GIS AND REMOTE SENSING - BASED MODELS FOR DEVELOPMENT OF AQUACULTURE AND FISHERIES IN THE COASTAL ZONE:

A case study in Baía de Sepetiba, Brazil.

by

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Submitted in partial fulfilment of the requirements

for the degree of Doctor of Philosophy

Institute of Aquaculture

University of Stirling

April 2003
Stirling University

ABSTRACT

Faculty of Natural Sciences

Institute of Aquaculture

DOCTOR OF PHILIOSOPHY

GIS AND REMOTE SENSING - BASED MODELS FOR DEVELOPMENT OF AQUACULTURE AND FISHERIES IN THE COASTAL ZONE: A case study in Baía de Sepetiba, Brazil.

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The use of Geographical Information Systems (GIS) in regional development is now becoming recognized as an important research tool in identifying potential aquaculture development and promoting better use of fishery resources on a regional basis.

Modelling tools of GIS were investigated within a database specifically built for the region of Sepetiba Bay (W44°50', S23°00') Rio de Janeiro - Brazil, where, water based aquaculture development potential for two native species of molluscs: Perna perna (brown mussel) and Crassostrea rhizophorae (mangrove oyster) was identified, and additionally potential for development of land-based aquaculture of the white shrimp, Litopenaeus vannamei.

Taking into consideration a mix of production functions including environmental factors such as water temperature, salinity, dissolved oxygen content, natural food availability as well as shelter from exposed conditions, several aquaculture development potential areas were found. The integration of sub-models comprised of thematic layers in the GIS including human resources available, general infrastructure present, regional markets as well as constraints to aquaculture development was developed.

Multi-criteria evaluation within sub-models and between sub-models resulted in identification of several distinct potential areas for mollusc aquaculture development, indicating significant production potential and job creation.

Basic field environmental data were collected in field trips in 1996, 1997 and 1998. Fresh market data were collected in 2001-2002 and were used to analyse market potential.

The map analyses undertaken with GIS based models support the hypothesis that promising locations for aquaculture development, their extent and potential production capacity can be predicted, making GIS use a useful tool for natural resource management and decision support.

Acknowledgements

I am most grateful to Dr. Lindsay Ross for his supervision, and unconditional support throughout all of my work on this project. I thank Dr. Jeanete Maron Ramos for supporting all phases of the research at USU - Universidade Santa Úrsula. Dr. Malcolm Beveridge for his helpful advice. Dr. Trevor Telfer is thanked for orientation especially in 1998 cruise aboard the RV Úrsula in Sepetiba Bay. Mr. Luiz Fernando Vianna, Mr. Richard P. Brinn, Mr. Fernando Moschen and Mr. Joel M. Braga Jr. for helpful assistance in field work measuring surface currents, collecting environmental data and verification of marine sites throughout Sepetiba Bay.s. Mr. William Struthers of the Institute of Aquaculture for his contribution of heavy metal analyses in sediment and biological samples, and Mr. Ricardo Pollery and Dr. Alessandra Casella for support in sediment analyses. Mr. John McArthur and Mr. Bill Jamieson both of the Environmental Sciences Dept. of Stirling University for GIS and map support. Dr. Lucia Campos-Creasey and Dr. Carlos Araújo Lima and Dr. Pierre Chardy for helpful comments in the manuscript revision.

None of this work would have been possible without the sponsorship provided by the Brazilian Government through CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) in the form of a CAPES grant, and Universidade Santa Úrsula who is thanked for financial and logistical support throughout all stages of this work. British Council is thanked for supporting a joint programme with CAPES which resulted in the 1998 cruise of the RV USU to the study area and support which enabled an upgrade of USU's GIS lab in Rio de Janeiro with the support of GISAP (GIS and Applied Physiology) - Stirling University. IFS - International Foundation for Science, is thanked for supporting work associated with this research and for sponsoring my participation in a SUCOZOMA workshop held in Puerto Montt, Chile allowing my presentation to a select group of aquatic science researchers in South America.

Several people are thanked for their help and discussions during this project,who I regret are not all mentioned here: my PhD. colleagues at the Institute of Aquaculture: Mr. Dr. M.Abdus Salam, Dr. Oscar Perez-Martinez, Dr. José L. Aguillar-Manjarez, Dr. Fernando Starling, Dr. Luis Perez-Carrasco, Dr. Natalio Garcia-Garbi and friends in Rio de Janeiro who so supported in local data collection many ways including Marco A. de C. Mathias, Jomar Carvalho Filho, Silvio Jablonski, Gilberto Barroso and Fernando Moshen.

Lastly, I thank my family for their support, encouragement and love.

Declaration

The work described in this thesis was undertaken by the candidate, and embodies the results his own research. Where appropriate I have acknowledged the nature and extent of the work carried out by others.

Philip C. Scott
2003

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List of Acronyms and Abbreviations

AVHRR	Advanced Very High Resolution Radiometer
AHAAP	Alaska High Altitude Aerial Photography
ASCII	American Standard Code Language
ASFA	Aquatic Sciences and Fisheries Abstracts
CASI	Compact Airborne Spectrographic Imager
CPRM	Companhia de Pesquisa de Recursos Minerais
CZCS	Coastal Zone Color Scanner
DN	Digital number
EMATER	Empresa de Assistencia Tecnica Agricola Rural
FEEMA	Rio de Janeiro State Environmental Control Agency [Fundação Estadual de Engenharia do Meio Ambiente]
FIPERJ	Rio de Janeriro State Fisheries Office [Fundação Instituto de Pesca do Rio de Janeiro]
GIS	Geographical Information Systems
GPS	Global Positioning System
HCMP	Heat Capacitiy Mapping Mission
IBAMA	Brazilian Institute of the Environment and Renewable Natural Resources [Instituto Brasileiro de Meio Ambiente]
ICZM	Integrated Coastal Zone Management
IDB	Inter-American Development Bank
IEF	Rio de Janeiro State Forest Agency [Instituto Estadual de Florestas]
INPE	Brazilian Space Agency [Instituto Nacional de Pesquisas Espaciais]
IOA	Institute of Aquaculture
GERCO	Programa de Gerenciamento Costeiro
LANDSAT TM	LANDSAT Thematic Mapper
MMA	Ministry of Environment, Water Resources and Legal Amazon [Ministério de Meio Ambiente, Recursos Hídricos e da Amazônia Legal]
PESAGRO	Rio de Janeiro State Agricultural Research Agency [Empresa de Pesquisa Agropecuária do Estado do Rio de Janeiro]
PNGC	National Coastal Management Plan [Plano Nacional de Gerenciamento Costeiro]
RS	Remote Sensing
SAWC	South Atlantic Central Water
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SEMA	Rio de Janeiro State Secretary of the Environment [Secretaria Estadual de Meio Ambiente]
SERLA	Rio de Janeiro Water Resource Management Agency [Fundação Superintendência Estadual de Rio e Lagoas]
SPOT	Systeme Probatoire pour l'Observation de la Terre
SUCOZOMA	Sustainable Coastal Zone Management
TIFF	Tagged Information File Format

Chapter 1
General Introduction

1.1 Introduction

By the late 1990s, the western region of Rio de Janeiro, which includes Sepetiba Bay (Baía de Sepetiba) was beginning to experience the socio-economic and ecological consequences of urban sprawl and industrial pollution. Most of the changes had occurred during the 1970s. The fact that mangroves in Brazil are protected by law, and that fishermen in the study area generally respect the shallow waters which are important for the initial phases of shrimp development, has not been sufficient to guarantee the livelihood of those dependent on coastal natural resources such as fisheries. The number of people exploiting professionally, artisanally or for recreational purposes, the various stocks of fish and shellfish available in the study area, has increased over the years. For better overall natural resources management, there is a need for a good understanding of the actors in the area and their impacts. This is urgent and requires the kind of spatially comprehensive analysis that is now possible.

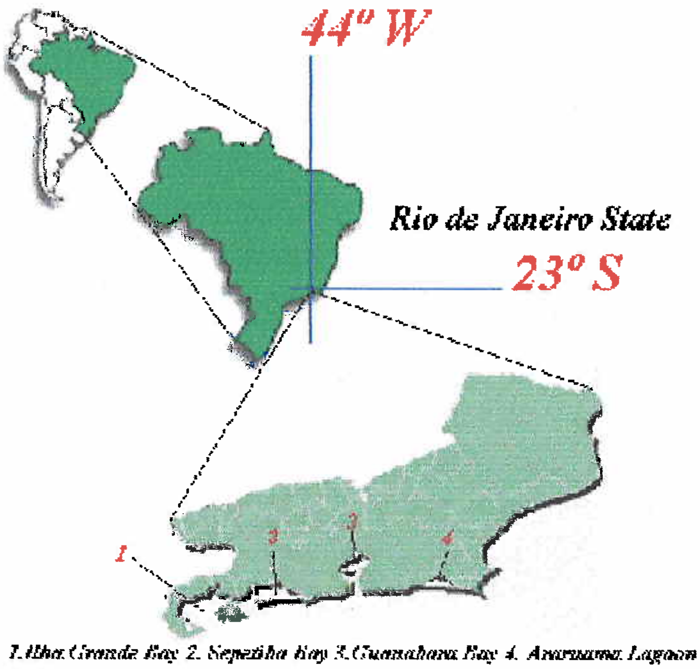

Figure 1.1 Regional position of the State of Rio de Janeiro, Brazil.

Due to its special maritime connections and strategic location on the 7,364 km Brazilian coastline, Rio de Janeiro state is a priority (Fig 1.1). The state has an 636 km coastline where

80% of its ca. 13 million inhabitants compete for living and working space amidst mangroves, coastal lagoons, coastal marshes, beaches and islands. Among this population are the artisanal fishermen.

Fishing in nearshore coastal waters and shallow shelf areas constitutes over 90% of the employment possibilities in fisheries and is an essential and conservative component of coastal communities. Estuarine and lagoon resources, in particular, have a major socio-economic importance in fisheries (Caddy and Griffiths, 1995).

Coastal waters have always provided access to marine living resources which are important both as a source of food and for leisure purposes. With human population growth occurring preferentially along coastlines, these waters have not only become valuable as leisure sites but also as ultimate discharge sites for several polluting activities. This is clearly the case for Brazil where currently the coastal population density is 87/km^2 which is 5 times that of the national average, 17/km^2 (Ministério do Meio Ambiente, 1999). This trend of expansion and utilisation of natural resources highlights the urgent need to develop and implement an Integrated Coastal Zone Management (ICZM) scheme.

An (ICZM) is "a planning and co-ordinating process which deals with development management and coastal resources and which is focused on the land water interface". (Clark, 1992). The driving forces for ICZM include the high rate of population growth, poverty, dwindling natural resources, large-scale, quick-profit commercial enterprises which degrade resources, lack of awareness about management for resource sustainability among local people, lack of understanding of the economic contribution of coastal resources to society and lack of serious government follow-up and support for conservation programmes. All of these can be identified in the study area. The overall goal of Integrated Coastal Management (ICM) is "to improve the quality of life of human communities who depend on coastal resources while maintaining the biological diversity and productivity of coastal ecosystems" (GESAMP, 1996).

In Brazil, the government began its coastal management policy, constituted by law in 1988, which later became the Plano Nacional de Gerenciamento Costeiro (PNGC). This was revised recently in 1997 to become the PNGC II. At the present time, the state department responsible for guiding the elaboration of the coastal management plan for the state of Rio de Janeiro, Fundação Estadual de Engenharia do Meio Ambiente (FEEMA), is still developing this plan, and so official information is unavailable (FEEMA, 1999).

One of the key issues in managing the environment is 'sustainability'. Snedaker and Getter (1985) defined sustainable resources use as "the resource not be harvested, extracted or utilised in excess of the amount which can be regenerated. In essence, the resource is seen as a capital investment with an annual yield; it is, therefore, the yield that is utilised and not the capital investment which is the resource base. By sustaining the resource base, annual yields are assured in perpetuity"

Because aquaculture and fisheries production in coastal zones are such important food sources and revenue generating activities to coastal populations, planned and Integrated Coastal Zone Management (ICZM) has an important role in promoting sustainability of natural coastal resources.

Barg (1992) reviewed the socio-economic benefits arising from aquaculture activity which includes the provision of food, contributing to improved nutrition and health, generation of income and employment and also in part to compensate for the low growth rate or decline of capture fisheries. Sustainable development of aquaculture can contribute to the prevention and control of aquatic pollution since it relies essentially on good water quality resources. It is in the interest of growers to select good water quality and productive areas, and maintain unpolluted conditions. Furthermore, culture of molluscs can in certain cases counteract the process of nutrient enrichment in eutrophic waters. This is one of the assumptions maintained by the Swedish government in their Sustainable Coastal Zone Management of Marine Resources programme (SUCOZOMA) where mussel farms will be tested for their potential to reduce nutrient levels in coastal waters (SUCOZOMA, 1999). Haamer (1996) designed a model showing that if mussel farms were developed to cover from 1% to 2.4% of fjord surface waters around the Orust and Tjörn islands in Sweden, the Dissolved Inorganic Nitrogen (DIN) level could be reduced by 20%, effectively the same as in the cleaner, more open waters of the Skageraak.

1.2 GEOGRAPHICAL INFORMATION SYSTEMS

UNITAR (1995) described Geographic Information Systems (GIS) as being "as significant to spatial analysis as the inventions of the microscope and telescope were to science" and that they represent "the biggest step forward in the handling of geographic information since the map" GIS systems have evolved, and been commercially developed by a number of companies, into sophisticated and sometimes expensive packages. GIS has found its use in several sectors of modern society from municipal planning, sales, marketing and infrastructural planning to precision farming.

There are several definitions for GIS. According to Burrough & McDonnell (1998), these can be toolbox based, database or organisation-based. For the purposes of this study, the database definition which states that GIS is "a database system in which most of the data are spatially indexed, and upon which a set of procedures operate in order to answer queries about spatial entities in the database" does not suffice, since several queries will be made to, and based on, manipulations and extrapolations to the database and which go well beyond simple database query. The 'toolbox-based' definition complements the previous one and is much more appropriate as it defines GIS as "a system for capturing, storing, checking, manipulating, analysing and displaying data which are spatially referenced to the earth" (DeMers, 1997). It is the analysis subsystem, which is the heart of the GIS and it is this aspect that differentiates several competing GIS software.

Knox and Smith (1997) reviewed early major implementations of GIS and found that in one of its earliest examples, the Canadian government designed a GIS to manage forestry and other types of land use. The academic sector took an interest in GIS potential in its earliest stages and had a large role in its development. Harvard University created its own GIS, called SYMAP (Knox and Smith, 1997). From the academic sector stemmed commercial companies such as Environmental Systems Research Institute (ESRI) which was initially created as a non-profit organisation and Intergraph, a well known supplier to the GIS market. These have grown and developed successful applications packages such as ARC/INFO, launched in 1982, one of the most widely used in the world. Some systems were aimed basically at teaching. One such system was OSU-MAP for the PC developed by Ohio State University, which was originally a single disk GIS installation.

Another similar system was IDRISI developed at Clark Labs, an educational and research institution located at Clark University in Worcester, Massachusetts, USA. The organisation, founded in 1987, (Eastman, R.J. 1997) has developed training materials in the form of tutorial exercises and data that guide the new user through the concepts of GIS and Image Processing. Because of its low cost and advanced capabilities, IDRISI has been a popular choice for teaching GIS and Image Processing at the university level. Clark Labs has developed for UNITAR (United Nations Institute for Training and Research) a training program with a set of exercises using real-world data to explore environmental issues (IDRISI, 2002). It has a very large academic user base.

1.3 GIS USE IN AQUACULTURE AND FISHERIES

In this section, a review of the applications of GIS in aquaculture and fisheries is presented with emphasis placed on aquaculture-related GIS.

1.3.1 AQUACULTURE

A search of the 'Aquatic Sciences and Fisheries Abstracts' (ASFA) database using the keywords "aquaculture and GIS" retrieves only 83 titles for the period 1978-2002. Although the ASFA database is fairly comprehensive, it does not cover all studies in the so-called 'grey literature', some of which have been identified and are referred to in the course of this study. Even including such references, the fact remains that despite the usefulness of GIS as an aquaculture-assisting tool it is still far from being widely adopted in the sector. However, some progress has been made and Table 1.1 summarizes the most pertinent applications of GIS and Remote Sensing for aquaculture and fisheries.

Table 1.1 GIS & Aquaculture studies employing GIS and Remote Sensing Techniques (1987-2002).

DATE	AUTHOR(S)	PURPOSE	REGION – COUNTRY	RESOLUTION (PIXEL SIZE)	GIS/RS SOFTWARE USED	REMOTE SENSING SUPPORT
2002	Scott, Vianna and Mathias	Aquaculture Potential Study for Rio de Janeiro	Brazil	30 m x 30 m	Spring 3.5, ARC-VIEW 3.2	LANDSAT
2002	Geitner	Cage trout in marine environment	Denmark	100 m x 100 m	ARC-VIEW 3.2, ARC-VIEW GIS 8.2	No
2002	Perez, Telfer and Ross	Mariculture site selection	Spain	1.1 km x 1.1 km	IDRISI 2.0	AVHRR
2002	Bonetti, Beltrame and Bonetti	Shrimp culture, hydrological suitability index	Brazil	-	ARC-VIEW 3.2/ Surfer	-
2002	Barroso and Bonetti	Shellfish planning study	Brazil	4 m x 4 m	IDRISI 32	Aerial photos
2001	Hassen and Prou	Aquaculture nonpoint loading in the environment	France	30 km x 30 km	-	Landsat
2000	Klotz-Shiran, Booth and Hecht	Mariculture site selection	South Africa	1.1 km x 1.1 km	-	-
2000	Salam, A. Md.	Coastal aquaculture development. Ph.D.	Bangladesh	30 m x 30 m	IDRISI 2.0	Landsat
1999	Soletchnik *et al.*	Cultivated oyster mortality analysis	France	-	ARC-VIEW 3.0	No
1998	Aguillar-Manjarez & Nath	Continental assessment for warm water fish culture of tilapia, clarias, carp	Africa	5 km x 5 km	ARC 7.0, IDRISI v. 1.0, ERDAS v. 1.0, IDA v. 4.2	No
1998	Fuchs *et al.*	Assessing aquaculture impact	Viet Nam, New Caledonia, Indonesia	30 km x 30 km	ARC-INFO, ARC-View	Landsat MSS
1997	Habbane *et al*	Regional site suitability for mussels, salmon, oyster, lobster	Canada	1.1 km x 1.1 km	-	SPOT, LANDSAT, AVHRR,MEIS-II, FLI
1997	Shahid *et al*	Shrimp farming area selection study	Bangladesh		-	Landsat
1997	Kapetsky & Nath	Continental assessment for tilapia, carp, tambaqui pacu culture	Latin America	9 km x 9 km	Arc 7.0.3	No
1997	Jarayabhand	Site suitability and carrying capacity for shrimp aquaculture	Thailand	(vector)	ARC-INFO - ERDAS	No
1996	Aguillar-Manjarez	Regional aquaculture development model for shrimp	Mexico	1.1 km x 1.1 km	Arc-Info	-
1995	Gutierrez-Garcia	Regional aquaculture development model for tilapia and carp	Mexico	250 m x 250 m	IDRISI 2.0	
1994	Kapetsky	Continental assessment for warm water fish culture	Africa	-	IDRISI	Landsat
1994	Smith *et al.*	Oyster management tool	USA	500 m x 500 m	IDRISI	IRS 1-A
1993	Ibrekk	Site suitability for salmon & rainbow trout	Norway		OSU-MAP	-

GIS & Aquaculture studies employing GIS and Remote Sensing Techniques (1987-1999). (continued)

DATE	AUTHOR(S)	PURPOSE	REGION – COUNTRY	RESOLUTION (PIXEL SIZE)	GIS/RS SOFTWARE USED	REMOTE SENSING SUPPORT
1993	Sudarshana	Site selection for coastal aquaculture	India	18 km x 18 km	-	-
1993	Ross, Mendoza and Beveridge	Salmon cage site selection	UK		OSU-MAP	No
1992	Shahid *et al*	Coastal shrimp areas – study	Bangladesh	30 m x 30 m	No	-
1992	Paw *et al.*	Brackish water aquaculture	Philippines	72.5 m x 72.5 m	ARC-INFO/IDRISI	-
1992	Karki	Siting for carp hatcheries	Nepal	2 km x 2 km	OSU-MAP	No
1992	Legault	Oysters, clams, mussels habitat and lease management	Canada	20 m x 20 m	SPANS	No
1992	Chacon-Torres	Chlorophyll and suspended solids observations in Lake Patzcuaro, Mexico, using multispectral imagery	Mexico		-	No
1991	Ali, Ross and Beveridge	Siting carp farming sites.	Pakistan	75km x 75 km	spreadsheet	No
1990	Flores-Nava	Regional warm freshwater fish farming potential	Mexico	1.2 km x 0.816 km	OSU-MAP for the PC	-
1990	Kapetsky *et al.*	Regional catfish and crawfish farming assessment	USA	-	ELAS	-
1990	Kapetsky *et al.*	Assessing country potential for tilapia & catfish	Ghana	2 km x 2 km	IDRISI	No
1990	Krieger & Muslow	Salmonid and mussel farm siting	Chile	-	ROOTS 4.0, GRASS 3.0	No
1989	Kapetsky	Regional suitability assessment shrimp and fish	Malaysia	-	ERDAS 7.2	SPOT
1989	Pheng	Coastal resources management	Malaysia		SPANS	SPOT- Landsat
1988	Kapetsky, Hill and Worthy	Catfish farming siting	USA		ELAS	no
1987	Meaden	Trout farming siting	UK	10km x 10 km	spreadsheet	no
1987	Kapetsky	Aquaculture development	Zimbabwe	30 m x 30 m	No	Landsat

Historically, the detailed study of locations for potential sites for trout (*Oncorhynchus mykiss)* farms in England and Wales (Meaden, 1987) is one of the most important. The 'spreadsheet approach' with 10 km^2 land area blocks being represented as individual cells is in effect very similar to a raster GIS. Sixteen successive spreadsheets were developed as 'map layers' with 'production functions', (variables which can affect productivity). For the final output, the 'production function' layers were weighted according to feedback from established trout farmers in Britain. Based on all the information layers, Meaden's model identified new areas not usually perceived or associated as good 'trout-farming country' and others which showed limited growth potential. The output map was a spreadsheet representation of the country area (Fig 1.2), with the cells shaded according to suitability.

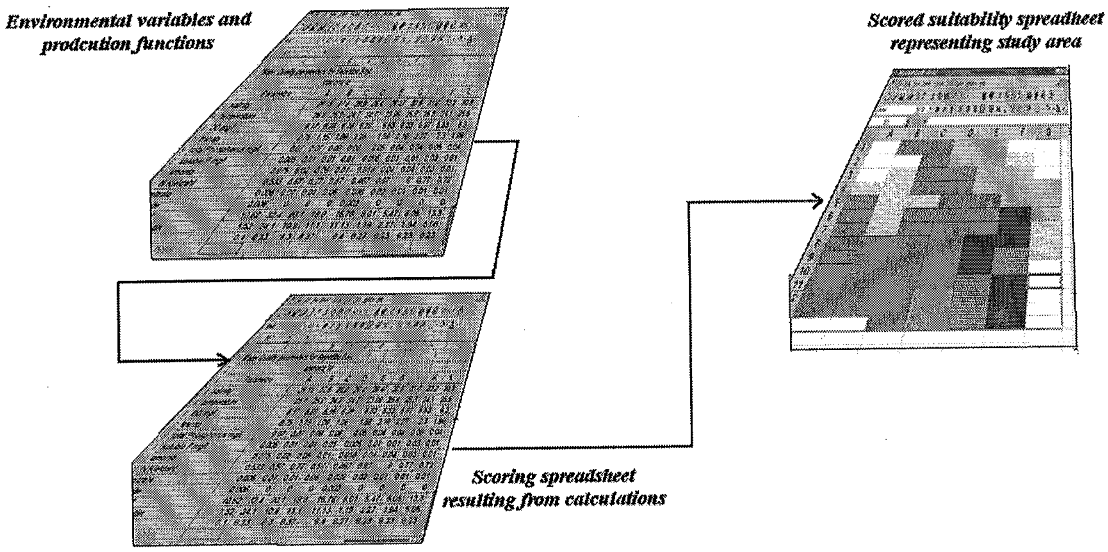

Figure 1.2 Schematic representation of spreadsheet use in aquaculture GIS.

The 'spreadsheet GIS approach' was also used by Pauly *et al.* (1997) in a study which . developed a software (**B:RUN**) based on LOTUS 1-2-3 for data entry and production of low-level geographic information system, available free of any copyright restrictions. It has been used by the authors to simulate stock dynamics of demersal fish and fleet operations in the coastal waters of Brunei Darussalam.

The need for good analysis tools, capable of handling the many distinct components of an aquaculture information database, including climate, water quantity and quality, soil types, markets, infra-structure and other general information for integration through specific mathematical operations for output, followed parallel to GIS software development. Ali, Ross and Beveridge (1991) developed a simple GIS system intended for analysing best opportunities for extensive carp farming in Pakistan using an electronic spreadsheet (View Sheet). Several sheets (layers) were made containing information on the available parameters and simple mathematical models produced a final spreadsheet with a grey-scale visual representation of Pakistani carp farming potential. By attributing values to cells in a spreadsheet, this study also effectively used the same tesseral technique, or 'grid' concept, of raster-based GIS software.

One of the pioneering applications of GIS for aquaculture is that of Kapetsky, McGregor & Nanne (1987), who implemented a GIS study for the Gulf of Nicoya, Costa Rica, in order to assist in finding the most promising locations and their areal extent for various aquaculture development opportunities. It was also one of the early attempts at integrating a satellite image into an aquaculture GIS. Three kinds of aquaculture development opportunities were evaluated in terms of optimum locations and land and water surface areas available: (1) culture of molluscs in intertidal and sub tidal areas as well as suspended culture of molluscs and cage culture of fish, (2) extensive culture of shrimp and fish in existing solar salt ponds, and (3) semi-intensive shrimp farming along the gulf shoreline outside mangrove areas. The study approach used was later included by the United Nations Institute for Training and Research as a GIS (IDRISI) training exercise in "Applications in Coastal Zone Research and Management" (UNITAR, 1995).

An early use of GIS software (ELAS) for predictive modelling of new potential areas for expanding the US catfish *(Ictalurus punctatus)* aquaculture frontier was undertaken by Kapetsky, Hill and Worthy (1988). The study was implemented to identify and inventory areas which were physiographically suitable for catfish farming, based on soil characteristics and susceptibility to flooding, in Franklin Parish, Louisiana, USA. The region had, at the time, over 1,000 ha of farms producing nearly 1,000 tonnes of catfish from 40 different sites. Since a good correspondence was obtained between the locations of existing catfish farms and suitable locations determined by the GIS, the potential use of GIS for assisting location of new potential sites was very encouraging.

With the expansion of shrimp farming in the 1980s, several countries transformed mangrove areas into shrimp growing ponds. Malaysia had set a target for opening and developing 21,000 ha of shrimp ponds for the year 2000. It was in this context that FAO technical assistance conducted a training programme for the fisheries personnel on GIS technology (Kapetsky, 1989). Similar to the Gulf of Nicoya study, the objective of the aquaculture development GIS for Johor State, Malaysia, was to locate and quantify opportunities for further aquaculture development, targeted at shrimp (*Penaeus monodon)* farming in ponds and fish culture in cages. Locational criteria and rating systems were established by considering species physiology and culture technologies available at the time, in relation to the local environment and infrastructures.

This study was practical and able to verify, in the field, the predicted outcomes achieved by modelling, with several operating shrimp farms existing in the study area. Whereas the Malaysian studies used relatively sofisticated GIS packages (SPANS and ERDAS), GIS freeware such as OSU-MAP for the PC 3.0 was available and used creatively by Ross, Mendoza and Beveridge (1993) in a coastal aquaculture site selection exercise for salmon *(Salmo salar)* cage-culture development in Camas Bruaich Ruaidhe, Oban, Argyll, Scotland. This site selection was carried out by processing several information layers, (thematic maps) such as basic water quality needs for salmonid farming, and limitations, such as current velocities and exposure to inadequate wave heights predicted from a bathymetry/wind fetch/wind velocity relationship. Flores-Nava (1990) also used OSU-MAP to identify potential inland areas for aquaculture development of mojarra *(Cichlasoma urophthalmus)* and tilapia *(Oreochromis niloticus)* in the Yucatán Peninsula. This is one of the earliest references which takes into account socio-economic components in an aquaculture GIS study. Flores-Nava modelled the market demand and social environment through the creation of layers indicating availability and proximity of distribution centres and extension services. This concern on the ability of GIS site selection models to incorporate economic aspects of aquaculture was already shared by Muir and Kapetsky (1988). Flores-Nava also incorporated a sub-model which described the level of aquaculture intensification which reservoirs could withstand.

GIS are ideal for habitat mapping studies. This application can be used to investigate site suitability for aquaculture, by incorporation of many habitat-related layers portraying a range of factors. In this way, Krieger and Muslow (1990) contributed to GIS-assisted site suitability studies by incorporating a 'biological indicator' layer for siting fish farming and mussel culture in the subtidal regions of Yaldad Bay, southern Chile. In addition to the traditional map layers describing the physical environment, such as bathymetry, salinity, sediment types, organic content, etc., the authors included 'percentage of shells in the sediment', 'number of species' and 'density of macroinfauna' as supporting thematic maps used in their modelling (see Fig 1.3). This step improved the potential use of the GIS from a technically straightforward site selection assisting tool, which took into account traditional abiotic factors expressed as thematic layers, into a more sophisticated modelling tool with potential for marine benthic resource management.

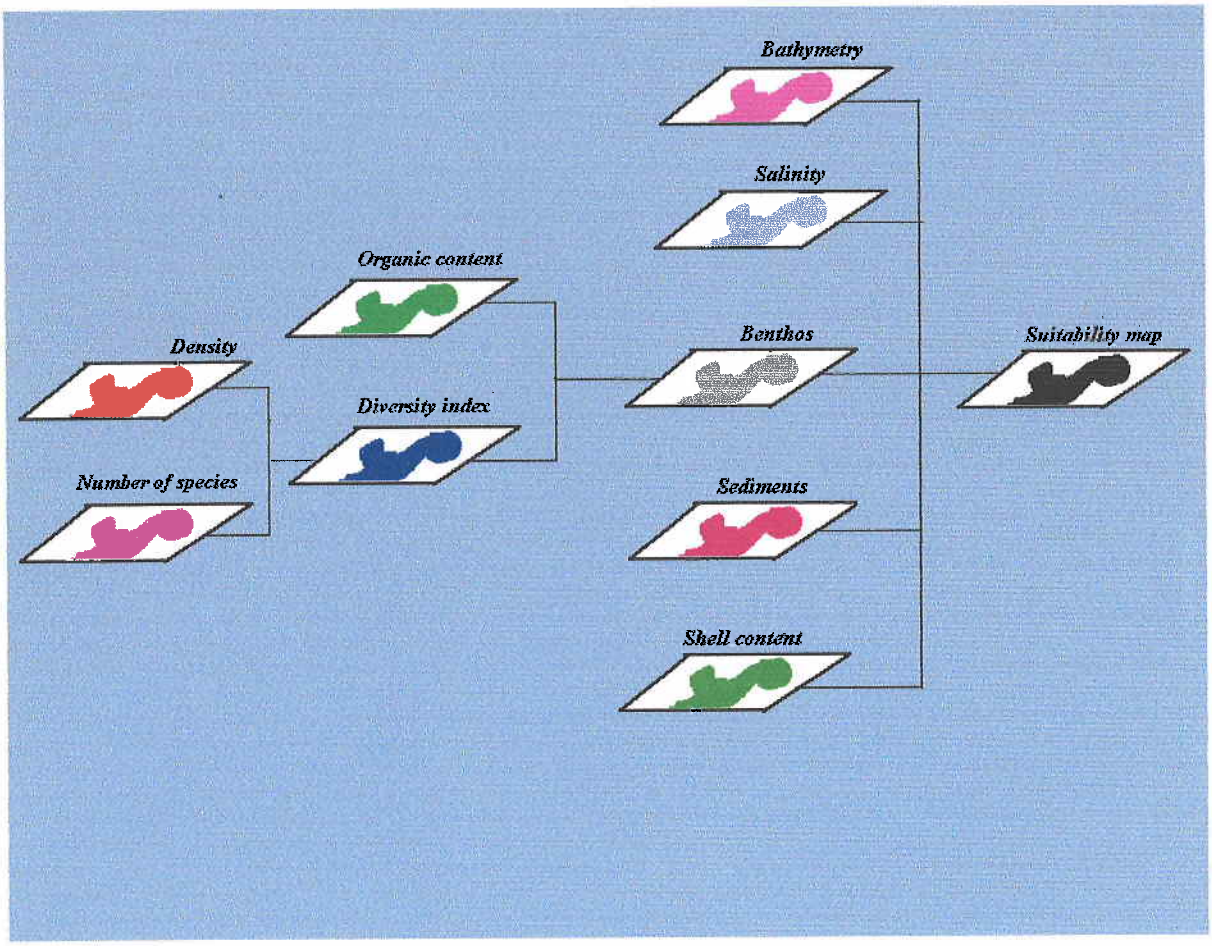

Figure 1.3 Benthic mussel site suitablility model for Yaldad Bay, Chile.
Adapted from Krieger and Muslow, 1990.

With GIS applications becoming more frequent, its potential application for coastal management became increasingly obvious. A good example of this is given by Legault (1992), who employed a GIS to determine areas for shellfish growing leases, shellfish harvesting zones and contamination or closure zones for the Eastern Prince Edward Island, Canada. A comparison was made between these areas, and an estimated cash value was determined. Further uses of the GIS were briefly explored, in particular, its usefulness as a planning tool to control pollution sources and to assist in prioritizing research surveys. A similar approach to Legault's GIS application was developed for the fisheries control of bivalve mollusc mudflats of Algarve, Portugal using ARC-View (João Cuña, unpublished, 1998). Other benthic resource researchers have been interested in the capabilities of GIS. Smith *et al.* (1994) for example, developed a desk-top GIS-based management information system with the intention of managing Maryland's Chesapeake Bay oyster populations. Still others used GIS as a site selection tool for preliminary assessment of coastal aquaculture potential such as Cansado-Marrero (1998)

GIS-assisted aquaculture potential estimates, on a larger scale, must rely on larger databases and these were available to Kapetsky (1994) at FAO through the UNEP/GRID project. This enabled a strategic assessment of aquaculture development potential on a continental scale for Africa. Based on the available knowledge of the biology and culture of the Nile tilapia *(O. niloticus)* and African catfish *(Clarias gariepinus)* the study concluded that 40 out of 48 countries had potential for warm water fish culture.

Aguilar-Manjarrez and Ross (1993) (Fig 1.4) developed a general model to assess factors in aquaculture.

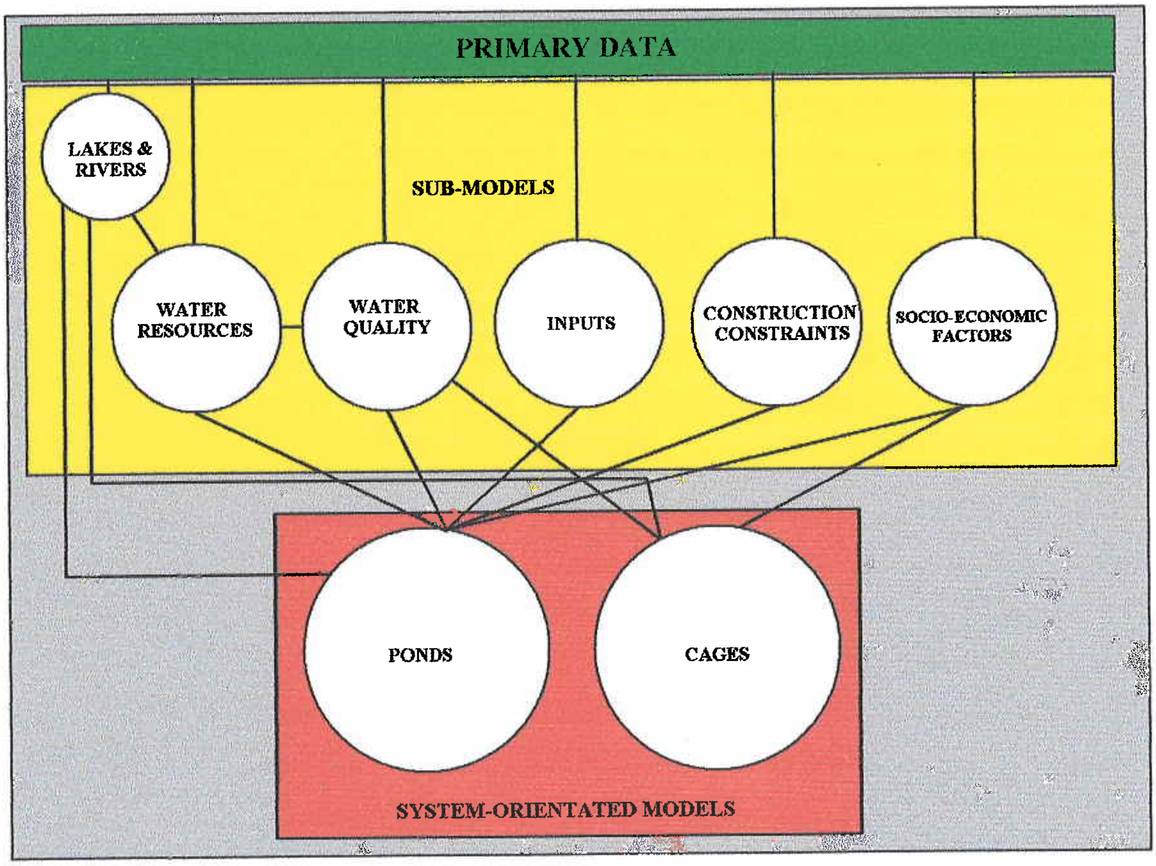

Figure 1.4 Aquaculture factors assessment model.
From Aguilar-Manjarrez and Ross (1993).

Aguilar-Manjarrez (1996) developed GIS-models for planning and management of coastal land-based aquaculture in the State of Sinaloa, Mexico. Based on the source data, sub-models were created focusing on three different themes: a) general environmental issues, b) water resources and c) water quality.

Figure 1.5 shows the water resources sub-model developed by Aguilar-Manjarrez (1996). These sub-models enabled multi-criteria and multi-objective decision-making concerning site selection and location. Aguilar-Manjarrez found it a useful tool, which he predicted would become increasingly easy to use with the development trend of digital map database adoption by government agencies. It was perceived at that time that GIS could be used for more than just making simple decisions and could actually incorporate another important component of aquaculture development planning i.e. the socio-economic component.

Gutierrez-Garcia (1995) expanded the concept that many factors important for aquaculture development including socio-economic ones, had a spatial component which could be quantified, scored and used in logical GIS models.

Figure 1.6 shows how she divided her task and developed three sub-models addressing the issues of a) social factors, b) production modifiers and c) markets, for Tabasco State, Mexico database. The resulting general model of socio-economic factors affecting aquaculture, with a few modifications to suit peculiarities of different regions, can be adapted and incorporated into other GIS assisted aquaculture modelling pursuits.

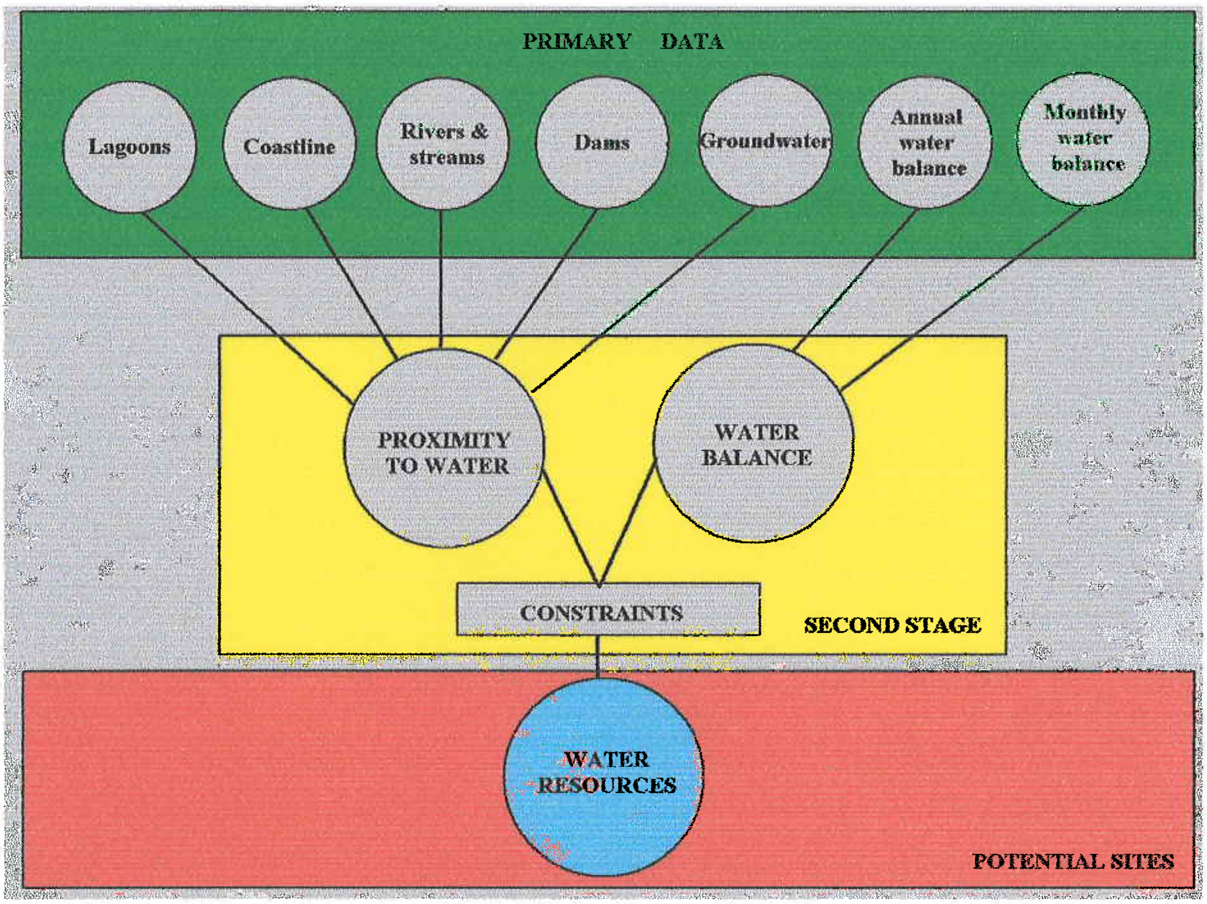

Figure 1.5 Coastal aquaculture planning models.
From Aguilar-Manjarrez (1996).

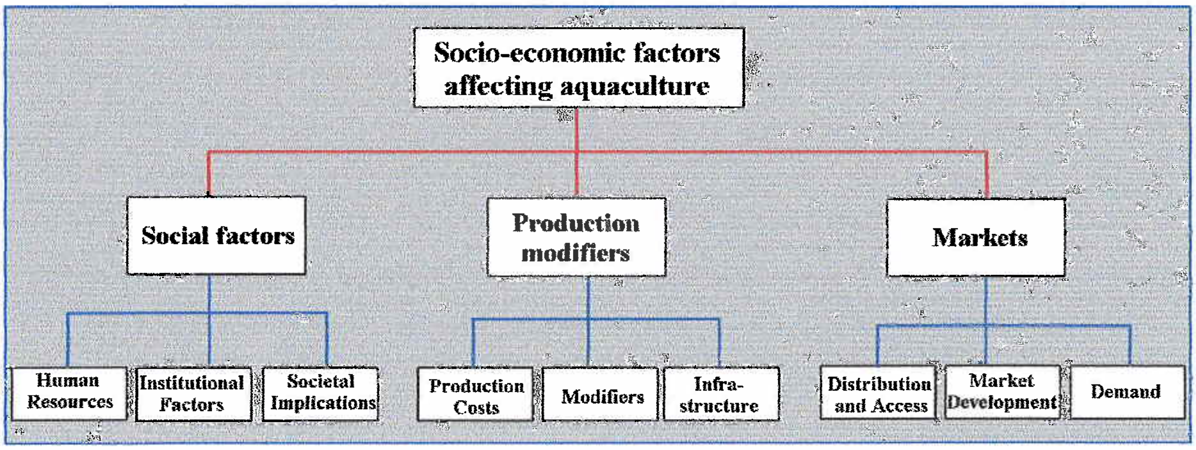

Figure 1.6 Socio-economic factors involved in aquaculture development.
From Gutierrez-Garcia (1995).

The flexibility of GIS systems for modelling aquaculture production potential was developed further by Kapetsky and Nath (1997) who added to the GIS capability, estimation of yield potential as number of crops per year possible for four species of warm water fish for Latin America. This was achieved by integrating elements of the models from POND© 3.0, a computer program written in the C++ programming language developed by the Biosystems Analysis Group (Department of Bioresource Engineering), of Oregon State University. POND is intended to guide decision making processes relevant to warm freshwater pond aquaculture and was written to provide educators, extension agents, managers, planners and researchers with a tool for rapidly analysing aquaculture systems under different management regimes, and to assist in the development of optimal management strategies (POND, 2003). The fish growth sub-model used in the GIS included ten parameters for each species.

This improvement enabled the prediction of potential fish yields over large geographic areas such as Latin America (Fig 1.7).

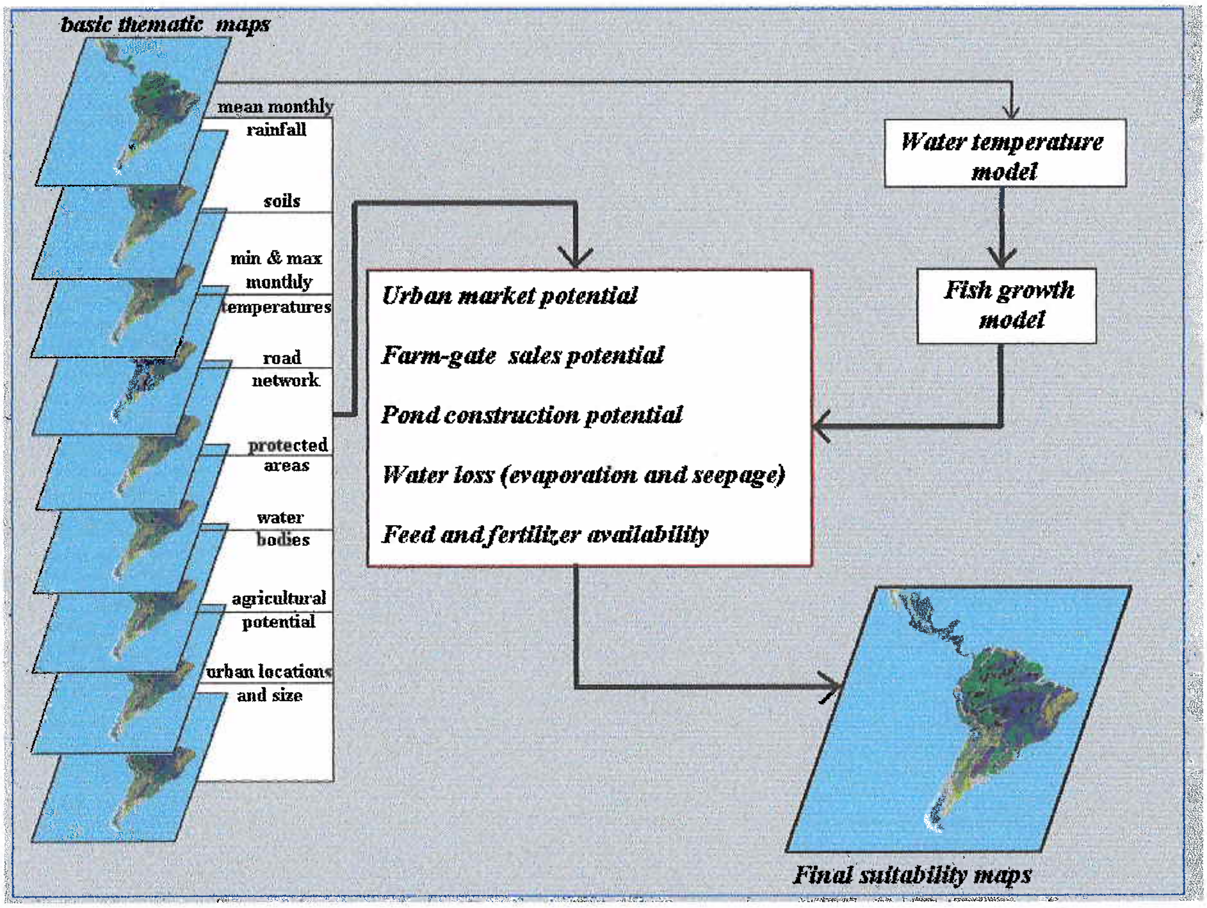

Figure 1.7 GIS for warm water fish aquaculture potential in Latin America with bioenergetic model. Adapted from FAO (1997).

Four species of warm water fish: tilapia *(O. niloticus)*, tambaquí *(Colossoma macropomum)*, pacu *(Piaractus mesopotamicus)*, and common carp *(Cyprinus carpio)* were considered in the study, and suitability maps were produced showing both small scale and commercial fish farming yield potentials. Commercial fish farming production assumed a 75% satiation feeding and harvest weights of 150 grams (tilapia), 600 grams (carp and tambaqui).

Following this method, Aguilar-Manjarrez and Nath (1998) recently updated an earlier strategic assessment of warm water fish farming potential for Africa with a modification which addressed the effects of high fish biomass, feed type and feeding levels on fish growth. By incorporating this bio-energetics model, different final outcomes were produced, reflecting a simulation of the conditions prevalent in commercial-scale fish culture. The study also increased the resolution of the previous study by a factor of 4 from an 18 km x 18 km grid to a 5 km x 5 km grid. However, it is questionable if this a relevant endeavour, once fish farming practised in most of the african continent is very low on inputs and intensity.

Whereas the Aguillar-Manjarez *et al.* (1998) study focused on increasing resolution and modelling degrees of intensification of the aquaculture operation, Jarayabhand (1997) who developed a shrimp farming GIS-assisted model took into account the sustainability issue by incorporating a carrying capacity sub-model. This attempt was resolved in the decision-making process by allowing for a cut-off point on the upper limit allocatable to aquaculture development, so as not to exceed the environments carrying capacity for Nitrogen and Phosphorus loads. This approach stems from the recognition that, world-wide, many coastal areas and mangroves have been lost in the 1990s to shrimp farms and that coastal and estuarine ecosystems do have a limit as to the amount of impact they can withstand (Naylor *et al.* , 1998). Jarayabhand's model (Fig 1.8) was therefore important as it used the GIS tool to assist planning for sustainable coastal aquaculture development.

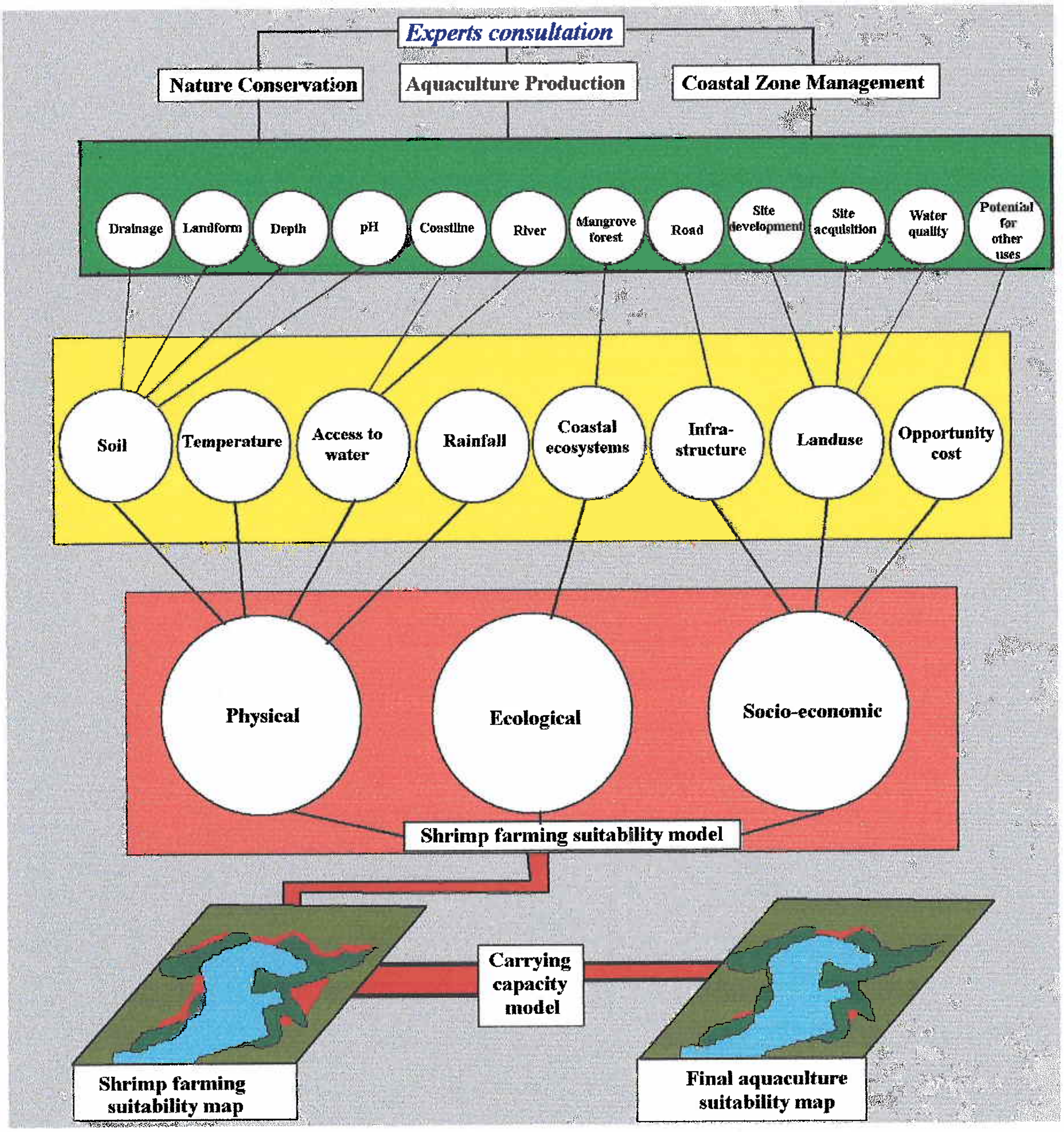

Figure 1.8 Shrimp farming GIS assisted model with a carrying capacity module.
Developed by Jarayabhand (1997).

The list of GIS applications in the fields of Natural Resources, Environment, Conservation and Wildlife and Land Based such cadastral mapping of fixed position entities is extensive (ESRI, 2003). Other uses of GISs which make use of its 'alternative scenario' capabilities are found in Emergency Management, Defense and Military areas. However, due to the highly variable characteristics of the aquatic milieu, and the limitations of knowledge about cultured marine organisms and their relationship with environmental parameters, agreement by workers in the field as to the importance of, and thresholds affecting development and growth of specific species will vary considerably, making prediction models harder to achieve acceptance until fully validated.

A common approach to manage the relative importance aquatic environmental variables in relation to aquaculture has been attempted by several authors with varying degrees of success (Jarayabhand, 1997; Salam, 2000; Aguilar-Manjarez, 1996; Pérez-Martinez, 2002 and Pérez-Sanchez, 2002). The common approach is to make use of the Analytical Hierarchy Process (AHP) developed by Saaty (1995), the methodology of which consists of establishing weights based on a 9 point scale. This methodology has been integrated by IDRISI GIS in a 'Multi-Criteria Evaluation' module. It is however, susceptible to the perception, subjectivity and competence of the interviewed people as will be seen in Chapter 6.

Further application and development of GIS in aquaculture siting, planning and development is clearly possible. So far it has mostly remained within the realm of identifying suitable sites for implementation, or extending suitable sites considering a series of production variables. In contrast to aquaculture, the benefits of GIS and RS use in terrestrial farming has led to precision farming, where feedback to farmers from GIS-RS experts, monitoring specific crops at specific locations guide them in caring for the best health/prodcution of the crops by indicating, in space and with time, areas where appropriate actions need to be made, such as the addition of fertilizers, pesticides or water. This process already exists and is evolving in terms of new and higher resolution sensors being launched by commercial ventures (Dudka 1997). The same type of feedback may be much more difficult to accomplish in water-based aquaculture systems which suffer in comparison to land-based operations, in that there is less room to make mistakes in the choice of a site. For example, much of aquaculture depends on the physico-chemical conditions such as temperature, salinity, oxygen, currents, dissolved nutrients and water exchange, which dictate whether or not an aquatic species to be cultured will thrive in an environment (Beveridge, 1996). The first International Symposium of GIS in Fisheries Science was held in 1999 Seattle, Washington, USA. It's second edition in 2002 (Brighton, Sussex, UK), included a section dedicated to aquaculture.

GIS is and will still be used in most sectors substantially as a simple cadastral database combining cadastral date and often factors aimed at simple database query and thematic map output capabilities. However, it is being used increasingly at the regional planning level.

A good example of this incipent use of GIS is that undertook by SEMA (SEMA, 1996) for the Sepetiba Bay basin, where the macrozoning process, took into consideration ecological and economic factors influencing land uses within the watershed, in urban, industrial, agricultural, touristic or nature conservation, but did not develop further than the cadastral and map output phases.

This opportunity leads us to suggest that GIS, being a flexible spatial analysis tool, can also be employed to incorporate within its modelling capabilities, variables in the economical and social sciences spheres. Thus potentially 'productive water surface' indicated in an aquaculture-oriented GIS predictive model can be further enhanced by incorporating local production costs and benefits. This approach is seen as a significant potential support for administrators in ammeliorating socio-economic conditions through GIS supported decision making.

1.4 Remote Sensing for Aquaculture and Fisheries

1.4.1 Introduction

Incorporating remote sensing (RS) techniques to traditional methods of marine stocks assessments as well as aquaculture applications can expand analytical possibilities. This section reviews some of the recent applications and summarises key areas where RS may be expected to contribute to the planning, monitoring and assistance of aquaculture development

The trend to use remotely sensed images to study and assist in selecting potentially suitable areas for aquaculture development integrated in a GIS is on the increase, as can be seen from a number of investigations summarised in Table 1.1 Green *et al.* (1996) reviewed remote sensing use for assessing and managing tropical coastal resources including aquaculture such as shrimp farming and cage siting but also other closely related topics such as seagrass, mangroves, algae, coral reefs and primary productivity measurements. Remotely sensed images, such as those obtained from the Landsat and SPOT platforms, are generated and furnished in a raster format. This format is highly compatible with raster-based GIS software, facilitating integration and consequent processes of image classification. This compatibility assists in generating new thematic layers which can incorporated into the GIS database, increasing the power of the decision making process.

RS images over land masses with sensors such as Landsat and SPOT have proven to be quite useful. Inland water bodies are easily identified. Kapetsky (1987) took advantage of Landsat's bands 1, 3 and 4 to isolate water bodies from vegetation. His study was able to locate 906 water bodies with a surface area between 21,000 and 45,000 ha over 32,400 km^2 of territory in Zimbabwe. From this area it was estimated that 7,000 tonnes of fish could be produced, thus demonstrating the usefulness of RS for locating and water bodies for potential fishery and aquaculture development. However, no other information about the water body was able to be interpreted from the RS image. A time-series would also be important to gauge the presence of these water bodies over the seasons.

1.4.2 MANGROVES AND AQUACULTURE

Mangroves are associated with several fisheries and shrimp farming. Green and Mumby (2000) have summarised several remote sensing techniques and sensors used for mangrove mapping. Combinations of sensor images can be processed in for different pusrposes. CNES-IFREMER (1987) used a SPOT RS image and GIS for identifying favourable tropical shrimp farming sites in New Caledonia. The study mostly employed SPOT's red/infrared capacity to clearly identify different vegetation types along the coastline as mangroves and associated mudflats. Scott and Vianna (2001) performed a similar study employing a single Landsat image in a GIS, to choose favourable areas for shrimp ponds based on proximity to mangrove areas as identified by supervised classification. Fuchs *et al.* (1998) used RS to assist in the assessment of shrimp aquaculture impact on the environment. A combination of Landsat and SPOT images, covering an area in Indonesia, enabled detection of an increase of 1,238 hectares of newly created ponds for the period 1991-1995. Land-use cover classification identified agricultural areas which were being converted from rice paddies to aquaculture ponds. Their conclusion was that satellite data can be very useful for aquaculture monitoring. Loubersac *et al.*, 1990 monitored the number of ponds and their state (full/empty) in New Caledonia, from which useful information could be extracted. Shahid *et al.* (1992) using infrared colour aerial photographs, Landsat MSS and Landsat TM images from two different dates, to study coastal shrimp farming areas in mangrove areas of Bangladesh. The investigation clearly showed that more mangrove areas were being cut down in the Sunderbans and were being replaced with shrimp growing ponds. Mangoves in the world vary considerably in many aspects including density, number of species, coverage, and water quality around them. Classification of Landsat TM images implies calculation of principal components and band ratios. CASI spectral data allows for greater detail and accuracy analyses of mangrove areas.

1.4.3 WATER TEMPERATURE

Water temperature is probably the most important factor in determining aquaculture production potential. Grenier *et al.* (1989) used Landsat TM and NOAA-AVHRR images to extract surface water temperature for detecting potential aquaculture sites in Canada. In a further step of this study carried out by Habbane, El-Sabh and Dubois (1997) AVHRR data was incorporated into a GIS to determine areal water-based culture potential for Atlantic salmon (*S. salar*), American oyster (*Crassostrea virginica*), blue mussel (*Mytilus edulis*) and American lobster (*Homarus vulgaris*) for the Baie des Chaleurs, Canada. The study developed an 'Aquaculture Production Index' (API) for waters in the area. The API ranges from unsuitable (0) to most suitable (1), and is based on a combination of variables: a) temperature (extracted from AVHRR images), b) salinity, c) current velocity and d) chlorophyll content. This study was, however, designed to be on a meso-scale and did not score culture suitability for the areas detected. It was only designed for preliminary evaluations. The areas were selected solely based upon the survival range for the species determined by the salinity and temperature variables. An interpolation of extreme values was effected for the API.

In fisheries, water temperature can help skippers to be more efficient in finding pelagic resources. Junior *et al.* (1998) developed a skipjack tuna (*Katswonus pelamis*) fisheries GIS model using SPRING-GIS, a freeware GIS software developed by Instituto Nacional de Pesquisas Espaciais (INPE) in Brazil. Skipjack tuna is an important pelagic fishery in the Southwestern Atlantic. The work carried out so far has applied AVHRR images, treated to generate surface temperature charts (SST), which are translated into fishing charts with an accompanying oceanographic bulletin for the guidance of skipjack tuna capture fishing fleet. In many operations, skippers are encouraged to record actual surface temperature, quantity fished, and geographic position for feedback into the database. Feedback which supports the skipjack tuna locating GIS model so far has proved far from ideal. Similar work is being carried out in the Canary Islands by the Instituto Español de Oceanografia by Ariz *et al.* (unpublished) for bigeye tuna *Thunnus obesus*. Interpretations of SST images derived from AVHRR show that higher landings of bigeye tuna correlate more strongly with interfaces of, and pockets of, warmer waters and upwelling water. Tuna are visual predators and, due to their physiological characteristics, prefer water of higher temperature, high oxygen concentration and low level of turbidity, to prey successfully (Ramos *et al.* 1996).

This line of research i.e., methods of indirect remote sensing of fish resources, using knowledge about the pelagic species habits. was reviewed by L aurs (1989) and updated in Edwards (2000). Pelagic fishes tend to congregate where there is abundant supply of food and around certain water temperature. These conditions are related to sea-surface temperature, water colour, upwelling areas, fronts and water mass fronts. In this respect the AVHRR and CZCS sensors have been very important. AVHRR interpretation has been used to direct tuna and salmon fishing fleets and can reduce search time by 25-40%. Although the preparation of the interpreted data into guidance fishing charts involves considerable costs and know-how, and additionally the difficulty of time delay and cloud cover, estimations made during an 18 month experimental period in the northeastern US showed that fishermen could have savings in excess of US$5000 per year using the charts. However, but most were not ptrepared to pay more than US$50 per year for them, meaning that it would be an uneconomic venture. (Edwards, 2000).

1.4.4 SEDIMENT LOADINGS

Rises in sediment loadings may be a result of land-based activities such as urban development, deforestation and even aquaculture development. The eventual deposition of such sediments may have impacts on estuarine communities (Edwards and Clark, 2000). Currents a re i mportant i n d etermining coastal activities a nd t hey can b e d etected from R S images b y i nterpreting p atterns o f w ater t urbidity (Lo, 1 991). E stuarine and c oastal w aters tend to be turbid wherever there are rivers bringing in sediments. Larger amounts of suspended sediments brought by currents can be detrimental to aquatic organisms such as mussels and oysters. Sediment plumes can be observed from Landsat images. Their identification and direction pattern can be a good indicator for filter feeding aquaculture endeavours. However, the relationships between suspended sediment concentrations and radiances tend to be sensor, site and season specific and no universal algorithm has been forthcoming (Edwards and Clark, *op. cit.*).

Associated with coastal aquaculture environments are several important aspects which can be tackled with remote sensing support such as the issue of changing land use. Coastal areas are good examples where this can be applied. Using satellite imagery, and with support of airborne sensors (CASI), information on the amounts of suspended sediments and phytoplankton can be obtained (Fuchs *et al.*, 1998). The synoptic view afforded by RS also allows the establishment of optimal sampling locations for field work.

Using remotely sensed images to locate appropriate aquaculture sites can be approached in more than one way. Sudarshana *et al.* (1993) used data from the IRS 1-A to select sites for 'coastal aquaculture' on the West Coast of India in the estuaries of the Kali and Aghanashimi. Principal emphasis was placed on selecting low lying areas, and mangroves. The methodology developed used an indicator for aquaculture selection based on 'bioturbation' as interpreted from satellite imagery analysis. This indicator was developed as a composite result of the analysis of four parameters: a) benthic biomass against band 1, b) phaeopigment quality in water against band 2, c) sediment particle size against band 3 and d) concentration of humic substances in the sediment against band 4. As these factors are found to influence the spectral radiance over water in estuarine areas the 'bioturbation indicator' as indicated by remotely sensed images could become a useful tool in other ecological studies. However interesting, bioturbation is a phenomenon caused by burrowing activities of many organisms ranging from small marine annelids to terrestrial anteaters. It would be necessary to know which group is responsible for the bioturbation observed in the RS images used. Also, bioturbation may be easily confused with other sediment disturbing activities. Problems such as tidal height or current velocities at the time of the sensor overpass need to be associated in order for this proposed index based on sediment suspension be considered suitable for aquaculture site selection.

Another common application of remote sensing potentially useful to aquaculture is its use in marine pollution studies i.e. detection and mapping of superficial oil slicks. Discharge of oil, especially in coastal areas, causes great loss to quality and productivity of marine environments (Clark, 1993).

With the use of RS images it is possible to greatly enhance a GIS-assisted aquaculture or fisheries planning project as RS data can be used to identify and quantify a range of important environmental characteristics of study areas. Some of these are water related such as: bathymetry, suspended solids, surface temperature, chlorophyll-*a*, salinity, total phosphorus content and current direction. In coastal areas, important thematic maps comprise cover type on adjacent land and islands including vegetation types such as mangroves, wetlands, seagrass reef flats, macroalgae etc. (Clark, 1993, Meaden and Chi, 1996, and Clark, 2000).

1.5 GIS, RS AND FISHERIES

A recent review of the fisheries management applications was undertaken by Meaden (2000). He found the range of problems that affect fisheries stocks and their management are variably manifest in the spatio-temporal domain and as so, decisions on their management and remediation could best be made with use of GIS. The most important area that supports the potential use of GIS for fisheries management is habitat mapping, which has been evolving since the early 1990s to present. However, the several examples found in the literature all have the common characteristic of being in the context of dynamic environments such as coastal and marine areas. Thus, assessment of information quality is an important issue regarding the usability of a data sets. The importance of factors including relative accuracy and precision, and the procedures for collecting, maintaining and distributing data are dealt in detail by Meyer *et al* (2000). Examples of GIS use in fisheries studies can be found for a variety of species including cephalopods *Sepia officinalis* and *Todarodes pacificus*, and fish such as anchovies, sardines, jack mackerel and sparids (*Pterogymnus laniarus*) Meaden (2000). Concurrently, fisheries-specific GIS software is being developed by researchers to meet specific demands. Three different approaches were presented in the last GIS-Fisheries and Aquaculture Symposium (Kiefer, A., Afonso-Dias et al., and Itoh, K. (2002). UNITAR (1995) used a GIS to demonstrate how data derived from spatial manipulation might be used in a fisheries resource inventory and management, with an example of shrimping activities in Tampa Bay, Florida, US. Although only three basic layers were used for this GIS (seagrass beds, bathymetry and shrimping areas) their spatial analysis and manipulation were able to assist in answering which areas were most suitable for shrimping closure or for the use of Fish Excluding Devices (FED).

Because of its spatial-analytical nature, GIS has the potential of being employed for in fisheries regulation. The need to guarantee the sustainability of fish stocks so as to ensure the maintenance of the fishing industry and its back-up industrial sector to ensure the continuance of supply (Meaden and Chi, 1996) is a good incentive for increased use of GIS in fisheries planning and regulation efforts. An early mention of a GIS/fisheries application was a workshop held in Libya by FAO for the development of a GIS and Marine Fisheries (Meaden, 1994). Meaden and Chi (1996), elaborated a document which considers many aspects relative to the use of GIS applications in marine fisheries. This document also includes case studies of GIS applied to marine fisheries and coastal zone resources management. The research applying GIS for fisheries exploitation and management is confirmed in a recent paper by Meaden and Kemp (1997) who have recently designed an integrated Fisheries Computer Aided Monitoring system called FISHCAM, which integrates a GIS (ArcView) and a GPS with a relational database which may be housed in an on-board computer. The proposal is ambitious but has definite advantages concerning monitoring catches, their quantities and precise geographic locations as well as providing new information which can be used to integrate fishing data with environmental data. RS images from platforms such as Landsat, SPOT and AVHRR can easily be integrated in this system, potentially increasing FISHCAM's usefulness to both fishermen and fisheries managers.

1.5.1 DIRECT REMOTE-SENSING OF FISHERIES RESOURCES

Edwards (2000) reviewed research into assessing coastal fisheries resources and found examples of direct remote sensing for the Pacific herring (*Clupea pallasii*), Japanese pilchard (*Sardinops melanostictus*) and the capelin (*Mallotus villosus*) by CASI or aerial photography. As the capelin spawns in shallow waters (0-5 m), aerial surveys carried out to produce an index of relative abundance as an indicator of the status of capelin stocks. CASI has also been used to detect Pacific herring schools at a spatial resolution of 4 m.

Some important coastal fisheries and shrimp resources are associated with seagrass meadows. Ferguson and Korfmacher (1997) used RS and GIS for management of seagrass meadows in North Carolina, USA. They found that spatial monitoring of seagrass meadows supported by integration of Landsat TM imagery gave satisfactory results being regarded as cheaper than would be possible with aerial photographs. Mumby and Green (2000) describe methods of mapping area estimation and nature of seagrass beds using a variety of satellite sensors, airborne digital imagery (CASI) and aerial photography with reasonable acuracy (~ 60% or better).

1.5.2 RS AND PRIMARY PRODUCTIVITY

Primary productivity in coastal waters is also a key factor in siting aquaculture operations. A strong indication of productivity is phytoplankton abundance measured as chlorophyll-*a* concentration. Planktonic matter in surface waters is readily detected by remote sensing due to the strong spectral signature of chlorophyll-*a*. Seawater can be divided into two classes: Case 1 water and Case 2 water (Sathyendranath and Morel 1983). Biomass can be estimated from chlorophyll-*a* measurements obtained by remote sensing, but in coastal zones, (Case 2 waters), this is more difficult, due to the amounts of suspended sediments and yellow substance/*Gelbstoff* determined by absorbance at 440 nm (Clark, 1993). Chlorophyll-*a* and inorganic sediments are not separable and suspended sediments, which dominate the total reflectance, behave as a broad band making inshore determinations of chlorophyll-a complex (Baban, 1997).

This type of work is still developing (Bagheri and Dios 1990, Braga *et al.* 1993, Costa *et al.* 1998, Ekstrand 1992, Forster *et al.* 1993, Pattiaratchi *et al.* 1994, Tassan and Ribera d' Alcala 1993, Baban 1997) and should improve with SeaWiFS and similar new sensors as well as modelling development leading to improved compensation for the effects of silt and yellow substance (Edwards, 2000). Determining a correlation for chlorophyll-*a* concentration and the DN from an RS image demands calibration with values observed in the field for the study area. Table 1.2 summarises some examples of correlations found for chlorophyll-*a* and surface reflectance.

A good example of the application of RS imagery in monitoring water quality in aquaculture areas is that of the indication of chlorophyll-*a* concentrations, providing a warning for algal blooms and red tides which are toxic to fish and shellfish. A review of the application of RS to determine toxic algal blooms and eutrophication was carried out by Edwards and Clark (2000). This type of assessment of RS was carried out by Chacon-Torres *et al.* (1992) for Lake Patzcuaro, Mexico, using a SPOT image. This technique could be useful in diminishing losses such as those experienced in the May-June 1988 red tide bloom affecting the Skagerrak area of Scandinavia, where 480 tonnes of caged salmon were lost and 200 marine fish farms were eventually evacuated. At the time, this event was closely monitored by the Nansen Remote Sensing Center in Norway who used AVHRR data and were able to give information on the sea surface temperature distribution and the advection movement of the ocean fronts which, combined with airborne and *in-situ* observations, clearly demonstrating the usefulness of this technology (Johannessen *et al.* 1988).

Although the technology for detecting developing blooms and direction of its travel has made significant advances, it is still questionable who would pay for it and whether it could be used practically to give an early warning. However attractive phytoplankton biomass information is to coastal planners, even using higher accuracy sensors such as SeaWiFS, extensive field survey is needed for calibration, and this may prove to be expensive and impractical. The information available from an image is relative to a single point in time. Most aquaculture is developed in the coastal zone where sediment loads are more or less constantly present and the better perspectives for close correlation with primary production with RS imagery still lie with open ocean waters and a combination of sensors such as SeaWiFS and AVHRR (Edwards, 2000).

Table 1.2 Algorithms developed for extracting Chlorophyll *a* concentrations from Landsat TM. Bands TM1 = band 1, TM2 = band 2, TM3 = band 3.

AUTHOR	STUDY AREA	ALGORITHM
Pattiratchi *et al.* 1994	Cockburn Sound, Australia	$Chl\ a\ (\mu g\ l^{-1}) = 0.302 - 0.1\ TM1 + 0.234\ TM3$
Ekstrand, 1992	Stockholm, Sweden	$Chl\ a\ (\mu g\ l^{-1}) = 116.78 + - 31.19(TM1/\log TM3 + 1)$
Costa, 1998	Ubatuba, Brazil	$Chl\ a\ (\mu g\ l^{-1}) = 0.060914 + 0.109172\ TM2 + 0.214841\ TM3$
Baban, 1997	Norfolk, UK	$Chl\ a\ (\mu g\ l^{-1}) = -770 + 4768 * (TM3/TM1) - 24.6\ (TM2+TM3)/2$

1.6 CONCLUSIONS

The potential of applying RS for assisting aquaculture and fisheries is there, but needs to be carefully analysed in the cost-effectiveness aspect. RS images come from a variety of sensors with different capabilities, resolutions, frequency of overpass and importantly, cost. RS images can be expensive, and are many times not available to the prospective purchaser because of cloud cover, which in some regions may present a chronic obstacle. On the positive side, cost allowing, in those areas where cloud cover is less of a problem, an important reference image library can be built allowing for change over time studies. With all this said, there are some promising examples of RS integration is fisheries and aquaculture which support its utility in preventing economic loss of aquaculture stocks through early warning by monitoring water quality.

Little progress has been made in directly assessing surface pelagic fisheries, as well as indirectly through algorithms which associate sea surface temperature variablility. Monitoring development of shrimp farming in coastal ponds seems another promissing approach. The relatively high cost of technology associated with use of RS in fisheries may be partially recovered when working with species of high commercial value. Examples of indirect assessment of fisheries resources such as the Queen Conch (*Strombus gigas*) and *Trochus niloticus* were reviewed by Mumby and Green, (2000) and are based on habitat mapping. These studies however were conducted in areas exceptionally favourable for RS observation such as shallow, clear waters.

Progress in applying RS and GIS to aquaculture and fisheries management is being made and it will be most surprising if this does not continue. In favour of this, concur simultaneously the depletion of natural stocks of fisheries resources making them more valuable, the increase in world population and the steady reduction of IT and computing costs and to a lesser extent, more RS resources potentially available at affordable costs.

1.7 AIMS AND OBJECTIVES OF THIS THESIS

The aim of this research work was to address two principal questions:

Can GIS supported by Remote Sensing, be used to predict promising locations for coastal aquaculture development in Sepetiba Bay, Rio de Janeiro ? If so, what would be the area extent and production potential ?

What are the economic consequences of this development in terms of job creation and natural resource exploitation?

In order to answer these questions, three aquaculture species were examined: Two species of commonly cultivated filter feeding marine organisms native to Sepetiba Bay, and one exotic marine shrimp, widely cultured throughout Brazil: These are:

Perna perna the brown mussel which is found in many coastal areas along the Rio de Janeiro coastline and has a mature industry base in Southern Brazil.

Crassostrea rhizophorae the mangrove oyster which is found commonly throughout the bay and is a promising potential species for warmer latitudes of Brazil, where *Crassostrea gigas*, the japanese oyster does not fare well.

Litopenaeus vannamei a marine shrimp, native to Equador and Colombia, which enabled the development of shrimp farming into an important industry in Latin America and now the predominant cultured species in Brazil from North to South.

It is expected that the fulfilment of these aims will contribute to efforts already under way by the Rio de Janeiro environment secretariat (SEMA) who is currently developing its state coastal zone management plan (GERCO), the state fisheries office (FIPERJ) in promoting sustainable local aquaculture development, and the agriculture extension service (EMATER) by showing areas with potential aquaculture development to local stakeholders.

CHAPTER 2
MATERIALS AND METHODS

2.1 INTRODUCTION

This chapter describes the various data sources used throughout the study and how they were standardised and assembled into the GIS database. Some of the information was available already in the form of maps or charts, while other had to be collected in the field, and analysed *in situ* or in the lab. The collating of the data was done in the lab mostly using IDRISI. The resulting thematic maps are used throughout the study and their integration into the models developed is treated in Chapter 6.

Two broad categories of activities were carried out during the course of this research: a) laboratory based and b) field based operations. It is important to recognise that these are different working environments which require careful consideration and balance for overall best results. Laboratory and field-based equipment have different functions and a good knowledge of their capabilities and limitations is very important for the best development of the GIS database. Ideally the field based and lab-based operations must work hand in hand.

Several types of field data needed to be collected ranging from observations on land-use, vegetation cover, water and soil properties etc., and had to be stored in an organised way for subsequent integration into the GIS database. Ideally, the time delay between field data acquisition time and preliminary data processing in the GIS database should be minimal.

It was possible to reduce this time delay by 'taking the laboratory to the field' and using a portable computer with GIS software installed. In this way, it was possible to add information and data to the database, while navigating through the study area with a previously digitised map or even remotely sensed images displayed as a backdrop in real time. In the early, data gathering stages of the study this approach however was not available. Field based operations relied upon notes taken during several field trips where information was input into tables using printed reference maps and charts as well as geographic positions read from a hand held GPS.

2.2 LABORATORY BASED OPERATIONS

2.2.1 COMPUTERS

All laboratory based operations were undertaken in the working environment of the Geographical Information Systems and Applied Physiology (GISAP) facilities of the Institute of Aquaculture (IoA), Stirling University. GISAP facilities include five dedicated GIS workstations, which are networked to several servers on campus.

Operating system

All software utilised in this project was operated under Windows NT version 4/ Service Pack 3 operating system (O/S). The O/S was subjected to continuous maintenance being upgraded to Service Pack 6 by mid-2001. Details of the principal desktop computer workstations used are described in Table 2.1

Table 2.1 Description of the computing resources used in the study.

DESCRIPTION/ COMPUTER			
Lab ID	PC14760	PC10622	PC16002
Function	GIS and RS processing	Digitising, Scanning	GIS and RS processing
Manufacturer	DELL		DELL
Hard Disk capacity (GB)	17	1.99 + 2 .0	1.99 + 6.5
System	Microsoft Windows NT 4.00.1381	Microsoft Windows NT 4.00.1381	Microsoft Windows NT 4.00.1381
Processor speed (MHz)	333	150	2 x 400
Processor type	x86 Family 6 model 5 stepping 0	x86 Family 5 model 2 stepping 12	x86 Family 6 model 5 stepping 1
RAM (MB)	128	80	512
Display	DELL Monitor 21”	Mitsubishi Diamond Pro 900u 19”	DELL 21” Trinitron
Refresh frequency (Hz)	75	70	85
Settings (of desktop area in pixels)	1280 x 1024	1280 x 1024	1280 x 1024
Graphics Adapter driver	Diamond Fire GL 1000PRO	Matrox Graphics MGA Millenium II	Intergraph Intense 3D Pro
Graphics card manufacturer	Diamond Multimedia Systems, Inc	Matrox graphics	Intergraph Corporation
Adapter info	3Dlabs PERMEDIA2	Chip MGA 2064W-R1	RealiZm II
Memory Size (MB)	8	4	16

File and data storage

The result of working with large raster format images, as in this study, demands substantial storage capacity. Two alternative solutions offering higher storage capacity were also employed. One was a WangDAT 3200 tape drive. DAT tapes can store 2 GB of uncompressed data or alternatively 4 GB with data compression option, the backup speed being 22 MB/min. File access was about 30 seconds on average for the 93.7 m tape (2Gb). Alternatively files were backed-up on re-writeable (CD-RW) compact disks, written from a Hewlett-Packard CD-Writer Plus 7200 series. Each CD had a storage capacity of 650 MB. Data was backed up on a weekly basis or more often, depending on the need. All storage media such as data tapes and CD's as well as purchased CD's with Landsat images were stored in a fireproof safe.

The Sepetiba database comprised several raster images extracted or derived from a basic Landsat image and vector files digitised from paper maps. Each band of the original Landsat image furnished by INPE spanned 3,520 columns x 3,200 rows requiring 11,000 Kb of storage memory. A three-band composite image also required 11,000 Kb of storage space. However, the area selected for this study covering the whole Sepetiba Bay and environs was limited to 1,966 columns by 1,342 rows, requiring approximately 2,577 Kb of storage memory. The principal workstation used for the project had approximately 17 Gigabytes (GB) of storage capacity (Table 2.2). In this study the number of operations using the IDRISI image files could generate as many as 20 to 30 new intermediate image files for each sub-model. Initially, storage of these files consumed much storage capacity, but as the study evolved, each sub-model developed was registered as an IDRISI macro language file format (IML) which enabled the macro to delete all files generated at intermediate levels and which were unnecessary for the final results. This provision both conserved storage capacity and reduced the amount of unnecessary images in the computer's hard disk.

Table 2.2 Storage characteristics of the study.

Hard disk storage capacity	17 Gb
Storage capacity used by the study	4.33 Gb
1 Landsat whole area image (3,200 columns x 3,200 rows)	11,000 Kb
1 Study area window (1,966 columns x 1, 342 rows)	2,577 Kb

Printing

Results were printed on a networked Hewlett-Packard LaserJet 1200 or Epson Stylus Color 777 C inkjet printer.

Digitising Images

Fig 2.1 indicates the forms of data input formats commonly available, although these are not always accessible to the general public for one reason or another. Finding alternative methods to enter images into a GIS is important in order to build the best-supported models.

Paper maps such as admiralty charts, physical and political maps measuring up to 1.20 m x 0.80 m were partially digitised using a Calcomp III digitising board (model 34480) with active area = 914 x 1219 mm.

The maps were used specifically to extract certain spatial features, such as outlines and contours, as well as used in geo-referencing the Landsat image.

The puck's button functions were reassigned for use with both Tosca and Digi-Edit digitising software, so that buttons 0, 1, 2 and 3 corresponded to button functions digitise, snap, end (finish) and toggle respectively. Digitising software included TOSCA, and Tsoft DIGI-EDIT for Windows version 1.050. At the beginning of this study, the paper maps used were digitised using the DOS-based TOSCA software (Jeffrey F. Jones, IDRISI Project). Later, other maps were digitised using an improved version of TOSCA marketed as DIGI-EDIT 1.0 for Windows. In the course of this project, several paper maps were consulted, from which it was necessary to extract selected information to complement the GIS database. Point, line and polygon information are exemplified as point location of oyster or mussel banks along the coastline (points), road network (lines), and urban or conservation areas (polygons). The key settings configuration for the digitising board was set to that of the factory default for 'CalComp 2000 ASCI'. To digitise, a Calcomp 6-button model puck was used.

Some digitising was also achieved using the mouse and on-screen tools available in image processing software such as PaintShop Pro 5, and in IDRISI, the GIS software used in this study.

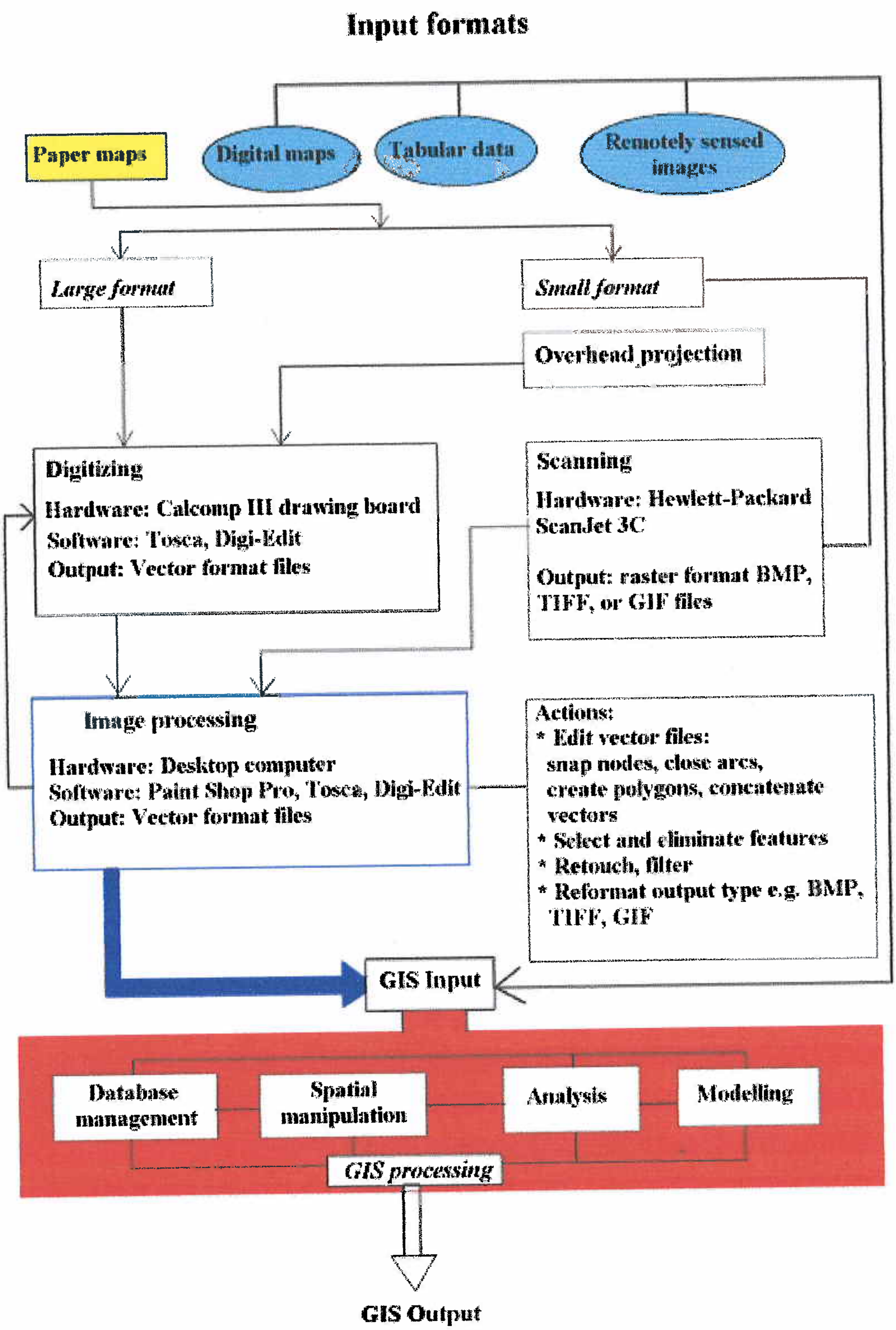

Figure 2.1 Operations for incorporating paper maps into GIS database.

2.2.2 *SCANNED IMAGES*

Much useful and relevant information for this study was available only as printed images such as choropleth maps illustrating government agency reports or in published papers, many of which were less than A4 size paper. Selected images were scanned on a Hewlett-Packard flatbed scanner (model ScanJet 3C; Descan II v 2.8), and saved as bitmap images. Choropleths were typically scanned at 150 dpi resolution. Scanning images is a very efficient way of incorporating information as raster layers into a GIS. Vector layers can be derived from rasterized scanned images by digitising in image processing software.

2.2.3 *MAPS USED*

A list of maps used is presented in Table 2.3. The nautical maps were published the Brazilian Naval Hydrographic Office (DHN), the military maps were published by the Military Cartographic Service and general ordnance type maps sued were published by the Brazilian Institute of Geography and Statistics (IBGE). Another source of data included choropleth maps, were obtained from studies and reports as A-4 size such as that by SEMA (1996). These were scanned, saved as bitmap images and later incorporated into the GIS database by use of the import facility of IDRISI (Fig 2.2).

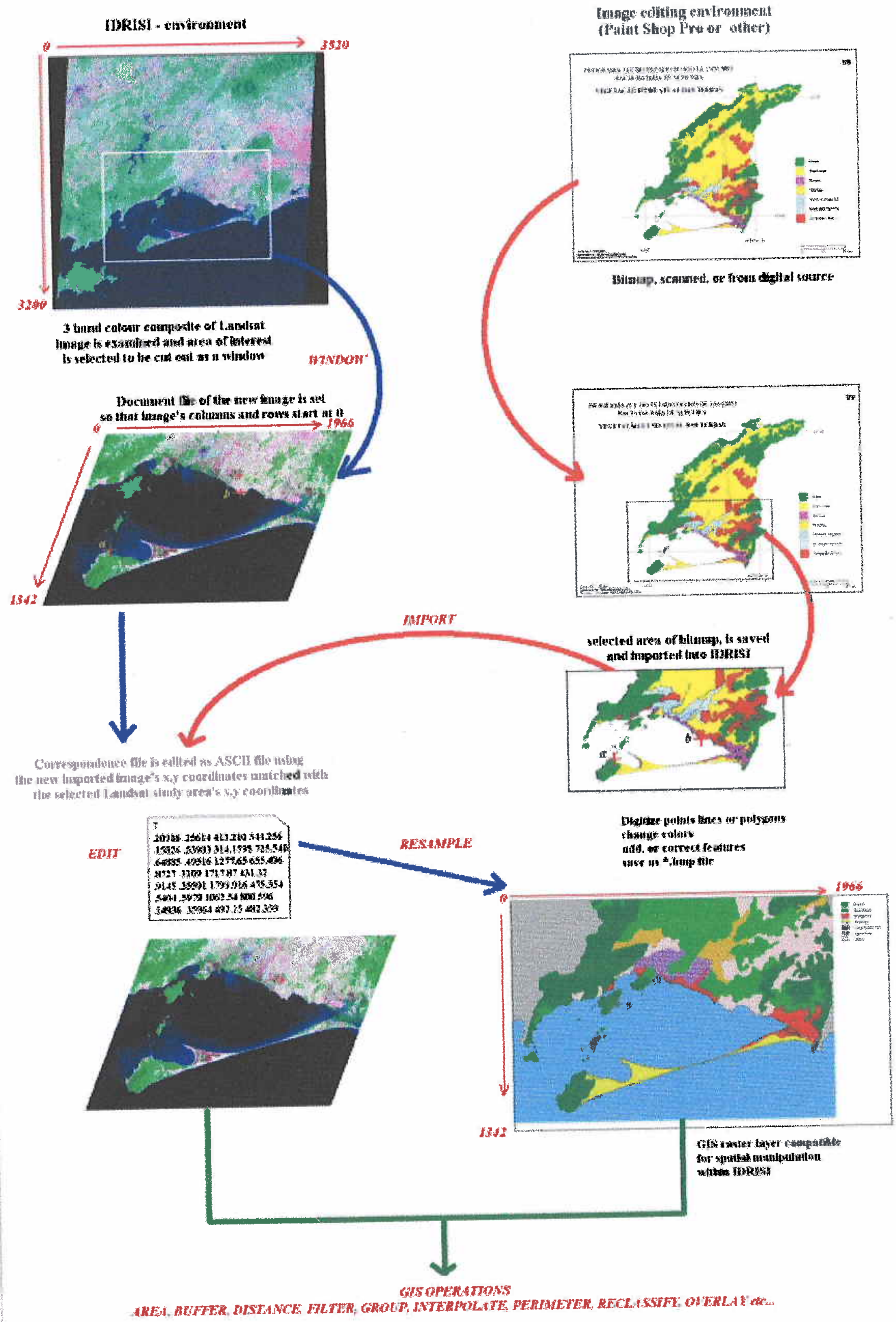

Figure 2.2 Spatial manipulations of digital information for incorporation into GIS. Complementary maps were scanned and resampled to match Landsat TM window of study area.

Table 2.3 Maps used in this study.

ID number	Type	Region/Area	Scale	Produced by	Identification	Date
1	Nautical	Barra do RJ – Ilha Grande	1: 120 015	DHN	Nº 1620	1986
2	Nautical	Porto de Sepetiba	1: 20 000	DHN	Nº 1623	1982
3	Nautical	Ilha Grande – Central	1: 40 067	DHN	Nº 1631	1980
4	Nautical	Ilha Grande – Guaíba	1: 40 090	DHN	Nº 1621	1983
5	Military	Barra de Guaratiba	1: 25 000	GSG - ME	SF.23-Z-C-III-2-NE	1981
6	Military	Pedra de Guaratiba	1: 25 000	GSG - ME	SF.23-Z-C-III-2-NO	1981
7	Military	Restinga da Marambaia	1: 25 000	GSG - ME	SF.23-Z-C-III-1-NE	1981
8	Military	Itaguaí – S	1: 25 000	GSG - ME	SF.23-Z-A-VI-3-SE	1981
9	Military	Itaguaí	1: 25 000	GSG - ME	SF.23-Z-A-VI-3-NE	1981
10	municipal	Município R.J.	1: 60 000	IPLANRIO	-	1990
11	municipal	Estado R.J.	1: 400 000	SEMAM / IEF	-	1994
12	Nautical	Baía de Sepetiba	1: 40 122	DHN	1622	1991
13	Territorial	Marambaia	1: 50.000	IBGE	SF-23-Z-C-111-1	1986
14	Territorial	Itaguaí	1: 50.000	IBGE	SF-23-Z-A VI-3	1976
15	Territorial	Mangaratiba	1: 50.000	IBGE	MI 12743/4	1992
16	Territorial	Santa Cruz	1: 50.000	IBGE	SF-23-Z-A-VI-4	1993
18	Nautical	Ilha Grande e Sepetiba	1: 120.000	DHN	1609	1976
19	Nautical	Ilha Grande e Sepetiba	1: 80.000	DHN	1607	1996

Diretoria do Serviço Geográfico do Ministério do Exercito (GSG - ME), Diretoria de Hidrografia e Navegação (DHN), Instituto Brasileiro de Geografia (IBGE), Secretaria de Meio Ambiente Municipal- Instituto Estadual de Florestas (SEMAM / IEF), Instituto de Planejamento do Rio de Janeiro (IPLANRIO).

2.2.4 *REMOTELY SENSED IMAGES*

Satellite imagery was integrated into the GIS in the form of TIFF images. The satellite images used in this study were acquired from the Brazilian Space Agency - Instituto Nacional de Pesquisas Espaciais (INPE) (Table 2.4).

Table 2.4 Details of Landsat images used in this study.

Image	Path	Row	Quadrant	Date	Correction level	Bands	Cost (US$)*
Image 1	217	76	A	11/08/87	5	1,2,3,4,5,7	500
Image 2	217	76	A	11/08/96	5	1,2,3,4,5,7	500
Image 3	217	76	A	04/12/94	5	1,2,3,4,5,7	500

* Prices from INPE to Brazilian customers (2002).

Landsat TM images covering a large part of South America are received in Brazil by INPE, which then processes and distributes Landsat TM products on CD-ROM as full frame (185 km x 185 km), quadrants (approximately 92 km x 92 km) or sub-quadrants 46 km x 46 km in 1 to 7 spectral bands. The quadrants are identified by letters A, B, C and D and additional quadrants N, S, E, W and X are defined to permit easy selection by the client of interest area for 9 possible quadrants. The images used in this study were of Path 217, Row 76, quadrant A (See Fig. 2.3). The Landsat images are defined in 9 possible quadrants:

Although most remote sensing processing software can open INPE supplied format files of Landsat images, INPE provides a useful image processing software called **L2TIFF** that converts the file format into a TIFF (tagged information file format) that can be recognised by most image processing software, including IDRISI.

All scenes supplied by INPE have the same level of basic radiometric correction consisting of an equalisation of the sensors in order to eliminate the "striping" effects of Landsat-TM data. No histogram equalisations are applied in relation to the sun elevation angle. The geometric corrections are those requested by the purchaser. Level 4 correction consists of a resampling along the lines to remove variations due to the satellite's mirror and to align the pixels between adjacent sweeps. Level 5 correction, also known as "systems corrections", consists of resampling in both directions and application of a cartographic projection of the user's choice.

Level 5 correction includes geometric correction resampled using a 'nearest neighbour' algorithm. Currently INPE has implemented only two projections: Space Oblique Mercator

(SOM) and Universal Transverse Mercator (UTM). Level 6 correction is identical to level 5 however utilising the "cubic convolution" algorithm for resampling. All the images used in this study were purchased with level 5 correction.

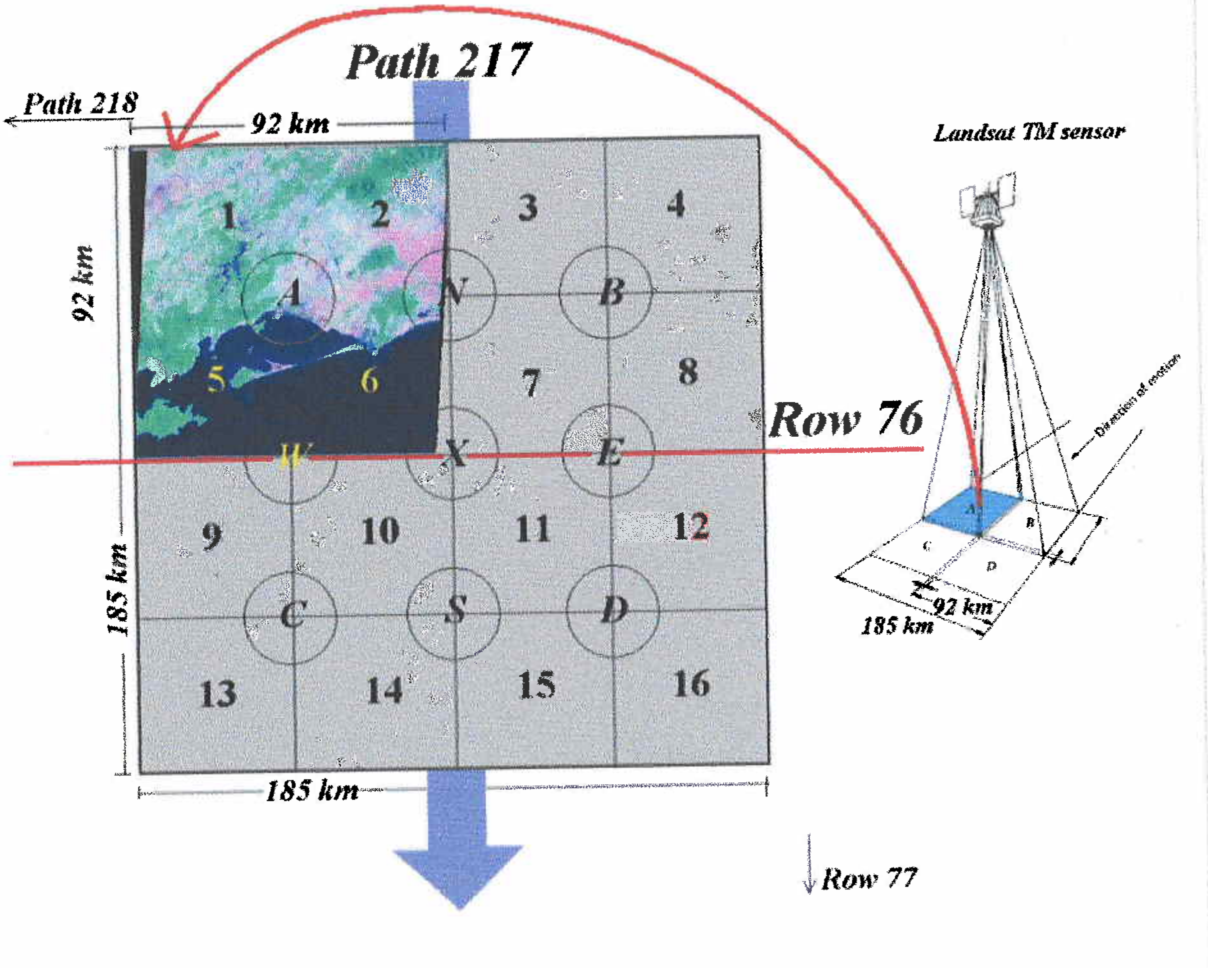

Figure 2.3 Spatial position of the study area within Landsat framework.
Satellite observation route defined by paths and rows. Quadrants N = North, S = South, W = West, E = East, X = central quadrant of the scene.

2.2.5 GIS SOFTWARE

The GIS software used in the present study was IDRISI for Windows version 2.0. developed by the Graduate School of Geography at Clark University, Worcester, MA, USA. It provides professional-level geographic research tools needed for research but is also flexible and simple enough to be used as teaching tool. The package has proven to be quite versatile for investigations and has a wide international user and support base.

The software used in this study contains a collection of over 150 program modules that provide facilities for input, display and analysis of geographic data. In this thesis, these modules will be indicated in bold and capital letters.

Traditionally, IDRISI has been attractive because of its raster analytical functionality, covering GIS and remote sensing needs from basic database query, to more importantly, spatial modelling, and image enhancement and classification (Eastman, 1997). IDRISI's analytical modules were periodically cleaned of 'bugs' and made available to users as downloads from their website (http://www.clarklabs.org). Currently, the company does not support updates for version 2.0.

IDRISI has import tools for a range of file formats ranging from desktop publishing, raw raster image files and other GIS software packages including ARC-INFO, MAP-INFO, ERDAS, ATLAS-GIS GRASS, and SURFER.

GIS technology tends to be expensive in terms of software, hardware and training. However, the IDRISI project's philosophy has been to adopt the notion of democratisation of technology and considers that tools such as GIS should not be reserved solely for those with large budgets, but should be available to all who have a need for them. The IDRISI project is essentially a non-profit organisation committed to maintaining the viability of the organisation and the continued improvement of the software. Currently the latest version of the product, IDRISI KILIMANJARO is relatively affordable at US$ 600 for a single academic license (IDRISI, 2003).

2.2.6 IMAGE MANIPULATION

Paint Shop Pro 5, a raster-format image editing software, proved to be a relatively workable tool to learn. With practise, images were manipulated and processed prior to or during the modelling phases carried out in the 'full' GIS environment. Paint Shop Pro 5 allows for extensive image editing with more ease than possible in the 16 bit version of IDRISI for Windows 2.0. Pre-treatment or editing of images allowed for the elimination of features of no interest while retaining others (see Fig 2.2 for example) and although this is also possible in IDRISI, it is more cumbersome.

Specifically, on-screen digitisation in IDRISI has limitations related to the buffer capacity for the vector file being worked upon, often leading to the abrupt termination of the program due to insufficient available memory problems, resulting in total loss of files in the digitisation process. Paint Shop Pro 5 also allows direct scanning of images, editing, and saving in a wide variety of digital formats, including as bitmaps or tagged information file format (TIFF).

To make use of image files edited in Paint Shop Pro 5, a process of resampling the imported images in the IDRISI environment is necessary (see Fig 2.2). Once the bitmap image has been imported and saved as an IDRISI image file, it must be resampled to match the spatial definitions of the base image which is being worked upon. To accomplish this, an ASCII file containing a number of corresponding coordinate pairs must be created and saved as a 'correspondence file' in IDRISI.

Cutting a window of the study area

The Landsat file supplied by INPE covers the upper left hand quarter of the full scene for path 217 row 76 (Fig 2.3). As the focus of this study concerns the coastal area of Sepetiba Bay, as well as nearby adjacent coastal areas, a selection was made based on the fact that most water quality data available for the area coincides with the area spanned by admiralty chart number 1622 published by the Brazilian Naval Hydrogaphic Office DHN (see Fig 2.2). It could be argued that a study of this nature should include the entire hydrographic basin relative to Sepetiba Bay. However, at the start of this study there was insufficient information to show the boundaries of this hydrographic basin, which is beyond the limits of this quadrant and would possibly involve the purchase of a second partial scene, that of path 217 row 75 quadrant C. Usually Landsat images can be displaced up to 10% north or south without extra cost to the client. Considering that most of the processes which directly affect fisheries and potential aquaculture development are within close range of the coastline, the subset image was considered appropriate.

Once this subset window of the study area was defined, it was extracted using the **WINDOW** option of the 'Reformat' menu in IDRISI. This option offers a 'batch window', cutting option that will process multiple images (such as individual bands) for the same specified area, as determined by column and row, or if the image is geo-referenced, by geographical position. The area windowed and cut for study covered columns 845 to 2,810, and rows 1,268 to 2,609 of the original Landsat image (Fig 2.2).

Georeferencing

To geo-reference is to establish the relationship between page coordinates on a planar map and known real-world coordinates. (AGI, 1999).

In IDRISI, the geographic files are assumed to be stored according to a grid reference system where grid north is aligned with the edges of the raster image or vector file. Documentation files for all images contain information about the reference system used by that file when referring to geographic locations. The particulars of the reference system (e.g., projection, datum and origin) are contained in a *reference system parameter file*. Each grid reference system must have a reference system parameter file. The only exception is the system identified by the keyword *plane.* Any image or vector file with a *plane* coordinate referencing system is understood to use an arbitrary plane system for which geodetic and projection parameters are unknown, and for which a reference system parameter file is not provided (Eastman, 1997)

Georeferencing the satellite image.

Although the INPE Landsat TM image was furnished as geo-referenced, the import process using TIFF format conversion did not retain coordinate information in latitude and longitude. Therefore when this image was imported into IDRISI its reference system was re-set to *plane*, and had to be subsequently geo-registered.

Geo-registration is also known as 'rubber sheeting' or 'resampling'. It is the process of stretching and warping an image to fit a particular grid reference system. Resampling is accomplished by identifying a series of x,y coordinates of two pairs of points that represent the same place within both a new and an old or previous coordinate system (Eastman 1997). The x,y, coordinate pairs are entered directly in the **EDIT** facility of IDRISI, or alternately, entered in a spread sheet application such as Microsoft Excel or any text editor. The list is then saved as a text or MS-DOS format file, which can be easily imported into IDRISI.

Georeferencing the satellite image requires that clear ground control points (GCP) be known from a source such as a map, or field coordinates of locations derived with a Global Positioning System (GPS).

In this study, as the satellite image imported into the GIS was non-geo-referenced, a list of over 150 point coordinates, which were clearly identifiable both on the Landsat satellite image of Dec 04, 1994 image as well as on admiralty chart DHN 1622, was generated. These points were typically small islands, headlands, railroad track and vehicle road crossings, i.e. points which are unlikely to change over time.

For all these points, their coordinates in the Landsat image was noted along with their corresponding coordinates in degree, minute and decimal minute from the admiralty chart DHN 1622. (Appendix 1).

As this admiralty chart was used for many notations and references to field data, several features were digitised. This digitisation was one of the first tasks of the laboratory-based operations, and was done using TOSCA digitisation software. The coordinate pairs for the resulting vector file which were geo-referenced to the Landsat image are found in Appendix 2.

The visual identification of the ground control points on the Landsat TM image was effected on a false colour composite image using bands 742, saturated at 2.5% generated in IDRISI using the module **COMPOSIT.** This band combination provides good contrast between reflectances coming from water bodies, urban structures and vegetation, showing urban areas in tones of magenta, vegetation showing in familiar green tones and water bodies in dark colours. Contrast between soil and water interfaces are marked which facilitates identification of road and river crossings, which are commonly used geo-referencing sites.

The admiralty chart and all other digitised paper maps were then geo-registered to the Landsat image using the module **RESAMPLE.** 'RESAMPLE' registers the data in one grid system to a different grid system covering the same area. The process uses polynomial equations to establish a rubber sheet transformation, as if one grid were placed on rubber and warped to make it correspond to the other.

The process involves constructing and development of a set of polynomial equations to describe the spatial mapping of data from the old grid to the new one. The new grid is then filled with data values by resampling the old grid and estimating, if necessary, the new value (Eastman, 1992).

Before geo-referencing resampling can be done, the windowed-out part of the full Landsat TM image has to have its IDRISI 'document file' altered so that its minimum **x** and **y** coordinates are set to zero. The maximum **x** and **y** then become the number of rows and columns for the satellite image spanned, in this case 1966 columns and 1342 rows.

The type of resampling used was the 'linear' with 'nearest neighbour'. In general, one should use the lowest order of polynomial that provides a reasonable solution since the effect of poor control point specification gets dramatically worse as the order of equation used increases. It is also, necessary to ensure that there are an adequate number of control points for the order chosen. Linear sampling requires a minimum of 3, quadratic sampling requires 6 and cubic sampling requires 10.

In practice however, at least twice the minimum are required for a reasonable fit (Eastman, 1992). A peculiarity of the specific 'windowed section' of the satellite image used in this study was that a large area (48.4%) is covered with open waters, where ground control points are very scarce or non-existent.

In coastal areas sand spits or mangrove islands represent important sites but are unsuitable as good ground control points for geo-referencing due to their mobility.

During the first resampling trials, correlations resulted in grossly distorted resampled images. To improve the geo-referencing of the Landsat TM image to the admiralty chart a technique was similar to that used in nautical navigation – triangulation (Fig 2.4) was employed which consisted of drawing several reference lines (as vector files overlying the raster satellite image), from well established reference points to increase the number of reference points from both sources.

One peculiarity of the satellite image window studied is that it includes a small coastal island out at sea, Lage da Marambaia, which facilitated extending reference lines out to noteworthy points on the coastline.

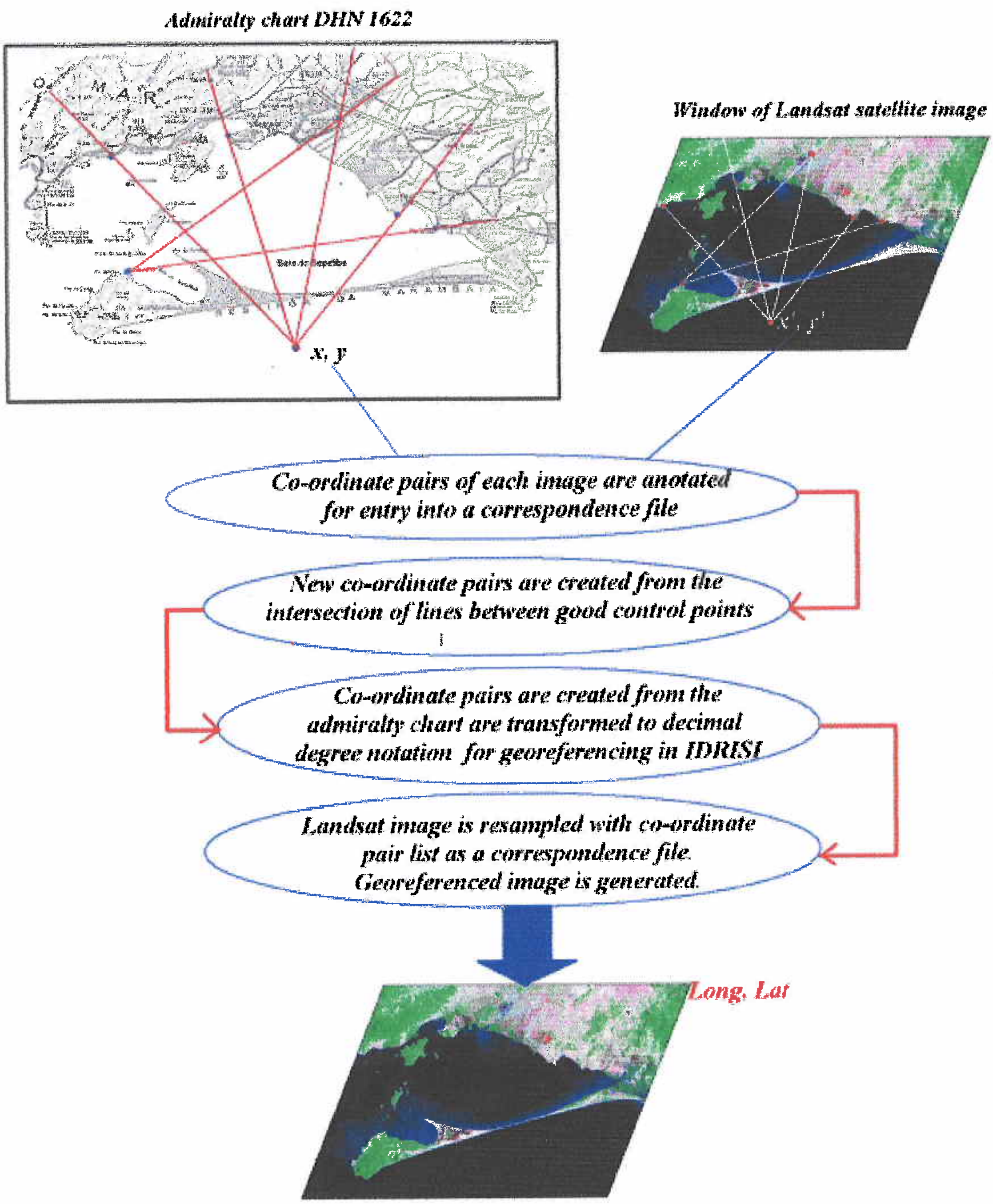

Figure 2.4 Steps followed for georeferencing the cut-out window of the study area.

Other auxiliary lines were also developed from other points in order to produce lines with reference points on the intersection of lines over open water. Thus, new 'virtual' control points were created for the correspondence file over the otherwise featureless open water stretches. Corresponding lines were also drawn on admiralty chart DHN 1622 from the same control points as those used on the Landsat TM image. The intersection of the lines provided corresponding points with known latitude-longitude coordinates.

This process was found to be adequate for the geo-referencing proposed. To use the longitude, latitude, coordinates in the IDRISI correspondence file, they were converted to decimal format by using the formula:

Decimal degree = Longitude or Latitude degrees + (minutes + decimal minutes/60)

As all field data points recorded on the GPS were in degree, minute and decimal minute format, they had to be converted to degree and decimal degree format for geo-referencing by spreadsheet. An example is given in Fig 2.4. Due to IDRISI's geo-referencing system, longitudes West of Greenwich, and South of the equator must be specified as negative numbers. The final coordinate value has to be specified in scientific notation for entry into IDRISI's correspondence file.

All field points were thus converted into decimal degree format in order to match the GIS environment (see appendix 1). The resampling process is summarised in Fig 2.5. The accuracy of the resampling is verified by its Root Mean Square (RMS) error, the distance between the input (source) location of a ground control point and the retransformed location for the same GCP (ERDAS, 1997). In other words, it is the difference between the desired output coordinate for a GCP and the actual output coordinate for the same point, when the point is transformed with the transformation matrix. RMS error is calculated with a distance equation:

$$\mathbf{RMS} = \sqrt{(x_r - x_i)^2 + (y_r - y_i)^2}$$

where x_i and y_i are the input source (GCP) coordinates and x_r and y_r are the retransformed coordinates.

The RMS error is expressed as a distance in the source coordinate system. In this case the units are pixels. The process and results of the resampling operation are illustrated in Figs. 2.5 and 2.6. The overall RMS error achieved with the image rectification in this project was 3.078, (see Table 2.5 which means that any pixel could be in error by as much as 90 m. When rectifying Landsat TM data, ERDAS (1997) recommends an of ± 30 m, and therefore the

RMS error should not exceed 0.50 In the present study, the RMS error over the area was judged to be sufficient for modelling purposes.

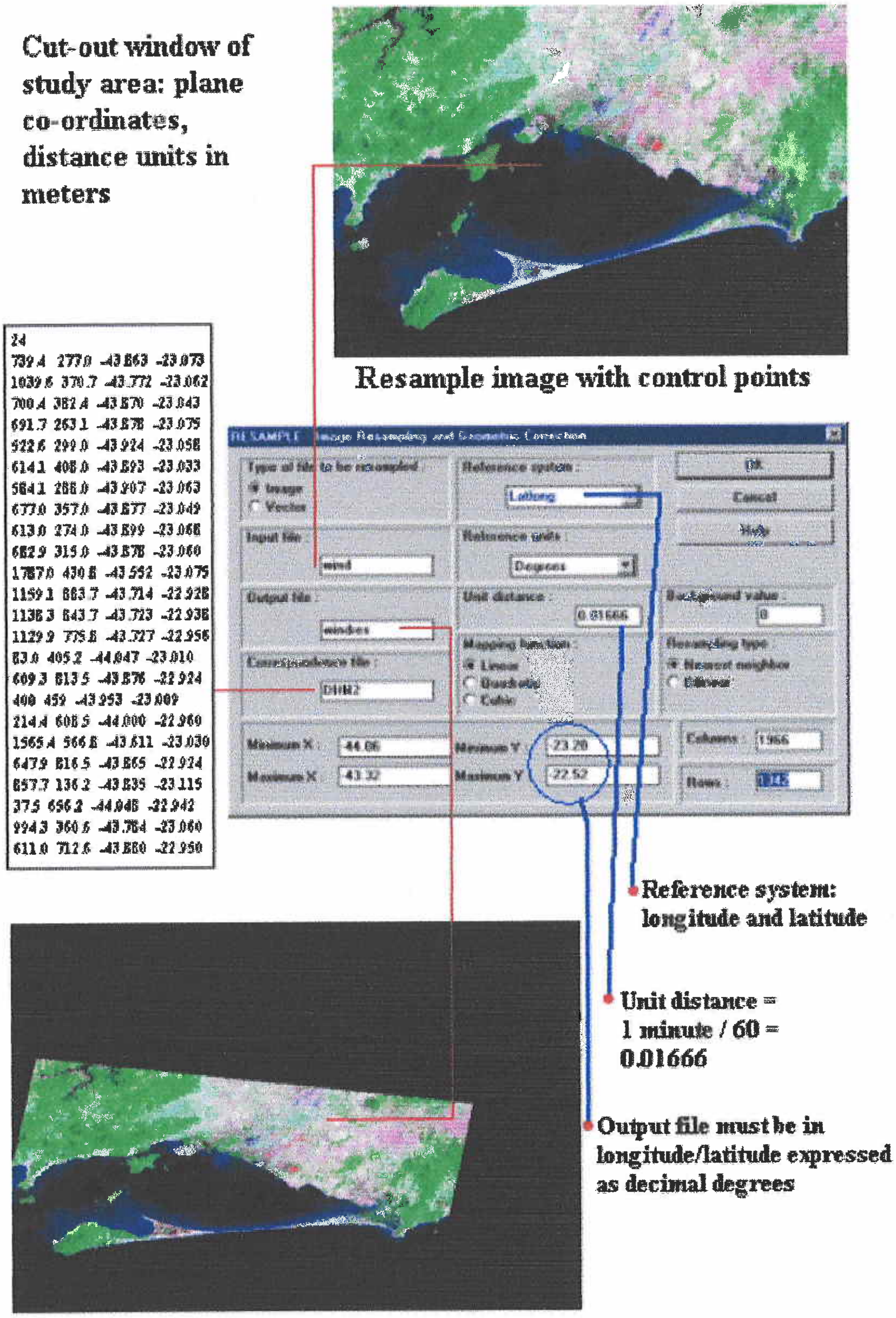

Figure 2.5 Resampling Landsat TM plane coordinates to longitude and latitude coordinate system.

Resample: Summary of Transformation

Computed polynomial surface : Linear (based on 24 control points)

Coeficient	X	Y
	135639.3499915736250000	107742.2455669621050000
b0		
b1	3373.2237179039660200	534.3147077957235210
b2	-565.9885112465267410	3641.9123988303115300

Note: Figures are carried internally to 20 significant figures. Formula shown is the back transformation (new to old).

Table 2.5 Control points used to georeference windowed area of Landsat TM image.

Overall RMS = 3.078090

Control Point	Old X	Old Y	New X	New Y	Residual
1	739.40000	277.00000	43.86300	23.07300	1.42948
2	1039.60000	370.70000	43.77200	23.06200	6.26391
3	700.40000	382.40000	43.87000	23.04300	2.56287
4	691.70000	263.10000	43.87800	23.07500	3.62177
5	522.60000	299.00000	43.92400	23.05800	2.19747
6	614.10000	408.00000	43.89300	23.03300	2.70558
7	584.10000	288.00000	43.90700	23.06300	0.83683
8	677.00000	357.00000	43.87700	23.04900	1.58741
9	613.00000	274.00000	43.89900	23.06800	1.60062
10	682.90000	315.00000	43.87800	23.06000	2.16690
11	1787.00000	430.80000	43.55200	23.07500	4.28488
12	1159.10000	883.70000	43.71400	22.92800	0.28763
13	1138.30000	843.70000	43.72300	22.93800	4.04762
14	1129.90000	775.80000	43.72700	22.95600	1.84130
15	83.00000	405.20000	44.04700	23.01000	1.79884
16	609.30000	813.50000	43.87600	22.92400	2.37571
17	400.00000	459.00000	43.95300	23.00900	2.07804
18	214.40000	608.50000	44.00000	22.96000	5.87161
19	1565.40000	566.80000	43.61100	23.03000	1.01493
20	647.90000	816.50000	43.86500	22.92400	0.87949
21	857.70000	136.20000	43.83500	23.11500	1.74315
22	37.50000	656.20000	44.04800	22.94200	3.72203
23	994.30000	360.60000	43.78400	23.06000	5.87908
24	611.00000	712.60000	43.88000	22.95000	2.15396

Resolution

Resolution refers to the smallest spacing between two displayed elements; the smallest size of feature that can be mapped or sampled (Burrough & McDonnell, 1998). The present study used Landsat images, which are obtained with a maximum resolution of 30 m x 30 m, thus determining the maximum resolution of all further analyses. The satellite image used in this study spanned 1,966 columns and 1,342 rows containing 2,638,372 pixels.

2.3 FIELD BASED OPERATIONS

2.3.1 GPS SYSTEM

To identify the coordinate positions of points of interest in the study area, including ground control points (GCP) as well as data collection points, a Garmin GPS 45 hand-held Global Positioning System (GPS) was used. The GPS is capable of receiving signals from up to 12 satellites for positioning. Its precision level is about 10-15 m when there are 9 satellite signals being received and is capable of acquiring a position in ~ 20 seconds. If used with a DGPS its positional accuracy is about 5-10 m or 15 m RMS.

2.3.2 CURRENTS

Surface currents in Sepetiba bay were measured using semi-submerged drogues. The drogues were constructed from lightweight plywood 0.5 x 0.5 m sections joined at right angles. A thin bamboo pole was affixed at the cross-section and used as a flagmast to identify the drogue and to secure a weight that maintained the drogue just below the water surface (Figs 2.6.and 2.7). Currents were measured in three areas of the bay: within the island chain in the western region, in the N-S transects in the middle portion of the bay and along N-S transects in the shallower and more constricted east end of the bay close to the mangroves of Guaratiba.

Drogues were sequentially placed in the water from a speedboat, their initial geographical position in longitude and latitude and time being recorded (Appendix 3). As many as 8 drogues were sequentially dropped along a transect. As the last drogue of the series was launched, the speedboat returned along the transect line towards the first drogue position, recording the time and position of the intermediary drogues. The speedboat then returned directly to the last drogue dropped and began its final return trip collecting position and time information. The areas surveyed are identified in Fig. 2.8.

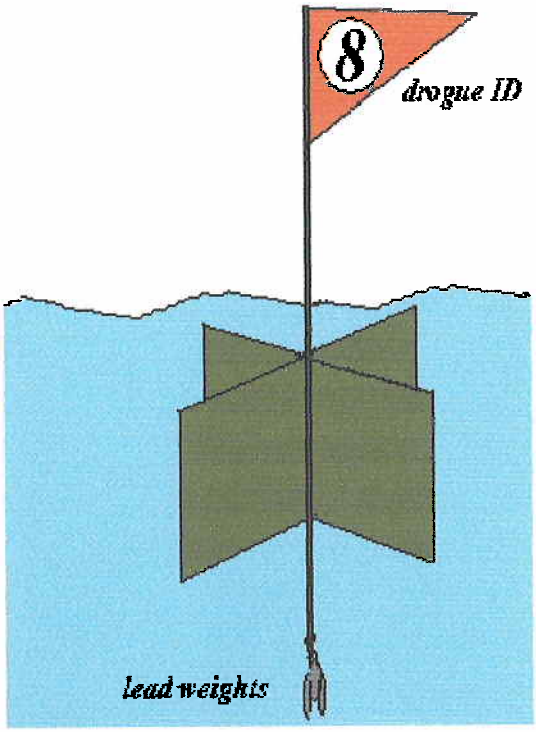

Figure 2.6 Drogue used for current measurements.

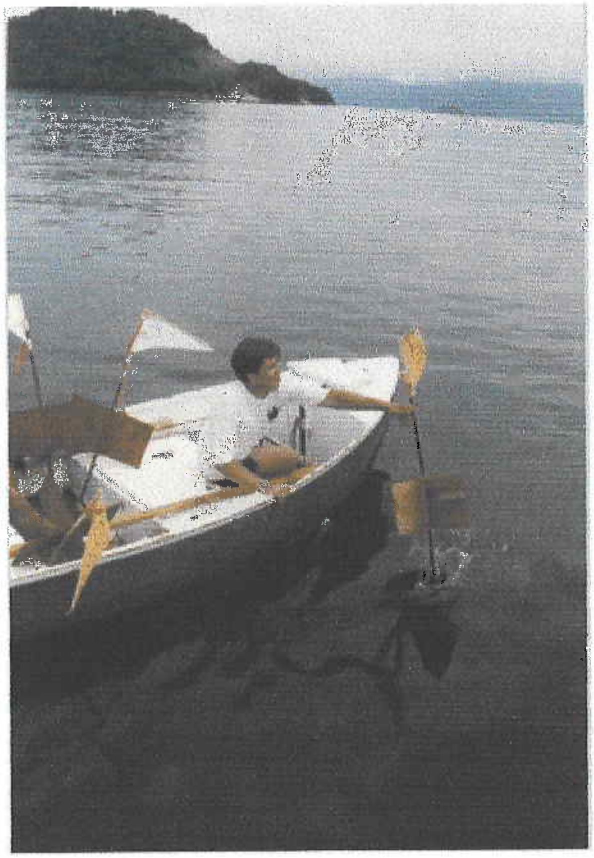

Figure 2.7 Launching drogues in Sepetiba.

2.3.3 *SALINITY AND TEMPERATURE*

Salinity and temperature are important variables that vary considerably in space and time. Although it was not possible to do extensive surveying of these variables during this research, fields measurements were made in order to provide a range of values for consideration during the modelling process. Figure 2.8 shows the distribution of points for which salinity, temperature and depth measurements were taken on several field trips to the bay.

These measurements were taken at the same time as other data collecting activities were being undertaken such as measuring of current speeds, bottom sediment sampling, and site reconnaissance trips. Salinity was measured using a Bio fauna Aquamarine salinity refractometer, with a scale of 1-100‰ with 0.1‰ precision, temperature with a lab thermometer (± 0.1 °C) and depth was recorded from the on board echo sounder, a 2D Hummingbird model 00, equipped with single beam transducer 128V x 64H, super-twist LCD display, depth capability of 200 m. Appendix 4 shows geographic position, temperature, salinity and depth values recorded during the field surveys.

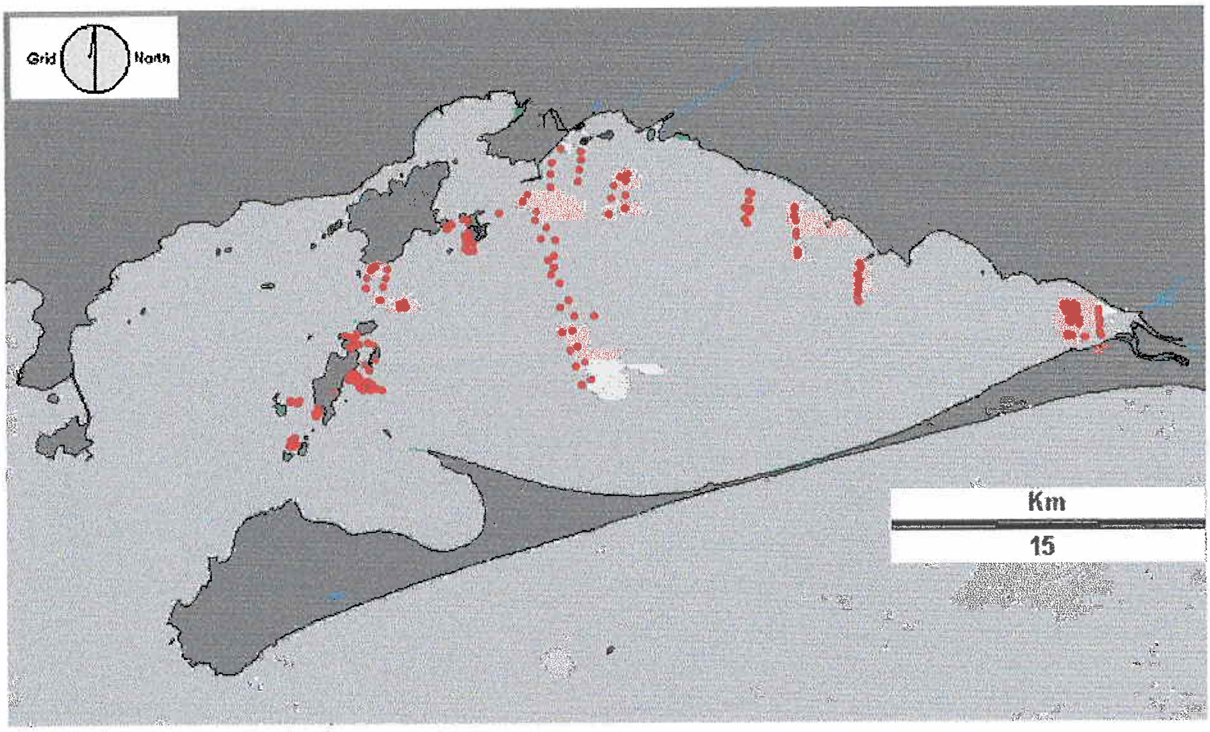

Figure 2.8 Points where current measurements were taken using drogues.

2.3.4 HEAVY METALS

Contamination of bottom sediments and biota in Sepetiba Bay by heavy metals has been reported by several authors (Pfeiffer et al, 1985; Lima et al, 1986; Lacerda and Resende, 1986; Lacerda et al, 1989; Carvalho et al, 1991; Carvalho et al, 1993; Lacerda et al, 1983; Rezende and Lacerda, 1986; ALERJ, 1996 and FEEMA, 1997). With the objective of verifying existing values in the bay, some at sites of particular interest, bottom sediment and biological samples were collected from several points in the bay (Fig. 2.9). Specifically, zinc and cadmium were considered more important because they are known to accumulate in filter feeders and high levels present a health hazard for consumers of shellfish. The samples were analysed by Companhia de Pesquisa de Recursos Minerais (CPRM) and by the Institute of Aquaculture of Stirling University following standard methods and procedures (see APHA, 1992). Results of these analyses are in Appendix 5.

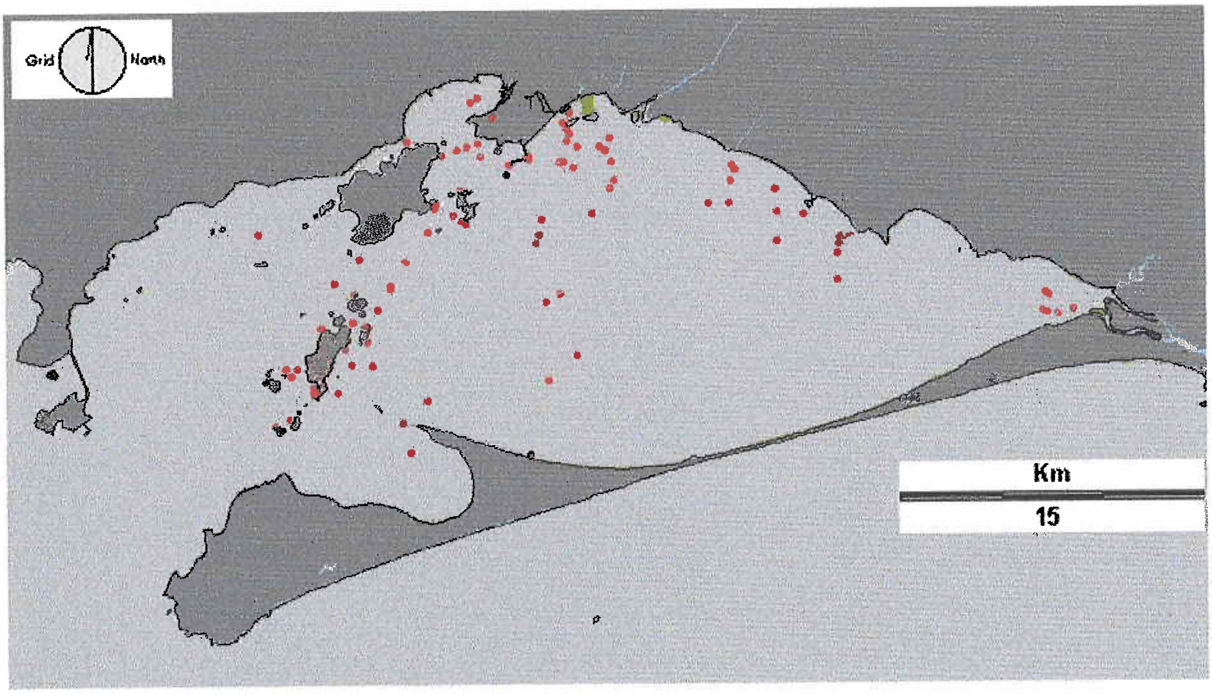

Figure 2.9 Distribution of water quality measurement points.

2.3.5 LAND USE VERIFICATION (GROUND TRUTHING)

Observations of characteristic vegetation, ground cover, patterns of land use, positions of crossroads, industrial sites and other points of interest were recorded using GPS during field trips over the landside of the study area (Appendix 7). These data were important because it provided information for manual geo-referencing of the Landsat image with coordinates other than those collected from the paper maps utilised as well as provided a better feel for the actual land cover in relation to the Landsat TM 742 colour composite image. These ground control points are illustrated in Fig. 2.10.

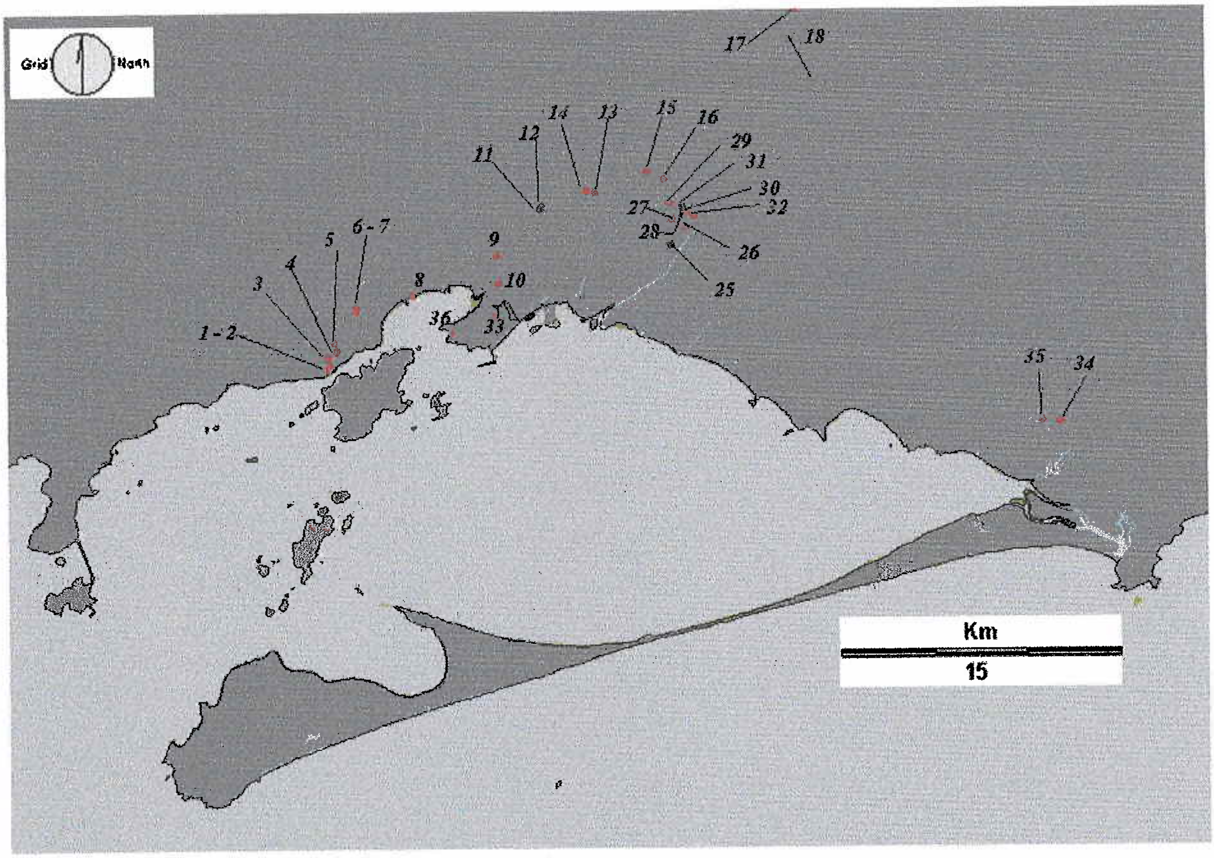

Figure 2.10 Distribution of land use field verification points.

2.3.6 SEDIMENTS

Table 2.6 shows the types of sediments found in several sampling sites illustrated in Fig 2.11. The samples were collected using a Van Veen bottom grab (Fig 2.12). This data was used to verify Ponçano's (1982) sediment distribution map for the bay. The samples were treated following the methodology of Suguio (1973) and Folk-Ward (1957), and were oven-dried for 24 hours at 100 °C and treated for 10 min in vibrating GRANUTEST granulometer. The samples passed through a set of 6 sieves with mesh sizes of 2mm (–1 Phi), 1 mm (0 Phi), 0.5 mm (1 Phi), 0.250 mm (2 Phi), 0.125 mm (3 Phi), and 0.0625 (4 Phi).

Table 2.6 Sediment classification from sites in Sepetiba Bay.

DATE	SAMPLE ID	SITE		CLASSIFICATION	PHI UNITS Φ
08-98	D1	43°47'58"	22°56'21"	Coarse silt	4.97
"	D2	43°48'00"	22°57'54"	Medium silt	5.33
"	D3	43°48'58"	22°57'47"	Fine sand	2.93
"	D4	43°50'00"	22°58'34"	Medium silt	5.27
"	D5	NA	NA	Medium silt	5.50
"	D6	NA	NA	Coarse silt	4.40
"	D9	43°46'24"	22°58'48"	Coarse silt	4.27
01-97	C1	43.41.919	23.01.909	Fine sand	2.06
"	C2	43.36.980	23.01.128	Coarse silt	4.71
"	C3	43.38.008	23.01.484	Medium silt	5.09
"	C4	43.37.399	23.01.700	Coarse silt	4.98
"	C5	43.54.927	23.01.854	Very fine sand	3.43
"	C6	43.39.366	23.01.931	Coarse silt	4.54
"	C7	43.43.047	23.02.557	Coarse silt	4.42
"	C9	43.54.877	22.57.302	Fine sand	2.11
"	C10	43.54.591	23.00.329	Very fine sand	3.37
"	C11	43.57.005	23.00.048	Very fine sand	3.23
"	C14	43.55.209	22.59.825	Coarse silt	4.37
07-96	B1	43.49.807	22.57.611	Medium silt	5.33
"	B2	43.50.501	22.56.428	Medium silt	5.50
"	B3	43.49.655	22.59.373	Coarse silt	4.10
"	B4	43.49.476	23.00.838	Very fine sand	3.80
03-96	A1	43.52.420	22.56.954	Medium silt	5.50
"	A2	43.53.849	22.58.627	Medium sand	1.47
"	A3	43.54.633	22.59.384	Very fine sand	3.37
"	A4	43.56.161	23.00.741	Very fine sand	3.07
"	A5	43.56.730	23.00.090	Medium sand	1.37
"	A6	43.56.102	23.00.659	Medium sand	1.33
"	A7	43.51.720	22.57.412	Very fine sand	3.07
"	A10	43.53.952	22.57.539	Coarse silt	4.57
"	A11	43.48.844	22.55.599	Medium silt	5.83
"	A13	43.51.053	22.55.922	Medium silt	5.63
"	A14	43.50.405	22.56.216	Medium silt	5.90
"	A15	43.49.876	22.56.089	Coarse silt	4.17
"	A16	43.48.799	22.56.726	Medium silt	5.10
"	A17	43.47.802	22.55.982	Very fine sand	3.73
"	A18	43.47.872	22.56.863	Coarse silt	4.50
"	A21	43.43.300	22.58.469	Medium silt	5.33

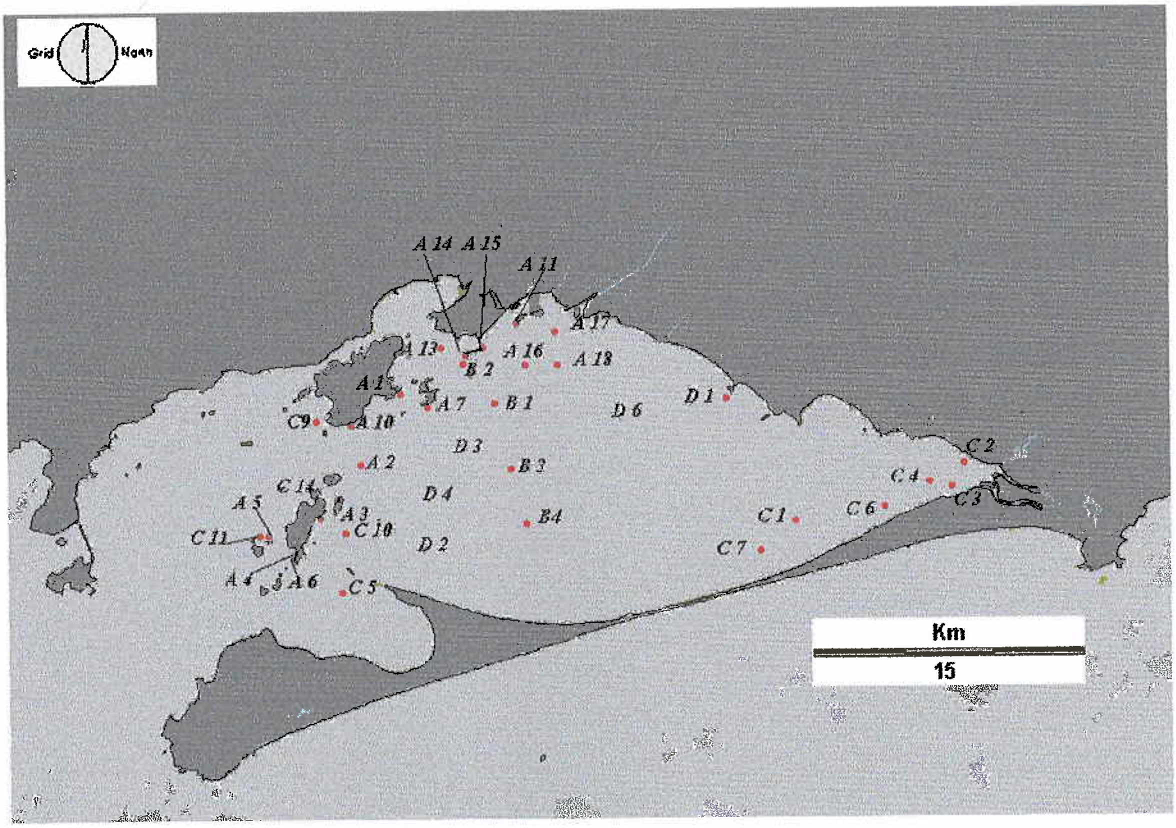

Figure 2.11 Distribution of bottom sediment sampling sites.

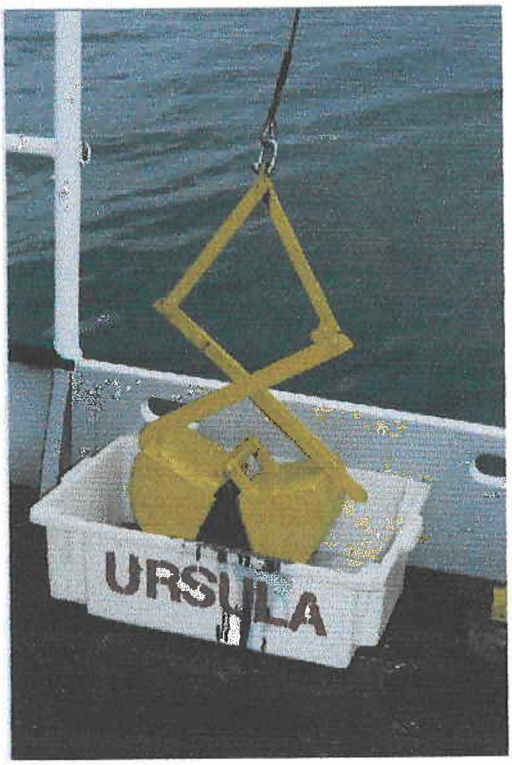

Figure 2.12 Van Veen grab.

2.3.7 *MUSSEL DISTRIBUTION*

Although mussel growth in the bay is possible, it is limited in many places by a lack of substrate for the mussel larvae to settle. In other places salinity is too low for successful spat fixation. As mussel aquaculture is not currently practised in Sepetiba bay, ground truth for this factor was based on local knowledge of the bay's natural mussel banks present on submerged rocks and rocky coastlines and also the sites where the fish traps are installed, as they have mussel growing on them. Other sites were investigated by consulting with a local expert who had 10 years of fishing and diving experience in the bay. Figure 2.13 shows the 10 sites identified by the expert. In his experience, mussel bank sites were more abundant in the past. In an attempt to confirm this, a culture trial was started with 10 mussel starter ropes, measuring 1 m in length and 7 cm in diameter. The young mussels were purchased from the Jurujuba fishing cooperative in Niterói and placed in Sepetiba waters on April 1996. The ropes (Figure 4.3) were transported across Guanabara Bay in a 15 minute trip, from where they were transferred to a pick-up truck in Rio, arriving in Itacuruçá port in 2.5 hours. With the aid of a 50HP engine speedboat, the mussel ropes were transported to, and installed at the 10 sites listed in Table 2.7 within 4 hours of arrival. At the time of installation a sample of the bottom sediment was taken with a Van-Veen grab, and visually assessed for sediment type. No lab analysis was undertaken.

The expert's rationale for siting the experimental mussel culture installation included shelter from wind, proximity to the shore, distance from industrial pollution sources, distance from navigational areas, closeness to own his own residence (site 10), and subjective knowledge of water quality aspects, the most important of which were salinity and temperature.

The mussel ropes were visually inspected by diving once a month for the first three months. The mussels were checked for survival during this period, but growth was not measured.

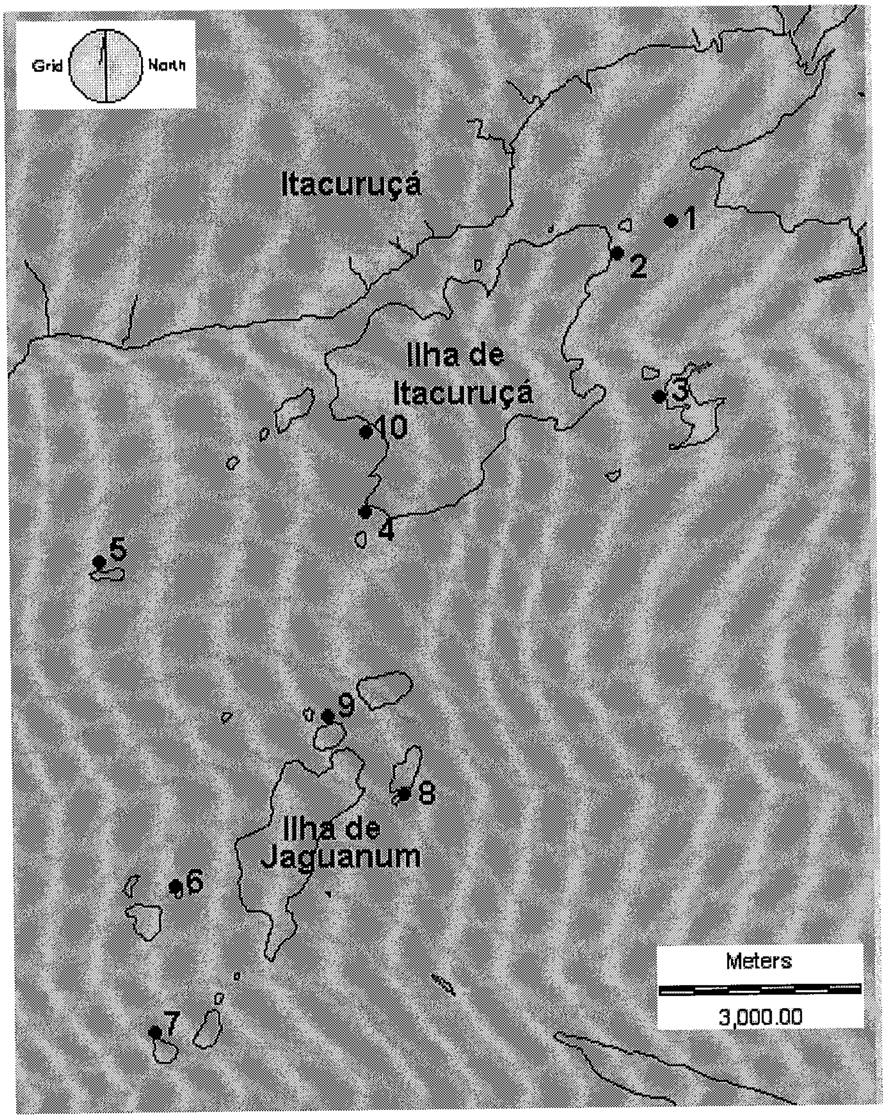

Figure 2.13 Experimental mussel culture installation sites.
1. Bóia Vermelha 2. Laje - Praia do Leste 3. Ilha do Martins 4. Boa Vista 5. Ilha Jurubaíba 6. Ilha da Bala 7. Ilha do Bernardo 8. Ilha Bonitinha 9. Ilha do Bicho Grande 10. Praia Grande.

Ropes 1 and 10 had heavy infestation of ascidians, which apparently stifled mussel growth. After 3 months, most of the experimental mussel ropes had disappeared. It is believed that they were taken away by unauthorised people, possibly interested in keeping the anchor part which held the rope to the buoy. The experiment was discontinued.

Considering that the artisanal fish traps managed by the fishermen of Pedra de Guaratiba are good sites for mussel spat settling and therefore collection for on-growing *in situ*, or in other sites, the relative position of the 42 traps found and their state of repair was recorded on 30.01.97 as can be seen on Fig 2.14 and Table 2.8.

Table 2.7 Sites selected for mussel culture trial.

Mussel rope id	Mooring site	Longitude	Latitude	Sediment type
1	Bóia Vermelha	43.51.400	22.55.628	Mud
2	Laje - Praia do Leste	43.52.038	22.55.756	Gravel
3	Ilha do Martins	43.51.788	22.56.830	Gravel
4	Boa Vista	43.54.536	22.57.394	Gravel
5	Ilha Jurubaíba	43.57.052	22.57.512	Gravel
6	Ilha da Bala	43.56.759	23.00.236	Gravel
7	Ilha do Bernardo	43.57.265	23.01.354	Rocky/Gravel
8	Ilha Bonitinha	43.54.706	22.59.774	Gravel
9	Ilha do Bicho Grande	43.55.330	22.59.107	Rocky/Gravel
10	Praia Grande	43.54.427	22.56.798	Mud

This information was used to indicate potentially good mussel growing waters, despite the absence of their more frequent on-growing natural substrate which are rocks. The importance of the fish traps should not be underestimated since their sites are frequently visited by fishermen and therefore a positive indication of their interest and ease of access to this area for food and income. However, since the traps were traditionally built using mangrove wood for the stronger and more structural parts of the fish traps, their maintenance today has become very difficult, as local mangroves are protected from felling. The fish trap sites could become again productive in a new way, i.e. mussel production or mussel spat collecting locations, or even fish farming in net-pens. Since the traps are frequently destroyed by time and weather conditions, and so the record of mussel survival and longevity on these structures has not been evaluated, adequate studies must be carried out before mussel aquaculture is attempted on a commercial basis. However it is interesting to note that 62% of the fish traps are either in good conditions or new, an indication of interest in the structures economic and production potential. The use of this information for the subsequent modelling developed in this study is principally designed to make use of all the available information in the region, including the strategic positioning of Sepetiba's fish traps.

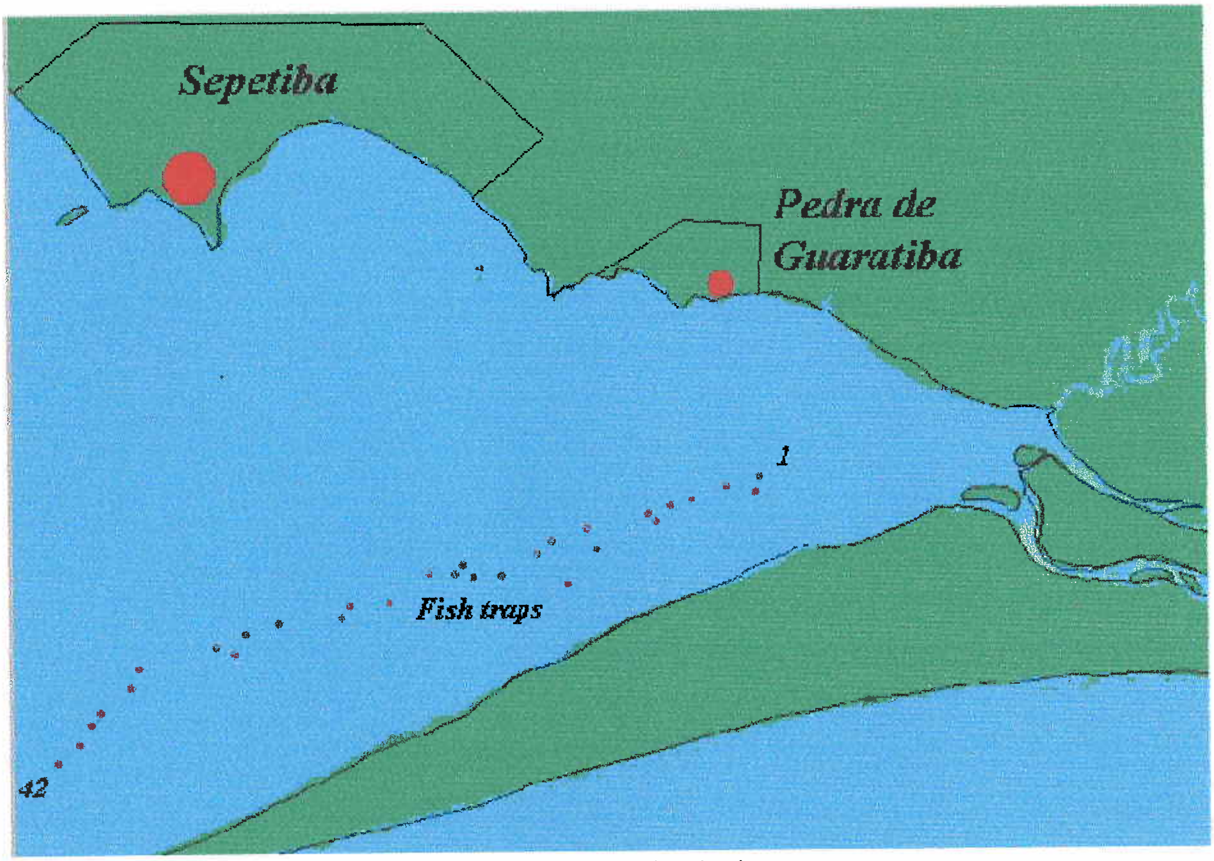

Figure 2.14 Distribution of 42 fish traps along the Marambaia Island.

Table 2.8 Fish traps (*cercadas*) position and usage status in Sepetiba Bay.

Co-ordinates		**Number of traps**	**Depth (m)**	**Status**
Longitude W	Latitude S			
43.38.013	23.01.554	2	1.8	in use
43.37.965	23.01.473	2	3.3	in use
43.38.200	23.01.498	2	3.6	in use
43.38.452	23.01.538	1	-	Broken
43.38.593	23.01.563	1	-	in use , new
43.38.704	23.01.641	2	2.7	in use
43.38.765	23.01.587	1	-	in use
43.39.141	23.01.750	2	-	in use
43.39.180	23.01.613	1	1.8	in use
43.39.366	23.01.931	1	-	in use new
43.39.366	23.01.931	1	-	in use, old
43.39.439	23.01.650	2	3.0	In use
43.39.548	23.01.725	1	-	In use, new
43.39.814	23.01.821	1	3.0	In use
43.40.011	23.01.800	1	3.0	In use
43.40.065	23.01.714	1	3.0	In use
43.40.128	23.01.762	1	-	In use
43.40.298	23.01.735	1	-	In use
43.40.594	23.01.876	1	3.3	In use
43.40.858	23.01.854	1	-	In use
43.40.936	23.01.916	1	3.3	In use
43.41.362	23.01.886	2	3.6	Broken
43..41.594	23.01.964	1	-	in use, new
43.41.604	23.01.921	2	3.9	in use, new
43.41.695	23.02.040	1	3.3	In use
43.41.803	23.01.980	1	3.96	In use, new
43.41.803	23.01.980	1	3.96	Broken
43.42.345	23.02.022	1	-	In use
43.42.419	23.02.128	1	3.96	In use
43.42.651	23.02.257	1	-	In use
43.42.730	23.02.320	1	-	In use, new
43.42.823	23.02.438	2	-	Broken
43.42.994	23.02.527	1	4.3	In use, new
Total		**42**	**-**	**-**
In use		**36**	**-**	**-**
Average depth		**-**	**3.2**	**-**

CHAPTER 3
STUDY AREA: BAÍA DE SEPETIBA
RIO DE JANEIRO – BRAZIL

3.1 INTRODUCTION

In this chapter, basic environmental data depicting the important conditions in the study area are presented as parts of a framework essential for the functioning of the GIS database developed. The digital description of the area in the form of raster and vector layers is based on inputs from several sources mostly obtained by digitisation of available maps, nautical charts and cartograms which had to be cut, adjusted and referenced to the limits of the windowed area of the Landsat TM image used, as described in Chapter 2. The source maps are listed in Table 3.1, and had the area of interest for the study identified and processed through geo-referencing as explained in the preceding chapter. The standardization of these data was a fundamental procedure in order to make operational the GIS models later developed in Chapters 6 and 7.

A general description of the study area is given in the form of maps showing basic characteristics of air temperature, rainfall, climate, water resources, soil types, conservation areas, vegetation and land use distribution around Sepetiba bay. These will later integrate in the land-based shrimp farming potential GIS model dealt with in Chapter 5.2. Additionally, maps for water surface currents, bottom sediments type distribution and general surface water salinity are described in little detail, as they will be treated specifically and developed for the water-based GIS aquaculture models of mussel and oyster potential determination in Chapter 5.1.

Table 3.1 List of maps and chart sources partially incorporated into GIS database for this study.

Maps were incorporated by digitisation. Diretoria do Serviço Geográfico do Ministério do Exercito (GSG - ME), Diretoria de Hidrografia e Navegação (DHN), Instituto Brasileiro de Geografia (IBGE), Secretaria de Meio Ambiente Municipal- Instituto Estadual de Florestas (SEMAM / IEF), Instituto de Planejamento do Rio de Janeiro (IPLANRIO). Secretaria Estadual de Meio Ambiente (SEMA).

ID number	Type	Region/Area	Scale	Produced by	Identification	Date
1	Nautical	Barra do RJ – Ilha Grande	1: 120 015	DHN	Nº 1620	1986
2	Nautical	Porto de Sepetiba	1: 20 000	DHN	Nº 1623	1982
3	Nautical	Ilha Grande – Central	1: 40 067	DHN	Nº 1631	1980
4	Nautical	Ilha Grande – Guaíba	1: 40 090	DHN	Nº 1621	1983
5	Military	Barra de Guaratiba	1: 25 000	GSG - ME	SF.23-Z-C-III-2-NE	1981
6	Military	Pedra de Guaratiba	1: 25 000	GSG - ME	SF.23-Z-C-III-2-NO	1981
7	Military	Restinga da Marambaia	1: 25 000	GSG - ME	SF.23-Z-C-III-1-NE	1981
8	Military	Itaguaí – S	1: 25 000	GSG - ME	SF.23-Z-A-VI-3-SE	1981
9	Military	Itaguaí	1: 25 000	GSG - ME	SF.23-Z-A-VI-3-NE	1981
10	Municipal	Município R.J.	1: 60 000	IPLANRIO	-	1990
11	Municipal	Estado R.J.	1: 400 000	SEMAM / IEF	-	1994
12	Nautical	Baía de Sepetiba	1: 40 122	DHN	1622	1991
13	Territorial	Marambaia	1: 50.000	IBGE	SF-23-Z-C-111-1	1986
14	Territorial	Itaguaí	1: 50.000	IBGE	SF-23-Z-A VI-3	1976
15	Territorial	Mangaratiba	1: 50.000	IBGE	MI 12743/4	1992
16	Territorial	Santa Cruz	1: 50.000	IBGE	SF-23-Z-A-VI-4	1993
18	Nautical	Ilha Grande e Sepetiba	1: 120.000	DHN	1609	1976
19	Territorial	Sepetiba Basin	1:250.000	SEMA	-	1996
20	Nautical	Ilha Grande e Sepetiba	1: 80.000	DHN	1607	1996

3.2 GEOGRAPHICAL LOCATION AND DESCRIPTION.

Rio de Janeiro state lies roughly 44°00 W 23°00 S. Its coastline is profiled by the existence of several water bodies. Neighbouring states are Minas Gerais to the north, and Sao Paulo to the west. In contrast to other coastal states, Rio de Janeiro's coastline lies roughly in an East-West direction. The three most important bays are Guanabara, Sepetiba and Ilha Grande (Fig 3.1). Sepetiba Bay is located approximately 60 km southwest of the metropolis of Rio de Janeiro. Moura *et al.* (1982) described it as a coastal lagoon enclosed by a barrier island (Marambaia), dominated by fluvial processes (Guandú delta, Fig 3.2), and a coastal floodplain fringed by mangroves notably the Guaratiba mangroves

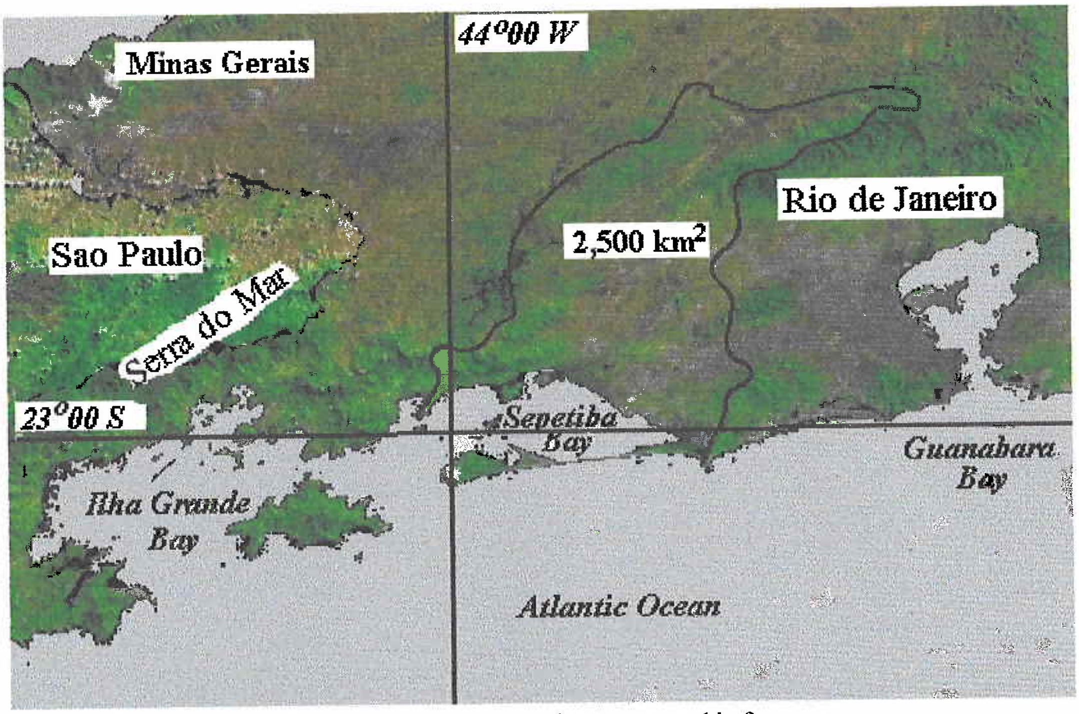

Figure 3.1 Sepetiba Bay location in relation to other prominent geographic features. Sepetiba hydrographic basin is outlined (Source adapted from EMBRAPA 2003).

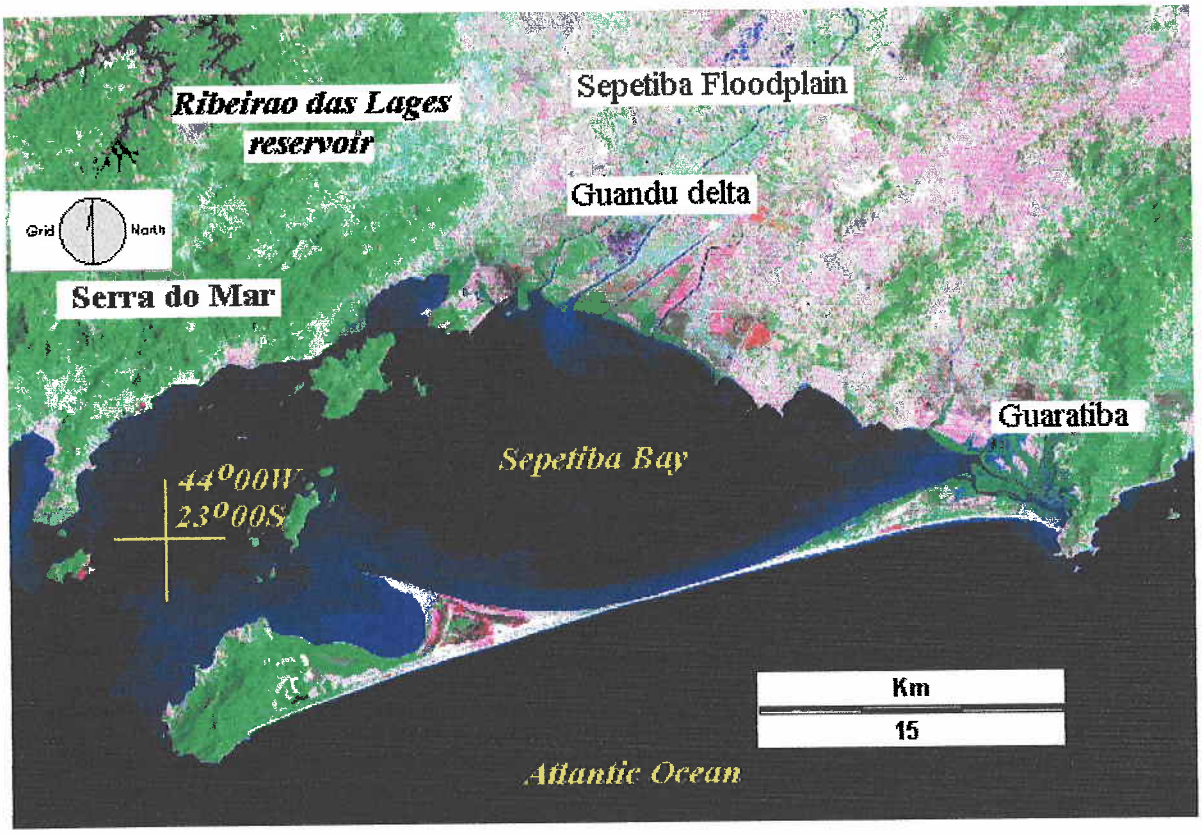

Figure 3.2 Sepetiba Bay Study area as seen by Landsat TM on April 12, 1994.

Sepetiba's hydrographic basin (Fig 3.1) covers about over 2,500 km^2, which corresponds to about 4.4% of Rio de Janeiro state (SEMA, 1996). The limits defined for this watershed were established by the Laboratório de Geo-Hidroecologia (GEOHECO), starting from the peaks of the Serra do Mar mountain range (see Fig. 3.1) where the rivers flow into Sepetiba begin, forming the Guandú river watershed. According to these criteria, to the west only a small portion of the municipalities of Rio Claro and Piraí are included. Figure 3.3 shows the three municipalities with coastline on the bay: Mangaratiba, to the west, Itaguaí, in the central portion, and Rio de Janeiro in the eastern part of the bay.

The rivers which begin in the Serra do Mar mountain range (Fig. 3.1) are responsible for transporting sediments which have formed an extensive plain interspersed with marshes. As the area has become developed, the plain demanded rectification and construction of major drainage canals such as the Canal de São Francisco, the Canal do Itá and the Canal Pedro II. The 'Sepetiba Lowlands' area is characterised by SEMA as "a metropolitan frontier" (SEMA, 1996).

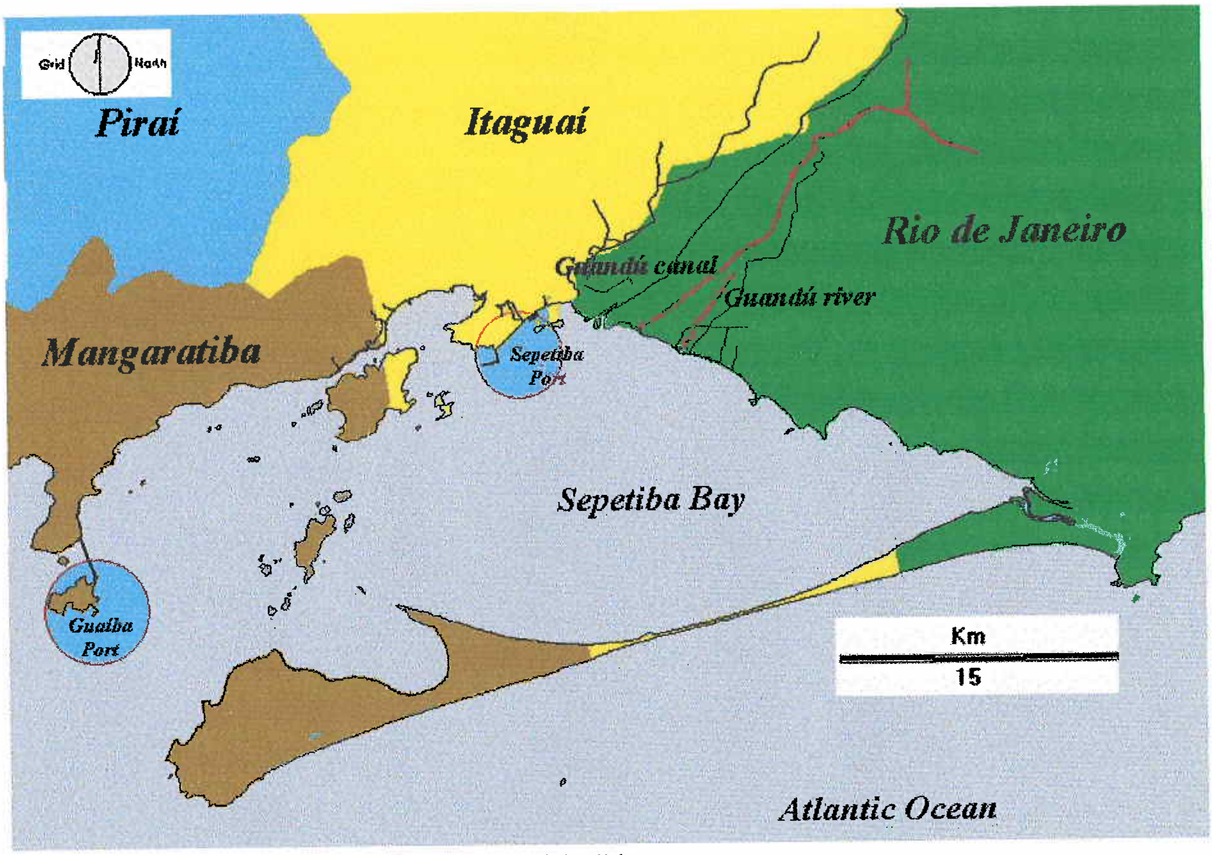

Figure 3.3 Sepetiba Bay and its neighbouring municipalities.

During the last decades the region has been settled in a series of 'suburban rings' around Rio de Janeiro's metropolitan zone intermingling areas of high population density with diluted urbanization in the midst of several real estate ventures which are still awaiting land valuation.

The fact that Sepetiba is served by important road and rail links between the neighbouring states of São Paulo and Minas Gerais confers upon it a strategic position. However this strategic position is also defined by industrial-urban concentrations outwith the Sepetiba Lowlands (Rio de Janeiro, São Paulo, Minas Gerais), which has induced strip development using the area as a 'passageway' or goods export-import corridor rather than as an 'environmental unit'. The development plan for the expansion of the Port of Sepetiba is in progress and will play an important role in the local economy and environment.

3.2.1 The Port

The port of Sepetiba is located in the central part of Sepetiba Bay on the northern shore (Fig 3.3). It was inaugurated in 1982, and began its activities receiving coal and alumina. It is strategically located as it is within a 500 km radius of many industrial and commercial companies in Brazil, which account for about 70% of the Brazilian GNP (CDRJ, 1999).

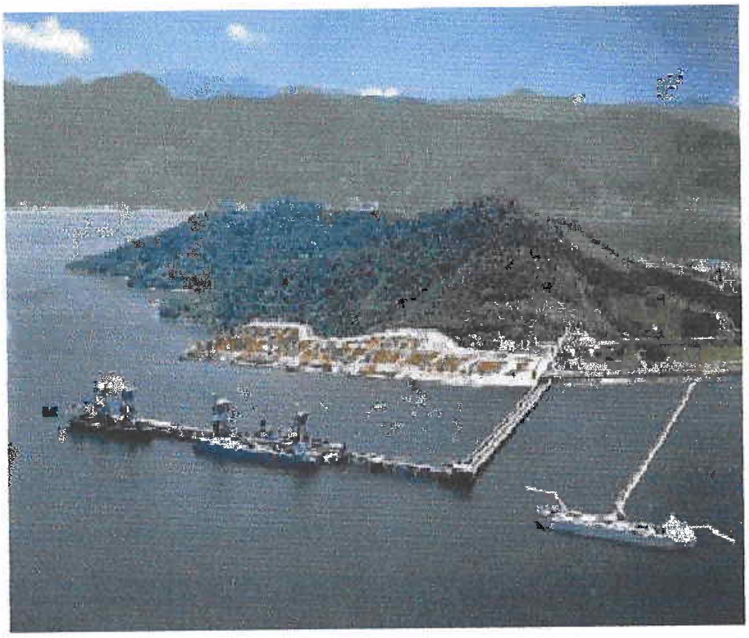

Figure 3.4 Port of Sepetiba. Final planned layout.
(Photo credit: CDRJ, 1999).

The port currently has a handling capacity for 7 million tonnes of cargo and is being expanded to enable ships of up to 150,000 tonnes to dock and move an estimated 18-20 million tonnes/yr. of cargo including iron ore, coal, grains and additionally an estimated one million containers. It is projected to be the only Hubport in the south Atlantic concentrating on cargo. Its design includes 'roll-on roll-off' facilities (Fig 3.4).

The Port of Sepetiba has demanded a global investment of US$ 350 million of which US$150 million are loaned from the Inter-American Development Bank. The project is a partnership between the Brazilian Development Bank (BNDES) and private initiative and its completion date was scheduled for September 1998. The port's characteristics are described by CDRJ (1999). These include an access channel 22 km long, 200m wide and on average 15m deep. The docking pier is 540 long, 40 m wide and can berth simultaneously two 90,000t and two 45,000t cargo ships (CDRJ, 1999). The access area has two silos for holding alumina with a static capacity of 30,630 t.

3.2.2 *TEMPERATURE*

Most of the coastal area of Sepetiba has a mean annual air temperature above 23.5° C as can be seen in Figure 3.5. Higher mean annual temperatures occur in the lowland areas reaching over 23.5° C in the central region to its highest values (>24° C) between the Pedra Branca e Mendanha mountains. With increasing altitude, temperatures decrease and are less than 17° C in the upper parts of Mazomba and Couto in the Tinguá range.

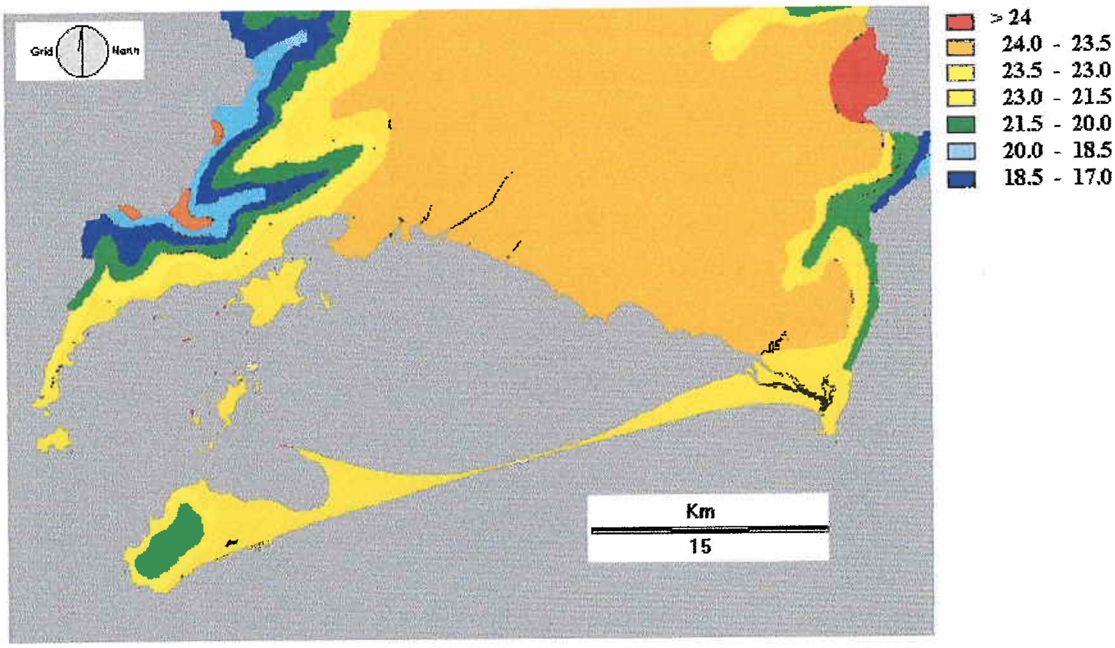

Figure 3.5 Mean annual temperature in Sepetiba region
Adapted from SEMA (1996), and georeferenced to Landsat TM cut-out window of study area.

3.2.3 *RAINFALL*

Figure 3.6 shows the mean annual rainfall from a monthly time series covering 1970 to 1990 (SEMA 1996). As can be seen, the coastal strip on the northern side of the bay can be broadly divided into an eastern portion where rainfall ranges from 1000 - 1200 mm y^{-1}, and a western portion where rainfall ranges 1400 – 1800 mm y^{-1}.

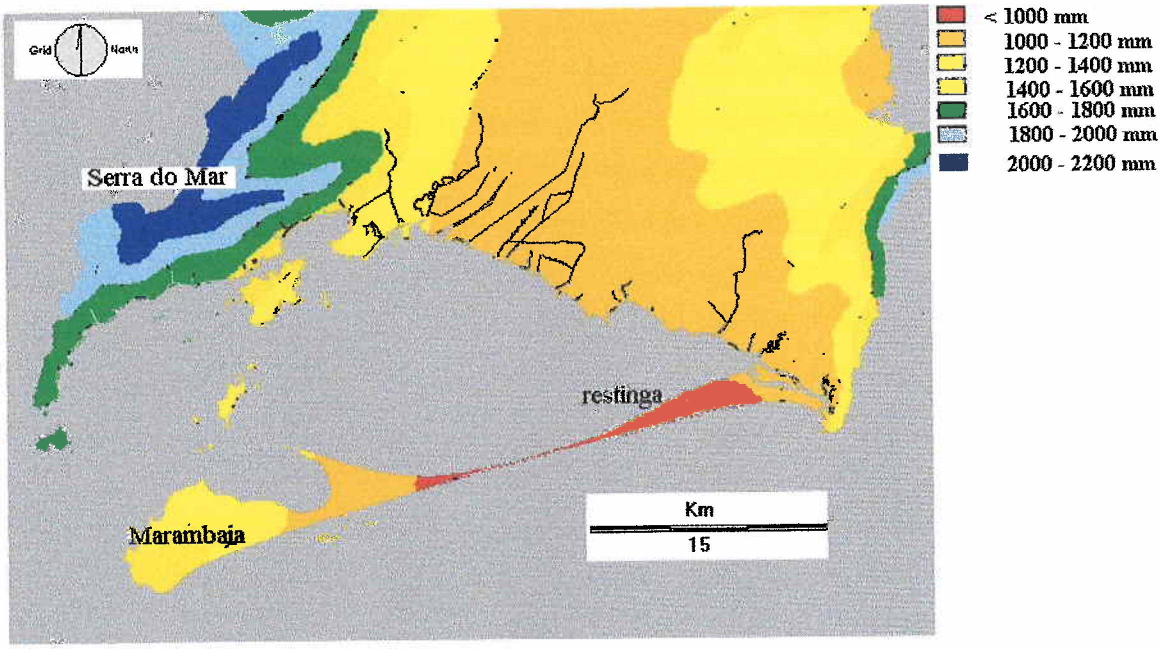

Figure 3.6 Mean annual rainfall in mm y^{-1} in Sepetiba region .
Adapted from: SEMA (1996), and georeferenced to Landsat TM cut-out window of study area.

These two portions also reflect the topography. The western portion is hilly to mountainous with altitudes over 800 m being very common. Rainfall in this region can be quite concentrated and causes severe erosion on hillsides. The eastern end and central portion of the basin is comprised of lowlands. Moisture laden air coming from the sea precipitate as they are forced to rise by the Serra do Mar. Most of the area on the mainland (northern) side of the bay receives rainfall of 1200 –1400 mm per year. The eastern part of the Marambaia island is rather drier, (<1000 mm per year). In this area, xerophytic vegetation known locally as *restinga* grows on the sand dunes.

3.2.4 CLIMATE

Climate Classification- The Köppen System

According to Atkins (2000), this system was devised by Waldmir Köppen (1846-1940). It identifies five primary climate types:

1. Tropical moist climates: all months have an average above 18° C – no real winter season;

2. dry climates: deficient precipitation most of the year. Potential evaporation and transpiration exceed precipitation.

3. moist mid-latitude climates with mild winters: warm-to-hot summers with mild winters. - average coldest month is below18° C and above -3° C;

4. moist mid-latitude climates with severe winters - warm summers. The average temperature of the warmest month exceeds 10° C and the coldest monthly average drops below -3° C.

5. Polar climates: extremely cold winters and summers.

SEMA (1996) identifies in its climatic cartogram, three climatic types for Sepetiba (Fig 3.7) based on the Köppen's classification (Table 3.2).

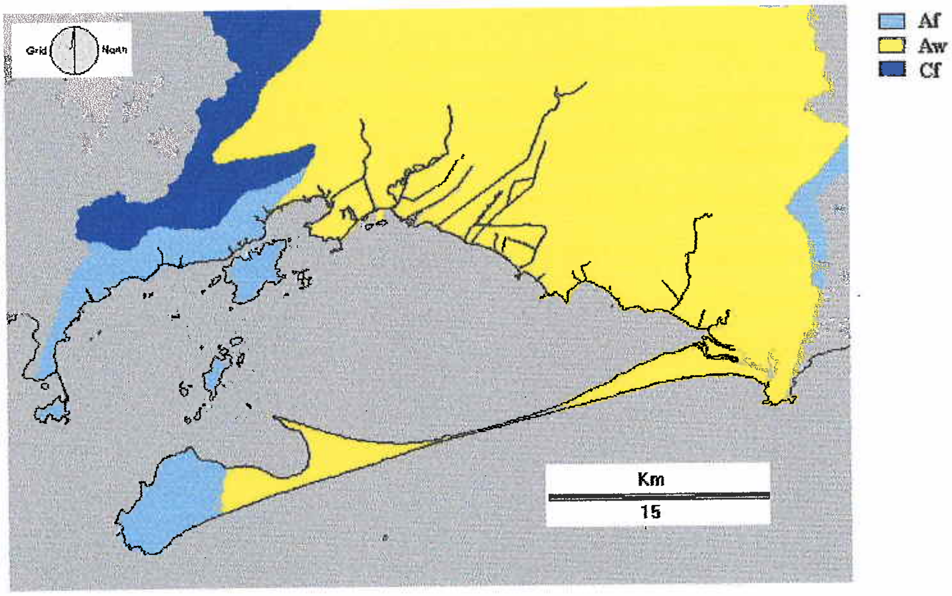

Figure 3.7 Köppens's climatic classification for Sepetiba region.
Adapted from SEMA (1996), and georeferenced to Landsat TM cut-out window of study area.

Type **Aw** is the predominant mostly affecting the lowlands and lower reaches of the Serra do Mar which flanks it to the west and other hillsides towards the east. **Aw** type is characterised by a slight drought in the winter months and higher average temperatures (above 18° C) all year round. They obtain the same amounts of precipitation as Af, rain rates fluctuate greatly during the year and from year to year. The second type, **Af,** mostly affects the islands and western reaches of the bay. climate is a tropical moist climate, (wet) with small variations (less than 3 C. Solar radiation is constant year round, the diurnal temperature is larger than the seasonal variation, moist and subject to convective showers most every afternoon. It is the type of climate with higher year-round precipitation and also higher temperatures. **Cf** climate (cool and wet) is confined mostly away from the coastline and at higher altitudes. It is characterised by hot muggy summers and mild winters. Afternoon convection is common in summer, tropical storms also.

Table 3.2 Criteria for Köppen climate classification.

Category	Subcategory		Definition
A (Tropical)			Average temperature of the coolest month 18°C or higher
		f	Precipitation in driest month at least 6 cm
		m	Precipitation in driest month < 6 cm but >= 10 - r/25
		w	Precipitation in driest month < 10 - r/25
B (Dry)			70% or more of annual precipitation falls in warmer six months and r < 2t + 28
			70% or more of annual precipitation falls in cooler six months and r < 2t
			Neither half of year with more than 70% of annual precipitation and r < 2t + 14
	W		r < 1/2 upper limit of applicable requirement for B
	S		r < upper limit for B but more than 1/2 that amount
		h	t >= 18°C
		k	t < 18°C
C (Warm temperate Rainy – Mild winter)			Average temperature of warmest month greater than 10°C and of coldest month between 18° and 0°C
	s		Precipitation in driest month of summer half of year less than 4 cm and < 1/3 the amount in wettest winter month
	w		Precipitation in driest month of winter half of year less than 1/10 of amount in wettest summer month
	f		Precipitation not meeting conditions of either s or w
		a	Average temperature of warmest month 22°C or above
		b	Average temperature of each of four warmest months 10°C or above; temperature of warmest month below 22°C
		c	Average temperature of from one to three months 10°C or above; temperature of warmest month below 22°C
D (Cold forest, severe winter)			Average temperature of warmest month > 10°C and of coldest month 0°C or below
	s		Same as under C
	w		Same as under C
	f		Same as under C
		a	Same as under C
		b	Same as under C
		c	Same as under C
		d	Average temperature of coldest month below - 38°C
E (Polar)			Average temperature of warmest month <= 10°C
	T		Average temperature of warmest month between 10° and 0°C
	F		Average temperature of warmest month 0°C or below
H (Highland)			Temperature requirements same as E, but due to altitude (generally above 1500 m)

t = average annual temperature °C; r = average precipitation in cm.

3.2.5 *WATER RESOURCES*

Figure 3.8 shows the divisions of the hydrographic system of Sepetiba Basin determined by topographic maps for the economical-ecological zoning program undertaken by SEMA (1996). The figure shows Sepetiba bay as the final receptor of ten sub-basins which comprise the main hydrographic basin.

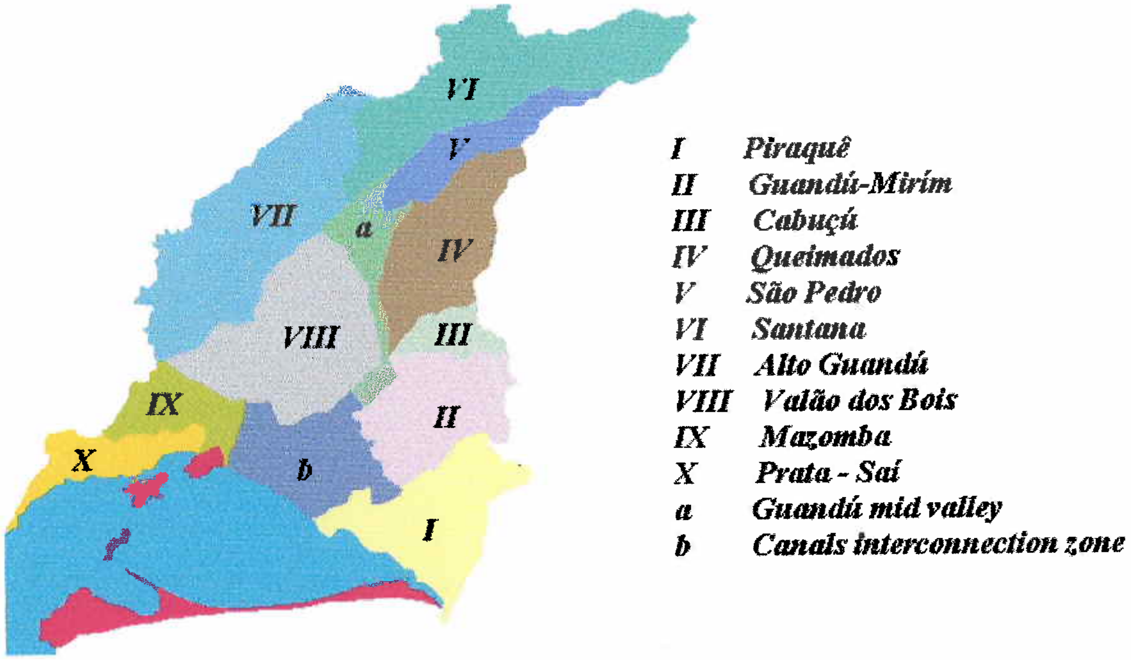

Figure 3.8 Hydrographic system of Sepetiba Basin.
Adapted from: SEMA (1996).

The positions of the main rivers and canals flowing into Sepetiba Bay (Fig 3.9) which was obtained by superimposing a vector file of rivers and canals digitised from admiralty chart 1622 onto the Landsat base image. The most important volumes entering Sepetiba Bay are summarised in Table 3.3. Dib (1992) having studied the transportation of suspended sediments and concentration of heavy metals in river bottom sediments of the Sepetiba Basin, found that: The Guandú river (7) has the highest transport capacity for silt and clay in the dry and rainy season. The São Francisco canal (9) is the second greatest transporter of silt and clay to the bay and is the greatest contributor of sediments to the bay. The Guarda river (12) is one of the greater contributors of clay.

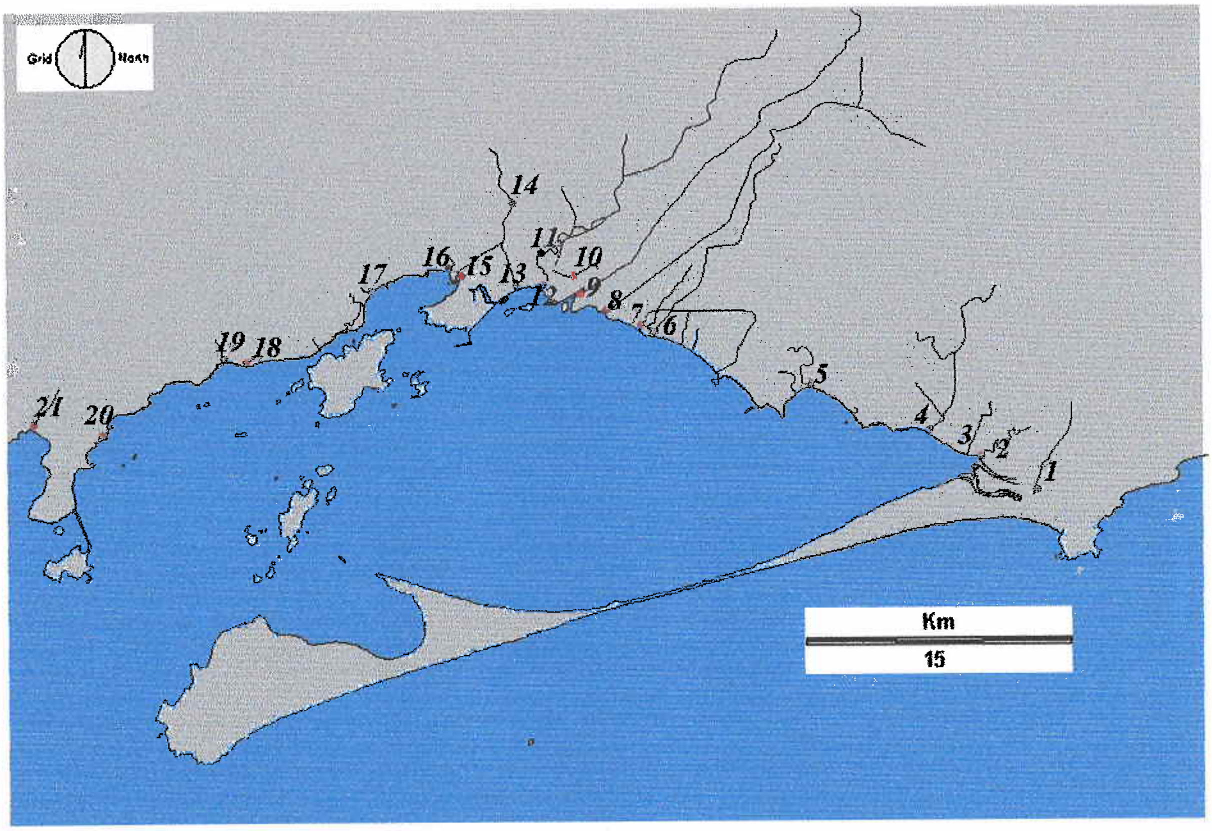

Figure 3.9 Main river and canal outflows into Sepetiba Bay.

1. Rio do Portinho 2. Rio Piracão 3. Rio Piraí 4. Rio Piraquê 5.Rio do Ponto 6. Canal do Itá 7.Rio Guandú 8. Canal do Guandú 9. Canal São Francisco 10. Canal Sto Agostinho

The Piraquê river (4) although one of the smallest, had a significant contribution of suspended materials, mostly due to intense urbanization process along its watershed. The river Cação (15) showed consistently high levels of Zn (417 µg l^{-1}) and Cd 2 µg l^{-1} . This fact is most probably related to its proximity to the Ingá zinc ingot manufacturing plant and the Port of Sepetiba, which normally imports mineral coal for industries in the area including a thermo-electric plant.

Table 3.3 Characteristics of main freshwater contributors to Sepetiba Bay.
Adapted from Dib, 1992.

NAME	VELOCITY $m\ s^{-1}$	DEPTH m	WIDTH m	VOLUME $m^3\ s^{-1}$	SILTE $g\ l^{-1}$	CLAY $g\ l^{-1}$
Rio Guandú	0.91	5.7	127.0	341.99	0.075	0.20
Canal de São Francisco	0.73	6.3	141.0	278.45	0.070	0.22
Rio da Guarda	0.45	3.6	35.5	36.58	0.090	0.26
Canal do Guandú	0.90	2.1	19.0	30.15	0.300	0.39
Valão dos Bois	0.45	2.0	39.3	28.31	0.070	0.40
Rio Cai-tudo	0.40	2.8	43.0	27.58	0.055	0.23
Rio Piraquê	0.40	2.9	23.8	17.0	0.045	0.90
Rio Cação	0.71	1.1	15.3	9.27	0.100	0.13

3.2.6 Soils

The predominant soil types in the coastal lowlands of the bay are **gleysols** and **planosols** (SEMA, 1996) (Fig 3.10). Gleysol soils have a texture (Tables 3.4 and 3.5) which make them prone to flooding and usually costly to improve. Although the natural fertility of these young sediments is usually high, they are heavy clay soils, and therefore are less suitable for crops with small seeds. Over the South American continent, they are frequently used for extensive cattle grazing during the season when these soils are not inundated. Otherwise, they may be used for rice cultivation. Near sea level, such as in Sepetiba, crops include sugarcane, rice, bananas, cocoa and coffee. In river valleys near urban centres the soils are intensively used for horticulture, as in the rural areas of Campo Grande, Itaguaí and Santa Cruz. They are suitable for rice, jute, sugarcane and good pastures but must be drained (FAO-Unesco, 1971).

Planosols are also found in the urban area of Sepetiba. They are characterised by a heavy texture, impermeable B horizon, and inundation for part of the year. They are not very suitable for crops as the subsoil is impervious and quite difficult to break. They are good for rice cultivation, although this is not practised in Sepetiba. Both soils types may have low content of sodium salts.

Table 3.4 Principal characteristics of Eutric Gleysol (saline phase) for South America. Adapted from FAO- World Soils Map.

		ORGANIC MATTER				SOLUBLE SALTS		
HORIZON	DEPTH	%C	%N	C/N	pH	SO_4^{--}	CL^{--}	TEXTURE
A	0-10	4.1	0.34	12	5.2	0.3	2.2	Silty clay loam
Cg_1	-38	1.0	0.21	5	7.1	0.9	3.8	Silty clay
Cg_2	-60	0.7	0.04	17	6.6	1.2	3.3	Silty clay
Cg_3	-112	1.6	0.13	12	6.2	2.0	2.5	Silty clay
Cg_4	-150	2.7	0.15	18	4.7	4.4	3.0	Silt loam

The fertility of the soils in Sepetiba has been recognized since colonial times (1700s). The drainage of its basin in order to rehabilitate these lands for agricultural purposes was initially achieved by the Jesuits who owned over 1.074 km^2 in this region, prior to their expulsion from Brazil in 1759.

Table 3.5 Principal characteristics of Eutric Planosol for South America.
Adapted from FAO- World Soils Map.

		ORGANIC MATTER				SOLUBLE SALTS		
HORIZON	DEPTH	%C	%N	C/N	pH	-	-	TEXTURE
A/E_1	0-18	1.0	0.10	10	5.4	-	-	Sandy loam
E_2	- 25	0.3	0.03	-	6.5	-	-	Sandy loam
BE/Bt_1	- 50	0.7	0.06	-	6.8	-	-	Clay
Bt_2	- 65	0.4	0.04	-	7.5	-	-	Clay
Bck	-85	0.1	0.02	-	8.5	-	-	Clay loam
C	- 150+	0	-	-	7.5	-	-	Clay loam

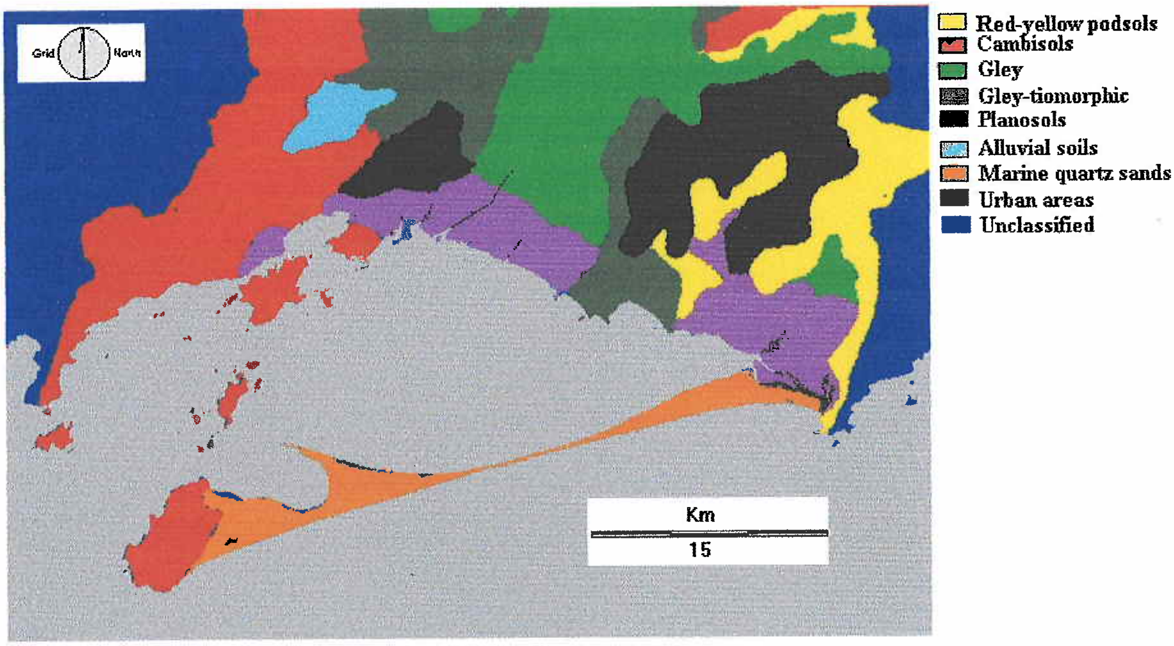

Figure 3.10 Soil types distribution around Sepetiba Bay.
Adapted from SEMA (1996) cartogram and georeferenced to LandsatTM cut-out window of study area.

Without maintenance, the drainage situation worsened as canals and ditches deteriorated and new roads and railroads were built with narrow-gauge drainage pipes. The basin area, estimated by Goes (1942) to be around 1,800 km^2 , was largely covered by swamps, mangroves and flooded lands. Goes considered the recovery of drainage ditches and canals of this hydrographic basin by the Vargas government to be a triumph. This restoration of canals in the early 1940s included 270 km of canals, 620 km of ditches and 50 km of dikes, and removing obstruction from 1,400 km of waterways. The objective was to recover pastures and plantation areas from the 'desolate campaign of the mangroves and marshes'. Recently the work has been repeated at a cost of over US$ 75 million (FEEMA, 1993).

3.2.6 VEGETATION AND LAND USE

Figure 3.11 was derived from an interpretation conducted by SEMA (1996) from a compilation of available land use maps, for the Sepetiba area at the scale of 1:100,000. SEMA reclassified land use into 7 categories. These generalise sub-categories, i.e. Forests = native forests + forestry projects + secondary growth; Grasslands = fields and lowlands (in some cases); Restinga = Sand dune vegetation and beach sand, Mangrove = mangroves + degraded mangroves + flooded lowlands (in some cases).

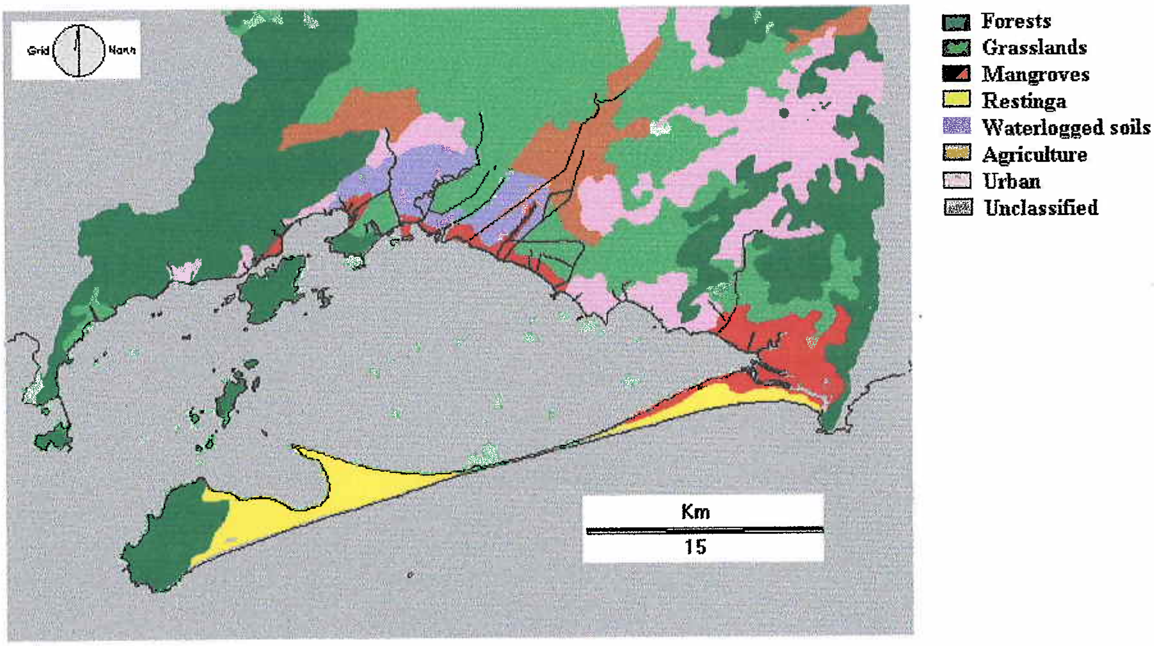

Figure 3.11 Land use in the study area. Adapted from:
Adapted from SEMA (1996) cartogram and georeferenced to LandsatTM cut-out window of study area.

3.2.8 CONSERVATION AREAS

Sepetiba Basin has several legal environmental conservation units shown in Figure 3.12. These include two important state parks; *Parque Estadual da Pedra Branca (2) on* the eastern end of the bay which is established as a Permanent Preservation Area (APP) by resolution CONAMA 05/85 (art.2 of the Brazilian Forestry Code), and is defined as 'Ecological Reserve'. This park covers 12,500 ha and harbours remnant portions of Atlantic (rain) Forest ecosystem. It overlooks the Guaratiba region, most noteworthy for its well developed mangroves, protected in the second park known as *Reserva Biológica e Arqueológica de Guaratiba (1).* This park covers 2,800 ha of exuberant mangroves and salt barrens found also in the eastern end of Sepetiba bay. This area contains over 40 middens, locally known as *sambaquís*, which are mounds of remnants left by ancient indigenous peoples the Tupi-Guaranís, containing mostly seashells and artefacts. The presence of numerous middens along the Rio de Janeiro coastline confirms the importance of shellfish as food source for native populations (Lamego, 1964). The *Parque Estadual das Serras do Madureira/Mendanha (3)* is still in the proposal stage and will protect about 6,000 ha of forested areas.

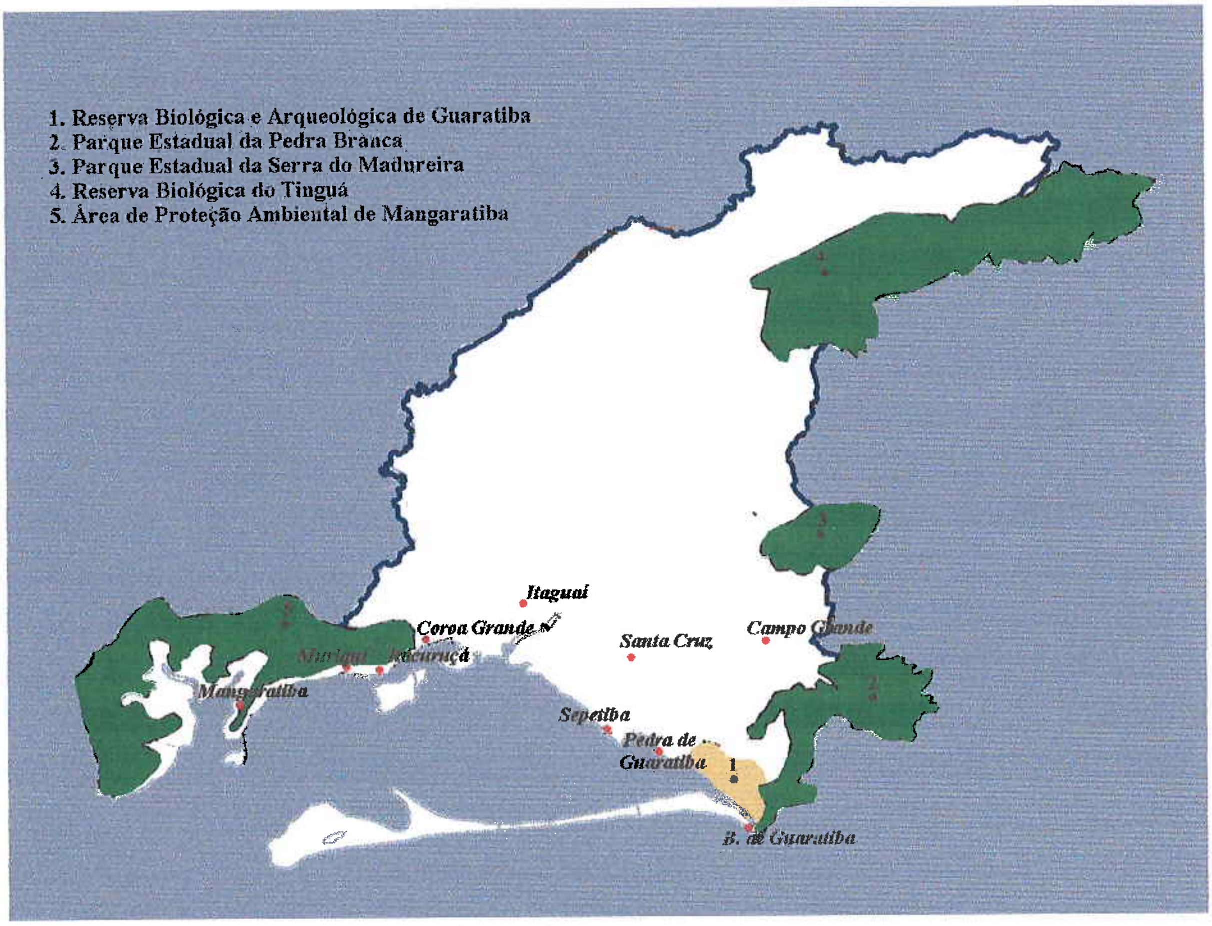

Figure 3.12 Environmental Conservation Areas in the Sepetiba Bay Basin.
Adapted from: SEMA (1996).

Further away from the bay, to the northeast is the *Serra do Tinguá* a Biological Reserve (4) and to the southwest the *Mangaratiba Environmental Protection Area* (5), which prohibits land use at altitudes over 100 m in the municipality of Mangaratiba, which includes most islands in the bay. Also protected by legal instruments are all other mangrove areas fringing the bay as well as the sand dunes and their vegetation on the Marambaia island (which is under the Ministry of Defence administration). Of the five parks existing in the area, only three will be of concern as part of their limits fall within the study area. These are Reserva

Biologica e Arqueologica de Guaratiba, Parque Estadual da Pedra Branca and Area de Protecao Ambiental de Magaratiba.

3.2.9 GEOMORPHOLOGY AND OCEANOGRAPHY

Lamego (1944) proposed the generally accepted explanation for Sepetiba Bay's origin, as being a result of the coastal current moving in a north-easterly direction headed for the Guaratiba headland. This is a classical example of a barrier beach developing landward from a sea island as described in Garrison (1999). An emergent *tombolo* protruded from Marambaia island, being fed by river-borne sediments from the adjacent coastal plain, mainly the Guandú and Itaguaí rivers. The shallow coastal waters allied with an effective sediment barrier provided by the islands chain of Madeira, Itacuruçá, Furtada, Jaguanum and Marambaia and several other smaller ones (see Fig 3.13) allowed the *tombolo* to bridge and connect to the continent. As it attained considerable size, wind helped it to advance and build sand dunes. Eventually the newly formed barrier beach took an West-East direction accommodating for a new secondary internal current. So far, the eastern end of Sepetiba bay, Guaratiba, has not closed. The Canal do Bacalhau channel provides fresh seawater exchange from that end. The barrier beach today shelters the internal waters of the semi-enclosed bay and a newer spit has formed from the main barrier beach towards Jaguanum island.

Ponçano (1976), who studied in detail the sedimentation of Sepetiba Bay, took a different view and suggests that river-borne sediments were less important to the formation of the barrier island than attributed by Lamego. He concluded that another spit departed the eastern end of the bay and that with action of coastal eddies brought sediments of coastal shelf origin to feed sand bars which formed the bulk of the barrier beach. Both sand spits eventually joined, closing the bay from open water exposure. In any case, the result of these processes has led to the formation of a reasonably well protected, semi-enclosed coastal lagoon, which is fed by nutrients brought through rivers draining a the basin.

3.2.10 CURRENTS

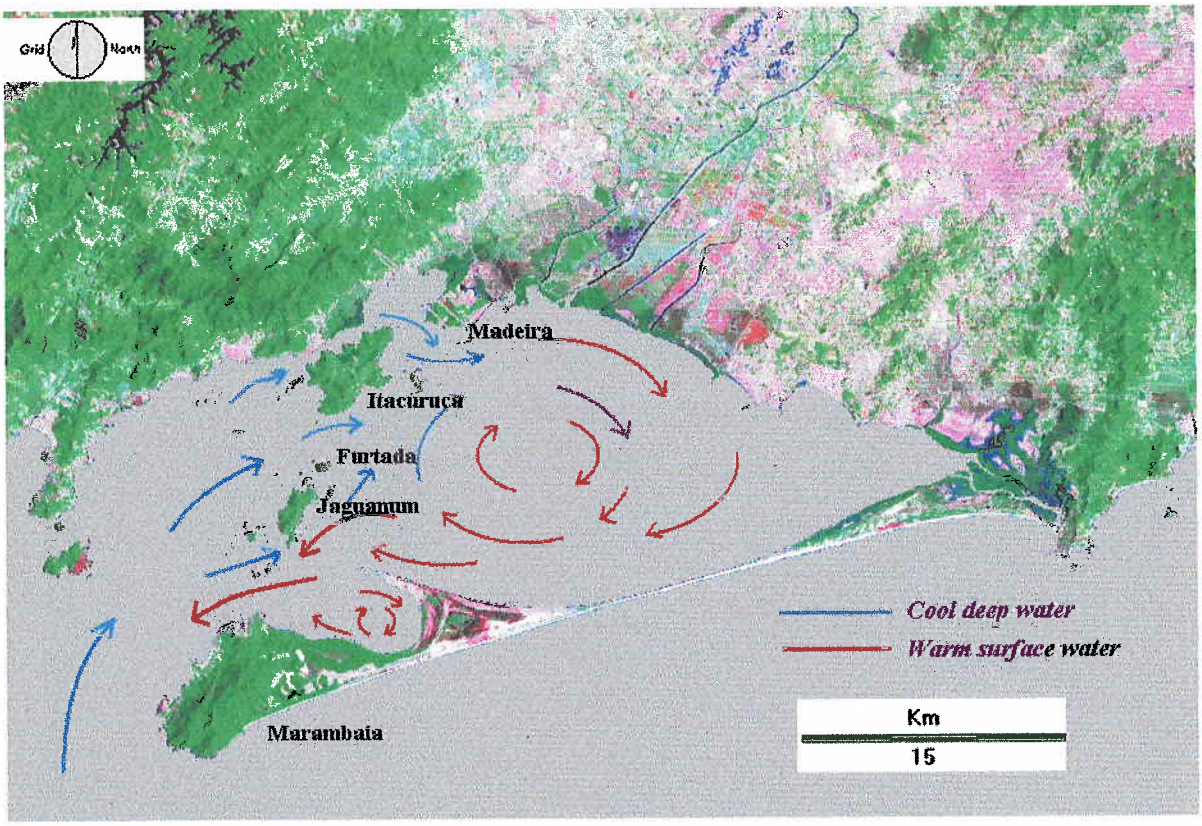

Figure 3.13 General seawater circulation pattern for Sepetiba bay.
After Moura et al. (1982) and Matsuura (1986).

An important characteristic of this region is its coastal upwelling system. The warm oceanic waters of the Brazil Current (>20 °C , Salinity 36‰) come from the north flowing in a southwest direction, over the South Atlantic Central Water (SACW) which has the same properties of the tropical convergence waters. This SACW has accentuated penetration over the continental shelf, at the end of spring and in summer (Dec – Jan) (Matsuura, 1986). Moura *et al.* (1982) and Matsuura (1986) suggest that these cooler (14 – 18°C) SACW waters probably coming north from the Falklands system, also penetrate Sepetiba bay via its deeper channels in the west end, moving towards the Guandú river mouth, and rising to the surface as they warm up (Fig 3.13). These in turn, circle the lagoon (bay) and leave the bay as surface currents over the same channels as they entered.

Detailed data on water circulation patterns for the bay are very scarce but his findings agree with those of Signorini (1980a) that the circulation is tidally driven. Signorini (1980a) used a finite numerical model for studying the circulation of the Sepetiba Bay and Ilha Grande Bay using naval oceanographic data. He concluded that Sepetiba has a 'strong tidal signature' where alternating flows of up to 0.75m/s with a period of 6.21 hours were present. The SACW which penetrates over the lower levels of the continental shelf around Marambaia and Ilha Grande islands is more noticeable at the end of spring and during summer (January), at which point a pronounced thermocline is formed at 20-50m depth. During autumn and spring this water mass stays receded from the margin of the continental shelf and the vertical temperature over the continental shelf becomes uniform.

Detailed knowledge of currents inside Sepetiba bay is poor. Fragoso (1995) developed a circulation model based on data collected by the Instituto de Pesquisas Hidroviárias (INPH) in 1990.

The results of his model were based on hourly readings taken by the INPH campaign, at 1 metre depth intervals, taken for a complete tidal cycle from four stations observed during spring and neap tides. The velocities obtained from this model showed lowest values of 0.19 m/s, the highest being 0.98 m s^{-1}. Higher velocities were always found at the open end of the bay. Rosman (1998) modelled transportation of contaminants from fresh water sources into the bay. Even though there are 21 sources of freshwater into the bay, most of them are small contributors. Slow currents and low volumes of freshwater input such as the Piraquê river result in a lower dilution factor at the eastern end of the bay than elsewhere.

3.2.11 BOTTOM SEDIMENTS

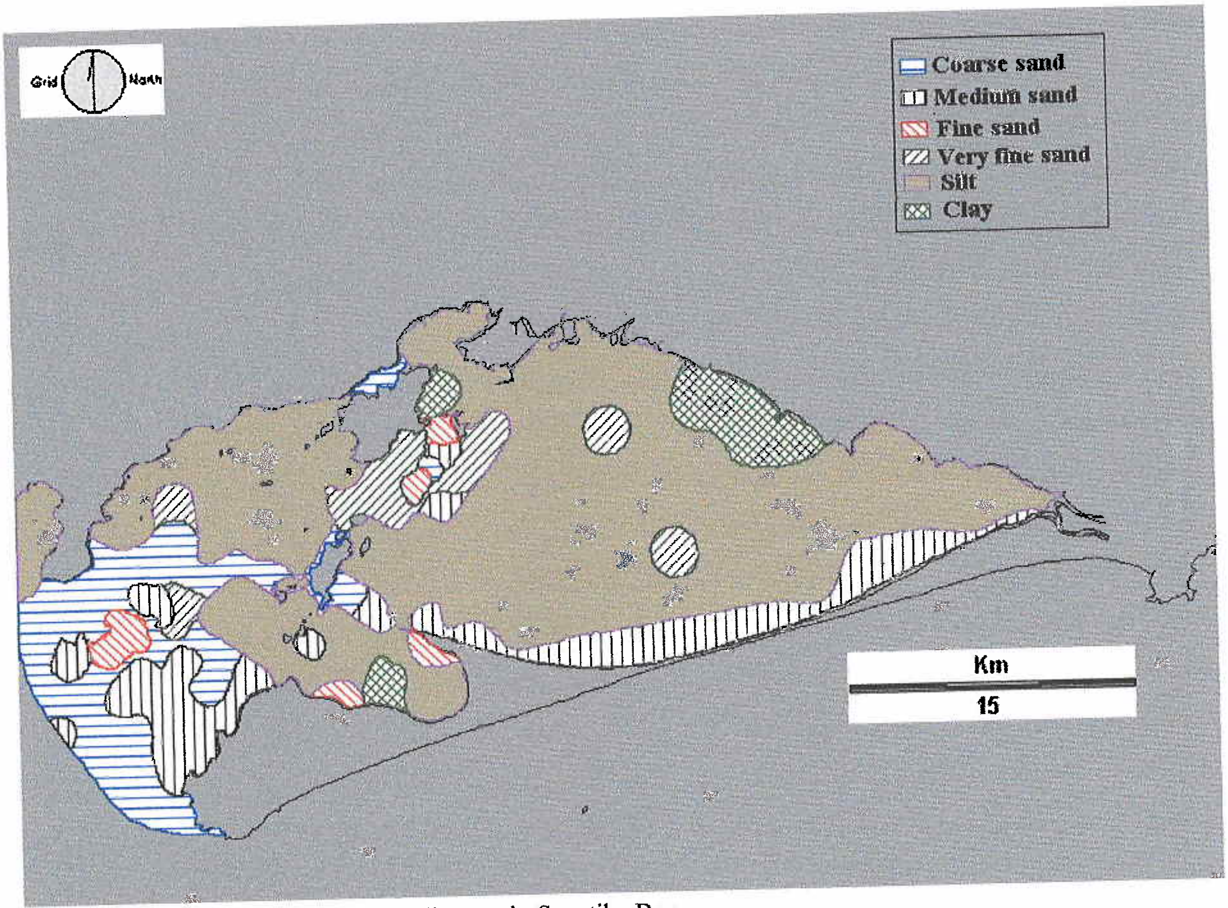

Figure 3.14 Distribution of bottom sediments in Sepetiba Bay.
Adapted from Ponçano (1976), and georeferenced to Landsat TM cut-out window of study area.

The sheltered conditions offered by Sepetiba Bay inspired the installation of a major sea port.

As the life span of a port complex ultimately depends on sediment dynamics and rate of changes (Ponçano, 1976), a study was made by Geomecânica S.A. using a 2 km x 2 km grid, where 273 surface sediment samples were collected from the bay and adjacent areas just outside. The result is a sediment distribution map (Fig 3.14) classified according to the Wentworth's scheme (Table 3.6), which clearly shows that the central and eastern portions of the bay are dominated by bottom sediments composed mostly of silt, of terrigenous origin. The western end of the bay is dominated by medium to coarse sands, a confirmation of the existence of swift bottom currents (Tait, 1981). This knowledge of the bottom sediment distribution can be useful for studies considering distribution of benthic communities (Ponçano, 1976). More information on bottom sediment quality and distribution has recently become available from a seismic profiling campaign carried out by FEEMA (1997).

Table 3.6 Wentworth classification of particle grades and Phi scale.
From Tait, 1981

GRADE NAME	PARTICLE SIZE (mm)	PHI UNITS
Boulder	> 256	Beyond – 8.0
Cobble	256 - 64	-8.0 - (- 8.0)
Pebble	64 - 4	-6 - (-2.0)
Granule	4 - 2	-2.0 - (-1.0)
Very coarse sand	2 - 1	-1.0 - 0
Coarse sand	1 - 0.5	0 - 1.0
Medium sand	0.5 - 0.25	1.0 - 2.0
Very fine sand	0.125 - 0.0625	2.0 - 3.0
Silt	0.0625 - 0.0039	4.0 - 8.0
Clay	> 0.0039	Beyond 8.0

3.2.12 Water Quality

The water quality data history for Sepetiba Bay is very poor. A series of cartograms depicting water surface temperature, salinity, dissolved oxygen, chlorophyll-*a* and ammonia contents was produced by SEMA (1996) based on average values compiled by FEEMA as a result of a major water quality sampling campaign carried out in 1990. Sepetiba Bay has a marked estuarine characteristic, and as Tait (1981) points out, estuarine waters "are not a simple dilution of seawater".

Moura *et al.* (1982), describes the Mangrove of Guaratiba and the Sepetiba Bay as 'a model of two interdependent mixohaline environments, both in equilibrium between the continental and the open marine influences'. This evidence was corroborated by his studies of Foraminifera in Sepetiba.

Moura *et al.* (1982) concluded that due to the degree of restriction in the eastern end of the bay, mangrove environment developed and produced an endemic, diversified and specialized Foraminifera association consisting essentially of texaluriids.

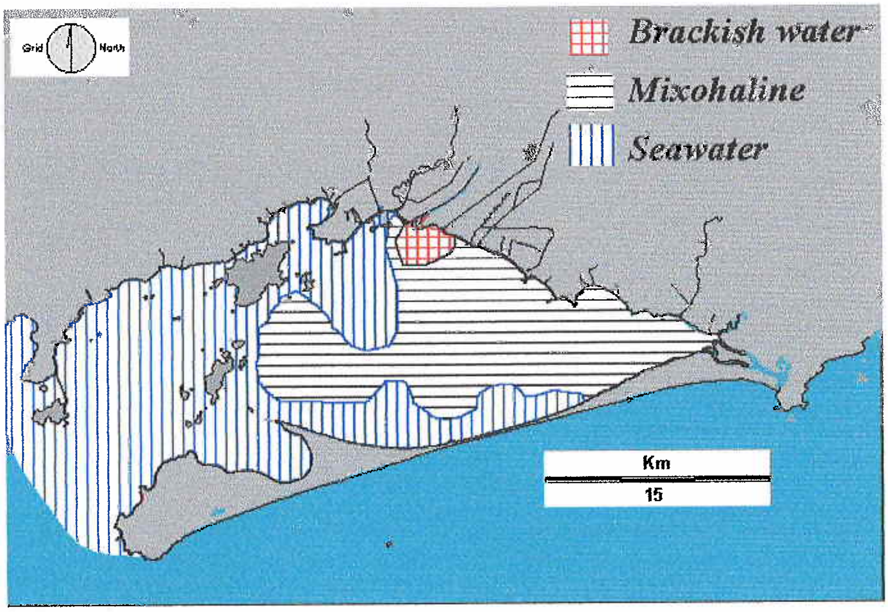

Figure 3.15 Surface salinity in Sepetiba Bay.

Adapted from Moura et al.(1982), and georeferenced to Landsat TM cut-out window of study area..

On the other hand the western end of Sepetiba Bay, which is open towards the marine environment contains low species diversity of Foraminifera and restricted associations consisting essentially of rotaliids. Figures 3.15 and 3.16 show the surface and bottom salinity provinces described by Carvalho Brito and Jobim (1979).

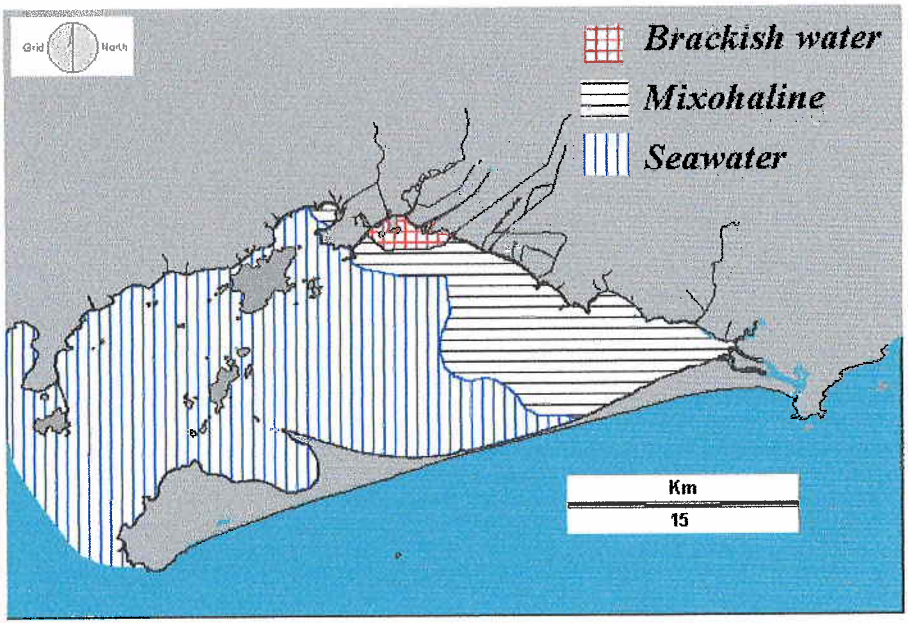

Figure 3.16 Bottom salinity in Sepetiba Bay.

Adapted from Moura et al.(1982), and georeferenced to Landsat TM cut-out window of study area.

These are divided into 3 provinces: brackish water 5-18‰, mixohaline 18-30‰, and seawater 30-40‰. These surface and bottom salinity provinces have variable geographical limits on a diurnal basis.

3.2.13 WATER COLOUR

Few surveys in Sepetiba have been comprehensive in collecting simultaneously the many water quality parameters necessary for better understanding its dynamics. Water colour changes markedly in estuarine waters as a function of several factors. Oliveira (1971) surveyed over 100 points in the bay using the total apparent colour classification scheme described in Sverdrup (1948). The results are illustrated in Figure 3.17. Oliveira judged this method to be important for shallow waters because it translated an association of organisms related to a specific water colour over a period of time. The colours identified in Oliveira's study were correlated with supplementary information regarding their relevance to fisheries, which was obtained with interviewed fishermen. Specifically important to them were colours associating the presence of white shrimp in feeding behaviour over the muddy bottoms.

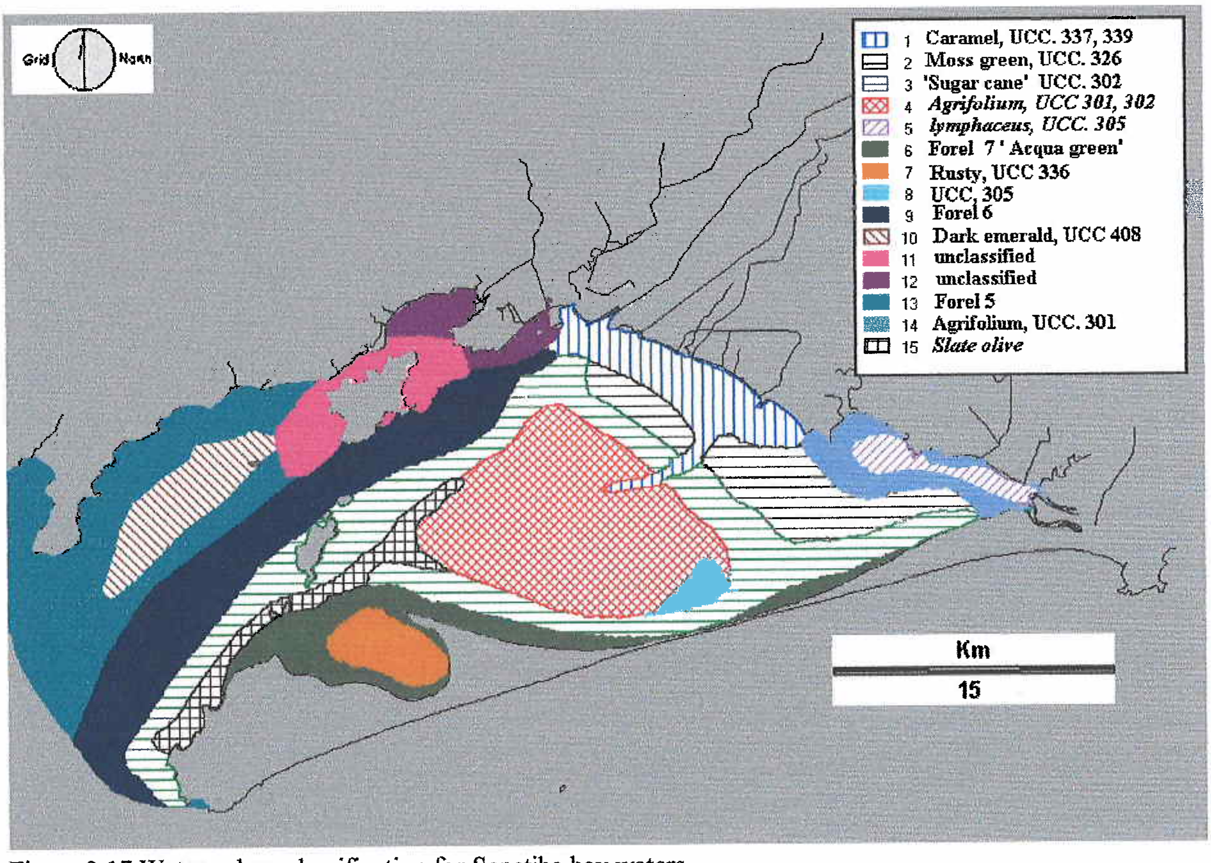

Figure 3.17 Water colour classification for Sepetiba bay waters.
Adapted from Oliveira, 1971 and georeferenced to Landsat TM cut-out window of study area.

According to fishermen, the white shrimp create this type of colour by lifting bottom sediments with their pereiopods and pleopods as they search for prey and food particles. Skates and rays are said to produce a different colour effect, as they disturb deeper and darker coloured layers of sediments. Mullets are said to prefer waters with the *agrifolium* colour. Oliveira supplemented these reports from the fishermen with biological samples taken throughout the bay and their associated water colours. For example, waters corresponding to *moss green* colour were associated with abundance of white shrimp larvae. Other organisms such as blue-green algae, echinoderms, mullets, and benthic diatoms were also associated with specific water colours. The range of colours and hues perceived in Sepetiba Bay and their association with certain biological activities of specific fisheries resources characteristic to the bay may still be useful in other GIS based studies.

CHAPTER 4
SELECTION OF CULTURE SPECIES AND LOCAL PRODUCTION METHODS

4.1 INTRODUCTION

Aquaculture development in the coastal zone depends on the natural resources available, including the species and the prevailing conditions in the physical environment. In this chapter, some of the previous aquaculture efforts undertaken in Sepetiba are briefly reviewed in order to justify the selection of the species chosen for the GIS models proposed. A short description of the local production systems for mussel, oysters and shrimp is given. The success in farming aquatic species will depend on the biological potential of a given area which includes a combination of several environmental parameters dealt specifically in Chapter 5. Some of these were chosen, then mapped, scored, and input as into the GIS database as reclassified images to become working elements for the GIS models.

4.2 AQUACULTURE IN SEPETIBA

Aquaculture initiatives in Sepetiba have been mostly been undertaken in the more sheltered, eastern end of the bay. The actual sites are shown in Figure 4.1 and summarised in Table 4.1. The aquaculture concept is not alien to local artisanal fishermen as many have installed large bamboo fish traps or fish-corrals which capture and maintain mullets alive for up to several weeks much in the way of other man-made aquaculture structures such as net pens or fish cages

The first species to be reared under scientific conditions was the Pink shrimp (*Farfantepenaeus paulensis* and *Penaeus brasiliensis*). 32 adult specimens were captured outside the bay in 1974 and taken to an aquaculture facility owned by Cia. Souza Cruz (a subsidiary of British American Tobacco Co.) where they spawned in captivity. Shrimp larviculture technology was in its incipient stages but Cia. Souza Cruz discontinued its operations transferring its equipment and materials to the state of Rio de Janeiro's aquaculture department Empresa de Pesquisa Agropecuária do Rio de Janeiro (PESAGRO), later renamed Fundação Instituto de Pesca do Rio de Janeiro (FIPERJ).

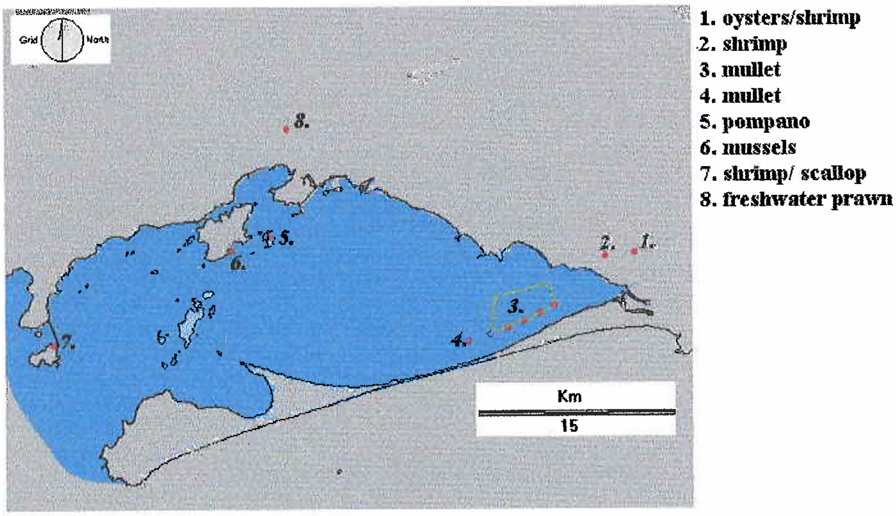

Figure 4.1Location of aquaculture initiatives and species tried in Sepetiba Bay.

The palisades of the fish traps also serve as growing structures for brown mussels *Perna perna,* which are occasionally harvested and sold in local markets. Several mussel longlines were installed along the southern coast of Itacuruçá island but the initiative was abandoned in one year.

Table 4.1 Main aquaculture initiatives in Sepetiba Bay region.

SPECIES	INITIATIVE	YEAR
Farfantepenaeus paulensis and *Penaeus brasiliensis*) b	Cia. Souza Cruz	1973
F. paulensis and *P. brasiliensis*)[a]	Fundação Instituto de Pesca do Rio de Janeiro (FIPERJ) – successful larviculture, for stocking enhancement.	1974
Trachinotus spp.[b]	Pereira & Magalhães, Cage culture (on-growing) of Pompano.	1978
Macrobrachium rosenbergii[b]	FIPERJ – post-larvae production	1984
M. rosenbergii[b]	Hotel Charles – on growing freshwater prawns	1984
Mugil spp.[a]	Japan International Cooperation Agency (JICA) funded project. On-growing	1990
Perna perna[b]	mussel longlines	1995
Crassostrea rhizophorae[a]	FIPERJ – Larviculture only – spat production	1998
Penaeus schmitti[b]	Mineirações Brasileiras Reunidas (MBR) – shrimp cage culture	1998

a. state run project
b. private entrepreneurs

PESAGRO succeeded in spawning pink shrimp under its new lab conditions in 1975. (Thomas and Cataldo de Castro, 1982). The post-larvae were put for on-growing in earthen ponds in the Sepetiba area. However, in the subsequent years, PESAGRO switched from its research emphasis focused on reproduction aspects of the native *F. paulensis* to that of the exotic freshwater prawn, *Macrobrachium rosenbergii.* Due to the relative technical ease of reproduction and on-growing aspects of this species, it remained as the main concern of this state-run lab for several years. Millions of *M. rosenbergii* post-larvae were produced and shipped to all parts of the state, as well as to other states in Brazil, but only one site (Hotel Charles) in the bay area is known to have engaged in semi-commercial on-growing. Mineirações Brasileiras Reunidas is currently attempting cage culture of white shrimp (*P. schmitti*) at Ilha da Guaíba (Scott, unpublished).

Subsequently, PESAGRO attempted cage-culture of mullets (*Mugil spp.*) with financial support from the Japanese International Cooperation Agency (JICA). PESAGRO and its Japanese cage-culture specialists selected a site, which coincidentally was close to the artisanal fishermen fish corrals. Due to a poor communication process, this technical attempt was met by the fishermen with bitter hostility. They did not appreciate the state-project considering it an intrusion into their affairs and a disregard for their 'traditional' rights to the area (Martino, unpublished).

Juvenile pompano (*Trachinotus spp*), a local species, was captured by Pereira & Magalhães (personal communication) and used in on-growing trials in floating fish-cages at Ilha do Martins. This was attempted in collaboration with local fishermen from Ilha da Madeira, but eventually failed as nets were severely damaged by puffer fish, which ate dead fish lying on the bottom or entrapped in the mesh.

Recently (1998), FIPERJ has initiated spat production of local mangrove oysters (*C. rhizophorae*). This is a first attempt at culturing a local native mollusc. The broodstock were collected in the local mangroves of Guaratiba, conditioned in the FIPERJ aquaculture station and oyster spat was successfully produced.

4.3 CULTURE SPECIES SELECTION

Bivalve molluscs certainly represent the most important aquaculture candidates for the study area. Sepetiba has limited but definitely exploited populations of several bivalve molluscs including brown mussels (*Perna perna*), mangrove oysters (*Crassostrea rhizophorae*), venerid clams (*Anomalocardia brasiliana*) and the mangrove mussel (*Mytella falcata*). These species grow in the bay and natural seed sources for these can be found in the area. Sepetiba bay also is an important feeding and reproduction environment for many fish species, some of which have culture potential, including groupers, mullets, flatfish and snook. So far, bivalve molluscs are the only group actually cultured in the bay. Their culture requires low investment and running costs making them a good option. This is in line with the Brazilian Ministry of Agriculture and Fisheries which in its development strategies policies for the period 2000-2001 has proposed action lines and credit for the development of 'aquaculture production chains' which include bivalve molluscs, specifically mussels and oysters, and the exotic white shrimp *Litopenaeus vannamei.* These marine species were selected as the best options for aquaculture development (Proença, 2002). In this study, site selection modelling for the brown mussel *Perna perna,* the native mangrove oyster *C. rhizophorae*, and the exotic white shrimp *L. vannamei* was developed.

Mussel and oyster culture have long attracted the attention of aquaculture and fisheries development institutions in Rio de Janeiro. Moreira (1985) developed a mariculture manual for *P. perna* and *C. gigas* for the Cabo Frio region. Magalhães and Ferreira (1997) have recently summarised the current technical practices commonly used for the culture of brown mussels in Brazil.

The exotic white shrimp *L. vannamei* is now cultured semi-intensively to intensively in most coastal states of Brazil. It is a hardy species, tolerant of a wide range of environmental conditions and a total business success so far. It is considered by the Brazilian Agriculture Ministry as a good model of the aquaculture production chains (Proença 2002).

A list of fish species occurring in the bay is listed in Appendix 7. Of these, so far only *Centropomus paralellus* is being grown experimentally in Ilha Grande (Bastos, pers. comm. 2002). The mullet *Mugil liza* has been raised experimentally in Cabo Frio (Moreira op. cit.) and in Florianopolis (Cerqueira, 2000 pers c omm.) but still insufficient information on the environmental requirements of Brazilian Atlantic coastal species exists for a good modelling study. Consequently, no specific fish species was selected. To develop a particular fish farming potential model of its own in this study.

In conclusion, for reasons of familiarity, abundance, existence of tested farming systems in the country, and general market acceptance of brown mussels and mangrove oysters in Rio de Janeiro, these two bivalve molluscs were chosen for the modelling exercise. The white shrimp *L. vannamei* was chosen because of the popularity it has acquired as a hardy culture organism, well adapted to conditions in most states along country's coastline and holds a well developed internal and export markets. The bay has been a traditional supplier of shrimp, but due to overfishing, locally caught shrimp are rare and expensive. The availability of land surface area adjacent to the bay, which could potentially be converted into shrimp growing ponds is an asset not to be overlooked.

4.3.1 PRODUCTION SYSTEMS

Mussels.

The brown mussel (Fig. 4.2) production system shown in Fig. 4.4 is likely to be adopted in Sepetiba and will probably follow that already employed in other coastal regions of Brazil, the closest of being Ilha Grande, Niterói, Cananéia, Ubatuba and Santa Catarina .

Mussel seed sources are an important consideration as the culture begins by obtaining seed from mussel beds on rocks on the coastline. These are graded manually by fishermen and family members and placed into cotton 'socks' protected by a 7 mm nylon mesh netting. These starter ropes (Fig. 4.3) are suspended from 20 - 40 l plastic floaters and kept vertical in the sheltered waters by a 500 - 700 g cement weight attached to the bottom of the rope. They are cultured for several weeks until they have grown enough and are solidly attached to the rope and can be placed in open waters for on-growing.

At 0.5 m intervals along the main longline surface cable, a 40 - 60 l floater is placed in order to support the main longline cable and also a single mussel on-growing rope. Each starter rope contains about 1,000 mussel 'seed' (2-4 cm) which are placed in a 1.2 - 2m long cotton 'sock' which is further enveloped by a 40-60 mm plastic mesh providing additional support. The length chosen for the on-growing mussel varies from region to region, and is generally dictated by local productivity and experience.

The longer ropes are employed in waters with higher productivity. The ropes are kept vertical by hanging a 0.5 - 0.7 kg cement weighted the bottom end. The starter ropes are removed after 3 months after stocking.

These are moored to concrete bottom weights of 400 - 1,000 kg concrete weights (Magalhães and Ferreira, 1997, Bastos (2003) pers. comm. To attach the mussel ropes to the on-growing floaters, a 3 mm Ø polypropylene cable is used. To attach the cement weights to the mussel ropes to the floater a 2 mm Ø polypropylene cable is used. Fifty such production sites have been implemented with World Bank support in Ilha Grande and Angra dos Reis area, 40 km south from Sepetiba. In Santa Catarina state, this system is commonly used, but a different system employing a ropes suspended from floating rafts measuring 7 x 7 m Is also used. This system is used in shallow, low energy sites. Mussel production systems are generally set up within close range (up to 200 m) of fishermen's homes, in sheltered shallow (5-25 m deep) coastal waters.

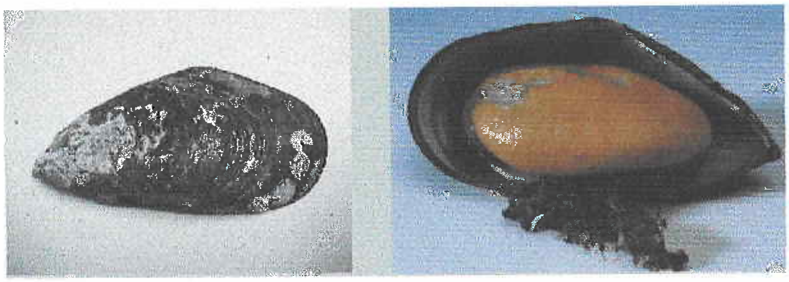

Figure 4.2 Brown mussel *Perna perna* .
(photo credit LCMM - UFSC)

Figure 4.3 Experimental mussel rope used in study area.

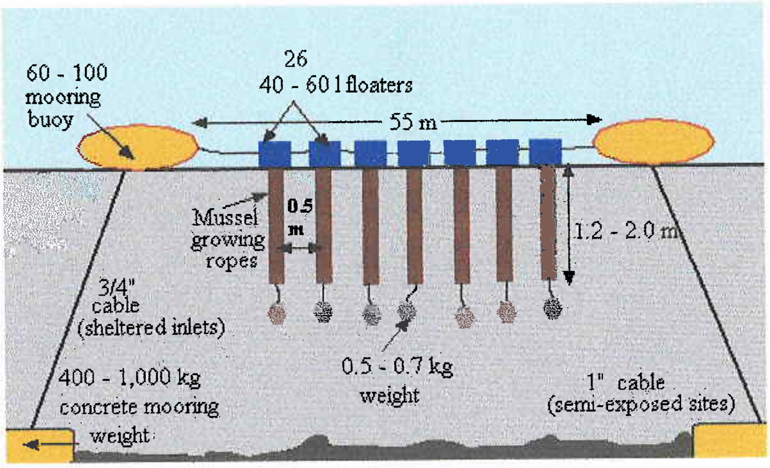

Figure 4.4 Mussel production system widely employed in Brazil.

Table 4.2 Potential mussel production based on Ilha Grande system.

Mussel culture summary		
Potential production	$t\ ha^{-1}\ y^{-1}$	30
On-growing cycle	months	8
Average production	$t\ ha^{-1}$	20
Dressout	%	20
Schucked mussel meat	$kg\ ha^{-1}$	4,000
Mussel meat price - (farm gate)	$£\ ha^{-1}$	619.46

In Santa Catarina state (Annonymus, 1995) where mussel production is well established, production output is 2.5 kg of shucked meat per 1.2 m of rope (dress-out of about 20%). Annual production per 7 x 7 m module is 4 tonnes of shucked meat. Retail market price varies between R$3,00 and R$5,00/kg (£ 0.62 - 1.03) (Scott *et al.* 2002). In Jurujuba, Niterói (Rio de Janeiro), each mussel rope yields about 500 mussels (1kg - 6kg) per year (with shells). This longline cultivation system is the same analysed by Fagundes (1997) whose economic analysis indicates a low operational cost and a profit returns at the lowest market price at the time of the study (1996) R$1,00/kg (£ 0.21) even under the minimal husbandry practices. An estimate of the potential economic value of mussel farming is given in Table 4.2.

Oysters

The oyster being considered for aquaculture development and GIS modelling in this study is *Crassostrea rhizophorae* (Fig 4.5) a native to Sepetiba bay.

Figure 4.5 *C. rhizophorae* growing on *Rhizophora mangle* prop roots

The closest oyster farming region to Sepetiba is Cananéia, SP, south of Sepetiba about 250 km. The system adopted in Cananéia, São Paulo, consists of a metal rack measuring 10m x 1 m supported on cement legs and installed in the intertidal zone approximately 30 cm above the seabed. 25 crossbars keep the structure in shape. To this rack, a 25 mm netlon base measuring 1 x 10 x 0.2m is fixed and used to support young on-growing oysters. Once the oysters are in place, a second mesh (8 mm) is used for protection from predators as well as for shading. This system is described by Fagundes *et al.* (1996) and uses a final stocking density of 125-250 oysters m^2. Market sized individuals (5 cm high) are obtained after 22 months. Figure 4.6 shows a similar system of bamboo construction developed by artisanal fishermen in Itaucuruçá Island in Sepetiba Bay.

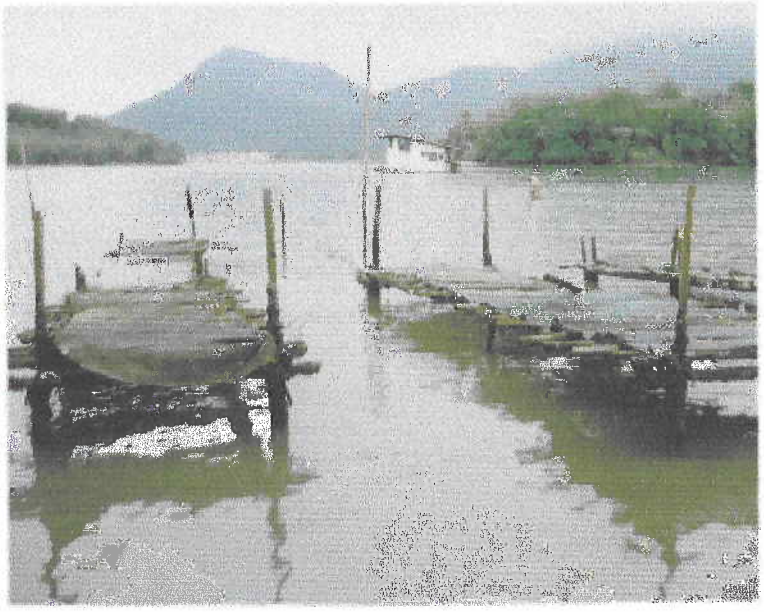

Figure 4.6 Experimental oyster ongrowing racks in Sepetiba.

To obtain the oyster seed, or spats, two systems are commonly used. The first is by providing a suitable settling surface such as aluminium strips. Oysters larvae present in mangrove waters become fixed to the surface and from then on referred to as oyster spat. The strips are transferred to a solid polypropylene support sheet measuring 35 cm x 90 cm x 8 mm and are separated from each other by a 7 cm gap. Each support sheet holds 16 aluminium strips with oyster spat. These are placed on the on-growing racks. The supporting rack is covered with a 2.5 cm gauge 'netlon' netting.

The oyster support sheets are placed over the net on the racks, and enclosed with an 8 mm gauge netting so as to protect the young oysters from predation. Using this method they attain commercial size (5 cm) in 22 months, with oyster densities ranging between 125 to 250 m^2 . The second spat collection system uses scallop shells as substrate. Once collected, the scallop shells are later re-arranged into 1m long strings where each substrate is separated from the other by a 7 cm spacer, usually a PVC pipe section. Each string is composed of 14 layers. Each rack may hold 100 strings. The lateral extremities are fixed so that currents will not compress the strings overcrowding the oysters. The culture system is protected with the 8 mm 'netlon' netting. The Cananéia production system for *C. rhizophorae* is summarised in Table 4.3.

tonnes of *L. vannamei*, with an average productivity of 5,458 kg ha y^{-1}. The usual production practise is described by Mathias (2003) and is shortly summarised here. The first phase in *L. vannamei* production is to stock starter post-larvae (PL) in 30 to 50 m^2 tanks provided with artificial aeration. Seawater supplied from an abstraction point is filtered through 300 μ nylon mesh before being allowed to enter PL rearing tanks. On-growing ponds are gradually filled with seawater after being fertilised with superphosphate at a rate of 4 g/m^2. The PLs are gradually acclimatised to these intermediate on-growing pond conditions in a way that salinity does not vary more than 3 PSU per hour and temperature no more than 1 C per hour. PLs remain in these ponds for about 20 days and are fed pelleted feeds containing 40% protein. Feeding is carried out at 2 hour intervals. After another 20 days, they are transferred to final on-growing ponds. The average size of the on-growing pond is 2 ha. Care is taken so that predatory fish eggs or juveniles do no enter the on-growing ponds. For this a 500-100μ nylon mesh is fitted in to slots in the sluice gate structures which allow water to enter the ponds. Fertilisation of the pond water is regularly adjusted, and satisfactory water quality is considered when transparency is between 25-40 cm. Shrimp are cultured for a total period of 100-120 days when the attain a mean weight of 12 g. Seawater exchange is accomplished by pumping from estuarine areas a rate of 15% of the pond volume per day. To ensure a sufficient level of dissolved oxygen content, the ponds are equipped with paddle-wheel aerators, at a rate of 2 – 6 HP ha^{-1}. These are usually activated when the DO level falls to 3 mg l^{-1}, or biomass reaches 0.2 kg m^2. Table 4.4 summarises the production figures for white shrimp culture systems usually found in Brazil.

Table 4.4 Potential white shrimp production based production current brazilian farming system. Data based on Mathias, (2003).

Shrimp culture summary		
Stocking density	PL_{25} m^{-2}	25
Cycle	Days	100 – 120
Survival rate	%	50-60
Average weight at sale	(g)	12
Average production	kg ha^{-1} y^{-1}	3,600
Farm gate price	£/kg	1.65
Gross earnings	£ ha^{-1} y^{-1}	5,940

4.4 PRELIMINARY CONCLUSIONS

So far, aquaculture initiatives in the Sepetiba area have been largely disconcerted and discontinuous, sometimes supported by the state government by its fisheries agency FIPERJ. Generally, the region's aquaculture potential is recognised by many, and iniciatives have been carried out by a few pioneers without sufficient knowledge about the aquatic environment, mostly due to scarcity of data. Better knowledge of the environment would contribute towards a more sound approach of aquaculture siting and species selection.

The bay is also intensively used by several other parties with distinct ends, including those associated with tourism and recreation, commercial shipping, military practices, fishing, and conservation. With population increase, an important traditional stakeholder in this coastal area - the artisanal fisherman – is under increasing pressure for survival, and the little aquaculture experience consolidated over the past 20 years in the area is still insufficient to offer him a sound enough alternative means of subsistence.

However effective aquaculture supporting institutions such as FIPERJ, PESAGRO and EMATER have been in the past assisting its development, they still agglomerate the local human resources and training capacity with potential to change this scenario. Still, attention must be given that research and extension agents do not underestimate inherent difficulties in developing aquaculture in an area undergoing progressive urban development as well as increasing environmental degradation. Possibly, a multi-institutional, in-depth review of the recent history of aquaculture development in the Sepetiba region would be beneficial in determining what development strategies and policies would be most realistic.

So far, two types of difficulties are most apparent to explain for the slow progress of sound and economically feasible aquaculture systems in the Sepetiba area.

The first is of a technological nature, and the second relative to the market. Throughout Brazil, on-growing of pink shrimp has been unable to perform competitively with that of white shrimp. Fish with aquaculture potential such as the Pompano, have so far have not been successfully spawned in captivity. Additionally, pompano as well as mullets, traditionally have low market demand. Mangrove oysters, apparently have a large size variabilty under culture conditions, and are usually smaller than the competing market alternative, japanese oysters. Wild mussels - scraped from rocks - are still very abundant in Rio de Janeiro, also commanding very low prices.

In a broader view however, world-wide per capita consumption of seafood products such as fish, has almost doubled in under half a century. Demand has increased and supply has declined. The International Food Policy Research Institute says that the rise in seafood prices is remarkable when set in the context of prices for other animal products – such as beef, chicken, pork and milk- which have plummeted in real terms over the past 30 years. This trend signals a promise of a 'blue revolution' where aquaculture is expected to contribute more and more to supplies. (The Economist, 2003). Consumer awareness of product quality and origin is on the increase especially for products such as shellfish.

Thus, the choice of three species chosen for this GIS study - *Perna perna, Crassostrea rhizophorae* and *Litopenaeus vannamei* is regarded at the moment as the most adequate, and it is hoped that the outcomes will contribute to local and regional knowledge, potentially being useful for better management of natural resources in Sepetiba and Brazil.

CHAPTER 5
DEVELOPMENT OF A GIS FOR ASSESSING WATER-BASED AQUACULTURE SITE SUITABILITY

5.1 DEVELOPMENT OF A GIS FOR ASSESSING MUSSEL AND OYSTER CULTURE POTENTIAL IN SEPETIBA BAY

5.1.1 DATABASE DEVELOPMENT

A common image on which all the subsequent analyses could be based, was developed by cutting out a window from the Landsat TM image. This image (Fig. 5.1) became the baseline area used in all further work in the GIS. The selected area was so chosen because it covers all of Sepetiba bay, as well as inland areas of potential significance to the study including

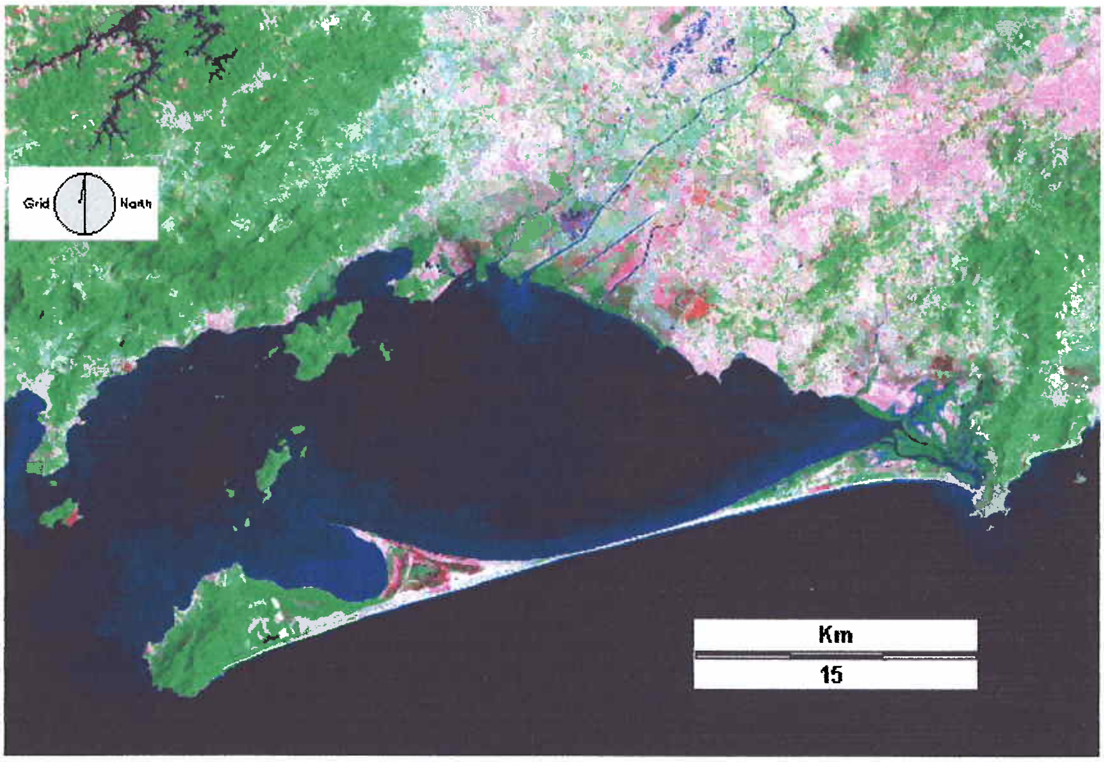

Figure 5.1 Landsat 5 TM image of study area window.

those considered important for a water-based aquaculture site suitability GIS treated in the current section of this chapter as well as those in the next section, such as markets, services and transportation grid. The first step taken was to make a broad classification in order to identify the area covered by water and that covered by land. This was done by looking at the range of z values of pixels in the water areas and land areas and recording their values. Next, using the **RECLASS** module of IDRISI a simple reclassification procedure was carried out where all the z values found over the water surface were reclassified as the same. All other z values were reclassified into a second group thus separating all pixels relative to water body into one group and those relative to land into another group.

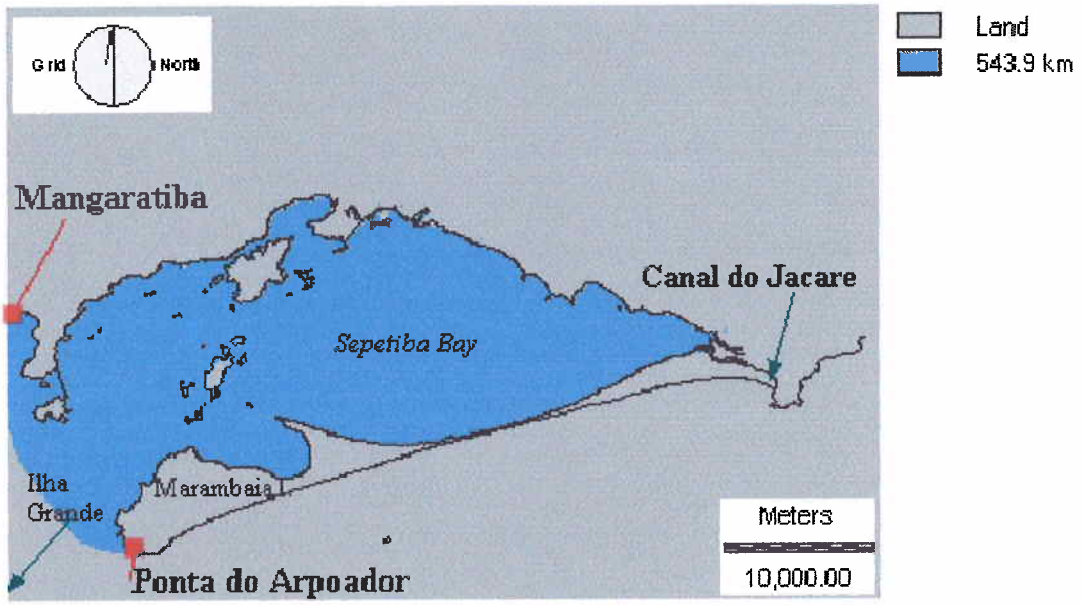

Figure 5.2 Delimitation of the water surface of the study area.

Few references were found in the literature which delimits Sepetiba Bay as hydrographical entity. The study area's limits were arbitrarily selected. References quote the surface of Sepetiba Bay as covering 519 km^2 (Lacerda *et al.* 1987), however these do not state which western points were considered to enclose the bay for its area determination. In this study, the western limits were set so as to include the Bay of Mangaratiba. The reason for this being that although the town and bay of Mangaratiba lie outside the catchment area for Sepetiba, it is largely under the influence of Sepetiba bay. The extent of this boundary line is justified as the economic life of Mangaratiba is closely related with the fisheries, the ports and tourism activities, which occur within its municipal boundaries in the bay. A curved line extending from the Ponta do Arpoador on Marambaia island (Fig. 5.2) was extended to the western end of Mangaratiba bay to define the limit of the western side of the study area.

This limiting line, is roughly midway between Marambaia Island and Ilha Grande (not visible in Fig. 5.2) and marks the western front of the bay, which is open to the sea.

Using the **AREA** module of IDRISI the area covered by water was determined to be 544 km^2. In clear water conditions, water depth can be estimated using a combination of bands, however, since Sepetiba's waters are rather turbid, this estimation was not attempted.

Many of the thematic layers found in this section were derived from cartograms published by the environment authority SEMA (SEMA 1996). These were used after being rectified to the base windowed area of the Landsat TM image used.

5.1.2 SCORING AND RECLASSIFYING

Each thematic map developed and incorporated into this GIS database, was important to achieve the final prediction outcomes of the models. However, in some cases, the degree of detailed information about specific themes was less than desirable. In order to pursue the overall purpose of this research which was to build and test site selection models for mussel, oyster and shrimp culture sites in and around Sepetiba, simple re-classification schemes were adopted and applied with the understanding that the supporting layers in the GIS could be in the future, rectified or updated bestowing greater accuracy and credibility to the prediction outcomes. The scoring system adopted in this study follows that used by Kapetsky and Nath (1997), where a 4-point scale was used, the highest score (4) being that relative to the best conditions (Most Suitable), for the purpose of the outcome, whereas the lowest score (1) was reserved for areas which are inadequate (Unsuitable). Areas may also be scored as (3) Suitable or (2) Moderately Suitable. The scoring system used was whenever possible, based on supporting figures for production of each species, and based on literature. The reclassification of the layers in function of the scoring attributed was achieved by using IDRISI's reclassification module **RECLASS**. The next sections briefly describe the importance of each production function for the species and its scoring reclassified in a table, supported wherever possible by literature references.

5.1.3 WATER QUALITY

Aquaculture development depends on a series of physical and environmental variables. In coastal waters some of the most important of these are: water temperature, salinity, and dissolved oxygen because they limit aquatic species growth capacity. Other water quality related parameters include the waters' natural productivity and its dissolved inorganic nutrients. To minimise risk of destruction to aquaculture installations, shelter from storms, wind and waves also needed to be considered.

Several environmental thematic layers necessary for modelling aquaculture in the study area were created for the GIS, using techniques described in Chapter 2, one for each environmental theme i.e. water temperature, salinity, dissolved oxygen content, chlorophyll-*a* content, faecal coliform content, and natural indicators.

Water temperature

Optimal water temperature for aquatic species is based on the sum of internal chemical (mostly enzymatic) reactions. Different enzymes have different optimum temperatures (Landau, 1992). The optimum temperature for an organism is that which allows the most reactions to go on at efficiencies closest to the maximum (Landau, 1992).

In the case of the filter feeder *Mytilus*, selective filtration of algal cells goes on as long as temperatures are 15° - 25°C, but will slow down considerably when temperature either increases or decreases (Landau, 1992).

Figure 5.3 was obtained by scanning a cartogram produced by SEMA (1996), and geo-referencing it to the base satellite image used throughout this study. The temperature ranges were later reclassified for suitability.

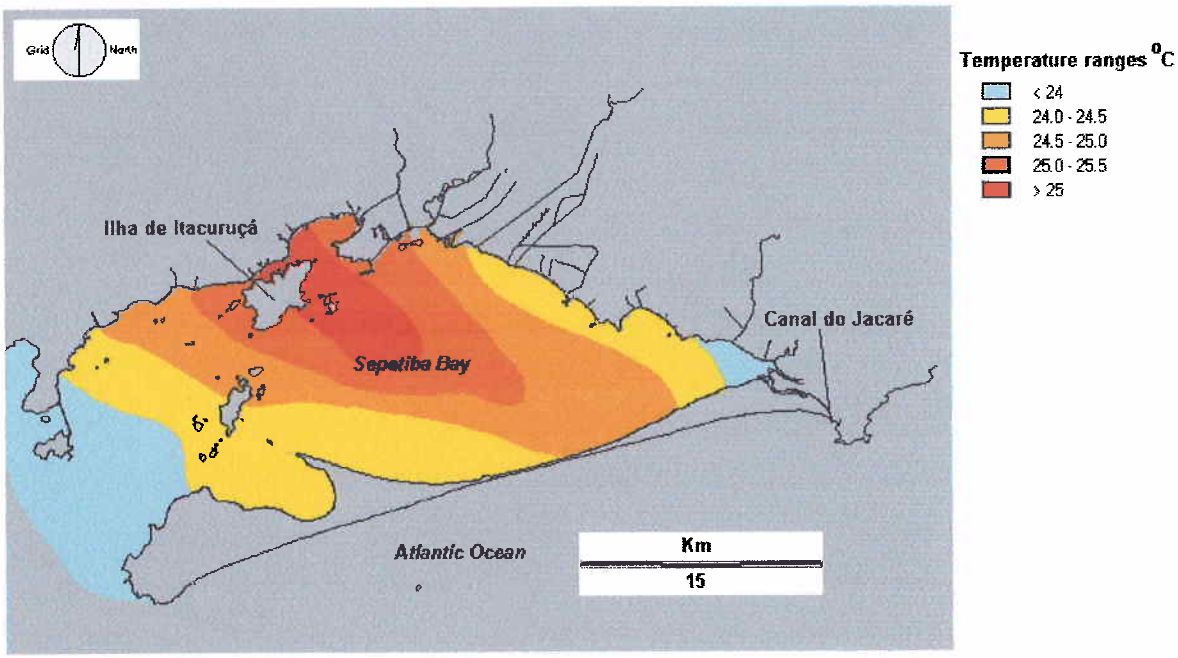

Figure 5.3 Mean annual surface water temperature.
Adapted from SEMA (1996) cartogram and geo-referenced to LandsatTM cut-out window of study area.

The circular pattern of currents in the study area is such that higher water temperatures tend to be found in the north and central region of the bay, while the cooler ocean waters tend to be found at the open end of the bay on the western side, and to a lesser extent also on the eastern side of the bay as it intrudes from the open coastal Atlantic waters to the bay via the Canal do Jacaré. (Fig 5.3). Generally, the temperature range found in the bay is suitable for the culture of both mollusc species considered.

The brown mussel *Perna perna,* one of the two filter feeding molluscs which are proposed for aquaculture development in this study, is also found widely distributed along the eastern coast of South America (Rios, 1985). Acuna (1977) and Tomalin (1995) point that growth of *P. perna* is faster in periods of high temperatures and slower in the winter months.

Marques *et al.* (1998) studied its growth at Ubatuba (23° S) and found that the typical water temperature range varies from 19° – 33.9°C. There, *P. perna* is cultivated satisfactorily with a growth rate of 24-26 mm y^{-1}. In Venezuela, Velez and Epifanio (1981) found positive growth correlation with food availability at temperatures of 21°C and 28°C.

Schurink and Griffiths (1992) who investigated the physiological energetics of mussels in South Africa found that *P. perna* grows faster at temperatures beyond 20°C. Suplicy (*pers. com.*) working in Southern Brazil with the same species, found from practical experience that the best growing sites are found in areas which have a temperature range from 19° - 24°C.

The second filter feeding mollusc considered for aquaculture development in the study area is *C. rhizophorae*. Water temperature is also important for growth of *C. rhizophorae* or *C. brasiliana,* species which are generally regarded as the same (Pereira *et al.* 1991). Their distribution range extends from the Caribbean to Santa Catarina, Brazil. Pereira *et al.* (1988) successfully cultivated mangrove oysters at Cananéia, São Paulo, in temperatures ranging from 18.2° – 31.4°C. Lemos *et al.* (1994) who cultured mangrove oyster larvae and found maximum survival at 20°C, and concluded that the younger stages require cooler waters. This study is limits site suitability to the on-growing phase. Due to the similarity of water temperature range requirements for both species, and considering the lack of more detailed information on growth performance under the full range found in the literature, in order to enable subsequent development of the models presented in the following chapters, one common scoring system was developed and adopted for both species as shown in Table 5.1. Figure 5.4 shows the reclassification results for the study area in function water temperature suitability for mollusc growing .

Table 5.1 Water temperature suitability scoring for mollusc culture based on temperature (°C)
Temperature range suitability adopted based on literature survey. Ranges do not reflect actual growth performance but rather potential.

Interpretation	Score
Most Suitable – 25 - 28°C	4
Suitable 20° - 25°C	3
Moderately suitable 17° - 20°C	2
Unsuitable < 17°C >28°C	1

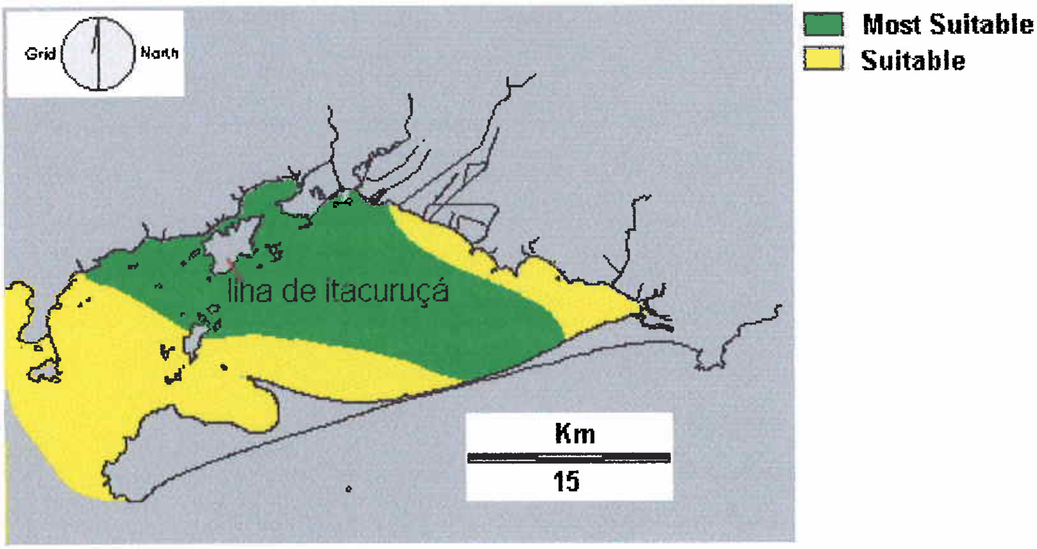

Figure 5.4 Temperature suitability reclassified image.

The reclassified image (Fig 5.4) shows a region containing the most suitable conditions according to the scoring system adopted in table 5.1, which is that around Ilha de Itaucuruçá and the central part of the bay, while all other areas falls within the suitable category. Due to the weakness of the data quality and coverage available, which was based on SEMA (1996), the reclassification results which indicate a large coverage potentially suitable for developing either longline mussel culture or rack-based oyster culture in function of surface water temperature is taken only as an indication of such.

Salinity

Salinity is defined as the ratio of conductivities of sea water to standard of 32.4356 g KCl / kg water (standard water). Its unit modern unit is the practical salinity unit (psu).

Mussels - Salinity is important in regulating the physiology of marine organisms although changes in salinity do not affect the growth of bivalves as much as variation in temperature (Laing and Spencer, 1997).

Figure 5.5 (SAL) shows the mean annual surface salinity in Sepetiba bay as found by FEEMA (SEMA, 1996). According to Marques *et al.* (1991) the mussel *P. perna* develops optimally at salinities ranging from 31.5 psu to 35.8 psu.

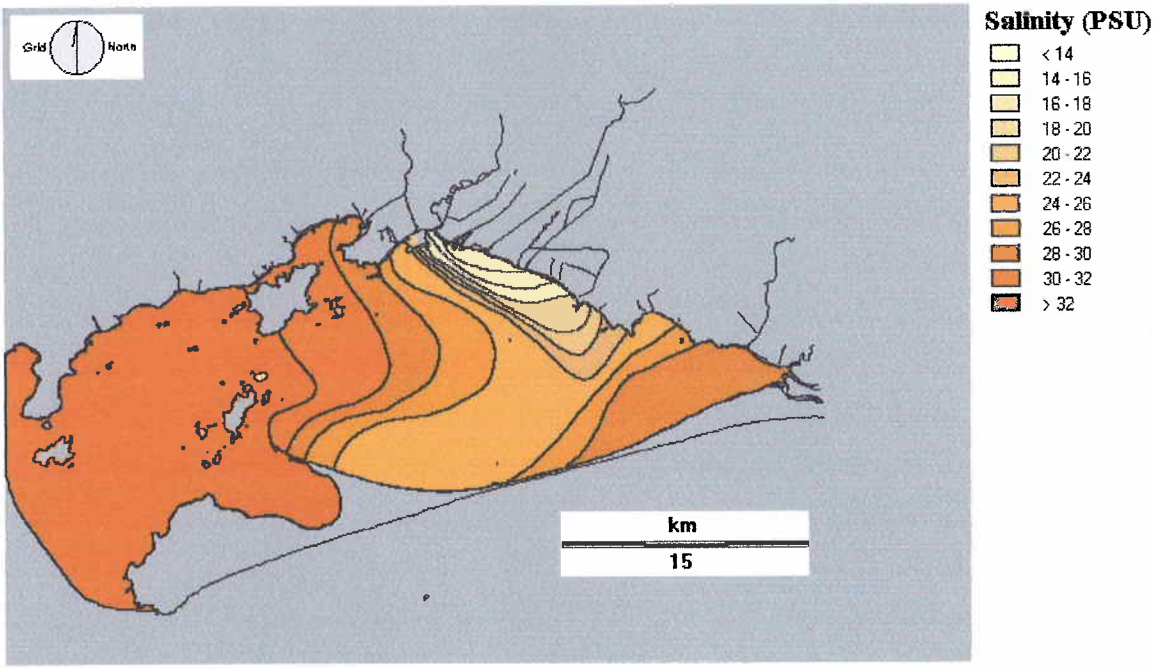

Figure 5.5 Mean annual surface salinity (psu) concentration.
Adapted from SEMA (1996) cartogram and geo-referenced to LandsatTM cut-out window of study area.

However, he successfully conducted culture of *P. perna* at stations where surface salinity became as low as 12 psu in the rainy season (Marques *et al.* 1991). Although it is generally agreed that *P. perna* is an organism preferring fully marine environments, no data on growth performance based on varying salinity conditions was found.

Suplicy (pers. com.) considers salinities between 30 psu to 40 psu to be feasible for *P. perna* culture. SEBRAE (1996) reports on mussel culture experiments undertaken in Espirito Santo, Brazil under salinity regimes ranging from 3.8 psu to 38 psu, noting that that sites where prolonged exposure to salinities lower than 10 psu did not show significant mortality or reduction in growth. However, the yearly average salinity for the two culture sites was 22.8 psu and 34.6 psu. Most bivalves usually only feed at higher salinities, so they should be preferably sited where, for as long a period as possible, salinity is within their optimum range (Laing and Spencer, 1997).

Table 5.2 shows the salinity suitability scoring system adopted in this study for the mussel growing area selection. Figure 5.6 (SALTXT) shows the reclassified image based on the SEMA 1996 data. The indication is that, with the exception of the areas close and around the mainland fresh water sources such as the rivers and canals in the northern side of Sepetiba bay, most of the area has acceptable salinity range for mussel culture.

Table 5.2 Suitability scoring for mussel growth based on salinity (psu).
Salinity range suitability scoring adopted based on literature survey. Ranges reflect an indication of expected growth performance.

Interpretation	Score
Most Suitable - Coastal waters, regular mussel habitat salinity > 22 psu	4
Suitable - Coastal waters, in areas subject to increased freshwater influence during rainy season 18-22 psu	3
Moderately Suitable - 14-18 psu	2
Unsuitable - Salinity lower than found in areas prefered by mussels. <14 psu	1

Although Figure 5.6 shows large areas in the central part of the bay reclassified as Most Suitable for mussel culture, one must bear in mind that the salinity data available for this study represents only the annual mean, which does not properly take into account large surface salinity variations occurring during the rainy season, when vast amounts of freshwater come into the bay forming surface 'freshwater tongues' extending far into the bay, as shown in Chapter 3 (Figures 3.16 and 3.17) and as confirmed in field trip measurements.

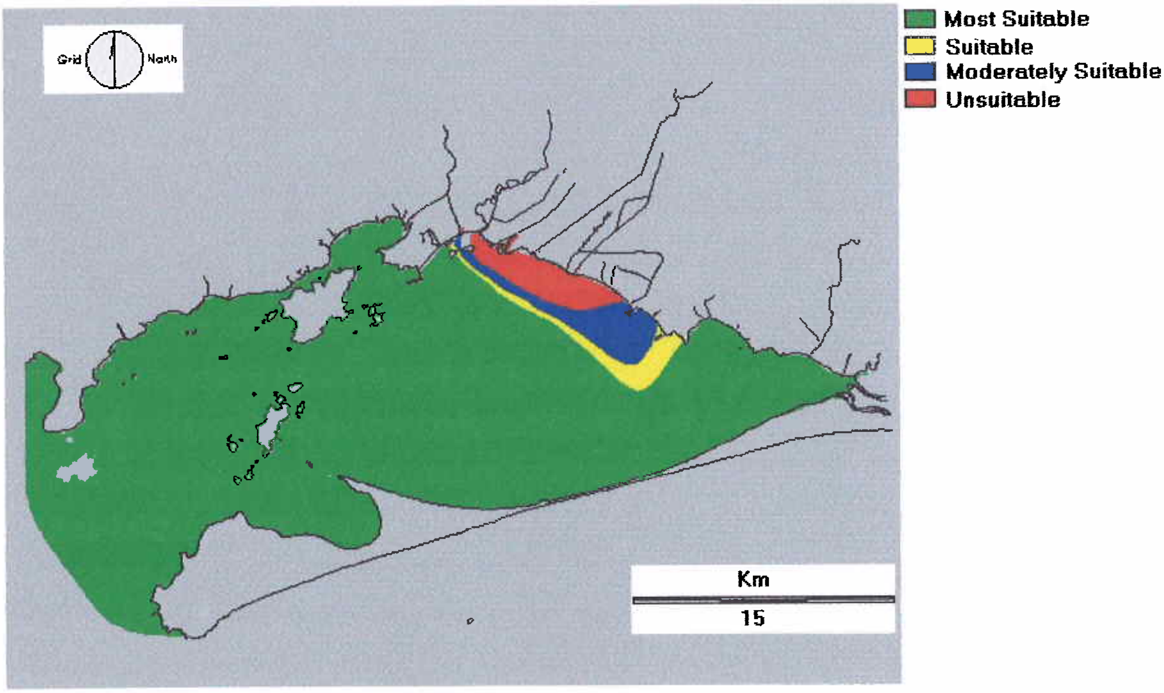

Figure 5.6 Surface salinity, reclassified suitability for mussel culture.

Although this is a seasonal condition, its duration may be enough to hinder mussel growth and even cause production losses as their byssus holdfasts can weaken in conditions of extended low salinities causing the mussels to drop from their culture installations. Thus, for a more precise salinity suitability scoring, a more comprehensive survey would be needed on a larger scale.

Oysters - Salinity requirements for oysters vary from species to species. Wakamatsu (1973) considers *C. brasiliana* as a euryhaline species able to survive salinity ranging from 8 psu to 35 psu, with the most suitable culture range between 15 psu to 25 psu. Table 5.3 shows the suitability scoring system adopted in this study for the oyster growing area selection.

Table 5.3 Suitability scoring for oyster growth based on salinity (psu).
Salinity range suitability scoring adopted based on literature survey. Ranges reflect an indication of expected growth performance.

Interpretation	Score
Most suitable Salinity fluctuation typical of areas where *C. rhizophorae* naturally occurs. 0 - 28 psu	4
Suitable Salinity suitable for *C. rhizophorae*. 28 - 30 psu	3
Moderately suitable > 30 psu	2

Figure 5.7 shows that the bay can be roughly split into a western, more saline area and an eastern, more brackish area, which is more suitable for oyster on-growing.

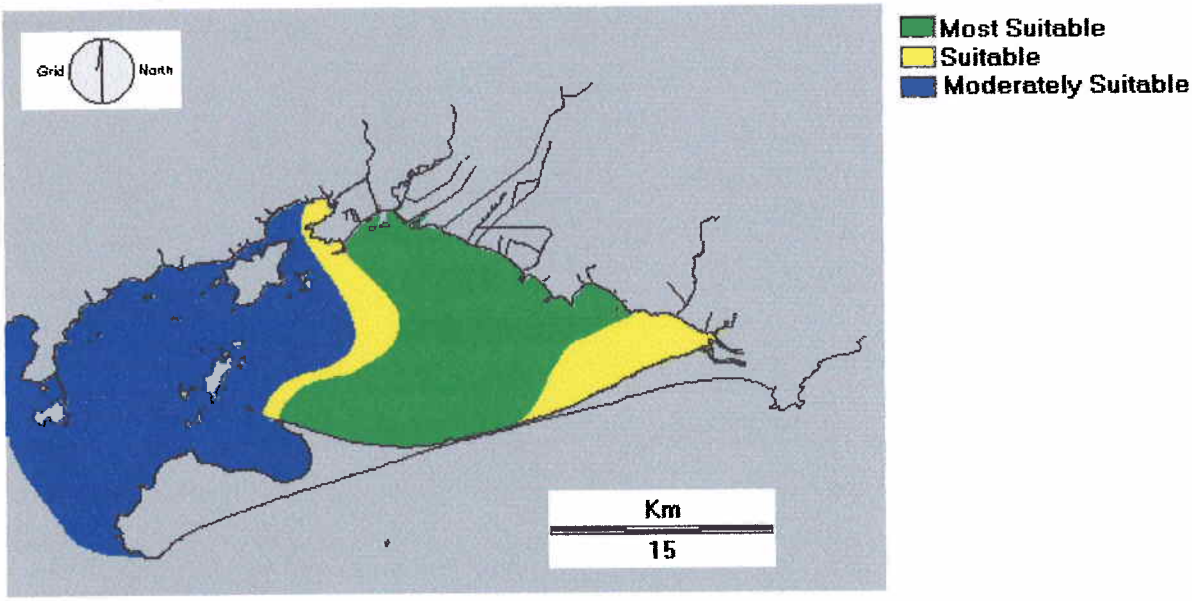

Figure 5.7 Surface salinity, reclassified suitability for mangrove oyster culture.

This reclassification result is in agreement with the perception of the state fisheries technicians and extension workers who have long elected the eastern end of Sepetiba bay as the site for their aquaculture lab site as mentioned in Chapter 2. The result of this reclassification is that a large area in the central part of the bay is suitable for oyster culture (Fig 5.7). Most of the areas classified as Most Suitable and Suitable fall in the central and eastern half of the bay, much of it along the mainland.

C. rhizophorae has its natural habitat in Sepetiba Bay, among *Rhizophora mangle* prop roots in mangrove areas. To date, naturally produced oysters are harvested mostly on the eastern end of the bay. The result of the image reclassification (Fig 5.7) shows this area as Suitable and is interpreted here as a good indication of the scoring system adopted.

Dissolved oxygen content

Aquatic animals are generally very good at removing oxygen from the water. Dissolved oxygen (DO) in aquatic culture is one of the most critical parameters for successful aquaculture. In the marine environment, the action of waves, winds and currents usually favours saturated levels of dissolved oxygen (8 –12 mg l^{-1}). Under restricted culture volume conditions, many aquaculturists will try to maintain a DO level of at least 5 mg l^{-1} (Landau, 1992).

Bivalve molluscs generally have a fairly high tolerance to low dissolved oxygen concentrations and can also adapt by reducing their metabolic activity rate, to the extent of using anaerobic respiration to provide energy needs (Laing and Spencer 1997).

A pumping oyster removes about 5 per cent of the oxygen content of the water passing through the mantle cavity. Bivalve molluscs can close their valves in cases where water conditions are poor, including when DO levels are low. Although they are able to withstand long periods like this, they build up an 'oxygen debt' which has to be repaid when the are able to restart pumping water through their systems (Walne, 1979).

Figure 5.8 shows the mean annual surface water dissolved oxygen concentration found in Sepetiba bay (SEMA, 1996).

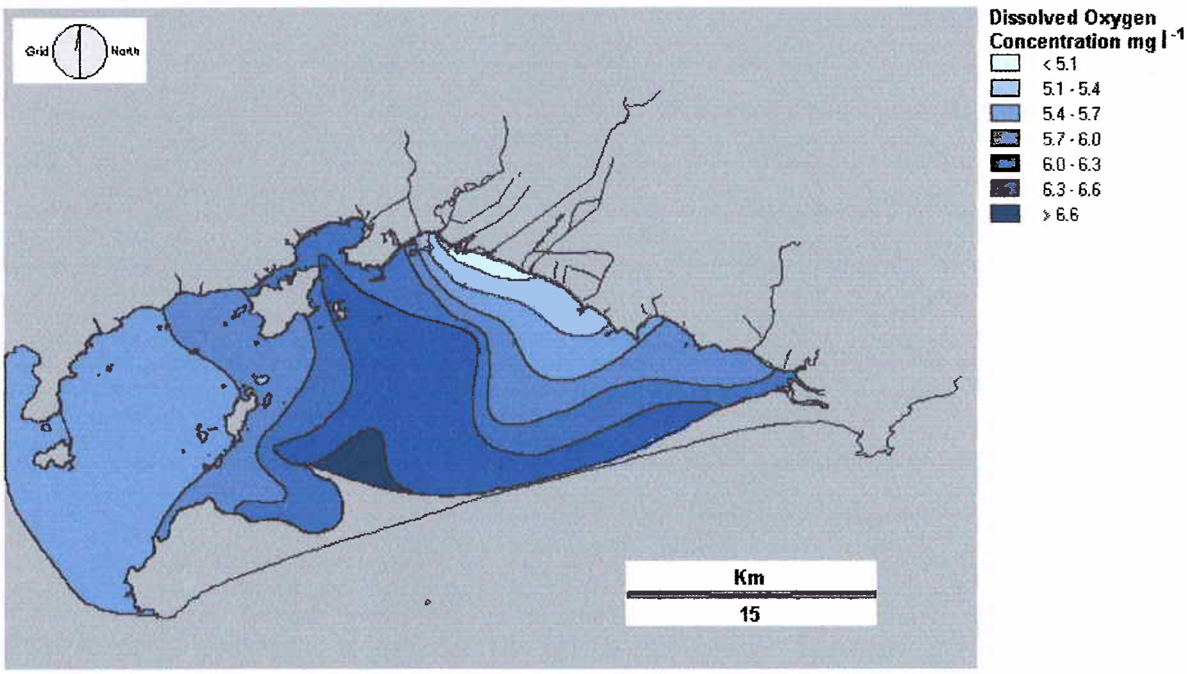

Figure 5.8 Mean annual dissolved oxygen concentration mg l^{-1}.
Adapted from SEMA (1996) cartogram and geo-referenced to LandsatTM cut-out window of study area.

Table 5.4 shows the scoring system adopted in this study. It assumes that most aquatic species need oxygen for their physiological needs, and also bivalve molluscs can withstand periods of low concentrations.

A lower limit of 2 mg l^{-1} was set to take into account events where these waters might have an extra load of organic matter which will increase the Biological Oxygen Demand (BOD) placing the culture organisms at risk for several hours or even maybe more than a day.

Table 5.4 Suitability scoring for dissolved oxygen content (mg l^{-1}) for bivalve molluscs cultivation. Oxygen suitability scoring adopted reflect an indication of expected tolerance.

Interpretation	Score
Most Suitable Enough oxygen for respiration, food digestion and growth >5 mg l^{-1}	4
Suitable Enough oxygen for respiration 3-5 mg l^{-1}	3
Moderately Suitable Enough oxygen for respiration 2-3 mg l^{-1}	2
Unsuitable Low level of dissolved oxygen for extended periods may cause mortality and stock losses. <2 mg l^{-1}	1

SEBRAE (1996) has reported successfully conducting mussel and oyster culture in sheltered mangrove areas in Espirito Santo, Brazil with DO levels of the waters ranging from 3.2 – 12 mg l^{-1}. Figure 5.9 shows the reclassified suitability image where most of the bay area falls within the Most Suitable category for the criterion dissolved oxygen content.

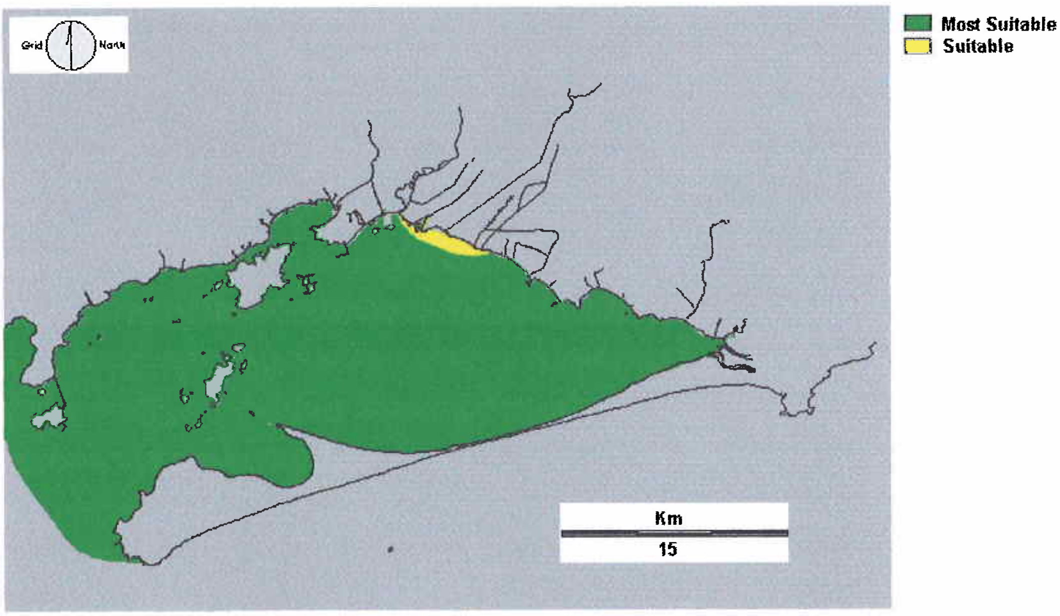

Figure 5.9 Dissolved oxygen concentration is most suitable in most of Sepetiba bay.

It must be said that the database for this thematic layer consisted of water samples collected only at the surface during daytime, by FEEMA's 1990 water quality data gathering campaign.

If samples were collected below the surface, or even close to the bottom, and/or during night hours, the oxygen concentration distribution profile could well be different, possibly showing different suitable, as well as unsuitable areas.

Also, most of the sampling stations for the above data are well away from mangrove areas, where higher levels of organic matter and detritus exist and could contribute towards lower DO values. Lower subsurface DO levels would be detrimental especially to bottom culture of oysters close to mangrove areas.

Phytoplankton biomass

Phytoplankton constitutes the main food source for filter feeding molluscs such as mussels and oysters. As such, it was considered that a layer representing its concentration would be a useful indication of site suitability for the filter feeding aquaculture species concerned. Phytoplankton abundance is indicated by chlorophyll-*a* concentration in water samples. Page and Hubbard (1987) studied blue mussel growth (*Mytilus edulis*) in relation to water temperature and potential food availability, and found that temporal variation in the growth of mussels, correlated with chlorophyll-*a* concentration. Favourable mussel culture production areas such as the Marennes–Oléron regions in France and Ria de Arosa in Spain have high phytoplankton biomasses situated between 10-40 $\mu g\ l^{-1}$ Chl-*a* (Héral, 1991). Table 5.5 shows the suitability scoring criteria adopted for primary productivity suitability scoring used in this study.

Table 5.5 Primary production suitability scoring for mollusc culture based on Chl-*a* ($\mu g\ l^{-1}$) concentration. Chl-*a* concentration suitability scoring adopted based on literature survey. Ranges reflect an indication of expected growth performance.

Interpretation	Score
Most Suitable Productive waters – Plentiful supply of phytoplankton for filter feeders. Good growth potential. (Héral, 1991) 18 – 30 ($\mu g\ l^{-1}$)	4
Suitable Average growth conditions 10-18 ($\mu g\ l^{-1}$)	3
Moderately suitable Areas with lower nutrients concentrations/moderate growth potential 6-10 ($\mu g\ l^{-1}$)	2
Unsuitable Poor, oligotrophic waters < 6 ($\mu g\ l^{-1}$)	1

Coastal waters with river runoff tend to have a fertilising effect for phytoplankton, and this is the case in Sepetiba, where there are 18 rivers and canals contributing nutrients for primary production enhancement. Also, the study area has many shallow areas (0-3 m) where microphytobenthos can develop. Chlorophyll-*a* distribution information available for Sepetiba bay is very scarce and limited and is shown in Fig. 5.10.

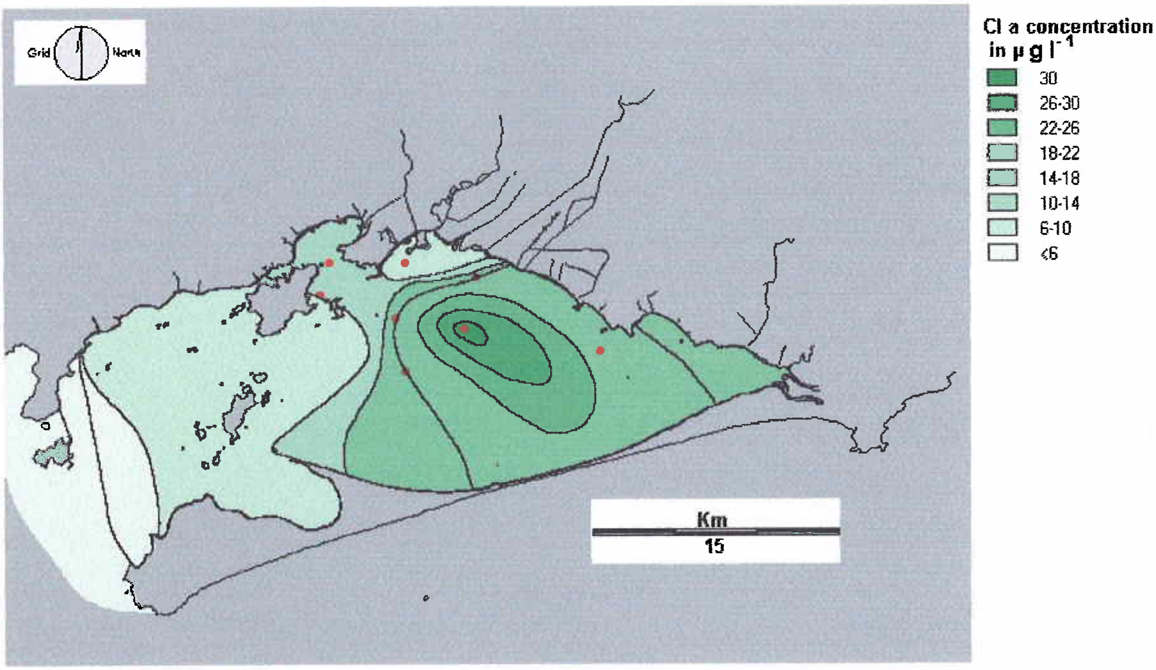

Figure 5.10 Mean annual Chlorophyll-*a* (µg l^{-1}) concentration distribution.
Feema sampling stations indicated as red dots. Adapted from SEMA (1996) cartogram and georeferenced to LandsatTM cut-out window of study area.

This chlorophyll-*a* distribution represents the annual mean, which was based on only eight sampling stations covering less than half of the water surface of the bay, monitored on a monthly basis for 10 months by FEEMA in the year 1990.

Since then, no further regular sampling surveys have been made covering large areas of the bay. The interpolation results of such a low number of sample points over such a large and dynamic area is likely to produce a gross generalisation of the Chl-*a* distribution. However it was the only source of data available at the time of this study. In order to complement and develop broader picture of the sparse Chl-*a* distribution information available for the bay, especially in those areas furthest away from the sampling stations used by FEEMA, an improvised Chl-*a* distribution map was created using the available Lansat TM image. This was done as a *one-off* study to contribute towards the overall model and not intended to reflect actual Chl-*a* concentration over the bay from one isolated snapshot. Additionally the study area is the study area lies in coastal area where silt coming in from rivers and yellow substance from decaying organic matter coming from terrestrial run-off, make for difficult interpretation of Chl-*a* from Landsat satellite imagery. More detailed and concise Chl-*a* layer addition would be potentially very useful to GIS/RS studies involving filter-feeding molluscs in the coastal area. The new map (Fig. 5.11) is an interpretation obtained by applying the algorithm developed by Costa *et al.* (1998) for the coastal waters of the neighbouring state of São Paulo, which has the same general characteristics as those which are found in Sepetiba bay.

This model uses a relation between bands two and three of Landsat-5 TM. Costa *et al.* (1998) found using the following equation:

When this algorithm was applied to the satellite image containing the study area it produced a range of values for Sepetiba Bay, comparable with that found by SEMA (1996) (6 - 30 $\mu g\ l^{-1}$ Chl-a). This range is also similar to that found by Machado *et al.* (1998) where values range between 3 to 20 $\mu g\ l^{-1}$ Chl-*a* predominate. Costa's analysis of Chl-*a* was based on radiometrically and atmospherically corrected Landsat TM image. (Costa, pers. com. 2003) Costa used the technique described by (Chavez 1988) and Markham and Barker (1987). The image in this study was supplied by INPE with level 6 whereas the image used in this study was not.

Costa (1998) carried out corrections for illumination and radiometric correction for the sensor and correction to minimise atmospheric effects. Costa estimates that the effect of the algorithm applied to the Sepetiba area in an image not atmospherically corrected, as was used in the present study, may have overestimated Chl-*a* concentration. Costa's algorithm does not use band TM1, which is the most affected by the atmospheric effect.

The satellite image interpretation of Chl-*a* concentration produced using Costa's algorithm (Fig 5.11) was incorporated in the GIS, as a subsidiary proxy layer together with FEEMA data (Fig 5.10) by means of an **OVERLAY** operation. Fig. 5.12. shows this result in which only the highest value of each image was retained. This image was smoothed of abrupt differences between values, using a 3 x 3 pixel **FILTER**.

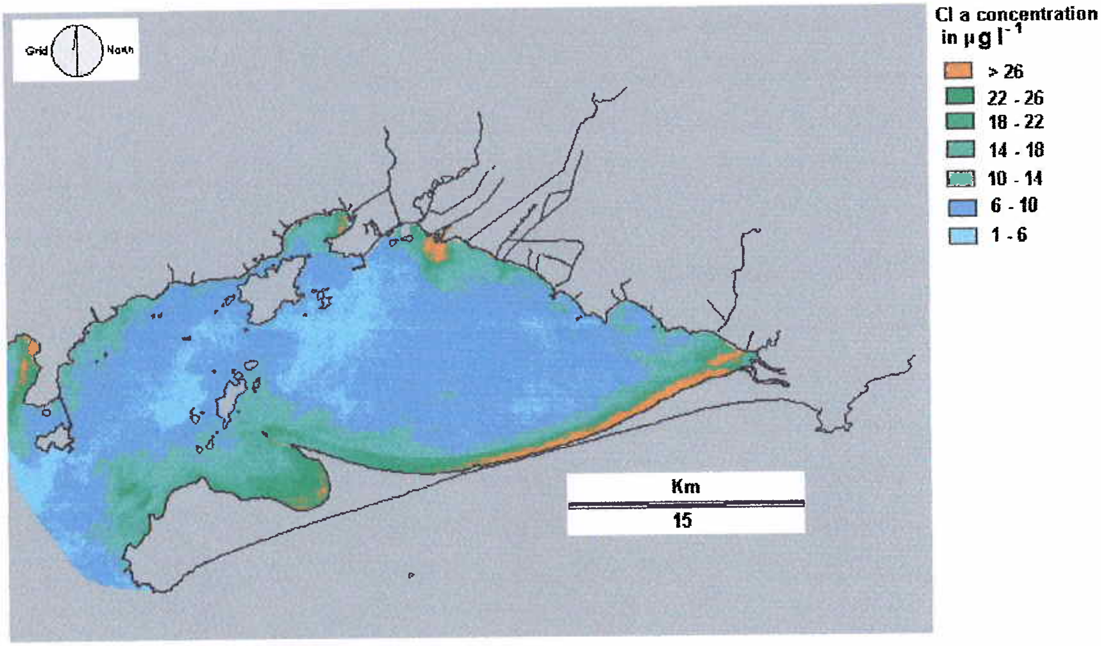

Figure 5.11 Chlorophyll-*a* (µg l^{-1}) distribution interpreted from satellite image.

Figure 5.11 shows conspicuously higher Chl-*a* (> 26 µg l^{-1}) concentration areas in front of the Canal de São Francisco and a area visible as a long narrow strip extending from the Rio Piracão on the southern edge of the bay westwards along the Restinga da Marambaia. This comes from the fact that interpretation of waters with high sediment loadings is very difficult. The interpretation of Fig 5.12 is that the central-eastern portion of the bay is a potentially higher productivity area, favourable for shellfish cultivation, but also as an area to pay attention in case eutrophic conditions evolve or toxins from algal blooms build-up.

Increase of raw sewage resulting from urban sprawl and insufficient treatment facilities, associated with seasonal conditions may favour plankton blooms, still rare in the area, but could potentially translate into potential losses for aquaculture ventures. The present site suitability analysis is not intended to predict areas prone to algal blooms.

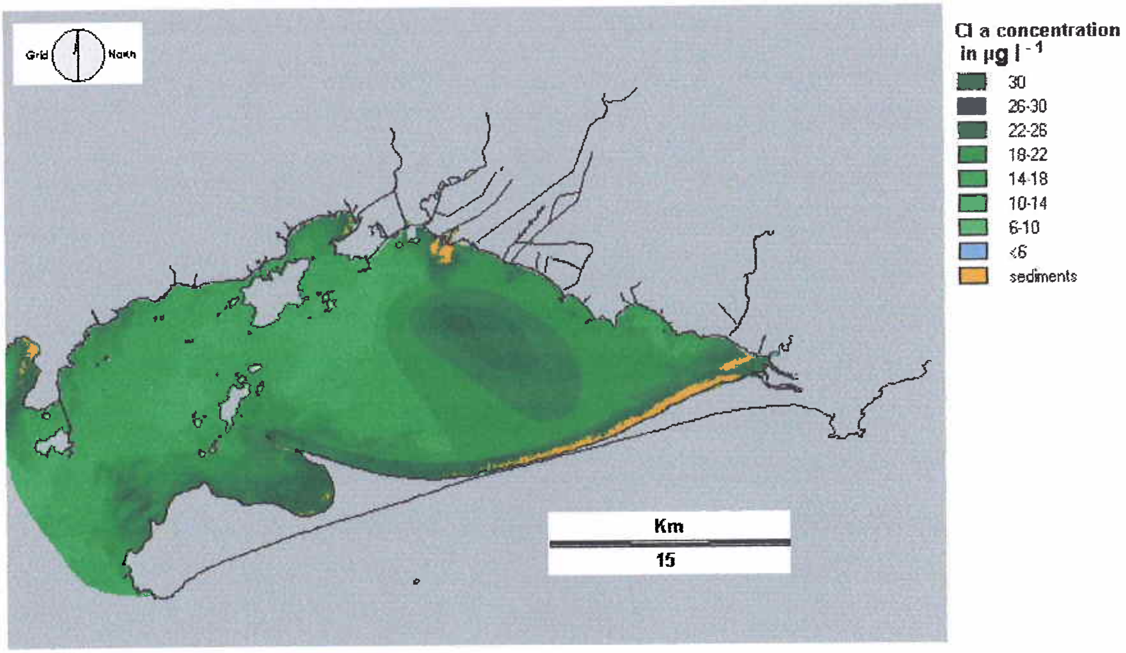

Figure 5.12 Results of Chlorophyll-*a* (µg l^{-1}) distribution interpreted from overlay operation. Satellite interpretation and SEMA (1996) data overlayed with maximum values kept.

The final reclassified image for mollusc farming areas (Fig 5.13) which was obtained by applying the scoring criteria described in Table 5.5 shows 300.7 km^2 of areas classified as Most Suitable for bivalve mollusc culture.

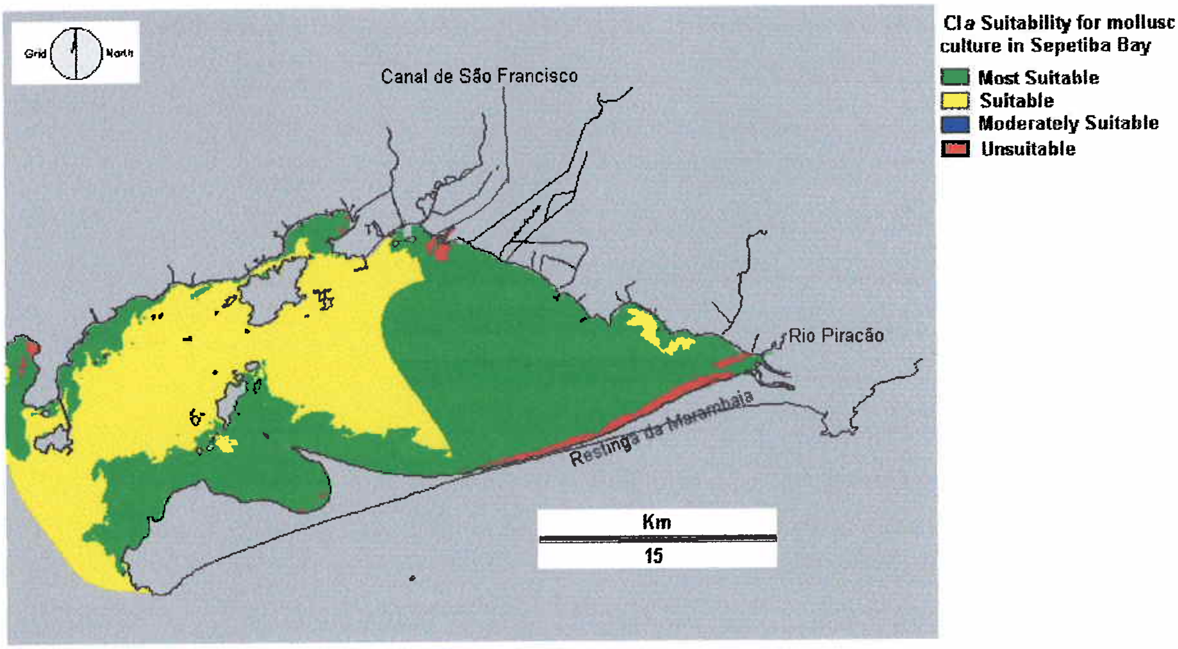

Figure 5.13 Site suitability for bivalve mollusc culture as function of food availability. Bivalve mollusc food availability interpreted as Chlorophyll-*a* concentration derived from satellite image interpretation and SEMA (1996) data.

These areas are present in the north-eastern part of the bay where mangrove oysters naturally grow, as well as in the south-western areas where brown mussels grow. They also include all the areas in and around mangroves where high natural productivity occurs.

Two areas were reclassified as Unsuitable. They are in front of the Canal de São Francisco and the long narrow strip along Restinga da Marambaia extending from the Rio Piracão westwards on the southern edge of the bay (Fig 5.13).

Faecal coliforms

Bivalves selectively filter phytoplankton from the seawater during feeding. However, in the process they take in some bacteria and viruses.

Some of these, especially those originating from domestic sewage discharges, which typically contain pathogenic bacteria such as *Salmonella* sp., *Shighella* sp., *Clostridium* and non-pathogenic *Escherichia coli* can cause serious illness in human consumers if they remain in the bivalve when it is eaten (Laing and Spencer 1997, Shumway 1992). In the UK it is a statutory requirement that shellfish beds from which harvested bivalves are intended for consumption must be classified according to the faecal coliform levels of the bivalve flesh (Table 5.6). This classification is issued initially on a provisional basis after sampling fortnightly for 3-4 months and a full classification may be achieved after a year of continuous sampling at monthly intervals. The EC has established directive 91/492/CEE in 15.07.91 published in DOCE number L268 which states the conditions for production areas including the location and the boundaries of production areas are to be fixed by the competent authority, and are classified into three groups.

Case 1 areas: molluscs can be collected for direct human consumption and must comply with the following requirements:

1. The possession of visual characteristics associated with freshness and viability, including shells free of dirt, an adequate response to percussion, and normal amounts of intravalvular liquid.

2. They must contain less than 300 faecal coliforms or less than 230 *E. coli* per 100 g of mollusc flesh and intravalvular liquid based on a five-tube, three-dilution MPN-test or any other bacteriological procedure shown to be of equivalent accuracy.

3. They must not contain *Salmonella* in 25 g of mollusc flesh. (http://158.169.50.70/eur-lex/en/lif/dat/1991/en_391L0492.html).

Case 2 areas: molluscs can be collected but only placed on the market for human consumption after treatment in a purification centre, after relaying. Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three-dilution MPN-test of 6,000 faecal coliforms per 100 g of flesh or 4,600 *E. coli* per 100 g of flesh in 90% of samples.

Case 3 areas: , molluscs can be collected but only placed on the market after relaying (moving the molluscs to approved areas) over a long period (at least two months), whether or not combined with purification, or after intensive purification for a period. Live bivalve molluscs from these areas must not exceed the limits of a five-tube, three-dilution MPN-test of 60,000 faecal coliforms per 100 g of flesh.

Table 5.6 Criteria for classifying shellfish harvesting areas in the UK. Source Laing and Spencer (1997).

Classification category	Faecal coliform bacteria (*E. coli* per 100 g flesh)	Comment
A	Less than 300 (<230 *E.coli.*) in all samples	Suitable for consumption
B	Less than 6,000 in all samples	Depuration needed (or relaying in a category A area or cooking by an approved method)
C	less than 60,000 in all samples	Relaying (minimum of 2 months) in category A or B area needed (or cooking by an approved method)
Prohibited	Above 60,000	Cannot be taken for placing on the market.

In the absence of habitual methods of detection of virus and virological norms, sanitary control will be based on faecal bacteria (Casabellas, 1991).

In Brazil, the national environment council in its resolution Nr. 20 (CONAMA, 1986) specifies the following water quality standards for faecal coliform tolerances in marine and brackish marine waters (water classes 5 and 7) specifically for the purpose of harvesting or farming aquatic species:

> *"For harvested or intensively on-grown species which will be consumed uncooked, mean concentration not to exceed 14 faecal coliforms per 100 ml, with not more than 10% of samples exceeding 43 faecal coliforms per 100 ml. For other uses not to*

exceed a limit of 1,000 faecal coliforms per 100 ml in 80% or more of at least 5 monthly samples in any month."

The Brazilian Food Health Standards Division (Divisão de Vigilância Sanitária de Alimentos - DINAL) states that shellfish should not contain an *E. coli* MPN more than 102 per gram of meat. According to the Codex Alimentarius standards, in France, acceptable culture areas are classified as having an *E. coli* MPN of 160/100 ml of sample of flesh meat, not to be exceeded in 90% of the samples during one year and an *E. coli* MPN of 500/100 ml sample of flesh meat not to be exceeded in 10% of the samples taken during the year. Although CONAMA sets at 14 MPN of *E.coli* per ml of culture water as the limit for harvesting of animals to be consumed uncooked, a limit set at this level would be unrealistic, especially considering that fiscalisation or monitoring of coastal waters is all but inexistent. For the purposes of this study, the classification scheme proposed for culture waters for bivalve molluscs was that suggested by Magalhães and Ferreira (1997) and CONAMA (1986) and scored accordingly as shown in Table 5.7.

Table 5.7 Water suitability scoring for mussel/oyster culture based on *E.coli* MPN/100 ml.
Adapted from Magalhães and Ferreira (1997).

Interpretation	Score
Most suitable Culture, natural harvesting or stocking of molluscs allowed *E. coli* MPN/100 ml = <70	4
Suitable Culture, natural harvesting or stocking of molluscs allowed, Depuration before sales or consumption mandatory *E. coli* MPN/100 ml = 70 - 700	3
Unsuitable Culture, natural harvesting or stocking in these waters prohibited. *E. coli* MPN/100 ml >700	1

During the period of this study, neither *E. coli* or total coliform count data for the bay waters was available. No shellfish water area classification existed for Rio de Janeiro state. This is still an initiative which is being discussed by federal and state authorities. The EU directive cited previously may not be adequate for subtropical water conditions as found in the Rio de Janeiro area. For the modelling purposes of this study, proxy data was created by freely digitising on-screen, concentration zones based on the proximity of the waters to the closest urban centres and freshwater discharges into the bay such as rivers and canals as indicated in Fig. 5.14. The rationale being coastal waters with high MPN o *E. coli* will be highest closer to human agglomerations and freshwater courses carrying untreated domestic sewage from the watershed.

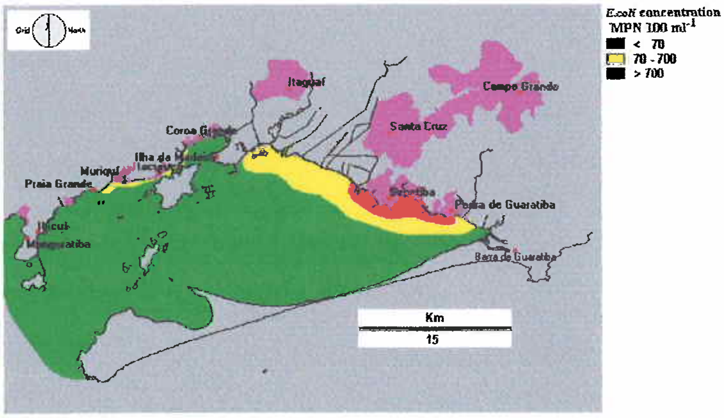

Figure 5.14 Proxy layer representing *E.coli* concentration (MPN 100 ml $^{-1}$) distribution in Sepetiba bay.

The zone with highest potential organic and bacterial pollution from sewage discharges is known to be close to the town of Sepetiba where an underwater pipeline discharges raw sewage into the bay.

Figure 5.15 shows the reclassified proxy layer of *E. coli* concentration suitability image adopted for this study, which when analysed with the AREA module of IDRISI, indicates 478 km^2 classified as Most Suitable, 48 km^2 classified as Suitable, and 14 km^2 of Unsuitable areas. This evaluation of the proxy layer shows that about 88% of the bay falls within the Most Suitable category, a temporary, proxy indication to allow the models in the following chapter to be developed. Real data can be input into the model when it becomes available.

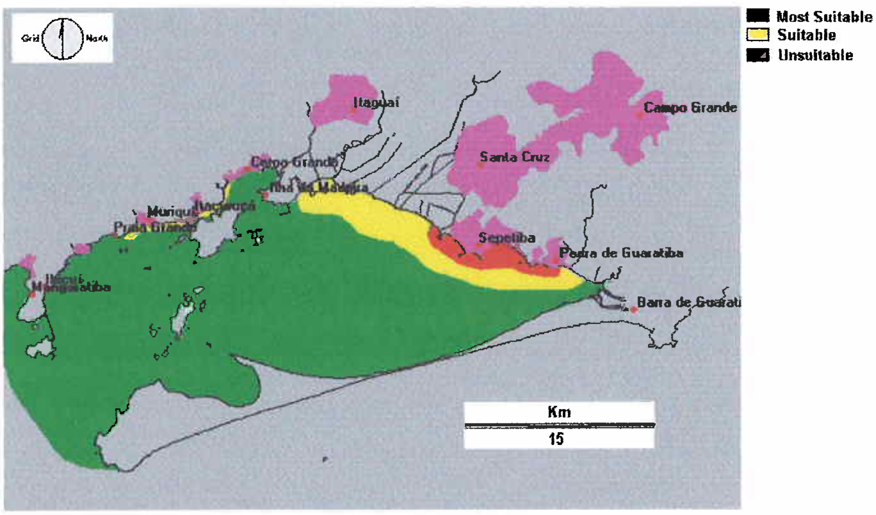

Figure 5.15 Suitable areas for bivalve culture in function of faecal coliform content of culture waters.
Proxy layer developed for the study area based on CONAMA (1986) AND Magalhães and Ferreira (1997).

Natural Indicators

Throughout the study area, mussels and oysters occur naturally. They occur wherever local conditions allow them to grow. Since it would be quite difficult to survey all the areas where these two species naturally occur, a layer was developed to indicate many visited where the existence of these two species was confirmed and other areas where conditions based on proximity should be suitable. For the oyster *C. rhizophora,* a good natural indicator representative of the water conditions where it naturally grows can be said to be those areas in and around the local mangroves. To identify mangrove coverage in the study area, a supervised classification procedure was carried out using the LANDSAT TM data, creating a colour composite image of bands 354. To all the mangrove areas determined in this new image, a DISPERSE routine was carried out. The resulting image was overlaid with the image containing only the bay waters, and a buffer was applied limiting to within a 100 m radius extending from the mangroves bay side limits. Similarly, natural conditions for development of the mussel *P. perna* exist in many parts of the bay. During the field trips carried out throughout the study period, these sites were recorded for those places where adult mussel populations were found. These were mostly along the rocky coasts around Jaguanum and Marambaia Islands, as well as on the bamboo and mangrove wood structures of the fish traps in the Guaratiba region. To indicate areas of probable favourable growth conditions, a 100 m radial zone was extended into bay waters from selected point data (Appendix 1). Figure 5.16 shows the results of this layer development.

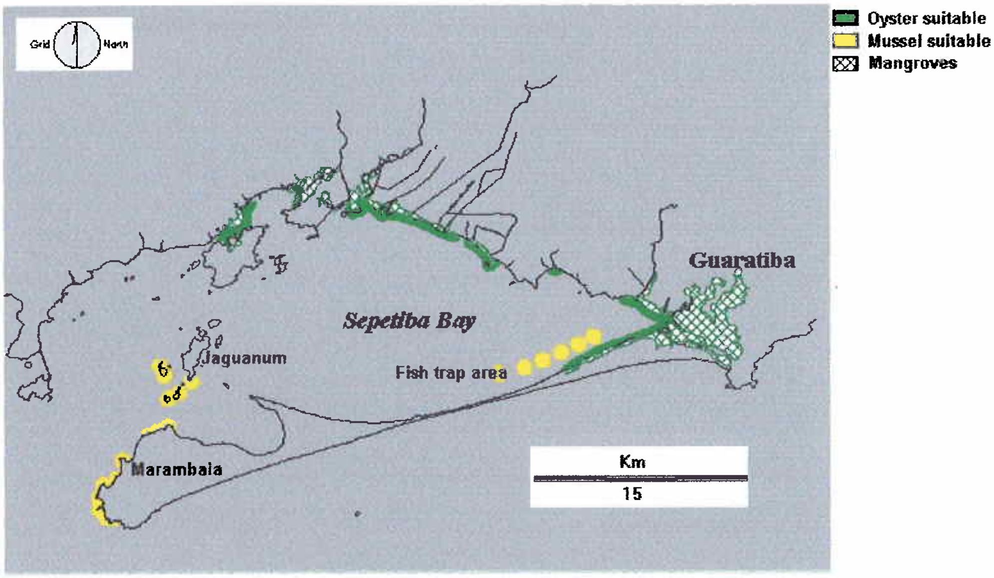

Figure 5.16 Layer indicating favourable areas for mollusc growth, based on natural indicators.

Natural indicators considered for bivalve mollusc culture included natural populations of mussels and oysters identified in field work.

5.1.4 INFRASTRUCTURE

Aquaculture development depends on a series of infrastructural elements, some relating to physical infrastructure others relating to social aspects. Some of these include:

Technical support

Several stages of aquaculture development demand the support of specialised technicians. These technicians are usually fisheries, aquaculture and agriculture extension personnel paid by local governments. They are important in passing on scientific know-how which enables the activity to develop. The know-how, or technical support layer, was created by considering distance of the coastal area from the locations of extension offices found in the region. The most distant one is in Rio de Janeiro (FIPERJ), which is only 60 km away. In general for this study, it was judged that sufficient number of technically trained staff (about 50-100) are present in the region, close enough to cover the advice needs for at least the initial phases of aquaculture development and production. In this way, the 'technical support' layer was created with a Most Suitable classification encompassing the whole study area. Because the layer shows suitability for the whole region, it is not shown here. It is included in the modelling, as the reality of other regions may be different, and the model will still be pertinent, even if a new layer reflecting local reality has to be input.

Road Network -

The extent of the road network and its quality are important for the flow of raw materials and services to and from the production sites, as well as allowing production to reach local, regional and foreign markets. Solutions to aquaculture problems sometimes depend on the prompt arrival of a technician or piece of equipment to the production site. The suitability scoring criteria shown in Table 5.8 took into account the fact that Sepetiba region is relatively well served by primary tarmac covered roads, where average travel speed is about 50 km/h. The transportation of goods, services and raw materials currently uses this road network. These roads serve all the local ports, which are points of access for fishermen, and potentially aquaculture. The topography of the region is such that the road network in the eastern part of the study area is slightly more distant from the shoreline because it lies in flat coastal lands. Access to the water, by road, is possible from several coastal towns (Fig. 5.17). In contrast, the coastal mountains which predominate in the eastern side make for a short distances between shoreline and service roads.

Table 5.8 Suitability scoring for accessibility of goods and services in the bay.

Suitability in function of distance (km) of potential mollusc culture sites to closest port/ primary road. Access by small boat powered by 15 HP engine, able to travel about 10 km/h.

Interpretation	Score
Most suitable 30 min boat ride to port / road. 0-5 km	4
Suitable 60 min boat ride to port / road. 5-9 km	3
Moderately Suitable 90 min boat ride to port / road. 9-14 km	2
Unsuitable Over 90 min boat ride to port / road. >14 km	1

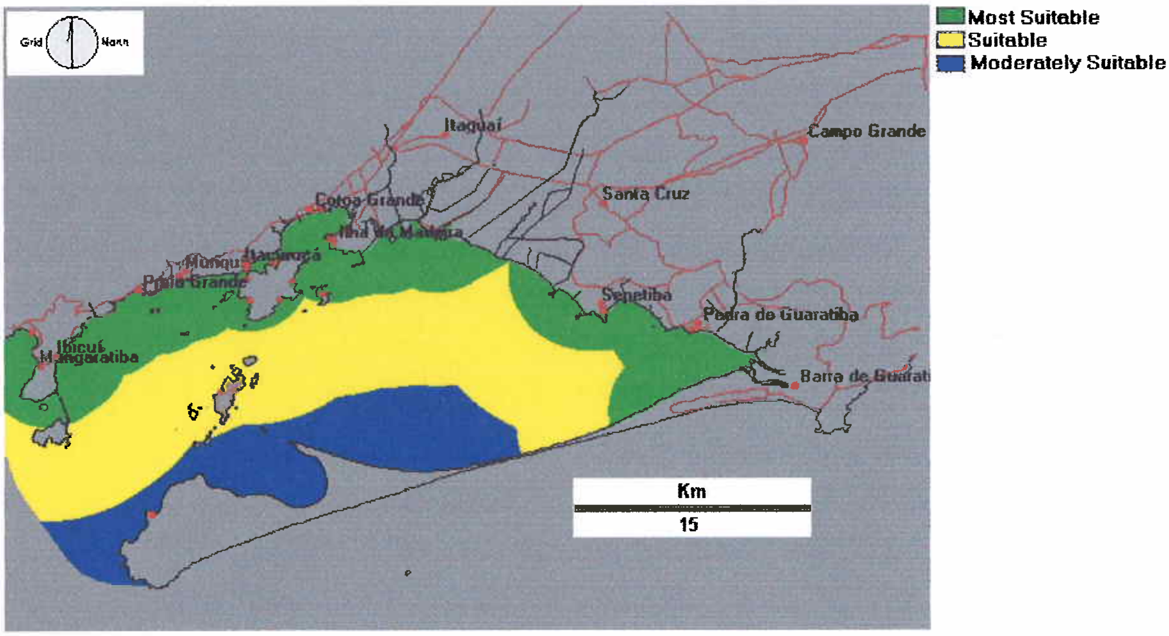

Figure 5.17 Mollusc site suitability reclassified in function of distance (km) to closest port/ primary road..

Location of Fishermen

Fishermen usually are targeted as actors in development of coastal aquaculture. As with other livestock, proximity of the persons involved in the caring of and maintenance of the cultivation systems favours lower costs and facilitates surveillance. The presence of fishermen in and around the bay was introduced into the GIS as an indication of favourable locations where aquaculture could successfully develop. This was input as a point file based on point locations such as a fishermen co-operatives, or residences on islands obtained in the course of the field work. Distance from these point location was 'as the crow flies', and did not take into account other considerations such as type of transportation used to cover distance which may vary from person to person, depending on size of boat and engine power.

Table 5.9 shows the scoring system utilised for reclassifying the study area in terms of the distance between fishermen locations and potential culture sites. The results of this reclassification are illustrated in Figure 5.18.

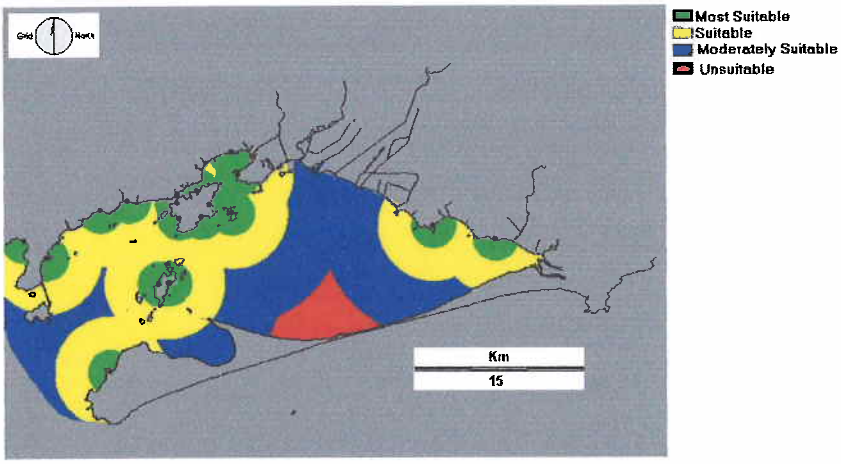

Figure 5.18 Suitability of mollusc cultivation sites as a function of distance from fishermen. Fishermen locations are indicated as black dots.

Table 5.9 Suitability scoring adopted for distance of potential cultivation sites from fishermen. Distance considered from fishermen residences or co-operatives

Interpretation	Score
Most suitable Site within visual distance enabling adequate surveillance. Access by dugout canoe or small boat and small engine (< 15 Hp) within half hour. <0.9 km	4
Suitable Site within acceptable distance, added transportation costs and time: Access time = half hour by small boat small engine 0.9 < 1.5 km	3
Moderately Suitable Site accessible if small boat and small engine available: Access time = 1 -2 hours. 1.5 – 3.0 km	2
Unsuitable > 3 km	1

5.1.5 Seed sources

Mussel seed

Mussel seed sources are essential to the development of the on-growing phase. Mussel seed can be scraped off rocks where they grow, or alternately their spat can be gathered at the appropriate times of the year from artificial collectors placed in sites close to where they breed and grow. The scoring system adopted in Table 5.10 was based on the travel distance and time from the main concentrations of fishermen houses or cooperatives to the mussel seed sources. The means of transportation available considered is their current canoes or small boats mounted with a 1 cylinder (15 HP) engine. The reclassification of the distance image from the fishermen point data sites using the scoring system of Table 5.9 is shown in Figure 5.19.

Table 5.10 Mussel seed source suitability scoring adopted for potential cultivation sites.

Suitability interpreted as ease of access to mussel seed sources from fishermen sites by small boat and 15 HP engine, able to travel about 10 km/h.

Interpretation	Score
Most Suitable Mussel seed sources such as fish traps, rocky outcrops and coastal sites where mussel grow, accessible within 15 minutes. 0 – 2.5 km	4
Suitable Mussel seed sources as above, accessible within 15 - 30 min 2.5 – 5.0 km	3
Moderately Suitable Mussel seed sources as above, accessible within 30 - 60 min 5 – 10 km	2
Unsuitable Mussel seed sources accessible only over 60 min travel time > 10 km	1

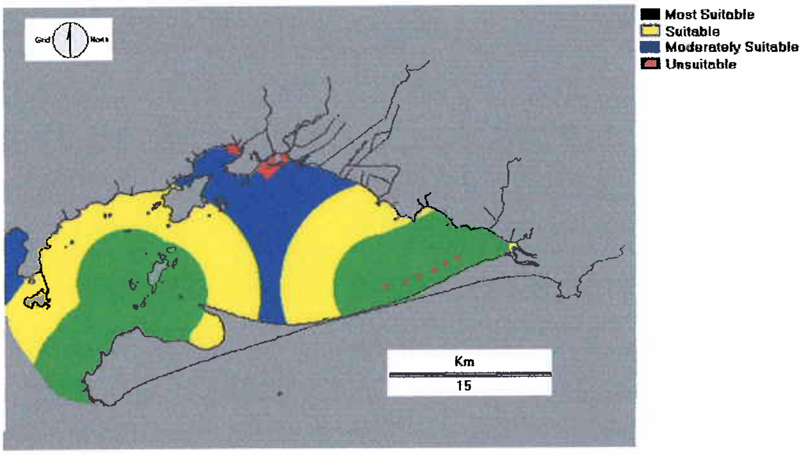

Figure 5.19 Suitability of potential mussel cultivation sites as function of distance from fishermen.

Distance considered from fishermen residences or co-operatives to naturally available mussel seed sites. Natural adult mussel populations are indicated as red dots.

Oyster seed

Oyster seed have two possible sources. One source is natural, i.e. the spat can be collected after settling on artificial collectors in mangrove areas where oysters naturally grow, or alternatively they can be mass produced by means of artificial spawning induction accomplished by the aquaculture production unit run by FIPERJ (Fig. 5.20). The suitability scoring system adopted in Table 5.11 considers that oyster spat would be transported normally over mainly secondary road by bicycle or car. Approximately the same travel speed could be attained by small boats and canoes normally used by the fishermen in the area if seed were transported over the water surface.

Table 5.11 Suitability scoring adopted for distance of potential cultivation sites from oyster seed sources. Access by car on secondary roads, travel speed about 10 km/h.

Interpretation	Score
Most Suitable Oyster seed sources such as spat collection devices placed in mangroves or alternatively FIPERJ fisheries lab, accessible within 15 minutes by vehicle or small boat with small engine (<15 HP) 0 – 2.5 km	4
Suitable Seed sources accessible within 15 - 30 min 2.5 – 5.0 km	3
Moderately Suitable Seed sources accessible within 30 - 60 min 5 – 10 km	2
Unsuitable Seed sources accessible in over 60 min travel time > 10 km	1

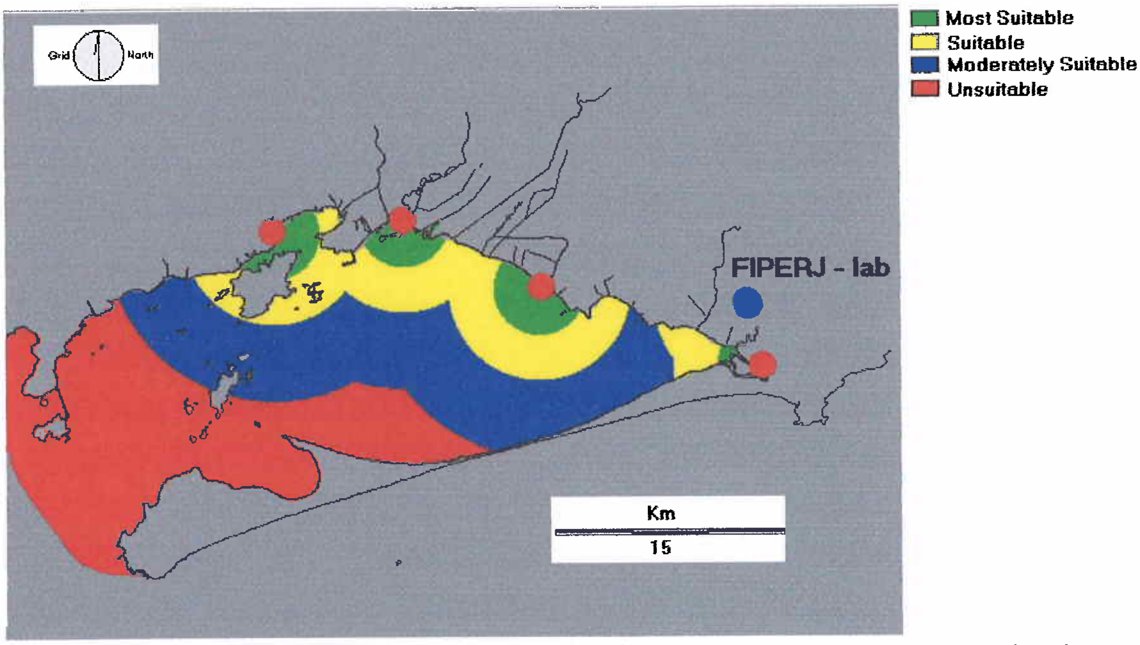

Figure 5.20 Suitability of oyster cultivation areas as function of distance from naturally occurring sites. Oyster seed supply from naturally occuring sites detected during field work are indicated as red dots, or alternatively, produced by FIPERJ hatchery, indicated as blue dot.

5.1.6 PHYSICAL FACTORS

Bathymetry

With respect to mussel, fish cage culture, and oyster farming there are different depth requirements to be considered.

According to Bompais (1991) sites for floating mussel culture should be in the 7 – 30 m range. If SCUBA inspections of the installations and culture ropes are to be carried out during the culture period, ideally, the culture ropes should be up to 14 m depth maximum, as this allows greater working time for divers (and thus lower operating costs) by avoiding decompression procedure. The same rationale follows for floating fish cages, where divers frequently have to monitor the cage bottom for removal of dead fish, as well as examine the underlying seabed for accumulation of detritus and uneaten food pellets.

Oyster culture is generally carried out in intertidal flats in the 0-5 m depth range, with culture trays or bags placed on low-lying racks made of wood which are either staked in the sediment or cemented to rocky substrate (Iversen, 1972).

Oysters can be cultured in deeper waters if they are suspended from rafts or floating longlines.

Due to the predominant tidal range in the region (up to 1.8 m) and taking into consideration the previous experience of fishermen in the local communities with the rack culture system, oyster culture area was defined as being between 0-3 m deep. These areas were identified from the GIS bathymetric database digitised from admiralty chart DHN 1622, with its depth contour lines enclosed so as to form polygons of equal depth ranges, each one identified separately. This vector file was then rasterised within IDRISI using the POLYRAS module which shows a fringe area 0-3 metres deep, an intermediate fringe area of depths ranging 3-5 m, a large central plain with depths ranging between 5-10 m and deeper waters ranging from 10-20 m towards the open end of the bay (Fig. 5.21).

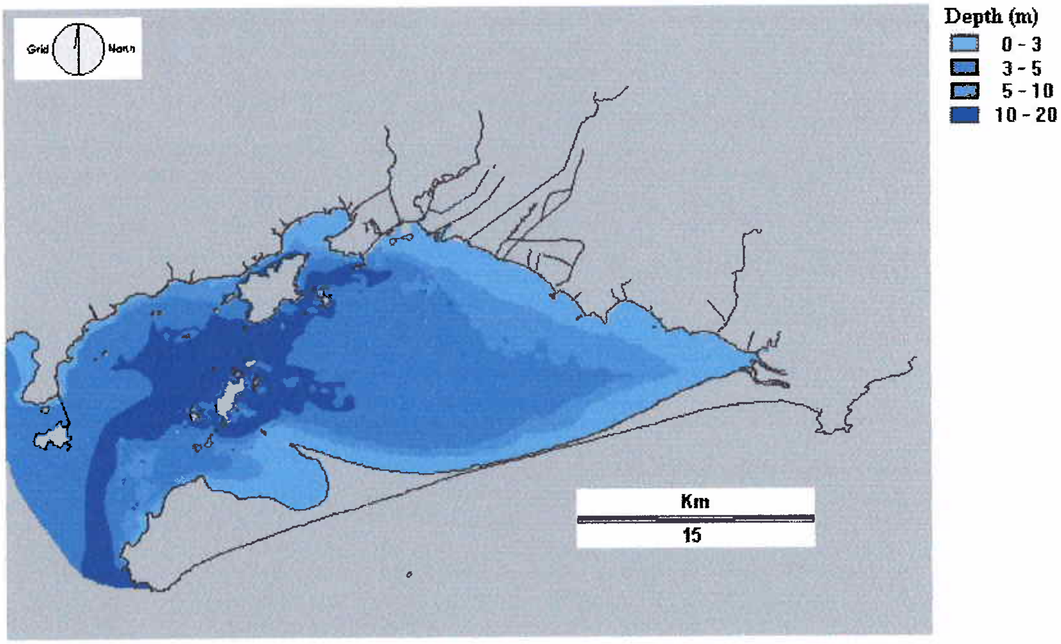

Figure 5.21 Depth ranges (m) in Sepetiba bay.
Bathymetry digitised from DHN admiralty chart 1622, and georeferenced to Landsat TM cut-out window of study area.

This image was then reclassified according to the suitability scoring criteria for mussel longline culture systems earlier described, is summarised in Table 5.12. This classification can also be extended to floating fish cage culture systems.

Table 5.12 Suitability scoring for mussel and cage fish farming installations based on depth (m).

Interpretation	Score
Most suitable Adequate distance from the seabottom, avoiding undesirable influence of resuspended bottom sediments, low mooring costs due to less quantity of cables and diver inspection possible without decompression time. 5- 10 m	4
Suitable Adequate distance, but potentially prone to influence of resuspended bottom sediments. Larger waves in shallow areas can be potentially more dangerous on structures. 3-5 m	3
Moderately suitable Diving decompression time necessary, higher mooring costs involved due to increase in cable lengths needed. 10-20 m.	2
Unsuitable Too shallow to accommodate hanging mussel ropes, or deeper waters involving decompression time for divers and higher mooring costs. <3 >20	1

Figure 5.21 was analysed with IDRISI **AREA** module revealing 246 km^2 in the Most Suitable range, 96 km^2 in the Suitable range 81 km^2 in the Moderately Suitable range and 121 km^2 in the Unsuitable range for mussel and fish cage farming.

Similarly, a reclassification was carried out to identify the areas suitable for oyster culture in Sepetiba bay. The suitability scoring system adopted is shown in Table 5.13.

Table 5.13 Suitability scoring for oyster farming sites based on depth (m)

Interpretation	Score
Suitable Within the tidal range, suitable for rack and tray oyster culture system. 0 – 3 m	4
Unsuitable Too deep for rack and tray oyster culture system. > 3 m	1

In this case, the scoring criterion was relatively simple, since it was considered that all areas between sea level and 3 m depth are suitable for oyster culture. Although areas deeper than 3 metres can be used, this study considered only culturing oysters on racks planted in the intertidal zone.

Reclassification of the bathymetric layer for Sepetiba Bay shows that 121 km^2 of coastal area were classified as suitable for oyster cultivation using the rack and tray system which can be employed in the intertidal range in waters less than 3 m deep. 423 km^2 were found to be unsuitable (Fig. 5.22).

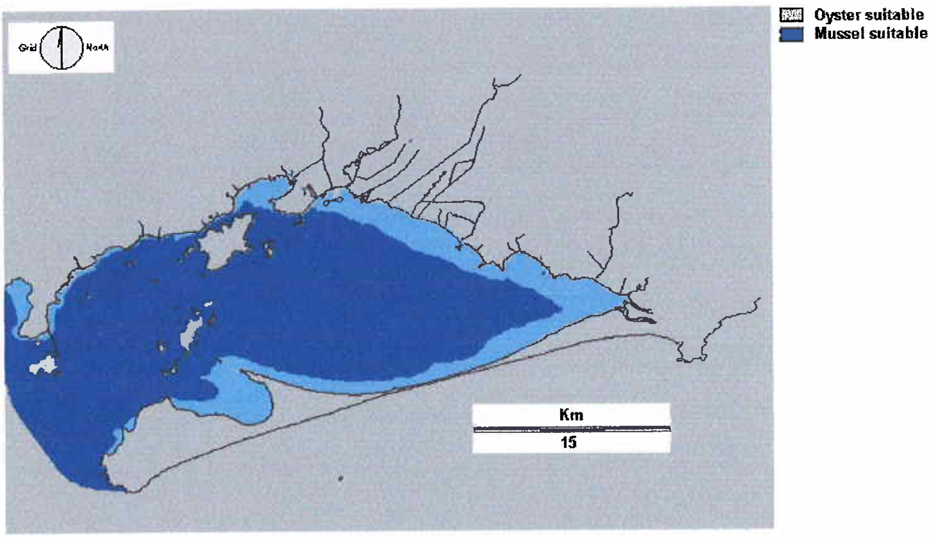

Figure 5.22 Depth range suitability for mussel and oyster culture.

Shelter

Protected or sheltered areas are important in aquaculture development as they require less investment in mooring structures and are less prone to damage. A layer consisting of shelter from exposure to severe weather conditions was created.

Since waves are a good indicator of exposed conditions, wave height was chosen as a layer to be developed which would give a good indication of sheltered areas for mussel and oyster culture sites. According to Beveridge (1996) most inshore floating fish cage structures are designed to withstand significant wave heights only up to about 1 - 1.5 m. Floating mussel longline installation requirements are similar to floating fish cages, but are more flexible than floating cage structures and can withstand more severe weather conditions than most rigid-structured floating cages. For the purposes of this study, the maximum exposure tolerable for mussel longline potential installation sites was considered equivalent to that for floating fish cages, i.e. waves up to 1.5 m.

Calculating wave heights

Wave height can be predicted using water depth, wind speed and wind fetch data for a particular point in space. To create a thematic map layer with potential wave heights for the study area, an IDRISI macro was constructed incorporating the formula in the U.S. Army Corps of Engineers Shore Protection Manual, 1984, for forecasting waves in shallow waters.

$$H = \frac{speed\,0.283\tanh\left[0.530\left(\frac{9.8depth}{Speed}\right)^{0.75}\right]\tanh\left\{\frac{0.00565\left(\frac{9.8Fetch}{Speed}\right)^{0.5}}{\tanh\left[0.530\left(\frac{9.8depth}{Speed}\right)^{0.75}\right]}\right\}}{9.8}$$

Where:
speed = wind surface speed,
fetch = distance over unimpeded water surface,
depth = depth in m.

In order to carry out the calculation of the maximum significant wave height in shallow waters within the facility of IDRISI's image calculator, the equation was broken down into 7 steps as shown in Table 5.14.

Table 5.14 Maximum significant wave heights expressions entered into IDRISI image calculator.

Names of images used are enclosed in brackets. Result of each expression is an image. Final result is maximum significant wave height for the Sepetiba Bay.

Step	Expression
A	0.530*(((9.8*[DEPTH])/[SPEED2])^.75) = wave1
B	.00565*((9.8*[DEPTH])/[SPEED2]/[SPEED2])^.5) = wave2
C	((2.718^[WAVE1])-(2.718^-[WAVE1]))/((2.718^[WAVE1])+(2.718^-[WAVE1])) = wave3
D	[WAVE2]/[WAVE3] = wave4
E	((2.718^[WAVE4])-(2.718^-[WAVE4]))/((2.718^[WAVE4])+(2.718^-[WAVE4])) = wave5
F	(0.283*[WAVE3])*[WAVE5] = wave6.
G	([SPEED2]*[WAVE6])/9.8 = wave7

However, it was finally decided that by using a multi-step macro which broke each equation down to its simplest form was better. In this way, alternative wind velocities and wind fetches, can be investigated in subsequent studies. This detailed macro is found in Appendix 8 and enables the calculation of wave height for any pixel across the water surface using the layers containing depth value, wind fetch and wind speed.

Depth layer

The depth information necessary for the significant wave height calculation was made available as a bathymetric thematic layer which was digitised from Admiralty chart 1622 (Fig. 5.21). The creation of this layer (BATHYDIS) is described earlier in the previous section. The depth ranges used for determining maximum significant wave height used in this study were 0-3m, 3-5m, 5-10m and 10-20m.

Creating the wind speed and wind fetch layers

Wind Speed

Wind speed was assigned as an attributed value directly to the pixels covering all the water surface area. Two wind directions were used: that due North-east and that due South-east.

The only long-term series of wind speed data available for the area is that recorded by the meteorological station 'Ecologia Agrícola' in Itaguaí municipality of Rio de Janeiro.

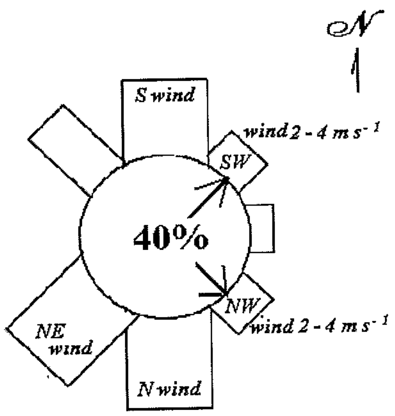

Figure 5.23 Average wind frequency and velocity (m s^{-1}) by direction for 1943-1970 period.
Source: Metereological station Ecologia Agrícola, municipality of Itaguaí, RJ. Percentage in circle represents calm period.

Wind speed data used was obtained in the form of a wind rose available in FIDERJ, 1978. To choose the most significant wind direction from this wind rose, (Fig. 5.23) local fishermen were consulted.

Several fishermen were informally interviewed and asked which winds they judged to be the most damaging in the region. Their consensus is that Southwest and Northwest winds are worse, because the SW wind generates higher waves which sometimes are able to cause damage along the coast, and the NW wind mostly because it causes choppy seas and makes for slow return navigation Wind speed observations used in this study is the maximum found for the SW and NW winds of the wind rose (4 m s^{-1}). Monthly wind speed data sheets recorded by the for the stations of Ilha Guaíba and Marambaia show that winds due North, South and North-West, can reach velocities of up to 20 m s^{-1}. This value was found looking through the monthly log books. For the purpose of this modelling exercise, the maximum value for the wind velocity from the two directions presented in the wind rose as being potentially the most troublesome to aquaculture operation (SW and NW) were used. If a more detailed study is required in the future, 'worst case scenarios' can be looked at, inputting wind values to re-run the maximum significant wave height model. To run the maximum significant wave height prediction model, an image (Fig. 5.24) was created with a uniform wind velocity speed of 4 m s^{-1}, generalised over the whole area of the bay's water surface.

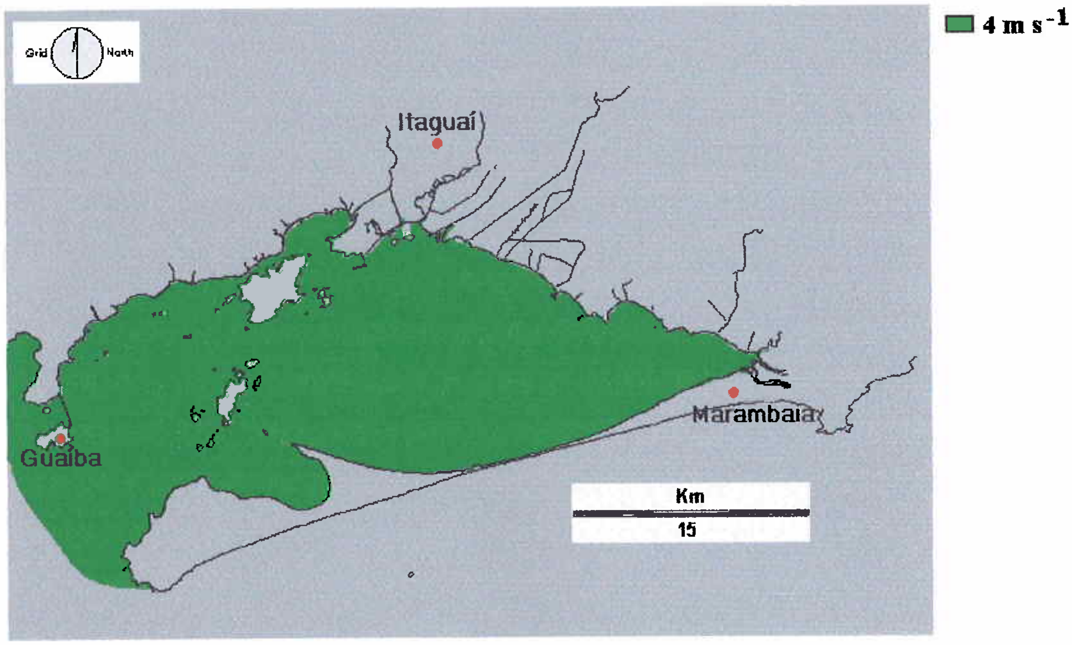

Figure 5.24 Wind speed layer developed for Sepetiba Bay.
Red dots indicate wind data sampling stations from which wind rose was generated.

Wind Fetch

Fetch is the stretch of water over which the wind blows (Sverdrup *et al.* 1970). The greater the fetch, the greater potential for generating higher waves (US Army Corps of Engineers, 1984). As can be seen in Figure 5.24, in Sepetiba Bay, fetch is mostly limited to the stretch of open water which lies between the sand barrier beach (Marambaia Island) and the continent, which is approximately 16 km at its widest. However, there is one relatively narrow area in the bay, which potentially has an almost unimpeded fetch from the open Atlantic Ocean. This is located between Ilha Grande and Ilha da Marambaia.

In this study, wind fetches were considered as starting from the edges of features in the study area. Since the bay is mostly enclosed, the starting point for the SW wind fetch begins at the land/water interface of all SW lying features such as the islands and the Marambaia Island. Where the bay was open to the Atlantic ocean, the fetch begins at a short distance away from the coastline in the open Atlantic.

Due to the geographic disposition of the bay, winds due East or West will normally have the long fetches, however these are very rare in the region, as can be seen in the wind rose (Fig. 5.23).

Because the bay is protected by Marambaia Island, a 40 km sand barrier beach on its southern boundary, SW winds have limited action. However, there is one significant gap between Ilha Grande to the west and Marambaia Island, which allows for longer fetches which in reality are the most damaging. Winds due South-east are considered the second most damaging.

To create the wind fetch layer the methodology presented by UNITAR (1995) was employed. The module **INITIAL** of IDRISI, was used to create two 'force images' for the study area using the a magnitude direction of 45° to represent a force equivalent to the SW, and another image with a magnitude direction of 135° to represent the NW wind. These two images are proposed as the wind fetch layers, used in the image algebra calculation macro in order to obtain a layer with the maximum significant wave height distribution over the bay.

To determine the fetch length along these two directions, a dispersion routine (**DISPERSE** module) was used, with zero as a starting value on the feature edges such as the coastline, or at the water boundary (Atlantic Ocean). The **DISPERSE** routine, attributes incremental values to pixels along the wind fetch path. To obtain the distance at any point along the fetch surface, the pixel values were multiplied by the pixel resolution, which for this Landsat satellite image is 30m. These operations are summarised in Figure 5.25.

Values outside the water surface were discarded by an **OVERLAY** (multiply) operation where a template image in which all pixels not over water surface were attributed a value of zero. In order to facilitate comprehension resulting images (Figures 5.26 and 5.27) show the fetch layers for SW and NW winds reclassified into three broad significant fetch range categories: 0-5 km, 5-10 km and 10-15 km fetches.

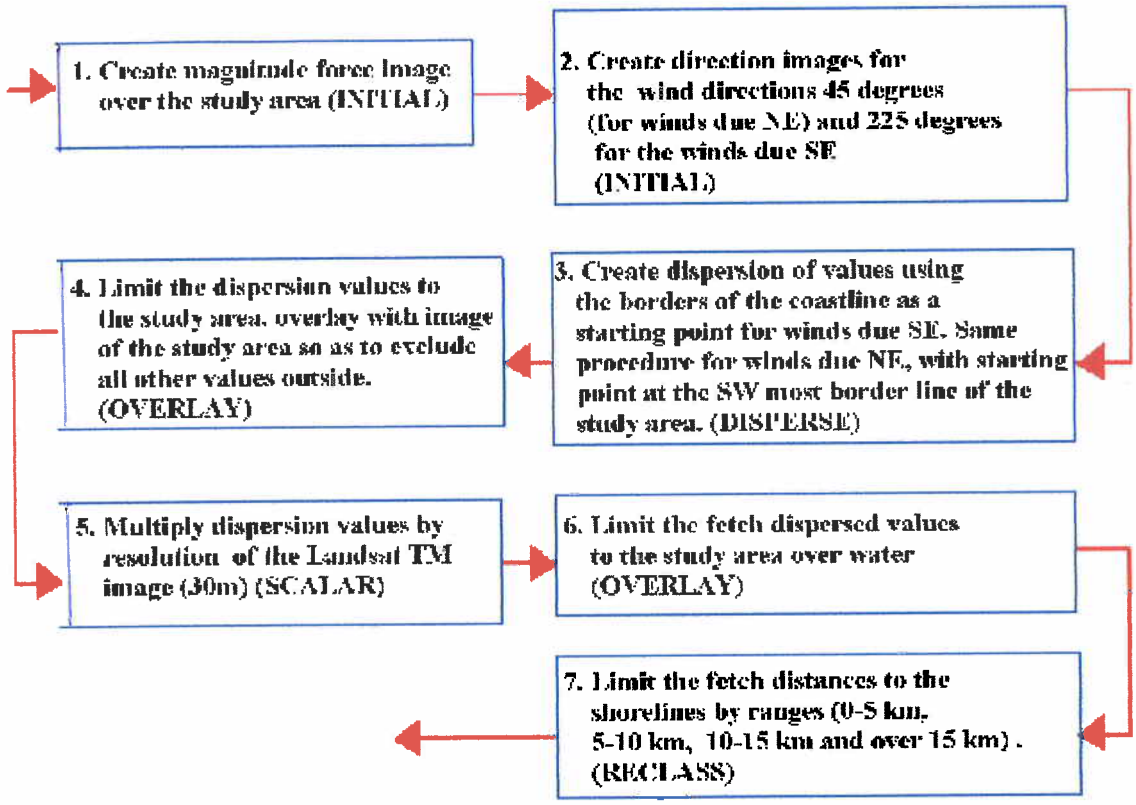

Figure 5.25 Summary of steps taken to create the ' wind fetch' image creation.

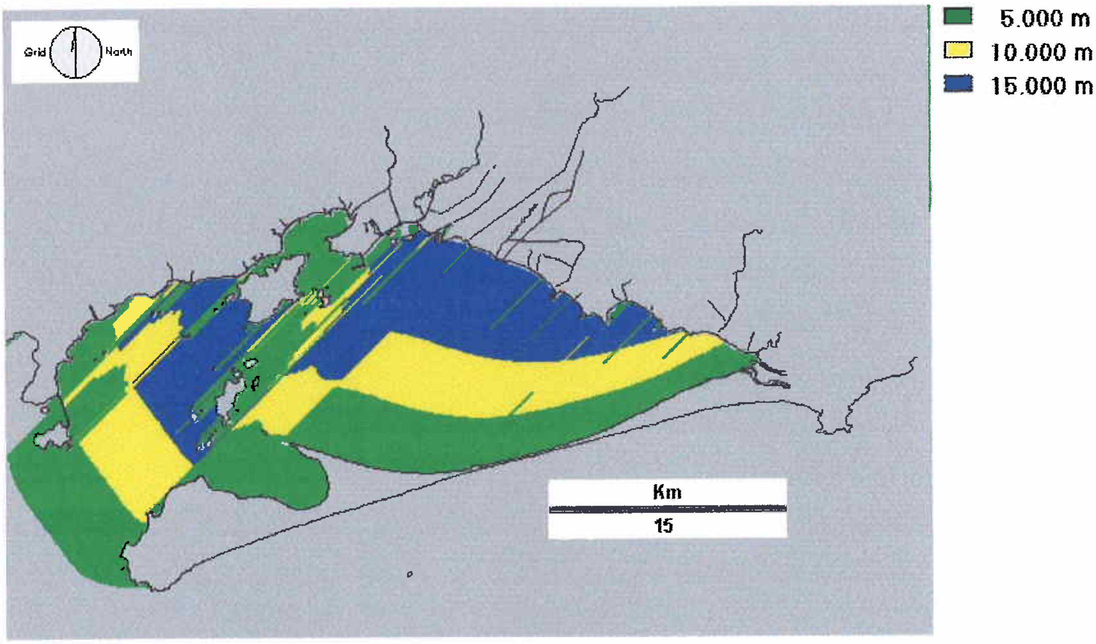

Figure 5.26 Wind fetch layer for the SW wind, reclassified for study area.

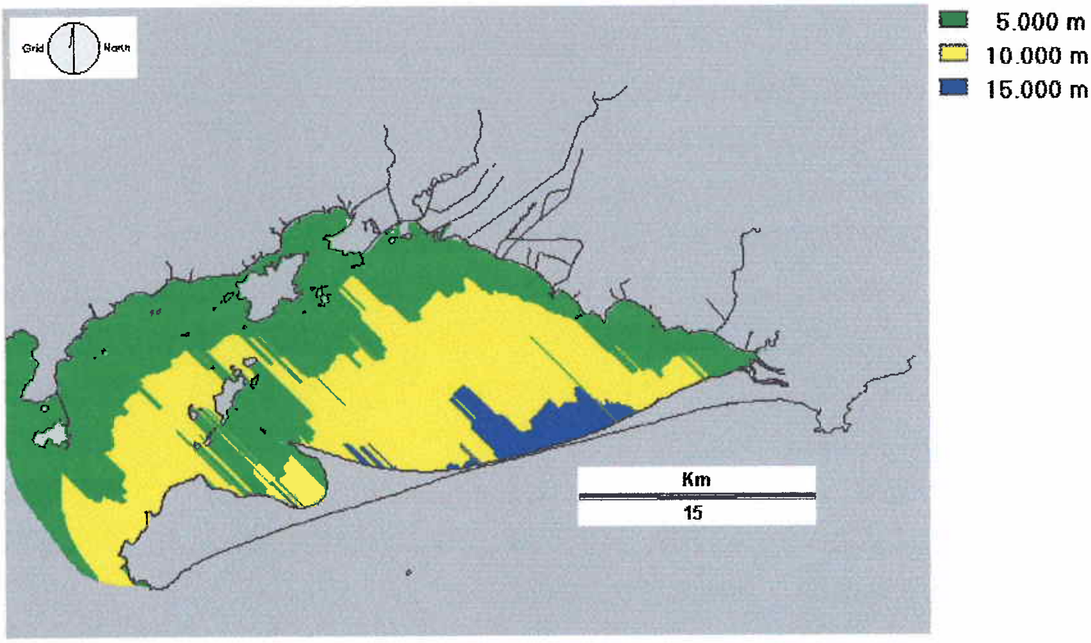

Figure 5.27 Wind fetch layer for NW wind, reclassified for study area.

Maximum Significant Wave Height

Creating the layer Maximum Significant Wave Height layer entailed using the wind fetch, wind speed and water depth thematic layers in the macro developed in the beginning of this chapter, which incorporates the significant wave height prediction formula. Thus, two maximum significant wave height layers were created. One for waves generated by the SW wind, and another for waves generated from NW wind. Figure 5.28 shows the predicted distribution of wave heights for Sepetiba Bay, based on depths, wind speed and fetch for SW wind.

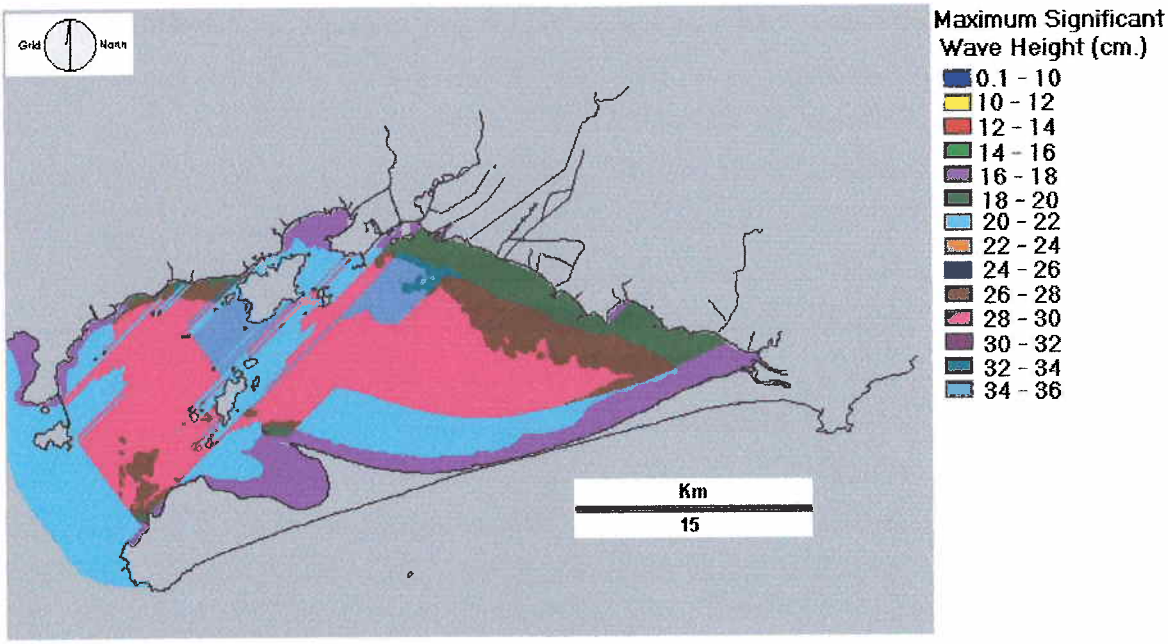

Figure 5.28 Maximum significant wave heights predicted for SW wind.

The results of the predicted wave heights show relatively small waves, the highest being less than 0.4m. Wave heights between 0.20 and 0.36 m predominate in most areas of the bay. One area with higher waves predicted (0.34 - 0.36) is that of the SW face of Ilha de Itacuruçá, which in practice is considered by local fishermen as a 'rough' area of sea, to be avoided during bad weather.

Maximum wave heights predicted with the model for the NW wind (Fig. 5.29), shows a smaller wave heights ranging from 0.1 – 0.24 m, mostly attributable to the short fetch. In this sub-model most of the bay shows wave heights less than 0.2 m high.

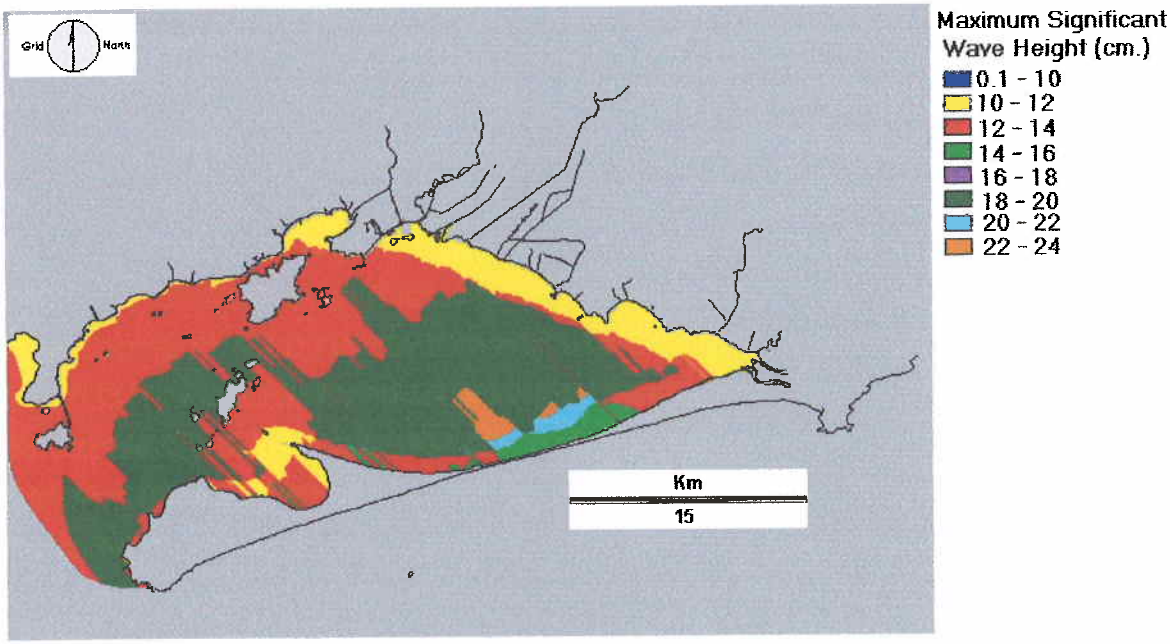

Figure 5.29 Maximum significant wave heights predicted for NW wind.

By combining the two resulting maximum significant wave height images for the SW and NW winds using the OVERLAY (maximum value option) module, one image (Fig 5.29 WAVEOK) was obtained where only the highest significant wave height values from either image remained. It was subsequently reclassified according to the scoring system shown in Table 5.15, resulting in Fig. 5.30.

Table 5.15 Site suitability scoring of mollusc culture areas in function of maximum significant wave height (m).

Interpretation	Score
Most Suitable Smallest wave action: calm sheltered waters. Minimum construction and maintenance costs, suitable for both mussel and oyster culture structures. < 0.20	4
Suitable – Small waves: Calm sheltered waters, suitable for mussel and oyster culture structures. 0.20 – 0.35	3
Moderately suitable Small to medium height waves: Implies in higher mooring costs for mussel anchors, and is less suitable for oyster culture rack system structures.. 0.35 – 0.50	2
Unsuitable Waves formed in areas exposed to long wind fetches. Potential significant material damages. > 0.5	1

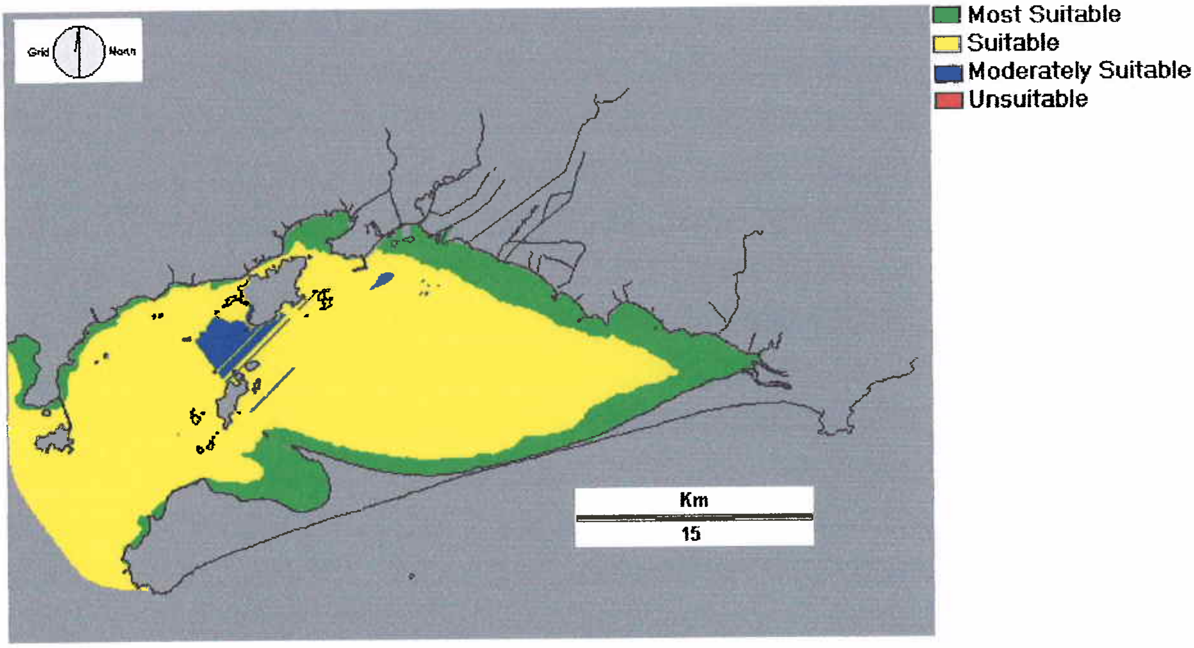

Figure 5.30 Site suitability for mollusc cultivation as a function of significant wave heights.

Prediction made using U.S. Army Corps of Engineers Shore Protection Manual, 1984.

Surface currents

Consideration of water hydrodynamics is important for water based aquaculture. Under favorable conditions bivalves will remain open and pumping water for most of the day. The major role of the water current is undoubtedly feeding, but it also carries away waste products and brings in a supply of oxygen (Walne, 1979).

As current velocities increase, construction costs for cages and installing moorings increase (Beveridge, 1996). Aquaculture production can increase with increased current velocity as it brings new supplies of oxygen, phytoplankton and food particles important for mollusc culture, as well as provides for removing faeces, and wastes. Stocking rates can also increase. Beyond a certain point, current action can be detrimental to the installations by deforming fish net enclosures resulting in less volume for fish, causing crowding and increasing stress. With increased current velocities fish also have to expend more energy maintaining their position in space, adversely affecting their growth.

For bivalve cultivation Laing and Spencer, (1997) consider that sheltered areas with tidal flows of 0.5 –1.0 m s^{-1} provide the best conditions, giving sufficient water exchange to supply the animals with an adequate supply of food and oxygen and for the removal of wastes. They also consider that for tray cultivation of oysters, sites that have only a minimal flow of water where water is exchanged by the tides can be successful. Hickman (1992), found current flows recorded at several longline and raft mussels cultivation sites to vary from 0.03 – 1.5 m s^{-1}. The suitability scoring adopted for this study is summarised in Table 5.16. Knowledge of current patterns and velocities for Sepetiba Bay is still very limited.

Table 5.16 Suitability scoring for bivalve mollusc culture sites in function of current speed (m s^{-1}).

Interpretation	Score
Most suitable Site has circulation enabling good flow of water favouring food supply, while carrying away wastes. 0.5 – 1.0	4
Suitable 0.3- 0.5 and 1.0 –1.3	3
Moderately suitable 0.1 – 0.3 and 1.3 – 1.5	2
Unsuitable Site poor circulation of water can lead to build up of toxins, organic matter and anoxia. Very dynamic circulation may cause stress on organisms as well as fadigue of culture structures. < 0.1 > 1.5	1

In order to develop the surface water current velocity layer, a base image containing surface current modelling results determined by Fragoso 1995 in his simulation model was adapted into the database by geo-referencing. This set of values was complemented by an overlay of a specific dataset of results obtained from several field trips made to Sepetiba bay for collection of surface current data using drogues. Surface currents were measured in several areas throughout the bay, including around islands, in the centre, and in the eastern end. The combined results regarded only the highest values of both images.

The surface currents measuring methods have been described in Chapter 2. The procedure for data processing is summarised in Fig. 5.32 and begins with a list of GPS positions for all the drogue locations over time which was then imported into IDRISI as an ASCII file.

These were geo-referenced with the Landsat image base layer and displayed on-screen. Knowing the initial, intermediate and end positions of each drogue path, a set of lines which depicted its trajectory was digitised on-screen (Fig. 5.33a). Next, each line was measured using the VECLONG module (Fig. 5.34) and by using the length of time travelled by the drogue over each pair of positions, the surface current speed for that stretch was determined.

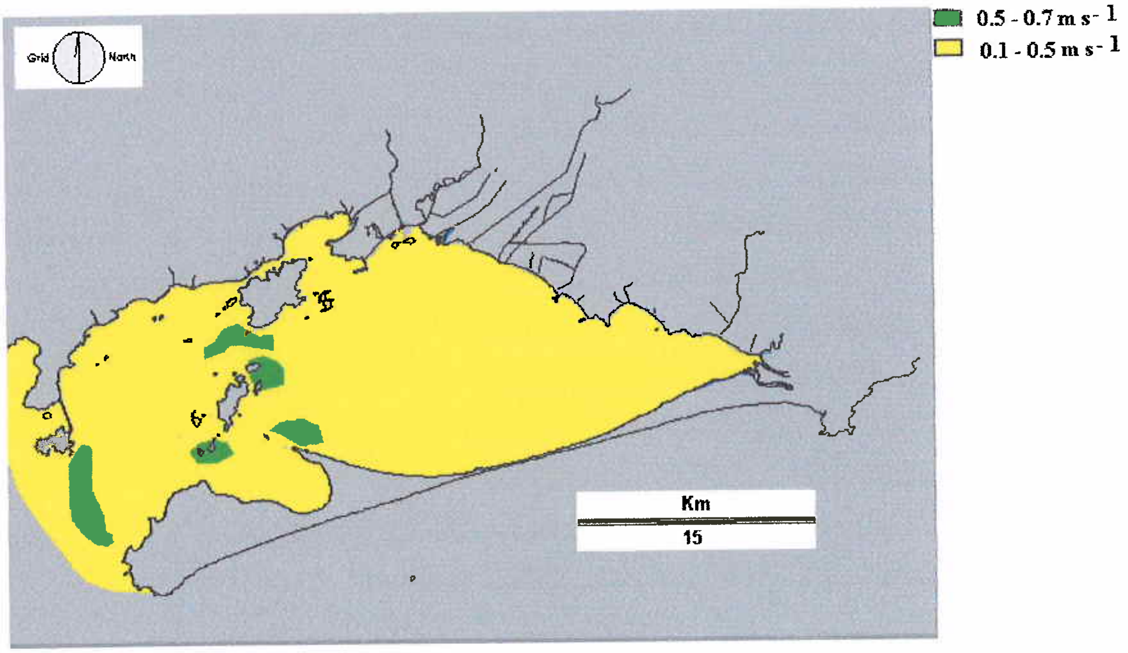

Figure 5.31 Surface current velocities (m.s^{-1}).
Adapted from Fragoso (1995) and georeferenced to Landsat TM cut-out window of study area.

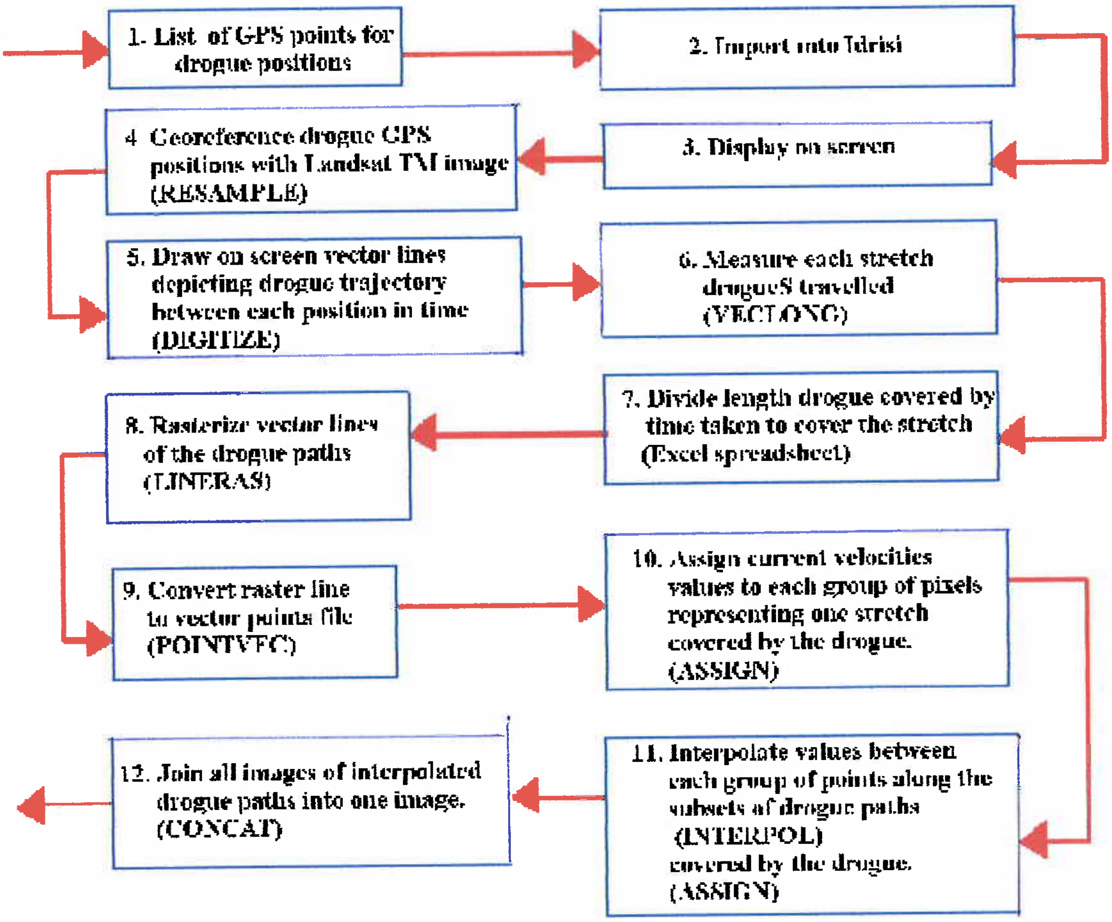

Figure 5.32 Flowchart summary of current data measured in the field into GIS database.

In order to determine intermediate values between measured stretches (drogue runs), the vector lines of the drogue paths were rasterised using the LINERAS module (Fig 5.33a) and then converted into a point vector file using the POINTVEC module (Fig. 5.33b). Using ASSIGN, current velocity values were assigned to the pixels along the drogue paths (Fig. 5.34a). The result of interpolating the current velocity values between each group of pixels along the subsets of the drogue paths measured is shown in Fig. 5.34b.

Finally, the subsets of all drogue study sections considered was compiled into a new image CURRENTS (Fig 5.37) incorporating data from Fragoso's study (Fig. 5.31) in an overlay operation where the maximum value of current velocity of either image remained. This resulting image (Fig. 5.35) was then reclassified according to the suitability scoring system shown in Table 5.16 into Fig. 5.36 (CURENTOK), which was used in the final suitability model.

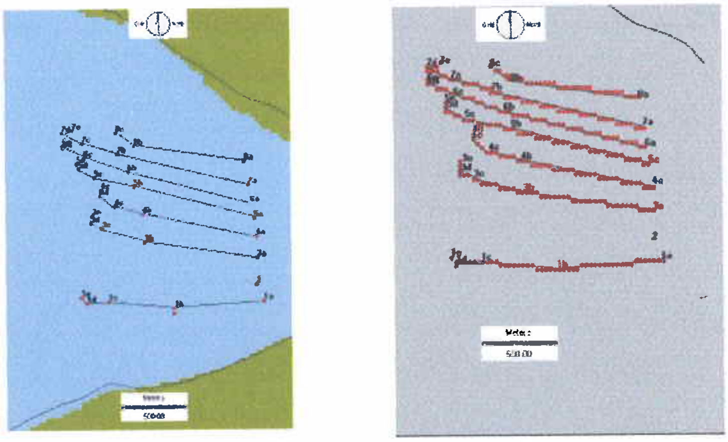

Figure 5.33 (a) Vector points showing current direction (b) Drogue path lines rasterized

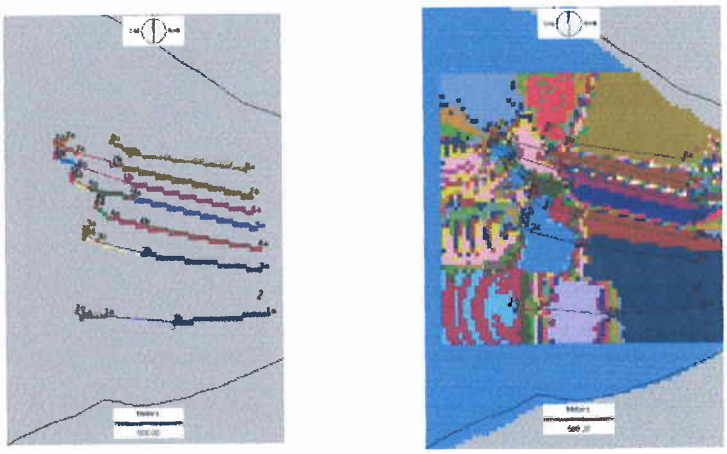

Figure 5.34 (a) Current velocities assigned, (b) Results of interpolated current velocities

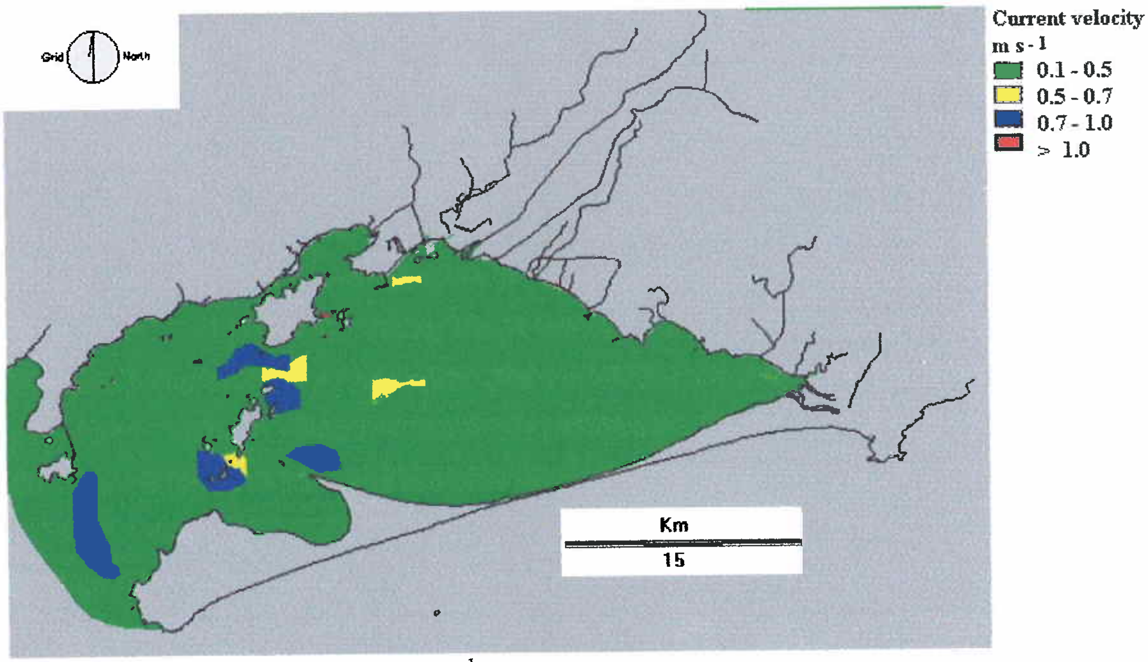

Figure 5.35 Surface current velocities (m.s^{-1}) in Sepetiba Bay.

Current velocities in Sepetiba Bay. Results of compilation of drogue data with background data over the bay.

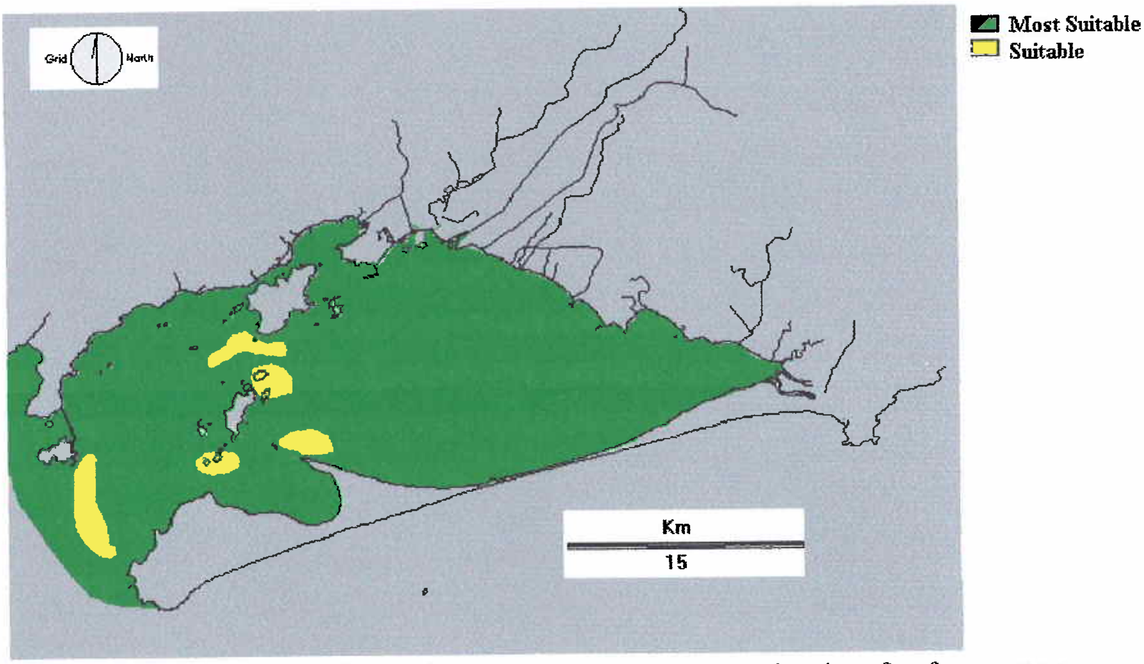

Figure 5.36 Suitability of Sepetiba Bay for bivalve mollusc culture as a function of surface currents.

5.1.7 MARKETS

Because of Sepetiba Bay's history of being an important shellfish producer, the coastal populations as well as nearby cities were naturally considered as potential consumers, generally prone to buy seafood, including mussels, oysters, and shrimp. An indication that this market may be expanding is the fact that the Rio de Janeiro fisheries office - FIPERJ, has recently upgraded its oyster seed hatchery faciltity to better support aquaculture as an economic alternative for local artisanal fishermen subsistence.

Market potential

The market potential for this study was based on spatial information on population size and purchasing power in the study area which currently (2002) has about 800,000 inhabitants. Sepetiba is adjacent to the wider area of metropolitan Rio de Janeiro, currently with a population of ca. 5.5 million people (CIDE, 2000). It is expected that aquaculture products will in part find their way into the wholesale marketplaces of Rio de Janeiro, This is supported by Jablonski (1997) who studied wholesale fish markets in Rio de Janeiro and estimated that 67,124 tonnes (whole fish) were commercialised in 1996. This would mean an average per capita fish consumption of 16.4kg equivalent. The study points a steady increase in seafood demand with 57% of sales already coming from imported sources (out of state). Aquaculture products already in this market include fresh Chilean Atlantic farmed salmon and farm-raised *Litopenaeus vannamei* are becoming more important in this market with competitive prices In a recent survey, Scott *et al.*(2002) estimated an annual market demand for over 15,000 dozen oysters and 48,000 kg of cooked mussel meat for Rio de Janeiro metropolitan area.

Population centres

The largest urban concentrations in the study area are Campo Grande and Santa Cruz. These two cities are very close to Rio de Janeiro and were included in the same category. The largest wholesale market in the State of Rio de Janeiro, is CEASA, a central food supplies market which lies close to Campo Grande. According to Jablonski (1997) about 80% of seafood marketed at CEASA comes from southern Brazil (over 1,000 km away from Campo Grande) and about 20% from other regions in the State of Rio, the closest of which is Angra do Reis about 150 km distant from Campo Grande.

Table 5.17 summarises the population characteristics of the main urban concentrations in the study area. These towns were reclassified according to Table 5.18. The two largest cities Campo Grande and Santa Cruz, represent the largest market potential in terms of potential consumers. Itaguaí, and the towns of Barra de Guaratiba and Pedra de Guaratiba were reclassified into the second most promising markets. Coroa Grande and Sepetiba are the medium size coastal towns. There are several other coastal towns with populations of less than 7,000 inhabitants each, which were considered individually smaller markets for commercial aquaculture products However, considering them as a group and taking into account their seaside hotels and restaurants (developed as a separate layer), they represent another market alternative. The reclassified image showing mollusc on-growing site suitability in the bay, as a function of market potential expressed as proximity to population centres and distance from different sizes of populations is shown in Figure 5.37. It was obtained in an overlay operation followed by a reclassification according to the scoring criteria described in Tables 5.18 and 5.19. Both these images were based on distance 'as the crow flies' from the town areas to potential sites in the bay.

Table 5.17 Population aspects of towns in the Sepetiba area.
(Adapted from CIDE, 2000).

City/town	**Area (km^2)**	**Population**	**Density (people/ km^2)**	**Annual growth rate (%)**
Campo Grande	171.6	380,942	2,219.0	1.15
Santa Cruz	163.7	254,500	1,554.4	1.15
Pedra and Barra de Guaratiba	151.7	60,774	400.5	1.15
Itaguaí	175	50,906	290.9	2.08
Mangaratiba	155	8,728	56.3	2.38
Coroa Grande	274	8,697	31.7	2.08
Vila Muriqui	53	4,346	82	2.38
Itacuruçá	23	3,543	154.0	2.38

Table 5.18 Site suitability scoring for mollusc culture in function of distance from market potential. .
Market potential was based on distance fresh/live molluscs travel to reach wholesale/retail distribution points.

Interpretation	Score
Most Suitable	
Good market potential	4
0 - 5 km of a population centre	
Suitable	
Average market potential	3
5 - 7 km of a population centre	
Moderately Suitable	
Limited market potential	2
7 - 10 km of a population centre	
Unsuitable	
Small market potential - 7 - 10 km of a population centre	1

Table 5.19 Site suitability scoring for mussel and oyster culture in function of distance from market size. Potential was based on number of potential consumers and distance from the culture sites.

Interpretation	Score
Most Suitable	
Good market potential	4
Large markets, population > 250,000 inhabitants	
Suitable	
Average market potential	3
Markets with population range: 50,000 - 250,000 inhabitants	
Moderately Suitable	
Limited market potential	2
Moderate size markets, population range: 7,000 - 50,000	
Unsuitable	
Small market potential	1
small coastal towns , street markets, population < 7,000	

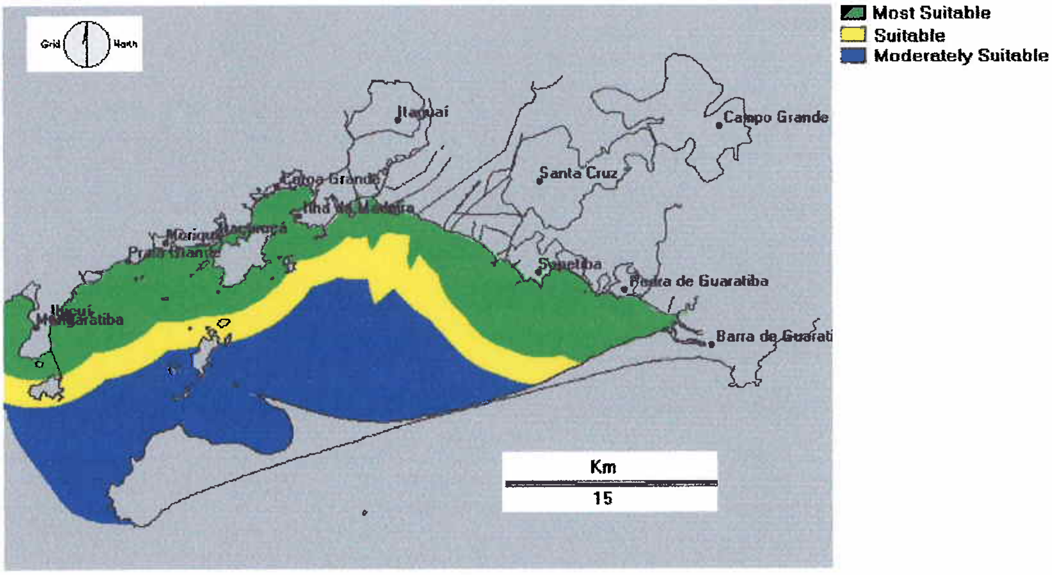

Figure 5.37 Site suitability for mollusc culture in Sepetiba Bay as a function of markets.
Layer a result of market size as number of potential consumers, and distance from potential cultivation sites.

Purchasing power

Success of selling aquaculture products depends not only on the number of potential consumers within a certain distance, but very importantly, in its purchasing power. Purchasing power can also indicate people's ability to overcome distance. Those who have economical means, can overcome distance in order to acquire desired products, even if these may be away from their home area. In order to take best advantage of the statistical data in the database, the tabular data presented in Table 5.21 was transformed into a raster layer depicting purchasing power distribution in the region.

Table 5.20 Population centres and % of households earning 5-10 Minimum Wages per month. (Adapted from CIDE, 2000).

Population centre (rural and urban combined)	**% of households with 5-10 MW.**
Campo Grande	7.4 - 13.2
Santa Cruz	7.4 - 13.2
Mangaratiba	7.4 - 13.2
Sepetiba	7.4 - 13.2
Vila Muriqui	7.4 - 13.2
Itacuruçá	5.1 -7.4
Itaguaí	5.1 -7.4
Guaratiba	5.1 -7.4
Coroa Grande	3.2 -5.1

These areas were represented by bands extending from each population center. Market potential as indicated by purchasing power was then rated as indicated in Table 5.22. In the Sepetiba region, local monthly minimum wage (MW) in Aug, 2002 was R$200, or the equivalent of £41.30. Five towns in the area have 7.4 to 13.2% of households earning between £206.49 - £412.97 per month, i.e. between five and ten MW per household per month. Based on the distance bands projected from areas with different purchasing potential, Figure 5.38 was created, which shows a reasonably large area classified as Most Suitable around the towns of Itacuruçá, Muriqui and Praia Grande, which even if possessing relatively smaller populations, are closer to potential aquaculture sites, include seaside restaurant and hotel outlets have higher purchasing potential, and thus represent overall higher potential market.

Table 5.21 Suitability scoring adopted based on household purchasing power.
Suitability indicated as percentage of households earning 5-10 Minimum Wages per month. (Adapted from CIDE, 2000).

Interpretation	Score
Most Suitable Households buying power = 7.4 – 13.2 MW	4
Suitable Households buying power = 5.1 -7.4 MW	3
Moderately Suitable Households buying power = 3.2 -5.1 MW	2
Unsuitable Households buying power = 7.4 - 13.2 MW	1

Table 5.22 Suitability scoring adopted based on distance from potential consumers.
Suitability indicated as distance from households earning up to 5-10 minimum wages per month.

Interpretation	Score
Most Suitable Within 7 km of potential consumers	4
Suitable 7 - 12 km from potential consumers	3
Moderately Suitable 12 - 14 km from potential consumers	2
Unsuitable Over 14 km from of potential consumers	1

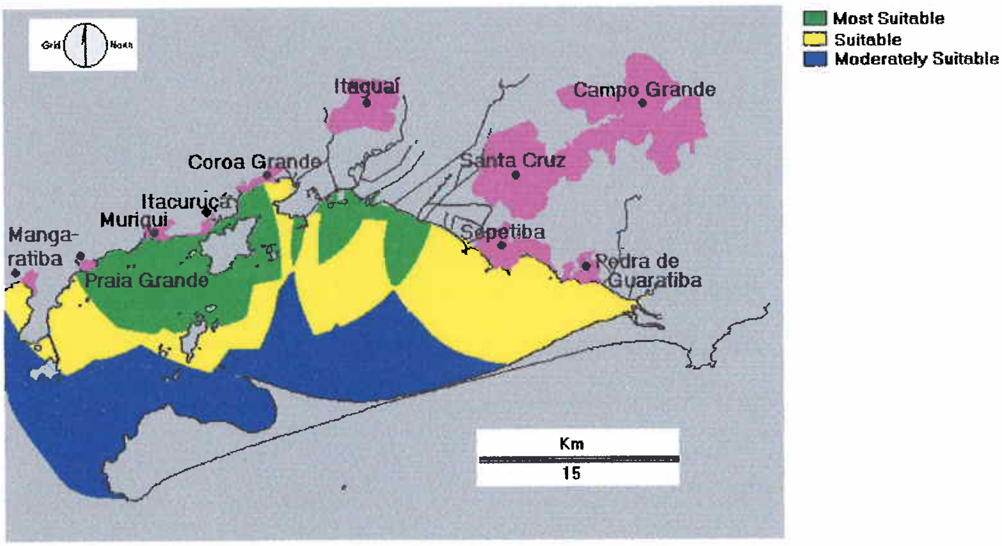

Figure 5.38 Final site suitability for mollusc culture in function of potential markets .

Market was considered a function of: 1.size of population centres 2. distance from potential consumers 3. distance from consumers with significant purchasing power.

5.1.8 CONSTRAINTS

Several spatial constraints to the development of aquaculture activities were identified in Sepetiba Bay. Effectively, navigation areas, polluted or contaminated areas, areas used by the Brazilian military and fishing areas used by bottom trawlers were considered as impediments.

These were the constraints to aquaculture development selected from a 32 items considered as potential constraints identified by a group of professionals from various fields composing the 'expert panel' consulted. Most members of this panel easily identified conservation, military, navigation and port usage as well as polluted areas as constraints for aquaculture development. Other areas considered as constraints by the group included water depth, conflicting uses of the area such as by tourism and fishing activities, as well as legislation and markets.

Navigation

As large cargo ships navigate regularly in and out of the bay to the ports of Guaíba and Sepetiba, a well-established and signalled route is charted. This route was digitised as a polygon vector from chart DHN 1622, and incorporated into the database as a raster layer. The charted width of this navigation route is 300 metres. For the modelling purposes of this research, this constraint zone was widened into a 450 m buffer zone as illustrated in Figure 5.39. Possibly, a wider buffer zone of about 1000m could be considered to take into account general safety of the aquaculture installations due to foul weather and navigational positioning difficulties or navigational errors of pilots.

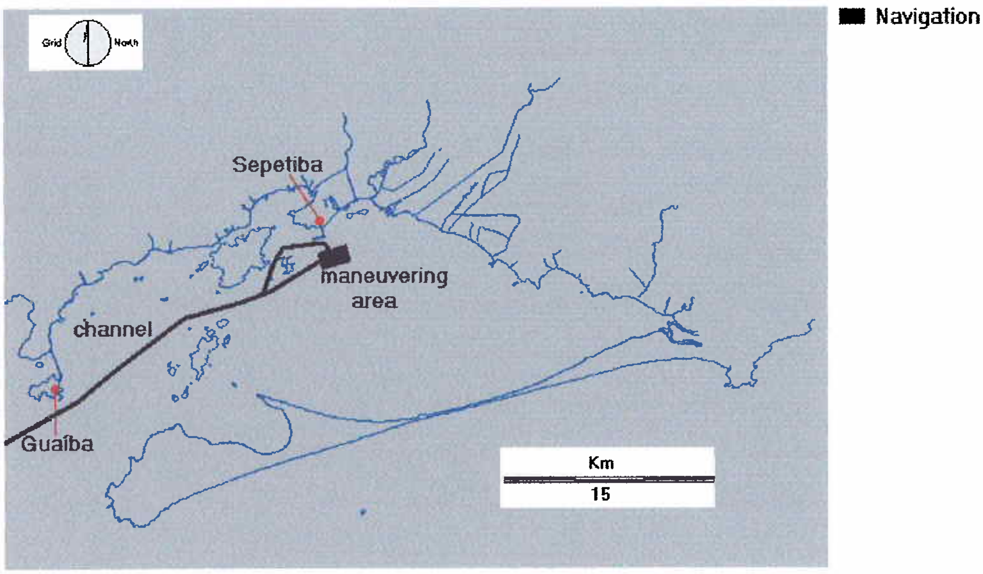

Figure 5.39 Navigation constrained areas for aquaculture development.

Constraints include navigation routes and maneuvering areas for cargo vessels in Sepetiba Bay ports Guaiba and Sepetiba signaled in admiralty charts.

Fishing

Another area of constraint for aquaculture development is that which is intensively used by shrimp or bottom trawlers. Installing aquaculture structures in these areas would create problems with fishermen who traditionally exploit this area.

Local fishermen using floating gill nets have lost their gear to shrimp trawlers creating much animosity (Begossi, 1995). Currently, the mid portion of the bay is mostly occupied by bottom trawlers, operating mainly at nighttimes. The delimitation of this usage area (Fig. 5.40) was done manually (on screen digitising), and by approximation, based on the orientation of two persons knowledgeable of the fishing habits in the study area. This includes most areas over 3 m deep which small shrimp trawlers cover during their fishing activities. This area is mostly that sheltered by the Itacuruçá-Jaguanum-Marambaia island chain, which is typically less than 20 metres deep.

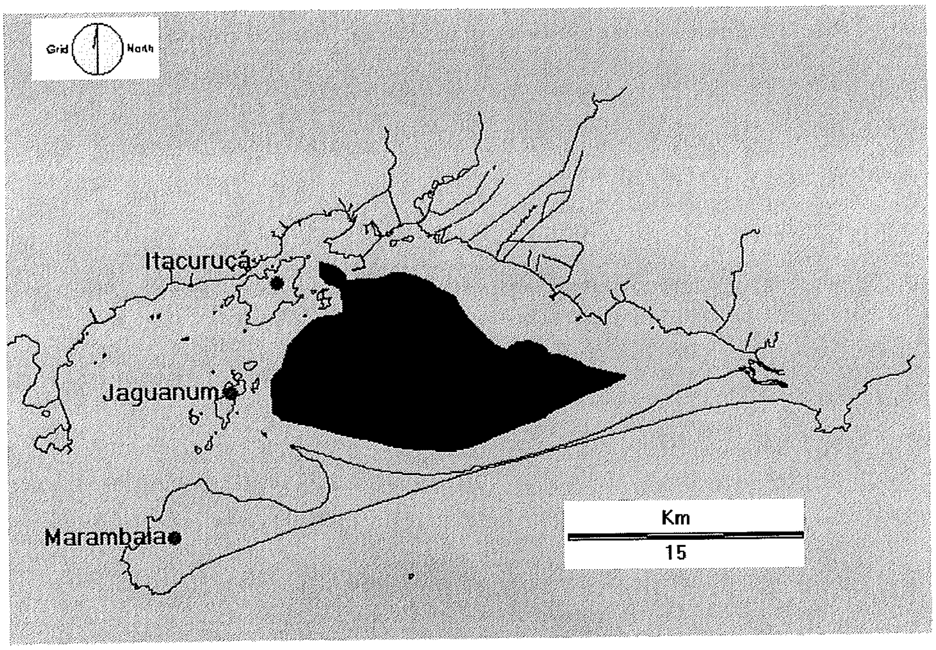

Figure 5.40 Fishing constrained areas for aquaculture development.

Area constrained is that used by small bottom trawlers fishing mostly for shrimp. Red dots indicate larger islands.

Pollution

Delimiting the areas affected by pollution was handled by incorporating an area in which sediment and water is most widely accepted as being contaminated by heavy metals originating from industries discharging their effluents in the rivers of the catchment basin, or directly into the bay waters. Two approaches were used to create a constraint layer for contaminants.

Firstly, the main point sources of contamination were established, based on the main river outflows (Canal de São Francisco and the Canal do Guandú (Fig. 5.41), and point sources such as the Ingá zinc production facility. From these points, since few studies that precisely map the contamination effects of the pollution above mentioned, an buffer zone consisting of a 7 km radius from the point sources was drawn based on the sampling sites carried out by an independent survey (ALERJ 1996). This 7 km radius buffer zone is a tentative way of avoiding contaminated waters and their direct negative effects on bivalve growth such as shell deformations in oysters by excess cadmium and zinc absorption. Heavy metals bioavailability in Sepetiba waters is still to be determined, but significant contributions have been made by Lacerda *et al.*(1983) who studied its concentration in the mangrove mussel *Mytella guyanensis,* the distribution of Mn, Zn, e Cu in swimming crabs (Lacerda *et al.* , 1987) and heavy metal distribution, availability and fate in Sepetiba Bay (1989).

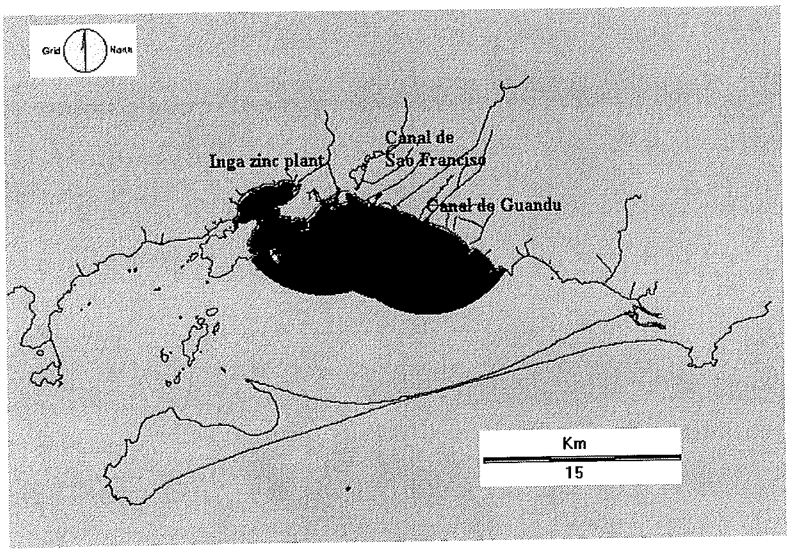

Figure 5.41 Constrained areas for aquaculture development as a function of point pollution sources.

The general consensus of technicians, consultants and extension officers is that this area (Fig. 5.41) is subject to pollution effects and is least recommended for aquaculture implementation. It would seem difficult to obtain approval for development in this area.

Secondly, based on a survey undertaken by FEEMA/GTZ (1997) where bottom sediments from across the bay were analysed for zinc concentration, a vector point file was created indicating the geographical position of each sampling station. This file was converted to a values file with the equivalent concentration of zinc ($\mu g.l^{-1}$). This vector file was then interpolated using IDRISI's INTERPOL module in order to produce an estimated concentration range layer over the bay area (Fig. 5.42).

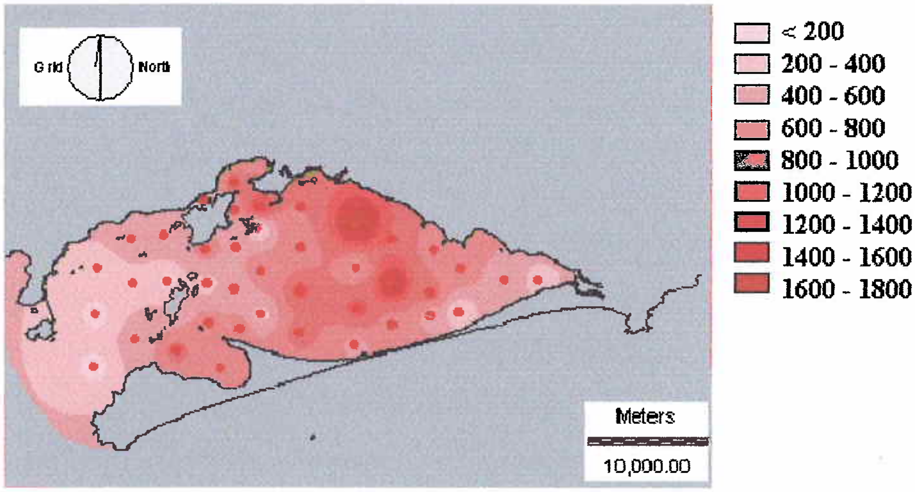

Figure 5.42 Zinc concentration ($\mu g.l^{-1}$) in bottom sediments of Sepetiba Bay.

Raw data obtained from FEEMA - GTZ (1997) report and interpolated in the Sepetiba database. Red dots represent FEEMA-GTZ sampling stations.

In order to produce a constraint layer that would cover a 'worst case scenario', where in fact, zinc in sediments are bioavailable to biota, presenting build-up during a culture cycle, based on the 1977 resolution of the Brazilian Environment Ministry (FEEMA 1997) suggesting a safe level of less than of 800 $\mu g.l^{-1}$ of zinc in sediments of coastal environments, a reclassification of Fig 5.42 was carried out blanking out all areas where values are in excess. The result is shown in Fig. 5.43 which was merged by overlay to those areas considered unsuitable by technicians due to proximity to point pollution sources (Fig. 5.41).

In conclusion, the constraint area layer developed for mussel and oyster culture due to contamination from heavy metals in sediments in the bay, was used primarily to integrate in the models subsequently developed in this study. Better supporting information as regards the actual bioavailability of contaminants in the sediments to the water column ad therefore potentially impacting water based aquaculture systems for filter feeding molluscs, under the conditions prevailing in Sepetiba Bay, needs to be further investigated. Issues which could modify the shape of this constraint layer, are related to the amount of contamination in different areas of the bay, and the likelihood of these sediments being stirred up by various sorts of coastal navigation in function of depth and vessel tonnage. In the present study, this proxy layer precludes about 50% of the bay.

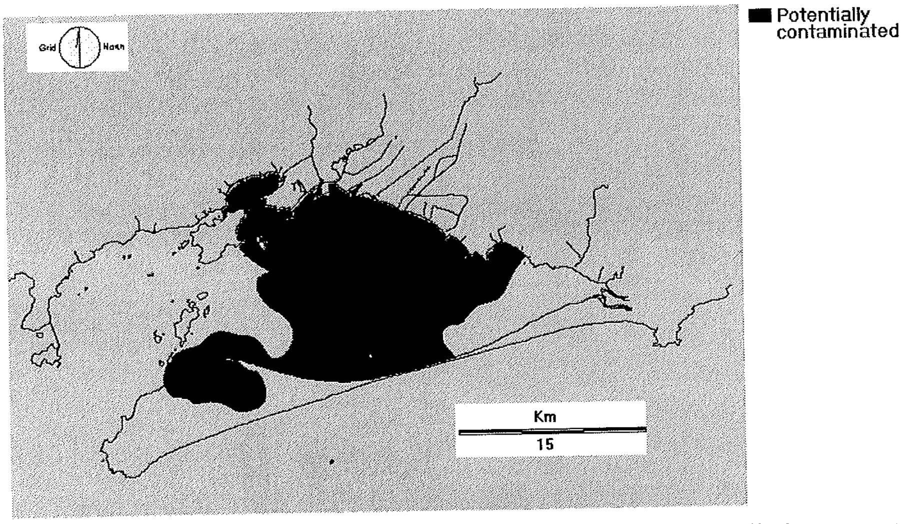

Figure 5.43 Constrained areas for aquaculture development due to pollution or contamination.

Military Use

The Brazilian military maintain a target shooting range on the Restinga de Marambaia, and so have a security exclusion area charted on admiralty chart DHN 1622 from which this area was digitised and imported into the GIS database (Fig. 5.44). Fishing vessels are allowed passage but must not stop. It is unlikely that the military authorities will allow aquaculture installations or permits in this exercise area.

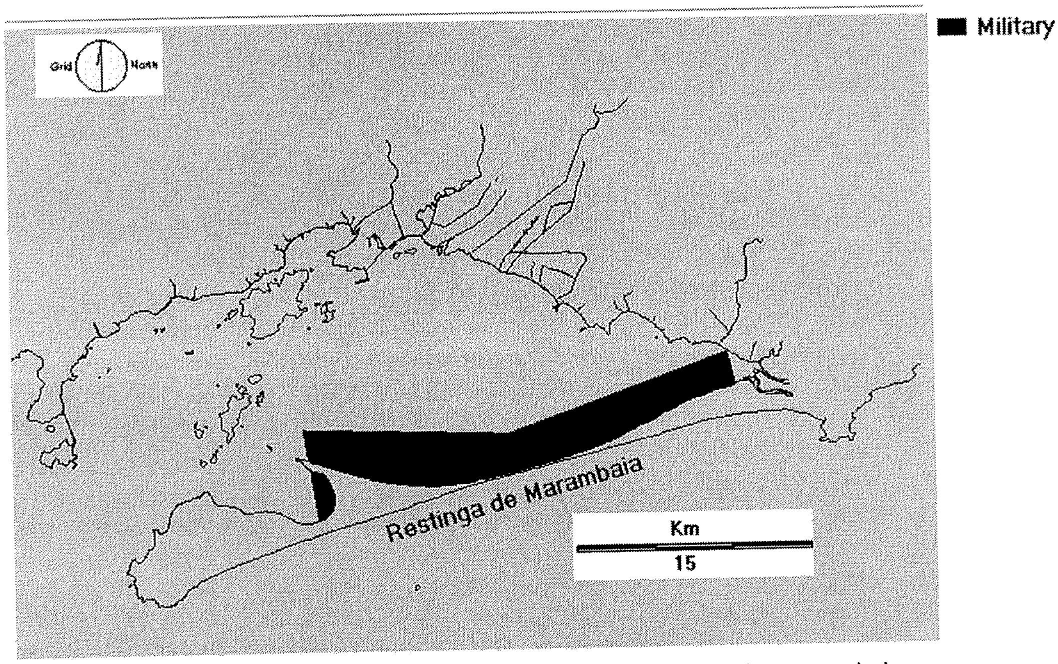

Figure 5.44 Constrained area for aquaculture development due to military restriction.

Total Constraints

Mussel farming. Figure 5.45 shows the total constrained area for installation of mussel longlines. This includes all of the previous constraint layers as well as a constraint layer for depths less than 3 m, as this was considered too shallow for installation of the longline anchoring system. The study area in the bay was found to contain 18,759 ha suitable for modelling for mussel culture (34.5% of the study area).

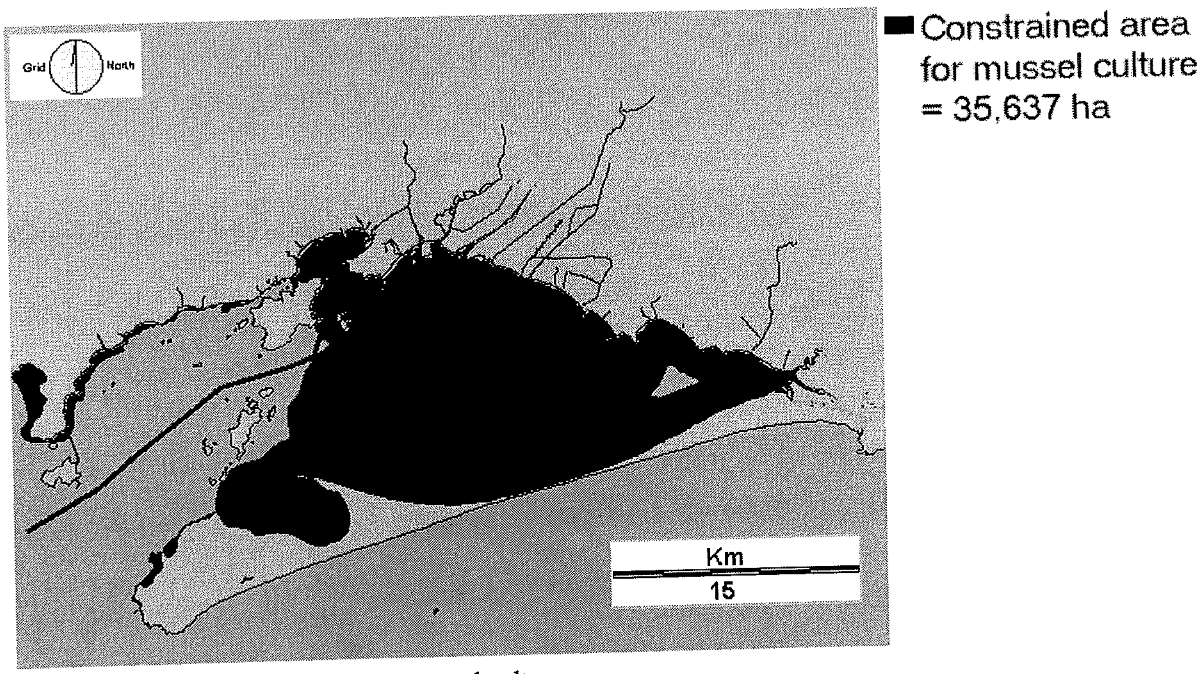

Figure 5.45 Total constraint area for mussel culture.

Oyster farming. Figure 5.46 shows the total constrained area for installation of intertidal oyster culture. This includes all of the constraint layers previously described as well as a constraint layer for depths greater than 3 m, considered unsuitable for installation of intertidal rack system for mangrove oyster cultivation. The study area in the bay was found to 2,407 ha suitable for modelling for mangrove oyster culture (4.43% of the study area).

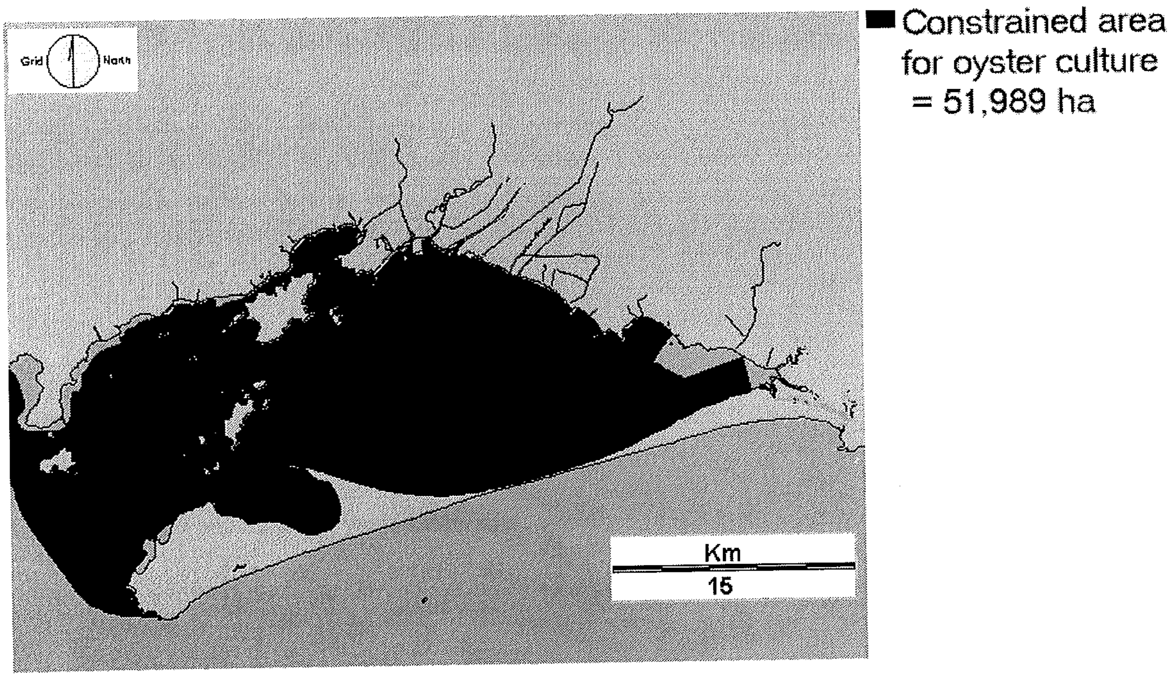

Figure 5.46 Total constraint area for oyster culture.

Table 5.23 summarises the areas and percentages imposed by each constraint to mollusc culture development in Sepetiba Bay.

Table 5.23 Constraints for aquaculture usage detected in Sepetiba Bay.

Area	hectares	% of the bay
Total area of the bay	54,400	100.0
Water and sediment pollution or contamination	11,710	21.5
Usage by small fishing trawlers	15,424	28.4
Usage by commercial navigation	1,219	2.2
Usage by military	8,191	15.1
Areas with zinc contaminated bottom sediments (> 800 $\mu g\ l^{-1}$ Zn)	26,461	48.6
Areas deeper than 3 m (oyster culture system constraint)	42,225	77.6
Areas between 0 – 3 m (mussel culture system constraint)	12,172	46.0
total impeded areas (excluding depth constraint)	33,391	61.4

5.2 DEVELOPMENT OF A GIS FOR ASSESSING SITE SUITABILITY FOR LAND-BASED WHITE SHRIMP CULTURE AROUND SEPETIBA BAY.

5.2.1. DATABASE DEVELOPMENT

The layers needed to be developed in this GIS were those associated with production function criteria for white shrimp production. These layers were developed from the general database and reclassified as suitability images. These include technical support, roads network, farmland, shrimp seed availability, seawater sourcing, freshwater sourcing, soil quality suitability, vegetation and land use analysis, climatic factors including: rainfall and air temperature, a layer indicating appropriate areas for shrimp culture based on natural factors and finally layers to describe marketing potential. Although water quality is most important for shrimp culture, it was not treated as an independent thematic layer in the database because it was assumed that:

- All the seawater available in the bay was considered as adequate in terms of temperature (24 – 30°C) and salinity (7 – 32 psu) ranges for *L. vannamei*,
- Dissolved oxygen content in intensive shrimp production ponds is largely maintained by supplemented by artificial aeration obtained by employing paddle-wheel aerators,
- Chlorophyll-*a* content is not a very relevant criterion in this type of aquaculture production because semi-intensive and intensive shrimp culture is largely dependant on artificial feeds supplementation,
- Water quality chemical p arameters such as ammonia and nitrites, which t end to build up during the culture period, are usually monitored by daily or weekly water testing, and diluted by water exchange.

5.2.2 SCORING AND RECLASSIFYING

In this land-based GIS database, the thematic maps developed were scored following the methodology used in the previous section (5.1). The re-classification scheme adopted was applied with the understanding that the supporting layers in the GIS could be in the future, rectified or updated, in order to bestow greater accuracy to the model prediction outcomes.

5.2.3 Infrastructure

Technical Support

Shrimp aquaculture technical know-how is present in the study area in the form of the FIPERJ fisheries research lab, hatchery and extension office. On the assumption that FIPERJ experts are trained and equipped to provide basic services including disease diagnostics, feeding trials and general aquaculture techniques, a **DISTANCE** algorithm was applied taking FIPERJ lab as a departure point and extending to the limit of 45 km. This was done in function of the maximum extent normally met by the extension service, which is within the local municipalities of Rio de Janeiro, Itaguai and Mangaratiba (Fig. 3.3). Distances were projected 'as the crow flies' departing from the fisheries lab. Figure 5.47 shows the results of the suitability scoring adopted in Table 5.24, where for example, potential farm sites within a 5 km radius could easily be reached over the main road network within about 10 min by car.

Table 5.24. Suitability scoring for technical support accessibility.

Suitability in function of distance (km) of potential shrimp culture sites to primary roads. Access by vehicles able to travel about 50 km/h over the primary road network.

Interpretation	Score
Most Suitable Site accessible within 10 min. from FIPERJ lab 0 – 5 km	4
Suitable Site accessible within 40 min 5 – 30 km	3
Moderately Suitable Site accessible within 90 min 30 – 45 km	2
Unsuitable Site accessible over 90 min > 45 km	1

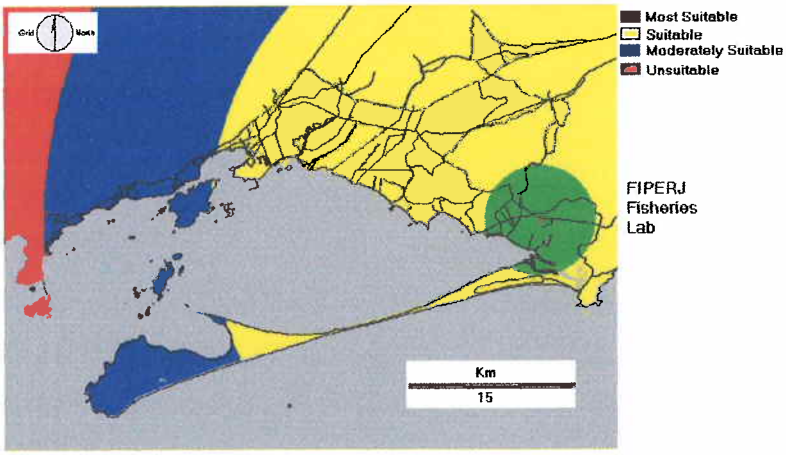

Figure 5.47. Site suitability in function of distance from specialised aquaculture technical support.

Access to Goods and Services

This layer was based on distance from the potential farm sites via secondary dirt roads in Sepetiba to the main paved road network. As a layer with secondary roads was not created the rationale for suitability scoring is described in Table 5.25. It is based on the fact that reasonable access to primary roads leading to local towns and interstate routes is necessary for heavy duty vehicles for hauling in deliveries of equipment, feed and fertilizers as well as hauling out aquaculture production. Access of services including technical assistance needed in several phases of the business is also important. In this study the maximum distance considered acceptable from farm site to a main road via a secondary dirt road was 10 km. By contrast, in other regions of Brazil, it is quite common for shrimp farms to be separated from the main paved roads by distances ranging from 2 to 150 km. As can be seen in Fig. 5.48 the paved road system in the region is reasonably well developed, and so, a large portion of the study area was found to be most suitable for shrimp culture. The unsuitable sites lie mostly in the Marambaia Island, and in the Serra do Mar, where there are no roads.

Table 5.25. Suitability scoring access to goods and services.

Suitability in function of distance (km) of potential shrimp culture sites to primary roads. Travel times assume distance able to be covered by vehicles = 10 km/hour on secondary roads.

Interpretation	Score
Most Suitable Access to main road network with 15 min. 0 – 2 km	4
Suitable Access to main road network with 30 min. 2 – 5 km	3
Moderately suitable Access to main road network with 60 min. 5 – 10 km	2
Unsuitable > over 10 km	1

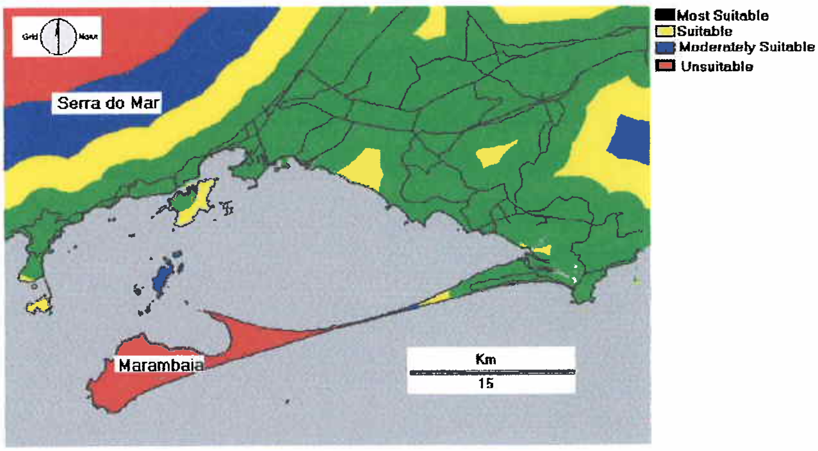

Figure 5.48. Site suitability in function of access to goods and services in the region.

Land Availability

Farmland and semi-intensive agriculture operations in the area were used as an important indication of land availability and suitability for shrimp pond construction. This layer (Fig. 5.49) was based on interpretation of the LandsatTM 354 composite and supervised classification backed by ground truthing. Table 5.26 describes the reclassification scheme adopted. As the study area experiences steady urban development, a buffer zone of 500 m from other types of land use was maintained around the agriculture coverage where potential shrimp farm could be developed. This buffer was based on the impressions of two shrimp farm managers and their experience. Several potential development areas are shown in Fig. 5.49, which can be grouped in three areas: Magaratiba, Itaguaí and Guratiba. The largest area is Itaguaí, known for its tradition in agriculture mainly cassava, guava, sugarcane and coconut plantations, many of which were visited during ground truthing.

Table 5.26. Suitability scoring for shrimp culture site suitability in function of land use adequacy.

Interpretation	Score
Most Suitable	4
Permanent or seasonal agriculture plots, pastures, farmland	
Unsuitable	1
All other uses	

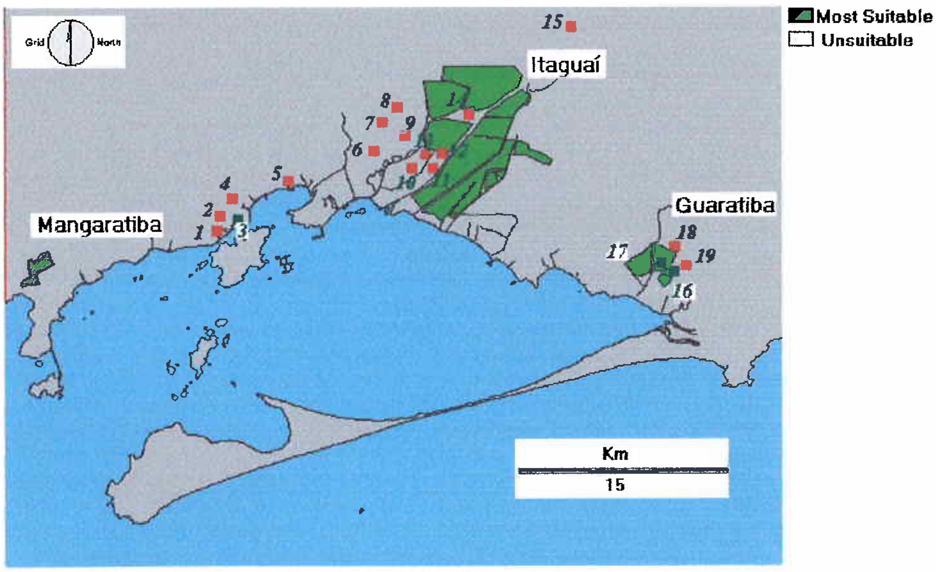

Figure 5.49. Site suitability in function of land availability for shrimp pond construction.

Squares represent selected ground control points: 1 – sandy beach, 2 – suburban area, 3 - 5, 6 forest/ grassland interface 7 – 9 exposed rock-covered areas, 10 – 13 industrial-suburban area, 14 – agriculture, 15 – urban area of Itaguaí, 16 – wetlands by road, 17- pasture, 18 – farmland, 19 – Fisheries lab – marshland. Green polygons (Most Suitable) represent continuous areas of agricultural use.

__Shrimp post-larvae availability__

Shrimp post-larvae are fragile organisms and should be swiftly transported to shrimp on-growing ponds. The proximity of the shrimp post-larvae hatchery enables minimal losses. In this respect, the study area is fortunate to have a fully equipped shrimp post-larvae production facility (FIPERJ). As the region lies within subtropical climate, minimum travel time means better and more economical, with minimal losses of shrimp post-larvae during transportation. In practice, shrimp post-larvae many times are flown in from production facilities very distant to farm sites, however, this produces considerable rise in costs. Table 5.27 shows the suitability scoring adopted in this study which was based on the assumption that FIPERJ would be able to furnish shrimp post-larvae in sufficient quantity.

Table 5.27. Suitability scoring for shrimp seed availability. Distance 'as the crow flies' over the region.

Interpretation	Score
Most Suitable Post-larvae can be delivered within an hour 0-15 km	4
Suitable Post-larvae can be delivered within 1-3 hours 15 - 60 km	3
Moderately suit able Post-larvae can be delivered within 3- 6 hours 60 – 140 km	2
Unsuitable >140 km	1

Travel times assume distance able to be covered by vehicles = 60 km/hour on main roads.

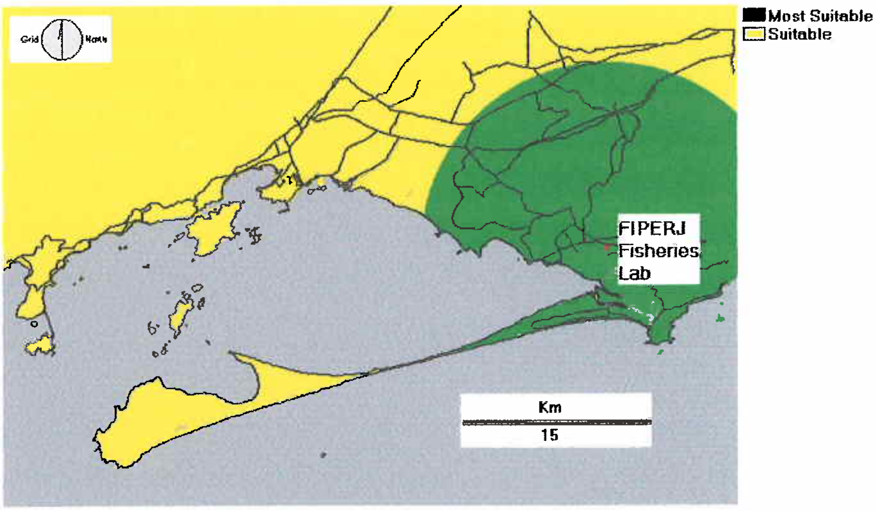

Figure 5.50. Shrimp culture site suitability in function of distance from shrimp post-larvae source.

5.2.4 PHYSICAL FACTORS

Seawater availability

The basic pre-requisite for successful rearing of penaeid shrimps is the availability of seawater. Sepetiba bay's mainland shoreline extends for approximately 55 km. In practice, most shrimp farms tend to install their seawater pumping stations on the coastline, or very close to it. However, many farms do site their pumping stations within the intertidal range, sometimes upstream in estuarine areas. In coastal areas with low lying lands, seawater can be distributed via a feeder canal to ponds which may be sited considerably distant from the shoreline. In this study, potential farm sites were limited to a maximum distance from the shoreline of 7 km, based field observations. This is the case in the Guaratiba and Guandú regions, where mangrove vegetation and brackish waters are found up to 7 km away from the bay's coastline. Thus, potentially, shrimp culture sites could be built a distance of up to 7 km away from the bay's waters including mangrove water canals to a limited extent. Figure 5.51 shows the suitability of the study area reclassified in function of Table 5.28. Distance 'as the crow flies' from the coastline was used to reclassify potential sites from sources for abstracting seawater for pond filling. This criterion was judged to be sufficient for the initial stages of modelling, but would have to be carefully revised taking into consideration year round variation of tidal range.

Table 5.28. Site suitability scoring shrimp culture as a function of distance from seawater abstraction points. Distances refer to 'as the crow flies' from the coastline.

Interpretation	Score
Most Suitable Lowest cost for seawater abstraction and distribution. Seawater available most of mean tidal ranges. 0 – 1 km	4
Suitable Higher pumping costs and water head. 1 – 2.5 km	3
Moderately suitable Maximum distance from coastline (Guaratiba) found in the study area. Highest water head. Seawater abstraction may be limited in times of high rainfall or low tides. 2.5 – 7 km	2
Unsuitable > 7 km	1

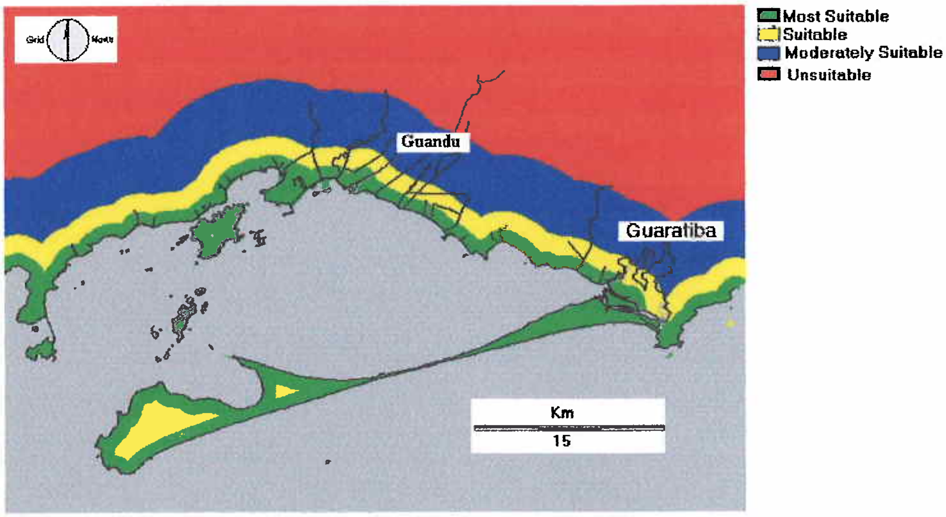

Figure 5.51.Shrimp culture site suitability in function of seawater availability for filling shrimp ponds.

5.2.4 PHYSICAL ENVIRONMENT

Freshwater availability

Freshwater sources are mostly important as means of maintaining adequate salinity in shrimp ponds. Shrimp farms tend to be located in the tropics and subtropics and so, on-growing ponds are subject to high evaporation rates. To control salinity, construction design many times will include a pumping station or a sluice gate mechanism in local freshwater courses as a means of providing freshwater for mixing with seawater in a mixing canal or pond before distribution. In this way, adequate salinity for shrimp culture can be delivered to the on-growing ponds. To develop a freshwater intake layer for Sepetiba, a vector file describing the main rivers and canals present around the bay was digitised, rasterised, and distance algorithm applied to it. Subsequently, it was reclassified by the criteria shown in Table 5.29. The freshwater volume available from these sources varies considerably from $17 m^3 s^{-1}$ for the Rio Piraquê to $342\ m^3 s^{-1}$ for the Guandú canal (Fig 5.52). In shrimp culture, it is usual for some percentage of pond water to be exchanged daily. In Brazil, under semi-intensive to intensive conditions this is usually about 20%. Depending on the extent of the areas identified by the shrimp culture potential prediction model, the available freshwater sources layer may need to be better developed.

Table 5.29. Suitability scoring for shrimp culture sites in function of freshwater availability. Freshwater sites considered are major water courses such as rivers and drainage canals.

Interpretation	Score
Most Suitable Freshwater source within 500m of a mixing canal. Lower construction costs. 0 - 0.5 km	4
Suitable Abstraction, pumping and water distribution costs increase. 0.5 - 1 km	3
Moderately suitable Maximum distance for water pumping and distribution at reasonable cost. 1- 1.5 km	2
Unsuitable > 1.5 km.	1

Proximity to freshwater sources was used as an indication of freshwater available to potential shrimp farms in the study area. From the climatic data collected, it is clear that rainfall is abundant in the area (1000 - 2000 mm y^{-1}) and during the rainy season, may be a contributing factor to cover maintenance of pond water salinity. Also to be considered in a future study using the current model as a base, freshwater sources in the study area could be reclassified in function of water temperature. This could be important for some areas such as those adjacent to the Mazomba River which descends from the Serra do Mar approximately 400 m high, probably having cooler waters than those of the Itaguaí and Itá rivers which travel over lowland regions for several kilometres.

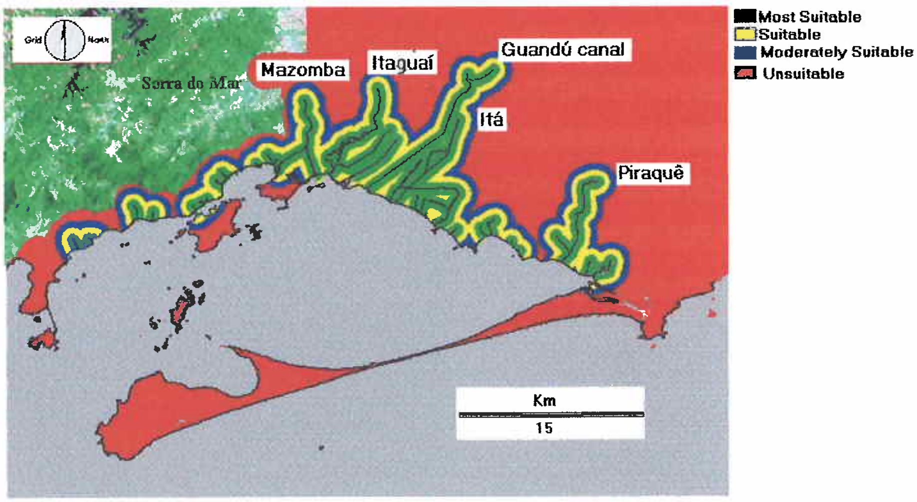

Figure 5.52. Suitability in function of freshwater availability for regulating salinity in shrimp ponds.

Soil quality

Figure 5.53 shows the reclassified image of soil quality in terms of its suitability for pond construction and for shrimp culture, as reclassified according to Table 5.30. Sepetiba lowlands are dominated by gley, gley-tiomorphic and planosols, all containing high levels of clay, a condition favourable for pond construction. Gley-tiomorphic soils however are less suitable as they tend to be acid, a condition which can become unfavourable during pond construction, if sulphur is present, producing acid sulphate soils, not recommended for shrimp culture.

Although yellow latosols were not found in the within study area, they were found in the base maps studied covering the wider area. Because these soils are abundant in the state of Rio de Janeiro, and are in fact, are suitable for pond construction, its classification as Moderadely Suitable was maintained in the scoring system adopted, as this can enable analysis of other areas in the state using the same model developed.

Cambisols are recent, shallow soils, present in the study area but generally unsuitable for pond construction as they tend to be low in clay and silt, and have high seepage rates.

Alluvial soils are sandy soils and can be found in the region mostly around the Mazomba River. Marine quartz sands are found in the Marambaia Island. Both these types of soils favour water seepage in ponds and so, are unsuitable for pond construction. Soils in urban areas were reclassified as unsuitable.

Table 5.30. Suitability scoring for shrimp pond construction in function of soil quality.

Interpretation	Score
Most Suitable Gley – rich soils, favourable for pond construction and shrimp production.	4
Suitable Gley-tiomorphic, planosols and yellow podsols - rich soils good for pond construction.	3
Moderately suitable Yellow latosols – suitable for pond construction, but may produce acid conditions in ponds.	2
Unsuitable Cambisols, alluvial soils, marine quartz and urban areas	1

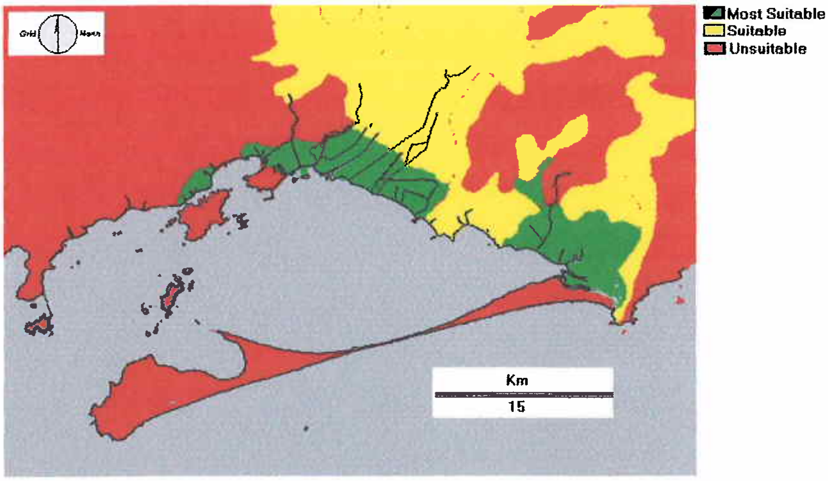

Figure 5.53. Shrimp culture site suitability in function of soil characteristics for shrimp pond construction.

Vegetation and land use

The reclassification results of the vegetation and land use layer shown in Figure 5.54, used the supervised classification results of the LandsatTM image. The Most Suitable category included all types of vegetation, including grasslands, agricultural areas and mangroves. Some of these areas are flat, low-lying areas, close to the seashore, where topography generally favours pond construction, but many areas thus classified are in fact are on hilly countryside. All areas classified as urban/suburban use or sandy terrain including most of Restinga da Marambaia were considered unsuitable because of its use for human occupation in the former case or high seepage rates in the latter case. All areas identified with wetlands and salt barrens were merged into the Suitable category (Table 5.31). These areas usually involve higher pond construction costs associated with initial drainage of the terrain before building of dikes can begin. Additionally, coastal waterlogged areas may potentially indicate acid soil conditions.

Many areas which at this stage were classified as suitable are in effect unsuitable due to one or more constraints, which are dealt with at the end of this chapter.

Table 5.31. Suitability scoring for shrimp pond locations in function of vegetation and land use.

Interpretation	Score
Most Suitable	4
All vegetated areas including grasslands, agriculture, and mangroves.	
Potentially transformed into shrimp ponds at low costs.	
Suitable	3
Waterlogged soils. Drainage of terrain can increase pond construction costs.	
Unsuitable – Sandy areas such as beaches Restinga and urban/suburban areas	1

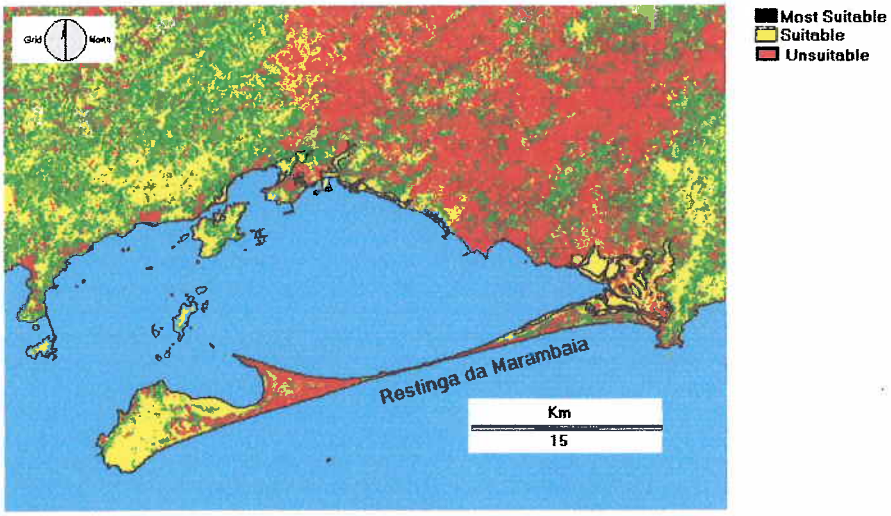

Figure 5.54. Shrimp culture site suitability in function of vegetation cover and land use

5.2.5 CLIMATE

Figure 5.55 shows the reclassification results which describe the climatic types found for the study area using the Köppen classification system. In general, warm tropical climate is favourable for white shrimp culture. However, *L. vannamei* is also cultured successfully in other types of climate including warm temperate climates typical of southern Brazil as in Santa Catarina, where the shrimp farming industry now thrives. For the purposes of this research, the reclassification scheme adopted in Table 5.32 considered as suitable, only the classes **Aw** and **Af** of Koppen's classification system, found in the study area and described in Table 3.2 (Chapter 3).

Table 5.32. Suitability scoring of Köppen classification of local climate for shrimp culture. Based on SEMA 1996 data.

Interpretation	Score
Most Suitable Tropical climate (warm, higher precipitation) – year round growth for shrimp **Aw**	4
Moderately suitable Tropical (cool, lower precipitation) – good growth conditions **Af**	2
Unsuitable Warm Temperate (rainy, mild winter) – shorter growing season **Cf**	1

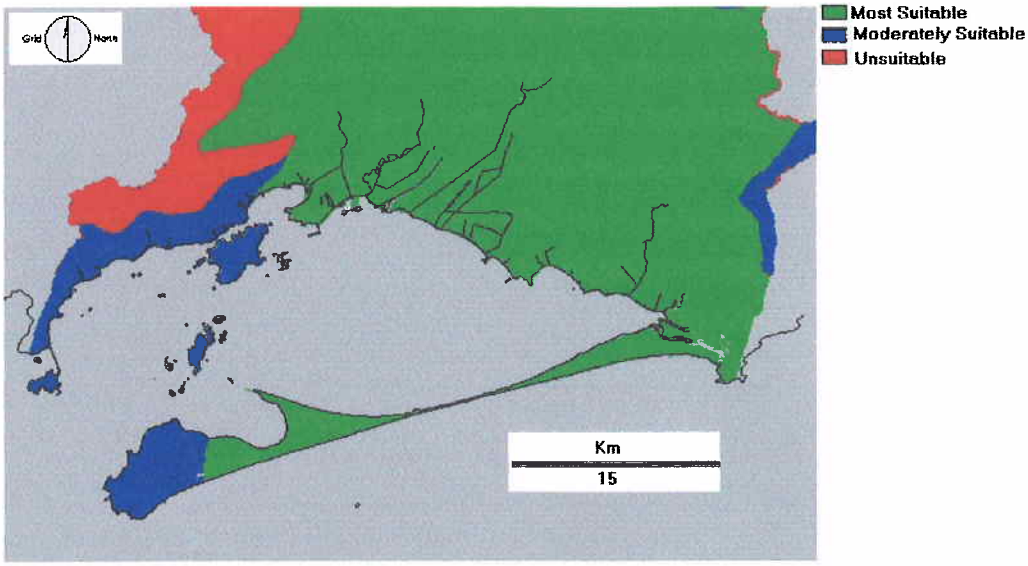

Figure 5.55. Shrimp culture site suitability in function of appropriate climate.

Rainfall

Because of the regions highly variable topography, rainfall and air temperature vary considerably. In an attempt to make better use of the available information on rainfall and air temperature, two additional layers were created hoping that they would improve results. Thus Fig. 5.56 shows rainfall suitability for shrimp farming areas according to the reclassification system adopted in Table 5.33 for data obtained from a rainfall distribution cartogram (SEMA, 1996) input into the database. A large portion of the study area has annual rainfall values between 1000-2000 mm. This range was considered suitable, as it contributes to replenishment of the freshwater sources in the catchment area, and supports maintenance of adequate salinity in the shrimp ponds either directly through rainfall over the pond surface, or alternatively by contributing to the river sources which in turn are used by the farm by means of pumping stations or diversion of water courses. Areas with yearly rainfall values over 2000 mm were reclassified as unsuitable because of the likelihood of flooding and damages to pond dikes potentially causing loss of production. Some of these areas are located at the base of the hills in the Itacuruçá - Muriquí region, by the sea. Areas with rainfall values under 1000 mm, are associated with a temperature regime which contributes towards undesirable salinization of pond water, leading to shrimp stress and hence lower productivity. Large areas of the study area were re-classified as Suitable to Most Suitable.

Table 5.33. Shrimp culture site suitability scoring as function of mean annual rainfall.

Interpretation	Score
Most Suitable – 1000- 1200 mm –	4
Suitable 1200 – 1600 mm	3
Moderately suitable 1600 – 2000 mm	2
Unsuitable 1000 mm > 2000 mm	1

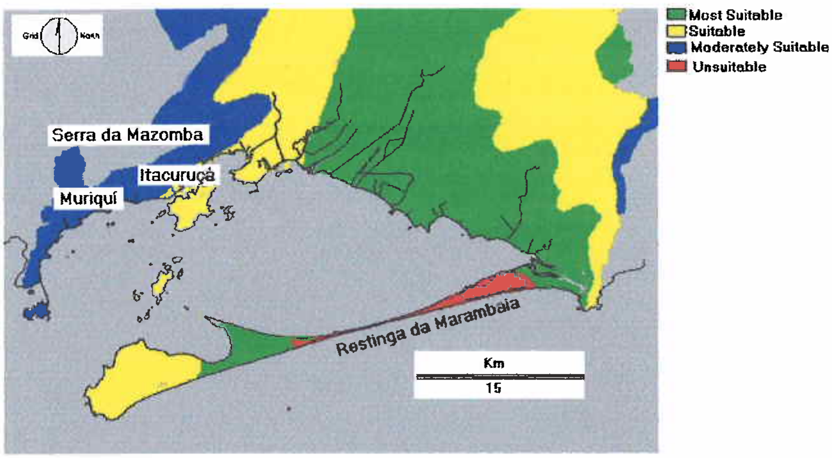

Figure 5.56. Shrimp culture site suitability in function of rainfall.

Air temperature

Air temperature was given a similar approach as given to rainfall. The information available in the SEMA 1996 cartogram was used as described in Table 5.34 to indicate water temperature suitability for shrimp culture as shown in Fig 5.57. In fact, *L. vannamei* is cultured in a wide temperature range, and where optimal culture conditions exist, such as in north-eastern Brazil where on average air temperature is about 27 °C year round, they allow three on-growing cycles per year. The reclassification scheme adopted was arbitrated with the support of an aquaculture expert and shrimp farm manager with many years hands on experience in white shrimp farming.

Table 5.34. Shrimp site suitability scoring in function of air temperature (°C).

Based on SEMA 1996 cartogram, arbitrated with support of a shrimp aquaculture expert.

Interpretation	Score
Most Suitable	4
Best growing conditions	
> 24.0	
Suitable	3
23.5 – 24.0	
Moderately suitable	2
21.5 - 23.5	
Unsuitable	1
< 21.5	

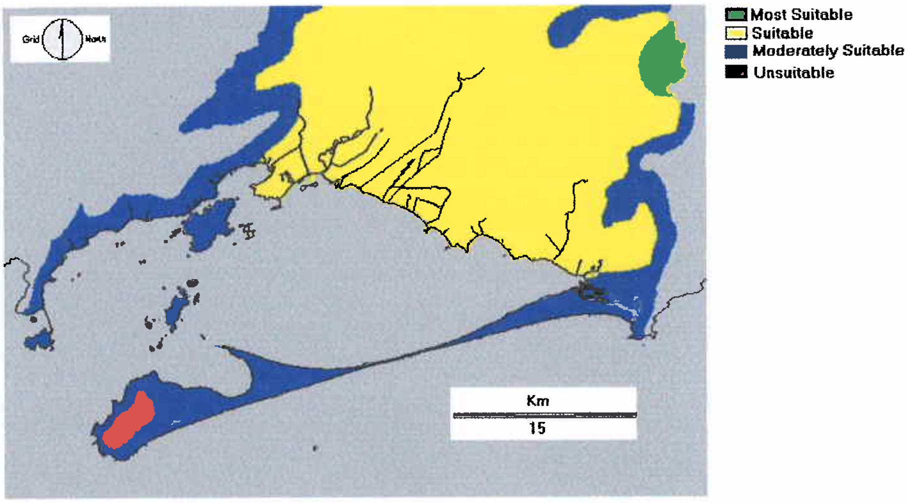

Figure 5.57. Shrimp culture site suitability in function of air temperature.

Natural Indicators - Mangroves

In the sheltered conditions where mangroves naturally occur along the coastline, abundant supplies of organic matter and nutrients favour wild shrimp post-larvae growth. Thus, the presence of mangroves usually indicates good growing conditions for shrimp. All the mangrove covered areas were identified by supervised classification of the LandsatTM image. This was used to create a 'natural indicator layer' consisting of a buffer zone around the mangrove limits, as an indication of bands with similar conditions as those which are naturally favourable for shrimp. The mangrove coverage itself was considered a constraint layer, since it is protected by law. The thresholds presented in Table 5.35 were agreed upon after field verification in the Guaratiba area and by arbitration with a shrimp farming expert familiar with similar areas along the Brazilian coastline. The resulting image (Figure 5.58) shows the reclassified results.

Table 5.35. Suitability scoring for shrimp culture potential in function of proximity to Natural Indicators.

Interpretation	Score
Most Suitable Closest to typical mangrove habitat, including *Rhizophora mangle* plants 0 - 0.7 km –	4
Suitable Within influence of mangroves, transition zone, areas with *Avicennia nitida* and *Laguncularia racemosa* predominance. 0.7 – 1.4 km	3
Moderately suitable Normally out of direct contact with present mangrove coverage, but potentially within past mangrove coverage, such as salt barrens and fields with with *Salicornia sp* . 1.4 - 2.1 km	2
Unsuitable > 2.1 km.	1

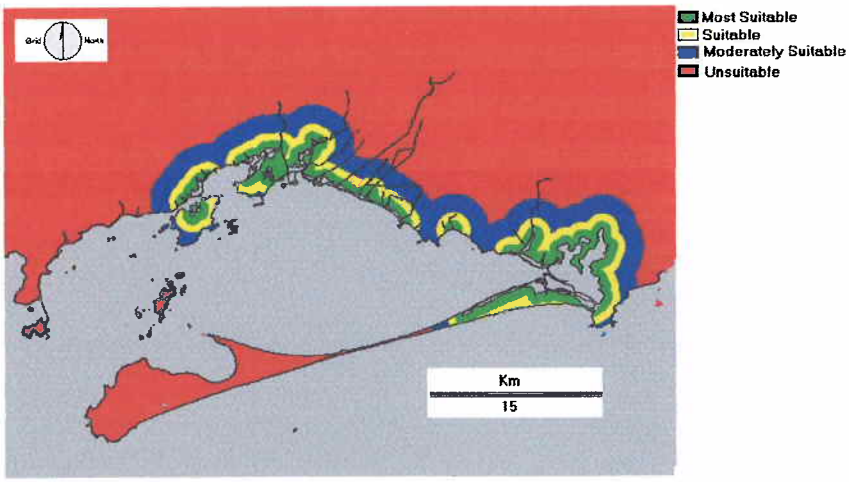

Figure 5.58. Shrimp culture site suitability in function of proximity to mangrove areas.

5.2.6 MARKETS

Market potential for white shrimp was based on the rationale developed in the previous section, as described for mussel and oyster market potential. It is a function of the distance from the population centres, number of people in these centres area their purchasing power. Figure 5.59 illustrates suitability as distance from major towns in the study area, using the reclassification scheme adopted in the previous section (Table 5.18).

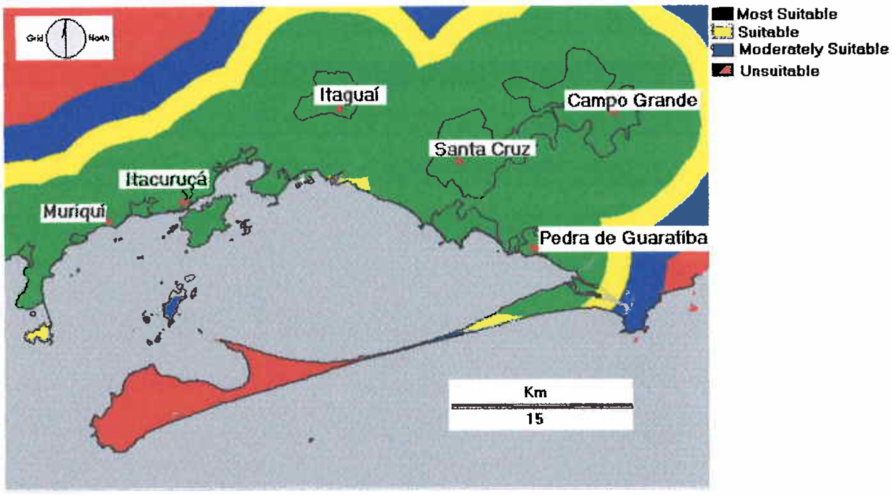

Figure 5.59. Shrimp culture site suitability distance from population centres.

Figure 5.60 illustrates suitability as distance from purchasing power of the population centres as described in Table 5.21. The reclassification scheme adopted is also that used for mussels and oysters (Table 5.22).

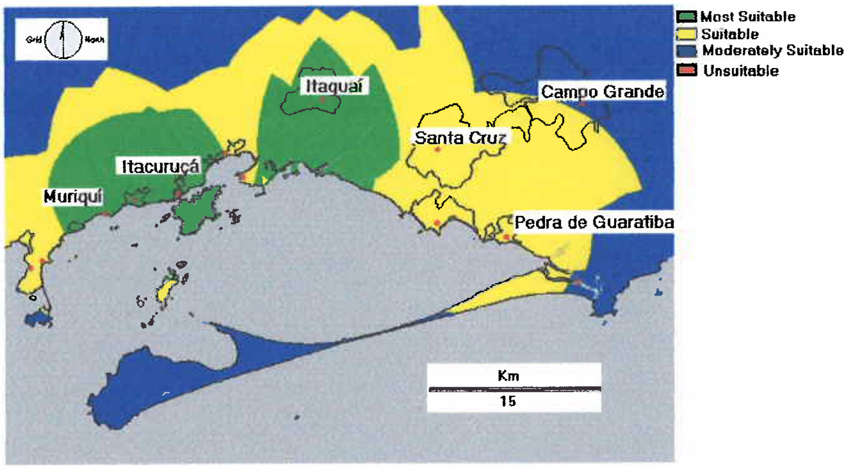

Figure 5.60. Shrimp culture site suitability in function of purchasing power of local populations.

Figure 5.61 illustrates site suitability in function of seafood consumption likelihood, taking into account that coastal populations and additionally including outlets such as small restaurants and hotels found along the coast which probably contribute to higher consumption of seafood. Populations living in town centres away from the coast traditionally consume less seafood than coastal populatins. The reclassification scheme adopted is described in Table 5.36.

Table 5.36. Suitability scoring for shrimp culture potential in function of proximity to seafood consumption. Consumption indicated in function of proximity to potential consumers.

Interpretation	Score
Most Suitable Sites closest to roadside seafood restaurants and hotels. 0 – 1km	4
Suitable Sites within influence of coastal towns, coastal roads and tourist seafood catering 1 – 7km	3
Moderately suitable Sites further from coastal towns, within most of study area. 7 - 45km	2
Unsuitable > 45km	1

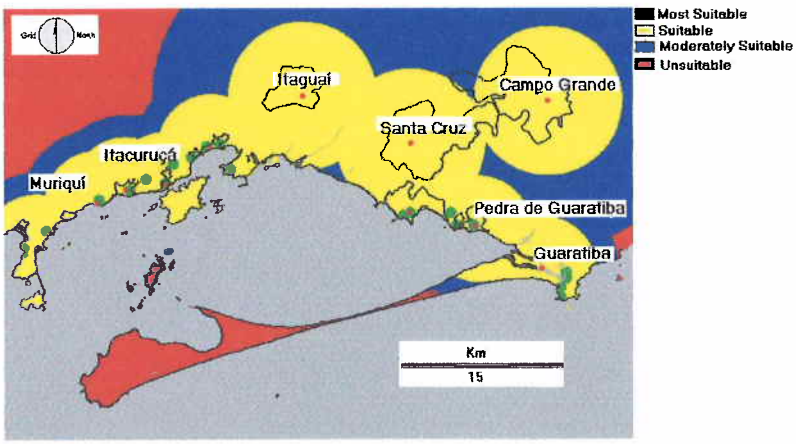

Figure 5.61. Shrimp culture site suitability in function of proximity to potential fish consumption.

5.2.7 CONSTRAINTS

Many criteria were used to develop a land-based shrimp culture development constraint layer. It is the result of adding all areas where shrimp culture is unfeasible or impeded by legislation. It consists of: urban/suburban areas; mangrove areas; nature parks/reservation/protection areas, a 300m buffer zone along rivers, a 500m buffer zone around some important and potentially hazardous industrial sites identified during ground truthing phase, as well as all areas beyond 7km from the coastline, and all areas above 5m altitude. The final constraint layer is shown in Fig. 5.62.

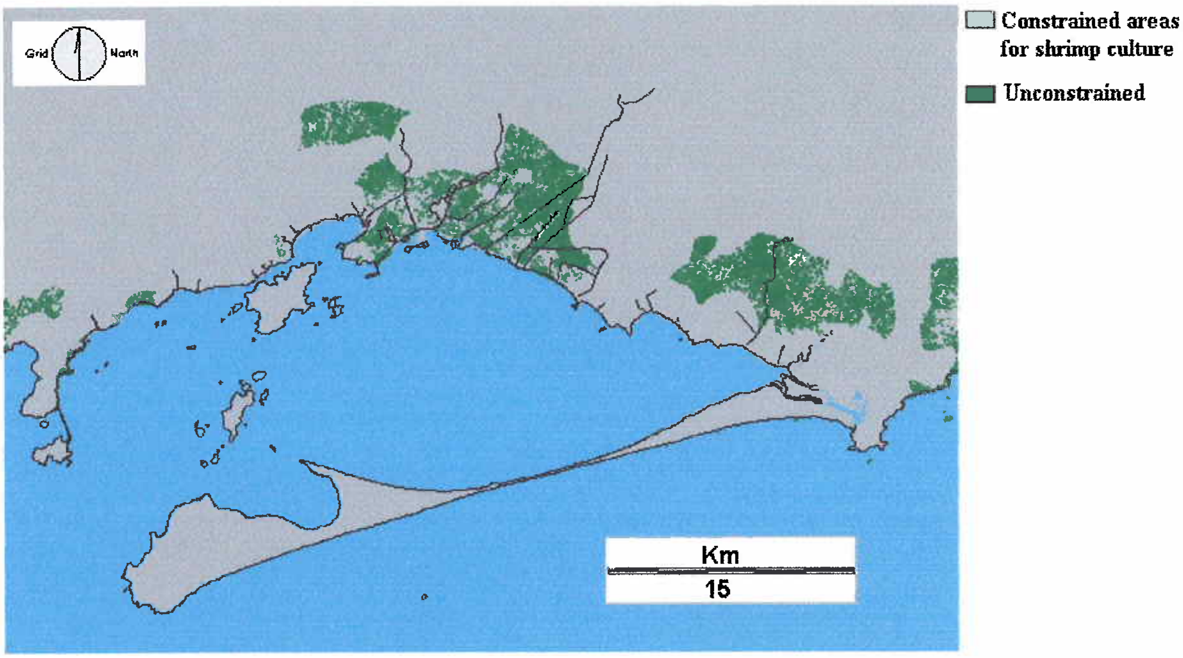

Figure 5.62. Total constrained areas for shrimp farming.

CHAPTER 6
COMBINING GIS SUB-MODELS USING MULTI-CRITERIA EVALUATION TO DETERMINE AQUACULTURE PRODUCTION POTENTIAL

6.1 INTRODUCTION

To determine aquaculture potential, sets of production functions, also referred as criteria were identified and grouped following a logical system into species-specific sub-models designed to reach a specific outcome, i.e. suitable areas for aquaculture production. The methodology followed is along the lines of Aguillar-Manjarrez and Ross (1993); Gutierrez-Garcia (1995); Aguillar-Manjarez (1996); Jarayaband (1997) and Perez-Martinez (2002).

The framework for this study, relies on assigning weights to each production function within the sub-models designed for each species. This process was based on judgement obtained from the best knowledge available about the study area, including interviews with professionals well acquainted with the topic and the area. The sub-models of each species-specific model also needed to be weighed in the context of their relative importance towards the projected outcome, i.e., site suitability for aquaculture development.

The sub-models developed for each of the three species concerned are as much as possible, specific. Because of the many similarities in the physiological requirements of mussels and oysters, the ensuing presentation follows the framework of the sub-model, with comments on the specifics for each species.

Following initial exploratory modelling as indicated from the literature, it became clear that it was important to canvas a wider and broad-based audience of professionals, collecting their views and judgements by means of a questionnaire. In a second phase, this collection of weightings assigned to specific production functions (criteria) was focussed on a smaller science/aquaculture-based group who rated several aspects pertinent to the principal sub-model identified for mussel and oyster culture (water quality, basis for organism survival, growth and socio-economic aspects of aquaculture development).

The natural range of values for each of the production functions important for aquaculture development in Sepetiba Bay, and the local set of constraints present, were developed into raster images as described in the previous chapter. These images were combined into four sub-models (water quality, infrastructure, physical factors and markets), designed to identify the potential for mussel and oyster culture, and for shrimp culture using infrastructure, physical factors, climates and markets sub-models. The sub-models were subsequently adjusted with a composite constraint image, including all types of development impediments encountered, the final objective being to arrive at an image depicting the best possible sites for aquaculture development in Sepetiba Bay.

The decision making process for each species sub-models was assisted by using Multi-Criteria Evaluation (**MCE**) in order to find the most suitable sites for aquaculture development. In this way, sets of similar criteria were combined to achieve intermediary resulting images. These were once again combined in a final MCE to achieve the principal objective being to identify all suitable areas for each species, considering all production factors involved and limiting constraints to the activity .

In order to use the multi-criteria evaluation decision making tool present in IDRISI, a set of relative weights for each criterion in the sub-models had to be developed. This was accomplished by making a series of pairwise comparisons of the relative importance of each criterion being evaluated in each sub-model. These comparisons were made using the **WEIGHT** module of IDRISI.

These pairwise comparisons were then analysed to produce a set of weights that sum to 1. The factors and their resulting weights were used as input for the **MCE** module for a weighted linear combination. The procedure by which the weights were developed is described and follows the logic developed by Saaty (1977) under the Analytical Hierarchy Process (AHP).

To identify the realtive importance of production factors and constraints related to aquaculture development, a questionnaire was developed and applied to a number of professionals.

6.2 METHODS

6.2.1 QUESTIONNAIRE DEVELOPMENT

In a first phase, a simple questionnaire was applied to a group consisting of 19 professionals from the Economics, Urban Planning, Aquaculture consultancy, Fisheries research and extension, Biology and Environmental Sciences areas. Some of these were fellow lecturers at Universidade Santa Úrsula and others, invited guests which were assembled for a Workshop held on 26/11/1997. All members of the group were familiar with the general area of Sepetiba. The group was considered as a local 'expert panel'.

The purpose of the questionnaire was explained as being a means to collect views and judgements and determine ranks for aquaculture variables in a site selection process using GIS. The questions asked of the participants were as follows:

Before the participants answered the questionnaire, and in order to level out the general understanding of the group on the issue, an introductory, brief explanation about mariculture was given. Broadly, it was described as being "an activity which utilises the marine/coastal environment to grow food organisms such as oysters, mussels, shrimp or fish under controlled conditions".

It was also explained that aquaculture is practised in coastal sites such as protected bays where shellfish including mussels and oysters growing on floating structures or alternatively on fixed racks situated in the intertidal zone, as well as fish in floating sea cages or shrimp in coastal ponds. For this type of production to occur, the group was alerted that some issues are restrictive to the activity in one way or another, (constraints) and they should be listed.

The basic distinction between constraints and limiting factors (production functions) was made. Constraints were defined as those factors which due to some 'higher force' could actually impede the development of the activity as for example in the case of a specific legislation ruling out use of an area for the purpose, or in the case of heavy pollution of the environment.

Limiting factors (production functions or variables) were defined as those variables which could increase or diminish production, as a function of their intensity, such as in the case of water temperature or salinity which affect the physiology of an organism, or alternatively natural availability of foodstuffs affecting growth. The group was asked to list those factors which they judged could increase, or reduce the biological production of farmed organisms.

Additionally a brief description of the geographic study area, western Rio de Janeiro and specifically Sepetiba Bay, was given.

The complete list of all participants, their occupation and area of expertise is found in Appendix 9. With all of the participants in the meeting room, the questionnaire session followed, lasting for about two hours, where each person independently noted down what factors he/she considered as being relative to 'production function variables' or 'constraints to aquaculture development'. The complete list obtained is shown in Appendix 10. Once the individual listing of production function variables was completed, they were asked to group production function variables into similar function groups, in an attempt to identify potential sub-models, and finally, to score each variable in the sub-models using AHP.

6.2.2 QUESTIONNAIRE RESULTS

The group was able to identify a total of 71 different factors they judged pertinent to aquaculture production (Appendix 10). Many of these factors were identified by multiple respondents.

A total of 195 individual replies was collected. The number of sub-models identified by respondents varied from 0-5. The number of production function variables associated with each sub-model varied from 1 - 8 (Table 6.1) Forty-two percent those interviewed, grouped production functions into associations they considered as distinct sub-models. However, another 57.8% of the group, did not identify sub-models, putting all the identified production function variables into one single model.

Table 6.1 Questionnaire respondents (abbreviated) and number of production function variables found.

Respondent		Variables per sub-model
1	A. G.	7, 4, 4, 1
2	A. d. M.	12
3	C. P.	6
4	C. T.	4, 5, 4
5	C. G. F.	5, 3, 6
6	E. A.	8, 2
7	E. C.	5
8	G. S.	19
9	J. A.	7, 5, 4, 4
10	J. C. C.	12
11	J. L. C.	7
12	J. F.	6, 4, 8, 2, 2
13	L. L.	5
14	L. F. V.	7, 5, 4, 1
15	L. J.	2, 6, 2, 2
16	M. C.	7
17	M. L.	6
18	S. R. P. M.	5
19	Y. W.	9

The questionnaire results were analysed and regrouped as production function variables according to the nearest matching category into sub-models. The respondents easily identified broad areas of related variables such as 'water quality standards and concerns', 'general infrastructure needs', 'aspects of the physical environment' and finally 'market related topics' as summarised in (Table 6.2). However, several topics (19.5% of the total) identified by the interviewed group as 'production factors' were interpreted by the author as being in fact constraints and therefore reclassified.

Table 6.2 Distribution of questinnaire replies grouped in broad categories.
n = number of replies in each category.

Category	n	%
Constraint related	38	19.5
Water quality related	55	28.2
Infrastructure related	39	20.0
Physical environment related	32	16.4
Market related	21	10.8
Others	10	5.1
Total	**195**	**100**

When the production functions were re-grouped (Table 6.3), water quality related variables were found to be the most important (34.2%), followed by infrastructural variables (26.7%) and then closely by physical environment variables (19.9%). Market related variables accounted for only 13.0% of the total.

Table 6.3 Production function variable distribution according to suggested sub-model groups.
n = number of replies in each category. % indicates percentage of total replies

Variables	n	%
Water quality related	55	34.2
Infrastructure related	43	26.7
Physical environment related	32	19.9
Market related	21	13.0
Others	10	6.2
Total	**161**	**100**

A possible explanation for the relatively high agreement that a Water Quality sub-model is most important can be explained by the professional composition of the interviewed group largely constituted of Life Scientists (Table 6.4).

Table 6.4 Distribution of professional backgrounds of questionnaire respondents.
n = number of respondents per category

Professional categories	n	%
Life Sciences	13	68.4
Architecture/Engineering	4	21.1
Economics	2	10.5
Total	**19**	**100**

6.2.3 WEIGHT DETERMINATION.

Weights for the production functions and the sub-models were developed using the WEIGHT module of IDRISI, in which weights are produced following the Analytical Hierarchy Process (AHP) logic. Multi-Criteria Evaluation (MCE) was used as the decision support tool as it allows a combination of criteria to achieve a single composite basis for final decision making.

The weights obtained in this phase of the study were eventually used on the base criteria images used were those developed earlier (Chapter 5) which represent system-related suitability of water quality, infrastructure, physical environment and market variables. These are finally combined with development constraints layer with the objective of achieving a single final aquaculture suitability map.

During the interview process more emphasis was placed on a water quality sub-model. In order to re-assess the relative importance of functions related to the water quality sub-model, a choice of water quality related variables was selected from those identified by the main group and offered for rating to a smaller group of aquaculture experts, using the AHP logic.

The optimal range of environmental variables for successful culture of a given species, may be more easily agreed upon by experts than their inter-relationships within a model. The latter may be subject to individual interpretation, depending on the expert's specific aquaculture objectives and also his professional background.

Expert Rating
In this second phase, a focused evaluation was carried out by a select group of aquaculture experts consisting of experienced personnel from the state aquaculture and fisheries research and extension office of Rio de Janeiro, Fundação Instituto de Pesca do Rio de Janeiro - (FIPERJ). All those interviewed had many years of experience in diverse aspects of aquaculture production ranging from culture of unicelular algae, rotifers, marine shrimp, mussels and oysters. This second interview phase was carried out on 12/8/98. The group was asked to rate the following production variables: salinity, dissolved oxygen, temperature, chlorophyll-a and faecal coliforms (*Escherichia coli* count). Secondly the group was asked to rate the importance of markets, siting, technical support, fishermen location, and seed availability in an overall model. The experts were asked to use the nine-point scale illustrated in Figure 6.1, where one variable must be rated in terms of its importance relative to another.

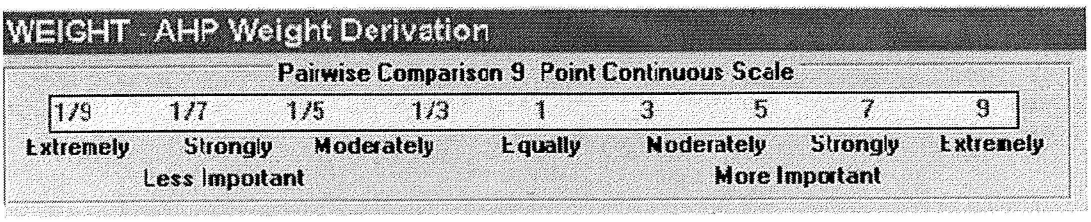

Figure 6.1 Pairwise 9 point scale of relative importance comparison scale of Idrisi Weight module.

The aquaculture production functions were presented as a group in a 'Water Quality Sub-model', which the experts were asked to rate by pairwise comparison, filling in a matrix of cells, moving from column to column from left to right, generating a Pairwise Comparison File (PCF). Each cell was considered relative in importance of the row variable to its corresponding column variable as illustrated in Figure 6.2, using the nine-point scale. The result of these is summarised in Table 6.5.

	salok	oxyok	tempok	clorok	ecolok
salok	1				
oxyok	1	1			
tempok	1/3	1/3	1		
clorok	1	1	5	1	
ecolok	1/5	1/5	1/5	1/5	1

Figure 6.2 Example of rating with 9 point pairwise comparison scale.
The files used are water quality criteria image files: salinity (SALOK); dissolved oxygen content (OXYOK); surface water temperature (TEMPOK); Chlorophyll-*a* content (CLOROK) and faecal coliforms (ECOLOK)

Consistency ratios (CRs) with values near zero show good consistency, while values higher than 0.10 indicate that the relative importance comparisons should be reconsidered. It can be seen that the partial consistency ratios for salinity, dissolved oxygen and temperature are generally higher than those related to chlorophyll-*a* content and *E. coli* count. This may be because the former variables have a more direct relation to physiological requirements of most marine organisms, while the latter may be interpreted in two ways: High chlorophyll-*a* values may be interpreted as an indication of waters rich in algal content important for shellfish nutrition, or alternatively, as an indication of poor water quality or deterioration. In excessive amounts, such as in noxious dinoflagelate blooms, they can be a hazard to human health.

Table 6.5 Results of the WEIGHT module for water quality parameters in Water Quality sub-model.

Respondent	Variable	Eigenvector of weights	Criteria images and partial consistency ratios						Consisten ratio
1. A. D. M.	Salinity	0.0920	SALOK	0.00					
	Oxygen	0.0647	OXYOK	-2.21	0.00				
	Temperature	0.3484	TEMPOK	2.58	0.38	0.00			
	Chlorophyll	0.3824	CLOROK	1.16	2.91	-1.90	0.00		
	E. coli	0.1125	ECOLOK	-2.78	0.74	3.90	0.60	0.00	0.25 (lo
2. C. T.	Salinity	0.3197	SALOK						
	Oxygen	0.1056	OXYOK	-0.03	0.00				
	Temperature	0.4074	TEMPOK	0.27	-3.14	0.00			
	Chlorophyll	0.0597	CLOROK	-2.36	-2.77	-1.83	0.00		
	E. coli	0.1075	ECOLOK	4.03	4.02	3.21	-5.20	0.00	0.26 (lo
3. G. Z..	Salinity	0.2635	SALOK	-	-	-	-	-	
	Oxygen	0.1010	OXYOK	-	-	-	-	-	
	Temperature	0.3017	TEMPOK	-	-	-	-	-	
	Chlorophyll	0.3017	CLOROK	-	-	-	-	-	
	E. coli	0.0322	ECOLOK	-	-	-	-	-	0. (acceptab
4. J. T.	Salinity	0.2288	SALOK	0.00					
	Oxygen	0.2069	OXYOK	-2.11	0.00				
	Temperature	0.4080	TEMPOK	0.78	-3.03	0.00			
	Chlorophyll	0.1229	CLOROK	1.14	1.32	0.32	0.00		
	E. coli	0.0334	ECOLOK	-3.85	2.81	0.00	5.32	0.00	0.16 (lo
5. L. T.	Salinity	0.1238	SALOK	0.00					
	Oxygen	0.0834	OXYOK	2.48	0.00				
	Temperature	0.2793	TEMPOK	1.26	-3.65	0.00			
	Chlorophyll	0.4745	CLOROK	-5.17	-3.31	-0.70	0.00		
	E. coli	0.0390	ECOLOK	1.82	2.86	-2.17	-4.00	0.00	0.21 (lc
6. S. P. R.	Salinity	0.2676	SALOK	-	-	-	-	-	
	Oxygen	0.2676	OXYOK	-	-	-	-	-	
	Temperature	0.1100	TEMPOK	-	-	-	-	-	
	Chlorophyll	0.3097	CLOROK	-	-	-	-	-	
	E. coli	0.0451	ECOLOK	-	-	-	-	-	0 (acceptak

The results of this attempt to obtain the relative importance of production variables is summarised in Table 6.5. Here, it can be seen that only two of the six replies arrived at acceptable CRs which would support use of the variable weights in an MCE analysis.

During the same session, the six experts interviewed were asked to rate other production related variables detected by the larger broad-based group as important, and so, considered in this research as sub-models on their own. These were: markets, in terms of their existence, size and general acceptance of fishery/aquaculture products; siting, as a general indication of its importance in relation to the infrastructure and accessibility to the road network, to services and goods important for production; technical support, as in the availability of trained aquaculture experts to assist in all phases of production; fishermen location, as in the importance of their proximity to those with natural conditions and appropriate environment for aquaculture production purposes, and finally; seed availability, either as in the possibility of obtaining it from naturally occuring areas or from laboratories producing it in large quantities.

The relative importance of these and other production function results is shown in Table 6.6. Four of the six experts achieved acceptable CRs in their pairwise comparisons between sub-models. The participants who obtained low consistency ratios in their pairwise comparisons had lowest CR's for those factors pertaining directly to their participation in the aquaculture process, i.e. Technical support (CR=3.77) or Seed Availability (as in lab produced seed) CR=5.86, which may indicate the presence of some unknown bias in their response.

A satisfactory explanation for lower CRs obtained in the water quality sub-model as opposed to that obtained in the more general production function sub-models, remains to be investigated, and might require further research with larger expert groups taking into account issues which could reduce bias in one or another production function.

Table 6.6 Results of the weight module for aquaculture sub models, as attributed by specialists.

Respondent	Variable	Eigenvector of weights	Criteria images and partial consistency ratios						Consistency ratio
1. A. D. M.	Market	0.0358	Mkt	-	-	-	-	-	
	Site	0.4311	Towns	-	-	-	-	-	
	Technical Support	0.1048	Fiperj	-	-	-	-	-	
	Fishermen location	0.0920	Fishers	-	-	-	-	-	
	Seed availability	0.3364	Seed	-	-	-	-	-	0.05 (acceptable)
2. C. T	Market	0.3440	Mkt	0.00					
	Site	0.2070	Towns	1.34	0.00				
	Technical Support	0.0640	Fiperj	-0.37	3.77	0.00			
	Fishermen location	0.0278	Fishers	0.00	1.55	2.69	0.00	---	
	Seed availability	0.3572	Seed	0.04	-1.27	-1.42	2.00	0.00	0.11 (low)
3. G. Z.	Market	0.2621	Mkt	-	-	-	-	-	
	Site	0.1844	Towns	-	-	-	-	-	
	Technical Support	0.2106	Fiperj	-	-	-	-	-	
	Fishermen location	0.1585	Fishers	-	-	-	-	-	
	Seed availability	0.1844	Seed	-	-	-	-	-	0.09 (acceptable)
4. J. T.	Market	0.3609	Mkt	0.00	0.00				
	Site	0.4174	Towns	4.16	0.00	0.00			
	Technical Support	0.0356	Fiperj	-4.00					
	Fishermen location	0.0532	Fishers	-1.78	1.16	-1.51	0.00		
	Seed availability	0.1329	Seed	-3.72	5.86	0.73	-0.50	0.00	0.24 (low)
5. L. T.	Market	0.0693	Mkt	-	-	-	-	-	
	Site	0.0693	Towns	-	-	-	-	-	
	Technical Support	0.0693	Fiperj	-	-	-	-	-	
	Fishermen location	0.2749	Fishers	-	-	-	-	-	
	Seed availability	0.0571	Seed	-	-	-	-	-	0.03 (acceptable)
6. S. P. R.	Market	0.2616	Mkt	-	-	-	-	-	
	Site	0.0600	Towns	-	-	-	-	-	
	Technical Support	0.1325	Fiperj	-	-	-	-	-	
	Fishermen location	0.2616	Fishers	-	-	-	-	-	
	Seed availability	0.2843	Seed	-	-	-	-	-	0.07 (acceptable)

6.2.4 Integration of weights from the questionnaires with the GIS models

To apply the impressions obtained from the two groups interviewed and to establish primary model weights, it was decided that a unique set of weightings based on these, together with data from the literature on the types of aquaculture concerned should be developed. Though to some degree subjective at this stage, it permitted the models to be developed and then be subject to sensitivity analyses to assess the significance of the critical assumptions concerned. This set of MCE weights for the site suitability prediction models for mussels, oysters and shrimp is shown in Table 6.7. These weights are in the core of the modelling decisions and affect essentially the outcomes of the prediction models.

To appreciate the weights attributed, the pairwise comparison matrix which shows the relative importance of each criteria in the sub-models is initially presented, by species, in the sub-model, where it is justified and briefly discussed (Section 6.3). In cases where lack of sufficient information for grounding the factor weights was found, the author arbitrated to the best of his knowledge in order to allow weight derivation for input towards the MCE decision support tool used throughout the modelling. Finally, Table 6.8, shows the factor weights assigned for the sub-models of each species-specific site suitability model.

Table 6.7 Factor weights for sub-models used in multi-criteria evaluation for aquaculture species models.

	Model		
	Mussel	**Oyster**	**Shrimp**
Sub-model	**Factor weights**	**Factor weights**	**Factor weights**
Water Quality	Mcemuss	Oystwq	-
Temperature	0.4343	0.4399	-
Salinity	0.2079	0.2069	-
Dissolved Oxygen	0.2183	0.1950	-
Chlorophyll-a content	0.1119	0.1262	-
E. coli content	0.0276	0.0320	-
Consistency Ratio	0.06	0.06	-
Infrastructure	Infra	Oytinfra	SInfra
Technical support	0.0723	0.0983	0.1661
Road network	0.0723	0.1586	0.0480
Fishermen	0.4277	0.2270	-
Seed sources	0.4277	0.5161	0.3294
Local agriculture			0.4565
Consistency Ratio	0.01	0.05	0.05
Physical Factors	Physmus	Oytphys	SPhys
Wave exposure	0.6586	0.5396	-
Current velocity	0.1562	0.2970	-
Depth aproprpriate	0.1852	0.1634	-
Coastline distance	-	-	0.1275
Freshwater distance	-	-	0.0569
Soil quality	-	-	0.5590
Vegetation and land use	-	-	0.2566
Consistency Ratio	0.03	0.01	0.04
Climate			Sclimate
Rainfall	-	-	0.0833
Air temperature	-	-	0.4530
Climate	-	-	0.4021
Mangroves	-	-	0.0616
Consistency Ratio	-	-	0.05
Markets	MMkts	OMkts	SMkts
Market distance	0.1562	0.1562	0.1782
Purchasing Power	0.6586	0.6586	0.7514
Fish Consumption	0.1852	0.1852	0.0704
Consistency Ratio	0.03	0.03	0.03

Table 6.8 Factor weights used in multi-criteria evaluation for aquaculture suitability sub-models.

	Factor weights	**Factor weights**	**Factor weights**
Sub-model	*Mussel*	*Oyster*	*Shrimp*
Water Quality	0.2860	0.3999	-
Infrastructure	0.1002	0.1076	0.1250
Physical Factors	0.1602	0.2653	0.3750
Climate	-	-	0.3750
Market	0.4536	0.2272	0.1250
Consistency Ratio	0.10	0.06	0.00

6.3 Development and Weighting of Sub-Models

6.3.1 Water Quality Sub-Model

Water temperature was considered the most important criterion of this sub-model, followed very closely by Salinity, Dissolved Oxygen, and Chlorophyll-*a* as an indication of food source in the water (Table 6.9).

Mussels

The faecal coliform count in the water, although important from the perspective of being an indication of potential hazard to human health, was considered less important than other factors in terms of adequacy for mussel growth. Mussels are known to thrive in waters with significant numbers of faecal coliforms. However they can become stressed if they are subjected to spend many hours in waters with low dissolved oxygen levels, or salinity which is not within its preferred range.

Table 6.9 Pairwise comparison matrix for mussel water quality sub-model. Consistency ratio = 0.06 .

Factor	Temperature	Salinity	Dissolved oxygen	Chlorophyll *a*	Faecal coliforms
Temperature	1				
Salinity	1/3	1			
Dissolved oxygen	1/3	1	1		
Chlorophyll	1/3	1/3	1/3	1	
Faecal coliforms	1/9	1/7	1/9	1/7	1

Oysters

The pairwise comparison matrix shown in Table 6.10 is very similar to the mussel water quality sub-model, because both organisms share many environmental requirements. However, slightly more importance was given to the faecal coliform count variable because oysters are very often cultured closer to the shore and are therefore more exposed to sewage runoff than cultured mussels. Oysters are also frequently eaten uncooked. Higher coliform counts could be an indication of higher water temperatures and also more polluted water conditions, while dissolved oxygen levels remain within the acceptable range. Chlorophyll-*a* content was also slightly more important because oysters are more limited in their feeding requirements, requiring specific sizes and qualities of phytoplankton for good growth (Velez 1989 and Lemos 1994).

Table 6.10 Pairwise comparison matrix for oyster water quality sub-model. Consistency ratio = 0.06.

Factor	Temperature	Salinity	Dissolved oxygen	Chlorophyll *a*	Faecal coliforms
Temperature	1				
Salinity	1/3	1			
Dissolved oxygen	1/3	1	1		
Chlorophyll	1/3	1/3	1/2	1	
Faecal coliforms	1/9	1/5	1/7	1/7	1

6.3.2 INFRASTRUCTURE SUB-MODEL

The infrastructure sub-model was based on distances of potential culture sites from infrastructural elements. These are the technical support base in the region (represented by FIPERJ); the local roads network; the fishing villages and/or community cooperative centres from which culture operations could be based, as well as distance from wild mussel banks in the bay, or oyster spat obtained in natural spatfall in mangrove areas i.e. primary seed sources. Adult mussels and mussel seed are found on rocks and rocky shores of islands in the bay. Their geographical positions were recorded the field reconnaissance phase, and their locations were digitised on-screen. Oyster spatfall area was considered equal in all mangrove areas. Weights in this sub-model attributed more importance to distance from the fishermen's home base and from mussel seed sources, as these two elements were likely to be more critical for production. Although technical support is also important, it is probably only as important as access to roads when mussel farmers need to find support and solutions to technical problems, but much less important than distance from culture site for day-to-day management and culture 'starter' seed.

Mussels

Technical support, in the form of visits from fisheries extension agents depends on the difficulty of access to the potential sites. The local fisheries extension service, has a roadside base on interstate BR-101 so, any site close to a road, is relatively easily accessible. However, reaching those sites which may be on islands, or in mangrove areas, accessible only by boat, imposes greater difficulty hence the 'strongly more important' rating given in the PCF shown in Table 6.11.

Of the many residential sites occupied by fishermen, very few were found to be close to roads. The distance from sites where mussel seed naturally occur was found to be more important than distance to technical support, as people have started mussel culture in places where seed supply is available, even if with little or no technical support. By the same token, communication among fishermen is likely to be important in transmitting information and cultural practices, such as aquaculture. Thus, closeness to naturally occurring mussel seed banks was judged less important than distance to other fishermen, or fishermen organizations such as a co-operatives.

Table 6.11 Pairwise comparison matrix for mussel infrastructure sub-model.
Consistency ratio = 0.01.

Factor	**Technical support**	**Distance from roads**	**Distance from fishermen**	**Distance from mussel seed sites**
Technical support	1			
Distance from roads	1	1		
Distance from fishermen	3	1	1	
Distance from oyster banks in mangroves or hatchery	7	3	2	1

Oysters

Because of the culture system adopted, i.e. racks in the intertidal area, *C. rhizophorae* is most likely to be farmed closer to the mainland, instead of on island fringes where water depth increases abruptly. Slightly less importance was given to distance from technical support than for mussels, because these sites would be more easily accessible by vehicle/boat combination (Table 6.12), and also, because fishermen cooperatives on the mainland are on the roadside. However, distance from an oyster hatchery, such as the local hatchery, or alternatively from mangrove spat settling sites, was considered strongly more important than distance from technical support, because, there is only one oyster hatchery in the state, and because collection of natural oyster spatfall in mangroves is still not practised in the region. If fishermen have easy access by means of their own canoes, or reasonable walking distance to the FIPERJ hatchery, or mangrove areas where they can collect oyster spat, distance to the road network becomes less important. Likewise, closeness to other fishermen was judged only slightly more important than that of seed sources because it can facilitate exchanges and bartering including that of oyster seed.

Table 6.12 Pairwise comparison matrix for oyster infrastructure sub-model. Consistency ratio = 0.05.

Factor	**Technical support**	**Distance from roads**	**Distance from fishermen**	**Distance from mussel seed sites**
Technical support	1			
Distance from roads	1	1		
Distance from fishermen	3	1	1	
Distance from oyster banks in mangroves or hatchery.	7	3	2	1

Shrimp

The shrimp culture potential infrastructure sub-model followed a similar rationale to that employed in the mussel and oyster models, i.e. it was based on distance of potential culture sites in the mainland area of Sepetiba Bay region to several infrastructural elements.

The pairwise comparison matrix which shows the relative importance of each production function in the infrastructure sub-model is shown in Table 6.13. The roads network was found less important than availability of good technical support. However, shrimp seed supply was found more important than technical support, because it is argued that many operations fail to succeed if they do not have a steady, reliable supply of seed. As there are more than 20 comercial labs producing shrimp post-larvae in the country, and air shipment of these is a common practice, its importance was judged only slightly more than that of technical support. Availability of agricultural land was found to be much more important than that of technical support, as without the land, the activity itself cannot occur. Shrimp seed supply was rated much more important than the roads network, as even if the latter is poor, if the seed are available, they can be transported by more rudimentary means without significant loss. Agricultural land availability was judged more important than the road network because it is the main factor which enables the activity to happen, and it often does, in remote sites with poor roads network. Seed availability, was rated equally as important to agricultural land availability for the activity depends totally on both.

Table 6.13 Pairwise comparison matrix for the shrimp infrastructure sub-model.
Consistency ratio = 0.05.

Factor	Technical support	Roads network	Shrimp seed supply	Agriculture availability
Technical support	1			
Roads network	1/5	1		
Shrimp seed supply	2	5	1	
Agriculture availability	4	9	1	1

6.3.3 *PHYSICAL FACTORS SUB-MODEL*

Mussels

Even if mussels can grow in relatively exposed sites, mussel culture has lower operating costs and risks if it is carried out in relatively sheltered sites. Therefore in this sub-model, water current velocities were deemed much less important than shelter from wind and wave action (Table 6.14). Another factor incorporated in this sub-model is a 'natural indicator' layer consisting of a buffer zone of 100 m around mussel sites identified during the ground truthing and field verification phase. It is assumed that physical conditions including currents, shelter and water temperature, present in locations where mussels naturally occur, should be similar around these areas, and could be useful indicatation of surrounding conditions. However, physical conditions can vary substantially over short distances and so, this 'proxy natural indicator' layer, was considered moderately less important than the predicted protection from wave and wind action as developed in the shelter layer as indicated by the maximum significant wave height model described in Chapter Four.

Table 6.14 Pairwise comparison matrix for mussel physical factors sub-model.
Consistency ratio = 0.03.

Factor	Shelter	Currents	Natural Indicators
Shelter	1		
Currents	1/5	1	
Natural Indicators	1/3	1	1

Oysters

The natural indicator layer of good oyster growing areas was based on a 100m radius around mangrove areas identified by supervised classification of the satellite image during the database development phase. During ground truthing, it was found that there are areas where mangroves have been cleared more recently than the image date, or otherwise are in the process of regeneration after recent clearance. In this way, the natural indicator layer may not be totally adequate to indicate all areas otherwise suitable for oyster growth. Considering that oysters generally tend to be cultured in the shallows of estuaries and protected areas of bays, current velocities were considered slightly less important than in the oyster factors PCF (Table 6.15). Natural indicators of oyster areas, were considered slightly less important than local current velocities, which may vary significantly in branches of mangrove estuaries and shallow areas.

Table 6.15 Pairwise comparison matrix for oyster physical factors sub-model.
Consistency ratio = 0.015.

Factor	**Shelter**	**Currents**	**Natural Indicators**
Shelter	1		
Currents	1/2	1	
Natural Indicators	1/3	1/2	1

Shrimp

Shrimp culture depends fundamentally on seawater availability. Although freshwater availability is important, it was considered much less so than seawater availability in function of the site location distance from the coastline. Soil quality was considered much more important because in some cases, even where good seawater may be available, acid soils can result in poor shrimp growth performance in ponds with acidified water, thus reducing profitability.

The natural indicator layer for potentially adequate areas for shrimp culture was developed as a buffer zone extending for 2000 m beyond the edge of the mangrove zone.

Soil quality was considered to be much more important than freshwater sources, because, sandy soils and cambissols present in the study area, would make for very poor ponds because of high seepage rates adding to construction and operating costs. Replenishing ponds with freshwater sources would not solve the problem. Due to the indications given by mangrove vegetation as to the quality of the environment, this layer was considered much more important than closeness to fresh water but slightly less important than soil quality, mostly because soil quality changes less notably than vegetation cover and land use. The pairwise comparison matrix which shows the relative importance of each production function is shown in Table 6.16.

Table 6.16 Pairwise comparison matrix for the shrimp Physical Factors sub-model. Consistency ratio = 0.04.

Factor	**Marine Coastline**	**Freshwater Sources**	**Soil Quality**	**Vegetation and Land Use**
Marine Coastline	1			
Freshwater Sources	1/3	1		
Soil Quality	4	8	1	
Natural Indicators	3	4	1/3	1

6.3.4 MARKETS SUB-MODEL

Mussels and Oysters

A single pairwise comparison matrix was developed for mussel and oyster sub-models, as markets for shellfish are commonly grouped together separately from other seafood types such as finfish and even more so than cattle, pig, or chicken meat, the most commonly available alternatives in the area. Minimum wages (MW) per household income was taken as an indication of consumer purchasing power for seafood.

This factor was considered more important than actual fish consumption per capita, or distance to fish markets (Table 5.15). If consumers do not have the money to pay for seafood from aquaculture, it is hardly feasible to produce. However, if consumers have more available income to spend on seafood including 'value added' products, then marketing strategies could be developed to encourage higher seafood consumption. While market distances to the producing areas remain relatively the same over time or even become less important over time as roads improve and urban areas expand, household income can vary more significantly, limiting or expanding demand. In Brazil, seafood consumption is much lower than red or white meat consumption, though currently educational campaigns and public awareness of the advantages to health in consuming seafood suggest a trend of increase in demand. However, in this sub-model, seafood consumption was considered less important than actual distance to market, and much less important than consumer purchasing power.

Table 6.17 Pairwise comparison matrix for the markets sub-model.
Consistency ratio = 0.015.

Factor	Market distance	Purchasing power	Fish consumption
Market distance	1		
Purchasing power	3	1	
Seafood consumption	1/3	1/5	1

Shrimp

The pairwise comparison matrix developed for the shrimp model followed very closely that developed for oysters and mussels, but included the incorporation of a layer which plotted areas with higher purchasing power as well as higher seafood consumption than the values found by plotting only the statistical data from Fundação CIDE for the region. This layer was developed by creating a buffer zone plotting around a number of restaurants and hotels, most located like a string of pearls by the seaside around the bay. In this way shrimp farms located up to 1,000 m from a roadside restaurant or hotel, could benefit from additional customers possibly willing to buy at the farm gate, fresh produce for the customer plate. In this matrix, more emphasis was given to purchasing power, since shrimp is generally a more expensive commodity costing about £1.5/kg. Seafood consumption was considered less important than market distance, as shrimp is a valued commodity, and can support finding its way to a better paying market. It was also considered much less important than consumer purchasing power, as the latter will pay extra to receive fresh seafood even if they are a long distance from the source. These considerations were used to develop the pairwise comparison matrix shown in Table 6.18.

Table 6.18 Pairwise comparison matrix for the shrimp markets sub-model.
Consistency ratio = 0.03.

Factor	Market distance	Purchasing power	Fish consumption
Market distance	1		
Consumer purchasing power	5	1	
Seafood consumption	1/3	1/9	1

6.4 OVERALL WEIGHTING OF THE MODELS

Having listened to the judgements and views of the panel experts and having experimented with the AHP process during the exploratory phase of weight development, a specific pairwise comparison matrix was determined by the author for each species site-suitability model and carried out. The results of the predictive models using the PCFs are described in Chapter 7.

6.4.1 MUSSEL CULTURE POTENTIAL MODEL

Table 6.19 Pairwise comparison matrix for the Mussel culture potential model.
Consistency ratio = 0.1.

Sub-model	MCE- Water Quality	MCE- Infrastructure	MCE- Physical Factors	MCE- Markets
Water Quality	1			
Infrastructure	1/3	1		
Physical Factors	1/3	2	1	
Markets	3	3	2	1

The market sub-model is the predominant driving force in this model. Although mussel prices are generally low (£0.80/kg), when compared to other seafood products, it is relatively abundandant in the form of wild harvested, cooked, schucked mussels sold in the street markets. Water quality was the second most important factor considered, because whereas mussels can be grown in many sites, issues such as food supply, salinity and *E.coli* concentration were deemed more important than aspects relative to the physical environment or the general infrastructure needed to undertake the culture.

6.4.2 OYSTER CULTURE POTENTIAL MODEL

Table 6.20 Pairwise comparison matrix for the Oyster culture potential model.
Consistency ratio = 0.06.

Factor	MCE- Water Quality	MCE- Infrastructure	MCE- Physical Factors	MCE- Markets
Water Quality	1			
Infrastructure	1/3	1		
Physical Factors	1	2	1	
Markets	1/3	3	2	1

The market component is driving sub-model for oyster culture, with purchasing power being the most important aspect. But because oysters are cultured close to the mainland in intertidal waters, the water quality aspect is almost as important. For best results, oysters need good quality water and constant food supply. The scarcity of information on water circulation and otherwise appropriate siting cues as construed by natural indicators including mangrove areas, weighed more in the decision making process. General infrastructure for developing oyster culture systems was found satisfactory, and less important than the other factors.

6.4.3 SHRIMP CULTURE POTENTIAL MODEL

Table 6.21 Pairwise comparison matrix for the Shrimp culture potential model.
Consistency ratio = 0.00.

Factor	MCE- Infrastructure	MCE- Physical Factors	MCE – Climate & Natural Indicators	MCE- Markets
Infrastructure	1			
Physical Factors	3	1		
Climate	3	1	1	
Markets	1	1/3	1/3	1

Because of the perception despite its price (£1.50/kg) that local and foreign markets are buying white shrimp from aquaculture production sites in a regular fashion, and because the general infrastructure in Sepetiba is considered generally good for land-based aquaculture, the higher weights in this decision making process fell on the physical environment and climatic factors sub-models., with soil quality and air temperatures being the major influencial factors in this PCF.

CHAPTER 7
COMBINATION OF SUB-MODELS TO DETERMINE AQUACULTURE POTENTIAL

7.1 Mussel culture potential model

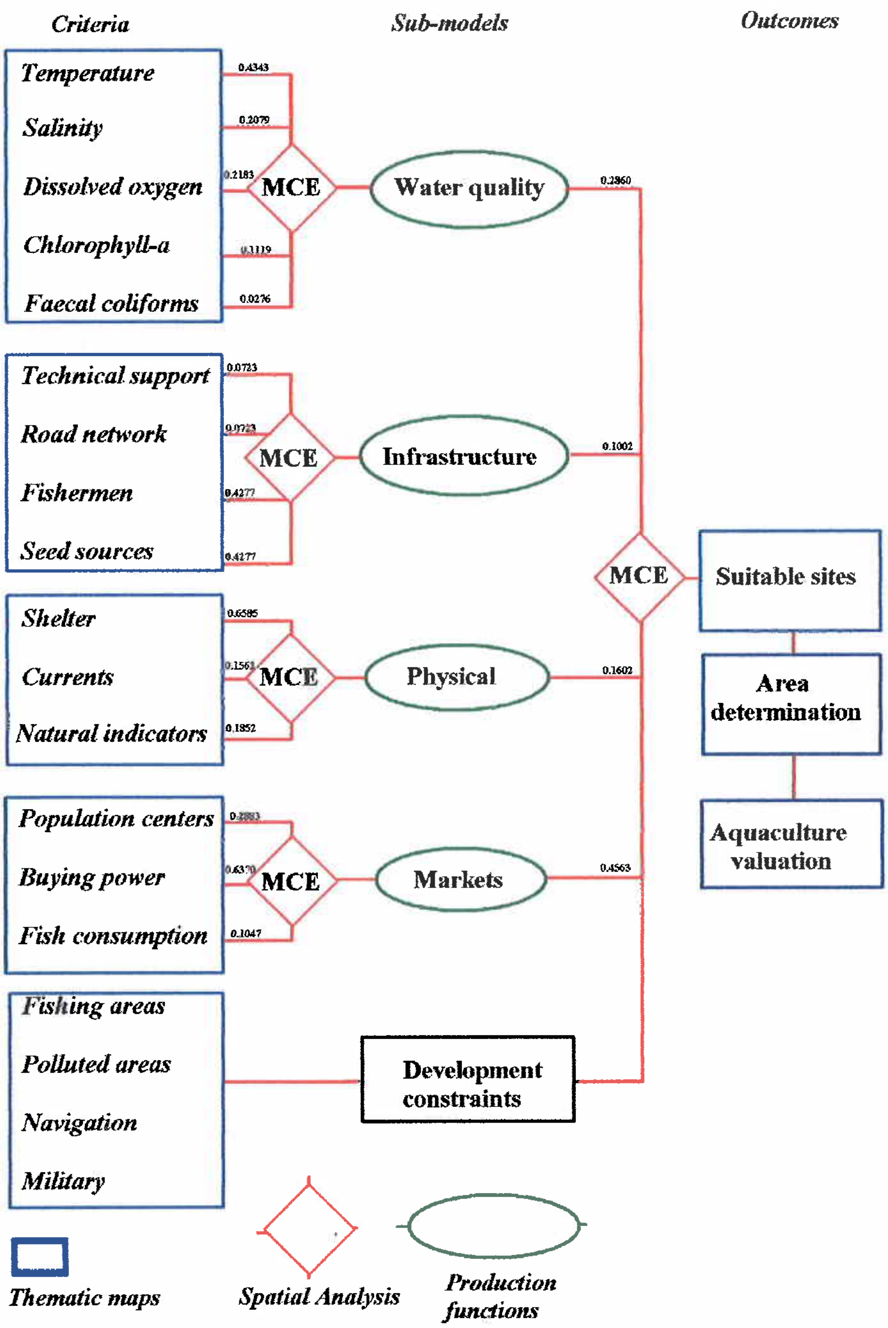

Figure 7.1 Mussel culture site suitability model.

Weights indicated were assigned by the author for different factors in sub-models.

In the previous chapter, the weights for each of the production functions was decided upon. The weights attributed to the criteria and sub-models and their integration in the general mussel site suitability prediction sub-model is shown in Fig 7.1. All the constraints identified in Chapter 5.1 were processed in IDRISI in a final **MCE** with the sub-models. This result was further processed with **FILTER** to remove small isolated groups of potentially suitable areas and subsequently **OVERLAID** with a **DISTANCE** generated buffer image as described in Table 7.1. The purpose of this last overlay was to substantially narrow down the potential areas.

Table 7.1 Reclassification criteria for suitability of mussel culture sites.
Suitability as a function of distance for visual surveillance.

Interpretation	Score
Most Suitable Up to 90 metres from shoreline - Best surveillance and access to culture system	4
Suitable 90 – 600 m from shoreline - Within close access and fair surveillance distance	3
Moderately Suitable 600 – 800 m from shoreline - limit of surveillance and reasonable access	2
Unsuitable > 800 m from shoreline	1

The final result (Fig. 7.2) shows three areas with continuous coverage of significant production potential: Area 1 includes Ilha de Itacuruçá, closest to the mainland. Area 2, embraces Ilha de Jaguanum, located midway between the mainland and I. da Marambaia, and Area 3, Ilha Guaíba on the western end of the bay.

The total production potential of Sepetiba Bay including all three suitability classes sums to 2,992 hectares of water surface area suitable for mussel culture, of which only 5.9% was found to be Most Suitable.

The areas inside the three areas considered in more detail account for 66.3% of the total suitable areas found. The areas excluded from the detailed analysis are those in front of the town of Muriquí and those in front of I. de Marambaia (Fig 7.2) because the former is subject to the effects of rapid urbanization while the latter has the least concentration of fishermen and is most distant to markets and infrastructure and so is less likely to be chosen for start-up projects.

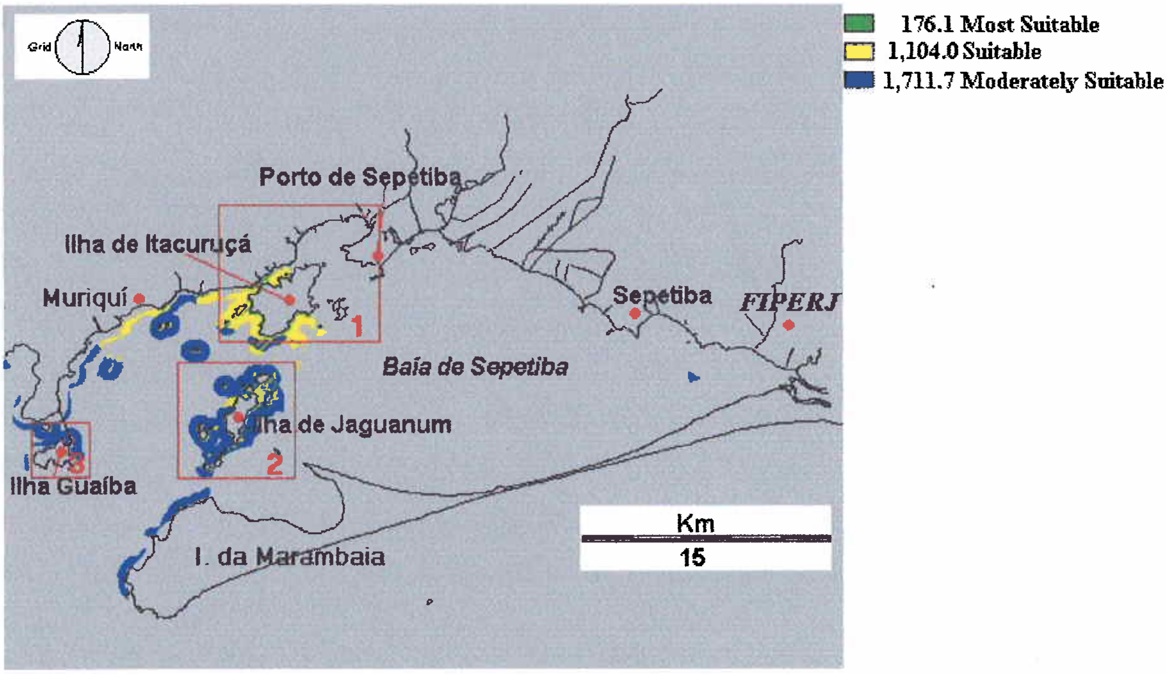

Figure 7.2 Model prediction outcome for mussel culture site suitability in Sepetiba Bay .
Three areas in Sepetiba Bay: Itacuruçá, Jaguanum and Ilha Guaíba.

AREA 1 - ITACURUÇÁ

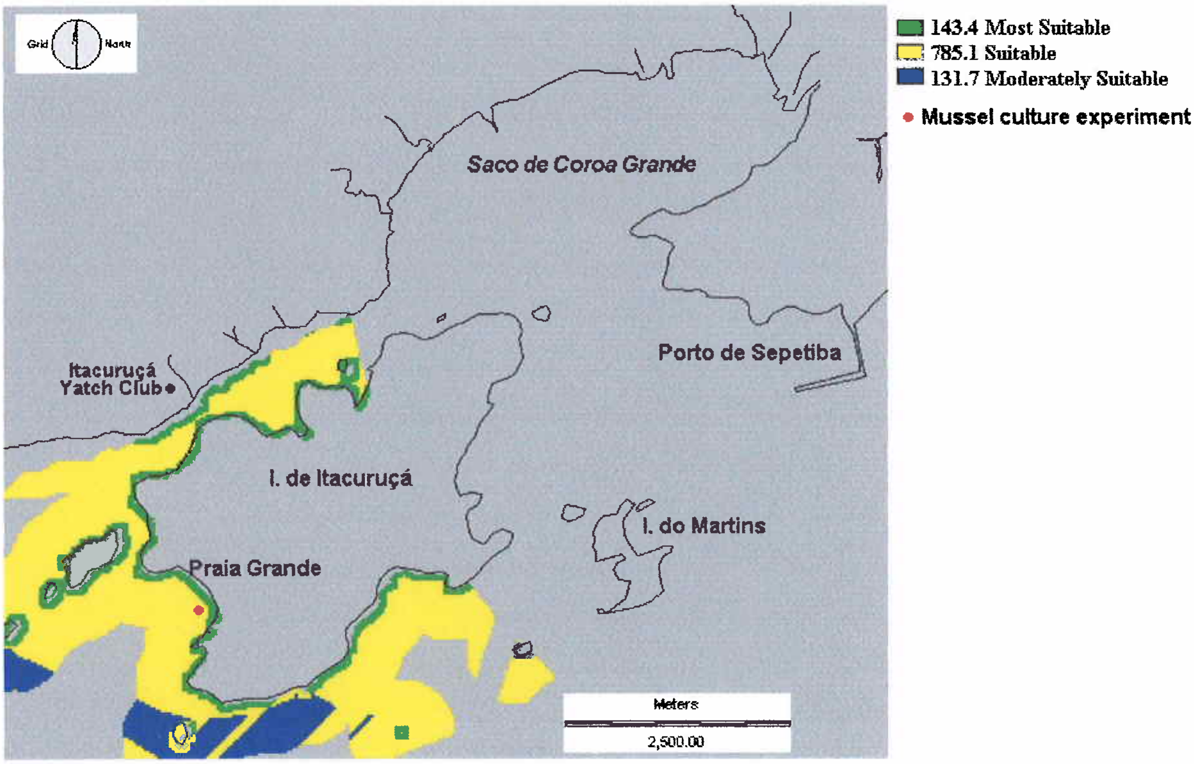

Figure 7.3 Mussel culture potential of Area 1 Itacuruçá.
Red dot indicates experimental culture site in Praia Grande.

Table 7.2 shows that the Itacuruçá island area and its surroundings hold a significant development potential concentrating 35.4% of all Sepetiba Bay's mussel culture potential, an extent of 1,060 ha of water surface mostly situated along its southern and western coastlines (Fig. 7.2). The areas are sufficiently distant from the influence of the Port of Sepetiba and the contaminated bottom sediments around it, as well as sufficiently distant from Saco de Coroa Grande bay and its freshwater inflows. Ilha de Itacuruçá is only 250 m away from the mainland (Fig. 7.3) and therefore has better access to goods and services than other islands further in the bay.

Recently (February, 2002) one of the sites predicted in this model (Praia Grande, Fig 7.3), was chosen by Universidade Castelo Branco (UCB) as their site for implementing an experimental mussel growing module.

No results of UCB's aquaculture trials are yet available, but the site was carefully chosen by an expert in mollusc culture. The adjacent mainland town of Itacuruçá certainly has enough market potential for farmed mussel placement as it has a busy Yacht Club, is the main tourist port for the 'Costa Verde' as the region is known, and includes several seaside restaurants. It is also located very close to the main road network leading to larger markets in Rio and other large towns.

AREA 2 - JAGUANUM

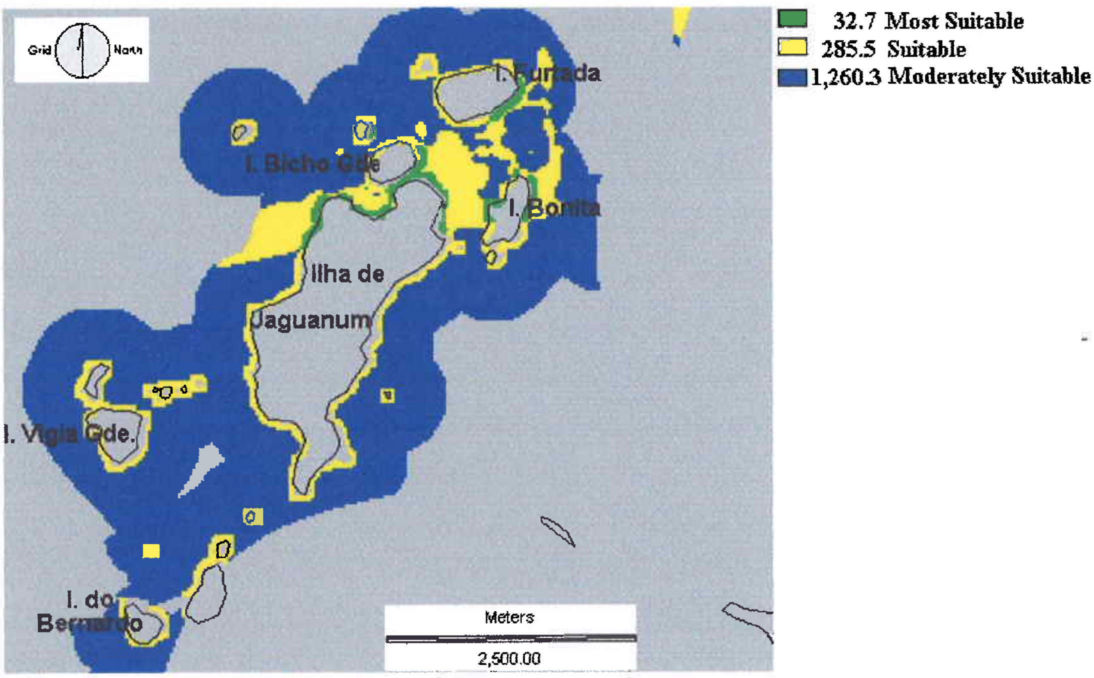

Figure 7.4 Mussel culture potential predicted for Area 2: Jaguanum. Mussel culture covering over 1,579 ha of suitable areas.

Table 7.2 also shows that Jaguanum island and several peripheral smaller islands has good mussel culture development, as illustrated in Figure 7.4. A total of 1,579 ha of suitable sites for mussel culture are found accounting for 52.8% of all the suitable areas. Its potential success is enhanced by the fact that it has a well established resident artisanal fishing community, a few small hotels and is a "must" stop for schooners departing Itacuruçá port with tourists on 'Costa Verde' tours for lunch and sunbathing.

Two potential sites in this region may generate area usage conflict. Nearby Ilha Bonita which is mostly a resort island, and the southern side of Ilha Furtada which is a 'hot spot' for sport fishing. Other good areas identified included as Suitable include Vigia Grande and Bernardo islands, which are clearly good mussel growing areas as they are natural mussel banks as identified during field verification trips.

AREA 3 -GUAÍBA

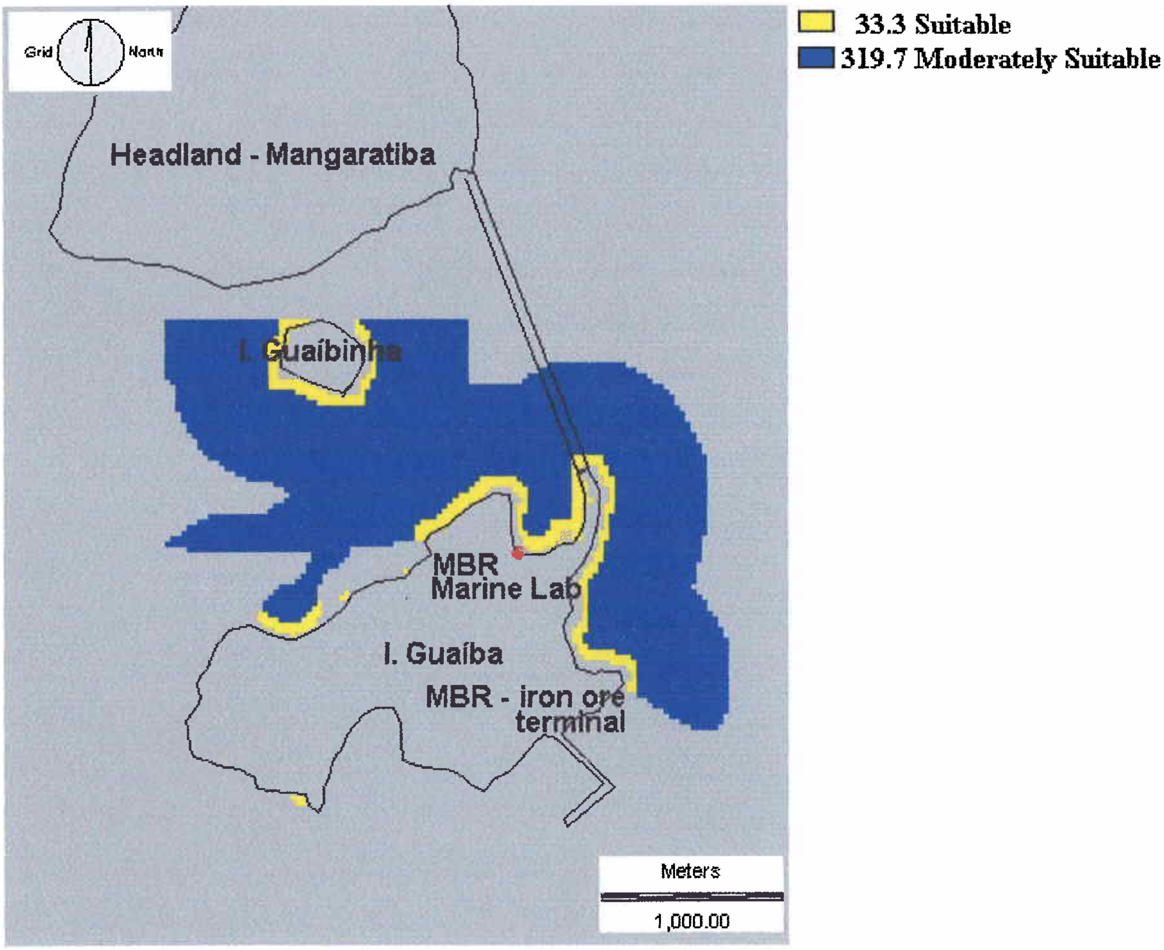

Figure 7.5 Mussel culture suitability for Area 3: Ilha Guaíba.
Ilha Guaíba in Sepetiba Bay is connected by a railway bridge to the mainland. 353 ha of suitable areas.

The third area Ilha Guaíba, and Ilha Guaibinha, just south of Mangaratiba on the mainland (Fig. 7.5). Although more distant to larger coastal towns, the model suggests that 353 ha are suitable for mussel on growing (Table 7.2). The island is situated in waters up to 25 m deep, with good water circulation. The area holds 11.8% of all Suitable areas for mussel culture detected in the bay. Due to its proximity to the mainland it is a very promising aquaculture development region, being close to markets, goods and services. However, because Mineirações Brasileiras Reunidas (MBR) has an iron ore export terminal on Guaíba island, aquaculture investment on this site should be carefully considered. MBR has itself invested in a marine biology laboratory on the island where it experiments with mollusc and crustacean culture. However, the company's focus activity is iron ore mining and export.

Table 7.2 Summary of potential suitable mussel cultivation sites.
Area in hectares.

Area	**Most Suitable**	**Suitable**	**Moderately Suitable**	**Total**
Area 1 (Itacuruçá)	143.4	785.1	131.7	1,060.2
Area 2 (Jaguanum)	32.7	285.6	1,260.3	1,578.6
Area 3 (Guaíba)	---	33.3	319.7	353.0
Total	**176.1**	**1,104**	**1,711.7**	**2,991.8**
% of total	**5.9**	**36.9**	**57.2**	**100**

According to a market survey undertaken in Rio de Janeiro, Scott *et al.* (2002), the estimated annual mussel consumption in the wholesale and retail markets including restaurants and supermarkets is about 48,000 kg. The product most typically negotiated is cooked and shucked mussel meat conditioned in 0.7-1.0 kg plastic bags kept under refrigeration. By interviewing fisheries technicians and mussel growers in the southern region of the state of Rio de Janeiro, the same study estimated local productivity in 2002 to be about 20,000 kg ha^{-1} y^{-1} (cooked, shucked mussel meat). Using the regional longline production system described in Chapter 4, each hectare can produce 20-25t of mussel meat per year.

7.2 OYSTER CULTURE POTENTIAL MODEL

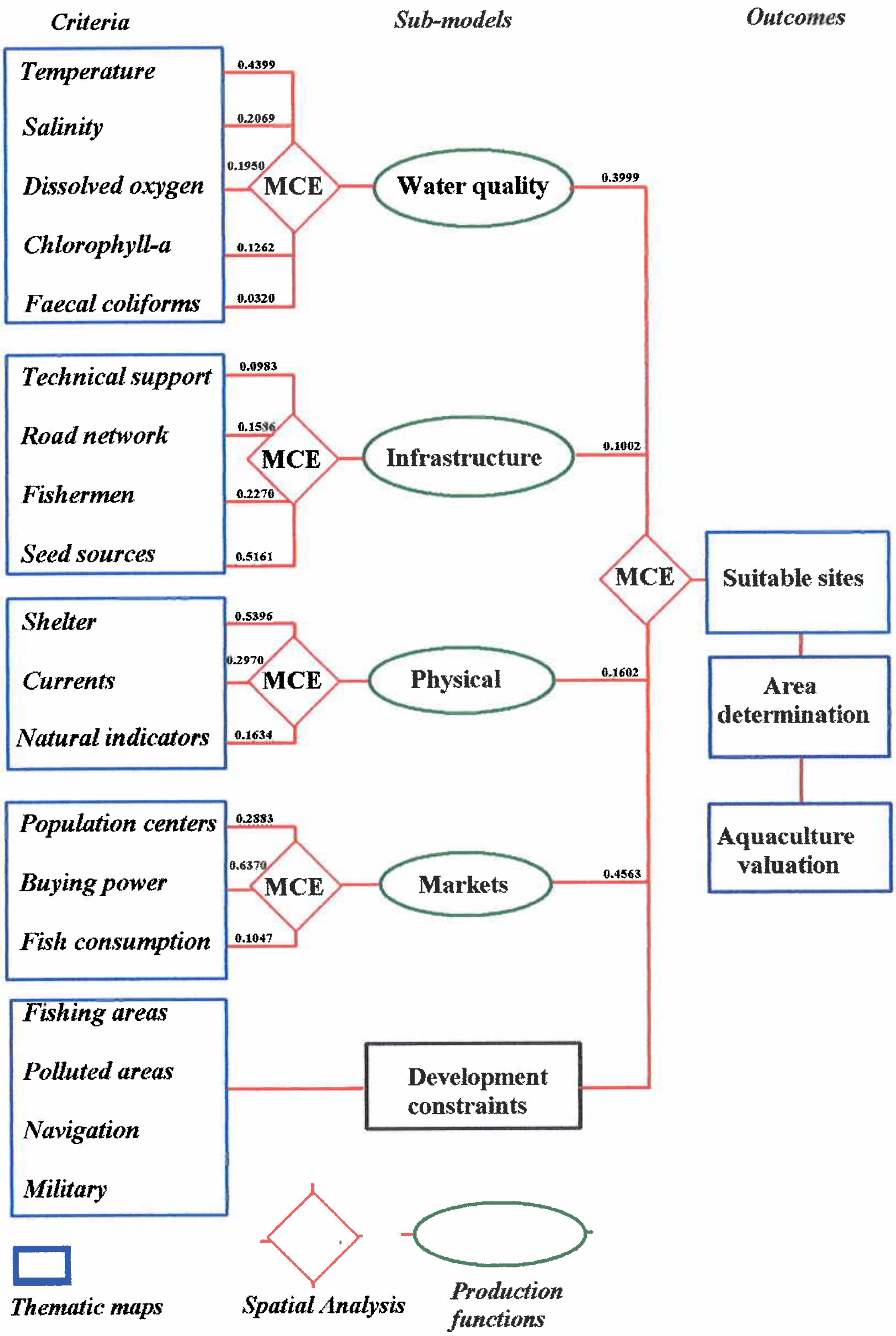

Figure 7.6 Oyster culture site suitability model.
Weights assigned by the author to different factors and sub-models.

In a similar way as for mussels, the constraints and production factors for the oyster culture model were processed in a final MCE using the set of weights shown in Fig. 7.6. This result was processed one step further with FILTER to remove small isolated groups and subsequently OVERLAID with a DISTANCE generated buffer image, the purpose being to narrow down potential areas to those most likely to be effective as described in Table 7.3.

Table 7.3 Reclassification criteria for suitability of oyster culture sites .
Suitability as a function of adequate distance for visual surveillance of the culture installations.

Interpretation	Score
Most Suitable	
Up to 300 metres from shoreline -	4
Best surveillance and access to culture system	
Suitable	
300 - 460 m from shoreline -	3
Within close access and fair surveillance distance	
Moderately Suitable	
460 - 570 m from shoreline -	
limit of surveillance and reasonable access	2
Unsuitable	
> 570 m from shoreline	1

The final result (Fig. 7.7) shows three areas, with continuous areas of significant production potential: Area 1 - Guaratiba, in the area fringing the largest mangrove areas in the region, Area 2, the mainland coastline extending from Itacuruçá to Mangaratiba, and Area 3, the more isolated, Ilha da Marambaia. The total production potential of Sepetiba Bay including all three suitability classes sums to 1,603 ha of water surface area for oyster culture, of which only 11.7% was found to be Most Suitable for oyster culture.

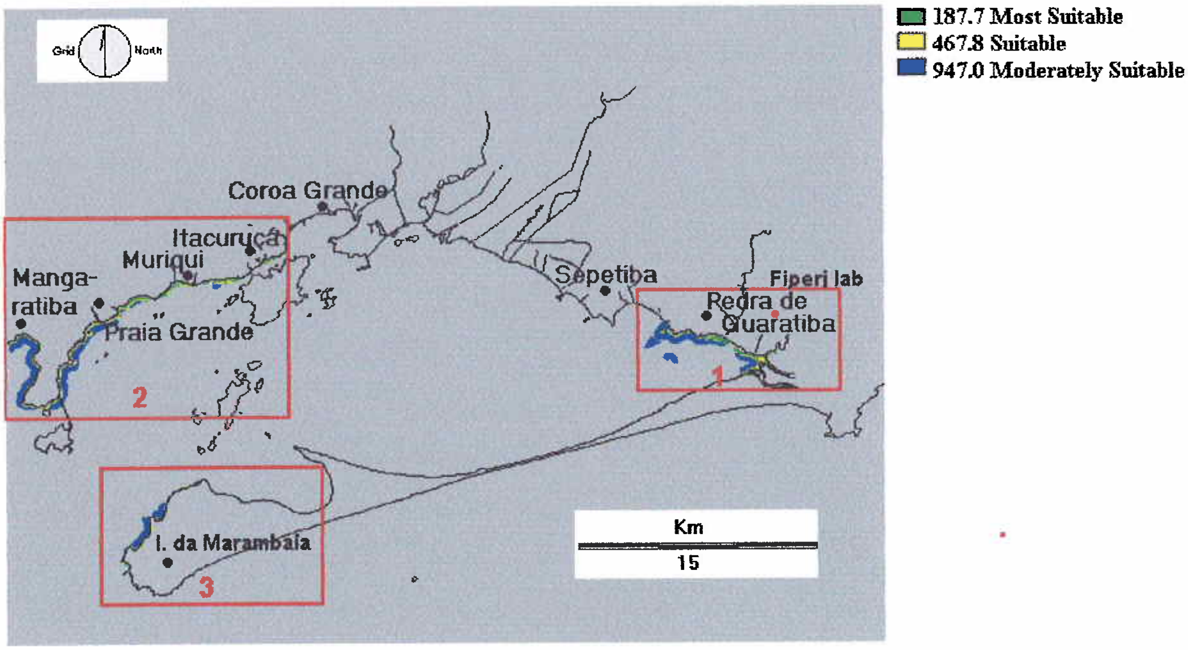

Figure 7.7 Model prediction outcome for oyster culture site suitability in Sepetiba Bay. Three areas with significant potential for mangrove oyster cultivation.

AREA 1 - GUARATIBA

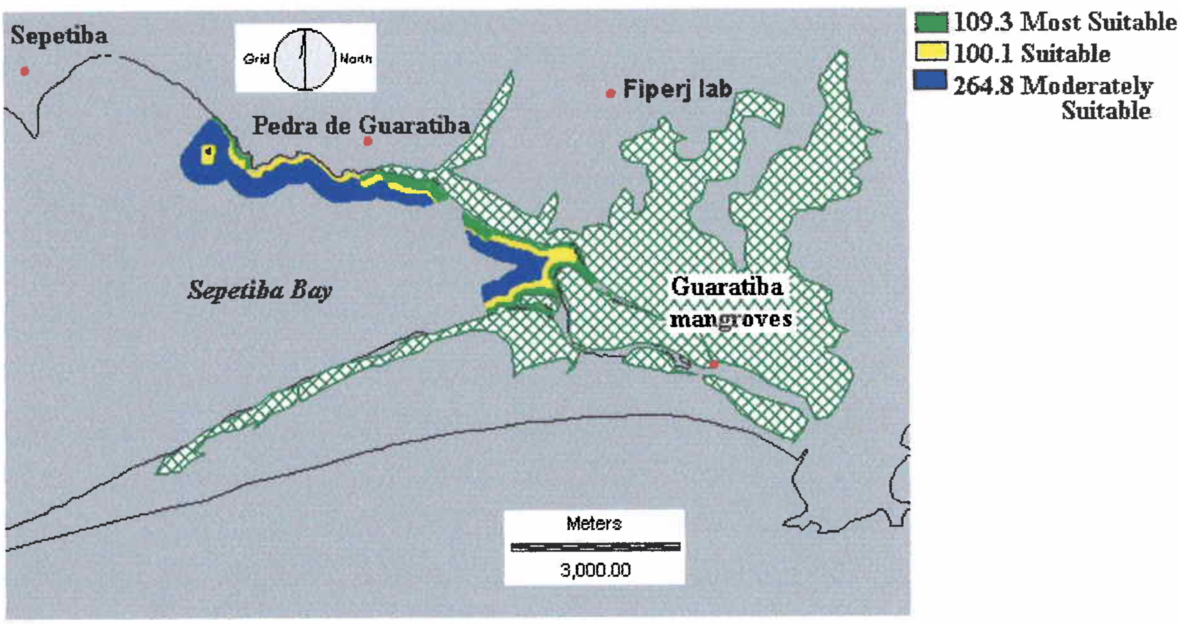

Figure 7.8 Oyster culture potential close-up of Area 1: Guaratiba.
Native mangroves identified by supervised classification of Landsat TM image are indicated in green hatch.

Figure 7.8 shows a close up on Area 1 where over 100 ha classified as Most Suitable areas for oyster culture were identified. The main reasons for this are a) environmental suitability and proximity to mangroves which are naturally good sites for oyster growth, b) closeness to technical support base (FIPERJ hatchery), capable of producing oyster seed, c) proximity to markets, general infrastructure, fishing communities, and d) adequate distance from potential culture sites for sufficient surveillance, as re-classified and described in Table 7.3.

AREA 2 - ITACURUÇÁ-MANGARATIBA

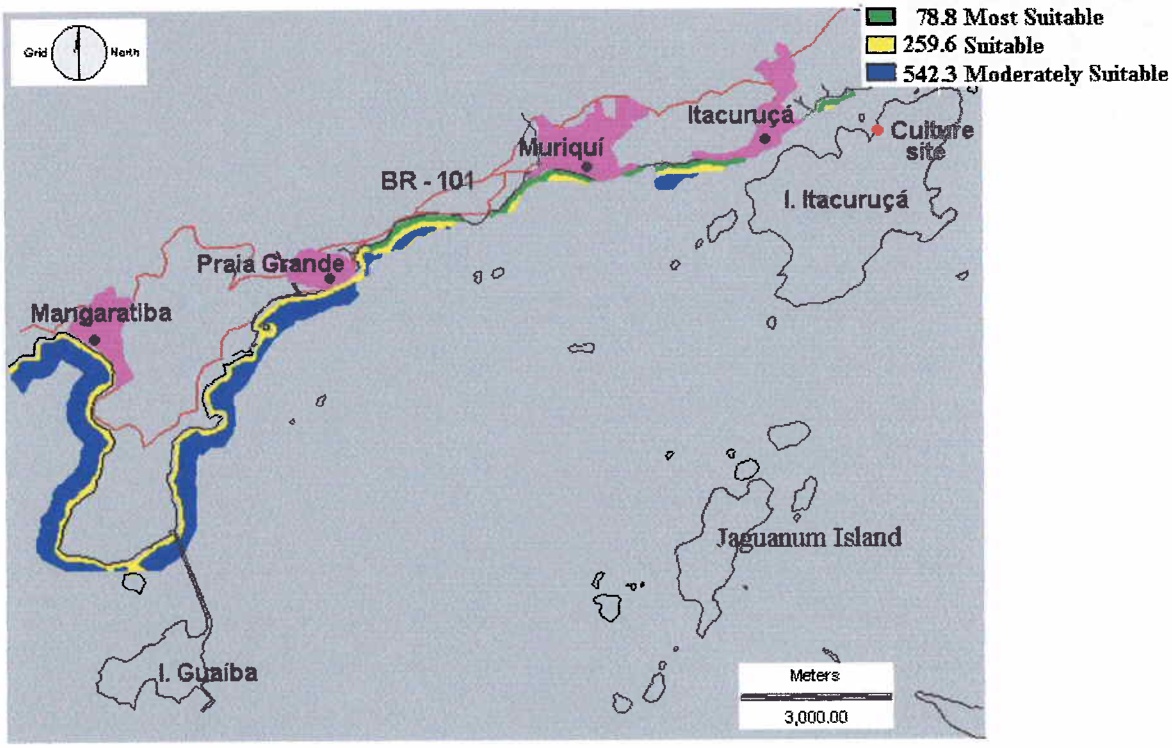

Figure 7.9 Oyster culture potential of Area 2: Itacuruçá-Mangaratiba.
Oyster culture potential of 881 ha.

This area is mostly contained along the coastal interstate highway BR-101 (Rio-Santos) between the towns of Itacuruçá and Mangaratiba (Fig. 7.9). Several areas classified as Most Suitable lie within close proximity of Itacuruçá, Muriquí and Praia Grande, coastal towns with significant weekend tourist traffic. An experimental oyster culture installation currently exists on the island of Itacuruçá, within 500 m of areas predicted by the model.

AREA 3 -MARAMBAIA

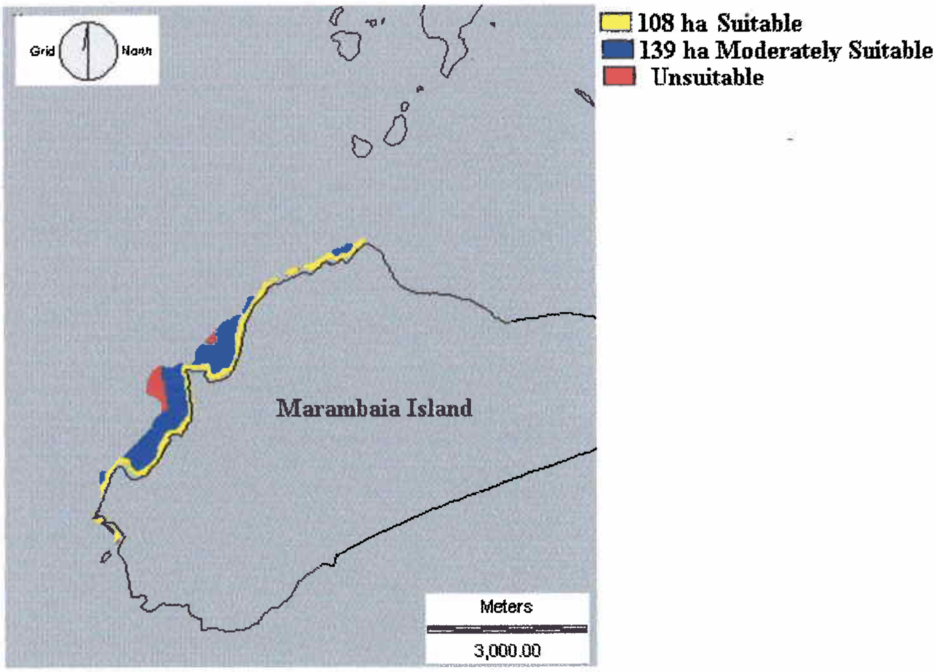

Figure 7.10 Oyster culture potential of Area 3: Ilha de Marambaia.
Oyster culture potential of 248 ha.

Area 3 refers to Marambaia Island where the prediction model found 248 ha of suitable areas (Fig. 7.10). Marambaia Island has only one small fishing community. However, considering this area's favourable physical factors including salinity and primary productivity, despite its distance to markets, could become a good option to begin oyster culture. Also in the same area, Jaguanum Island (Fig 7.9), although having a fishing settlement of about 100 families (Begossi 1992), and having natural oyster populations growing on its rocky coastline as identified during field trips, was mostly eliminated from the prediction outcomes because of water depth constraint.

Table 7.4 Summary of potential suitable oyster cultivation sites.
Area in hectares.

Area	Most Suitable	Suitable	Moderately Suitable	Total
Area 1 (Guaratiba)	109.3	100.1	264.8	474.2
Area 2 (Mangaratiba)	78.7	259.6	542.3	880.6
Area 3 (Marambaia)	---	108.1	139.9	248
Total	**188**	**467.8**	**947**	**1,602.8**
% of total	**11.7**	**29.2**	**59.1**	**100**

7.3 - SHRIMP CULTURE POTENTIAL MODEL

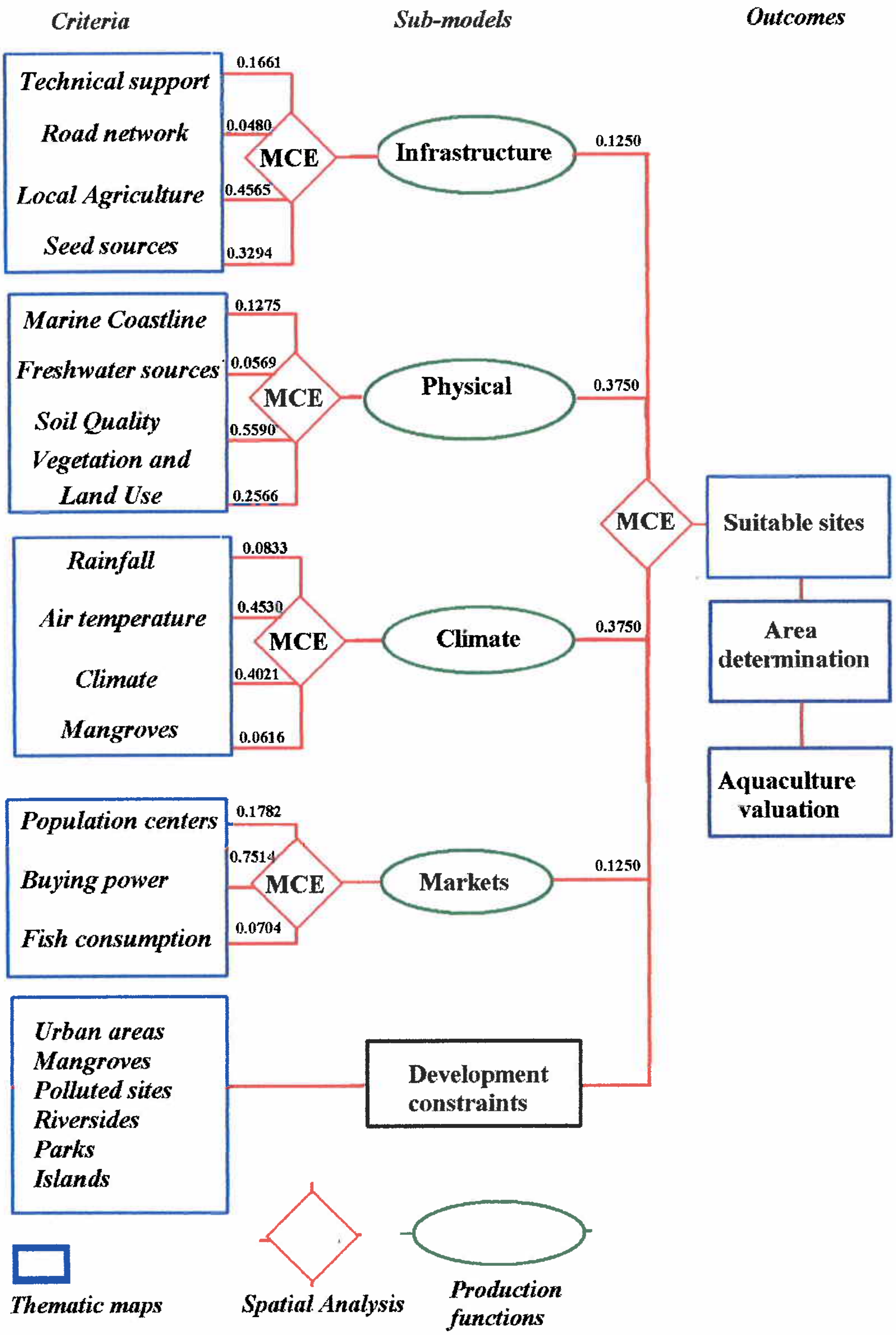

Figure 7.11 Shrimp culture site suitability model.

Weights assigned by the author to the different factors and sub-models.

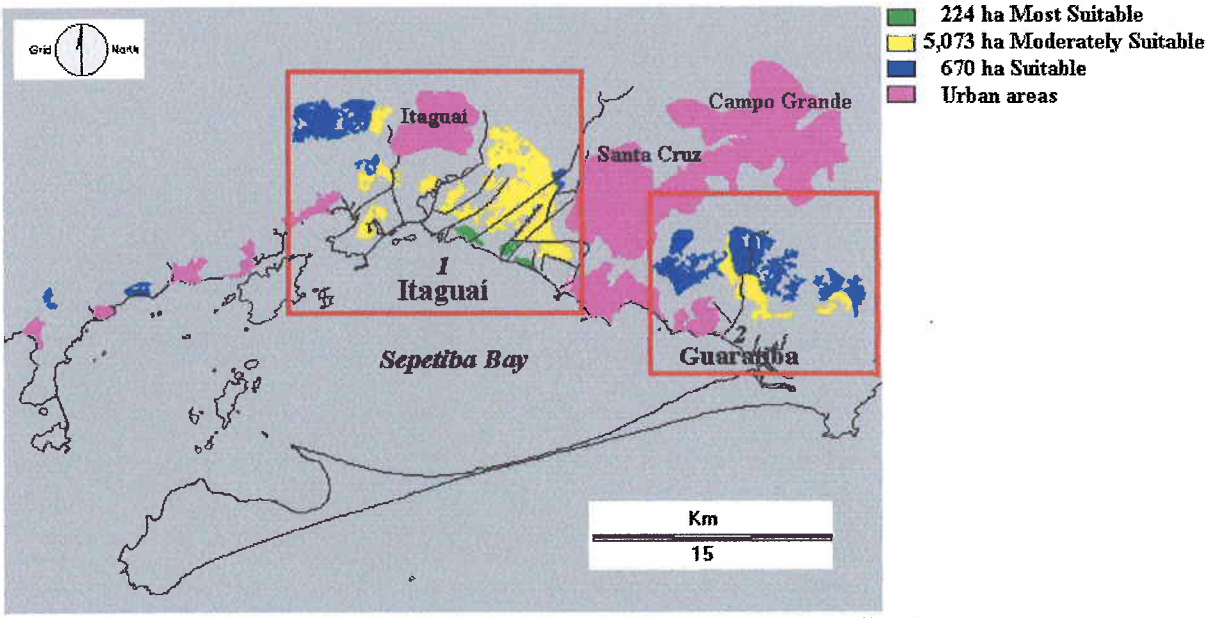

Figure 7.12 Model prediction outcome for shrimp culture potential around Sepetiba Bay. Shrimp culture potential of 6,874 ha.

The shrimp culture site selection model was designed as illustrated in Figure 7.11. It follows a similar rationale and design to that for mollusc culture site selection models. Two main differences are the absence of a water quality sub-model and emphasis given to a climatic sub-model. The absence of the water quality sub-model is justified because shrimp culture is a land-based operation where there is some degree of control over the water quality differently than is possible for mollusc culture, which is carried out on open coastal waters and thus subject to predominant conditions imposed by currents. The emphasis placed on a climatic factor layer for land-based aquaculture is justified because factors such as air temperature and rainfall, play an important role, affecting water temperature in ponds where usually only about 20% of the volume is exchanged as opposed to open water bivalve mollusc culture, where water temperature is totally dependent on seawater circulation. Furthermore, climate related aspects such as rainfall, may cause direct or indirect difficulties to culture conditions by 'pushing away' seawater from coastal areas making abstraction of seawater temporarily impossible. Erosion of upland areas in the watershed, or in areas adjacent to ponds can result in addition of large amounts of suspended solids to pondwater making shrimp feeding less efficient as well as lowering salinity to uncomfortable levels, and to a lesser extent and indirectly so, by causing extra loading and abrasion of water pumping equipment.

The overall multi-criteria evaluation result for the shrimp culture site suitability model predicted the outcome illustrated in Figure 7.12. Only 3.3% of the total of 6,874 ha were re-classified as Most Suiable for shrimp culture. Two principal potential areas emerge, one slightly separated from the other by the Santa Cruz-Campo Grande urban complex. Area 1 (Itaguaí) covers 4,291 ha of suitable areas, whereas Area 2 (Guaratiba) covers 2,583 ha of suitable areas. Table 7.5 summarises the findings of the shrimp model.

Table 7.5 Summary of potential suitable shrimp cultivation sites.
Area in hectares.

Area	**Most Suitable**	**Suitable**	**Moderately Suitable**	**Total**
Area 1 - Itaguaí	224	3,087	980	4,291
Area 2 - Guaratiba	0	597	1986	2,583
Total	**224**	**3,684**	**2966**	**6,874**
% of total	**3.3**	**53.6**	**43.1**	**100**

7.3.1 - AREA 1.-ITAGUAÍ

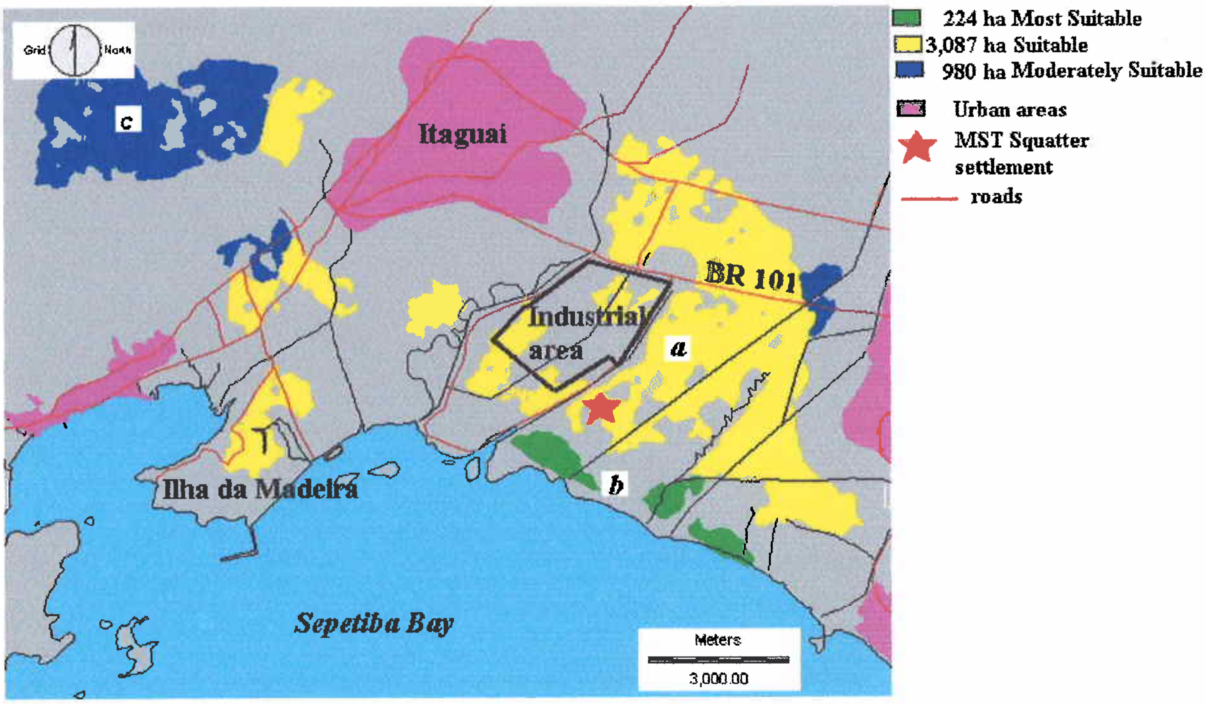

Figure 7.13 Suitable areas for shrimp culture in Area 1: Itaguaí

Area 1 contains 4,291 ha of lands suitable for white shrimp culture. Of these, only 224 ha were re-classified as Most Suitable. Figure 7.13 shows a close up of this area, which lies mostly south of the interstate BR-101 which connects Rio de Janeiro to São Paulo. The results of the MCE modelling indicate three patches (Fig 7.13*b*) classified as Most Suitable and another 3,087 ha (Fig 7.1*a*) of Suitable areas mostly lying between the shoreline and the BR-101. During the ground truthing part of this research both areas were visited. Part of area (*a*) possesses all the qualities for a good shrimp culture development, but is very close to an industrial area, which raises concern as to the potential hazard these activities may pose to an operating shrimp farm. Also, part of the industrial zone was re-classified as Suitable, most probably due to supervised classification process where some agricultural activity still being developed in the area. A visit in January 2003 revealed that land between *a* and *b* is mostly occupied by agriculture and grazing. Part of this area (about 900 ha), adjacent to a drainage canal with a seafront is currently being used as pasture and being claimed from the federal government for settlement by members of the MST (Movimento dos Sem Terra). Although this area could probably be used for shrimp culture, there are questions such as for how long suitable water quality will be, given the poor history of sewage treatment in the state of Rio de Janeiro and the steady growth rate of Itaguaí and Santa Cruz and. However, the location of Area 1, could hardly be better in terms of access to primary paved roads, proximity to conducive ecosystems for shrimp growth, sources of fresh and seawater, and existence of local markets and export terminals, and access to technical assistance.

7.3.2 - AREA 2 - GUARATIBA

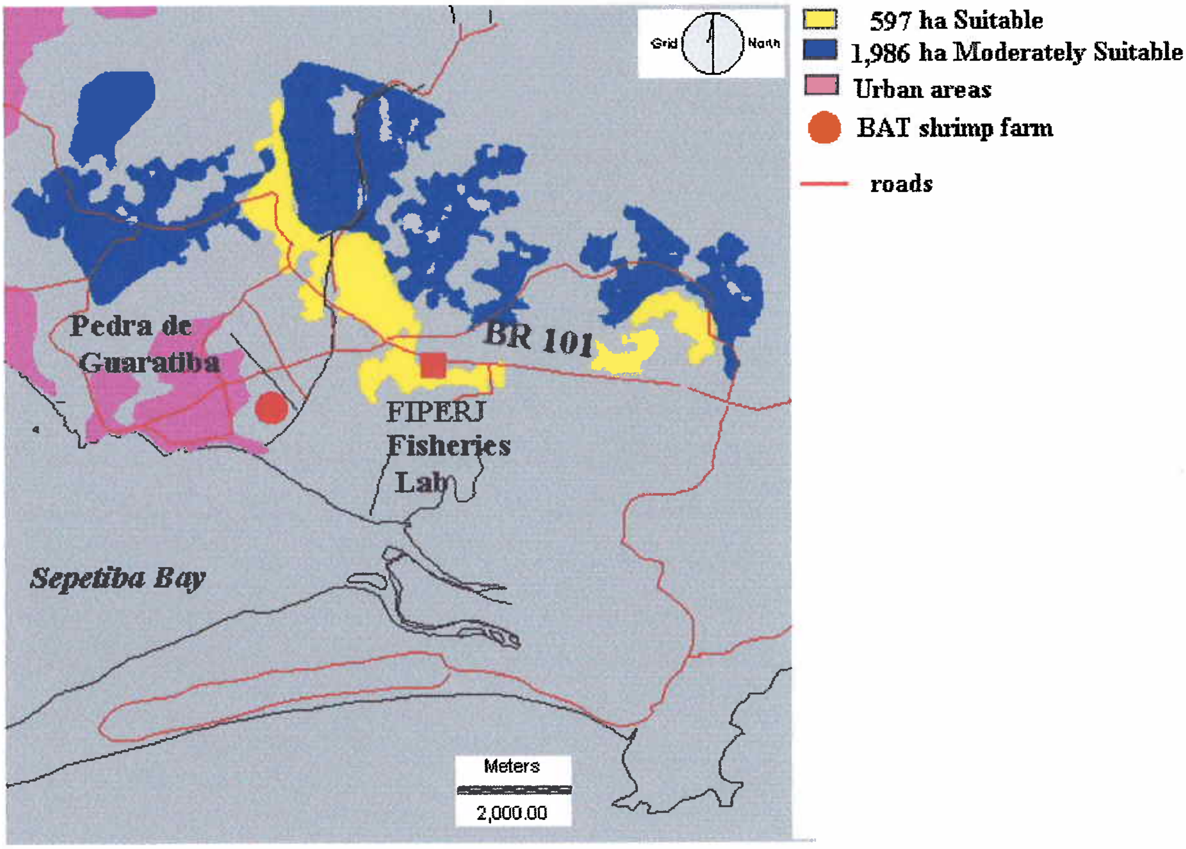

Figure 7.14 Suitable areas for shrimp culture in Area 2: Guaratiba.

Figure 7.14 shows the suitable areas in the region of Guaratiba, which in fact is the birthplace of shrimp culture in Brazil, as carried out experimentally by BAT, (Cia. Souza Cruz) in the early 1970s. The first shrimp ponds were built east of the fishing village Pedra de Guaratiba, and close to the mangroves of Guaratiba. The region nowadays is considerably protected from industrial development, the scenery dominated by farmland, mangrove canals and salt barrens. To date, the state (FIPERJ) hatchery is active, and potentially could be used to bolster the region's economic performance supporting sustainable use of the environment with shrimp aquaculture. Because producing aquaculture research, seed and dissemination of expertise is FIPERJs mission statement, any potential site nearby could at an advantage. However, a close-up GIS-assisted investigation employing aerial photographs and using a larger scale than was attempted in this research could prove useful to verify actual land availability and other local conditions.

An interesting finding about Itaguaí and Guaratiba areas is the percentage covered by each suitability class. While in the Itaguaí areas classified as Most Suitable and Suitable cover 48.2% of the total area (6,874 ha), in Guaratiba, this percentage falls to 8.7%. This indicates that Area 1 has a larger development potential but may not necessarily indicate long-term maintenance of the shrimp culture conditions.

7.4 - DISCUSSION

7.4.1 - MUSSEL CULTURE POTENTIAL DEVELOPMENT.

Rio de Janeiro currently has a wholesale market for about 50 tonnes per year of cooked mussel meat (SEBRAE, 2002). Sepetiba Bay covers 540 km^2 and of this, 176 ha were classified as Most Suitable for mussel cultivation. The total production potential from this area could be as much as 3,520 t y^{-1}. Based on 20t ha y^{-1} production figure estimated for the region (Bastos and Avellar, pers. com.) a development of only 1.4% (2.4 ha) of these areas considered as best (Most Suitable) would suffice to satisfy the current demand for cooked mussel meat in Rio de Janeiro.

Magalhães and Ferreira (1997) estimated that 52 direct and indirect jobs are associated with each hectare of mussel culture. Fagundes (1996) estimates 10 people to tend for one hectare of mussel longlines. Based on these, mussel culture development to meet Rio de Janeiro current demand, could potentialy employ about 125 people turning over about £38,400 per year. These calculations were based on the current selling price of £0.80/kg for the wild harvested mussel (Table 7.6). According to SEBRAE (2002) local consumers pay as much as three time more for cultured mussels imported from Santa Catarina, bearing a health certification seal which guarantees quality controlled by origin. If this price could also be achieved for locally cultured mussels, potentially, gross earnings of this business could generate about £92,160 per year. However, not all consumers are aware of the dangers involving consumption of contaminated shellfish, nor may be willing to pay extra for cultured mussels so that the market demand for a quality product could be limited and may take some time to expand.

It is useful to consider the existing mussel growing industry in Santa Catarina when examining the potential of Rio de Janeiro. The average mussel grower in Santa Catarina, carries out his activity mostly based from the mainland, in a total area of about one hectare of coastal sea, culturing ca. 2,200 mussel ropes, installed mostly on longlines, or less commonly, hanging from floating platforms planted in shallow coastal waters. Santa Catarina currently has an agglomeration of 1,100 producers in 148 demarcated culture areas in 10 'aquaculture parks' occupying 900 hectares. There are 6 mussel processing units and about 6,000 people are directly involved in the activity. Total production of mussels for 2000 for Santa Catarina was 11,364.8t, a slight decrease from the previous year, 10,667.1 t. It is noteworthy to mention that Santa Catarina has a strong fisheries extension service (EPAGRI) which has supported aquaculture growth, and a strong tourist business base.

By contrast, mussel growing in Rio de Janeiro has developed in a scattered fashion, some of which is island based, such as around Ilha Grande, separated from the mainland by deeper waters (>7m) where mussel culture using ropes hung from platforms is unfeasible. The existing growers use exclusively the longline system where 2 - 12 longlines are spaced 2m apart, and manage at most 600 mussel ropes. The local infrastructure of these sites is very poor; most do not have electricity and must travel by boat to the mainland for supplies and services. According to Proença (2001) the region concentrates 89% of Rio de Janeiro state's mussel growers, which are estimated to be about 50, while another 30 sites are in the process of development. Local fisheries statistics is very poor, and there are only five fisheries field officers to cover the extension and data collection needs for the whole state of Rio de Janeiro.

In this study, three areas were identified by the model developed in the GIS as having good potential for mussel culture development. Of these, Area 1, Itacuruçá island probably bears the most resemblance to mussel culture conditions in Santa Catarina because of its proximity to the coast, extent of shallow areas, influence of tourist activity, extension service availability, and proximity to urban markets. It would seem reasonable to promote development preferentially in this area as it is closest to the mainland's infrastructure, and has also recently been supplied with electricity which can facilitate post-harvest operations. Of the three areas discussed in detail, it has the largest extends for 143.4 ha classified as Most Suitable.

The fishing population of Jaguanum island could benefit highly from mussel culture development (Area 2). Begossi and Figueiredo (1995) estimated that there are about 100 families distributed in nine settlements over Jaguanum. There, fishermen have lost income as a result of conflicts with trawlers, having practically abandoned the use of their traditional drifting longlines and set gillnets. Because the island has frequent transportation to the mainland and has an intense tourist traffic especially as a lunch stop, locally produced aquaculture products potentially have an excellent local market in the form of value-added product served in cooked meals, as well as an outlet to mainland markets made possible because of the regular traffic.

In conclusion, this research found that of the three municipalities involved in the coastal area, most of the mussel culture potential is contained within the boundaries of the municipality of Mangaratiba. This municipality has very steep hillsides, close to the sea, with very limited flat terrain. Its agricultural or industrial development potential is very limited. Its hillsides are also protected from tree felling. Thus it would seem logical that Mangaratiba promote its coastal water surface through development of mussel culture, as well as other water related activities including sports and tourism.

For this to happen, the demand for cultured mussels must still increase. This could be accomplished by promoting the cultured product vis-à-vis the wild-harvested mussel informing consumers about the benefits of the former and potential hazard to human health from the latter. The survey carried out by SEBRAE (2002) shows that much of the mussel meat currently sold in the market is harvested close to raw sewage discharge sites along Guanabara Bay, where it locally cooked, shucked, bagged and sold in street markets and restaurants without any sanitary inspection or health certification whatsoever. From this, it is reasonable to expect that current demand for cultured mussels can expand considerably if a quality product such as cultured mussels from Sepetiba bay becomes available

Table 7.6 Summary of development needs and mussel culture potential for Sepetiba bay.

Estimated mussel consumption year (t y^{-1})	48
Total potential production area (ha)	2,992
Production area identified as Most Suitable (ha)	176
Estimated potential productivity (shucked mussels) t ha y^{-1})	20
Production area needed to meet current demand (ha)	2.4
Most Suitable potential required to meet demand (% of total)	1.4
Gross earnings by meeting current demand (£ y^{-1})	38,400
Investment needed to fulfil current demand (£)	7,200
Job creation potential (posts)	24

Farm gate price of shucked cooked mussels = £0.80/kg (Estimates based on SEBRAE, 2002). Floating longline culture system, where 10 persons tend for one hectare in production. Investment cost per hectare = £3,000 (Fagundes *et al.* (1996) and Ilha Grande mussel growers association.

7.4.2 *OYSTER CULTURE POTENTIAL DEVELOPMENT.*

SEBRAE (2002) estimated the market demand for fresh live oysters in Rio de Janeiro metropolitan area to be about 15,000 dozens per year. In the three areas considered, a total of 1,603 ha of suitable areas were found (3% of the bay area) of which only 188 ha are considered Most Suitable, an equivalent of 11.7% of the bay area (Table 7.9). Fagundes *et al.* (1996) estimate that about 10 direct and indirect jobs are associated with each hectare of oyster cultivation. Due to its high natural productivity, oyster culture development in only less than one hectare of the Most Suitable areas identified in this study would theoretically be enough to satisfy the current demand.

Considering that oyster culture in the state of Rio is in a very primitive state of art, its development could probably generate roughly 20-50 direct and indirect new jobs turning over an approximately £6,150 annually if it would engage in supplying the current demand with cultured oysters at selling prices of £0.41 per dozen, the same price paid to fishermen in the Guaratiba area for the wild harvested product sold on the roadside. This value is almost five times less than what is paid in the wholesale markets of Rio de Janeiro for the competitive product, cultured *C. gigas* oysters (Table 7.7), which currently accounts for probably 99% of the product offered in fish markets and supermarkets. The native product, *C. rhizophorae* is an alternative using Sepetiba's natural potential. From the consumer perspective, the latter enjoys more popularity but much less credibility, so oyster culture development should be accompanied by health certification process and effective marketing in order to succeed with consumers.

Table 7.7 Summary of oyster culture production potential

Estimated oyster consumption year (dz y^{-1})	15,000
Total potential production area (ha)	1,603
Production area identified as Most Suitable (ha)	189
Estimated potential productivity (dz ha-1 y^{-1})	100,000
Production area needed to meet current demand (ha)	0.2
Most Suitable potential required to meet demand (% of total)	0.1
Gross earnings by meeting current demand (£ y^{-1})	6,150
Investment needed to fulfil current demand (£)	150
Job creation potential (posts)	2

Farm gate price of dozen oysters = £0.41. (Estimates based on SEBRAE, 2002). Rack-based culture system, where 10 persons tend for one hectare in production. Investment cost per hectare = £1,000 (Fagundes *et al.* (1996).

Three potential areas for oyster culture were identified. Area 1, with the most potential raises few questions as to its suitability as it is close to environmentally protected area (Guaratiba Reserve) and in an area of lesser urbanization. However Area 2, which encompasses over one half of Itacuruçá island where no potential for oyster culture was detected, may hold more potential than currently identified. Because of its proximity to Zn, Cd and other types of industrial pollution sources much of it was excluded in the constraint layer. Nonetheless, an oyster culture installation does currently function on the northern side of Itacuruçá island. This installation, sponsored by a local NGO, has succeeded in interesting and guiding fishermen sufficiently to establish rack-based oyster culture along the mangrove fringe of Itacuruçá island in 2000. While no published results are available, the initiative is unique for the whole of the bay. If experimental culture of oysters in this area were followed with laboratory analyses showing that acceptable contaminants levels present in oyster meat were below maximum acceptable levels, then the livelihoods of these fishermen could improve markedly if they engaged in the activity, filling the market gap for fresh oysters. One basic difficulty of this group found was obtaining *C. rhizophorae* seed. Despite the proximity to local mangroves and fisheries laboratory, oyster seed had to be flown in from Alagoas, distant over 3,000 km. The socio-economic importance of this potential alternative activity in the area lies mostly with the local stakeholders, members of 26 families of fishermen identified by Begossi (1992) living in the area.

Many areas identified as Most Suitable and Suitable (338 ha) are located along beaches in and between the coastal towns of Muriqui, Praia Grande and Mangaratiba. These areas may prove to become unfeasible in the medium-term range because of competitive use for leisure activities as well as water pollution increase from sewage outfalls of growing coastal towns. If the model had a better water quality database, the confidence in its results would be greater. This is especially important for studies of coastal areas where filter feeding mollusc culture is being contemplated.

Additional improvements to the present *C. rhizophorae* oyster prediction GIS model can subsequently be made. The limited market for oysters and the technological difficulties regarding culture of this species has so far constrained its development. Possibly aquaculture potential for another species such as *C. gigas* could be attempted. As its is exotic to the region, and would more in-depth knowledge of local oceanography, it presents a considerable challenge.

7.4.3 SHRIMP CULTURE POTENTIAL DEVELOPMENT.

According to SEBRAE (2002), the annual market consumption of shrimp for the Rio de Janeiro, both wholesale and retail is estimated to be 528,000 kg per year. As shown in Table 7.8, if the region were to develop shrimp culture to meet current demand, it would require 176 ha of ponds in production. In practice, an additional 25% area margin is needed for the construction of pond dikes, service buildings and manoeuvring areas, adding up to a total of 220 ha. This area represents 98% of the Most Suitable areas found in both areas (Itaguaí and Guaratiba) and could turn over roughly £686,400 per year.

In economic and strategic terms, Rio de Janeiro is currently a major importer of fresh shrimp, most originating from shrimp culture in the north-eastern states of Brazil, mainly Rio Grande do Norte, Ceará and Bahia. The market standard specimen is a 12 g white shrimp of the species *L. vannamei*. Prices paid by the wholesaler at the farm gate are currently about £1.30/kg. According to shrimp culture consultants (FISHTEC, 2003 pers. com and Mathias, 2003 pers com.) the construction cost per hectare of built shrimp pond is estimated to at £7,500. Table 7.8 summarises the investment needed to build enough pond area in order to meet the Rio de Janeiro state demand for shrimp as well as the potential gross earnings and job creation potential from such an aquaculture industry if installed in the Sepetiba area.

Table 7.8 Summary of development needs and shrimp culture potential for Sepetiba Bay.

Estimated shrimp consumption year (t y^{-1})	528
Total potential production area (ha)	6,874
Production area identified as Most Suitable (ha)	224
Estimated potential productivity (kg ha^{-1} y^{-1})	3
Production area needed to meet current demand (ha)	220
Most Suitable potential required to meet demand (% of total)	98.2
Gross earnings by meeting current demand (£ y^{-1})	686,400
Investment needed to fulfil current demand (£)	1,320,000
Job creation potential (posts)	440

Farm gate price of whole white shrimp (12g) = £1.30/kg. (Estimates based on SEBRAE, 2002). Additional 25% land area allowance for service buildings and pond dikes. Two persons to tend for each hectare in production. Investment cost per hectare of built pond = £7,500 (Mathias, 2003).

If 15% of the total area considered Most Suitable and Suitable (3,908 ha) were put to shrimp culture, 440 ha, 880 jobs producing 1,319 tons, or 2.5 the current demand of Rio de Janeiro.

This has the potential of becoming a significant agribusiness sector with potential to supply at least in part the demands of neighbouring states such as São Paulo and Minas Gerais or alternatively foreign markets. Other benefits of developing this shrimp culture potential, is the creation of approximately 880 direct jobs and the creation of a dynamic business which can grow based on the on processing plants and wholesale markets available in Rio de Janeiro at a much lower cost than that of production sites found in north-eastern Brazil.

7.5 MODELS VALIDATION

Validation of models is accepted as being achieved when the model output compares favourably with 'real' environmental data from an independent location (Pérez *et al.* 2001). The GIS based models developed during this research predict the location of suitable sites for mollusc and white shrimp aquaculture. However, the lack of quantitative and qualitative data and the fact that there are very few sites and limited production where this activity is currently being carried out, posed a difficulty in validating the model.

In order to satisfy at least partly the validation of the models, sites where mollusc culture has been attempted in the study area were plotted in the final suitability maps (Fig. 7.15).

Mussel culture sites.

Four sites were identified having mussel culture initiatives. Three of them (Ilha de Jurubaíba, Ilha Duas Irmãs and Praia Grande currently have mussel culture in operation (July, 2003) and according to the managers, performing successfully. The fourth site, Ponta do Boi was an experimental culture site during the 1980's and it is not known why the culture was discontinued at that site.

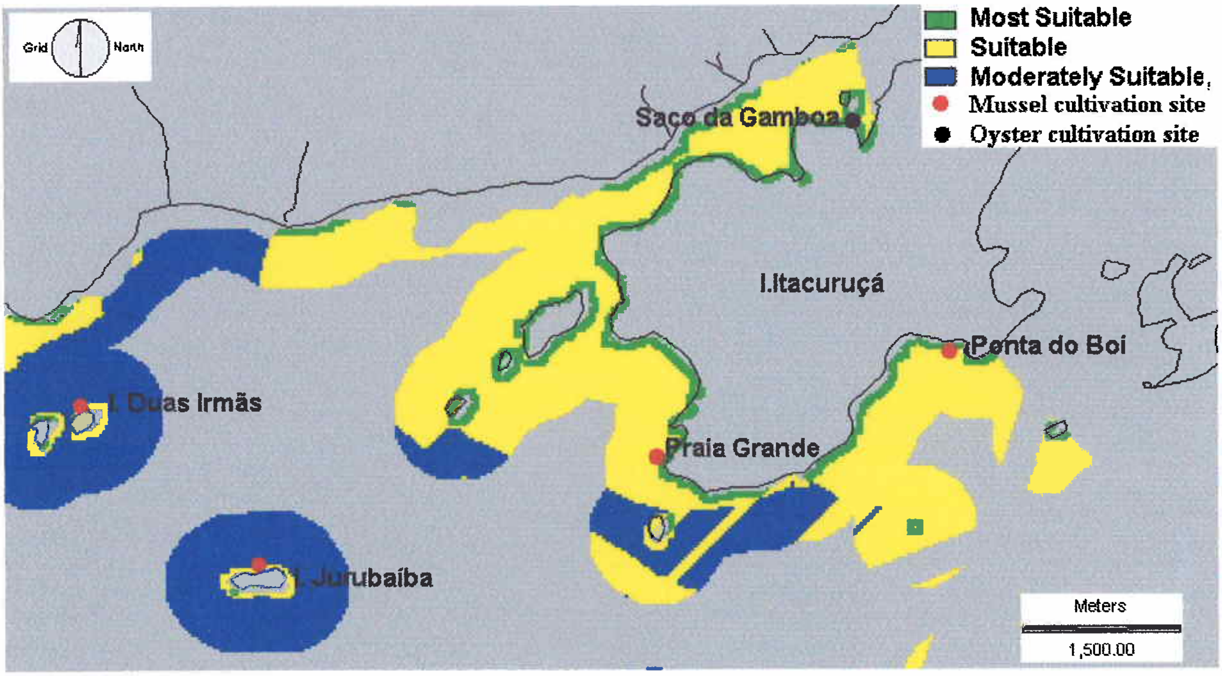

Figure 7.15 Location of mollusc culture installations in sites found by model prediction outcomes.

All four sites fall within the model's suitability prediction area. One could argue that these points would not validate the model's predictions, as common sense of an experienced person working in the region would suggest siting mussel culture in the same areas. In fact, the prediction model only confirms these sites, but also suggests many others which possibly might escape even the trained eye.

Oyster culture sites

For the oyster site suitability culture prediction model, only one small experimental culture site exists throughout the whole of the bay (Saco da Gamboa, Fig 7.15). However, it is not sited in one of the oyster model's prediction output areas. Unfortunately the potential for oyster culture development derived from the model can not be validated, because of the inexistence of the activity to date in the region. The culture installation located in Saco da Gamboa, may not be a very suitable site, because despite it is within those areas eliminated by the oyster suitability model in the constraint layer. Although some effort is being made by locals to culture oysters in this area, its proximity to Zn, Cd contamination sources, and the fact that it is in an area with regular boat traffic may put at risk any production because of potential contamination of oysters from sediments resuspended into the water column. The development of this initiative should be if possible be followed up by research.

Shrimp culture sites

Validation for the shrimp culture potential predicted, is unfeasible as there are no current shrimp culture facilities around Sepetiba Bay. The closest facility is the local fisheries station FIPERJ, which has harboured shrimp research since the 1970s, but has discontinued its investigation in marine shrimp culture. This general area, which has been in the past (late 1960s and early 1970s) utilised by British American Tobacco Co. for this purpose, was excluded in this model because it now covers areas of mangrove growth protected by law, or suburban areas considered as constraints.

CHAPTER 8
GENERAL DISCUSSION

8.1 OVERVIEW

The purpose of this study was to investigate the use of GIS supported by remote sensing, and to predict promising locations for coastal aquaculture development. If natural indicators of biological productivity and other aquaculture production functions could be assembled into a GIS, what would be the production potential and economic consequences of this development in terms of job creation and natural resource exploitation ?

In an attempt to answer these questions, three species were considered in this investigation; two native filter feeding molluscs, representing water-based culture systems, ie within the open water body, and one exotic penaeid shrimp, produced in a land-based culture system, in which water is run through a shore-based unit.. These were:

1. the marine brown mussel *Perna perna* found in tropical and subtropical environments in the Atlantic;

2. the estuarine *Crassostrea rhizophorae* a mangrove oyster found commonly from the Caribbean to the warmer latitudes of southern Brazil, and

3. the exotic marine shrimp *Litopenaeus vannamei,* the most widely cultured shrimp throughout all latitudes in Brazil.

Mussels and oysters were chosen because they are sessile organisms, directly dependent on the quality of the aquatic environment in which they live, whose natural presence would support verification of the prediction models developed in this research. Though not extensively developed, they have an established market value which allows for some economic analyses of the potential assessed. The exotic marine shrimp was chosen because it is now an important commodity in the country, and currently the most important commercial shrimp species in Latin America, in high demand both in internal and export markets. The water and land-based production systems, though potentially located within the same geographical unit, were subject to slightly different selection criteria related to their system requirements.

The region of Sepetiba Bay, Rio de Janeiro was chosen for this investigation, as a site with apparent but relatively unrealised and possibly limited potential. While it has many potential natural advantages, and has good infrastructure and access to the major markets of Rio de Janeiro and its surrounding development, there are also significant levels of industrialisation and organic discharge, and potential constraints of land access for onshore developments. Thus the area is only likely to be selectively suitable for various forms of aquaculture. Generally, natural resource related data, including coastal oceanographic data, is very scarce, and Rio de Janeiro is no exception. GIS practitioners usually attempt to locate the necessary data from existing sources, either in paper or digital form (Nath *et al.,* 2000). At the time of this study no public digital data was available. However, even though limited by data sources, the development of GIS aquaculture prediction models was attempted in view of the potential benefits of socio-economic analyses and discussions derived from it. Its development and validation was in turn a test of the potential for applying GIS as a planning tool in the absence of well organised data sources, using a range of supplementary and proxy elements.

The main approach of this work was to study the interaction of environmental, physical, infrastructural and market parameters developed as independent layers in a GIS environment, integrated in species-specific models which would simulate the best conditions for siting cultivation installations satisfying a given set of aquaculture production criteria. Such a generalised approach would if effective be potentially applicable in a wider range of species, location and production contexts.

For the molluscs, the first step was to map out different water quality related environmental parameters over the bay. Through field trips each species considered was identified with respect to its natural growing environment.. A set of thematic layers including water surface salinity, dissolved oxygen and temperature were set up in the GIS, using a remotely sensed image (Landsat 5) as a raster format backdrop which served as a base for further integrated analyses.

For the analyses of the site suitability for aquaculture development of the three species considered, species-specific sub-models were developed taking into consideration selected production functions. These were supplemented in the case of mussels with practical field trials with experimental cultivation ropes, albeit over a limited period. Water quality parameters, infra-structural support, physical factors associated with the production structures, and market aspects vary significantly in space.

The total areal extent for mussel and oyster cultivation potential, and hence the potential of aquaculture development was determined by using the base raster Landsat image and the outcome layers of the production function sub-models integrated using multi-criteria evaluation (MCE). Around Sepetiba Bay, penaeid aquaculture development potential was modelled in a similar way, using a sub-model specifically developed in this research for white shrimp *L. vannamei*. Estimates of potential returns from aquaculture exploitation of these three species were also produced, based on the current market conditions in metropolitan Rio de Janeiro.

. The results suggest that on a biotechnical basis there is significant bivalve mollusc and penaeid shrimp aquaculture potential that could be developed in the region.. From the analysis of the GIS prediction model, however, it was clear that a majority of the bay's waters are inappropriate for mussel or oyster farming because of pollution constraints. Other constraints which excluded aquaculture development included areas for conservation, fisheries, military operations, and navigation areas. In broad terms, however, market and access conditions did not create major constraints for most parts of the bay, though infrastructure access, particularly that of obtaining oyster seed, was a potential siting factor.

8.2 GIS POTENTIAL

The main objective of using GIS in the project was to test its capacity as a tool to find new development sites, and to examine its effectiveness of use in relatively data-limited conditions, developing various techniques to create a workable and potentially testable decision-making system. Field work, based on several map sources, and direct onboard hydrographic and benthic sampling, helped in obtaining a clearer picture of the spatial variability of environmental parameters in this relatively dynamic coastal area In this context, GIS was able to provide an objective basis for decision making, using the Analytical Hierarchy Process (AHP) and its decision making process, multi-criteria evaluation (MCE), present as modules in IDRISI GIS software. The production function variables were presented to a range of professionals who, based on their professional experience, determined the weights which contributed to a method-based evaluation, rather than relying on an individual 'expert opinion' which many times can be biased or unfamiliar with different conditions present over wide geographical areas, resulting in unrealistic ratings for a specific site.

A primary defining factor for location was salinity, though tradeoffs between sub-optimal salinities and production potential could not be explored in detail. A major constraint identified across all production systems was the location of pollution sources and their potential dispersion in areas of the Bay. These apart however, other water quality factors had a relatively negligible effect. To define further the useful area for water-based aquaculture, it was also possible to develop a significant wave height prediction sub-model in the GIS, which gave the physical factors sub-model (Shelter) the extra credibility needed for integration into the general model. In this respect the results for this sub-model worked reasonably well. However, due to the generally sheltered conditions present in most of the bay, the results of this sub-model did not significantly reduce potentially productive areas from the maximum significant wave height constraint. Further investigation on the maximum speeds winds reach in the area, and length of time these winds last may further constrain areas which were considered suitable in this study.

An interpretation of the waters' suitability as natural productivity as indicated by phytoplankton biomass, was determined by using a RS image and a Chlorophyll-*a* determination algorithm. This image was used in association with the historical data available for this study, based on Chl-*a* cartograms published by FEEMA (1996), which were scanned and geo-referenced to the GIS database. The indication of mollusc bivalve food availability was estimated as an integration of the two mentioned layers. There are several drawbacks and limitations with this method. The first being that determination of Chl-*a* in coastal waters through RS images is made difficult when suspended sediments, yellow substance and tidal action may all be present. . RS images such as Landsat TM are available in theory every 16 days, weather permitting. Even if the image is available, it has to be cloud-free to be of much use, a problem which increases especially during the summer months, because of cloud cover produced by high evaporation rates. The cost of image acquisition is still another drawback. A lower cost RS-based alternative would be to explore Chl-*a* content using SeaWiFS imagery which is cost-free if 30 days or older. Still, because the study area has many rivers and an increasingly eroded catchment basin, the problem of suspended sediments and yellow substance making readings difficult would probably persist, and would not eliminate other important costs including field surveys for calibration purposes and RS lab-based analysis.

The development and application of market and price models in this assessment was limited by the lack of more detailed information on market preference and purchasing behaviour. The use of conjoined estimates of the size of potential markets and their distance from production sites was not sufficiently clear or numerically explicit to give much additional weight too selection criteria, though it did broadly confirm the market potential. Further and more sensitive work would be required to develop an approach which could determine whether such factors were critical. A potentially more serious issue might be that of consumers perceptions of product from specific areas of the Bay they considered to be at risk of pollution, whether or not this was actually the case.

8.3 SENSITIVITY ANALYSIS

In the previous chapters, the strategies and techniques for tackling the GIS supported modelling for aquaculture site suitability in and around Sepetiba bay have been explained and described. The general approach assumed that the layers built within each sub-model were important in the decision-making process adopted, which relied primarily on multi-criteria evaluation. The basic approach to handling uncertainties in multi-criteria analysis is by sensitivity analysis (SA) (Saltelli *et al.*, 2000). Thus, SA is used to increase confidence in the model and its predictions by showing how the variation in the output of a model can be apportioned to different sources of variation, and also how the model depends upon the information fed into it (Perez-Martinez, 2002).

In this research, a considerable amount of judgement which involved that of a number of people with variable knowledge and background information about the set of production functions (criteria) chosen, was used. This judgement is ultimately the basis of the weighting process in each of the sub-models as well the general species specific model. However, substantial variation in responses required a further input of the author's 'best value' to permit the model to be operated, and explore some of the effects of value changes. Lodwick et al., (1990), identified fourteen types of sensitivity analysis which can be performed associated with geographical data sets, including those sensitivities due to linguistic interpretation of meaning in geographical data, map-making, and weight sensitivity due overlaying operations to assess suitability. Because the focus of this research was to identify broad areas of suitability rather than conferring a high degree of thematic map accuracy, and because errors or uncertainty associated with the GIS data sets were not investigated in this study, the use of

SA could not fulfil its main purpose, that being of increasing confidence in the models' outputs.

However, the effects of changes in key production functions and their interpretations could be developed in further studies, and those functions shown to have significant effect on model outcomes could then be subjected to more detailed analyses and more careful local survey. Equally, outcomes related to expected cropping p erformance, product quality and financial viability could be further specified to identify those locations and systems likely to exhibit the most cost-effective and locally or regionally competitive production system

A possible way of increasing site selection prediction precision, and the application of sensitivity analysis in GIS studies of this type would be to develop a method which could incorporate critical assessments regarding production costs based on experience and sensitivity analyses of a range of parameters important in the production model. This could potentially be accomplished by using a sound case-study spreadsheet and its alternatives (case variations) taking into account different construction and operating cost alternatives such as developed in Muir and Kapetsky (1988). This potentially could be developed as a module of the 'filter' type to be fitted over those areas initially indicated as promising in a typical GIS site selection study.

One of the major outcomes of the study was simply to demonstrate how insensitive the production potential was to many of the parameters chosen. Thus considerable input effort was expended to develop GIS layers which offered little more than very obvious discriminants of suitability. While it can be argued that the processing had to be done first to determine whether or not these parameters were sensitive or trivial, there is a case for considering whether a more simple initial screening process, perhaps involving expert panels, could have been used to reject the obviously unsuitable areas, and then focus with more precision within the higher suitability zones.

8.4 CONCLUSIONS AND DIRECTIONS FOR FURTHER RESEARCH

Because of the range of professionals from several fields of expertise, and different angles of perception about the various aquaculture production functions, multi-criteria evaluation used in the GIS became an important tool for weighing impressions of the 'expert panel' assembled in this research. This method resulted in a narrowing down of potential sites to a minimum from the eclectic characteristics of the panel. Even between experts in the same field consensus was low, so that weights developed for production functions varied considerably. Interviews with professionals for developing weights to be used in MCE should be carried out very carefully. Possibly 'Delphi' analyses can be used to improve the process of developing consensus and define the range levels around mean values derived from such panel analyses. This in turn could be used to explore more effectively the sensitivity of development outcomes to differing values of production functions.

A considerable area of the bay was classified as Most Suitable for the cultivation of *P. perna* (176 ha) and *C. rhizophorae* (188 ha) in Sepetiba Bay. However, the amount of heavy metals retained in the tissues of cultivated organisms for the period of culture (about 8 - 12 months) under the prevailing environmental conditions is unknown. Possibly, contaminant build-up may still be within the tolerance levels allowed for human consumption. This would also be subject to regulatory safe limits, and in some cases to export standards. This assessment should be attempted and compared with the levels in wild stocks currently harvested. These studies would contribute towards a system of mollusc-growing area classification (with, eg specified requirements for depuration, and testing regimes) , which would be important to ensure safety and establish consumer confidence, essential for industry growth.The sites identified as Most Suitable for both mollusc and shrimp cultivation in many cases match with sites where in the past, experimental or commercial cultivation has been attempted. The success rate at these sites should be followed up together with a study of the intuitive processes which led to their initial choice by entrepreneurs and see if and how they correspond to the AHP weighting process used in this study. *P. perna* and *C. rhizophorae* are two species which are characterised by living in quite distinct environmental regimes. This on one hand facilitated the spatial analyses carried out in this research. Further GIS aquaculture modelling in this region could benefit from incorporating a third species such as *Anomalocardia brasiliana,* a venerid clam, which thrives in an intermediate habitat between the two extremes occupied by *P. perna* and *C. rhizophorae:* low energy sites in mangroves and the exposed marine rocky outcrops. While both *P. perna* and *C. rhizophorae* feed on plankton, *A. brasiliana* depends mostly on microphytobenthos for its nutrition. Due to the restrictions of time and resources, the incorporation of this third molluscan species in the modelling exercises was not attempted. It could prove an interesting new study opportunity, with good commercial development potential, especially if supported by other coastal RS imaging alternatives such as CASI.Although information about bottom sediment quality and water colour were available, they were not integrated in the mollusc or shrimp site suitability prediction models. However, bottom sediment particle size is an important area of information which would be very useful in future habitat mapping of native shrimp and venerid clams. Bottom sediments can also help understand the water velocity patterns in the bay, while water colour may give indications of hydrodynamics.

The wave prediction model developed and incorporated in this study can be applied as an independent module in the form of an IDRISI macro. It has good application potential for similar studies in other coastal areas.

A significant finding is that the culture potential of *L. vannamei* predicted in modelling, is sufficient to completely satisfy the current market demand for the commodity in Rio de Janeiro. It also suggests, that it has significant potential for job creation and for development of a shrimp export sector. The impacts of additional supply on markets and prices, locally and externally, and the effects of culture of all three species on local economies and their multipliers, is also worth developing further, particularly with respect to the comparative advantages of the Sepetiba area, and the potential significance of the sector for local social and economic development. The work presented in this thesis provides a useful contribution to the use of GIS in aquaculture site selection in the coastal environment, especially in Rio de Janeiro state. It has shown that better coverage of the data is necessary to better assess this potential. In this type of assessment it is very helpful if control sites with actual mollusc cultivation are available in order to evaluate actual growth under the prevailing conditions and ultimately, to relate this to the development of carrying capacity assessment of the region so as to best manage and support sustainable development of a nascent aquaculture industry. Although significant aquaculture potential was predicted for the study area, the reasons for it not being developed so far to any great extent must have not been incorporated as some of the layers in the prediction model. If the physical, environmental, and marketing models have pointed out that aquaculture is feasible in the area, the reasons for its current state of underdevelopment must lie in other fields not considered in the model. In future work of this nature, attention must be given to identify additional criteria which may influence aquaculture development and can be incorporated into a GIS. These may include consideration of institutional support, availability of credit lines, cultural acceptability of change from fishing to farming organisms among others.

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Appendix 1. List of co-ordinate pairs used to georeference the Landsat satellite image used in the study based on admiralty chart DHN-1622.

Sites	Coordinates on Landsat 'Wind' image		DHN chart 1622 Longitude degrees	min	decimal minutes	Latitude degrees	min	decimal minutes	IDRISI decimal degrees	IDRISI decimal degrees
	x	y	x			y			x	y
Cais da Nuclep	696	898.9	43	50	0.8	22	54	0.24	-43.8467	-22.904
Campo Grande 1	1433.4	1061.9	43	37	0.58	22	53	0.5	-43.6263	-22.8917
Campo Grande 2	1468.9	1064.9	43	36	0.99	22	53	0.55	-43.6165	-22.8925
Campo Grande 3	1478.4	982.8	43	37	0	22	54	0.91	-43.6167	-22.9152
Canal de Sto Agostinho + linha de trem	1001.4	1005.7	43	44	0.6	23	53	0.6	-43.7433	-23.8933
Canal do Guandu 1 G1	981.4	840.6	43	45	0.95	22	55	0.9	-43.7658	-22.9317
Canal do Guandu 2 G2	1161.2	969.9	43	42	0.6	23	54	0.3	-43.71	-23.905
Canal do Ita 1	1063.6	803.9	43	44	0.78	22	56	0.73	-43.7463	-22.9455
Canal do Ita 2	1094.6	844.6	43	44	0.12	22	56	0.18	-43.7353	-22.9363
Canal do Ita 3	1213.2	961.9	43	41	0.7	22	54	0.5	-43.695	-22.9083
Coroa Grande, cais	631.3	879.5	43	52	0	22	54	0.4	-43.8667	-22.9067
From Lage M. to Afonso n	683.7	324.5	43	52	0.62	23	3	0.45	-43.877	-23.0575
From Lage M. to Afonso s	729	274.6	43	51	0.95	23	4	0.4	-43.8658	-23.0733
From Lage M. to Boca do Guandu	889.8	322.5	43	49	0.01	23	4	0.03	-43.8168	-23.0672
From Lage M. to Boca do Guandu	894.3	349.9	43	48	0.88	23	3	0.6	-43.8147	-23.06
From Lage M. to Boca do Ita	917.6	331.4	43	55	0	23	3	0.5	-43.9167	-23.0583
From Lage M. to Bonitinha	739.4	277	43	51	0.78	23	4	0.38	-43.863	-23.073
From Lage M. to Bonitinha	680.1	347.7	43	52	0.6	23	3	0.05	-43.8767	-23.0508
From Lage M. to Bonitinha	652.1	381.7	43	53	0.03	23	2	0.43	-43.8838	-23.0405
From Lage M. to Bonitinha	633.4	404.1	43	53	0.29	23	2	0.03	-43.8882	-23.0338
From Lage M. to Ilha Pescaria	917.5	330.9	43	47	0.6	23	3	0.8	-43.7933	-23.0633
From Lage M. to Ilha Pescaria	923.4	350.2	43	47	0.5	23	3	0.7	-43.7917	-23.0617
From Lage M. to Martins (E)	812.4	297.7	43	50	0.45	23	4	0.2	-43.8408	-23.07
From Lage M. to Martins (E)	812.5	297.2	43	50	0.58	23	3	0.19	-43.843	-23.0532

Appendix 1. List of co-ordinate pairs used to georeference the Landsat satellite image used in the study based on admiralty chart DHN-1622.

Sites	Coordinates on Landsat 'Wind' image		DHN chart 1622 Longitude degrees	min	decimal minutes	Latitude degrees	min	decimal minutes	IDRISI decimal degrees	IDRISI decimal degrees
	x	y	x			y			x	y
From Lage M. to Patio de Estocagem	852	310	43	49	0.73	23	49	0.73	-43.8288	-23.8288
From Lage M. to Patio de Estocagem	851.2	350.8	43	49	0.64	23	3	0.45	-43.8273	-23.0575
From Lage M. to Piracao	1353.9	445.4	43	40	0.8	23	3	0.25	-43.68	-23.0542
From Lage M. to Piracao	1522.5	550.06	43	37	0.55	23	2	0.99	-43.6258	-23.0498
From Lage M. to Porto Sepetiba (elbow)	832.7	303.4	43	50	0.08	23	4	0.19	-43.8347	-23.0698
From Lage M. to Porto Sepetiba (elbow)	825.9	353.9	43	50	0.8	23	3	0.35	-43.8467	-23.0558
From Lage M. to Pta Ferreiro	1170.7	399	43	43	0.99	23	3	0.5	-43.7332	-23.0583
From Lage M. to Pta Ferreiro	1181	407.9	43	43	0.79	23	3	0.4	-43.7298	-23.0567
From Lage M. to Pta Mangona N	513	297.9	43	55	0.6	23	3	0.4	-43.9267	-23.0567
From Lage M. to Pta Mangona S	627	243	43	53	0.8	23	4	0.65	-43.8967	-23.0775
From Lage M. to Pta. Grossa (Ita)	763.5	284	43	51	0.32	23	4	0.31	-43.8553	-23.0718
From Lage M. to Pta. Grossa (Ita)	700.4	382.4	43	52	0.2	23	2	0.55	-43.87	-23.0425
From Lage M. to Sai n	664.6	283.9	43	53	0.1	23	4	0.05	-43.885	-23.0675
From Lage M. to Sai s	691.7	263.1	43	52	0.65	23	4	0.49	-43.8775	-23.0748
From Lage M. to W Pta do Boi	789.6	291.5	43	50	0.85	23	4	0.03	-43.8475	-23.0671
From Lage M. to W Pta do Boi	758.3	366	43	51	0.2	23	2	0.99	-43.8533	-23.0498
From Pta Varejo Guandu	522.6	299	43	55	0.45	23	3	0.45	-43.9242	-23.0575
From Pta Varejo Guandu	614.1	408	43	53	0.55	23	1	0.95	-43.8925	-23.0325
From Pta Varejo to Bonitinha	474.6	311.4	43	56	0.7	23	3	0.01	-43.945	-23.0502
From Pta Varejo to Ilha Pescaria	584.1	288	43	54	0.44	23	3	0.8	-43.9073	-23.0633
From Pta Varejo to Ilha Pescaria	677	357	43	52	0.61	23	2	0.92	-43.8768	-23.0487
From Pta Varejo to Ilha Pescaria	709.4	381.2	43	51	0.99	23	2	0.62	-43.8665	-23.0437

Appendix 1. List of co-ordinate pairs used to georeference the Landsat satellite image used in the study based on admiralty chart DHN-1622.

Sites	Coordinates on Landsat 'Wind' image		DHN chart 1622 Longitude degrees	min	decimal minutes	Latitude degrees	min	decimal minutes	IDRISI decimal degrees	IDRISI decimal degrees
	x	y	x			y			x	y
From Pta Varejo to Ilha Pta Ipiranga	613	274	43	53	0.92	23	4	0.1	-43.8987	-23.0683
From Pta Varejo to Ilha Pta Ipiranga	682.9	315	43	52	0.68	23	3	0.6	-43.878	-23.06
From Pta Varejo to Ilha Pta Ipiranga	766.2	364	43	51	0.04	23	3	0.04	-43.8507	-23.0507
From Pta Varejo to Ita	550.6	300.3	43	55	0	23	3	0.5	-43.9167	-23.0583
From Pta Varejo to Ita	639	387.2	43	53	0.22	23	2	0.34	-43.887	-23.039
From Pta Varejo to Ita	651.9	399.6	43	52	0.95	23	2	0.18	-43.8825	-23.0363
From Pta Varejo to Martins	795.7	358.2	43	56	0.3	23	3	0.13	-43.9383	-23.0522
Guaratiba (Ponta da Praia Funda)	1787	430.77	43	33	0.1	23	4	0.52	-43.5517	-23.0753
Hangar 01 da Aeronautica	1159.1	883.66	43	42	0.86	22	55	0.69	-43.7143	-22.9282
Hangar 02	1138.3	843.7	43	43	0.35	22	56	0.3	-43.7225	-22.9383
Hangar 03	1129.9	775.8	43	43	0.6	22	57	0.34	-43.7267	-22.9557
Ilha Baleia (E)	1647.8	535	43	35	0.35	23	2	0.51	-43.5892	-23.0418
Ilha Bonita (N)	537.4	555.4	43	54	0.5	22	59	0.34	-43.9083	-22.989
Ilha Bonitinha (S)	528.35	527.47	43	54	0.75	22	59	0.8	-43.9125	-22.9967
Ilha da Bala, Centro	417	483.6	43	56	0.8	23	0	0.2	-43.9467	-23.0033
Ilha da Carapuca (N)	444.07	572.81	43	56	0.1	22	58	0.74	-43.935	-22.979
Ilha da Gamboa N	574.32	795.65	43	53	0.22	22	55	0.4	-43.887	-22.9233
Ilha da Guaiba, Ponta (N)	117.3	463.7	44	2	0.4	22	59	0.75	-44.04	-22.9958
Ilha da Guaiba, Ponta (S)	83.021	405.15	44	2	0.84	23	0	0.6	-44.0473	-23.01
Ilha da Jurubaiba (W)	375.59	641.74	43	57	0.09	22	57	0.58	-43.9515	-22.9597
Ilha da Pescaria (S)	1168.1	722.88	43	43	0.131	22	58	0.35	-43.7189	-22.9725
Ilha da Sapioeira	609.26	813.51	43	52	0.55	22	55	0.42	-43.8758	-22.9237
Ilha da Vigia Grande (S)			43	57	0.15	23	0	0.55	-43.9525	-23.0092

Appendix 1. List of co-ordinate pairs used to georeference the Landsat satellite image used in the study based on admiralty chart DHN-1622.

Sites	Coordinates on Landsat 'Wind' image		DHN chart 1622 Longitude degrees	min	decimal minutes	Latitude degrees	min	decimal minutes	IDRISI decimal degrees	IDRISI decimal degrees
	x	y	x			y			x	y
Ilha da Vigia Pq (S)	393.05	481.59	43	57	0.2	23	0	0.18	-43.9533	-23.003
Ilha das 2 irmas (E)	333.3	696.6	43	57	0.78	22	56	0.55	-43.963	-22.9425
Ilha de Guaraquecaba (N)	1381	657.75	43	39	0.6	22	59	0.9	-43.66	-22.9983
Ilha de Jaguanum (W)	462.4	518.7	43	55	0.9	22	59	0.78	-43.9317	-22.9963
Ilha do Bernardo (S)	409.8	400.07	43	57	0.15	23	1	0.54	-43.9525	-23.0257
Ilha do Bicho Peq (N)	485.2	574.6	43	55	0.4	22	58	0.91	-43.9233	-22.9818
Ilha do Cabrito (N)	214.4	608.5	44	0	0	22	57	0.62	-44	-22.9603
Ilha do Cavaco, (S)	1587.6	560.81	43	36	0.3	23	1	0.98	-43.605	-23.033
Ilha do Cavaco, (W)	1565.4	566.81	43	36	0.68	23	1	0.8	-43.6113	-23.03
Ilha do Frade (centro)	1717	431.44	43	34	0.38	23	4	0.35	-43.573	-23.0725
Ilha do Frances (NE)	827.87	865.28	43	48	0.62	22	55	0.12	-43.8103	-22.9187
Ilha do Furtado (E)	536.42	586.15	43	54	0.42	22	58	0.88	-43.907	-22.9813
Ilha do Gato (N)	647.86	816.52	43	51	0.88	22	55	0.44	-43.8647	-22.924
Ilha do Jardim (S)	471.4	713.4	43	55	0.24	22	56	0.7	-43.9207	-22.945
Ilha do Sai, Center	175.72	655.97	44	1	0.52	22	56	0.81	-44.0253	-22.9468
Ilha do Sino (W)	246.7	147.7	44	0	0.65	23	5	0.2	-44.0108	-23.0867
Ilha do Tatu (W)	1216.6	675.42	43	42	0.4	23	59	0.2	-43.7067	-23.9867
Ilha Guaibinha (S)	87.4	481.5	44	2	0.55	22	59	0.4	-44.0425	-22.99
Ilha Rasa de Guaratiba (N)	1756.6	405.1	43	33	0.7	23	4	0.7	-43.5617	-23.0783
Ilha Soco do Martins ©	639	689.9	43	52	0.39	22	57	0.45	-43.8732	-22.9575
Itaguai X railroad X (01)	1001.6	1005.7	43	46	0.7	22	52	0.89	-43.7783	-22.8815
Itaguai, (02)	921.12	963.18	43	44	0.6	22	53	0.6	-43.7433	-22.8933
Itaguai, (03)	1016.8	1101.9	43	44	0.68	22	51	0.3	-43.7447	-22.855
Lage da Marambaia ©	857.7	136.18	43	50	0.1	23	6	0.9	-43.835	-23.115

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Sites	Coordinates on Landsat 'Wind' image		DHN chart 1622 Longitude degrees	min	decimal minutes	Latitude degrees	min	decimal minutes	IDRISI decimal degrees	IDRISI decimal degrees
	x	y	x			y			x	y
Lage dos Cardos	492.46	482.48	43	55	0.495	23	57	0.42	-43.9249	-23.957
Lagoa Vermelha (south elbow)	480.45	205.23	43	56	0.5	23	4	0.85	-43.9417	-23.0808
Lagoa Vermelha (W)	462	199.7	43	56	0.84	22	4	0.94	-43.9473	-22.0823
Mangaratiba, Praia do Saco	37.51	656.24	44	2	0.87	22	56	0.5	-44.0478	-22.9417
Marambaia 00 poco	1620.4	511.19	43	35	0.85	22	2	0.84	-43.5975	-22.0473
Marambaia 01	1507.2	508.7	43	37	0.84	23	2	0.65	-43.6307	-23.0442
Marambaia 02	1504.6	488.8	43	37	0.8	23	2	0.91	-43.63	-23.0485
Marambaia 03	1429.7	470.7	43	39	0.3	23	3	0.05	-43.655	-23.0508
Marambaia 04	1502.9	546.2	43	37	0.8	23	2	0	-43.63	-23.0333
Marambaia 05	1362.3	482.7	43	39	0.83	23	2	0.49	-43.6638	-23.0415
Marambaia 07	1285.9	439.44	43	41	0.8	23	3	0.15	-43.6967	-23.0525
Marambaia 08 restinga verruga	994.25	360.63	43	47	0.03	23	3	0.58	-43.7838	-23.0597
Marambaia 09	656.44	381.43	43	52	0.87	23	2	0.5	-43.8812	-23.0417
Marambaia 10	646	278.6	43	53	0.49	23	3	0.9	-43.8915	-23.065
Marambaia 11	498.08	297.07	43	55	0.15	23	3	0.45	-43.9192	-23.0575
Morro da Mazomba	376.9	859.4	43	55	0.4	22	53	0.62	-43.9233	-22.8937
Pedra de Guaratiba	1472.9	643.3	43	38	0.08	23	0	0.38	-43.6347	-23.0063
Ponta Mangona	413.2	346.04	43	57	0.28	23	2	0.4	-43.9547	-23.04
Ponta da Bica	635.57	813.69	43	52	0.1	22	55	0.5	-43.8683	-22.925
Ponta da Cruz	692.39	823.44	43	51	0.1	22	55	0.45	-43.8517	-22.9242
Ponta do Afonso	315.23	727.51	43	57	0.9	22	56	0.08	-43.965	-22.9347
Ponta do Arpoador	263.04	122.7	44	0	0.4	23	5	0.75	-44.0067	-23.0958
Ponta do Barreiro	494.38	752.59	43	54	0.71	23	56	0.08	-43.9118	-23.9347
Ponta do Bispo	35.009	511.19	44	2	0.8	22	58	0.89	-44.0467	-22.9815
Ponta do Boi	635.3	732.8	43	52	0.3	22	56	0.8	-43.8717	-22.9467

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Sites	Coordinates on Landsat 'Wind' image		DHN chart 1622 Longitude degrees	min	decimal minutes	Latitude degrees	min	decimal minutes	IDRISI decimal degrees	IDRISI decimal degrees
	x	y	x			y			x	y
Ponta do Boi (W)	611	712.6	43	52	0.8	22	57	0.01	-43.88	-22.9502
Ponta do Calhau	557.81	676.06	43	53	0.84	22	55	0.5	-43.8973	-22.925
Ponta do Ferreiro	1459.1	641.36	43	38	0.3	23	0	0.35	-43.6383	-23.0058
Ponta do Furado	258.38	205.38	44	0	0.36	23	4	0.25	-44.006	-23.0708
Ponta do Gringo	591	807.7	43	52	0.91	22	55	0.45	-43.8818	-22.9242
Ponta do Guaia	724.09	810.15	43	50	0.68	22	57	0.75	-43.8447	-22.9625
Ponta do Ipiranga	1279.3	665.81	43	41	0.35	22	59	0.5	-43.6892	-22.9917
Ponta do Mudo	478.75	767.86	43	54	0.95	22	56	0.82	-43.9158	-22.947
Ponta do Piai	1239.5	681.36	43	42	0	22	0	0.15	-43.7	-22.0025
Ponta do Pimentel	144.6	597.6	44	1	0.25	22	57	0.65	-44.0208	-22.9608
Ponta do Sai	163.35	638.58	44	0	0.79	23	57	0.05	-44.0132	-23.9508
Ponta do Sino	243.68	174.79	44	0	0.7	23	4	0.75	-44.0117	-23.0792
Ponta do Sul	463.6	449.19	43	56	0.1	23	0	0.86	-43.935	-23.0143
Ponta do Tingui	236.04	697.5	43	59	0.38	22	56	0.3	-43.9897	-22.9383
Ponta do urubu	748.35	813.65	43	50	0.15	22	55	0.75	-43.8358	-22.9292
Ponta do Varejo	390.24	143.22	43	58	0.25	23	5	0.63	-43.9708	-23.0938
Ponta do Zumbi (N)	303.04	265.55	43	59	0.49	23	3	0.39	-43.9915	-23.0565
Ponta Grossa (Itacuruca)	513.6	677.3	43	54	0.6	22	57	0.36	-43.91	-22.956
Rio Cabucu, CG4	1610.1	854.8	43	35	0.15	22	57	0.28	-43.5858	-22.9547
Rio Cacao X	776.6	932.8	43	49	0.31	22	52	0.6	-43.8218	-22.8767
Rio Corumbi	395.6	755.7	43	56	0.48	22	55	0.8	-43.9413	-22.93
Rio da Guarda X Canal Sto. Agostinho	900.49	910.56	43	47	0.21	23	54	0.5	-43.7868	-23.9083
Rio do Ponto	1328.9	752.9	43	40	0.25	22	58	0.2	-43.6708	-22.97
Rio Guandu Mirim + Canal de Sao Pedro	1258.4	1140.7	43	40	0.4	22	51	0.86	-43.6733	-22.8643

Appendix 1. List of co-ordinate pairs used to georeference the Landsat satellite image used in the study based on admiralty chart DHN-1622.

Sites	Coordinates on Landsat 'Wind' image		DHN chart 1622 Longitude degrees	min	decimal minutes	Latitude degrees	min	decimal minutes	IDRISI decimal degrees	IDRISI decimal degrees
	x	y	x			y			x	y
Rio Mazomba X	823.5	1037.7	43	48	0.12	22	52	0.58	-43.802	-22.8763
Rio Piracao A	1621.7	602.1	43	35	0.6	23	1	0.31	-43.5933	-23.0218
Rio Piracao B	1629.7	628.9	43	35	0.45	23	1	0	-43.5908	-23.0167
Rio Piraque 7	1558.9	703.17	43	36	0.45	23	59	0.6	-43.6075	-23.9933
Rio Piraque 8	1538.4	667.9	43	36	0.89	23	0	0.18	-43.6148	-23.003
Rio Sai	188.8	677.7	43	0	0.1	22	56	0.5	-43.0017	-22.9417
Rio Santos	430.4	800.4	43	55	0.68	22	55	0.18	-43.928	-22.9197
Saco do Piai	1322.7	715.3	43	40	0.48	22	58	0.84	-43.6747	-22.9807
Santa Cruz	1251.3	946.4	43	41	0.15	22	59	0.9	-43.6858	-22.9983
Sepetiba Port 01 elbow	767.95	791.04	43	49	0.9	22	56	0.2	-43.8317	-22.9367
Sepetiba Port 02	763.2	810.7	43	49	0.92	22	55	0.88	-43.832	-22.9313
Sepetiba Port 03	806.3	856.7	43	49	0.1	22	53	0.21	-43.8183	-22.8868
X Rail T junction in Brisamar	768.46	958.24	43	49	0.4	23	53	0.42	-43.8233	-23.8903
X Rail track + Sta. Cruz Road	1440.9	976.24	43	37	0.6	22	54	0.95	-43.6267	-22.9158

Appendix 2. Correspondence file created for co-ordinate points digitised from DHN chart 1622 to Landsat windowed image (WIND) of study area.

Site	DHN coordinates		Landsat plane coordinates	
	x	y	x	y
Cais da Nuclep	45.30	61.30	696.0	898.9
Canal de Sto Agostinho + linha de trem	69.98	64.10	1001.4	1005.7
Canal do Guandu 1 G1	64.38	53.10	981.4	840.6
Canal do Guandu 2 G2	78.62	60.81	1161.2	969.9
Canal do Ita 1	69.30	49.71	1063.6	803.9
Canal do Ita 2	72.58	52.31	1094.6	844.6
Canal do Ita 3	82.28	59.62	1213.2	961.9
Coroa Grande, cais	38.50	60.60	631.3	879.5
Hangar 03	74.27	46.91	1129.9	775.8
Ilha Baleia (E)	109.60	23.30	1647.8	535.0
Ilha Bonita (N)	27.70	37.70	537.4	555.4
Ilha Bonitinha (S)	26.70	35.70	528.3	527.5
Ilha da Bala, Centro	18.00	33.90	417.0	483.6
Ilha da Carapuca (N)	21.00	40.10	444.1	572.8
Ilha da Gamboa N	33.20	55.10	574.3	795.6
Ilha da Jurubaiba (W)	16.80	46.00	375.6	641.7
Ilha da Pescaria (S)	76.30	42.30	1168.1	722.9
Ilha da Sapioeira	36.20	55.80	609.3	813.5
Ilha da Vigia Pq (S)	16.30	34.00	393.1	481.6
Ilha da Vigia Grande (S)	16.63	32.30	400	459
Ilha das 2 irmas (E)	14.20	50.50	333.3	696.6
Ilha de Guaraquecaba (N)	91.40	35.30	1381.0	657.7
Ilha de Jaguanum (W)	21.80	35.80	462.4	518.7
Ilha do Bernardo (S)	16.50	27.70	409.8	400.1
Ilha do Bicho Peq (N)	24.00	39.70	485.2	574.6
Ilha do Cabrito (N)	4.40	45.70	214.4	608.5
Ilha do Cavaco, (S)	105.50	25.80	1587.6	560.8
Ilha do Cavaco, (W)	103.90	26.50	1565.4	566.8
Ilha do Frances (NE)	52.90	57.15	827.9	865.3
Ilha do Furtado (E)	28.00	39.90	536.4	586.1
Ilha do Gato (N)	39.00	55.70	647.9	816.5
Ilha do Jardim (S)	24.70	50.00	471.4	713.4
Ilha do Sai, Center	2.09	49.40	175.7	656.0
Ilha do Sino (W)	1.16	11.02	246.7	147.7
Ilha do Tatu (W)	79.40	38.54	1216.6	675.4
Ilha Soco do Martins (C)	36.80	46.39	639.0	689.9
Itaguai X railroad X (01)	46.38	2.97	857.7	136.2
Lage da Marambaia (C)	23.56	32.91	492.5	482.5
Lage dos Cardos	99.20	25.85	1502.9	546.2
Marambaia 04	90.58	23.57	1362.3	482.7
Marambaia 05	96.93	33.22	1472.9	643.3
Marambaia 08 restinga verruga	16.01	23.68	413.2	346.0
Marambaia 09	38.10	55.50	635.6	813.7
Marambaia 10	42.39	55.66	692.3	823.3

Appendix 2. Correspondence file created for co-ordinate points digitised from DHN chart 1622 to Landsat windowed image (WIND) of study area.

Site	DHN coordinates		Landsat plane coordinates	
	x	y	x	y
Marambaia 11	13.30	52.82	315.2	727.5
Marambaia 12	2.74	8.61	263.0	122.7
Pedra de Guaratiba	26.91	52.60	494.4	752.6
Ponta Mangona	35.10	48.44	611.8	713.1
Ponta da Bica	26.85	50.30	498	719
Ponta da Cruz	30.73	46.31	557.8	676.1
Ponta do Afonso	2.84	15.26	258.4	205.4
Ponta do Arpoador	34.60	55.30	591.0	807.7
Ponta do Barreiro	44.76	54.23	724.1	810.2
Ponta do Boi	83.83	37.12	1279.3	665.8
Ponta do Boizinho	25.78	54.05	478.7	767.9
Ponta do Calhau	81.07	38.81	1239.5	681.4
Ponta do Ferreiro	0.94	48.39	163.3	638.6
Ponta do Furado	1.22	13.07	243.7	174.8
Ponta do Gringo	21.07	30.78	463.6	449.2
Ponta do Guaia	7.22	51.65	236.0	697.5
Ponta do Ipiranga	46.42	54.29	748.3	813.7
Ponta do Mudo	11.97	9.10	390.2	143.2
Ponta do Piai	6.58	19.60	303.0	265.5
Ponta do Sai	110.26	47.24	1610.1	854.8
Ponta do Sino	49.88	62.63	776.6	932.8
Ponta do Sul	19.38	54.19	395.6	755.7
Ponta do Tingui	58.83	59.56	900.5	910.6
Ponta do urubu	87.78	40.16	1323.5	716.0
Ponta do Varejo	88.02	72.11	1258.4	1140.7
Ponta do Zumbi (N)	55.10	68.73	823.5	1037.7
Ponta Grossa (Guaratiba)	108.33	28.97	1621.7	602.1
Ponta Grossa (Itacuruca)	109.19	30.16	1629.7	628.9
Rio Cabucu, CG4	103.03	34.13	1538.4	667.9
Rio Cacao X	3.96	50.80	188.8	677.7
Rio Corumbi	87.74	40.19	1322.7	715.3
Rio da Guarda X Canal Sto. Agostinho	84.67	57.79	1251.3	946.4
Rio do Ponto	47.52	52.37	768.0	791.0
Rio Guandu Mirim + Canal de Sao Pedro	47.45	53.80	763.2	810.7
Rio Mazomba X	51.09	56.80	806.3	856.7

Appendix 3. Drogue track positions and readings taken in Sepetiba Bay in 1996.

Date	Time	Drogue nº:	Waypoint	Sal PSU	Temp °C	Latitude	Longitude	Depth (m)
-	12:20	1	-	31	29	22°56'867	43°52'350	4.3
-		2	-	-	-	-	-	-
-		3	-	-	-	-	-	-
-		4	-	-	-	-	-	-
05.03.96	8:04	1	-	-	-	22°59'255	43°55'95	-
05.03.96	8:05	2	-	-	-	22°59'242	43°55'110	-
05.03.96	8:07	3	-	-	-	22°59'183	43°55'073	-
05.03.96	8:09	4	-	-	-	22°59'138	43°55'063	-
05.03.96	8:13	1	-	-	-	22°59'265	43°55'177	-
05.03.96	8:13	1	-	-	-	22°59'265	43°55'177	-
05.03.96	8:14	2	-	-	-	22°59'240	43°55'203	-
05.03.96	8:16	3	-	-	-	22°59'220	43°55'110	-
05.03.96	8:19	4	-	-	-	22°59'163	43°55'055	-
05.03.96	8:23	1	-	-	-	22°59'280	43°55'230	-
05.03.96	8:28	1	-	-	-	22°59'088	43°55'075	-
05.03.96	8:29	2	-	-	-	22°59'088	43°55'042	-
05.03.96	8:30	3	-	-	-	22°59'002	43°54'998	-
05.03.96	8:31	4	-	-	-	-----------	---------	-
05.03.96	9:03	1	-	-	-	22°59'013	43°55'293	-
05.03.96	9:02	2	-	-	-	22°58'968	43°55'290	-
05.03.96	9:00	3	-	-	-	22°58'972	43°55'145	-
05.03.96	8:55	4	-	-	-	22°58'957	43°54'968	-
05.03.96	9:10	1	-	-	-	-----------	------------	-
05.03.96	9:11	2	-	-	-	22°58'962	43°55'305	-
05.03.96	9:15	3	-	-	-	22°59'008	43°55'172	-
05.03.96	12:37	1	A	-	-	22°56'863	43°52'420	-
05.03.96	12:39	2	B	-	-	22°56'895	43°52'393	-
05.03.96	12:40	3	C	-	-	22°56'933	43°52'375	-
05.03.96	12:41	4	D	-	-	22°56'943	43°52'365	-
05.03.96	12:43	1	E	-	-	22°56'775	43°52'338	-
05.03.96	12:44	2	F	-	-	22°56'827	43°52'298	-
05.03.96	12:45	3	G	-	-	22°56'855	43°52'255	-
05.03.96	12:46	4	H	-	-	22°56'890	43°52'262	-
05.03.96	14:46	1	-	31	26	22°58'575	43°53'808	18.0
05.03.96	14:47	2	-	-	-	22°58'542	43°53'812	-
05.03.96	14:48	3	-	-	-	22°58'502	43°53'815	-
05.03.96	14:49	4	-	-	-	22°58'470	43°53'812	-
05.03.96	14:52	1	-	-	-	22°58'595	43°53'687	-
05.03.96	14:53	2	-	-	-	22°58'548	43°53'692	-
05.03.96	14:54	3	-	-	-	22°58'492	43°53'693	-
05.03.96	14:55	4	-	-	-	22°58'452	43°53'697	-

Appendix 3. Drogue track positions and readings taken in Sepetiba Bay in 1996.

Date	Time	Drogue nº:	Waypoint	Sal PSU	Temp°C	Latitude	Longitude	Depth (m)
05.03.96	16:25	1	-	31	26	22°59'385	43°54'602	4.6
05.03.96	16:27	2	-	-	-	22°59'638	43°54'638	-
05.03.96	16:29	3	-	-	-	22°59'280	43°54'660	-
05.03.96	16:30	4	-	-	-	22°59'207	43°54'745	-
05.03.96	16:35	1	-	-	-	22°59'398	43°54'588	-
05.03.96	16:38	2	-	-	-	22°59'288	43°54'628	-
05.03.96	16:40	3	-	-	-	22°59'268	43°54'657	-
05.03.96	16:42	4	-	-	-	22°59'220	43°54'952	-
05.03.96	17:59	1	-	-	-	22°59'385	43°54'602	-
05.03.96	18:00	2	-	-	-	22°59'638	43°54'638	-
05.03.96	18:02	3	-	-	-	22°59'280	43°54'660	-
05.03.96	18:04	4	-	-	-	22°59'207	43°54'745	-
05.03.96	18:10	1	-	-	-	22°59'398	43°54'588	-
05.03.96	18:13	2	-	-	-	22°59'288	43°54'628	-
05.03.96	18:14	3	-	-	-	22°59'268	43°54'657	-
05.03.96	18:19	4	-	-	-	22°59'220	43°54'952	-
06.03.96	10:07	1	-	-	-	22°58'957	43°54'968	-
06.03.96	10:09	2	-	-	-	22°59'682	43°54'897	-
06.03.96	10:10	3	-	-	-	22°59'737	43°54'882	-
06.03.96	10:12	4	-	-	-	22°59'813	43°54'813	-
06.03.96	10:42	1	-	-	-	---------	-----------	-
06.03.96	10:42	2	-	-	-	22°59'795	43°54'808	-
06.03.96	10:51	3	-	-	-	22°59'795	43°54'808	-
	-------	4	-	-	-	22°59'770	43°55'093	-
06.03.96	14:07	1	-	33	28	23°00'580"	43°56'145"	14.6
06.03.96	14:09	2	-	-	-	23°00'628"	43°56'200"	-
06.03.96	14:11	3	-	-	-	23°00'679"	43°56'267"	-
06.03.96	14:14	4	-	-	-	23°00'781"	43°56'319"	-
06.03.96	14:18	1	-	-	-	23°00'489"	43°56'207"	-
06.03.96	14:19	2	-	-	-	23°00'503"	43°56'209"	-
06.03.96	14:21	3	-	-	-	23°00'591"	43°56'290"	-
06.03.96	14:26	4	-	-	-	23°00'612"	43°56'191"	-
06.03.96	15:08	1	-	31	27	23°00'239"	43°56'627"	-
06.03.96	15:12	2	-	-	-	23°00'257"	43°56'726"	-
06.03.96	15:14	3	-	-	-	23°00'240"	43°56'836"	-
06.03.96	15:21	4	-	-	-	23°00'094"	43°56'738"	-
06.03.96	15:25	1	-	-	-	23°00'305"	43°56'664"	-
06.03.96	15:26	2	-	-	-	23°00'297"	43°56'715"	-
06.03.96	15:29	3	-	-	-	23°00'266"	43°56'831"	-
06.03.96	15:31	4	-	-	-	23°00'114"	43°56'647"	

Appendix 3. Drogue track positions and readings taken in Sepetiba Bay in 1996.

Date	Time	Drogue nº:	Waypoint	Sal PSU	Temp°C	Latitude	Longitude	Depth (m)
06.03.96	16:33	1	-	31	-	23°01'231"	43°56'822"	-
06.03.96	16:35	2	-	-	-	23°01'155"	43°56'854"	-
06.03.96	16:37	3	-	-	-	23°01'070"	43°56'889"	-
06.03.96	16:39	4	-	-	-	23°00'959"	43°56'945"	-
06.03.96	16:45	1	-	-	-	23°01'276"	43°56'952"	-
06.03.96	16:43	2	-	-	-	23°01'229"	43°56'994"	-
06.03.96	16:41	3	-	-	-	23°01'112"	43°57'001"	-
06.03.96	16:52	4	-	-	-	23°01'970"	43°57'326"	-
06.03.96	16:47	2	-	-	-	23°01'232"	43°57'055"	-
06.03.96	16:49	3	-	-	-	23°01'131"	43°57'233"	-
07.03.96	10:24	1	-	25	29	22°57'334"	43°51'784"	16.8
07.03.96	10:26	2	-	-	-	22°57'455"	43°51'820"	-
07.03.96	10:27	3	-	-	-	22°57'519"	43°51'845"	-
07.03.96	10:28	4	-	-	-	22°57'566"	43°51'878"	-
07.03.96	10:33	1	-	-	-	22°57'332"	43°51'884"	-
07.03.96	10:35	2	-	-	-	22°57'422"	43°51'926"	-
07.03.96	10:37	3	-	-	-	22°57'497"	43°51'967"	-
07.03.96	10:40	4	-	-	-	22°57'564"	43°52'014"	-
07.03.96	10:42	3	-	-	-	22°57'485"	43°52'023"	-
07.03.96	10:46	2	-	-	-	22°57'394"	43°52'045"	-
07.03.96	10:48	1	-	-	-	22°57'326"	43°51'986"	-
07.03.96	------	4	-	-	-	22°57'524"	43°51'928"	-
07.03.96	10:51	1	-	25	-	22°57'175"	43°51'977"	-
07.03.96	10:52	2	-	-	-	22°57'143"	43°51'925"	-
07.03.96	10:53	3	-	-	-	22°57'106"	43°51'855"	-
07.03.96	10:54	4	-	-	-	22°57'082"	43°51'786"	-
07.03.96	11:07	1	-	-	-	22°57'234"	43°51'971"	-
07.03.96	11:09	2	-	-	-	22°57'221"	43°51'913"	-
07.03.96	11:11	3	-	-	-	22°57'164"	43°51'829"	-
07.03.96	11:13	4	-	-	-	22°57'081"	43°51'716"	-
07.03.96	11:31	1	-	-	-	22°56'859"	43°51'835"	-
07.03.96	11:29	2	-	-	-	22°56'814"	43°51'888"	-
07.03.96	11:33	3	-	-	-	22°56'779"	43°51'941"	-
07.03.96	11:35	4	-	-	-	22°56'741"	43°52'016"	-
07.03.96	11:40	1	-	-	-	22°56'905"	43°51'849"	-
07.03.96	11:42	2	-	-	-	22°56'836"	43°51'871"	-
07.03.96	11:43	3	-	-	-	22°56'787"	43°51'865"	-
07.03.96	11:45	4	-	-	-	22°56'774"	43°51'984"	-
07.03.96	11:46	2	-	-	-	22°56'800"	43°51'058"	-
07.03.96	11:47	1	-	-	-	22°56'848"	43°52'213"	-
07.03.96	11:48	4	-	-	-	22°56'873"	43°52'271"	-

Appendix 3. Drogue track positions and readings taken in Sepetiba Bay in 1996.

Date	Time	Drogue n°:	Waypoint	Sal PSU	Temp°C	Latitude	Longitude	Depth(m)
14.06.96	13:59	1	118	-	-	22°56'262"	43°50'353"	13.7
14.06.96	14:00	2	119	-	-	22°56'479"	43°50'323"	-
14.06.96	14:01	3	120	-	-	22°56'669"	43°50'252"	-
14.06.96	14:02	4	121	-	-	22°56'887"	43°50'148"	-
14.06.96	14:03	5	122	-	-	22°57'064"	43°50'072"	-
14.06.96	14:04	6	123	-	-	22°57'262"	43°49'990"	-
14.06.96	14:05	7	124	-	-	22°57'460"	43°49'917"	-
14.06.96	14:06	8	125	34-	26.5	22°57'611"	43°49'807"	-
14.06.96	14:36	1	126	34	26.0	22°56'428"	43°50'501"	8.5
14.06.96	14:37	2	127	-	-	22°56'611"	43°50'420"	-
14.06.96	14:38	3	128	-	-	22°56'865"	43°50'411"	-
14.06.96	14:40	4	129	-	-	22°57'073"	43°50'246"	-
14.06.96	14:42	5	130	-	-	22°57'323"	43°50'183"	-
14.06.96	14:43	6	131	-	-	22°57'517"	43°50'157"	-
14.06.96	14:46	7	132	-	-	22°57'741"	43°50'015"	-
14.06.96	14:47	8	133	-	-	22°57'929"	43°49'926"	-
14.06.96	14:50	1	134	34	26	22°57'949"	43°49'945"	8.0
14.06.96	14:53	2	135	-	-	22°58'199"	43°49'948"	-
14.06.96	14:54	3	136	-	-	22°58'390"	43°49'926"	-
14.06.96	14:55	4	137	-	-	22°58'588"	43°49'880"	-
14.06.96	14:56	5	138	-	-	22°58'772"	43°49'803"	-
14.06.96	14:57	6	139	-	-	22°58'979"	43°49'736"	-
14.06.96	14:58	7	140	-	-	22°59'175"	43°49'694"	-
14.06.96	14:59	8	141	35	26.5	22°59'373"	43°49'655"	9.0
14.06.96	15:17	1	142	34	26.0	22°58'127"	43°50'055"	-
14.06.96	15:18	2	143	-	-	22°58'341"	43°50'057"	-
14.06.96	15:20	3	144	-	-	22°58'589"	43°50'086"	-
14.06.96	15:22	4	145	-	-	22°58'014"	43°50'073"	-
14.06.96	15:23	5	146	-	-	22°58'972"	43°50'030"	-
14.06.96	15:24	6	147	-	-	22°59'119"	43°49'954"	-
14.06.96	15:26	7	148	-	-	22°59'295"	43°49'938"	-
14.06.96	15:28	8	149	-	-	22°59'447"	43°49'184"	-
14.06.96	15:30	1	150	-	-	22°59'506"	43°49'818"	-
14.06.96	15:31	2	151	-	-	22°59'666"	43°49'749"	-
14.06.96	15:32	3	152	-	-	22°59'855"	43°49'717"	-
14.06.96	15:33	4	153	-	-	23°00'047"	43°49'678"	-
14.06.96	15:34	5	154	-	-	23°00'232"	43°49'642"	-
14.06.96	15:35	6	155	-	-	23°00'422"	43°49'581"	-
14.06.96	15:36	7	156	-	-	23°00'615"	43°49'528"	-
14.06.96	15:37	8	157	31	26.8	23°00'838"	43°49'476"	9.0

Appendix 3. Drogue track positions and readings taken in Sepetiba Bay in 1996.

Date	Time	Drogue n°:	Waypoint	Sal PSU	Temp°C	Latitude	Longitude	Depth (m)
14.06.96	15:55	1	158			22°59'528"	43°50'097"	
14.06.96	15:56	2	159			22°59'694"	43°49'978"	
14.06.96	15:58	3	160			22°59'953"	43°49'990"	
14.06.96	15:59	4	161			23°00'127"	43°49'883"	
14.06.96	16:00	5	162			23°00'353"	43°49'889"	
14.06.96	16:01	6	163			23°00'507"	43°49'791"	
14.06.96	16:02	7	164			23°00'689"	43°49'741"	
14.06.96	16:03	8	165			23°00'944"	43°49'723"	
14.06.96	14:45	1	1			22°57'539"	43°53'952"	
14.06.96	14:47	2	2			22°57'634"	43°53'998"	
14.06.96	14:48	3	3			22°57'727"	43°54'029"	
14.06.96	14:49	4	4			22°57'832"	43°54'064"	
14.06.96	14:50	5	5			22°57'951"	43°54'103"	
14.06.96	14:54	6	6			22°58'017"	43°54'163"	
14.06.96	14:55	7	7			22°58'151"	43°54'197"	
14.06.96	14:56	8	8			22°58'302"	43°54'268"	
14.06.96	15:13	1	9			22°57'551"	43°54'002"	
14.06.96	15:14	2	10			22°57'539"	43°54'249"	
14.06.96	15:15	3	11			22°57'581"	43°54'317"	
14.06.96	15:16	4	12			22°57'595"	43°54'374"	
14.06.96	15:18	5	13			22°57'674"	43°54'442"	
14.06.96	15:19	6	14			22°57'775"	43°54'493"	
14.06.96	15:20	7	15			22°57'872"	43°54'479"	
14.06.96	15:21	8	16			22°57'979"	43°54'587"	
14.06.96	15:44	1	17	16	29	22°55'599"	43°48'844"	
14.06.96	15:45	2	18			22°55'707"	43°48'878"	
14.06.96	15:46	3	19			22°55'799"	43°48'897"	
14.06.96	15:47	4	20	7	28	22°55'899"	43°48'905"	
14.06.96	15:48	5	21			22°56'017"	43°48'923"	
14.06.96	15:49	6	22			22°56'105"	43°48'953"	
14.06.96	15:50	7	23			22°56'224"	43°48'985"	
14.06.96	15:51	8	24	26	28	22°56'360"	43°49'024"	
14.06.96	16:14	1	25			22°55'345"	43°49'098"	
14.06.96	16:23	2	26			22°55'541"	43°49'341"	
14.06.96	16:24	3	27			22°55'660"	43°49'489"	
14.06.96	16:26	4	28			22°55'846"	43°49'581"	
14.06.96	16:27	5	29			22°55'985"	43°49'617"	
14.06.96	16:29	6	30			22°56'112"	43°49'667"	
14.06.96	16:31	7	31			22°56'263"	43°49'681"	
14.06.96	16:31	8	32			22°56'405"	43°49'718"	
14.06.96	16:57	1	34			22°56'271"	43°47'791"	

Appendix 3. Drogue track positions and readings taken in Sepetiba Bay in 1996.

Date	Time	Drogue nº:	Waypoint	Sal PSU	Temp°C	Latitude	Longitude	Depth (m)
14.06.96	16:59	2	35			22°56'386"	43°47'814"	
14.06.96	17:00	3	36			22°56'429"	43°47'834"	
14.06.96	17:02	4	37	6	29	22°56'537"	43°47'876"	
14.06.96	17:04	5	38			22°56'687"	43°47'911"	
14.06.96	17:06	6	39			22°56'836"	43°47'952"	
14.06.96	17:08	7	40			22°56'989"	43°47'988"	
14.06.96	17:10	8	41	24	29	22°57'129"	43°47'995"	
14.06.96	17:21	1	42	5	26	22°56'265"	43°47'962"	
14.06.96	17:24	2	43			22°56'422"	43°47'989"	
14.06.96	17:25	3	44			22°56'468"	43°48'063"	
14.06.96	17:27	4	45			22°56'586"	43°48'188"	
14.06.96	17:29	5	46			22°56'696"	43°48'244"	
14.06.96	17:31	6	47			22°56'868"	43°48'295"	
14.06.96	17:33	7	48			22°57'063"	43°48'345"	
14.06.96	17:35	8	49			22°57'209"	43°48'397"	
15.03.96	14:34	1	60			22°59'212"	43°42'516"	
15.03.96	14:35	2	61			22°59'310"	43°42'546"	
15.03.96	14:36	3	62			22°59'456"	43°42'609"	
15.03.96	14:37	4	63			22°59'592"	43°42'618"	
15.03.96	14:38	5	64			22°59'713"	43°42'628"	
15.03.96	14:39	6	65			22°59'826"	43°42'669"	
15.03.96	14:40	7	66			22°59'943"	43°42'716"	
15.03.96	14:41	8	67	28	27.5	23°00'079"	43°42'740"	
15.03.96	14:47	1	68	30	28	22°59'109"	43°42'530"	
15.03.96	14:50	2	69			22°59'216"	43°42'531"	
15.03.96	14:51	3	70			22°59'334"	43°42'590"	
15.03.96	14:52	4	71	30	28	22°59'471"	43°42'635"	
15.03.96	14:54	5	72			22°59'577"	43°42'620"	
15.03.96	14:55	6	73			22°59'687"	43°42'660"	
15.03.96	14:56	7	74			22°59'804"	43°42'713"	
15.03.96	14:57	8	75			22°59'939"	43°42'737"	
15.03.96	15:03	1	76	29	28	22°58'976"	43°44'059"	
15.03.96	15:05	2	77			22°58'805"	43°44'008"	
15.03.96	15:06	3	78			22°58'603"	43°43'979"	
15.03.96	15:07	4	79			22°58'384"	43°43'985"	
15.03.96	15:08	5	80			22°58'192"	43°43'959"	
15.03.96	15:09	6	81			22°58'034"	43°43'932"	
15.03.96	15:10	7	82			22°57'896"	43°43'921"	
15.03.96	15:11	8	83	29	29	22°57'784"	43°43'908"	
15.03.96	15:18	1	84			22°58'846"	43°44'042"	

Appendix 3. Drogue track positions and readings taken in Sepetiba Bay in 1996.

Date	Time	Drogue n°:	Waypoint	Sal PSU	Temp°C	Latitude	Longitude	Depth (m)
15.03.96	15:19	2	85			22°58'724"	43°43'981"	
15.03.96	15:20	3	86			22°58'516"	43°43'953"	
15.03.96	15:21	4	87	30	28.5	22°58'278"	43°43'953"	
15.03.96	15:24	5	88			22°58'073"	43°43'903"	
15.03.96	15:25	6	89			22°57'940"	43°43'919"	
15.03.96	15:26	7	90			22°57'843"	43°43'929"	
15.03.96	15:27	8	91			22°57'725"	43°43'906"	
15.03.96	15:33	1	92	28	29	22°57'180"	43°44'839"	
15.03.96	15:35	2	93			22°57'272"	43°44'879"	
15.03.96	15:37	3	94			22°57'391"	43°44'913"	
15.03.96	15:38	4	95			22°57'599"	43°44'975"	
15.03.96	15:39	5	95			22°57'599"	43°44'975"	
15.03.96	15:40	6	96			22°57'689"	43°45'021"	
15.03.96	15:41	7	97			22°57'810"	43°45'071"	
15.03.96	15:42	8	98	29	28	22°57'937"	43°45'117"	
15.03.96	15:47	1	99			22°57'118"	43°44'921"	
15.03.96	15:48	2	100			22°57'236"	43°44'962"	
15.03.96	15:49	3	101			22°57'319"	43°44'963"	
15.03.96	15:50	4	102	29	28	22°57'413"	43°44'990"	
15.03.96	15:52	5	103			22°57'461"	43°45'045"	
15.03.96	15:54	6	104			22°57'574"	43°45'102"	
15.03.96	15:55	7	105			22°57'704"	43°45'145"	
15.03.96	15:56	8	106			22°57'831"	43°45'179"	

Appendix 4. Surface salinity (PSU), temperature and depth values at different sites in Sepetiba bay.

Date	Time	latitude	longitude	surface salinity PSU	Surface Temperature °C	Depth m
15.1.97	-	22.55.307	43.52.839	30	27	6.7
15.1.97	-	22.54.653	43.51.086	28	29	2.1
15.1.97	-	22.54.577	43.50.895	29	28	1.2
15.1.97	-	22.55.616	43.51.083	31	26.5	4.3
15.1.97	-	22.55.076	43.50.639	22	27	4.9
15.1.97	-	22.56.157	43.49.906	10	29	9.4
15.1.97	11:03	22.55.436	43.48.938	14	29.5	1.2
15.1.97	-	22.55.261	43.48.727	20	29.5	0.6
15.1.97	-	22.56.044	43.48.628	11	30	4.3
15.1.97	-	22.56.125	43.48.081	2	29	1.5
15.1.97	11:34	22.56.878	43.56.878	5	31	0.0
15.1.97	-	22.57.651	43.48.529	3	29.5	6.4
15.1.97	-	22.57.651	43.48.529	26	29	6.4
15.1.97	-	22.59.493	43.50.034	28	29	7.9
15.1.97	-	23.01.318	43.50.292	30	29	8.8
15.1.97	-	23.02.959	43.51.046	29	29	0.3
15.1.97	13:09	23.01.324	43.53.350	31	28.5	4.6
15.1.97	-	23.01.759	43.54.089	31	30	1.2
15.1.97	-	23.02.448	43.53.993	31	28	2.4
15.1.97	-	23.00.792	43.55.551	35	25	7.6
15.1.97	-	23.00.201	43.55.084	33	27	10.4
15.1.97	13:54	23.01.341	43.57.256	34	27	7.3
15.1.97	-	23.00.279	43.57.322	33	27	9.1
15.1.97	14:40	23.00.097	43.56.474	35	25	7.9
15.1.97	-	22.59.283	43.55.723	35	24	20.4
15.1.97	-	22.59.250	43.54.901	31	28	9.8
15.1.97	-	22.59.745	43.54.630	33	26.5	14.0
15.1.97	-	22.59.060	43.54.209	30	29	10.1
15.1.97	-	22.58.632	43.54.766	34	25	24.4
15.1.97	-	22.58.297	43.55.188	33	26	21.9
15.1.97	15:15	22.57.831	43.54.466	34	27	25.9
15.1.97	-	22.58.058	43.53.339	30	29	15.8
15.1.97	-	22.57.477	43.52.690	30	28	20.1
15.1.97	-	22.56.624	43.51.721	31	28	18.3
15.1.97	-	22.55.753	43.52.019	31	27.5	6.4
15.1.97	-	22.55.680	43.51.641	30	26.5	5.5
15.1.97	15:37	22.55.650	43.51.383	31	27	5.5
15.1.97	-	22.55.846	43.50.642	29	28	5.2
15.1.97	-	22.56.131	43.49.939	28	29	10.1
15.1.97	-	22.56.332	43.49.134	9	30.2	10.1

Appendix 4. Surface salinity (PSU), temperature and depth values at different sites in Sepetiba bay.

Date	Time	latitude	longitude	surface salinity PSU	Surface Temperature °C	Depth m
15.1.97	-	22.56.521	43.48.804	3	30	9.8
5/3/96	-	22.56.954	43.52.420	31	29	4.3
5/3/96	-	22.58.627	43.53.849	31	26	18.3
5/3/96	-	22.59.84	43.54.633	31	26	4.6
6/3/96	-	23.00.741	43.56.161	33	28	14.6
6/3/96	-	23.00.090	43.56.730	31	27	0.0
6/3/96	-	23.00.659	43.56.102	31	26	0.0
7/3/96	-	22.57.412	43.51.720	25	29	16.8
15.03.96	11:53	22.55.922	43.51.053	34	28	0.0
15.03.96	12:01	22.56.216	43.50.405	34	28	0.0
15.03.96	12:10	22.56.089	43.49.876	35	28	0.0
15.03.96	12:21	22.55.726	43.48.799	35	29	0.0
15.03.96	12:37	22.55.982	43.47.802	13	29.5	0.0
15.03.96	12:51	22.56.963	43.47.872	26	29.5	0.0
15.03.96	13:05	22.57.861	43.45.623	29	29.5	0.0
15.03.96	13:21	22.57.075	43.44.886	32	30	0.0
15.03.96	13:42	22.58.469	43.43.300	32	30	0.0
15.03.96	13:55	22.59.239	43.42.550	31	28.5	0.0
	12:20	22.56.867	43.52.350	31	29	4.3
05.03.96	14:46	22.58.575	43.53.808	31	26	18.3
05.03.96	16:25	22.59.385	43.54.602	31	26	4.6
06.03.96	14:07	23.00.580	43.56.145	33	28	14.6
06.03.96	15:08	23.00.239	43.56.627	31	27	0.0
06.03.96	16:33	23.01.231	43.56.822	31	-	0.0
07.03.96	10:24	22.57.334	43.51.784	25	29	16.8
07.03.96	10:51	22.57.175	43.51.977	25	---	0.0
14.06.96	14:06	22.57.611	43.49.807	34	26.5	0.0
14.06.96	14:36	22.56.428	43.50.501	34	26	8.5
14.06.96	14:50	22.57.949	43.49.945	34	26	8.0
14.06.96	14:59	22.59.373	43.49.655	35	26.5	9.0
14.06.96	15:17	22.58.127	43.50.055	34	26	-
14.06.96	15:37	23.00.838	43.49.476	31	26.8	9.0
14.06.96	15:44	22.55.599	43.48.844	16	29	-
14.06.96	15:47	22.55.899	43.48.905	7	28	-
14.06.96	15:51	22.56.360	43.49.024	26	28	-
14.06.96	17:02	22.56.537	43.47.876	6	29	-
14.06.96	17:10	22.57.129	43.47.995	24	29	-
14.06.96	17:21	22.56.265	43.47.962	5	26	-
15.03.96	14:41	23.00.079	43.42.740	28	27.5	-
15.03.96	14:47	22.59.109	43.42.530	30	28	-

Appendix 4. Surface salinity (PSU), temperature and depth values at different sites in Sepetiba bay.

Date	Time	latitude	longitude	surface salinity PSU	Surface Temperature °C	Depth m
15.03.96	14:52	22.59.471	43.42.635	30	28	-
15.03.96	15:03	22.58.976	43.44.059	29	28	-
15.03.96	15:11	22.57.784	43.43.908	29	29	-
15.03.96	15:21	22.58.278	43.43.953	30	28.5	-
15.03.96	15:33	22.57.180	43.44.839	28	29	-
15.03.96	15:42	22.57.937	43.45.117	29	28	-
15.03.96	15:50	22.57.413	43.44.990	29	28	-
30.01.97	15.2	23.01.639	43.37.013	33	30	-
30.01.97	16.1	23.01.700	43.37.399	35	29	-
30.01.97	16.5	23.01.611	43.37.682	34	25.5	-
30.01.97	16.5	23.01.225	43.37.585	34	29.5	-
30.01.97	17.2	23.01.577	43.37.798	34	29	-
30.01.97	17.2	23.01.151	43.37.637	34	29.5	-
31.01.97	10.2	22.59.825	43.55.209	14	31	-
31.01.97	10.4	23.00.329	43.54.591	10	33	-

Appendix 5. Heavy metal content of sediments in Sepetiba Bay. Capes/BC samples were analysed at Institute of Aquaculture, Stirling University. All other samples were analysed by CPRM - Rio de Janeiro.

Field Trip ID	Date	Waypoint	Coordinates		Sample number	Metal content in sediments (ppm)											
			latitude	longitude		Cu	Pb	Zn	Ag	Co	Ni	Cr	Cd	Fe	Mn	Mo	V
Capes/BC	30.08.98	-	22°56'21"	43°47'58"	S1	32	29	894	-	-	-	87	11	-	450	-	-
Capes/BC	30.08.98	-	22°57'54"	43°48'00"	S2	32	44	578	-	-	-	87	22	-	413	-	-
Capes/BC	30.08.98	-	22°57'47"	43°48'58"	S3	83	1.0	107	-	-	-	5	2	-	135	-	-
Capes/BC	30.08.98	-	22°58'34"	43°50'00"	S4	100	15	788	-	-	-	102	9	-	328	-	-
Capes/BC	30.08.98	-	NA	NA	S5	77	1.3	460	-	-	-	53	5	-	408	-	-
Capes/BC	30.08.98	-	NA	NA	S6	0	2.1	280	-	-	-	65	4	-	465	-	-
Capes/BC	30.08.98	-	22°58'48"	43°46'24"	S9	18	1.1	1450	-	-	-	202	18	-	406	-	-
A	30.01.97	97	23.01.909	43.41.919	1	4	4	110	N(0.2)	1	1	8	0.8	0.4	42	N(2)	8
A	30.01.97	43	23.01.128	43.36.980	2	10	18	160	N(0.2)	7	9	34	14	2.65	800	N(2)	32
A	30.01.97	73	23.01.484	43.38.008	3	16	24	660	N(0.2)	8	12	52	5.6	3.2	700	N(2)	36
A	30.01.97	44	23.01.700	43.37.399	4	14	24	420	N(0.2)	8	12	50	3.4	2.9	480	L(2)	32
A	30.01.97	128	23.01.854	43.54.927	5	3	6	152	N(0.2)	2	2	10	1.4	0.74	285	N(2)	8
A	30.01.97	81	23.01.931	43.39.366	6	9	16	345	N(0.2)	6	10	38	1.2	2.8	335	L(2)	28
A	30.01.97	104	23.02.557	43.43.047	7	8	14	550	N(0.2)	5	8	30	6.4	1.9	215	N(2)	20
A	30.01.97	131	22.57.302	43.54.877	9	7	12	325	N(0.2)	5	7	30	12	2.05	300	N(2)	24
A	30.01.97	113	23.00.329	43.54.591	10	3	4	154	N(0.2)	2	3	14	2.4	0.84	112	L(2)	12
A	30.01.97	130	23.00.048	43.57.005	11	3	6	94	N(0.2)	1	2	10	0.6	0.45	78	N(2)	8
A	30.01.97	106	22.59.825	43.55.209	14	8	14	500	N(0.2)	5	8	32	1.8	2.4	200	L(2)	16
B	13.02.96	JVA	22.54.800	43.50.600	-	23	16	210	N(0.2)	2	N(1)	6	0.2	1.72	126	N(2)	8
B	13.02.96	JVA	22.54.600	43.52.700	-	13	18	410	N(0.2)	8	9	38	1.4	2.75	240	L(2)	40
B	13.02.96	JVA	22.55.800	43.55.100	-	9	10	82	N(0.2)	8	10	44	0.2	2.45	260	L(2)	40
C	05.03.96	*	22.56.954	43.52.420	1	13	22	720	N(0.2)	6	11	55	2.8	3.65	250	N(2)	36
C	05.03.96	*	22.58.627	43.53.849	2	3	10	205	N(0.2)	2	2	16	0.4	1.02	100	N(2)	12
C	05.03.96	*	22.59.384	43.54.633	3	3	8	116	N(0.2)	1	1	14	0.6	0.82	82	N(2)	8
C	06.03.96	*	23.00.741	43.56.161	4	4	10	148	N(0.2)	3	3	22	1.2	1.24	138	N(2)	16
C	06.03.96	*	23.00.090	43.56.730	5	2	4	80	N(0.2)	2	1	9	0.6	0.4	42	N(2)	8
C	06.03.96	*	23.00.659	43.56.102	6	5	8	200	N(0.2)	1	1	14	0.8	0.72	300	N(2)	12
C	07.03.96	*	22.57.412	43.51.720	7	9	18	410	N(0.2)	4	5	35	1.8	1.35	162	N(2)	24
C	14.03.96	*	22.57.539	43.53.952	10	19	30	1060	N(0.2)	4	5	45	4.4	3	315	N(2)	44

Appendix 5. Heavy metal content of sediments in Sepetiba Bay. Capes/BC samples were analysed at Institute of Aquaculture, Stirling University. All other samples were analysed by CPRM - Rio de Janeiro.

Field Trip ID	Date	Waypoint	Coordinates		Sample number	Metal content in sediments (ppm)											
			latitude	longitude		Cu	Pb	Zn	Ag	Co	Ni	Cr	Cd	Fe	Mn	Mo	V
C	14.03.96	*	22.55.599	43.48.844	11	18	34	425	N(0.2)	8	13	64	5.2	4	540	N(2)	40
C	14.03.96	*	22.56.271	43.47.791	12	13	26	820	N(0.2)	5	10	51	4.2	3.15	205	N(2)	32
C	15.03.96	50	22.55.922	43.51.053	13	14	28	1160	N(0.2)	6	10	50	4.8	2.45	250	N(2)	32
C	15.03.96	51	22.56.216	43.50.405	14	12	22	335	N(0.2)	7	11	54	1	3	230	N(2)	32
C	15.03.96	52	22.56.089	43.49.876	15	12	40	700	N(0.2)	5	6	43	7.6	3.05	146	N(2)	36
C	15.03.96	53	22.56.726	43.48.799	16	12	24	1200	N(0.2)	7	7	60	3.2	2.5	255	N(2)	32
C	15.03.96	54	22.55.982	43.47.802	17	19	42	1000	N(0.2)	6	12	63	5.6	3.4	164	N(2)	48
C	15.03.96	55	22.56.863	43.47.872	18	19	40	1260	N(0.2)	6	12	64	6.8	4	250	N(2)	40
C	15.03.96	56	22.58.469	43.43.300	21	17	28	124	N(0.2)	8	14	57	0.4	4.4	960	N(2)	52
C	15.03.96	59	22.59.239	43.42.550	22	17	28	124	N(0.2)	8	14	57	0.4	4.4	960	N(2)	52
D	13.02.96	JVA	22.54.80	43.50.60	-	5	6	40	N(0.2)	3	2	14	0.2	0.78	90	2	20
D	13.02.96	JVA	22.54.60	43.52.70	-	6	10	75	N(0.2)	2	3	20	0.2	1.08	114	2	12
D	13.02.96	JVA	22.55.80	43.55.10	-	5	4	7	N(0.2)	1	1	5	0.2	0.14	20	2	10
E	02.07.96	*	22°57'611"	43.49.807	1	9	18	600	N(0.2)	4	13	40	2.8	2.5	235	2	16
E	02.07.96	*	22°56'428"	43.50.501	2	11	20	840	N(0.2)	4	11	50	3.2	2.95	285	2	24
E	02.07.96	*	22°59'373"	43.49.655	3	6	12	400	N(0.2)	3	7	28	1.6	1.9	190	L 2	16
E	02.07.96	*	23°00'838"	43.49.476	4	4	10	210	N(0.2)	2	6	24	1	1.75	146	L 2	16

Appendix 6. List of sites visited in the Sepetiba bay catchment area and notes as to type of land cover for ground truthing part of GIS study.

Date	Position		Site	ID	Description
	longitude	latitude			
10.01.97	43.54.438	22.55.658	Itacuruçá	1	Sandy beach, in Itacuruçá, front of Universidade Federal do Rio de Janeiro lab. Buildings with concrete/asbestos roofing. Urban area, red tiled roofs, cobblestone road 10 m wide and sandy beach just after. Reflective.
10.01.97	43.54.430	22.55.572	Itacuruçá	2	Tile roofs, concrete, road. Some vegetation between houses.
10.01.97	43.54.405	22.55.326	Itacuruçá	3	Outskirts of Itacurucá, housing less dense, and smaller houses.
10.01.97	43.54.156	22.55.198	Itacuruçá	4	Local plants include marsh types such as Typhas, taboas, Vassouras, lírio do brejo and Cyperaceae, 20m alt., Soil sample number 1 taken. Area adjacent to the sea, probably was cleared and leveled.
10.01.97	43.54.174	22.54.973	Itacuruçá	5	Grassland composed of Capim grodura, capim colonião, Panicum spp, pasto limpo. Grass replanted hillsides for protection againts rainfall erosion, Poor growth, just above main coastal road BR101 between Rio and Santos.
10.01.97	43.53.478	22.54.291	Itacuruçá	6	Recently severely denuded area during 1996 torrential rains. Exposed rocky area. about 40 m altitude, very close to BR101. Same place where all the Macumba offerings are placed to the waterfall deity of afro-brazilian religion.
10.01.97	43.53.461	22.54.240	Itacuruçá	7	Same site as above, 50m altitude. Pyrite, sand and gravel large boulders of gneiss = 60% rock and = 5% water coverage. About 100 m or more of exposed rock in the middle of Atlantic rainforest.
10.01.97	43.51.871	22.54.123	Coroa Grande	8	Downtown Coroa Grande in front of railway line and station. Point represents coverage which includes cobblestone road, rail tracks at about 50% and grass, trees and houses = 50%.
10.01.97	43.49.406	22.53.478		9	Railroad rossing on tarmac road to Ilha da Madeira, at junction where police station is located. Wide strip of tarmac & railroad. Roadside are several heactares of cleared land with poorly developed grassland cover, with many patches of exposed reddish soil. Waterlogged soils from road side to the mangrove fringe.
10.01.97	43.49.477	22.54.179		10	Same general area as above, on Ilha da Madeira proper. Flat vegetation cleared areas, with exposed rusty coloured soils and poorly developed grassland just on the inside of the Port of Sepetiba entrance gates.

Appendix 6. List of sites visited in the Sepetiba bay catchment area and notes as to type of land cover for ground truthing part of GIS study.

Date	Position		Site	ID	Description
	longitude	latitude			
10.01.97	43.48.027	22.52.486	Itaguaí	11	Outskirts of Itaguaí, suburban type of coverage. Scattered tree cover, grassland, scattered houses, lots of houses under construction, some barren land.
10.01.97	43.47.989	22.52.429	Itaguaí	12	Road crossing at town of Itauguaí, about 250 m, south of the main highway crossing – low buildings. Bearing on the road.
10.01.97	43.46.471	22.52.293	Itaguaí	13	Down town Itaguaí, highly urbanized area. Point represents coverage >90% tarmac, several story buildings, dense urbanisation.
10.01.97	43.46.696	22.52.226	Itaguaí	14	Downtown Itaguaí, 95% buildings, tarmac roads and multi-story buildings. (15 on fig 5.49)
10.01.97	43.44.961	22.51.986		15	Proper farm pastures, well developed grassland. (14 on fig 5.49)
10.01.97	43.44.550	22.52.244	Itaguaí	16	Coconut plantation, 32.000 m2. 9 year old coconut trees spaced in 8 x 8m arrangement, on the margin of the Valão dos Bois river. About 4.000 cocunut trees. Low lying area, which has suffered flooding. (14 on fig 5.49)
12.01.97	43.40.307	22.48.524	Itaguaí	17	Reta de Piranema locale, with continous Eucalyptus tree plantation.
12.01.97	43.40.552	22.49.256	Itaguaí	18	Sand extraction sites in Piranema. Mounds of sand and pits with water collected from rain and phreatic layer.
12.01.97	43.43.213	22.43.525	Seropédica	19	Well developed pastures, farm grasslands to north and eastof this point. This is a small road by the old colonial farmhouse on the outskirts of Seropedica town, on the right side of the road going towards Itaguaí.
12.01.97	43.42.217	22.44.574	Seropédica	20	Newly laid tarmac, suburban housing type, downdown urban with lots of concrete.
12.01.97	43.41.839	22.45.062	Seropédica	21	Over 50% eucalyptus cover, very close to Federal University of Rio, (UFRRJ.)
12.01.97	43.41.425	22.45.369	Seropédica	22	End of eucalyptus plantation, just before beginning of (UFRRJ) campus, by the tarmac on the road to Itaguaí.
12.01.97	43.41.641	22.45.814	Seropédica	23	At the mango tree grove by the Dean's house at UFRRJ campus.
12.01.97	43.39.169	22.47.293	Seropédica	24	Large eucalyptus forest stand from the road to the west.

Appendix 6. List of sites visited in the Sepetiba bay catchment area and notes as to type of land cover for ground truthing part of GIS study.

Date	Position		Site	ID	Description
	longitude	latitude			
	43.44.662	22.53.913	Santa Cruz Industrial (SCIP)	25	Chemical industry - ACI Química. Mostly barren land, with poor vegetation growth, cut by drainage ditches. This area contains several industries and lies not far from the thermoelectric power plant on the shores of Sepetiba.
	43.44.162	22.53.551	(SCIP)	26	Chemical industry – BASF
	43.44.506	22.53.252	(SCIP)	27	Mint house - Casa da Moeda
	43.44.206	22.53.204	(SCIP)	28	Chemical industry – Cia. Panamericana manufacture of caustic soda hydrocloric acid, bleach, potash, carbonate, Chromium basic solution.
	43.44.502	22.52.874	(SCIP)	29	Chemical industry – Reynolds Latasa aluminium cans
	43.44.100	22.53.166	(SCIP)	30	Ecolab Anticorrosives, paint removers, lubrificantes.
	43.44.185	22.53.002	(SCIP)	31	Thermal isolation products – ceramic fibre Morganite Isol. Term.
	43.43.910	22.53.292	(SCIP)	32	Catalyser manufacturer Oxiteno & Fábrica Brasileira de Catalizadores
	43.49.747	22.55.003	Ilha da Madeira	33	Zinc ingot plant Ingá. Same site holds two cylindrical alumina depots for the port of Sepetiba.
	43.34.921	22.59.961	Guaratiba	34	Government Food research institute (Embrapa) lies in tens of hectares of Salicornia maritima fields close to salt barrens and mangrove fring area. (saltmarshes 18 on fig 5.49)
	43.35.387	22.59.843	Guaratiba	35	Aquaculture research station – produces oyster spat and has produced P. paulensis post larvae. Fiperj. Lies adjacent to EMBRAPA, in Salicornia maritima fields. Has a few fish ponds by road side.Also has a feeder canal that goes to the Guaratiba mangrove area. (19 on fig 5.49)
	43.50.993	22.55.225	Ilha da Madeira	36	Arinaldo's (the fisherman) house. Same place where most shrimp trawlers port. A few houses, dirt road and thick forest.

Appendix 7. Fish species commonly found in Sepetiba Bay (Andreata, 1997).

Family	Species
Ariidae	*Genidens genidens; Bagre marinus; Sciadeichthys luniscutis; Arius spixii*
Atherinidae	*Xenomelaniris brasiliensis*
Belonidae	*Strongylura timucu; Strongylura marina*
Bothidae	*Citharichthys spilopterus; Citharichthys arenaceus; Etropus crossotus; Etropus intermedius; Syacium micrurum; Syacium papillossum*
Carangidae	*Trachinotus falcatus; Trachinotus goodei; Trachinotus carolinus; Oligoplites saurus; Oligoplites saliens; Uraspis secunda; Selene setapinnis; Chloroscombrus chrysurus; Caranx crysas; Pseudocaranx dentex; Selene vomer; Selene spixii; Hemicaranx amblyrhynchus*
Centropomidae	*Centropomus parallelus; Centropomus undecimalis*
Clupeidae	*Pellona harroweri; Harengula clupeola*
Cynoglossidae	*Synphurus plagusia; Symphurus tesselatus*
Dasyatidae	*Dasyatis guttata; Dasyatis centroura; Gymnura altavela*
Diodontidae	*Chilomycterus spinosus; Chilomycterus schoepfi*
Engraulididae	*Anchoa tricolor; Anchoa januaria; Anchoa spinifera; Anchoa cubana; Anchoviella lepidentostole; Cetengraulis edentulus; Engraulis anchoita*
Ephippididae	*Chaetodipterus faber*
Gerreidae	*Diapterus rhombeus; Diapterus richii; Gerres aprion; Gerres lefroyi; Gerres gula; Gerres melanopterus;*
Gobiidae	*Gobionellus oceanicus; Gobionellus beleosoma; Gobionellus stigmaticus; Microgobius meeki; Awaous tajasica; Bathigobius soporator*
Haemulidae	*Conodon nobilis; Haemulon steidachneri; Pomadasys corvinaeformis*
Mugilidae	*Mugil liza; Mugil curema; Mugil* sp.
Muraenidae	*Lycodontis ocelatus*
Narcinidae	*Narcine brasiliensis*
Pomatomidae	*Pomatomus saltator*
Rajidae	*Psammobatis* sp.*; Raja castelnaui; Raja agassizi*
Rhinobatidae	*Rhinobatos horkeli*
Sciaenidae	*Isopisthus parvipinnis; Cynoscion leiarchus; Paralonchurus brasiliensis; Larimus breviceps; Menticirrhus americanus; Macrodon oncilidon; Pogonias cromis; Stellifer rastrifer; Stellifer brasiliensis; Stellifer stellifer; Ctenosciaena gracilicirrhus; Micropogonias furnieri; Cynoscion striatus; Cynoscion virescens; Umbrina coroides; Cynoscion microlepidotus*
Serranidae	*Diplectrum radiale; Dules auriga; Diplectrum radiale*
Soleidae	*Achirus lineatus; Achirus fasciatus; Trinectes maculatus paulistanus*
Squalidae	*Squalus cubensis*
Stromateidae	*Peprilus paru*
Syngnathidae	*Syngnathus dunckeri; Syngnathus pelagicus; Syngnathus rousseau; Hippocampus reidi; Oostethus lineatus*
Synodontidae	*Synodus foctens*
Tetraodontidae	*Sphoeroides testudineus; Sphoeroides spengleri; Sphoeroides nephelus; Sphoeroides adpersus; Lagocephalus laevigatus*
Triglidae	*Prionotus punctatus*
Trichiuridae	*Trichiurus lepturus*

Appendix 8. IDRISI macro file for sheltered area identification for mussels and oysters sub-model.

REM PHYSICAL FACTORS SUB-MODEL

rem SHELTER SUB-MODEL

rem SOUTHWEST WINDS FETCH SURFACE GENERATING MACRO
rem First, we need to create a magnitude force image with a value
rem (mag1) of one, over the whole area.
rem initial x mag1 3 1 1 1 bayneg m magnitude force 1
rem Second we need to create a direction image (aspsw)
rem 45 degrees direction i.e. an angle of 45 degrees
rem = direction the SW winds blow towards the NE
rem initial x ASPSW 2 1 45 1 bayneg m southwest winds
rem Third, values are dispersed using the bayneg source
rem image for a distance of 1230 pixels creating an image tmp001
rem disperse x LANDLINE mag1 aspsw 1230 none tmpSW1 1 100
rem next overlay is to eliminate all values outside study area
rem overlay x 3 tmpSW1 baypos tmpSW2
rem this scalar to put values in metres by multiply
rem ing the pixel x 30 (pixel size in landsat)
rem scalar x tmpSW2 SWFETCH 3 30
rem this reclass classifies the bay into 3 ranges
rem of fetch distances 1-5000m, 5000-1000m and over 15000m
rem reclass x i tmpSW3 FETCHSW 2 5000 1 5000 10000 5001 10000 10000
10001 15000 15000 15001 99000 -9999
rem maint x 1 tmpS*
rem NORTHWEST WINDS FETCH SURFACE GENERATING MACRO
rem First, we need to create a magnitude force image with a value
rem (MAG1) of one, over the whole area.
rem initial x mag1 3 1 1 1 bayneg m magnitude force 1
rem Second we need to create a direction image (ASPNW)
rem 135 degrees direction i.e. an angle of 135 degrees
rem = direction the NW winds blow towards the SE
rem initial x ASPNW 2 1 135 1 bayneg m Northwest Winds
rem Third, values are dispersed using the bayneg source
rem image for a distance of 1230 pixels creating an image tmp001
rem disperse x LANDLINE mag1 ASPNW 1230 none tmpNW1 1 100
rem next overlay is to eliminate all values outside study area
rem overlay x 3 tmpNW1 baypos tmpNW2
rem this scalar to put values in metres by multiply
rem ing the pixel x 30 (pixel size in landsat)
rem scalar x tmpNW2 NWFETCH 3 30
rem this reclass classifies the bay into 3 ranges
rem of fetch distances 1-5000m, 5000-1000m and over 15000m
rem reclass x i tmpNW3 FETCHNW 2 5000 1 5000 10000 5000 10000 10000
10000 15000 15000 15000 99000 -9999
rem maint x 1 1 tmpn*
rem SUBTRACTION PROBLEM
rem to create a subtraction image for disperse image from the bayline
rem to create a direction image 225 degrees direction

Appendix 8. IDRISI macro file for sheltered area identification for mussels and oysters sub-model.

rem i.e. an angle of 225 degrees = direction of the
rem ne winds blowing
rem initial x ASPNE 2 1 225 1 bayneg m northeast winds
rem disperse x bayneg mag1 ASPNE 1230 none tmpne 1 100
rem this scalar to put values in metres
rem scalar x tmpne tmpne2 3 30
rem scalar x tmpne2 tmpne3 2 36900
rem scalar x tmpne3 tmpne4 3 -1
rem this reclass to classify bay into 3 ranges of fetch distances
1-5000m, 5000-1000m and over 15000m
rem reclass x i tmpne2 tmpne3 2 5000 1 5000 10000 5001 10000 10000 10001
15000 15000 15001 99000 -9999
rem disperse x tmpbay5 mag1 aspne 1230 none tmpne 1 100
rem disperse x bayline mag1 aspsw 1230 none tmpbay1 1 100
rem scalar x tmpbay1 tmpbay2 3 30
rem overlay x 3 tmpbay2 baypos tmpbay3
rem reclass x i tmpbay3 tmpbay4 2 1 1 99999 0 -30 0 -9999
rem reclass x i tmpbay4 tmpbay5 2 1 0 1 0 1 2 -9999
rem overlay x 3 tmpbay4 tmpne tmpbay6
rem overlay x 3 tmpbay2 tmpbay4 tmpbay7
rem initial x aspsw 2 1 315 1 land m southwest winds
rem disperse x land mag1 aspsw 1230 none tmp005 1 100
REM WAVE SURFACE GENERATING SUB-MODEL
rem Wave height surface generating macro, based on depth, windspeed, and
fetch images this batch file for wind from NW direction
rem speed image must enter as square of m/s value
rem scalar x DEPTHS tmpw1 3 9.8
rem overlay x 4 tmpw1 SPEED4 tmpw2
rem scalar x tmpw2 tmpw3 5 0.75
rem scalar x tmpw3 tmpw4 3 0.53
rem overlay x 4 FETCHNW SPEED4 tmpw5
rem scalar x tmpw5 tmpw6 3 9.8
rem scalar x tmpw6 tmpw61 5 0.5
rem scalar x tmpw61 tmpw62 3 0.00565
rem scalar x tmpw4 tmpw7 3 -1
rem transfor x tmpw7 tmpw8 3
rem transfor x tmpw4 tmpw9 3
rem overlay x 1 tmpw9 tmpw8 tmpw10
rem overlay x 2 tmpw9 tmpw8 tmpw11
rem overlay x 4 tmpw11 tmpw10 tmpw12
rem overlay x 4 tmpw62 tmpw12 tmpw13
rem scalar x tmpw13 tmpw14 3 -1
rem transfor x tmpw14 tmpw15 3
rem transfor x tmpw13 tmpw16 3
rem overlay x 1 tmpw16 tmpw15 tmpw17
rem overlay x 2 tmpw16 tmpw15 tmpw18
rem overlay x 4 tmpw18 tmpw17 tmpw19
rem overlay x 3 tmpw12 tmpw19 tmpw20
rem scalar x tmpw20 tmpw21 3 0.283

Appendix 8. IDRISI macro file for sheltered area identification for mussels and oysters sub-model.

```
rem overlay x 3 SPEED4 tmpw21 tmpw22
rem scalar x tmpw22 WAVENW 4 9.8
rem Wave class reclass to areas safe from high waves
rem reclass x i WAVENW NW 2 4 0.01 .20 3 .20 .35 2 .35 .50 1 .50 1.0
-9999
rem maint x 1 1 tmpW*
rem SW wind wave height generating macro, based on depth-windspeed-fetch
images
rem This file for wind from SW
rem SPEED image must enter as square of m/s value
rem scalar x DEPTHS tmpx1 3 9.8
rem overlay x 4 tmpx1 speed3 tmpx2
rem scalar x tmpx2 tmpx3 5 0.75
rem scalar x tmpx3 tmpx4 3 0.53
rem overlay x 4 FETCHSW speed3 tmpx5
rem scalar x tmpx5 tmpx6 3 9.8
rem scalar x tmpx6 tmpx61 5 0.5
rem scalar x tmpx61 tmpx62 3 0.00565
rem scalar x tmpx4 tmpx7 3 -1
rem transfor x tmpx7 tmpx8 3
rem transfor x tmpx4 tmpx9 3
rem overlay x 1 tmpx9 tmpx8 tmpx10
rem overlay x 2 tmpx9 tmpx8 tmpx11
rem overlay x 4 tmpx11 tmpx10 tmpx12
rem overlay x 4 tmpx62 tmpx12 tmpx13
rem Scalar x tmpx13 tmpx14 3 -1
rem transfor x tmpx14 tmpx15 3
rem transfor x tmpx13 tmpx16 3
rem overlay x 1 tmpx16 tmpx15 tmpx17
rem overlay x 2 tmpx16 tmpx15 tmpx18
rem overlay x 4 tmpx18 tmpx17 tmpx19
rem overlay x 3 tmpx12 tmpx19 tmpx20
rem scalar x tmpx20 tmpx21 3 0.283
rem overlay x 3 SPEED3 tmpx21 tmpx22
rem scalar x tmpx22 WAVESW 4 9.8
rem Wave class reclass to areas safe from high waves
rem rem reclass WAVESW SW (4) 0.01 .20 (3) .20 .35 (2) .35 .50 (1) .50
1.0 -9999
rem reclass x i WAVESW SW 2 4 0.01 .20 3 .20 .35 2 .35 .50 1 .50 1.0
-9999
rem maint x 1 1 tmpX*
REM SUB-MODEL PROTECTED FROM WAVES from NW and SW quarters =
WAVEOK
rem overlay x 8 SW NW WAVEOK
rem reclass x i waveok wavedis 2 1 4 6 2 3 4 3 2 3 4 1 2 -9999
rem map and bmp file = wavedis
```

Appendix 9. Questionnaire respondents and training level.

Participant		Training/ level of qualification.
1	A. D.	Biologist, MSc student
2	A.d M.	Oceanographer, Fisheries officer
3	J. V. A.	Icthyologist, lecturer
4	C.M. T.	Biologist, MSc student
5	C.P.S.	Marine Parasitologist, lecturer
6	C.G. da F.	Biologist, MSc. Student
7	E.C.	Architect, lecturer
8	E.A	Benthic researcher, lecturer
9	J. L. C.	Economist, lecturer
10	J. C. M.	Biologist, fisheries officer
11	J. F.	Engineer, Hydrologist - lecturer
12	L. J.	Sanitary Engineer, lecturer
13	L. L.	Urban Planner, lecturer
14	G. S.	Biologist, producer
15	M. C.	Fisheries Engineer, aquaculture consultant
16	M. L.	Economist, lecturer
17	L. F. V.	Biologist, MSc. Student
18	S. P. R.	Animal Husbandry, aquaculture consultant
19	Y. W.	Benthic researcher, lecturer

Appendix 10. Constraints and production factors identified by respondents in questionnaire.

Identified factor	Reclassification status	n
1 agriculture density	Constraint	1
2 Area available	Constraint	1
3 conflicts, other uses of area	Constraint	4
4 conflicts, traditional fishermen	Constraint	1
5 conservation areas	Constraint	1
6 credit lines	Constraint	1
7 hydrographic basin	Constraint	1
8 Industrial density	Constraint	1
9 Legislation	Constraint	4
10 marine mammal routes	Constraint	1
11 Navigation	Constraint	1
12 Pollution, general	Constraint	7
13 pollution, heavy metals	Constraint	3
14 pollution, industrial	Constraint	3
15 pollution, pesticides	Constraint	1
16 pollution, sewage	Constraint	4
17 sediment quality	Constraint	3
18 Communications	Infra	1
19 Depuration facilities	Infra	1
20 distance, to roads	Infra	4
21 distance, to suppliers	Infra	3
22 electric power	Infra	2
23 extension/technical support	Infra	4
24 Fishermen organization	Infra	1
25 Infra-structure, general	Infra	2
26 labour availability	Infra	3
27 labour, trained	Infra	4
28 research, insufficient	Infra	1
29 security (theft)	Infra	1
30 seed availability	Infra	5
31 species selection & know-how	Infra	4
32 tradition, fishermen, aquaculture	Infra	2
33 Transportation	Infra	1
34 distance, from land	Market	4
35 distance, to consumers	Market	7
36 market, fish consumption	Market	1
37 market, general	Market	1
38 market, Income per capita	Market	1
39 market, product acceptance	Market	4
40 Market, product price	Market	2
41 Population density	Market	1
42 investment costs	Not applicable	4
43 macroalgae presence	Not applicable	1
44 Parasites	Not applicable	2
45 Political will power	Not applicable	1
46 Species, competitors	Not applicable	2
47 Climate	Physical	4
48 coastline contour	Physical	1

Appendix 10. Constraints and production factors identified by respondents in questionnaire.

Identified factor	Reclassification status	n
49 Predators	Physical	2
50 Production, "natural" capacity	Physical	4
51 Rainfall	Physical	3
52 Relief	Physical	1
53 Shelter	Physical	1
54 Tides	Physical	1
55 Water - Depth	Physical	4
56 Water, currents	Physical	6
57 Waves	Physical	3
58 Winds	Physical	2
59 land drainage	Water Q	1
60 Organic matter	Water Q	1
61 Red tides	Water Q	1
62 Water – DO	Water Q	5
63 Water - E. coli	Water Q	3
64 Water – Nutrients	Water Q	6
65 Water - pH	Water Q	3
67 Water – Phytoplankton	Water Q	6
68 Water – Quality general	Water Q	2
69 Water – Salinity	Water Q	10
70 Water – Temperature	Water Q	10
71 Water – Turbidity	Water Q	7
Total		195

Appendix 11. Idrisi Macro file for white shrimp site suitability model.

```
rem rem ********************************SHRIMP MODEL
rem rem INFRASTRUCTURE SUBMODEL
rem TECHNICAL SUPPORT
REM     distance from Fiperj Lab
rem distance x fiperj tmp001
rem scalar x tmp001 tmp002 3 30
rem overlay x 3 land tmp002 tmp003
rem categories are best (4) up to 5km from lab
rem rem (3) from 5 - 10km, (2) from 10-200km
rem(1)over 200km.
rem reclass x i tmp003 tmp004 2 4 0 5000 3 5000 30000 2 30000 200000 1 200000 999000 -9999
rem overlay x 3 land tmp004 STECDIS
rem rem access ************ROADS AND INFRASTRUCTURE sub-model
rem rem make distance from road network,then multiply by 30 to get meters (from pixels)
rem distance x ROADs tmp005
rem scalar x tmp005 tmp006 3 30
rem rem categories are best (4) up to 2km from a road,
rem (3) from 2-5km, (2) from 5-10km (1)over 10km.
rem reclass x i tmp007 tmp008 2 4 0 2000 3 2000 5000 2 5000 10000 1 10000 99999 -9999
rem overlay with Land image to get rid of values
rem over the bayarea
rem overlay x 3 LAND tmp008 SROADIS
rem maint x 1 1 tmp*
REM******Distance from existing AGricultural activities (cocounut/and other farms)
rem distance x farms tmp001
rem scalar x tmp001 tmp002 3 30
rem overlay x 3 land tmp002 tmp003
rem rem categories are best (4) up to 0.5km from farms
rem rem (1) over 0.5km.
rem reclass x i tmp003 tmp004 2 4 0 500 1 500 999000 -9999
rem overlay x 3 land tmp004 FARMDIS
rem Oyster seed submodel
rem distance from fiperj lab
rem distance module used, then scalar to multiply distance in pixels by 30 m
rem distance x fiperj tmp001
rem scalar x tmp001 tmp002 3 30
rem (4) 0-5km (3) 5km a 70 (2) 10km - 100 (1) >100km
rem reclass x i tmp002 tmp003 2 4 0 15000 3 15000 60000 2 60000 140000 1 100000 1000000 -
9999
rem overlay x 3 land tmp003 LABDIS
rem maint x 1 1 tmp*
rem ***********MCE *********************
rem infrastructure MCE....
rem mce x mcesinf sinfra
rem **********************PHYSICAL FACTORS SUBMODEL
rem rem **************************COASTLINE DISTANCE
rem rem make distance from coastline inland
rem ,then multiply by 30 to get meters (from pixels)
rem distance x coastl tmp001
rem scalar x tmp001 tmp002 3 30
rem overlay x 3 land tmp002 tmp003
rem rem categories are best (4) up to 0.5km from the coasltine,
rem (3) from 0.5 - 1km, (2) from 1-2km
```

Appendix 11. Idrisi Macro file for white shrimp site suitability model.

rem(1)over 15km.
rem reclass x i tmp003 tmp004 2 4 0 1000 3 1000 2500 2 2500 7000 0 7000 99000 -9999
rem overlay x 3 land tmp004 SCOAST
rem reclass x i tmp003 tmp005 2 0 0 7000 1 7000 99000 -9999
rem overlay x 3 land tmp005 BEYOND7
rem maint x 1 1 tmp*
rem rem **************************FRESHWATER SOURCES
rem distance x brivers tmp001
rem scalar x tmp001 tmp002 3 30
rem overlay x 3 land tmp002 tmp003
rem rem categories are best from the fresh water
rem source (4) up to 0.5km rem (3) from 0.5 - 1km,
rem (2) from 1-1.5km (1)over 1.5km.
rem reclass x i tmp003 tmp004 2 4 0 500 3 500 1000 2 1000 1500 1 1500 99000 -9999
rem overlay x 3 land tmp004 SRIVERS
rem rem **SOILS
rem soil types
rem unclassified = 0
rem red yellow latosols = 1
rem red yellow podsols = 2
rem cambisols = 3
rem Gley = 4
rem Gley - timorphic = 5
rem planosols = 6
rem aluvial soils = 7
rem marine quartz = 8
rem urban areas = 9
rem file = SSOLOS is already reclassified for shrimp farming
rem solos60 is based on sema map then reclassified as
rem red yellow latossols = 2
rem re yellow podsols = 3
rem cambisols = 1
rem gley = 4
rem gley tiomorphic = 3
rem planosols = 3
rem aluvial soils = 1
rem marine quartz = 1
rem urban areas = 1
rem reclass x i solos60 tmp001 3 solosok -9999
rem overlay x 3 land tmp001 SOILSOK
rem Vegetation and Land use..
rem forests = 1
rem grasslands = 4
rem mangroves = 4
rem restinga = 1
rem waterlogged soils = 3
rem agriculture = 4
rem urban = 1
rem reclass x i veget tmp001 3 vegeok -9999
rem overlay x 3 land tmp001 VEGEOK
rem mce x mcesphy ssphys
rem rem **************************NATURAL INDICATORS
rem RAINFALL
rem 1000- 1200 mm - 4

Appendix 11. Idrisi Macro file for white shrimp site suitability model.

```
rem  1200 - 1600 mm - 3
rem  1600 - 2000 mm - 2
rem  < 1000 mm     - 1
rem  > 2000 mm     - 1
rem reclass x i rainfal srainfal 2 4 2 3 3 3 5 2 5 7 1 7 9 1 1 2 -9999
rem AIR TEMPERATURE
rem climate2
rem stempe file is temerature over sepetiba (fig2.4)
rem temp ranges
rem > 24.        = 4
rem  23.5 - 24   = 3
rem  21.5 - 23.5 = 2
rem  < 21.5      = 1
rem reclass x i stempe STEMPE2 2 4 1 2 3 2 3 2 3 5 1 5 9 -9999
rem KOPPEN CLIMATE
rem climate as in Koppens Climate classification
rem file koppen shows 3 climate regions
rem see explanation in database building
rem koppen7 is reclassified into SKOPPEN
rem MANGROVE BUFFER
rem distance x manpos tmp092
rem scalar x tmp092 tmp093 3 30
rem overlay x 3 land tmp093 tmp094
rem rem categories are best from the mangrove proximity
rem source (4) up to 0.7km rem (3) from 0.7 - 2.1km,
rem (2) from 2.1- 3.5km (1) over 3.5km.
rem reclass x i tmp094 tmp095 2 4 0 700 3 700 1400 2 1400 2100 1 2100 99000 -9999
rem overlay x 3 land tmp095 tmp096
rem reclass x i manpos manneg 2 1 0 1 0 1 2 -9999
rem overlay multiply with negative image of mangrove tosubract mangrove areas from the buffer
rem overlay x 3 tmp096 manneg SMANBUF
REM mce x MCESNAT snatind
REM overlay x 7 mcesnat land MCESNAT2
REM ***********ACCESS TO MARKETS AND ROADS SUBMODEL
rem MARKET submodel
rem towns with more than 255-380k population= 4, 30-52k= 3, 3-9k= 2
rem group x towns y tmp021
rem reclass x i tmp021 tmp022 2 4 1 2 4 3 4 3 2 3 3 7 9 2 4 7 2 9 11 -9999
rem distance x tmp022 tmp023
rem distance is in pixels. multiply by 30 to get meters
rem scalar x tmp023 tmp024 3 30
rem town distances (4) 0-5 km  (3) 5- 7km (2) 7 - 10 (1) > 10
rem reclass x i tmp024 tmp025 2 4 0 5000 3 5000 7000 2 7000 10000 1 10000 99000 -9999
rem overlay x 3 land tmp025 SMKTDIS
rem**************************
rem *************************************PURCHASING POWER
rem first reclass so that town polygons reflect buying power
rem as individual class groups low,med,high.
rem reclass x i towns3 tmp023 2 4 1 3 4 12 13 4 14 15 4 11 12 3 4 5 3 9 11 3 13 14 2 8 9 -9999
rem reclass x i tmp023 buylow 2 1 2 3 0 3 6 -9999
rem reclass x i tmp023 buymed 2 1 3 4 0 1 3 0 4 5 -9999
rem reclass x i tmp023 buyhigh 2 1 4 5 0 1 4 -9999
rem for each class, create a distance from towns
rem and then reclass as (4) up to 7 km away
```

Appendix 11. Idrisi Macro file for white shrimp site suitability model.

```
rem from good (high) buying power, (3) 7 - 12 km
REM (2) 12-14 km and (1) > 14
rem Low Buying Power
rem distance x buylow tmp030
rem scalar x tmp030 tmp031 3 30
rem reclass x i tmp031 tmp032 2 4 0 7000 3 7000 12000 2 12000 14000 1 14000 999999 -9999
rem overlay x 3 LAND tmp032 tmp033
rem Medium Buying Power
rem distance x buymed tmp034
rem scalar x tmp034 tmp035 3 30
rem reclass x i tmp035 tmp036 2 4 0 7000 3 7000 12000 2 12000 14000 1 14000 999999 -9999
rem overlay x 3 LAND tmp036 tmp037
rem High Buying Power
rem distance x buyhigh tmp038
rem scalar x tmp038 tmp039 3 30
rem reclass x i tmp039 tmp040 2 4 0 7000 3 7000 12000 2 12000 14000 1 14000 999999 -9999
rem overlay x 3 LAND tmp040 tmp041
rem overlay add all these results and reclassify...
rem overlay x 1 tmp033 tmp037 tmp042
rem overlay x 1 tmp042 tmp041 tmp043
rem reclass so (4) 10-13  (3) 8-10 (2) 2-8
rem reclass x i tmp043 SBUYPWR 2 4 10 13 3 8 10 2 2 8 -9999
rem ******************************************
rem FISH OR SEAFOOD CONSUMPTION
rem seafood consumption
rem seafood consumption was based on a 16 kg/cap/year for coastal towns
rem and 8kg/cap year for towns more than 20 km away from the coast
rem coastal towns have higher seafood consumption
rem distance x COASTWN tmp001
rem scalar x tmp001 tmp002 3 30
rem categories are best (4) up to 5km from a coastal town
rem (3) from 5-7 km, (2) from 7-10km (1)over 10km.
rem reclass x i tmp002 tmp003 2 4 0 5000 3 5000 7000 2 7000 45000 1 10000 99000 -9999
rem overlay with Baypos image to get values over bay
rem overlay x 3 LAND tmp003 SFHIGH
rem inland towns have lower seafood consumption
rem distance x inldTWN tmp004
rem scalar x tmp004 tmp005 3 30
rem categories are best (4) up to 5km from a coastal town
rem (3) from 5-7 km, (2) from 7-10km (1)over 10km.
rem reclass x i tmp005 tmp006 2 4 0 7000 3 7000 14000 2 14000 45000 1 45000 99999 -9999
rem overlay with land image to get rid of values in the bay
rem overlay x 3 LAND tmp006 SFLOW

rem to take in account potentially strong areas of
rem seafood consumption i.e. coast side Restaurants
rem in the area, with a high buying power and consumption
rem distance x restos tmp001
rem scalar x tmp001 tmp002 3 30
rem reclass x i tmp002 tmp003 2 4 0 200 3 200 500 2 500 1000 1 1000 999999 -9999
rem overlay x 3 LAND tmp003 sresto1
rem overlay high and low areas with highest value maintenance
rem overlay x 9 sflow sfhigh sresto2
rem overlay x 1 sresto1 sresto2 sresto3
```

Appendix 11. Idrisi Macro file for white shrimp site suitability model.

```
rem reclass x i  sresto3 sresto4 2 4 7 9 3 5 7 2 4 5 1 1 4 -9999
rem mce x MCESMKT mcesmkt
rem rem ************************CONSTRAINTS
rem area in towns and buffer around them
rem distance x TOWNS tmp001
rem scalar x tmp001 tmp002 3 30
rem rem build a 1km buffer around towns
rem reclass x i tmp002 tmp003 2 1 0 1000 0 1000 99999 -9999
rem rem overlay with Land image to get rid of values
rem over the bayarea (Constraint towns)
rem overlay x 3 LAND tmp003 CONSTWN
rem mangrove areas
rem rem file MANPOS represents all mangrove areas=1
rem polluted areas
rem polluted areas around industries
rem distance x spollut tmp001
rem scalar x tmp001 tmp002 3 30
rem build a 0.5km buffer around polluted sites
rem reclass x i tmp002 tmp003 2 1 0 500 0 500 99999 -9999
rem overlay with Land image to get rid of values
rem over the bayarea ( shrimp pollution Constraint)
rem overlay x 3 LAND tmp003 CONSPOL
rem 30 meters from margins of rivers
rem distance x brivers tmp001
rem scalar x tmp001 tmp002 3 30
rem build a 30 m buffer around rivers
rem reclass x i tmp002 tmp003 2 1 0 30 0 30 99999 -9999
rem overlay with Land image to get rid of values
rem over the bayarea ( shrimp pollution Constraint)
rem overlay x 3 LAND tmp003 CONSRIV
rem all constraints (towns, polluted, mangroves,
rem conservation areas, river margins areas)
rem overlay x 1 CONSTWN MANPOS TMP001
rem Overlay x 1 TMP001 CONSPOL TMP002
rem overlay x 1 TMP002 CONSRIV TMP003
rem overlay x 1 TMP003 CONSGUA TMP004
rem overlay x 1 TMP004 MANPOS TMP005
rem overlay x 1 TMP005 CONSGUA TMP006
rem overlay x 1 TMP006 MARAMBA TMP007
rem overlay x 1 ISLANDS TMP007 TMP008
rem overlay x 1 BEYOND7 TMP008 TMP009
REM reclass x i tmp009 tmp010 2 1 1 6 -9999
rem reclass x i tmp010 SCONS 2 1 0 1 0 1 3 -9999
rem final mce
rem Mce x MCESFIN mcesfin
rem production potential study
rem group the areas
rem group x mcesfin Y slots
area x slots 1 2 shectres
```

Appendix 12. Idrisi Macro file for mussel site suitability model.

```
Rem WATER QUALITY SUBMODEL (for mussel) clorophyll parameters (4)=18>30 ug/l
Cl-a (3)=6-18 (2)=<6t
REM TEMPERATURE
rem temp ranges (4)=>25deg C (3)=<24-25
rem reclass x i TEMP tempoks 2 4 4 6 3 1 4 -9999
rem reclass x i tempoks temptxt 2 1 4 5 2 3 4 -9999
REM CHLOROPHYLL
rem reclass x i CLOROK clorokS 2 4 5 9 3 5 4 2 1 2 -9999
REM SALINITY
rem reclass SALINITY
rem salinity classes: (4)=14-28 (3)=28-32, 8-14 (2)= 32-34  (1)<8 >34
rem reclass x i SAL salokmu 2 4 7 12 3 6 7 2 4 6 1 1 4 -9999
rem reclass x i salokmu saltxtm 2 1 4 5 2 3 4 3 2 3 4 1 2 -9999
REM DISSOLVED OXYGEN
rem reclass DISSOLVED OXYGEN for mussel and oysters (4)=>5
rem reclass x i DO DOok 2 4 2 8 3 1 2 -9999
rem reclass x i dook dooktxt 2 1 4 5 2 3 4 3 2 3 4 1 2 -9999
REM CHLOROPHYL A
REM  this macro uses the algorithm
rem Cla = 0.060914 + 0.109172 TM2 + 0.214841 TM3
rem to extract clorophyl a values from coastal waters.
rem wind2 and wind3 image is bands 2 & 3 for the study region
rem scalar x wind2 tmp001 3 0.109172
rem scalar x wind3 tmp002 3 0.214841
rem overlay x 3 tmp001 tmp002 tmp003
rem scalar x tmp003 tmp004 1 0.060914
rem overlay x 3 tmp004 baypos tmp005
rem reclass x i tmp005 ClaTM 2 8 30 999 7 26 30 6 22 26 5 18 22 4 14 18 3 10 14 2 6 10 1 1
6 -9999
rem clatm is now overlaid so that the maximum values between this satelite derived
rem cla concentration image and the values found by FEEMA in the
rem ZEE study are maintained.
rem overlay x 9 clatm cloro ClaTM2
rem Now the Clatm2 image is reclassified in function of
rem aquaculture interest. higest score (4) to concentration of
rem 18-30 ug/l, score 3 to 14-18, 6-14 1nd 1 <6 or > 30...
rem reclass x i clatm2 clorok 2 4 5 8 3 4 5 2 2 4 1 1 2 1 8 99 -9999
rem clatm4 is just for display with the viab palette so that
rem the highest concetration appears from above.
rem reclass x i clatm2 clatm4 2 1 8 9 2 7 8 3 6 7 4 5 6 5 4 5 6 3 4 7 2 3 8 1 2 -9999
REM ECOLI
rem reclass ECOLI (for mussel and oysters)
rem reclass x i ECOLI ecoloks 2 4 4 5 3 3 4 2 2 3 1 1 2 -9999
rem (4)=<14, (3)=14-70, (2)=70-700, (1)=>700,
rem reclass x i ecoli ecolitxt 2 1 4 5 2 3 4 3 2 3 4 1 2 -9999
rem ********************************************
rem MCE for Water quality model for mussels....
rem weights for water quality submodel.
```

Appendix 12. Idrisi Macro file for mussel site suitability model.

```
rem input pairwise comparison file and output is
rem decision support file
rem weight x mcemuss mussdsf
rem Mce, the next step, asks for the output image
rem name rem and the decision support file to use,
rem created in the weight module
rem mce x mcemuss mussdsf
rem after mce, an edge effect remained at the bay's edge. This can be removed by a 3x3 filter
'mode' pass

rem filter x mcemuss mcewqM 3
rem delete x tmp*
rem ******************************************
rem INFRASTRUCTURE SUBMODEL
rem TECHNICAL SUPPORT
rem distance x FIPERJ tmp001
rem scalar x tmp001 tmp002 3 30
rem categories are best (4) up to 15km from FIPERJ,
rem (3) from 15- 30 km, (2) from 30-45km (1)over 45km.
rem reclass x i tmp002 tmp003 2 4 0 15000 3 15000 30000 2 30000 45000 1 45000 99000 -
9999
rem overlay with Baypos image to get rid of values over land
rem overlay x 3 BAYPOS tmp003 TECHDIS
REM ROAD NETWORK
rem rem access ROADS AND INFRASTRUCTURE sub-model
rem rem make distance from road network,then
rem multiply by 30 to get meters (from pixels)
rem distance x ROADs tmp001
rem scalar x tmp001 tmp002 3 30
rem categories are best (4) up to 5km from a road,
rem (3) from 5-9km, (2) from 9-14km (1)over 14km.
rem reclass x i tmp002 tmp003 2 4 0 5000 3 5000 9000 2 9000 14000 1 14000 99000 -9999
rem overlay with Baypos image to get rid of values over land
rem overlay x 3 BAYPOS tmp003 ROADIS
rem maint x 1 1 tmp*
rem FISHERMEN
rem rem fisherman distance to possible culture sites
rem (4) 0-.9km, (3) 0.9-1.5km, (2) 1.5-3.0km, (1) >3km
rem distance x FISHERS tmp001
rem scalar x tmp001 tmp002 3 30
rem reclass x i tmp002 tmp003 2 4 0 900 3 900 1500 2 1500 3000 1 3000 99000 -9999
rem overlay x 3 BAYPOS tmp003 fishdis
rem maint x 1 1 tmp*
rem SEED SOURCES
rem distance from mussel seed sources to fishermen villages and operation bases.
rem distance module used, then scalar to multiply distance in pixels by 30 m
rem distance x MUSSEL tmp01
rem scalar x tmp01 tmp02 3 30
rem reclassified because of degree of difficulty in
```

Appendix 12. Idrisi Macro file for mussel site suitability model.

```
rem going to mussel seed source sites
rem (4) 0-3km (3) 3-6km (2) 6-11km (1) >11km
rem reclass x i tmp02 tmp03 2 4 0 3000 3 3000 6000 2 6000 11000 1 11000 100000 -9999
rem overlaid with baypos image to exclude non study areas
rem final image is called SEED (for seed sources)
rem overlay x 3 baypos tmp03 SEEDMUS
rem maint x 1 1 tmp*
rem MCE for INFRASTRUCTURE
rem weights for INFRA
rem input pairwise comparison file and output is
rem decision support file
rem weight x INFRA INFRA
rem Mce, the next step, asks for the output image
rem name and the decision support file to use,
rem created in the weight module
rem mce x mceinfra INFRA
rem after mce, an edge effect remained at the bay's edge. This can be removed by a 3x3 filter
'mode' pass
rem filter x mcemuss WQMUS 3
rem delete x tmp*
rem *********************************************
REM PHYSICAL FACTORS SUBMODEL
rem SHELTER SUBMODEL enters here.....
rem CURRENTS SUBMODEL
rem file `currents` digitised on screen from information on Fragoso report
rem max vel = 69 cm/s
rem currents at 69 cm/s = class 3 suitable
rem reclass x i currents curents 2 4 1 2 3 2 3 2 3 4 1 4 5 -9999
rem NATURAL INDICATORS
rem distance from natural locations of mussel
rem distance module used, then scalar to multiply distance in pixels by 30 m
rem distance x MUSSEL tmp01
rem scalar x tmp01 tmp02 3 30
rem reclassified to within 300 m as indication of same conditions
rem (4) 0 - 600 (3) 600 - 1500 (2) 1500 3000 (1) >3000
rem reclass x i tmp02 tmp03 2 4 0 600 3 600 1500 2 1500 3000 1 3000 99999 -9999
rem overlay x 3 baypos tmp03 NATMUS
rem maint x 1 1 tmp*
rem MCE for PHYSICAL
rem weights physical
rem input pairwise comparison file and output is
rem decision support file
rem weight x physmus physmus
rem Mce, the next step, asks for the output image
rem name and the decision support file to use,
rem created in the weight module
rem mce x mcephyM physmus
rem *********************************************
REM MUSSEL SUBMODEL
```

Appendix 12. Idrisi Macro file for mussel site suitability model.

```
rem Mussel seed submodel
rem distance from mussel seed sources to fishermen villages and operation bases.
rem distance module used, then scalar to multiply distance in pixels by 30 m
rem distance x MUSSEL tmp01
rem scalar x tmp01 tmp02 3 30
rem reclassified because of degree of difficulty in
rem going to mussel seed source sites
rem (4) 0-2.5km (3) 2.5-5km (2) 5-10km (1) >10km
rem reclass x i tmp02 tmp03 2 4 0 2500 3 2500 5000 2 5000 10000 1 10000 100000 -9999
rem next reclass is so that highest score appears at top...
rem reclass x i tmp03 tmp04 2 1 4 5 2 3 4 3 2 3 4 1 2 -9999
rem overlaid with baypos image to exclude non study areas
rem final image is called SEED (for seed sources)
rem overlay x 3 baypos tmp04 SEED
rem maint x 1 1 tmp*
rem map file is musdis
rem MARKETS SUBOMDEL
REM POPULATION CENTERS
rem towns with more than 255-380k population= 4, 30-52k= 3, 3-9k= 2
rem group x towns y tmp02
rem reclass x i tmp02 tmp03 2 4 1 2 4 3 4 3 2 3 3 7 9 2 4 7 2 9 11 -9999
rem distance x tmp03 tmp04
rem distance is in pixels. multiply by 30 to get meters
rem scalar x tmp04 tmp05 3 30
rem town distances (4) 0-5 km  (3) 5- 7km (2) 7 - 10 (1) > 10
rem reclass x i tmp05 tmp06 2 4 0 5000 3 5000 7000 2 7000 10000 1 10000 99000 -9999
rem overlay x 3 BAYPOS tmp06 mktdis
rem ****************************
rem reclass the >250k pop towns to 1
rem reclass x i tmp03 tmp07 2 0 1 4 1 4 5 -9999
rem apply distance and reclass
rem distance x tmp07 tmp08
rem distance is in pixels. multiply by 30 to get meters
rem scalar x tmp08 tmp09 3 30
rem town distances (4) 0-5 km  (3) 5- 7km (2) 7 - 10 (1) > 10
rem reclass tmp09 into suitability accord to distance. sites
rem closest to towns have higher scores.
rem reclass x i tmp09 tmp010 2 4 0 5000 3 5000 7000 2 7000 10000 1 10000 99000 -9999
rem overlay x 3 BAYPOS tmp010 mkt250k
rem ********************************
rem reclass the >30-52k pop towns to 1
rem reclass x i tmp03 tmp011 2 0 1 3 1 3 4 0 4 99 -9999
rem apply distance and reclass
rem distance x tmp011 tmp012
rem distance is in pixels. multiply by 30 to get meters
rem scalar x tmp012 tmp013 3 30
rem town distances (4) 0-5 km  (3) 5- 7km (2) 7 - 10 (1) > 10
rem reclass tmp013 into suitability accord to distance. sites
rem closest to towns have higher scores.
```

Appendix 12. Idrisi Macro file for mussel site suitability model.

```
rem reclass x i tmp013 tmp014 2 4 0 5000 3 5000 7000 2 7000 10000 1 10000 99000 -9999
rem overlay x 3 BAYPOS tmp014 mkt30_52
rem ********************************
rem reclass the >3 - 9 k pop towns to 1
rem reclass x i tmp03 tmp015 2 1 2 3 0 0 2 0 3 99 -9999
rem apply distance and reclass
rem distance x tmp015 tmp016
rem distance is in pixels. multiply by 30 to get meters
rem scalar x tmp016 tmp017 3 30
rem town distances (4) 0-5 km  (3) 5- 7km (2) 7 - 10 (1) > 10
rem reclass tmp017 into suitability accord to distance. sites
rem closest to towns have higher scores.
rem town
rem reclass x i tmp017 tmp018 2 4 0 5000 3 5000 7000 2 7000 10000 1 10000 99000 -9999
rem overlay x 3 BAYPOS tmp018 mkt3_9k
rem ********************************
rem overlay to add scores of all towns into one image=tmp021
rem overlay x 1 mkt30_52 mkt3_9k tmp019
rem overlay x 1 tmp019 mktdis tmp020
rem overlay x 1 tmp010 tmp020 tmp021
rem overlay to remove values outside bay.
rem overlay x 3 BAYPOS tmp021 tmp022
rem reclass tmp022 into suitability scale. (1) 1-4, (2) 4-7, (3) 7-10 (4) 10-14
rem reclass x i tmp022 mktdis2 2 1 1 4 2 4 7 3 7 10 4 10 15 -9999
rem ********************************
REM BUYING POWER
rem first reclass so that town polygons reflect buying power
rem as individual class groups low,med,high.
rem reclass x i towns3 tmp023 2 4 1 3 4 12 13 4 14 15 4 11 12 3 4 5 3 9 11 3 13 14 2 8 9 -
9999
rem reclass x i tmp023 buylow 2 1 2 3 0 3 6 -9999
rem reclass x i tmp023 buymed 2 1 3 4 0 1 3 0 4 5 -9999
rem reclass x i tmp023 buyhigh 2 1 4 5 0 1 4 -9999

rem for each class, create a distance from towns
rem and then reclass as (4) to 7 km away
rem from good (high) buying power, (3) 7 - 12 km (2) 12-14 km and (1) > 14
rem Low Buying Power
rem distance x buylow tmp024
rem scalar x tmp024 tmp025 3 30
rem reclass x i tmp025 tmp026 2 4 0 7000 3 7000 12000 2 12000 14000 1 14000 999999 -
9999
rem overlay x 3 BAYPOS tmp026 tmp027
rem Medium Buying Power
rem distance x buymed tmp028
rem scalar x tmp028 tmp029 3 30
rem reclass x i tmp029 tmp030 2 4 0 7000 3 7000 12000 2 12000 14000 1 14000 999999 -
9999
rem overlay x 3 BAYPOS tmp030 tmp031
```

Appendix 12. Idrisi Macro file for mussel site suitability model.

```
rem High Buying Power
rem distance x buyhigh tmp032
rem scalar x tmp032 tmp033 3 30
rem reclass x i tmp033 tmp034 2 4 0 7000 3 7000 12000 2 12000 14000 1 14000 999999 -
9999
rem overlay x 3 BAYPOS tmp034 tmp036
rem overlay add all these results and reclassify...
rem overlay x 1 tmp027 tmp031 tmp037
rem overlay x 1 tmp036 tmp037 tmp038
rem reclass so (4) 10-13  (3) 8-10 (2) 2-8
rem reclass x i tmp038 buypwr 2 4 10 13 3 8 10 2 2 8 -9999
rem *********************************************
rem FISH OR SEAFOOD CONSUMPTION
rem seafood consumption
rem seafood consumption was based on a 16 kg/cap/year for coastal towns
rem and 8kg/cap year for towns more than 20 km away from the coast
rem coastal towns have higher seafood consumption
rem distance x COASTWN tmp001
rem scalar x tmp001 tmp002 3 30
rem categories are best (4) up to 5km from a coastal town
rem (3) from 5-7 km, (2) from 7-10km (1)over 10km.
rem reclass x i tmp002 tmp003 2 4 0 5000 3 5000 7000 2 7000 45000 1 10000 99000 -9999
rem overlay with Baypos image to get rid of values over land
rem overlay x 3 BAYPOS tmp003 highcon
rem inland towns have lower seafood consumption
rem distance x inldTWN tmp004
rem scalar x tmp004 tmp005 3 30
rem categories are best (4) up to 5km from a coastal town
rem (3) from 5-7 km, (2) from 7-10km (1)over 10km.
rem reclass x i tmp005 tmp006 2 4 0 7000 3 7000 14000 2 14000 45000 1 45000 99999 -
9999
rem overlay with Baypos image to get rid of values over land
rem overlay x 3 BAYPOS tmp006 lowcon
rem overlay x 1 lowcon highcon tmp007
rem reclass x i tmp007 fishcon 2 4 5 9 3 4 5 2 2 4 1 1 2 -9999
rem *********************************************
rem MCE for FISH AND SEAFOOD CONSUMPTION
rem weights fishcon
rem input pairwise comparison file and output is
rem decision support file
rem weight x fishcon fishcon
rem Mce, the next step, asks for the output image
rem name and the decision support file to use,
rem created in the weight module
rem mce x MCEMkt fishcon
REM *********************************************
rem CONSTRAINTS SUBMODEL
REM MUSSEL DEPTHS SUBMODEL
rem all depths ok for mussels i.e. > 3 m.
```

Appendix 12. Idrisi Macro file for mussel site suitability model.

```
rem reclass x i depths depthmus 2 1 4 30 0 1 4 -9999
rem all depths not ok for mussels i.e. < 3 m.
rem reclass x i depths DEPTH3 2 4 1 4 0 4 999 -9999
rem POLLUTION Submodel final file = HMETAL = a distance of 7 km away from point
sources mainly the Inga rem rem factory and the canals east of it.
rem used point vector file pollut and rasterized it.
rem pointras x POLLUT POLLUT 1
rem used reclass to put all points as same id value
rem reclass x i POLLUT tmp001 2 1 1 6 -9999
rem distance x tmp001 tmp002
rem run scalar to get distance in meters.
rem scalar x tmp002 tmp003 3 30
rem reclass to keep all values less than 7000 m
rem as class 1, discard the rest.
rem reclass x i tmp003 tmp004 2 1 0 7000 0 7000 999999 -9999
rem use overlay to black out areas outside the
REM study area in the bay.
rem overlay x 3 BAYPOS tmp004 HMETAL
rem maint x 1 1 tmp*
rem CONSTRAINTS
rem Study area of the bay minus all impediments
rem This adds the constrained areas of pollution,
rem navigation, military and trawler areas.
rem overlay x 1 HMETAL NAVIG tmp001
rem tmp001 = areas impeded by pollution and navigation
rem overlay x 1 tmp001 ARMY tmp002
rem tmp002 = areas impeded by previous and army
rem overlay x 1 TRAWL tmp002 tmp003
rem tmp003 = previous and trawler impeded area
rem overlay x 1 DEPTH3 tmp003 tmp004
rem tmp004 = previous and area less than 3 m depth
rem overlay x 1 tmp004 ZNSTAMP tmp005
rem tmp005 = previous and zinc contaminated areas
rem reclass x i tmp005 tmp006 2 1 1 5 -9999
rem overlay x 1 BAYPOS tmp006 tmp007
rem reclass x i tmp007 tmp008 2 1 2 3 0 0 2 -9999
rem reclass x i tmp008 MUSCONS 2 1 0 1 0 1 99 -9999
overlay x 1 land muscons musconF
rem ************************************
rem MCE for Mussel
rem SUITABILITY FOR MUSSEL
rem Final Suitability for Mussel Culture sub-model
rem weight x mcem mcem
rem mce x mcefmus mcefmus
rem filter x mcefmus mcemF 3
rem group x mcemF Y tmp001
rem area x tmp001 1 2 tmp002
rem reclass x i tmp002 tmp003 2 0 1 100 0 200000 999999 -9999
rem Final MUSSEL MARICULT SUITABILITY SUBMODEL
```

Appendix 12. Idrisi Macro file for mussel site suitability model.

```
rem rem BUFFER MODEL This one reclassifies the areas found
rem rem in the mce to within a buffer zone of 1000m from
rem the islands, as the best possible culture sites.
rem distance x land tmp001
rem scalar x tmp001 tmp002 3 30
rem the next reclass assumes best distance from land
rem to be (4) 0-300 m. (3) 300-600m (2)600 -1000
rem (0) 1000-11000
rem reclass x i tmp002 tmp003 2 4 1 90 3 90 600 2 600 800 1 800 99000 -9999
rem overlay x 3 tmp003 baypos mussbuf
rem overlay x 3 mussbuf mcemF tmp004
rem reclass x i tmp004 MUSPOT 2 4 14 20 3 12 14 2 9 12 1 1 9 -9999
rem group x muspot y tmp005
rem area x tmp005 1 2 tmp006
rem reclass x i tmp006 tmp007 2 0 0 100 0 3700 999999 -9999
rem overlay x 3 baypos tmp007 tmp008
REM AREA USES STUDY
rem area x baypos 2 6 ABAY
rem area x maricult 2 6 amaric
rem overlay x 9 hmetal navig tmp000
rem area impeded by HM pollution
rem area x hmetal 2 6 AHM
rem overlay x 8 army baypos tmp001
rem area impeded by military exercises
rem area x tmp001 2 6 AARMY
rem overlay x 9 tmp000 trawl tmp002
rem area impeded by trawling activity
rem area x trawl 2 6 ATRAWL
rem overlay x 9 tmp001 tmp002 tmp003
rem overlay x 1 bayneg depth2 tmp004
rem reclass x i tmp004 tmp005 2 1 0 1 0 1 2 -9999
rem overlay x 9 tmp003 tmp005 tmp006
rem overlay x 2 baypos tmp006 tmp007
rem reclass x i tmp007 tmp008 0 -1 1 -9999
rem area impeded by all the above activities
rem area x tmp007 2 6 AALL
rem area of water qualities
rem area x wq 2 6 AWQ
rem area x depth2 2 6 Adepth
rem rem BUFFER MODEL This one reclassifies the areas found
rem rem in the mce to within a buffer zone of 1000m from
rem the islands, as the best possible sites.
rem distance x land tmp001
rem scalar x tmp001 tmp002 3 30
rem reclass x i tmp002 tmp003 2 4 1 400 3 400 600 2 600 1000 0 1000 11000 -9999
rem overlay x 3 tmp003 baypos tmp004
rem overlay x 3 mcefinal tmp004 tmp005
rem reclass x i tmp005 pot 2 4 16 17 3 12 13 2 9 10 1 6 10 0 1 6 -9999
rem area x pot 2 2 poten
```

Appendix 12. Idrisi Macro file for mussel site suitability model.

```
rem tmp005 areas impeded by pollution
rem area x tmp001 1 2 tmp005
rem tmp006 areas impeded by trawlers
rem area x tmp002 1 2 tmp006
rem tmp007 areas impeded by navigation
rem area x tmp003 1 2 tmp007
rem tmp008 areas impeded by army
rem area x tmp004 1 2 tmp008
rem tpmstudy area of the study area
rem area x baypos 1 2 tmp009
rem tmp010 area with appropriate depths
rem area x depth2 1 2 tmp010

rem rem BUFFER MODEL This one reclassifies the areas found
rem rem in the mce to within a buffer zone of 1000m from
rem the islands, as the best possible sites.
rem distance x land tmp001
rem scalar x tmp001 tmp002 3 30
rem reclass x i tmp002 tmp003 2 4 1 400 3 400 600 2 600 1000 0 1000 11000 -9999
rem overlay x 3 tmp003 baypos oystbuf
rem overlay x 3 oystbuf tmpcons tmpoys
rem reclass x i depth2 deptneg 2 0 4 5 1 0 4 -9999
rem overlay x 3 deptneg tmpoys tmpoys2
rem overlay x 3 tmpoys2 oystmce tmpoys3
rem reclass x i tmpoys3 oysFIN 2 4 16 17 3 12 13 2 9 10 1 6 9 -9999
rem area x oysfin 2 2 OYSTPOT
REM Bathymetry
rem reclass x i depths bathydis 2 1  1 4 2 4 7 3 7 15 4 15 999 -9999
rem map file for depth range display...
rem MARICULT SUBMODEL FOR MUSSEL
rem rem BUFFER MODEL This one reclassifies the areas found
rem rem in the mce to within a buffer zone of 1000m from
rem the islands, as the best possible culture sites.
rem distance x land tmp001
rem scalar x tmp001 tmp002 3 30
rem the next reclass assumes best distance from land to be
rem (4) 0-400 m. (3) 400-600m (2)600 -1000 (0) 1000-11000
rem reclass x i tmp002 tmp003 2 4 1 400 3 400 600 2 600 1000 0 1000 11000 -9999
rem overlay x 3 tmp003 baypos mussbuf
rem overlay x 3 mussbuf tmpcons tmpmuss
rem reclass x i depth2 deptneg 2 0 4 5 1 0 4 -9999
rem reclass x i deptneg musdept 2 1 0 1 0 1 4 -9999
rem overlay x 3 musdept tmpmuss tmpmus2
rem overlay x 3 tmpmus2 oystmce tmpmus3
rem reclass x i tmpmus3 musfin 2 4 16 17 3 12 13 2 9 10 1 6 9 -9999
rem reclass x i musfin musfin2 2 1 4 5 2 3 4 0 1 3 -9999
rem area x musfin 2 2 mussPOT
REM ACCESS TO MARKETS AND ROADS SUBMODEL
rem MARKET submodel
```

Appendix 12. Idrisi Macro file for mussel site suitability model.

```
rem towns with more than 255-380k population= 4, 30-52k= 3, 3-9k= 2
rem group x towns y tmp02
rem reclass x i tmp02 tmp03 2 4 1 2 4 3 4 3 2 3 3 7 9 2 4 7 2 9 11 -9999
rem distance x tmp03 tmp04
rem distance is in pixels. multiply by 30 to get meters
rem scalar x tmp04 tmp05 3 30
rem town distances (1) 0-4 km  (2) 4-10km (4) >80
rem reclass x i tmp05 tmp06 2 1 0 4000 2 4000 10000 3 10000 80000 4 80000 1000000 -
9999
rem overlay x 3 BAYPOS tmp06 towns07
rem map comp and bmp file = towndist
rem DEPTHS SUBMODEL (for mussels)
rem rem Depths2 = all depths between 3m and 50m
rem are suitable for mussel culture.
rem reclass x i DEPTHS tmp001 2 4 4 16 0 0 4 -9999
rem rem group was used to eliminate small or spurious areas on the image. only the main
body of the bay is rem kept, i.e. group11.
rem group x tmp001 y tmp002
rem reclass x i tmp002 DEPTH2 2 4 11 12 0 0 11 0 12 999 -9999
rem rem depth3 is ideal for oyster culture on racks...(0-3 m range)
rem reclass x i depths DEPTH3 2 4 1 4 0 4 999 -9999
rem reclass x i depth3 tmp003 2 2 4 5 -9999
rem overlay x 1 depth2 tmp003 tmp004
rem reclass x i tmp004 maricult 2 1 2 3 2 4 5 -9999
rem maint x 1 1 tmp*
```

Appendix 13. Idrisi Macro file for Oystersite suitability model.

```
Rem WATER QUALITY SUBMODEL (for OYSTER)
Rem WATER QUALITY
rem TEMPERATURE
rem temp ranges (4)=>25deg C (3)=<24-25
rem reclass x i TEMP tempoks 2 4 4 6 3 1 4 -9999
rem reclass x i tempoks temptxt 2 1 4 5 2 3 4 -9999
rem SALINITY
rem salinity classes: (4)> 14-28 (3)=28-30 (2)= 30-32 (1) <14
rem reclass x i SAL salokOY 2 4 1 9 3  9 10 2 10 12 1 1 2 -9999
rem DISSOLVED OXYGEN oysters (4)=>5
rem reclass x i DO DOok 2 4 2 8 3 1 2 -9999
REM CHLOROPHYL-A
REM  this macro uses the algorithm
rem Cla = 0.060914 + 0.109172 TM2 + 0.214841 TM3
rem to extract clorophyl a values from coastal waters.
rem wind2 and wind3 image is bands 2 & 3 for the study region
rem scalar x wind2 tmp001 3 0.109172
rem scalar x wind3 tmp002 3 0.214841
rem overlay x 3 tmp001 tmp002 tmp003
rem scalar x tmp003 tmp004 1 0.060914
rem overlay x 3 tmp004 baypos tmp005
rem reclass x i tmp005 ClaTM 2 8 30 999 7 26 30 6 22 26 5 18 22 4 14 18 3 10 14 2 6 10 1 1
6 -9999
rem clatm is now overlaid so that the maximum values between this satelite derived
rem cla concentration image and the values found by FEEMA in the
rem ZEE study are maintained.
rem overlay x 9 clatm cloro ClaTM2
rem Now the Clatm2 image is reclassified in function of
rem aquaculture interest. higest score (4) to concentration of
rem 18-30 ug/l, score 3 to 14-18, 6-14 1nd 1 <6 or > 30...
rem reclass x i clatm2 clorok 2 4 5 8 3 4 5 2 2 4 1 1 2 1 8 99 -9999
rem clatm4 is just for display with the viab palette so that
rem the highest concetration appears from above.
rem reclass x i clatm2 clatm4 2 1 8 9 2 7 8 3 6 7 4 5 6 5 4 5 6 3 4 7 2 3 8 1 2 -9999
rem reclass x i CLOROK clorokS 2 4 5 9 3 5 4 2 1 2 -9999
REM ECOLI
rem reclass ECOLI (for mussel and oysters)
rem reclass x i ECOLI ecolokS 2 4 4 5 3 3 4 2 2 3 1 1 2 -9999
rem (4)=<14, (3)=14-70, (2)=70-700, (1)=>700,
rem ****************************************
rem MCE for WATER QUALITY
rem weights for water quality submodel.
rem input pairwise comparison file and output is
rem decision support file
rem weight x oystwq oystwq
rem Mce, the next step, asks for the output image name
rem and the decision support file to use, created in
rem the weight module
```

Appendix 13. Idrisi Macro file for Oystersite suitability model.

```
rem mce x tmp001 oystwq
rem after mce, an edge effect remained at the bay's edge. This can be removed by a 3x3 filter
'mode' pass
rem filter x tmp001 omcewq 3
rem ****************************************
rem INFRASTRUCTURE sub-model
rem TECHNICAL SUPPORT
rem distance x FIPERJ tmp001
rem scalar x tmp001 tmp002 3 30
rem categories are best (4) up to 15km from FIPERJ,
rem (3) from 15- 30 km, (2) from 30-45km (1)over 45km.
rem reclass x i tmp002 tmp003 2 4 0 15000 3 15000 30000 2 30000 45000 1 45000 99000 -
9999
rem overlay with Baypos image to get rid of values over land
rem overlay x 3 BAYPOS tmp003 TECHDIS
rem ROAD NETWORK
rem rem make distance from road network,then multiply by 30 to get meters (from pixels)
rem distance x ROADs tmp001
rem scalar x tmp001 tmp002 3 30
rem categories are best (4) up to 4km from a road, (3) from 5-10km, (2) from 10-15km
(1)over 15km.
rem reclass x i tmp002 tmp003 2 4 0 4000 3 4000 10000 2 10000 80000 1 80000 99000 -
9999
rem overlay with Baypos image to get rid of values over land
rem overlay x 3 BAYPOS tmp003 ROADiSO
rem maint x 1 1 tmp*
rem FISHERMEN
REM rem fisherman distance to possible culture sites
Rem rem (4) 0-.9km, (3) 0.9-1.5km, (2) 1.5-3.0km, (1) >3km
rem distance x FISHERS tmp001
rem scalar x tmp001 tmp002 3 30
rem reclass x i tmp002 tmp003 2 4 0 900 3 900 1500 2 1500 3000 1 3000 99000 -9999
rem overlay x 3 BAYPOS tmp003 fishdisO
rem maint x 1 1 tmp*
rem SEED SOURCES
rem distance from fiperj lab or mangroves seed
rem sources to fishermen villages and operation bases.
rem distance module used, then scalar to multiply
rem distance in pixels by 30 m
REM MANGROVE BUFFER
rem this is a 500 m buffer zone around the mangroves
rem which should have the highest availability
rem of mangrove oysters and spatfall for seeds.
rem reclass x i mangrov4 tmp001 2 1 1 99 -9999
rem distance x tmp001 tmp002
rem scalar x tmp002 tmp003 3 30
rem reclass x i tmp003 tmp004 2 1 0 500 0 500 30000 -9999
rem overlay x 3 tmp004 baypos tmp005
```

Appendix 13. Idrisi Macro file for Oystersite suitability model.

```
rem overlay x 9 tmp005 tmp001 manbuf
rem reclass x i manbuf manbuf2 2 4 1 2 -9999
rem distance x manbuf2 tmp006
rem scalar x tmp006 tmp007 3 30
rem (1) 0-2.5km (2) 2.5-5km (3) 5-10km (4) >10km
rem reclass x i tmp007 tmp008 2 4 0 2500 3 2500 5000 2 5000 10000 1 10000 100000 -9999
rem overlaid with baypos image to exclude non study areas
rem final image is called OYTSEED (for seed sources)
rem overlay x 3 baypos tmp008 OYTSEED
rem MCE for INFRASTRUCTURE
rem weights for submodel.
rem input pairwise comparison file and output is
rem decision support file
rem weight x oytinfra oytinfra
rem Mce, the next step, asks for the output image name
rem and the decision support file to use, created in
rem the weight module
rem mce x omceinf oytinfra
rem ****************************************
rem PHYSICAL ENVIRONMENT SUBMODEL
rem CURRENTS SUBMODEL
rem file `currents` digitised on screen from information on Fragoso report
rem max vel = 69 cm/s
rem currents at 69 cm/s = class 3 suitable
rem reclass x i currents curents 2 4 1 2 3 2 3 2 3 4 1 4 5 -9999
REM NATURAL INDICATORS
rem this is a 500 m buffer zone outwith the mangroves
rem areas in the bay which should have the best
rem natural conditions for mangrove oysters growth.
rem reclass x i mangrov4 tmp001 2 1 1 99 -9999
rem distance x tmp001 tmp002
rem scalar x tmp002 tmp003 3 30
rem reclass x i tmp003 tmp004 2 1 0 500 0 500 30000 -9999
rem overlay x 3 tmp004 baypos natoyt
rem PHYSICAL ENVIRONMENT MCE
rem weight x physoyt physoyt
rem Mce, the next step, asks for the output image
rem name and the decision support file to use,
rem created in the weight module
rem mce x tmp002 physoyt
rem after mce, an edge effect remained at the bay's
rem edge. This can be removed by a 3x3 filter 'mode'
rem  pass
rem filter x tmp002 omcephy 3
rem ****************************************
rem MARKETS SUBMODEL
rem markets as in Mussel model.
rem CONSTRAINTS SUBMODEL
REM OYSTER DEPTHS SUBMODEL
```

Appendix 13. Idrisi Macro file for Oystersite suitability model.

```
rem all depths ok for oysters i.e. < 3 m.
rem reclass x i depths deptoyt 2 4 1 4 0 4 999 -9999
rem POLLUTION Submodel final file = HMETAL = a distance of 7 km away from point
sources mainly the Inga rem rem factory and the canals east of it.
rem used point vector file pollut and rasterized it.
rem pointras x POLLUT POLLUT 1
rem used reclass to put all points as same id value
rem reclass x i POLLUT tmp001 2 1 1 6 -9999
rem distance x tmp001 tmp002
rem run scalar to get distance in meters.
rem scalar x tmp002 tmp003 3 30
rem reclass to keep all values less than 7000 m as class 1, discard the rest.
rem reclass x i tmp003 tmp004 2 1 0 7000 0 7000 999999 -9999
rem use overlay to black out areas outside the study area in the bay.
rem overlay x 3 BAYPOS tmp004 HMETAL
rem maint x 1 1 tmp*
rem CONSTRAINTS
rem Study area of the bay minus all impediments
rem This adds the constrained areas of pollution,
rem navigation, military and trawler areas.
rem overlay x 1 HMETAL NAVIG tmp001
rem tmp001 = areas impeded by pollution and navigation
rem overlay x 1 tmp001 ARMY tmp002
rem tmp002 = areas impeded by previous and army
rem overlay x 1 TRAWL tmp002 tmp003
rem tmp003 = previous and trawler impeded area
rem overlay x 1 depth2 tmp003 tmp004
rem tmp004 = previous and area more than 3 m deep
rem overlay x 1 tmp004 znstamp tmp005
rem tmp005 is a reclass puts all the above values
rem into one category, one value.
rem reclass x i tmp005 tmp006 2 1 1 99 -9999
rem overlay x 3 BAYPOS tmp006 oyscons
rem ****************************************
rem OYSTER FINAL SUITABILITY MCE
rem weight x omcefin omcefin
rem Mce, the next step, asks for the output image name
rem and the decision support file to use, created in
rem the weight module
rem mce x tmp003 omcefin
rem filter x tmp003 omcefix 3
rem Final OYSTER MARICULT SUITABILITY SUBMODEL
rem rem BUFFER MODEL This one reclassifies the areas found
rem in the mce to within a buffer zone of 1000m from
rem the identified best areas of the mce
rem as the best possible potential culture sites.
rem distance x land tmp001
rem scalar x tmp001 tmp002 3 30
rem the next reclass assumes best distance from land
```

Appendix 13. Idrisi Macro file for Oystersite suitability model.

```
rem to be (4) 0-120 m. (3) 120-240m (2)240 - 480
rem (0) >480
rem reclass x i tmp002 tmp003 2 4 1 300 3 300 460 2 460 570 1 570 120000 -9999
rem overlay x 3 tmp003 baypos oytbuf
rem overlay x 3 oytbuf oyscons tmp004
rem filter x tmp004 OYTPOT 3
rem overlay x 1 oytpot omcefix tmp005
rem overlay x 3 tmp005 oyscons tmp006
rem reclass x i tmp006 tmp007 2 4 7 9 3 6 7 2 4 6 1 1 4 -9999
rem filter x tmp007 OYTPOTF 3
rem area x oytpotf 1 2 tmp007
rem reclass x i tmp007 tmp008 2 0 230000 999999 -9999
rem run areas on tmp008 with following results...
rem areas = MS = 426 ha, Suit = 1380, Moder Suit 1509...
rem reclass x i OYTPOT OYTbest 2 1 4 5 0 0 4  -9999
rem reclass x i OYTPOT OYTgood 2 1 3 4 0 0 3 0 4 99 -9999
rem reclass x i OYTPOT OYTok 2 1 2 3 0 0 2 0 3 5 -9999
rem group x OYTbest y tmp005
rem area x tmp005 1 2 tmp006
rem reclass x i tmp006 tmp007 2 0 230000 999999 -9999
rem group x OYTgood y tmp008
rem area x tmp008 1 2 tmp009
rem reclass x i tmp009 tmp010 2 0 230000 999999 -9999
rem group x OYTok y tmp011
rem area x tmp011 1 2 tmp012
rem reclass x i tmp012 tmp013 2 0 230000 999999 -9999
REM AREA USES STUDY
rem area x baypos 2 6 ABAY
rem area x maricult 2 6 amaric
rem overlay x 9 hmetal navig tmp000
rem area impeded by HM pollution
rem area x hmetal 2 6 AHM
rem overlay x 8 army baypos tmp001
rem area impeded by military exercises
rem area x tmp001 2 6 AARMY
rem overlay x 9 tmp000 trawl tmp002
rem area impeded by trawling activity
rem area x trawl 2 6 ATRAWL
rem overlay x 9 tmp001 tmp002 tmp003
rem overlay x 1 bayneg depth2 tmp004
rem reclass x i tmp004 tmp005 2 1 0 1 0 1 2 -9999
rem overlay x 9 tmp003 tmp005 tmp006
rem overlay x 2 baypos tmp006 tmp007
rem reclass x i tmp007 tmp008 0 -1 1 -9999
rem area impeded by all the above activities
rem area x tmp007 2 6 AALL
rem area of water qualities
rem area x wq 2 6 AWQ
rem area x depth2 2 6 Adepth
```

Table 4.3 Potential oyster production based on Cananéia production system.

Oyster culture summary		
Starting density	Oysters / m^2	500
On-growing cycle	Months	26
Survival rate	%	50
Final average number of oysters	Dozen ha^{-1} y^{-1}	104.166
Average weight at sale	kg dz^{-1}	0.62
Average production	kg ha^{-1} y^{-1}	32,291
Farm gate price	£/ dozen	0.72
Gross Earnings	£ ha^{-1} y^{-1}	23,336.63

In practice, production figures are more difficult to estimate because they are subject to considerable variety of setbacks, including predation, parasitism, storms, variable water quality conditions, and theft. The figures presented so far are general estimations based on the literature available and serve as an initial indication of aquaculture potential for the modelling study.

Shrimp

The shrimp being considered for aquaculture development and GIS modelling in this study is *Litopenaeus vannamei* (Fig 4.7).

Figure 4.7 *L. vannamei* in aquarium.
(Photo courtesy of Jomar Carvalho Filho)

This exotic species is native to the Pacific coast of Mexico, Central America and South America north of Peru. The temperature range in its native habitats range from 20 - 30 C. According to the Brazilian Association of Shrimp growers (ABCC, 2003), in 2002, the country had 680 farms in production covering a total area of 11,016 ha, and produced 60,000