south-west of Caimanero.

### Table 8.6. Water quality coding assessment in the Huizache lagoon.

| ID | Longitude | Latitude | BA | | WT | | SAL | | DO | | WQ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | cm | score | ° C | score | ppt | score | mg/l | score | |
| 22 | -106° 13' 19" | 23° 5' 4" | 40 | 1 | 26.4 | 4 | 39 | 2 | 4.2 | 3 | 2 |
| 2 | -106° 13' 13" | 23° 5' 5" | 20 | 1 | 26.2 | 4 | 39 | 2 | 4.6 | 3 | 2 |
| 15 | -106° 13' 3" | 23° 5' 7" | 30 | 1 | 26.1 | 4 | 38 | 2 | 4.5 | 3 | 2 |
| 4 | -106° 12' 53" | 23° 5' 13" | 15 | 1 | 27 | 4 | 38 | 2 | 4.3 | 3 | 2 |
| 102 | -106° 12' 42" | 23° 5' 19" | 20 | 1 | 26.2 | 4 | 39 | 2 | 4.4 | 3 | 2 |
| 35 | -106° 12' 31" | 23° 5' 24" | 10 | 1 | 27 | 4 | 38 | 2 | 4.6 | 3 | 2 |
| 14 | -106° 12' 19" | 23° 5' 18" | 18 | 1 | 29 | 4 | 36 | 2 | 4.5 | 3 | 2 |
| 100 | -106° 12' 8" | 23° 5' 14" | 15 | 1 | 28 | 4 | 37 | 2 | 4.2 | 3 | 2 |
| 120 | -106° 12' 13" | 23° 5' 9" | 18 | 1 | 28 | 4 | 36 | 2 | 4.6 | 3 | 2 |
| 101 | -106° 11' 57" | 23° 5' 4" | 20 | 1 | 28 | 4 | 36 | 2 | 4.3 | 3 | 2 |
| **MEAN** | | | **20.6** | **1** | **27** | **4** | **38** | **2** | **4** | **3** | **2** |

TERMINOLOGY: WQ = Water quality model final score; BA = Bathymetry (depth measured in lagoon); WT = Water temperature; SAL= Salinity; DO = Dissolved oxygen.

### Table 8.7. Water quality coding assessment in the Caimanero lagoon.

| ID | Longitude | Latitude | BA | | WT | | SAL | | DO | | WQ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | cm | score | °C | score | ppt | score | mg/ l | score | |
| 68 | -106° 7' 47" | 22° 59' 54" | 26 | 1 | 28.5 | 4 | 100 | 0 | 1 | 1 | 1 |
| 105 | -106° 6' 53" | 22° 59' 47" | 24 | 1 | 29 | 4 | 100 | 0 | 1 | 1 | 1 |
| 82 | -106° 6' 18" | 22° 59' 39" | 21 | 1 | 30 | 4 | 99 | 0 | 1.2 | 1 | 1 |
| 71 | -106° 6' 54" | 22° 59' 24" | 28 | 1 | 28 | 4 | 99 | 0 | 1.1 | 1 | 1 |
| 77 | -106° 4' 52" | 22° 59' 29" | 20 | 1 | 31 | 2 | 101 | 0 | 0.8 | 0 | 1 |
| 75 | -106° 6' 26" | 22° 59' 22" | 22 | 1 | 30 | 4 | 98 | 0 | 1.3 | 1 | 1 |
| 28 | -106° 7' 7" | 22° 59' 13" | 22 | 1 | 30 | 4 | 93 | 0 | 1.7 | 1 | 1 |
| 6 | -106° 7' 6" | 22° 58' 54" | 22 | 1 | 30 | 4 | 95 | 0 | 1.5 | 1 | 1 |
| 7 | -106° 5' 59" | 22° 59' 15" | 20 | 1 | 31 | 2 | 105 | 0 | 0.8 | 0 | 1 |
| 69 | -106° 5' 25" | 22° 59' 15" | 20 | 1 | 30.5 | 1 | 110 | 0 | 0.8 | 0 | 1 |
| 33 | -106° 5' 7" | 22° 58' 56" | 38 | 1 | 31.9 | 2 | 101 | 0 | 0.9 | 0 | 1 |
| 16 | -106° 4' 12" | 22° 58' 59' | 34 | 1 | 30.9 | 2 | 100 | 0 | 1 | 1 | 1 |
| 39 | -106° 6' 22" | 22° 58' 35" | 31 | 1 | 31.4 | 2 | 100 | 0 | 0.9 | 0 | 1 |
| 9 | -106° 5' 45" | 22° 58' 37" | 31 | 1 | 31 | 2 | 101 | 0 | 0.9 | 0 | 1 |
| 25 | -106° 6' 41" | 22° 58' 16" | 25 | 1 | 31 | 2 | 95 | 0 | 1.8 | 1 | 1 |
| 3 | -106° 5' 33" | 22° 58' 7" | 31 | 1 | 31.2 | 2 | 100 | 0 | 0.8 | 0 | 1 |
| 37 | -106° 5' 7" | 22° 58' 21" | 38 | 1 | 31 | 2 | 95 | 0 | 1.5 | 1 | 1 |
| 78 | -106° 3' 52" | 22° 58' 38" | 30 | 1 | 31 | 2 | 105 | 0 | 0.8 | 0 | 1 |
| 44 | -106° 3' 19" | 22° 58' 34" | 32 | 1 | 30.9 | 2 | 100 | 0 | 1 | 1 | 1 |
| 20 | -106° 6' 20" | 22° 57' 43" | 22 | 1 | 30 | 4 | 102 | 0 | 1.7 | 1 | 1 |
| 46 | -106° 5' 51" | 22° 57' 40" | 37 | 1 | 31 | 2 | 96 | 0 | 1 | 1 | 1 |
| 91 | -106° 5' 6" | 22° 57' 51" | 34 | 1 | 31 | 2 | 99 | 0 | 1 | 1 | 1 |
| 66 | -106° 4' 28" | 22° 57' 54" | 34 | 1 | 31.2 | 2 | 98 | 0 | 1.3 | 1 | 1 |
| 89 | -106° 3' 59" | 22° 58' 11" | 33 | 1 | 30.9 | 2 | 108 | 0 | 0.6 | 0 | 1 |
| 5 | -106° 3' 52" | 22° 57' 38" | 34 | 1 | 31 | 2 | 98 | 0 | 1.2 | 1 | 1 |
| 200 | -106° 3' 25" | 22° 57' 16" | 26 | 1 | 32 | 2 | 100 | 0 | 1 | 1 | 1 |
| 210 | -106° 2' 45" | 22° 57' 32" | 20 | 1 | 31 | 2 | 102 | 0 | 0.8 | 0 | 1 |
| 81 | -106° 4' 18" | 22° 57' 25" | 35 | 1 | 31 | 2 | 98 | 0 | 1.5 | 1 | 1 |
| 204 | -106° 3' 21" | 22° 58' 3' | 30 | 1 | 31 | 2 | 101 | 0 | 1.6 | 1 | 1 |
| 17 | -106° 5' 41" | 22° 57' 3" | 22 | 1 | 32 | 2 | 102 | 0 | 1 | 1 | 1 |
| 106 | -106° 5' 8" | 22° 57' 8" | 37 | 1 | 31 | 2 | 91 | 0 | 1.8 | 1 | 1 |
| 47 | -106° 4' 35" | 22° 57' 10" | 35 | 1 | 31 | 2 | 95 | 0 | 1.3 | 1 | 1 |
| 111 | -106° 3' 57" | 22° 56' 46" | 37 | 1 | 31 | 2 | 98 | 0 | 1.1 | 1 | 1 |
| 8 | -106° 4' 43" | 22° 56' 36" | 36 | 1 | 31 | 2 | 97 | 0 | 1 | 1 | 1 |
| 30 | -106° 5' 24" | 22° 56' 23" | 20 | 1 | 32 | 2 | 98 | 0 | 1.5 | 1 | 1 |
| 54 | -106° 3' 30" | 22° 54' 11" | 49 | 1 | 27 | 4 | 25 | 4 | 4.1 | 3 | 3 |
| 55 | -106° 3' 26" | 22° 53' 56" | 20 | 1 | 27 | 4 | 30 | 4 | 4.5 | 3 | 3 |
| 103 | -106° 3' 35" | 22° 53' 52" | 38 | 1 | 27 | 4 | 30 | 4 | 4.6 | 3 | 3 |
| 60 | -106° 3' 30" | 22° 53' 37" | 40 | 1 | 27 | 4 | 29 | 4 | 4.6 | 3 | 3 |
| 73 | -106° 3' 31" | 22° 53' 25" | 48 | 1 | 27 | 4 | 30 | 4 | 4.6 | 3 | 3 |
| **RANDOM** | | | | | | | | | | | |
| 88 | -106° 7' 26" | 22° 59' 24" | 21 | 1 | 30.5 | 2 | 99 | 0 | 1.2 | 1 | 1 |
| 45 | -106° 6' 43" | 22° 59' 10" | 22 | 1 | 30 | 4 | 99 | 0 | 1.7 | 1 | 1 |
| 50 | -106° 6' 32" | 22° 59' 42" | 20 | 1 | 30 | 4 | 100 | 0 | 1 | 1 | 1 |
| 13 | -106° 5' 54" | 22° 59' 29" | 20 | 1 | 31.5 | 2 | 105 | 0 | 0.6 | 0 | 1 |
| 18 | -106° 4' 36" | 22° 59' 12" | 20 | 1 | 32.5 | 1 | 110 | 0 | 0.9 | 0 | 1 |
| 36 | -106° 6' 3" | 22° 58' 17" | 35 | 1 | 30.9 | 2 | 94 | 0 | 1.6 | 1 | 1 |
| 99 | -106° 4' 39" | 22° 58' 24" | 32 | 1 | 30.9 | 2 | 104 | 0 | 1.5 | 1 | 1 |
| 10 | -106° 5' 25" | 22° 57' 32" | 39 | 1 | 31 | 2 | 98 | 0 | 1.1 | 1 | 1 |
| 95 | -106° 3' 36" | 22° 54' 3' | 20 | 1 | 26.5 | 4 | 30 | 4 | 4.2 | 3 | 3 |
| 41 | -106° 3' 28" | 22° 53' 44" | 40 | 1 | 27.5 | 4 | 27 | 4 | 5 | 3 | 3 |
| **MEAN** | | | **29.4** | **1** | **30** | **3** | **90** | **0.56** | **2** | **1** | **1** |

TERMINOLOGY: WQ = Water quality model final score; BA = Bathymetry (depth measured in lagoon); WT = Water temperature; SAL= Salinity; DO = Dissolved oxygen.

### 8.4.5 Location of additional data

As a complement to the evaluation of the pre-selected sites, the position recording option of the GPS was used in static, uncorrected, averaging mode to locate additional data. Some of the most important data whose positions were recorded included the locations of the two shrimp hatcheries, the location of shrimp farms and recent deforestation practices. Moreover, due to the semi-closed nature of the lagoon system, three hydrological engineering schemes have been proposed to increase the amount of water in the lagoon system: (a) construction of channels for shrimp farm water intake and discharge to the ocean, (b) construction of a large channel parallel to the sand barrier, and (c) placement of a large tube across the sand barrier for water intake from the ocean into the lagoon system. The first two proposals have already been reviewed by various authors (CONSULTEC, 1990; Flores-Verdugo, In press) and have already been authorized by the Fisheries Secretariat. Evidence of this development is the large shrimp pond farm located in the Caimanero lagoon which has a very large channel that communicates the farm to the ocean for water intake (wastes from the farm are discharged into the lagoon) (**Plate IX**) and the beginning of the construction of the large channel in the Huizache lagoon (**Plate X**). The third proposal suggested by Flores-Verdugo has not been assessed in full, but it would have minimum environmental impact when compared to the other proposals, and it is clear that it would involve very high costs.

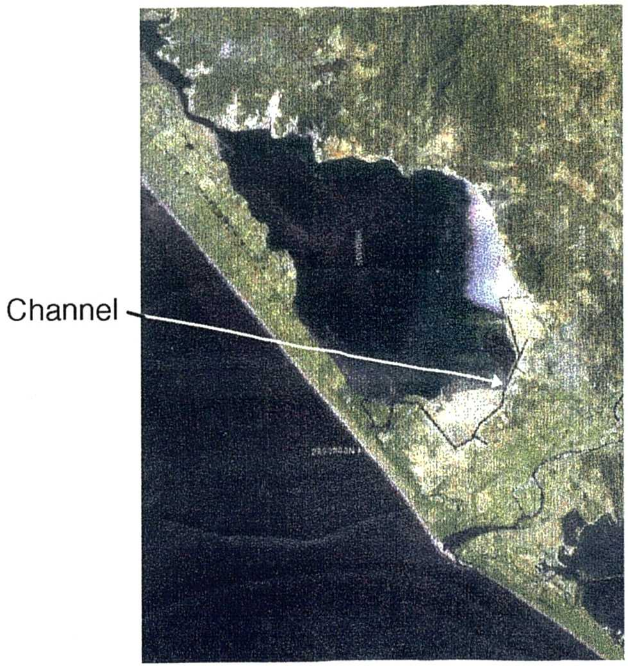

**Plate IX. LANDSAT view of channel that communicates a shrimp farm to the adjacent ocean (Summer, 1992).**

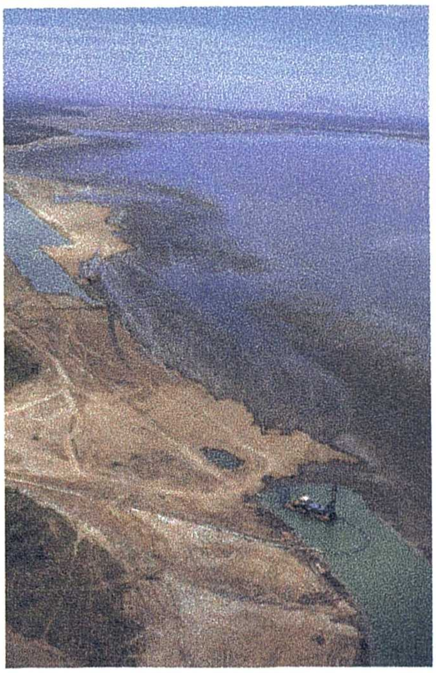

**Plate X. Aerial view of a new channel being constructed parallel to the sand barrier in Huizache (17 April, 1995).**

## 8.5 Modifications and adjustments to the database.

A number of changes had to be made to the original database as a result of the field verification study (**Table 8.8**). These changes included modifications of weights and scores for some factors in the models. Moreover, another important aspect of field verification involved additional data collection for the Huizache-Caimanero region as already noted.

A manual evaluation carried out by Flores-Verdugo (In press) was obtained for comparison with the GIS predictions. In Flores-Verdugo's study the primary objective was to identify potential sites for aquaculture with minimum environmental impact. As a preliminary manipulation, the author excluded areas which were proposed by him as conservation areas (e.g. mangroves, bird concentrations), then with the remaining land area he identified potential aquaculture sites based upon the shrimp farm waste discharges into the Huizache-Caimanero lagoon system. The results of Flores-Verdugo's study (**Figure 8.4**) suggest that minimum environmental impact of shrimp farm discharges can be achieved if they occur adjacent to the ocean and not in the lagoon system. Bearing this in mind, most suitable shrimp farm sites with minimum environmental impact are located along the sand barrier, moderate impact is located at each extreme of the lagoon system and the highest impact would be in the north parallel to the lagoon system.

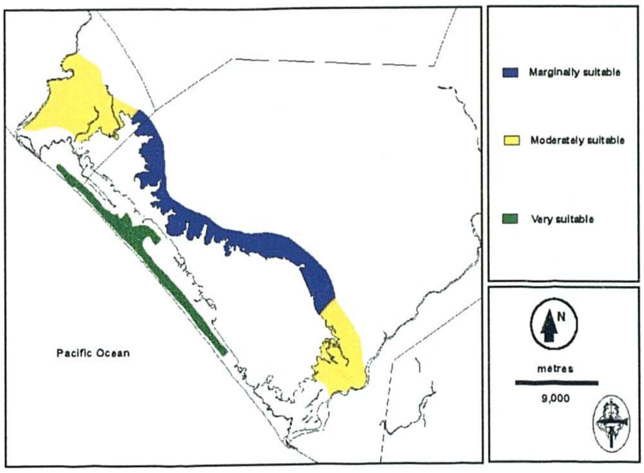

**Figure 8.4. Proposed potential sites for aquaculture development according to Flores-Verdugo( In press).**

## Table 8.8. Modifications to the database.

| CRITERIA | EXPLANATION | MODIFICATION |
|---|---|---|
| **ENVIRONMENT** | | |
| **Natural resources** | | |
| Lakes | Original data source defined some lagoons as lakes. | Lakes (i.e. in reality lagoons) were incorporated into the lagoons primary criteria. (State-level). |
| Monthly water balance | Vital to assess seasonal fluctuation of water availability. Use of hydrological regions for water availability evaluation. | New primary criteria. (State- and site-level). |
| Water flow for rivers Presidio and Baluarte. | Important for assessment of seasonal freshwater availability. | Weight adjustments in submodels. (Site-level). |
| Water quality | Data provided by Galindo-Reyes (1990, In press) was obtained and raw data was collected on the field for the Huizache-Caimanero lagoon system. | New primary criteria. (Site-level). |
| **Land uses** | | |
| Gravel roads | Road type original data source classification used the term "gravel" when in fact these roads were found to be "paved" in the field. | Higher weight in submodel. (State- and site-level). |
| Agriculture | Agriculture development update in the Huizache-Caimanero lagoon system. | Primary data replacement with two new primary criteria: a) more accurate agriculture classification for models and b) future agriculture developments for Time Series Analysis (TSA). (Site-level). |
| Irrigation | Original data source only available as point locations. Hence, difficult to relate to real impact. | Primary data replacement with new data source as polygons. (State-level). |
| Livestock rearing | The majority of the shrimp farms do not use organic fertilizers. High density areas of livestock are also indicative of erosion and herbicide use. | Primary data classification adjustments (State- and site-level). |
| Aquaculture | Shrimp farms location update and production figures. Inaccuracies in the original data source were found because some shrimp farms which were reported to be operating have not even been constructed to date. | Shrimp farms which have not been constructed were not included (i.e. adjustments to primary data). Production figures used for verification of results (i.e. location of successful and/or low production shrimp farms). |
| | Proposed sites for aquaculture development in the Huizache-Caimanero lagoon were obtained by Flores-Verdugo (In press) based on shrimp farm waste discharges. | Used for partial verification of results (i.e. new primary data). (State- and site-level). |
| **SOCIO-ECONOMIC** | | |
| **Social impact** | | |
| Land tenancy | Important source of information since aquatic resources are the preserve of cooperatives with some concessions. | New primary data. (Site-level). |
| **Production modifiers** | | |
| Hatcheries | The problem of natural postlarvae availability can be solved by hatcheries. | New primary criteria (Site-level) |
| Unimproved roads | Many sites in the Huizache-Caimanero lagoon are only accessible by unimproved roads. | Higher weight to unimproved roads in models. (State- and site-level). |
| Support centres | Research, training and extension centres were found to be of considerable importance in the development of aquaculture. | New primary data. (State- and site-level). |
| **Constraints** | | |
| Mangroves | Original data source classified some mangroves as forests. | Some mangroves (i.e. in reality forests) were incorporated into the forests primary criteria. (Site-level). |
| Proposed conservation areas | Areas in need of conservation were obtained by Flores-Verdugo (In press) for the Huizache-Caimanero lagoon system study area. | New primary criteria. (Site-level). |

Note: State-level = changes made to the Sinaloa state level planning database; Site-level = changes made to the Huizache-Caimanero site level planning database.

## 8.6 Evaluation of the accuracy of the database and of the environmental models

The field data were transferred to the 486 DX computer at Stirling, converted into DXF format and imported into IDRISI using the DXFIdris[8.5] module. It was then possible to cross-check the field observations with the predictions found in the simplified environmental model.

To evaluate the accuracy of the database and the model, a quantitative comparison was made between the scores obtained for the 60 land-based sample points (i.e. 20 sample points for each of the three suitability classifications) with the database and the model. **Table 8.9** shows the results of this evaluation.

Overall, the accuracy of the database was found to be 61% and this was considered to be extremely high when taking into account the dates during which the source data were created (i.e. 1969-1993, see **Table 7.2**). The highest correspondence between suitability classifications was found for the very suitable classification (89%), followed by the marginally suitable (51%) and the moderately suitable (44%). For each of the factors considered in the evaluation, it was found that topography had the highest accuracy (75%) and, not surprisingly (due to their spatial variability), soils were found to be the least accurate (48%). An evaluation of the scores assigned to each factor (i.e. 1 to 4) shows that the highest accuracy (100%) was found by the very suitable classification of the topography factor - in this case out of the 20 sample points all of them were scored by both the GIS model and the field model as very suitable. Conversely, lowest accuracy (20%) was found for the marginal classification of the soils factor, only 4 sample points were classified as marginally suitable by the field model in comparison to the GIS database.

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[8.5] DXFIdris is used to transfer vector data between IDRISI and DXF formats.

Table 8.9. Quantitative evaluation of the accuracy of the database and the environmental land-based model.

| | | ACCURACY OF DATABASE ( number of points correctly scored out of 20 possible ) | | | | | | | | | ACCURACY OF MODEL (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SUITABILITY | SOILS | | TOPOGRAPHY | | AGRICULTURE | | FORESTRY | | MEAN (%) | ACCURACY OF TESTED POINTS ON *THE FIELD* ( A ) | ACCURACY OF ORIGINAL MODEL ( *comparing* A with original model ) | ACCURACY OF FINAL MODEL ( *comparing* A with final model ) |
| | | DAT | FLD | DAT | FLD | DAT | FLD | DAT | FLD | | | | |
| **Very suitable** | 4 | 0 | 4 | 20 | 20 | 17 | 16 | 18 | 18 | | | | |
| | 3 | 18 | 16 | 0 | 0 | 2 | 1 | 2 | 0 | | | | |
| | 2 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | | | | |
| | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | | | | |
| | Accuracy (%) | **80** | | **100** | | **85** | | **90** | | **89** | **80** | **69** | **95** |
| **Moderate** | 4 | 0 | 0 | 20 | 13 | 4 | 8 | 19 | 6 | | | | |
| | 3 | 5 | 16 | 0 | 3 | 11 | 0 | 0 | 5 | | | | |
| | 2 | 9 | 4 | 0 | 4 | 0 | 10 | 0 | 3 | | | | |
| | 1 | 6 | 0 | 0 | 0 | 5 | 2 | 1 | 6 | | | | |
| | Accuracy (%) | **45** | | **65** | | **30** | | **35** | | **44** | **90** | **75** | **85** |
| **Marginal** | 4 | 0 | 0 | 16 | 7 | 0 | 5 | 2 | 1 | | | | |
| | 3 | 0 | 9 | 3 | 7 | 9 | 4 | 1 | 6 | | | | |
| | 2 | 4 | 11 | 2 | 6 | 0 | 5 | 0 | 0 | | | | |
| | 1 | 16 | 0 | 0 | 0 | 11 | 6 | 14 | 13 | | | | |
| | Accuracy (%) | **20** | | **60** | | **50** | | **75** | | **51** | **65** | **60** | **90** |
| **MEAN (%)** | | **48** | | **75** | | **55** | | **67** | | **61** | **78** | **68** | **90** |

TERMINOLOGY: **DAT** = number of points within each GIS database classification out of 20 possible; **FLD** = Number of points correctly scored out of 20 possible on the field.

The points tested on the field were about 78% accurate and, by comparing this to the original model used prior to field verification the overall accuracy was about 68%. However, the overall accuracy of the final model after field verification and model modifications and adjustments (**Table 8.8**) was found to be about 90%. Highest increase in accuracy between the original model and the final model was found for the marginal classification (30% increase), and the highest accuracy between suitability classes identified for the final model was found for the very suitable classification (95%). **Figure 8.5** shows the results of this spatial comparison, and **Plate XI** shows a representative section of one of the sites.

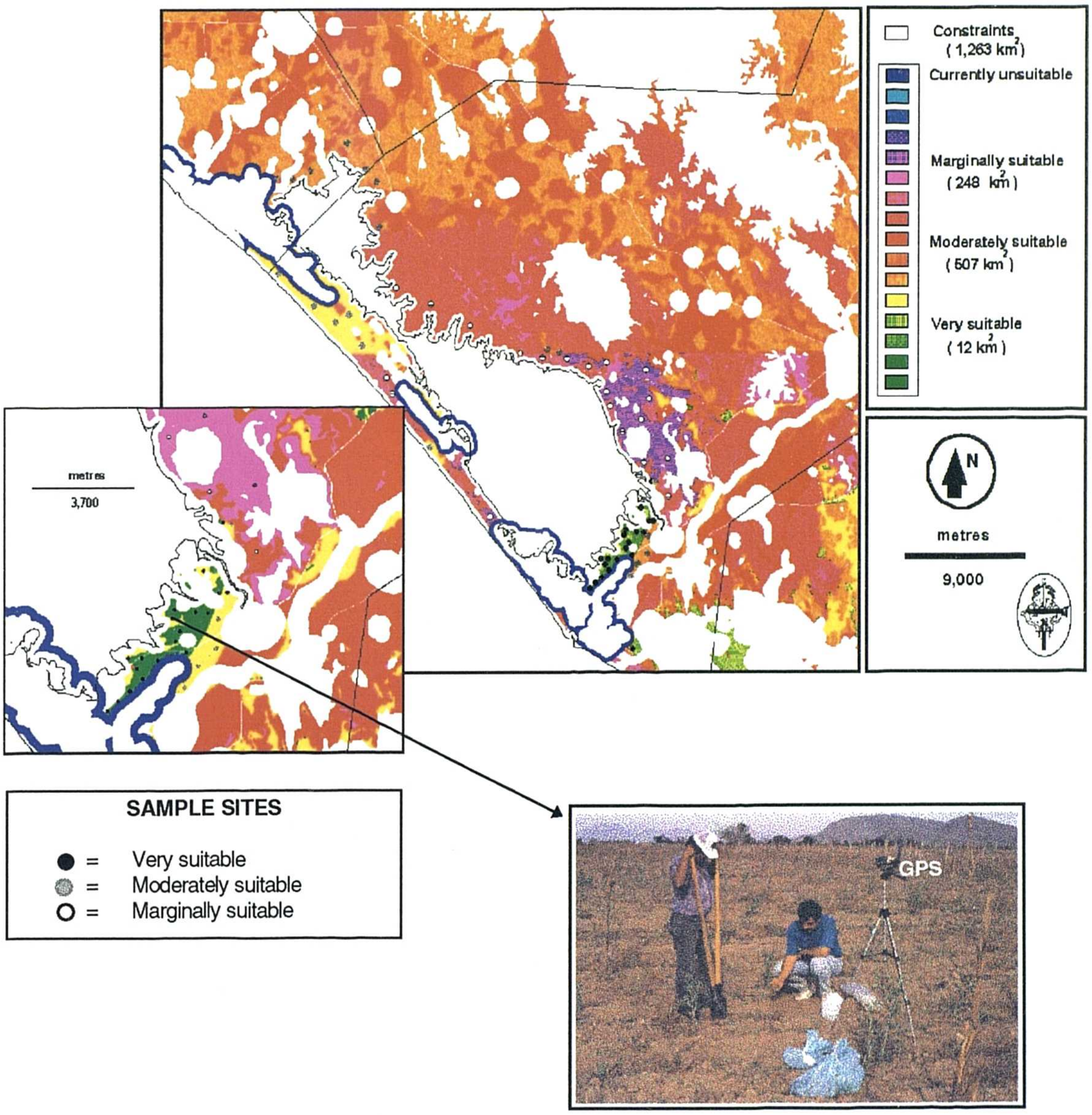

**Figure 8.5. Comparison between field survey and GIS-predictions, and an expanded area south-east of Caimanero lagoon shows the accuracy of the methods. Plate XI. A very suitable site (29 March, 1995).**

The water quality data (**Tables 8.8** and **8.9**) were developed by interpolating each factor (or point data) as shown in **Figure 8.6**, and **Plate XII** shows a representative section of one of these sites. Interestingly, best sites found by the model during the dry season located south-west of Caimanero coincide with the area where a shrimp farm has a very large water intake canal, meaning that the accuracy of the model was partially verified.

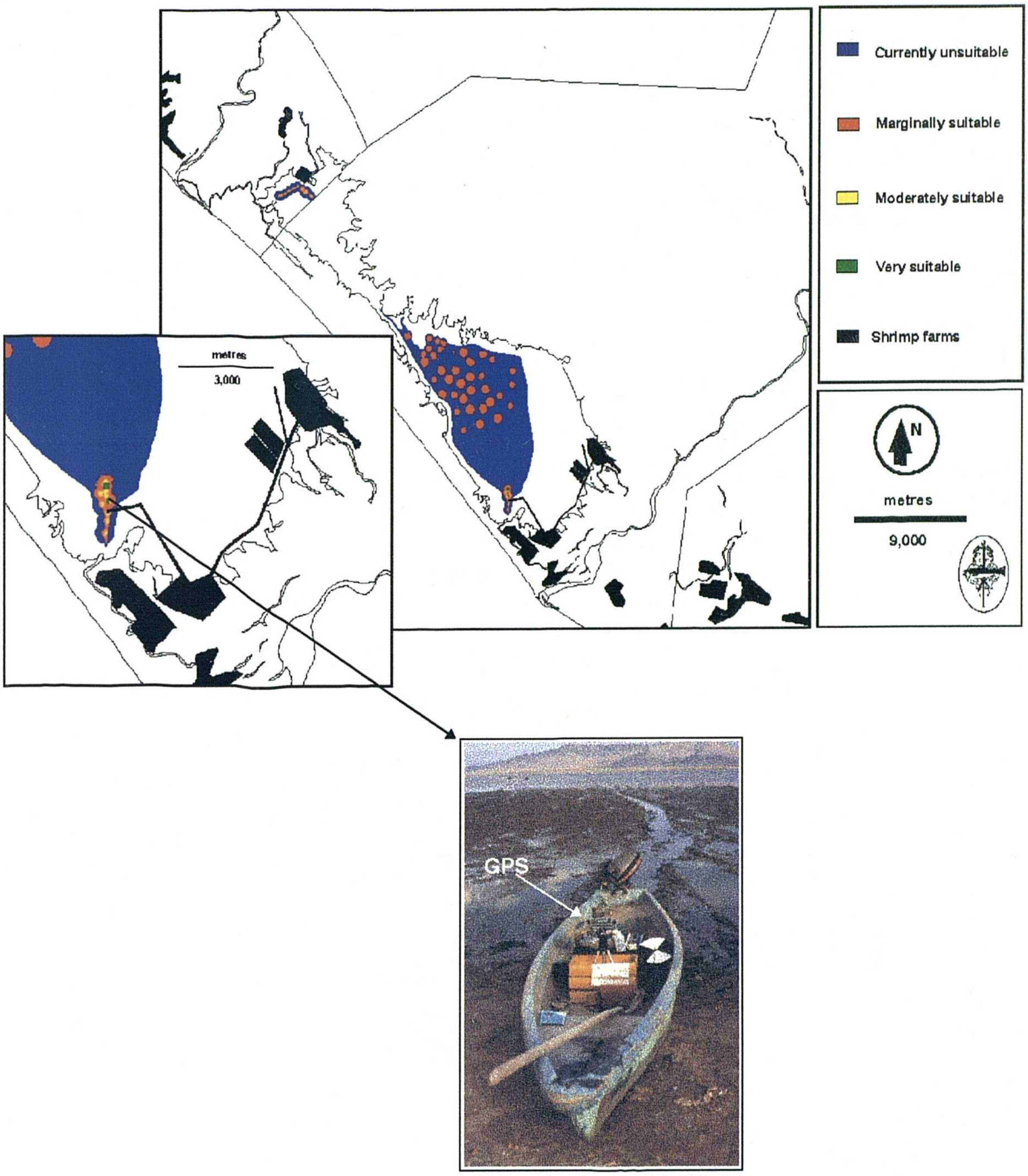

**Figure 8.6. Analysis of the water quality measurements, and an expanded area south-east of Caimanero lagoon shows the accuracy of the methods. Plate XII. Water quality sample site, Caimanero lagoon (16 April, 1995).**

## 8.7 Socio-economic evaluation

A socio-economic field verification study proved to be difficult, primarily because socio-economic data for this region were scarce (see **Appendix 4**), and secondly many of the data which are commonly used in socio-economic studies are only available in choropleth form (e.g. disposable income and markets). Consequently, point sampling would not have been a suitable procedure to follow. Despite this, by assessing the socio-economic GIS image derived from the models it was clear that the most suitable sites were concentrated in proximity to the towns of Villa Union and Rosario (see **Figure 7.11**). Therefore, instead of using SAMPLE to locate sample points, a more comprehensive field verification was established by making an appraisal of Villa Union and in Rosario by evaluating four of the site factors used in the spatial evaluation (i.e. population skills, roads, total population and markets). The results of this quick survey are presented in **Table 8.10.**

For data integration a mathematical expression was used based on the weights defined for the socio-economic model presented in Chapter 7. The mathematical expression of this new model was:

$$\mathbf{Z} = (PS \times 0.45) + (ROS \times 0.30) + (TP \times 0.10) + (SM \times 0.15).$$

Where, Z = final socio-economic score from field evaluation; PS = population skills score; ROS = road type score; TP = total population score; MS = sales/markets submodel score.

As shown in **Table 8.10**, most of the infrastructure and personnel to support aquaculture in the Huizache-Caimanero region is found in Rosario, primarily because of its proximity to the lagoon system. Conversely, although Villa Union is not in close proximity to the lagoon, there is a very good communication link, and therefore this town also has potential for aquaculture - plenty of supplies and equipment could be easily transported there. Because of this good communication, it is likely that people dedicated to a variety of activities like aquaculture and fisheries could be located there (e.g. some shrimp farm workers have their homes in Villa Union).

Although very simplistic, this socio-economic field verification was found to be in strong agreement with the results of the GIS predictions. Additionally, by visiting all the rest of the towns and villages in the area there was no doubt that Villa Union and Rosario were the most suitable areas with potential for supporting aquaculture development.

Table 8.10. Rapid socio-economic assessment of the very suitable sites for aquaculture in the Huizache-Caimanero region.

| | | POPULATION SKILLS | PS | ROADS | ROS | TOTAL POPULATION | TS | MARKETS | MS | Z |
|---|---|---|---|---|---|---|---|---|---|---|
| **Municipality of Mazatlán** | | | | | | | | | | |
| **Town** | Villa Union | Primary, secondary & tertiary sector | 4 | P/G/D/U | 4 | 11,363 | 2 | 50 | 3 | 4 |
| **Villages** | Barrón | Primary sector | 4 | D/U | 2 | 1,323 | 1 | 3 | 1 | 3 |
| | El Walamo | Primary sector | 4 | G/D/U | 3 | 2,609 | 1 | 5 | 1 | 3 |
| **Municipality of Rosario** | | | | | | | | | | |
| **Town** | El Rosario: | Primary sector | 4 | P/G/D/U | 4 | 47,416 | 4 | 80 | 4 | 4 |
| **Villages** | Agua Caliente | Tertiary sector | 1 | P/G/D/U | 4 | 12,764 | 2 | 10 | 1 | 2 |
| | Agua verde | Primary sector | 4 | P/G/D/U | 4 | 4,209 | 1 | 4 | 1 | 3 |
| | Apoderado | Primary sector | 4 | G/D/U | 3 | 1,864 | 1 | 2 | 1 | 3 |
| | Cajón ojo de agua | Primary sector | 4 | D/U | 2 | 1,013 | 1 | 1 | 1 | 3 |
| | Chametla | Primary sector | 4 | G/D/U | 3 | 2,632 | 1 | 6 | 1 | 3 |
| | Potrerillos | Primary sector | 4 | D/U | 2 | 1,284 | 1 | 1 | 1 | 3 |
| | El Pozole | Primary sector | 4 | G/D/U | 3 | 2,265 | 1 | 4 | 1 | 3 |
| | Los Pozos | Primary sector | 4 | D/U | 2 | 1,064 | 1 | 5 | 1 | 3 |

TERMINOLOGY: PS = population skills score; ROS = roads score; TP = total population score;
MS = markets score.

Source: Field visits and interviews with local people. Total population data obtained from INEGI (1991).

Note: Population skills refers to the skills of the economically active population; population skills threshold was defined in Chapter 4.

| TP | MS | SCORE |
|---|---|---|
| > 30,000 | > 60 | 4 |
| 20,000 - 30,000 | 40 - 60 | 3 |
| 10,000 - 20,000 | 20 - 40 | 2 |
| 1 - 10,000 | < 20 | 1 |

Note: Threshold according to frequency distribution.

## 8.8 SUMMARY AND DISCUSSION

### *Summary*

An important aspect of using a GIS is to verify the database and the outcomes of the models produced. This aspect of the work has been advanced markedly in recent years with the introduction of Global Positioning Systems or "GPS". These systems are small, and are totally adapted for field use and downloading of data into a portable or desktop computer.

Field verification was found to be dependent on the objectives of the survey, the nature of the factors being evaluated, the scale of evaluation, the required accuracy of the results, landscape complexity, time, and financial resources available. Bearing this in mind, a GARMIN GPS was programmed to use in the Huizache-Caimanero lagoon system to enable verification. The GPS was taken to a grid of pre-selected sites and at each field location a series of pre-determined factors (e.g. soil type, agriculture) was coded and keyed directly into the memory of the GPS unit. It was then possible to verify and compare field observations with the database, and with trends shown by the models.

Overall, the GPS proved to be a rapid and accurate interactive technique for field verification. Using this technique it was possible to update and modify the database and confirm the general accuracy of models.

Final GIS evaluations indicate that most suitable sites are found at each extreme of the lagoon system in proximity to the rivers and to the ocean. Here, water quantity and quality is most suitable, and soils are also suitable for pond construction.

*Discussion*

A preliminary visit to the lagoon on a vehicle and on foot was found to be of paramount importance for GPS testing and programming. Aerial analysis of the lagoon (e.g. aerial photographs and video), in particular, was extremely valuable enabling rapid familiarity with the area and assisting in selecting the best routes during ground surveys. Its greatest use was in locating numerous sites of interest, the positions of which could then be recorded on the ground (e.g. the new channel being constructed in Huizache parallel to the sand barrier). It also gave a good indication of the level of deforestation that is taking place adjacent to the lagoon for future agricultural land. Overall, great advantages were found by using this technique, even though the helicopter only became available after half of the evaluation had already been carried out on the ground.

The number and location of sample points was primarily dependent upon the objective of this study and the number of sample points selected were sufficient for database and model verification. However, had this study been entirely focused towards the construction aspect of shrimp ponds, the nature of the sampling design, as well as the sampling intensity, for soil evaluation, would have been very different, requiring a larger number of sample points and the use of additional assessment techniques including a soil assessment of disturbed and undisturbed soil samples, permeability assessments and taking soil samples from a 2 metre depth[8.6] (Coche and Laughlin, 1985; Davidson, 1992).

Since time and financial resources are an important consideration in field verification work, an estimation of the time involved in verifying the pre-selected sites is provided in **Table 8.11**.

Clearly, attempts to repeat the field verification work in this study would vary due to a number of factors involved (e.g. type of vehicle). However, since navigation was the main GPS operation used for field verification this is the focus of the time estimates presented in this table.

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[8.6] It is vital to assess deep soil layers because this soil will later make up the dikes and the shrimp pond bottom. Moreover, soil pH is particularly important in these deeper soil layers because it will greatly influence pond productivity.

**Table 8.11. Summary information of time involved to carry out environmental field assessment using GPS for navigation.**

| CRITERIA | LAND-BASED | WATER-BASED |
|---|---|---|
| Number of days for evaluation | 8 | 3 |
| Average number of pre-selected sites verified per day | 7.5 | 20 |
| Average time to locate a pre-selected site | 30 min | 15 min |
| Average time spent at each sample location | 15 min | 5 min |
| Average number of hours using GPS per day | 5.6 hrs | 6.6 hrs |

Note: A larger number of pre-selected sites were assessed per day in the water-based evaluation because site access was easier.

By considering the sample assessment carried out at each location, and the gain in quality of the database along with these time estimations, this information can be used as a general guideline for future field verification planning.

It is important to mention for time estimations that although the entire field verification was carried out single-handed, a driver facilitated the site verifications by driving while the author was using the GPS for navigating to the pre-selected sites and the driver also helped carry some of the field equipment (e.g. hole digger) to the pre-selected site on foot. Therefore, the number of pre-selected sites assessed per day was greatly increased.

The selection of sample locations was profoundly affected by the data available prior to the field verification. Overall, the largest constraint was attributed to the fact that land use maps for Huizache were not available and so the majority of the information for Huizache relied on the topographic paper map combined with the state-level maps on a 1:1000,000 scale. During field verification it was found that some sites which were apparently classified as mangroves, were in reality forest areas, and therefore they had been treated as areas of constraint prior to field verification. These sites were, in fact, found to be unsuitable for aquaculture and therefore the GIS predictions were not affected, but the database was edited to indicate the real use of these areas.

Similar to the "false" mangrove areas, since the agriculture paper map at 1:50,000 did not provide an agriculture classification then the state-level map was used for classification. In this case, the state-level agriculture paper map on a 1:1000,000 scale clearly classifies the southern region of Caimanero as land unsuitable for agriculture, for which reason it was classified as suitable for aquaculture during model creation. However, during field verification it was found that although the soil pH in the majority of these sites was found to be acid (average 5.8) these sites were, in fact, being used for seasonal agriculture so, clearly, this also had some effect on the GIS predictions prior to the field verification[8.7]. Nevertheless, since the pH of the soils was acid it was considered that these sites were not really suitable for agriculture, so these areas were considered as potential candidates for shrimp farm development. These potential problems of competition for land were not identified prior to field verification.

In addition to the above, the results of the water quality evaluation were not based on any prediction, since data were not available prior to the field verification work. Finally, the manual study carried out by Flores-Verdugo (In press) to evaluate aquaculture potential, as well as the identity of the proposed conservation areas, was not obtained until after field verification or, clearly, this data may have had an influence upon the outcome of the model used, as well as in the selection of sample locations.

Two different planning levels were examined in this study, and the importance and types of spatial factors varied between them because different factors dominated in each planning level. Although field verification did not involve the evaluation of all the factors used in the site-level spatial evaluation, the accuracy of the models was attributed to the fact that the predicted sites did follow the logic found by the GIS predictions in the prior planning levels. For example, all sample sites were distant from dangers of any pollution (e.g. away from urban developments) as defined in the state- and site-level models. Additionally, field verification results proved to be in close agreement with the GIS predictions for the Huizache-Caimanero lagoon system.

In terms of classification accuracy, the majority of the classifications established in **Chapter 4** proved to be suitable. However, an exception was found because during field verification it was noticed that the livestock rearing factor could be re-interpreted and new models could be created since high density areas of livestock are also indicative of erosion and of herbicide use, which could very well affect water quality.

Even though a large number of factors were taken into consideration there is an incredible amount of additional information (see **Appendix 4**) which could have been incorporated to enhance the present evaluation, but which was beyond the scope of the present study. For

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[8.7] In the primary data stage of the GIS-based models in this study, land not suitable for agriculture was given a high score. Moreover, when developing weights between factors, low production agriculture had one of the highest weights in the environmental models, so clearly the fact that there was seasonal agriculture instead of no agriculture did have some effect on the results.

example, many of the fish population and fisheries studies (Appendix 4) were commonly presented as data derived from sampling stations, meaning that they could be potential candidates for spatial evaluation. For example, due to the importance of the fisheries in the lagoon system an analysis could be made to locate the most suitable fishing grounds to avoid potential conflicts between lagoon users. Interestingly, although a larger number of factors could enhance this study there is also the question of how few criteria can be used by the models developed in this study, which could still produce a reliable answer.

During the dry season, fishing activity is closed and most of the shrimp farms are either not operating or operating at a minimum production level due to lack of water in the lagoon system. Conversely, during the wet season the opposite occurs. Hence, it would be important and particularly interesting if the same field verification could also be carried out in the wet season in order to compare results.

Without doubt a multi-disciplinary team (e.g. hydrological engineer, aquaculturist, fishermen, agriculturist) could enable a much more thorough evaluation of the lagoon region. For example, a cash crop evaluation could be carried out by an agriculturist whereby the crops found in some of the pre-selected sites from this study would be scored in terms of profitability. Clearly, when assigning costs to land uses other interesting GIS evaluations could be carried out by scoring land uses according to the amount of money that people would be willing to pay for a particular land-use area (Ross, pers. comm.; Brainard *et al.*, 1995). For example, since coconuts are no longer a very profitable activity in the region (Flores-Verdugo, pers.comm.), most of these areas could be potential candidates for shrimp culture (although a lining for the shrimp pond bottom would have to be considered because coconuts use sandy soils). Similarly, since many of the pre-selected sites in Caimanero were land areas dedicated to chilli, maize, beans and mango, an agriculturist could provide information about the types and levels of pesticides used for each crop. Finally, an agriculturist could indicate which of these crops is best suited to be adjacent to shrimp farm sites (i.e. crops that can withstand high salinity).

Due to the semi-closed nature of the lagoon system, shrimp farm discharges inside the lagoon are of major concern in order to avoid eutrophication. To evaluate this problem, and to arrive at possible solutions, two important factors must be incorporated into the analysis. Firstly, a comprehensive water quality programme is required to monitor shrimp farm discharges (i.e. nutrient levels) and pollutants from other activities (i.e. pesticides), and secondly, it is important to integrate data from the adjacent ocean, such as currents and tides, to consider the possibility of discharging wastes from farms into the ocean.

Enhancements could be made to the water quality spatial analysis in this study by obtaining annual data on the sample locations presented, then a time series analysis could be used to make a proper assessment of the lagoon's water quality. Likewise, if data were available for water quality measurements at different depths the spatial variability of some of the factors (e.g. dissolved oxygen) could be determined. Additionally, because the success of future aquaculture development in the Huizache-Caimanero lagoon system depends upon the success of current dredging operations to increase the amount of water in the lagoon, a time series analysis of the geomorphological evolution of the lagoon system would be a potential candidate for spatial analysis because it would enable researchers to understand the natural evolution of the lagoon system (e.g. an understanding of how the lagoon system became semi-closed) in order to develop strategies for establishing adequate dredging operations[8.8].

Because a water quality assessment in the lagoon system is vital for managing the development of future shrimp farming practices, in addition to the water quality measurements, an assessment of the sediments in the lagoon could be incorporated into this study's spatial analysis. Several studies (e.g. Rhoads and Germano, 1982, 1986; O'Conner *et al.*, 1989; Cullen, 1990) have found that traditional chemical and physical measurements in the water column are not sufficient to determine biological impacts of eutrophication. Rather, they have found that direct assessment of the benthic environment enables evaluation, prediction and management of the impact of enrichment, because the seafloor is a long-term indicator of overlying water quality. In this regard, Krieger *et al.* (1990) developed a study for assessing organic enrichment on the seafloor in Narragansett Bay on the north-east coast of the U.S. By using a REMOTS[8.9] camera, and then by incorporating this information into the GIS, the authors found that a time series analysis could be performed so changes in pollution could be rapidly quantified. Moreover, the authors found that REMOTS coupled with GIS was an efficient way to provide information about the conditions within a system and about how well mitigation procedures are working, as well as providing valuable information about major ecological gradients that can be used to locate long-term stations for more detailed studies and monitoring techniques.

Finally, in terms of enhancements, despite the socio-economic importance of the lagoon system there is a serious lack of such data available (see **Appendix 4**). In addition to the socio-economic factors used in this study a considerable number of additional socio-economic indicators could be surveyed and mapped to enhance this study's evaluation (**Table 8.12**).

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[8.8] Despite the potential of using GIS for geomorphological analysis of the Huizache-Caimanero lagoon system it is clear that this may only be possible if such data is available for spatial analysis.

[8.9] A REMOTS is an optical instrument that photographs vertical *in situ* profiles of the upper 20 cm of the sediment.

Additionally, many of the socio-economic factors used in this study could be enhanced by obtaining more detailed information.

**Table 8.12. List of additional socio-economic factors which should be mapped and surveyed for spatial analysis.**

| SOCIAL IMPACTS | PRODUCTION MODIFIERS | MARKET POTENTIAL |
|---|---|---|
| Non-government organizations. | Resources | Distribution system |
| Customs and traditions. | Related industries | Retail and wholesale outlets. |
| Environmental impacts on society. | Existing facilities | Infrastructure |
| Local legislation and policy. | | Technology level |
| Leases and permits. | | Consumption per capita. |
| Ownership or rights to land & water | | Profitability |
| | | Availability of products |

Ultimately, the use of choropleth data has been an important limitation for spatial analysis in this study and this was particularly the case of the Huizache-Caimanero socio-economic evaluation. Nonetheless, these types of spatial analysis are not always going to have to be based on choropleth data, because an increase in the awareness of the potential of use of GIS may very well increase the availability of relevant socio-economic factors for spatial analysis which will minimize the use of choropleth data, improving the accuracy of the spatial analysis. One means to obtain non-choropleth information would be from interviews and questionnaires.

Most suitable shrimp farming sites were found south-east of the Caimanero lagoon. Moderate sites were found at both extremes of the lagoon but also along the sand barrier, and finally, unsuitable sites were found north of the lagoon system parallel to the lagoon (**Figure 8.2**).

GIS predictions proved to be in very strong agreement with Flores-Verdugo's study (In press). However, a precise spatial comparison between the two results could not be made primarily because the areas predicted were based on an old map created manually by Ortiz (1970) and therefore Flores-Verdugo's results only provide rough guidelines as to where aquaculture has minimum environmental impact. Secondly, because his study was only focused on a single aspect of aquaculture site selection (i.e. shrimp farm waste discharges) it was not directly comparable to this GIS study.

More detailed field studies are required to determine the exact location of the new farms (**Figure 6.36**). Moreover, it is only possible to make assumptions about the exact shrimp pond area that can be constructed in this region because the success and the expansion of future shrimp farm development will probably be dependent upon the success of the hydrological engineering schemes to increase water volume and exchange in the lagoon system.

The maximum water volume reported by Soto-Lopez (1969) for the Huizache-Caimanero lagoon was 262 million $m^3$ during the month of September (see **Table 6.1**). Assuming that the hydrological engineering schemes previously described are successful and that the water volume increased two-fold (524 million $m^3$) and was maintained throughout the year, the water model for the wet season could then be used (see **Chapter 7**). Although, the data obtained is not sufficient to make a credible prediction (i.e. annual data is needed) with this model, it is fair to assume that such an increase in water volume would certainly mean that the water depth in the lagoon system would increase from a maximum of 1.20 m to about 3 m and salinity, and dissolved oxygen would no longer be a limitation (i.e. no stratification or depletion). Moreover, water exchange in the lagoon system would be improved and this would certainly benefit the existing shrimp farms as well as expansion of future aquaculture development.

Four potential activity conflicts were identified during the field verification: (1) agriculture, (2) fisheries, (3) aquaculture, and (4) conservation. In terms of competition for land adjacent to the lagoon system, agriculture is particularly problematic due to the large areas that are needed for further development. Hence, development of almost any other activity is most likely to compete with agriculture. In terms of competition for water, agriculture will also compete for freshwater with other activities. However, more important competition is found between fisheries, aquaculture and conservation because they need direct access to the lagoon system.

As has happened in the north of Sinaloa, agriculture activities are increasing continually in the Huizache-Caimanero region, and it is very likely that the future scenario in this region will be similar to the north in the sense that most of the land will be used for seasonal and intensive agriculture. Clearly, the future of the Huizache-Caimanero lagoon does not look good in terms of environmental conservation. Moreover, new shrimp farms will be constructed adjacent to many of the future irrigation schemes proposed by the Mexican National Water Commission (CNA) for agriculture development in the region, so there appears to be a serious lack of communication and coordination between the various institutions with regard to the varied interests for this lagoon system.

# CHAPTER 9

## GENERAL DISCUSSION

The main objective of the present study was to use GIS to devise rational strategies that could be used to enhance planning and management of coastal aquaculture development in Sinaloa State, Mexico. Overall, this study reveals the usefulness of GIS as an aquaculture planning tool, and shows on a reasonably objective basis the extent of opportunities for land-based aquaculture in Sinaloa. Although the main focus was on shrimp farming, the analytical methodology used to develop the GIS-based models in this study could be applied to different farming systems, and in other locations.

GIS can serve as an analytical and predictive tool to assess and direct aquaculture development very comprehensively when used to the full. Natural resources data benefit from the use of GIS, and it can play an important role in aquaculture development because data can be naturally partitioned by layers or areas thus enhancing its management and retrieval. Perhaps the greatest benefit of using GIS is that a number of aquaculture development scenarios can be investigated before development begins. Thus, it is clear that the use of GIS could help decision-makers in Mexico, and elsewhere, to make more rational use of the natural resources available.

By using the GIS-based models developed in this study the well-structured, stratified approach ensured that the outcome was more objective than could have been possible using manual techniques alone. With the development of these models better understanding of the siting criteria required for aquaculture development was also achieved.

The study showed that GIS can be used to make a very dynamic planning evaluation at different planning levels (seen clearly in **Figure 8.1**). Furthermore, by including a field verification study great improvements were achieved through model and database enhancement and development.

Appropriate management decisions were made much faster with GIS than with traditional manual map-making technology because analyses of large sets of spatial data were possible. The benefits from the GIS are in the form of better decisions achieved through GIS outputs which provide faster and more relevant information e.g. predictions of land allocation, solution of land use conflicts, area location estimates, as well as the ease with which the databases can be maintained and updated when compared to manual database and map-making methodology. Thus, as Davidson (1992) states, 'the use of GIS should not be seen as the end-point in information provision, but as a stimulus to the formulation of further questions, most of which could be suitable for solution by making further use of the system'.

The greatest potential of GIS is the fact that these systems are able to aid decision-makers in developing their ideas, expressing consistent judgement and to help them make rational decisions. As Campbell *et al.* (1992) state, "computer technology is a package which includes not only hardware and software but also people, personal skills, operational practices and corporate expectations...the computer package is not envisioned as an independent entity but rather to be embedded within the human and institutional context within which it is located". Decision-making played a key role in this study, at all stages of model development. Even before any GIS manipulations took place decisions had to be made by choosing the factors to be involved in the evaluation. Moreover, the most important spatial GIS manipulations were carried out only after factor and constraint assessment, classification and weight selection were established, meaning that the models were already operating on data derived from a series of sound decisions.

Models in this study were developed on the basis of integrating data into submodels or natural groupings rather than treating all data together. The general approach of establishing submodels within an overall model proved to be a meaningful way to integrate and to accomplish specific tasks. The overall purpose of the model is divided into stages whereby each solves a partial problem and the totality meets the overall purpose.

In addition to the environmental and socio-economic criteria used in the present study these models could also address non-economic or personal criteria. Meaden and Kapetsky (1991) give a perfect example: "Given this piece of land which I own (or rent), what is the best way of using it?". Moreover, the models were extremely flexible and dynamic in nature because of the ability to use MACRO files. It was shown that the ease with which a number of options or scenarios can be obtained within a GIS, linked to the flexibility of a model, enables "what if"? analyses that are simply not possible without the use of a GIS (e.g. analysis of land uses over time). Thus, modelling in GIS offers exciting possibilities in the management and use of natural and socio-economic resources and will play a key role in future evaluations.

One of the aims of this study was to evaluate the importance of aquaculture siting criteria. To this end, the basis for the assignment of weights between siting criteria was achieved during the state-level assessment by using the MCE decision-making technique, and enhanced through the use of questionnaires. The incorporation of the opinion of experts proved to be optimum for model development and adjustments. Great benefit was gained in this exercise by the feedback obtained, and further benefits from this technique could be obtained if decision-makers were brought together so as to make this technique more interactive and participatory. Additionally, a participatory technique would also provide interesting feedback on the way in which these models could be implemented, such as in the Fisheries and Environmental Secretariat (SMARNyP) in Mexico, or elsewhere.

Many ecological problems which have arisen from aquaculture development were perfectly suited for evaluation in this study. For example, by overlaying the area of the shrimp farms onto the mangrove zones it was shown that some shrimp farms are well within mangrove areas, so it was possible to evaluate to some degree the level of impact that a particular farm had on the environment. Moreover, the MOLA decision-making technique proved to be useful for discussion of the identified conflicts of land allocation and land use between aquaculture and other production activities. By using MOLA a compromise between activities was established in order to make better use of the natural resources available.

At a state-level it was possible to determine potential areas for aquaculture development, and it is at this stage that the assessment can allow managers to pin-point potential areas in order to conduct further investigations. From this, the Huizache-Caimanero lagoon system was chosen for more detailed studies because it was particularly interesting and suitable for GIS analysis (i.e. data available, proximity to technical support).

At a site-level for the Huizache-Caimanero lagoon the aims of the present study were met since the higher resolution more specific models developed did enable more detailed studies on environmental and socio-economic issues. For example, factors such as water quality evaluations were particularly relevant, whereas this would have been of minor relevance on a state-level. Moreover, it was also possible to evaluate the effects of the activities on their surroundings. For example, it was possible to make a more thorough evaluation of the development of the shrimp farms (e.g. production levels and state of development) and it is at this planning level that detailed information such as water quality and soils from each shrimp farm could be incorporated. Furthermore, on a site-level GIS predictions could allow managers to work with proponents and owners of shrimp farming sites in order to resolve and/or prevent activity conflicts, or to mitigate and altogether prevent contamination within and between activities. For example, shrimp farms waste discharges could be monitored to regulate water quality, and aquaculture-agriculture conflicts could be avoided by minimizing land salinization from aquaculture practices or by avoiding pesticides from agricultural run-off.

Due to the large, varied and complex data sets used, it was considered crucial to verify the accuracy of the database and the models, and great care was taken to have the most accurate data to achieve the best results. Even though it was impractical to check the accuracy of all of the data, a number of verifications were carried out during this study. For example, on a state-level, some of the raw data were able to be partially verified by comparing the same raw data from different information sources (i.e. INEGI, SPP), and on a site-level raw data verification was achieved during field work.

On a site-level for the Huizache-Caimanero lagoon, the coincidence between the manual and GIS techniques was almost identical. Nonetheless, these GIS verifications were co-incidental and should be used only as general guidelines due to the large differences between the two methodologies used. Moreover, the results of the two techniques do not have to agree because the GIS is more objective and more accurate when compared to the manual technique. For example, since the manual technique for the site-level study of the Huizache-Caimanero lagoon system was only based on a single factor (i.e. shrimp farm waste discharge) it meant that it was impossible to make a direct comparison. Additionally, even though the use of GPS for GIS verification gave accurate results, it was not possible to verify a number of other factors (e.g. a more accurate agriculture crop evaluation as indicative of inputs and/or pollution).

Field verification results proved to be in close agreement with the GIS predictions, and the GPS was a rapid and accurate interactive technique for field verification. By using this technique the final objective of this study, to verify the outcomes of the models produced, was met because it was possible to update and modify the database, and to confirm the general accuracy of the models developed. Overall, the accuracy of the database was found to be about 61%, and the accuracy of final model after field verification and model modifications and adjustments was about 90%. More importantly, the overall increase in accuracy of 22% between the original model used prior to field verification and the final model clearly demonstrates the need to include field verification work in any GIS study.

There are several factors which affected the results from this study. Some of these factors derived from the inaccuracy of the data, their spatial and temporal variability, the analytical approach and the underlying assumptions adopted. Nevertheless, the increasing availability of data and the greater capabilities of computer technology continue to expand the potential role of GIS. High quality graphical output, capabilities for easy updating, and the possibility of testing management options are making GIS particularly useful for providing information for decision-making, and many of the problems affecting this study's results will be minimized or eliminated as more data becomes available, and more experience is gained with aquaculture-orientated GIS.

The outcome of GIS modelling is strongly dependent on the quality of the raw data (primary data) and it is crucial to have full knowledge of the raw data that is available. Because it was not practical to verify the accuracy of the majority of the data, any errors from existing data records were also transferred into the GIS database. For example, when gathering data for water resources for the state-wide analysis a coefficient to estimate the water flow (i.e. a thematic map) calculated by INEGI (1995) was obtained. However, since the coefficient involved many different factors (i.e. permeability of the soils, land use and mean annual rainfall) it was difficult to interpret, primarily because very little information was provided to understand its use. Consequently, even though this data may have been accurate it was considered better not to include it in the GIS models unless more reliable information could be obtained.

An important aspect of data quality is the mapping purity[9.1] of the paper maps used in this study and this is of particular concern with respect to soils due to their spatial variability. Targets for purity have been set at 85% for the USA, 70% for The Netherlands and 80% for Britain (Davidson, 1992). However, in a case study in southern Scotland to determine mapping purity, Ragg and Henderson (1980) found results ranging from 37% to 74%. Hence, measures of such purity are significant if errors are to be assessed. Information regarding mapping purity was not provided by the data sources in this study, so this is an area of importance that should be addressed. Lastly, even though it was impractical to check the accuracy of all of the data used in this study, the increasing availability of digital and remotely sensed data world-wide may make it possible to verify the accuracy of a large portion of the database in the near future.

Approximately 90% of the data used in this study were incorporated into the GIS database by manual digitization. A total period of about 10 months was dedicated to digitizing, and an average of about 6 hours per day was spent digitizing a single map. Due to the vast amount of time spent digitizing this technique was prone to error and was also largely dependent

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[9.1] Mapping purity expresses the chance of a random site within a mapping unit coinciding with the taxonomic unit (Davidson, 1992).

upon the author's skills. Nonetheless, careful editing did solve the majority of the digitizing inaccuracies. For example, by re-setting the tolerance value with the Tolerance command in TOSCA the starting and ending nodes were snapped[9.2] together to create a polygon. Because digitizing proved to be very time consuming and was also prone to errors, future GIS studies should seek alternatives for data capture such as remotely sensed data inputs, raster scanning and line-following techniques. Although scanning has important limitations (i.e. a vast amount of editing is required) imminent improvements using this technology will make scanners more sensitive in order to allow greater discrimination between data and "noise". Meaden and Kapetsky (1991) state that, "it is likely that paper maps of the future will incorporate special links or bar codes to make feature recognition easier for automatic data capture".

Throughout the course of this study great care was taken to keep the GIS database up-to-date. Many advantages were found in including new data or replacing the old data to obtain better and more recent results. However, data editing was found to be very time consuming and towards the end of this study it became no longer practical to update some information. This also had some effect on the results. For example, because the second visit to Mexico was entirely focused on the field verification of the Huizache-Caimanero lagoon, it was not possible to update the wider shrimp farming activity in Sinaloa. This data is unavailable to the general public and would have required a lot of time to amass.

A great amount of data were obtained primarily from INEGI, but it was found that there were instances when the required data were not available in any form, or the data were available but at a resolution which was inadequate for the application in hand (i.e. the data were too coarse). Therefore, in many cases, surrogate data proved to be very useful. For example, for the state-level assessment it was not possible to obtain water temperature data, and so ambient air temperature was used. In a GIS study of Africa, Kapetsky (1994) found a close relationship between air and water temperatures. Conversely, because most of the thematic maps obtained were primarily created for agriculture, and not aquaculture, they had to be re-interpreted in terms of aquaculture suitability. However, some of the data used for agriculture were not the most suitable for aquaculture. For example, Kapetsky (1994) found that pond engineering thresholds established for agriculture could not be manipulated to make texture and slopes more sensitive to pond construction, and because these thresholds were also used in this study the results were also affected.

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[9.2] A snap tolerance is the tolerance radius in which the nodes of a digitized line are snapped to any node that falls within their tolerance radius. Snapped nodes are two nodes that share the same location but are independent points. When snapping nodes, all nodes that lie close enough to each other to fall within each other's tolerance are considered spatially identical and are snapped (Jones, 1995).

The use of choropleth data was an important limitation for spatial analysis in the present study, and this was particularly the case for the Huizache-Caimanero lagoon socio-economic evaluation. Nonetheless, it is considered that this will not be a major limitation in future GIS evaluations due to the likely increase in data availability.

In some cases gaps existed between the available datasets, so it was necessary to use the interpolation technique (e.g. DISTANCE module) to create layers. Even though this technique proved to be very useful it was noted that there was some level of inaccuracy because DISTANCE only created circular distance bands which, in most cases, did not give a very realistic representation of the factors involved (i.e. a city is commonly mapped as a point location). This limitation was taken into consideration, where possible, by using polygons as locations rather than points.

Because the GIS used in this study was raster-based it was crucial to select the appropriate scale according to the study objectives, as this would have a direct effect on the GIS results. For example, in a site selection study for salmonid cage culture, Ross *et al.* (1993) found that a 25 m x 25 m grid was too coarse and did not allow satisfactory processing beyond a bathymetric layer, whereas a 10 m x 10 m scale was suitable for the evaluation. In the present study, at a state-level, the 250 m x 250 m pixel size was primarily based upon the area of an average shrimp farm and proved to be satisfactory for general site assessments because it was small enough to represent each individual shrimp farm, while at the same time large enough to suit distance evaluations (particularly important at a state-level). Similarly, good results were obtained using a 20 m x 20 m pixel size[9.3] for the site-level evaluation of the Huizache-Caimanero lagoon, because this pixel size enabled more accurate representation of environmental factors (e.g. water quality). The only difficulties encountered with the scale selected were due to the limited computer speed and disc storage capacity (although a DAT backup was used).

As noted by Kapetsky (1994), the number of threshold values has a great influence on the results because thresholds define the number of land suitability classification classes. It was found that, at a preliminary stage of model development, the 1 - 4 score range for factors was useful because most thematic maps were already classified to a range of about four values. However, as the numbers of spatial manipulations increased it was commonly the case that the number of threshold values also increased and it became more difficult to distinguish between suitability classes. Conversely, a small number of thresholds would

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[9.3] Although satellite data were not used as a database layer, a 20 m x 20 m pixel size was also selected because SPOT data could be easily incorporated into this GIS study.

make the evaluation too coarse and a lot of data would be lost. To solve this problem, it was considered that the best solution was to establish a consistent classification that would enable spatial comparison between factors.

Although strong efforts were made to use objective thresholds, because the majority of the thresholds were identified through literature research (e.g. soils textural classes) and guidance from expert staff at Stirling and in Mexico, there was always some subjectivity. This feature is to some extent inevitable as "scoring" involves interpretation of data. Interestingly this is what allows flexibility in GIS modelling, while at the same time introducing subjectivity, and the balance between the two is an important consideration.

A single land classification type was not suited for all data because land classifications were found to be dependent on the nature of the data used for the evaluation. In this study, both the FAO and the Boolean methods were needed for the evaluation. An FAO classification was used for those factors requiring a limited boundary such as agriculture and population density, and a Boolean classification was used when a constraint was incorporated in the evaluation (e.g. mangroves). Moreover, although many efforts were made to take into account the "fuzziness" of many of the factors used in this study, it was found that the score range used (i.e. 1 to 4) was too small to be used with the FUZZY module of IDRISI; even when this range was stretched to 1 to 16 the resulting image would still contain 4 values (i.e. 1, 5, 10 and 16). The control points required for a fuzzy manipulation using the sigmoidal membership function[9.4] for each factor were calculated to be 1, 4, 5, and 6, for the 1 to 4 score range, and 1, 16, 17, and 20, for the 1 to 16 range. However, in both cases, the resulting image using the FUZZY module would only contain few values. If a larger score range could be used (e.g. 0-255 values), a fuzzy image could be created, then the SCALAR module of IDRISI would be used to multiply the fuzzy image with 255, this image would then be converted to byte binary which could then be used with MCE. In conclusion, since a very large data range was not suitable for this study, the fuzziness of the factors with the appropriate score range to be used in a MCE should be further developed. The fuzzy classification with the estimated control points could be applicable to most of the environmental factors, except for agriculture, livestock rearing, forestry and population density, where defined boundaries need to be applied. For the socio-economic factors, the fuzzy manipulation would only be applied for proximity ranges since most of the factors involved in the evaluation were used as choropleth maps, and finally, the constraints would not require a fuzzy classification since they are Boolean in nature.

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[9.4] Fuzzy offers three types of membership function (i.e. control points): sigmoidal, J-shaped or linear. The sigmoidal function is the most commonly used function in fuzzy set theory (Eastman, 1995).

Many advantages were found in using the MCE technique in conjunction with the Kendall coefficient of concordance statistical test, because this approach enabled evaluation of all site factors at once, and it was possible to define the relative importance of each site factor. It is evident from this study that different results can be produced at the weighting stage, due to different individuals considering different factors to be more or less important to their own objective. Nevertheless, a strong general consensus was obtained, and because it included expert opinion from various decision-makers this combined technique gave very useful results. However, to enhance the selection and adjustments of weights, a quantitative rather than a qualitative approach would be preferable. Kapetsky (1994) noted that bio-economic models could have greatly enhanced the choice of weights, so such models could be spatially linked to or built into this GIS study.

Fewer than 10% of the semi-intensive farms in Sinaloa are producing at their full capacity, mostly because of operational and consequently economic difficulties. Hence, bio-economic studies could be one of the best approaches to solve operational problems in the search for economic optimization of shrimp culture activity (Martínez-Cordero, pers.comm.). To carry out a bio-economic analysis a great deal of information would have to be obtained from the shrimp farms. Although a major effort was made to obtain as much data as possible about each shrimp farm during field verification (e.g. activity conflicts, legal permits, sources of postlarvae and markets), this information was non-existent or not-available. It was therefore beyond the scope of the present study to carry out such analysis. Nevertheless, it is suggested that since there is a large number of shrimp farms (approximately 125), a few representative farms could be chosen (e.g. 4) for the analysis. Factors that should be collected for a bio-economic analysis are presented in **Table 9.1**.

**Table 9.1. Important factors needed to carry out a bio-economic analysis for semi-intensive shrimp culture in Sinaloa.**

| ENVIRONMENTAL | BIOLOGICAL | PHYSICAL | ECONOMIC | MANAGEMENT |
|---|---|---|---|---|
| Water temperature | Shrimp growth | Soil quality | Equipment | Feeding |
| Water quality | Diseases | Pumping systems. | Construction | Water exchange |
| Rainfall | Postlarvae | Harvesting & stocking. | Funding | Aeration |
|  |  |  | Culture performance | Production |
|  |  |  |  | Fertilization |

Source: Martínez-Cordero (pers. comm.).

If the above data could be obtained, the relative importance of these factors could be evaluated using Kolmogorov-Smirnoff and Mann-Whitney tests (Shannon, 1975). Noriega-Curtis (pers.comm.) has found that many shrimp farms in Sinaloa have been abandoned due to socio-economic rather than environmental or biotechnological problems.

Uncertain data quality in a large database could have had a negative influence on the weights assigned by putting more reliability on the results than they deserved (Kapetsky, 1994). Nonetheless, the reliability of some of the data was assessed either by comparing information from different sources or by field verification.

The spatial operations used to develop the models in this study were entirely dependent upon the logic established by the user, so it is important that general guidelines are developed so as to enable comparison between other results. There are several pathways which can be used to construct a model to solve a particular problem in a GIS, and not all of them will give the same answer since the results of the spatial operation can be order dependent. Thus, a lot of thought was needed to decide upon the logical pathways for a problem. Here, even the numbers assigned to each category (i.e. 1 to 4 classification) were carefully chosen to obtain a reliable answer.

The GIS models presented in this study could be presented in the form of an expert system[9.5], forming an interface to the GIS, say IDRISI, to make it easy to use and to address changes. But this is only needed for the non-GIS professional and in fact would remove flexibility and weaken the full power of GIS, as GIS professionals could develop these models even further. In conclusion, a compromise has to be made between establishing strict guidelines while at the same time allowing flexibility for further GIS modelling. A sequence of steps to assist users to organize a GIS is proposed in **Table 9.2**.

GIS will continue to be primarily dependent upon the availability of the data. As Clark (1991) stated, "without data, the most sophisticated GIS soon runs dry". Government departments in Mexico hold a large quantity of data needed by various users. However, even though a great quantity of data was obtained for this study, many other data (e.g. most of the aquaculture data) was usually not made available due to confidentiality or for cost reasons. Unfortunately, in the majority of the cases, this confidentiality is unnecessary.

Government departments and other organizations should become more aware of the importance of data sharing, and adopt a positive approach to the marketing and use of their data. Similarly, of parallel importance to data availability is data quality, because it is necessary to have data which is accurate and reliable, standardized and in a compatible format to a range of end-users.

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[9.5] Intelligent or expert systems are based on formal sets of rules which may be modified. These systems are capable of learning from experience. Basically, it means that a great deal of time, or digital storage space could be saved during encoding, manipulation or retrieval stages of GIS functioning, because the programme is able to use logical rules (knowledge) in specific situations to short-cut, improve or restructure its procedures (Rhind and Green, 1988; Molenaar, 1989).

Table 9.2. Study recommendations.

SUGGESTED GUIDELINES

1. **Define the problem, outline the objectives of the study.**

2. **Determine the data that are required to solve the problem** (e.g. criteria selection).

3. **Ascertain and report the sources of data used** (i.e. particularly those organizations or government departments whose mandate is to collect data) and format (see Tables 3.4, 3.5, 3.6, 7.2 and 7.3).

4. **Evaluate data compatibility, quality, level of resolution and completeness.**

5. **Clearly define the area of study (km$^2$), the spatial coverage ( i.e. x and y format) and the pixel size (e.g. 250 m x 250 m).** In this study it was found that some of this information was not reported by some authors (see Table 1.1).

6. **List the criteria used in the study.** It was found that it was difficult to extract this information when comparing studies (see Table 3.3).

7. **Classify criteria according to the nature of the data used for the evaluation.** In this study two classification types were used and are recommended: FAO and Boolean.

8. **Many factors used in this study (e.g. soils), are better represented by a Fuzzy classification.** However, the score range used did not suit the Fuzzy methodology, so the fuzziness of the factors with the appropriate score range to be used in a MCE needs to be developed.

9. **Standardization of scores.** A 1 to 4 score range proved to be optimum primarily because it suited the FAO classification in terms of suitability of defined uses.

10. **The analytical methodology used to produce the GIS outputs should be briefly described.** It was found that it was very difficult to extract this information when comparing studies of this nature. For example, it is clear that the MCE and MOLA decision-making techniques played a major role in the development of this study. Furthermore, by using flowcharts and by including the mathematical expressions and the macro files it was possible to make a clear description of the methodology used.

11. **The 1 to 4 score range needs to be increased in cases were a large number of criteria are being evaluated in an MCE (e.g. more than 6 criteria).** Moreover, the number of criteria must be increased equivalently to achieve standardization (e.g. a multiple of four). Additionally, a score increase also has to signify an increase in suitability.

12. **Standardize thresholds.** Three techniques are suggested for this purpose: percentage, frequency and weights (i.e. MCE technique).

Table 9.2. Continuation.

**13. Manual digitizing should be carried out only until the study objectives are clearly met and the criteria involved in such analysis have been thoroughly evaluated in order to avoid unnecessary digitizing.** Moreover, it is important to include the level of accuracy of the database. In the present study, the spatial accuracy of the paper maps proved to be vital in order to maintain the same level of accuracy between the different maps that were digitized.

**14. Standardize use of terms to avoid confusion, and for comparison between future studies.** In the present study, a number of new terms were introduced such as a primary and secondary criteria.

**15. If weights are to be established, the MCE and the MOLA technique proved to be satisfactory and objective to obtain these values.** However, it is important that the number of factors used in either evaluation is kept to a minimum to achieve the best results (e.g. in an MCE a maximum of 13 is suggested). Great advantages in defining weights can be achieved by assigning scores in a rank order to the factors involved in the matrix evaluation (i.e. MCE), and this can be enhanced through the use of questionnaires (e.g. feedback). In this regard, the Kendall coefficient of concordance ranking test is recommended to examine the rank order of the scores chosen between decision-makers.

**16. Developing clear, logical flowcharts** (schematic diagrams of models) using well-defined spatial operations that can link the data together (this approach enables the user to think clearly about the steps needed to solve the problem).

**17. Data integration into submodels or natural groupings proved to be a meaningful way to accomplish tasks and is strongly recommended.** Moreover, it is important that the model remains as general as possible until the very end in order to avoid eliminating important criteria that could be used for other applications of the model. In this study, it was shown that a large range of outputs can be obtained from a single general model (e.g. culture system orientated models).

**18. The creation of a macro-file is facilitated by following the sequence: flowcharts - mathematical expressions - macro files.**

**19. It is vital to carry out a verification of the database and of the models produced to determine model accuracy and for further model enhancements and adjustments.** A GPS can be of enormous potential as a rapid and interactive technique.

**20. It would be useful if a colour scheme could be standardized for final GIS outputs.** For example, in the present study, when presenting suitability classifications, blue was always assigned to the low suitability classes whilst green always indicated the highest suitability.

Overall, due to the complexity and dynamic nature of a coast, the application of these GIS-based models is subject to many changes, so the "dynamic" aspect of the models in this study should be further developed. For example, the time series analysis aspect of this study could be greatly enhanced by incorporating remote sensing data. Chacon-Torres *et al.* (1988) and Meaden and Kapetsky (1991) give excellent reviews of the potential of remote sensing as a data source for aquaculture-orientated GIS research. Video imagery captured from airborne platforms has also been used for coastal applications (e.g. Everitt *et al.*, 1991; Debusschere *et al.*, 1992), and looks to become an important future source of thematic data on the coastal zone.

Although the Huizache-Caimanero evaluation did include some water-based evaluations, since the GIS evaluations in this study were primarily "land-based" (i.e. based upon the data available), it is vital that more "water-based" data is incorporated into the GIS system. The primary reason is the concern about the water quality and the carrying capacity of the marine sites. Flores-Verdugo (In press) suggests that a maximum of up to 10% of the water surface in a coastal lagoon should be used for aquaculture, unless shrimp farm wastes are discharged into the sea. Because there are a number of factors involved, this statement requires further research but a periodic monitoring scheme could be established and easily incorporated into the Huizache-Caimanero database to evaluate and predict responses in the environment (e.g. changes in the benthic ecosystem to organic loading). By using a time series integration numerous scenarios could be generated and rapid data analysis would allow remedial decisions to be taken to ensure proper water conditions for aquaculture activities, before site conditions are degraded to a point where further activity may be compromised.

In Mexico, one of the major reasons for poor planning and management is the lack of communication between Government departments and other organizations (e.g. private) for project developments - a perfect example has been illustrated in this study, for the Huizache-Caimanero region. Recently, FAO (1995b) developed a methodological guide for the formulation and implementation of local plans for the development of aquaculture in coastal lagoon areas of Mexico. Clearly, there is an urgent need to establish better communication links between departments which could solve many of the current problems (e.g. activity conflicts) that aquaculture in Mexico is facing at present. A proposed solution to establish communication links between departments would be either to create a Secretariat which could merge all development project data together, or to merge some institutions together whose development runs parallel to each other (e.g. Agriculture-Aquaculture-Fisheries-Conservation). Interestingly, due to Mexico's recent economic crisis, to minimise the number of personnel, the Fisheries Secretariat and the Environmental Secretariat have been merged together to create the Environmental and

Fisheries Secretariat. It is hoped that there will now be better communication links within this Government department, and consequently better planning and management.

The FAO (1995b) methodological guide for the formulation and implementation of local plans for the development of aquaculture in coastal lagoon areas of Mexico refers to a "bottom up" approach following modern development practices. This is initiated at the local level and is based on group participation from the communities, the economic agencies directly involved, and the experiences and the knowledge of the producers and those responsible for the sector. This data is then used to identify priorities of development. One or two municipalities (i.e. group of communities) are grouped within the State Planning Committee (COPLADE). In turn, departmental development plans (or sub-regions) and state plans constitute part of the development plans at a national level. The relationships established are two-way since the development starts at a local level but, at the same time, the formulation of local plans requires strategic indications of global relevance, derived from higher planning levels (FAO, 1995b).

**Figure 9.1** illustrates how this relationship works, and it can be seen that GIS is a useful tool in the bottom up planning approach proposed by FAO (1995b) as a more dynamic and interactive communication link is established between the different planning levels.

Despite the above, even incomplete data can produce high quality visual output in a GIS, and there is serious concern that attractively presented GIS results can give credibility to unreliable data and encourage political decision-makers to ignore the accuracy requirements of the GIS technique. As noted by Pellew and Harrison (1988) " nicely presented GIS results can lend credibility to unreliable data or ill-founded logic". More importantly, even though GIS could benefit aquaculture development in Mexico and elsewhere in a number of ways, there is some concern that all the work behind these types of studies may be taken for granted. Hence, it is likely that many developments will still be dependent upon interests of a particular land-owner or politician although it will be more difficult to ignore objective GIS studies.

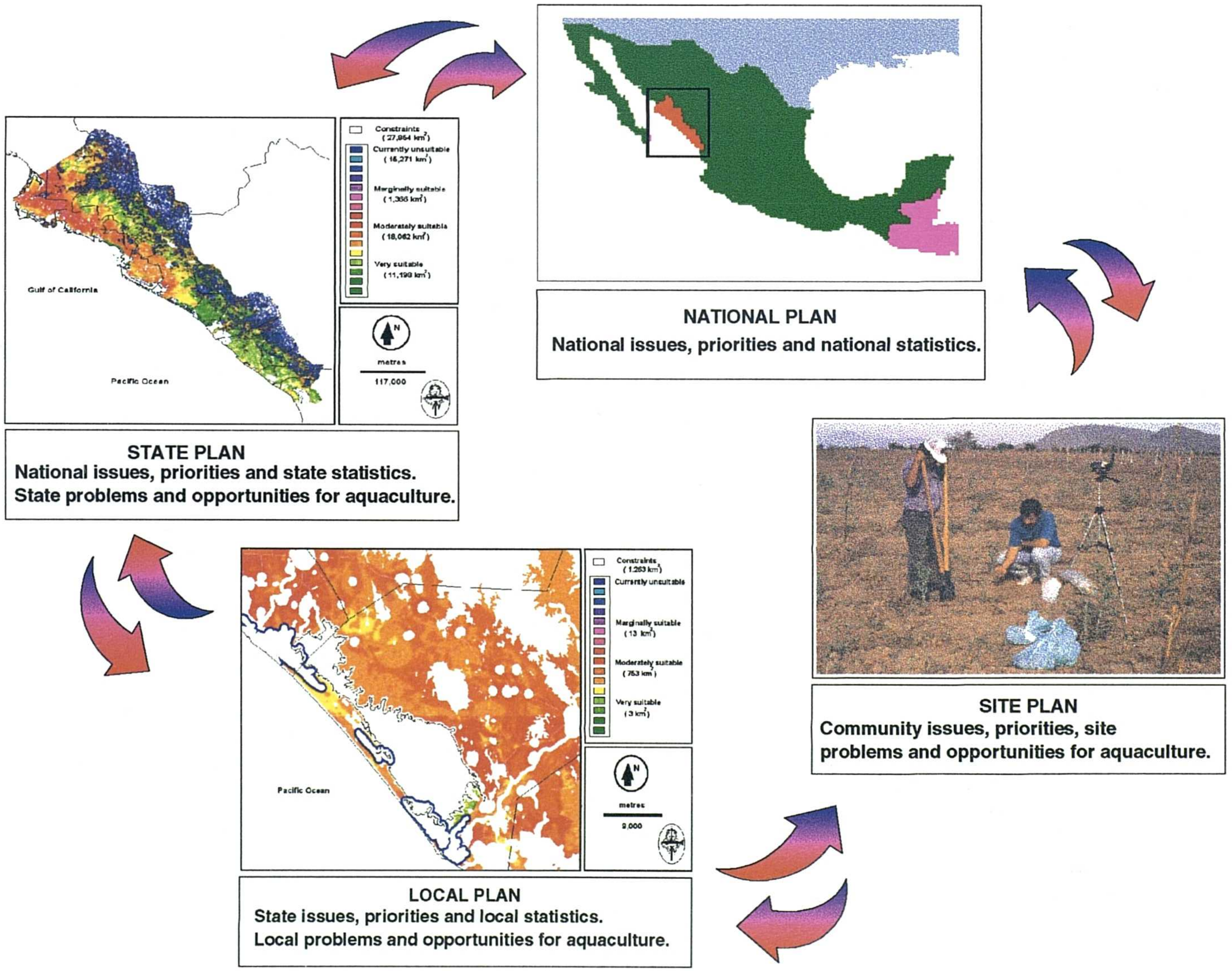

**Figure 9.1. Schematic diagram showing the dynamic and interactive relationships between national, state, local and site plans developed in this GIS study.** Note: This figure was created on the basis of the schematic diagram proposed by FAO (1995b) which, in turn, was based on a study by the British Columbia Commission on Resources and Environment (1994).

Even though many departments in Mexico are starting to become GIS-aware it is necessary for decision-makers to understand its full potential before they are able to formulate specific questions which can be addressed by GIS. Because GIS is only beginning to be used in Mexico there is concern that some of the major breakthroughs in its development, such as fuzzy methodology, will not be easily interpreted by a decision-maker who is not well aware of GIS, and it is likely that decision-makers in general would prefer nice images with simple boundaries. Consequently, as Black (1991) discussed, there may be problems between those who develop the GIS and those who apply it for planning purposes, so until these matters are resolved and adopted by aquaculture decision-makers, GIS will be a powerful but imperfect tool which may be open to misuse and misinterpretation.

The measure of annual production and growth of aquaculture in any country is important to planners. It not only guides them in quantifying and qualifying the scope of any planning effort, but it also demonstrates the continuous progress of the success of the previous plan, or points out any weaknesses. Planners also need to know what other countries are producing, as this may indicate new market opportunities, better technological applications or better planning (Nash, 1995). The responsibility for the collection of aquaculture data in Mexico has rested on the Fisheries Secretariat (SMARNyP) and this data is available in a yearly statistics book (Anuario Estadístico de Pesca) published by SMARNyP. Unfortunately, many problems were found with this data, the four principal ones being: (1) although there is an aquaculture section in the annual book, aquaculture data is merged with fish capture data, (2) besides the annual book, the wide range of other aquaculture data is commonly not available to the public, (3) data from the annual statistic book is not recent (it lags at least a year behind), and (4) relevant data for the different aquaculture centres in Mexico is supposed to be sent to, and compiled by, the Fisheries Secretariat (SMARNyP) in Mexico City. However, this data is apparently not summarized or evaluated in any way because it is not presented in the annual book or in any other source of information available to the public.

Bearing the above in mind, it is not surprising that banks, insurance companies and many other institutions have had many difficulties in supporting aquaculture projects. This also had an important effect upon the results of this study because it was very difficult to evaluate the development of the aquaculture sector ( e.g. lack and reliability of shrimp farm production data). To solve this particular problem, it is imperative that the fisheries' annual book is re-structured in order to achieve a logical aquaculture classification system[9.6]. As

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[9.6] A classification system is meant to be used for establishing a suitable definition of the sector (i.e. aquaculture), to describe the sector's limits and to classify or divide the sector into appropriate components (Nash, 1995).

discussed by Nash (1995), such classification systems should be determined by the structure of the country's aquaculture, its stage of development and national objectives - a classification system which is appropriate to the particular country gives rise to a wide variety of solutions. For example, in Sinaloa, where aquaculture is mostly based on the production of a single shrimp species (*Penaeus vannamei*), on a single set of usually applied production methods (pond culture) it would be pointless to design an elaborate classification system. On the other hand, because there are pressures to maximise social benefits to cooperatives in Sinaloa, then the classification system should be designed to enable this to be addressed. Furthermore, if the aquaculture sector in Sinaloa (or Mexico) diversifies then more complex classifications systems could be developed. Examples of complex classification systems are found in Greece and Turkey due to the wide range of aquaculture practices (Nash, 1995).

In summary, as discussed by Nash (1995), aquaculture data must be arranged in such a way that complications in the country are understood and accommodated. Planners, politicians, and sector managers therefore require information regarding returns on investment and levels of employment in aquaculture practices to make comparisons with capture fisheries. The classification system must be designed to provide relevant and detailed data to enable this analysis to be made. Only in this way can governments choose how to intervene in the sector.

The use of GIS technology in aquaculture is still in its infancy and, as discussed earlier, many problems affecting the full use of this tool remain. As discussed by Beveridge *et al.* (1994b) there is currently an incomplete understanding of the relationships between environmental factors and viability of aquaculture, and much more work needs to be carried out on the effects of aquaculture on the environment in general, and on the effects of aquaculture on resource degradation in particular, so that spatial impacts and their effects can be evaluated and predicted. For example, due to the increasing concern about the carrying capacity of marine sites in tropical countries, particularly in South East Asia (Chua and Tech, 1990), mangroves are being considered as filters of shrimp pond effluents. However, in a recent study by Roberston and Phillips (1995), the authors found that it was difficult to provide guidelines since more research is required on the effects that high ammonia and particulate matter loads in pond effluent have on nutrient transformations in mangrove sediments, and on forest growth. Similarly, socio-economic aspects affecting aquaculture have been poorly analyzed and used less as criteria for programming or predicting future aquaculture developments (e.g. Coche, 1985; Primavera, 1993). Furthermore, the use of these factors in GIS is almost non-existent (Gutierrez-García, 1995). Interestingly, however, as noted above GIS could be used to define these data deficiencies.

Although not a solution to the problem of planning and management of aquaculture in Mexico, GIS can be a powerful analytical tool in this area. For example, it was shown in this study that by considering different project development data for the Huizache-Caimanero region it was possible to evaluate and, to a certain level, predict potential conflicts and impacts on the environment between different project developments. This GIS study could be further developed by incorporating more field data to establish a more integrated approach between activities and to make more rational use of the natural resources available. GESAMP (1991) concluded that "aquaculture is a productive use of the coastal zone, but only if undertaken within the broader framework of integrated coastal zone management plans and national goals for sustainable development".

Despite the above, because GIS is just a tool, it has to be implemented carefully to ensure that it is capable of doing the job for which it is required - the success of GIS in Mexico will entirely depend upon its users (people with the right knowledge and skills). Use of GIS as a tool is about aiding managers to carry out their jobs more efficiently and effectively and, more particularly, about better decision-making.

A major advantage of GIS development in Mexico is the available data provided by INEGI (Tarleton, 1994). Most of the data used in this study, such as thematic maps, statistical information, and even digital cartography, was provided by INEGI. Many other digital products (e.g. transport and industries) are already available to the public on floppy and compact discs and it is clear that INEGI is and will play a key role in future GIS development in Mexico.

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# APPENDIX 1

Table A.1.1. Summary of monthly water balance in Sinaloa ( 1971 - 1989 ).

| RIVER BASIN | | STATION NAME | N. Of MONTHS W / POSITIVE WATER BALANCE | MONTHS w/ POSITIVE WATER BALANCE | HIGHEST | LOWEST | STATION SCORE | FINAL SCORE |
|---|---|---|---|---|---|---|---|---|
| **10** | A | Dimas | 12 | All year | August | April | 4 | 4 |
| | | Jocuixtita | 12 | All year | July | April | 4 | |
| | B | Quila | 12 | All year | August | May | 4 | 4 |
| | C | Baridaguato | 3 | July-Sept. | August | May | 3 | 3 |
| | | Culiacán | 1 | August | August | May | 2 | |
| | | El Varejonal | 1 | August | | May | 2 | |
| | | Sanalona | 3 | July-Sept. | August | May | 3 | |
| | | Santiago | 4 | July-Oct. | July | May | 3 | |
| | D | Guamuchil | 0 | None | August | May | 1 | 2 |
| | | Jaina | 2 | July-August | July | May | 2 | |
| | | Mocorito | 12 | All year | August | April | 4 | |
| | | Perícos | 1 | August | August | May | 2 | |
| | E | Tecusiapa | 4 | July-Sept. & November. | July | May | 3 | 3 |
| | F | Topolobampo | 0 | None | January | June | 1 | 1 |
| | G | Bamicori | 12 | All year | August | April | 4 | 2 |
| | | Choix | 1 | August | August | May | 2 | |
| | | El Fuerte | 1 | August | August | June | 2 | |
| | | Huites | 1 | August | August | May | 2 | |
| | | San Miguel Zapotitlán | 0 | None | September | June | 1 | |
| | H | El Carrizo | 0 | None | Jan | June | 1 | 1 |
| **11** | B | No data | | | | | 3 | 3 |
| | C | Rosario | 3 | July-Sept. | August | May | 3 | 3 |
| | D | Potrerillos | 6 | July-Oct.; Dec. & January. | August | May | 4 | 4 |

TERMINOLOGY: Numbers **10** and **11** = hydrological regions; STATION = meteorological station; HIGHEST = month with the highest water balance value; LOWEST = month with the lowest water balance value; SCORE = score for each individual meteorological station; FINAL SCORE = in cases where a river basin had more than one meteorological station the final score was found by calculating the mean between those stations. Score remained unchanged for river basins with a single station.

Note: There was no data available for river basin B, however, because the annual water balance score evaluation indicates that this region's annual water balance score (i.e. 3) is identical to the annual water balance in the Rosario river basin (C region **11**), this river basin was also assigned a final score of 3 for this monthly water balance evaluation to compensate for the lack of data.

## Table A.1.2. Raw data for monthly water balance in Sinaloa.

| RIVER BASINS | | STATION NAME | WATER BALANCE VALUES ( monthly mean values in mm ) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | HIGHEST | | | | | | | | | | | LOWEST |
| 10 | A | Dimas | **148** | **115** | **107** | **101** | **31** | **24** | **15** | **15** | **9** | **1** | **1** | **0** |
| | | | Aug | July | Sept | Oct | Dec | Nov | Jan | June | Feb | Mar | May | Apri |
| | | Jocuixtita | **305** | **221** | **181** | **127** | **100** | **62** | **42** | **33** | **20** | **14** | **13** | **6** |
| | | | July | Aug | Sept | Oct | June | Dec | Nov | Jan | Feb | Mar | May | Apri |
| | B | Quila | **131** | **109** | **108** | **82** | **26** | **24** | **22** | **15** | **8** | **5** | **3** | **1** |
| | | | Aug | July | Sept | Oct | Nov | Dec | Jan | June | Feb | Mar | Apri | May |
| | C | Baridaguato | **111** | **93** | **51** | -29 | -48 | -61 | -69 | -87 | -160 | -197 | -218 | -265 |
| | | | Aug | July | Sept | Oct | Dec | Nov | Jan | Feb | Mar | Apri | June | May |
| | | Culiacan | **12** | -34 | -75 | -83 | -87 | -90 | -93 | -118 | -193 | -212 | -231 | -256 |
| | | | Aug | Sept | Dec | Jan | Oct | July | Nov | Feb | Mar | Apri | June | May |
| | | El Varejonal | **110** | -24 | -52 | -81 | -92 | -95 | -119 | -181 | -197 | -219 | -238 | -265 |
| | | | Aug | Sept | Oct | Dec | Jan | Nov | Feb | July | Mar | June | Apri | May |
| | | Sanalona | **101** | **48** | **30** | -34 | -52 | -67 | -69 | -104 | -177 | -195 | -212 | -248 |
| | | | Aug | July | Sept | Oct | Dec | Nov | Jan | Feb | Mar | June | Apri | May |
| | | Santiago | **123** | **84** | **41** | **9** | -5 | -16 | -39 | -77 | -90 | -123 | -177 | -179 |
| | | | July | Aug | Sept | Oct | Dec | Jan | Nov | Feb | Mar | June | Apri | May |
| | D | Guamuchil | -13 | -41 | -76 | -82 | -86 | -110 | -123 | -126 | -192 | -244 | -268 | -282 |
| | | | Aug | Sept | Jan | July | Dec | Nov | Feb | Oct | Mar | Apri | June | May |
| | | Jaina | **90** | **77** | -1 | -40 | -56 | -68 | -70 | -101 | -176 | -200 | -210 | -260 |
| | | | July | Aug | Sept | Dec | Jan | Nov | Oct | Feb | Mar | June | Apri | May |
| | | Mocorito | **217** | **204** | **148** | **52** | **30** | **29** | **17** | **16** | **13** | **6** | **5** | **1** |
| | | | Aug | July | Sept | Oct | Jan | June | Nov | Dec | Feb | Mar | May | Apri |
| | | Pericos | **5** | -15 | -50 | -78 | -80 | -85 | -95 | -119 | -180 | -233 | -270 | -273 |
| | | | Aug | Sept | July | Oct | Jan | Dec | Nov | Feb | Mar | Apri | June | May |
| | E | Tecusiapa | **125** | **68** | **17** | **7** | -22 | -32 | -76 | -79 | -109 | -200 | -224 | -231 |
| | | | July | Aug | Sept | Nov | Jan | Dec | Oct | Feb | Mar | Apri | June | May |
| | F | Topolobampo | -75 | -83 | -93 | -95 | -103 | -105 | -131 | -161 | -167 | -195 | -211 | -220 |
| | | | Jan | Dec | Aug | Sept | Nov | Feb | Oct | Mar | July | Apri | May | June |

Source: Raw data for precipitation and evaporation provided by SMN (1993).

Note: Data created by the subtraction of precipitation - evaporation (i.e. both mean monthly values).
Values in "BOLD" are positive water balance values.
Number **10** = hydrological region.

## Table A.1.2. Continuation.

| RIVER BASINS | STATION NAME | WATER BALANCE VALUES ( monthly mean values in mm ) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | HIGHEST | | | | | | | | | | | LOWEST |
| 10 G | Bamicori | **230** | **208** | **138** | **46** | **31** | **31** | **27** | **24** | **16** | **13** | **5** | **2** |
| | | Aug | July | Sept | Oct | Nov | Jan | June | Dec | Feb | Mar | May | April |
| | Choix | **30** | -5 | -12 | -39 | -47 | -60 | -69 | -92 | -161 | -235 | -262 | -280 |
| | | Aug | Sept | July | Dec | Jan | Nov | Oct | Feb | Mar | April | June | May |
| | El Fuerte | **10** | -40 | -49 | -68 | -79 | -85 | -97 | -125 | -165 | -231 | -273 | -276 |
| | | Aug | Jan | Sept | Dec | July | Nov | Oct | Feb | Mar | April | May | June |
| | Huites | **43** | -7 | -19 | -75 | -89 | -93 | -113 | -133 | -184 | -241 | -247 | -281 |
| | | Aug | July | Sept | Dec | Jan | Oct | Nov | Feb | Mar | June | April | May |
| G | San Miguel Zapotitlán | -54 | -70 | -73 | -74 | -91 | -98 | -111 | -152 | -169 | -201 | -222 | -240 |
| | | Sept | Jan | Dec | Aug | Nov | Oct | Feb | July | Mar | April | May | June |
| H | El Carrizo | -20 | -22 | -35 | -42 | -57 | -82 | -95 | -100 | -108 | -109 | -155 | -163 |
| | | Jan | Feb | Mar | Dec | Apr | Nov | Sept | Aug | May | Oct | Jul | Jun |
| **11** B | No data | | | | | | | | | | | | |
| C | Rosario | **108** | **99** | **61** | -23 | -49 | -53 | -61 | -93 | -158 | -180 | -183 | -206 |
| | | Aug | Sept | July | Oct | Dec | Nov | Jan | Feb | Mar | June | April | May |
| D | Potrerillos | **217** | **163** | **141** | **98** | **5** | **0** | -8 | -29 | -43 | -48 | -68 | -87 |
| | | Aug | Sept | Jul | Oct | Dec | Jan | Nov | Feb | Mar | Jun | Apr | May |

Source: Raw data for precipitation and evaporation provided by SMN (1993).

Note: Data created by the subtraction of precipitation - evaporation (i.e. both mean monthly values).
Values in “BOLD” are positive water balance values.
Numbers **10**, **11** = hydrological regions.

# APPENDIX 2

## Digitizing configuration

### 2.1. The digitizing software

*IDRISI.DIG file:*

```
digitiz.id: Altek AC31 Revision B-Ver.1.12-Set dip switch bank 3
start col x:    3
end col. x:     7
start col y:    9
end col y:     13
start col z:   1
end col z:     1
reset:         ""
point mode:  " S0 \ 013 \ 010 "
line mode:  "  S2 \ 013 \ 010 "
digitize:     0
finish:       3
snap:         2
toggle:       1
baud rate:   9600
data bits:   8
stop bits:   1
parity:       odd
handshake: cts/rts
com port:    2
```

### 2.2. The Digitizer

*DIP switch settings for the ALTEK AC31 DATATAB digitizer:*

| **SWITCH NO.** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| **S1** | off | off | off | off | on | on | on | off |
| **S2** | off | off | off | off | off | on | off | off |
| **S3** | on | off | on | on | off | on | off | on |
| **S4** | on | off | off | on | on | off | on | on |

# APPENDIX 3

## Table A.3.1. Soil scores in Sinaloa.

| SOIL GROUP | SOIL TYPE | TEXTURE CLASS | SOILTX | SOILT | Z | SS |
|---|---|---|---|---|---|---|
| Luvisol | Lc+Bc+Vc/3 | 3 | 6 | 4 | 10 | 4 |
| | Lc+Hh/2 | 2 | 4 | 4 | 8 | 3 |
| | Lc+Vc/3 | 3 | 6 | 4 | 10 | 4 |
| | Lo/2 | 2 | 4 | 4 | 8 | 3 |
| | Lo+Hh/2 | 2 | 4 | 4 | 8 | 3 |
| | Lo+Hl/2 | 2 | 4 | 4 | 8 | 3 |
| | Lo+Ho/2 | 2 | 4 | 4 | 8 | 3 |
| | Lo+Vc+Hh/3 | 3 | 6 | 4 | 10 | 4 |
| | Lv+Hl/2 | 2 | 4 | 4 | 8 | 3 |
| Cambisol | Bc+Hh+Re/2 | 2 | 4 | 3 | 7 | 3 |
| | Bc+Lc/2 | 2 | 4 | 3 | 7 | 3 |
| | Bc+Lc+Vc/2 | 2 | 4 | 3 | 7 | 3 |
| | Bc+Lf+Re/2 | 2 | 4 | 3 | 7 | 3 |
| | Bc+Rc/2 | 2 | 4 | 3 | 7 | 3 |
| | Bc+Re/2 | 2 | 4 | 3 | 7 | 3 |
| | Bc+Re+I/2 | 2 | 4 | 3 | 7 | 3 |
| | Be/2 | 2 | 4 | 3 | 7 | 3 |
| | Be+Hh/2 | 2 | 4 | 3 | 7 | 3 |
| | Be+I+Be/2 | 2 | 4 | 3 | 7 | 3 |
| | Be+I+Hh/2 | 2 | 4 | 3 | 7 | 3 |
| | Be+Is/2 | 2 | 4 | 3 | 7 | 3 |
| | Be+Je/2 | 2 | 4 | 3 | 7 | 3 |
| | Be+Je+Hh/2 | 2 | 4 | 3 | 7 | 3 |
| | Be+Lo/2 | 2 | 4 | 3 | 7 | 3 |
| | Be+Rh/1 | 1 | 2 | 3 | 5 | 2 |
| | Be+Sg+Hh/2 | 2 | 4 | 3 | 7 | 3 |
| | Be+Vc+Hh/2 | 2 | 4 | 3 | 7 | 3 |
| | Be+Xl/2 | 2 | 4 | 3 | 7 | 3 |
| Solonchak | Z+Zo/3 | 3 | 6 | 3 | 9 | 4 |
| | Zg/1 | 1 | 2 | 3 | 5 | 2 |
| | Zg/2 | 2 | 4 | 3 | 7 | 3 |
| | Zg/3 | 3 | 6 | 3 | 9 | 4 |
| | Zg+Be/2 | 2 | 4 | 3 | 7 | 3 |
| | Zg+Hh/2 | 2 | 4 | 3 | 7 | 3 |
| | Zg+Re/2 | 2 | 4 | 3 | 7 | 3 |
| | Zg+Zt/3 | 3 | 6 | 3 | 9 | 4 |
| | Zg+Zo+Re/2 | 2 | 4 | 3 | 7 | 3 |
| | Zo/2 | 2 | 4 | 3 | 7 | 3 |
| | Zo/3 | 3 | 6 | 3 | 9 | 4 |
| | Zo+Je/1 | 1 | 2 | 3 | 5 | 2 |
| | Zo+Re/2 | 2 | 4 | 3 | 7 | 3 |
| | Zo+Re/3 | 3 | 6 | 3 | 9 | 4 |
| | Zo+Z/2 | 2 | 4 | 3 | 7 | 3 |
| | Zo+Zg/2 | 2 | 4 | 3 | 7 | 3 |
| | Zo+Zg/3 | 3 | 6 | 3 | 9 | 4 |

TERMINOLOGY: SOILTX = soil texture class multiplied by 2; SOILT = soil type score; Z = SOILTX + SOILT; SS = soils submodel or final score using the frequency distribution threshold. SOIL TYPE example: Bc + Lc/2: Bc = primary soil or most dominant soil; Lc = secondary soil; 2= medium texture class (SPP, 1982). Textural classes: 1, coarse; 2, medium; 3, fine (SPP, 1982).

## Table A.3.1. Continuation.

| SOIL GROUP | SOIL TYPE | TEXTURE CLASS | SOILTX | SOILT | Z | SS |
|---|---|---|---|---|---|---|
| Fluvisol | Je/1 | 1 | 2 | 2 | 4 | 1 |
| | Je/2 | 2 | 4 | 2 | 6 | 2 |
| | Je+Be/1 | 1 | 2 | 2 | 4 | 1 |
| | Je+Ff/2 | 2 | 4 | 2 | 6 | 2 |
| | Je+Fs/2 | 2 | 4 | 2 | 6 | 2 |
| | Je+Is/2 | 2 | 4 | 2 | 6 | 2 |
| | Je+Xh/1 | 1 | 2 | 2 | 4 | 1 |
| Rendzina | E/2 | 2 | 4 | 2 | 6 | 2 |
| Vertisol | Vc/3 | 3 | 6 | 1 | 7 | 3 |
| | Vc+Bc/3 | 3 | 6 | 1 | 7 | 3 |
| | Vc+Hh/3 | 3 | 6 | 1 | 7 | 3 |
| | Vc+Hh+Vp/3 | 3 | 6 | 1 | 7 | 3 |
| | Vc+I+Hh/2 | 2 | 4 | 1 | 5 | 2 |
| | Vc+I+Hh/3 | 3 | 6 | 1 | 7 | 3 |
| | Vc+I/3 | 3 | 6 | 1 | 7 | 3 |
| | Vc+Re/2 | 2 | 4 | 1 | 5 | 2 |
| | Vc+Re/3 | 3 | 6 | 1 | 7 | 3 |
| | Vc+Vp/3 | 3 | 6 | 1 | 7 | 3 |
| | Vc+Vp+Bc/2 | 2 | 4 | 1 | 5 | 2 |
| | Vc+Vp+Lc/3 | 3 | 6 | 1 | 7 | 3 |
| | Vc+Xh/3 | 3 | 6 | 1 | 7 | 3 |
| | Vp/3 | 3 | 6 | 1 | 7 | 3 |
| Regosol | Re/1 | 1 | 2 | 1 | 3 | 1 |
| | Re+Bc+Hh/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+Bc+I/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+Be+Hh/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+Be+I/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+Hh/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+Hh+Be/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+Hh+I/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+I/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+I+Bc/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+I+Be/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+I+Hh/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+I+Lf/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+Is/1 | 1 | 2 | 1 | 3 | 1 |
| | Re+Lo+Hh/2 | 2 | 4 | 1 | 5 | 2 |
| | Re+Zg+Be/1 | 1 | 2 | 1 | 3 | 1 |
| | Re+Zo/1 | 1 | 2 | 1 | 3 | 1 |
| | Re+Zg/1 | 1 | 2 | 1 | 3 | 1 |

**Table A.3.1. Continuation.**

| SOIL GROUP | SOIL TYPE | TEXTURE CLASS | SOILTX | SOILT | Z | SS |
|---|---|---|---|---|---|---|
| Phaeozem | Hh/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Bc/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Bc+I/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Bc+Jc/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Bc+Je/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Bc+Re/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Be/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+I/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+I+Rc/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+I+Re/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+I+Vc/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Je+Re/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Je+Zg/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Lo/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Lo+I/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Lo+Re/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Re+I/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Re+Vc/2 | 2 | 4 | 1 | 5 | 2 |
| | Hh+Vc/3 | 3 | 6 | 1 | 7 | 3 |
| | Hh+Vc/2 | 2 | 4 | 1 | 5 | 2 |
| | Hl/2 | 2 | 4 | 1 | 5 | 2 |
| | Hl+Ao/2 | 2 | 4 | 1 | 5 | 2 |
| | Hl+Be+Je/2 | 2 | 4 | 1 | 5 | 2 |
| Lithosol | I/2 | 2 | 4 | 1 | 5 | 2 |
| | I+Hh/2 | 2 | 4 | 1 | 5 | 2 |
| | I+Hg+Re/2 | 2 | 4 | 1 | 5 | 2 |
| | I+Re/2 | 2 | 4 | 1 | 5 | 2 |
| | I+Re+Be/2 | 2 | 4 | 1 | 5 | 2 |
| | I+Re+Hh/2 | 2 | 4 | 1 | 5 | 2 |
| | I+Re+Vc/2 | 2 | 4 | 1 | 5 | 2 |
| | I+Vc/3 | 3 | 6 | 1 | 7 | 3 |
| Xerosol | Xh/2 | 2 | 4 | 1 | 5 | 2 |
| | Xh+Hh/2 | 2 | 4 | 1 | 5 | 2 |
| | Xh+Je/2 | 2 | 4 | 1 | 5 | 2 |
| | Xh+Rc/2 | 2 | 4 | 1 | 5 | 2 |
| | Xh+Vc+Hh/2 | 2 | 4 | 1 | 5 | 2 |
| | Xh+Vc+I/2 | 2 | 4 | 1 | 5 | 2 |

# APPENDIX 4

**Table A.4.1. List of studies carried out in the Huizache-Caimanero lagoon system (1966 - 1995).**

| SUBJECT/AUTHOR | DATE |
|---|---|
| **I General biology of shrimps** | |
| Blake and Menz | 1980 |
| Cabrera | 1970 a |
| Chapa | 1966 |
| Edwards | 1977 |
| Edwards *et al.* | 1977 |
| Llunch *et al.* | 1972 |
| Mair | 1981 |
| Menz | 1976 |
| Menz and Bowers | 1980 |
| Menz and Blake | 1980 |
| Moctezuma and Blake | In press |
| Soto-Lopez | 1969 |
| **II Shrimp postlarvae biology** | |
| Mair | 1979a |
| Mair | 1979b |
| Mair | 1981 |
| **III Shrimp postlarvae immigration** | |
| Cabrera | 1970 b |
| Lopez | 1967 |
| Macías-Regalado | 1973 |
| Macías-Regalado and Calderón-Perez | 1979 |
| Macías-Regalado and Calderón-Perez | 1980 |
| Ortega and Núñez | 1974 |
| Poli | 1983 |
| Rogelio-Poli and Calderón-Perez | 1985 |
| Watkins | 1980 |
| **IV Fish population** | |
| Alvarez *et al.* | 1984 |
| Amezcua | 1977 |
| Blake and Blake | In press |
| Chapa and Soto-Lopez | 1969 |
| Edwards | 1977 |
| Menz | 1976 |
| Warburton | 1978a |
| Warburton | 1978b |
| Warburton | 1979 |

| SUBJECT/AUTHOR | DATE |
|---|---|
| **V Fisheries** | |
| Cárdenas | 1969 |
| De la Lanza *et al.* | 1993 |
| del Valle-L *et al.* | 1987 |
| Díaz-Gonzales and Soto-Lopez | 1988 |
| Edwards and Bowers | 1974 |
| Edwards | 1978 a |
| Hernanadez-Carballo | 1967 |
| Hernanadez-Carballo | 1991 |
| Paul and Bowers | 1983 |
| Sepúlveda | 1981 |
| Soto-Lopez | 1973 |
| Soto-Lopez and Bush | 1973 a |
| Soto-Lopez and Bush | 1973 b |
| **VI Crustaceans (not shrimp)** | |
| Paul | 1977 |
| Paul | 1981 |
| Paul | 1982 a |
| Paul | 1982 b |
| Williamson | 1980 |
| **VII Environment** | |
| Acuipesca Consultores | 1993 |
| Ayala-Castañares *et al.* | 1970 |
| De la Lanza and García-Calderón | 1991 |
| Díaz-Rubín *et al.* | 1992 |
| Edwards | 1978 b |
| Flores | 1982 |
| Gomez-Aguirre *et al.* | 1974 |
| Phleger | 1969 |
| Ray-Guzman and Sosa-Luna | 1982 |
| Sanchez-Santillan and De la Lanza | 1994 |
| Sui-Quevedo and Del Valle | 1986 |

### Table A.4.1. Continuation.

| SUBJECT/AUTHOR | DATE |
|---|---|
| **VIII Sediments** | |
| Arenas | 1979 |
| Arenas and De la Lanza | 1981 |
| Arenas and De la Lanza | 1983 |
| Arenas and De la Lanza | 1990 |
| De la Lanza | 1980 |
| De la Lanza | 1981 |
| De la Lanza | 1986 |
| De la Lanza | 1987 |
| De la Lanza and García-Calderón | 1991 |
| De la Lanza and Rodriguez-Medina | 1990 |
| Rodriguez-Medina | 1989 |
| **IX Hydraulic engineering** | |
| Chapa | 1966 |
| Cervantes-Castro | 1980 |
| Edwards | 1978 a |
| Gobierno del Estado de Sinaloa | 1987 |
| Kapetsky | 1981 |
| Secretaría de Pesca | 1980 |
| **X Aquaculture** | |
| Aguirre-Valenzuela *et al.* | 1978 |
| Aguirre *et al.* | 1980 |
| Cabrera | 1970 b |
| Cabrera | 1970 c |
| Cabrera *et al.* | 1981 |
| CONSULTEC | 1990 |
| Cosmocolor | 1991 |
| De la Lanza and García-Calderón | 1991 |
| Flores-Verdugo | In press |
| Velardo-Iribe *et al.* | 1978 |
| **XI Socio-economic** | |
| Acuipesca Consultores | 1993 |
| CONSULTEC | 1990 |
| De la Lanza and García-Calderón | 1991 |
| Díaz-Rubín *et al.* | 1992 |
| **XII GIS** | |
| Aguilar-Manjarrez and Ross | 1994,<br>1995 a,b |

Note: All studies have been based on environmental issues. Hence, the socio-economic studies are environmental studies which have included a very brief socio-economic evaluation.