ECOLOGY, CULTURE AND UTILISATION OF THE MUSSEL, BRACHIDONTES RECURVUS (RAFINESQUE), IN THE CONTEXT OF AN INTEGRATED MANAGEMENT APPROACH TO BOCA DEL RIO-MANDINGA ESTUARINE SYSTEM, VERACRUZ, MEXICO.

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

by

Jose Antonio Farias-Sanchez

Institute of Aquaculture
University of Stirling
Stirling, Scotland
May, 1991

ABSTRACT

The ecology and culture potential of the mussel, Brachidontes recurvus (Rafinesque), was investigated in the estuarine system of Boca del Rio–Mandinga, Veracruz, Mexico in order to establish the basis for its possible cultivation and utilisation in the context of integrated resource management.
This large ecosystem consists of three lagoons connected by channels or Esteros (total area, 2,350 ha); its dynamic hydrobiological characteristics are mainly determined by the interaction of tidal cycles with the rainy and north wind seasons. This results in important spatial and temporal changes in temperature and salinity distribution in the system which influence the life cycle of Brachidontes recurvus. A decrease in salinity and an increase in temperature triggers the main spawning period of this mussel in August, September and October, although the mussel population is reproductively active year round as shown by gonad development indices (Condition Factor and Seed Mean Gonadic Index), and the temporal occurrence of mussel larvae and spatfall. Recruitment of mussel spat occurs over most of the year on the sub–tidal mussel beds, whereas spat settement on aerial mangrove roots appears to be determined by salinity stratification and substratum availability.

Natural overcrowding limits growth of wild mussels and their mortality is caused by prolonged, extreme changes in salinity or by asphyxia or predation. Asphyxia kills approximately 80 % of the mussels forming aerial mangrove root clustersbecause parts of the clusters are knocked off by water currents and the mussels sink into the soft muddy susbtratum and suffocate.

Based on the physical and physiological requirements of Brachidontes recurvus, Laguna Redonda has suitable physiographic and hydrobiological conditions for rearing mussels stocked in polypropylene

onion bags suspended from wooden racks. Based on a preliminary analysis, socioeconomic factors also seem to be favourable for mussel culture. Mussel seed (30 mm) can be obtained from the natural population, using polypropylene onion bags as collectors or as by-catch from the local oyster fishery. Using this culture method, mussels can attain a minimum commercial size (50 mm) in 6 months at an average growth rate of 4 mm/month.

Annual minimum yields of 20 tons of mussels from a one hectare culture area in the most favourable zone of the estuarine system can be expected, but production for direct human consumption may be limited at present to a demand of approximate 20 kilos/week by local restaurants.
Two identified environmental constraints on commercial mussel culture are potential losses from bird predation and organic pollution caused by the discharge of untreated sewage into the estuarine system. Concentrations of coliform bacteria above the maxima recommended by international health agencies were registered in the water column and in mussel flesh analyzed during this study, especially when salinity was low.

While a small volume of cultivated mussels, after proper cleaning and cooking, could be consumed in local restaurants, nutrition trials indicated that larger quantities could be used successfully as a dietary component for cultured caridean and penaeid prawns.

A scheme for including mussels as part of the food chain in an integrated multispecies production system is proposed. The culture of Brachidontes recurvus should be established in Laguna Redonda, as part of this approach which includes an estuarine aquatic polyculture system (fish-molluscs-crustaceans) and an integrated fish farm operable on a family basis using traditionally reared animals and plants. Preliminary assessment indicates that optimisation of energy flow could be obtained by recycling non utilised energy produced by both sub-systems, through integration. These proposals and the information presented on Brachidontes recurvus , are provided as a baseline for the future testing of possible ecodevelopment schemes for Boca del Rio-Mandinga in order to establish a sustainable, multiple use management policy for this important tropical coastal ecosystem.

TABLE OF CONTENTS

DECLARATION

I hereby declare that this thesis has been composed by myself and is the result of my own investigations. It has neither been accepted or submitted for any other degrees. All the sources of information have been duly acknowledged.

Jose Antonio Farias Sanchez

LIST OF TABLES

natural events associated with mortality of the attached mussels.

Table 10. Monthly average and overall mean length of Brachidontes recurvus at three different localities of Boca del Rio–Mandinga estuarine system.

Table 11. Frequency of number of rings associated with shell length in the mussel Brachidontes recurvus.

Table 12. Seed Mean Gonadic Index values for Brachidontes recurvus in Horcones, Laguna Redonda and Laguna Mandinga during the study period.

Table 13. Monthly number of barnacle, oyster and mussel larvae in plankton during the period of study.

Table 14. Total number of planktonic larvae barnacles,oyster and mussel at the different stations during the period of study.

Table 15. Aquatic competitors (C), predators (P) and other organisms associated with the Brachidontes recurvus mussel population at Boca del Rio–Mandinga estuarine system.

Table 16. Concentration of coliform and meshophilic bacteria found in Brachidontes recurvus during experiment 1 from natural beds and off–bottom cultivation systems.

Table 17. Identification of coliform bacteria present in Brachidontes recurvus (experiment 1).

Table 18. Average physico–chemical parameters recorded during the experimental period (experiment 1) for coliform bacteria determinations

Table 39. Brands of canned mussel consumed by people interviewed in the port of Veracruz (number of interviewees= 20).

Table 40. Preliminary economic analysis for mussel culture in Boca del Rio–Mandinga estuarine system.

Table 41. Preliminary economic analysis for Fish/Shrimp culture cages in Boca del Rio–Mandinga estuarine system.

LIST OF FIGURES

Redonda during the second diurnal cycle in November, 1989. A, air and water temperature; B, salinity and tide level; C, dissolved oxygen.

Figure 9. Bathymetry of Laguna Redonda in metres.

Figure 10. Laguna Redonda bathymetric profile of the south west (A) and the North-East (B) connections to the rest of the estuarine system.

Figure 11. Monthly average climatic parameters for the Port of Veracruz over the experimental period. A, air temperature; B, rainfall; C, wind speed; D,insolation.

Figure 12. Monthly population structure at Estero Horcones from May 1989 to September, 1989.

Figure 13. Monthly population structure at Laguna Redonda from May 1989 to September, 1989.

Figure 14. Monthly population structure at Laguna Mandinga from May to September, 1989.

Figure 15. Total average Condition Factor 1 (CF1) and Condition Factor 2 (CF2) of Brachidontes recurvus during the period of study.

Figure 16. Temporal distribution of principal planktonic stages of fouling organisms expressed as percetage of total mean settlement over the whole experimental period.

Figure 17. Spatial distribution of principal planktonic stages of fouling organisms expressed as percentage of total mean settlement over the whole experimental period.

Figure 18. Proximal analysis values (% dry weight) determined for Brachidontes recurvus over the experimental period. A, moisture and protein; B, carbohydrate, lipids and total ash content.

Figure 19. Growth curves of Brachidontes recurvus cultivated on suspension using polypropylene bags (Experiment 2). Bars indicate standard deviation for each date.

Figure 20. Survival of Brachidontes recurvus cultivated in suspension using polypropylene bags (Experiment 2).

Figure 21. Monthly percentages of the total settlement of each group of fouling organisms, considering the four different collectors together.

Figure 22. Seasonal pattern of settlement of fouling organisms on spat collectors as % of total numbers from all stations over the whole experimental period. A, mussel shell collector; B, oyster shell collector; C, polypropylene bag collector; D, polypropylene rope collector.

Figure 23. Spatial pattern of settlement of fouling organisms on spat collectors as % of total numbers over all months. A, mussel shell collector; B, oyster shell collector; C, polypropylene onion bag; D, polypropylene rope collector.

Figure 24. Relative overall average settlement of fouling organisms on the different collectors considered the sampled months together. M, mussel spat; O, oyster spat; B, barnacles; P, polychaetes.

Figure 25. Average percentage saturation in the water recorded during at respiration experiment 1.

Figure 26. Average dissoved oxygen concentration during respiration experiment 1.

Figure 27. Weight specific respiratory rates of Brachidontes recurvus for experiment 2, 3 and 4; mussel bed heterogenous size, mussel bed homogenous size and cluster aerial roots (homogenous size) respetively. Bars indicate ±SE.

Figure 28. Average length growth curves for the P. setiferus feeding trial. Bars indicate ± SD. Diet 1, fresh frozen mussel; Diet 2, dry mussel meal; Diet 3, commercial balanced feedstuff.

Figure 29. Average total body weight growth curves for the P. setiferus feeding trial. Diet 1, fresh frozen mussel; Diet 2, dry mussel meal; Diet 3, commercial balanced feedstuff.

Figure 30. Distribution of moulting frequency of P. setiferus during the experimental period. Diet 1, fresh frozen mussel; Diet 2, dry mussel meal; Diet 3, commercial balanced feedstuff.

Figure 31. Average length growth curves for the M. rosenbergii feeding trial. Bars indicate ± SD. Diet 1 B. recurvus dry mussel meal; Diet 2, dry mussel meal; Diet 3, frozen meat; Diet 4, fresh meat. M. edulis was used in diets 2–4.

Figure 32. Average total body weight growth curves for M. rosenbergii during the experimental period. Bars indicate ± SD. Diet 1, B. recurvus dry mussel meal; Diet 2, dry mussel meal; Diet 3; frozen meat; Diet 4, fresh meat. M. edulis was used in diets 2–4.

Figure 33. Average 10 day period length specifc growth rates for M. rosenbergii. Diet 1, B. recurvus dry mussel meal; Diet 2, dry mussel meal; Diet 3, frozen meat; Diet 4, fresh meat. M. edulis was used in diets

2–4.

Figure 34. Average 10 day period weight specific growth rates for M. rosenbergii. Diet 1, B. recurvus dry mussel meal; Diet 2, dry mussel meal; Diet 3, frozen meat; Diet 4, fresh meat. M. edulis was used in diets 2–4.

Figure 35. Percentage of M. rosenbergii moulting for each 10 day period during the feeding trial. Diet 1, B. recurvus dry mussel meal; Diet 2, dry mussel meal; Diet 3, frozen meat; Diet 4, fresh meat. M. edulis was used in diets 2–4.

Figure 36. Diagraman of estuary and land–based food production subsystems and their interrelations as proposed for integrated rural coastal development.

Figure 37. Diagram of the Laguna Redonda system showing the position of lagoon–based and land–based food production units mentioned in the text.

LIST OF PLATES

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Dr Hadrian Stirling for his special friendship and enthusiastic supervision of this project.

To Dr. Don Macintosh for his patience and important contribution on the revision and supervision of the final manuscript version.

To Dr Lindsay Ross for believing in me as a friend and as a means of changing Mexican society.

To Professor Ronald Roberts for his support especially in the moments of financial crisis during the field stage of the project.

To Dr. Randolph Richards and Mrs. Julia Farrington for their support on dealing with the complex administrative nightmare.

To Mairi Beveridge and Laura Lew Sinclair for their frienship and support in the histology work.

To Dr Janet Brown, Matt Briggs and Simon Smith for their support during the **Macrobrachium rosenbergii** feeding trials in the Prawn Unit (Institute of Aquaculture Stirling University).

To Allan Porter for his help in the proximate analyses.

To Dr Mike V. Bell, NERC Unit of Aquatic Biochemistry, School of Molecular and Biological Sciences, University of Stirling, for the **Brachidontes recurvus** fatty acid analyses.

To Dr Alan C. Taylor, Department of Zoology, University of Glasgow for providing the facilities to analyse the **Brachidontes recurvus** and **Mytilus edulis** caloric content.

To the WELMET Protein Characterisation Facility, University of Edinburgh for the amino acid analysis of the **Brachidontes recurvus** and **Mytilus edulis** mussels.

Thanks also to:

Elizabeth Garcia, Lili Gonzalez, Paty Deveze, Edgardo Quinones, Luvina Bibiano, Margarita Galeana, Luis Gonzalez for their dedicated support in the field and laboratory work done in Veracruz Mexico.

Sheila Frize, Beatrice Dale, Alan Mc Brier, Betty Skinner for the typing of tables.

To Cathy Bargh for the typing of the manuscript and to Aillen Brady for the printing and editing of the final manuscript.

Special thanks for Dr Clive Fox in the critical moment for defeating the obstacles imposed by technology with computing tricks; for the access to his computer and sharing his coffe and friendship.

To all the **people behind the curtains** which in one way or another contributed to the present work, specially to Dina Lew, Fran Dolins and

Alan Stewart.

To Direccion General de Educacion Tecnologica Agropecuaria y Ciencias del Mar, Instituto Tecnologico del Mar, Veracruz, SEP, and The British Council and ODA, for the support and the grant to carry out the present work.

To my Parents

To my sister Cristy

To my brother Guicho, Laura, Lalis and Pierina.

To Ofe

To Tony, Danae and Lalo.

To all the people who believe and die fighting for Social Justice and Life.

To all the people who believe in me.

PLATE 1. Brachidontes recurvus estuarine mussel.

1. INTRODUCTION

1.1. General Background

Aquaculture or the farming of aquatic organisms has been increasing rapidly in recent years stimulating a continuous development of new technologies and research activities orientated towards optimizing the production of organisms cultivated in marine and brackish as well as fresh waters (Pillay, 1978; Gerhardsen, 1979; Kutty, 1980).
The particular features which have favoured aquaculture development have been: (a) the increasing problem of static or declining yields from capture fisheries in many areas of the world; (b) the opportunity which aquaculture offers to produce species with a particularly high export value, most notably penaeid shrimp, but also certain molluscs such as abalone and oysters.

It has been reported for 1988 that total world aquaculture production was approximately of 14.7 million metric tonnes (FAO, 1990), or about 18% of the total fisheries supply.
Aquaculture programs have been implemented in many countries to increase the utililzition of their natural resources (Mason, 1969; Bardach et al, 1972 ; Dare, 1980), but not always with good initial planning, as in the case of Mexico (Farias, 1989).

In Mexico two well marked periods of progress (before and after 1979) can be identified with respect to aquaculture. From 1959 to 1979 aquaculture development programmes received a great deal of support from the Mexican government with the main objective of stocking or restocking freshwater bodies (Herrera, 1981; Vazquez,1986); and enhancement of some coastal estuarine resources such as oyster and shrimp stocks, especially by engineering modifications of the physiography of some coastal estuarine systems (Kapetsky, 1981; Chavez and Torruco, 1988 a,b).
The experiences resulting from this first period included (a) the creation

of improvised technical working groups, e.g. general biologists turning into aquaculturists; (b) the introduction of some exotic species without a previous evaluatory study, such as some tilapia species (Morales, 1974); (c) a focus on establishing production systems which were monospecies and based on imported biotechnology (Farias, 1989).

The main general consequences of this situation were the creation of culture systems with low production and incorporating many technical mistakes or shortcomings which sometimes caused negative environmental impacts (Contreras, 1978; Cruz-Gomez et al., 1980; Contreras and Escalante, 1984; Chavez and Torruco, 1988b).
By the end of 1979 an important change was generated from the analyses of the general situation during the First Latin-American Symposium of Aquaculture at Mexico City, in which the following conclusions were stated:

1) Mexico lacked a native species inventory for the different aquatic ecosystems making up her aquatic resource base.
2) In the same way the hydrobiological information about these ecosystems was scarce.
3) There was a great diversity of agricultural and industrial by-products that could be utilised in aquaculture (De la Higuera, 1985).

These remarks led to the establishment of a new general approach to improve the efficiency of aquaculture that involved the following general guidelines:

- to continue working with the exotic species but try to adapt the biotechnology based on previous experience;
- to start coordinated programs to evaluate the natural resources;
- to initiate research programmes to utilise native species with aquaculture potential (Martinez, 1988) and to use by-products in combination with multispecies production systems, either polycultures or integrated fish farms (Edwards et al, 1983; Bao-Tong and Hua-zhu,

1984; Edwards, 1985; Arredondo, 1986; Olguin, 1986; Farias et al, 1988).

In recent years these recommendations have been considered to select new strategies for the development of estuarine areas that have been under traditonal exploitation schemes without an appropriate management policy.

1.2. Molluscs as a natural resource of the Mexican Eastern coastal estuarine system.

Mexico has considerable aquatic resources that can be divided into continental (e.g. inland freshwaters above sea level), with approximately 1.1 million ha and littoral waters with approximately 10,000 km of coastline, of which 15% are represented by coastal estuarine systems.
The importance of these ecosystems, with a great productive potential, has been widely discussed (Gunther, 1967 and 1969; Hildelbrand, 1969; Mc Hugh, 1967; Stuardo et al., 1974; Vannucci, 1969; Yanez and Nugent, 1975, cited by Yanez,1975).
Among the variety of organisms in these ecosystems, such as different fish species (Yanez & Nugent, 1977; Resendez,1979; Vargas et al., 1981), bivalve molluscs represent in diversity the second most important taxonomical group and the first in terms of commercial production (Aldana, 1988; Chavez and Torruco, 1988a). Bivalves are animals situated low in the food web, feeding directly on phytoplankton, bacteria and non living organic matter, compared to some species of fish at higher trophic levels that require a greater amount of protein (Halver, 1979), but produce smaller yields per unit of area (Bardach et al., 1972).Thus, the development of new mollusc fisheries and intensive aquaculture techniques for molluscs have been increasing rapidly, mainly on the Mexican Pacific Coast (Baqueiro, 1984).

Among the molluscs of the Eastern Mexican coast, the American oyster Crassostrea virginica (Gmelin), has been traditionally fished and semi-intensively cultivated (Palacios, 1987), but little attention has been paid to some other common molluscs such as the native mussels (Farias, 1988a).
Mussels on the Atlantic and Gulf of Mexico coasts have generally been regarded as competitors of the oyster (Field, 1922; Frey, 1946; Chestnut, 1949a,b; Camacho et al., 1980; Bahr and Lanier, 1981;

Lopez, 1985), but mussels can also be used in semi–intensive culture (Farias and Salinas, 1987); as human food (Varela, 1981; Baylon, 1987; De la Garza, 1987) or for terrestial (Davy and Graham,1984) and aquatic animal feed (Wickins, 1972; Halver, 1979; Beard et al., 1985; Anaya, 1989; Villanueva, 1990; Zamora, 1990); and as bioindicators of pollution (Fujiya, 1965; Phillips, 1978, 1980; Forstner and Wittmann, 1981). According to Cardenas (1969), many of the Mexican coastal lagoons have been irrationally exploited: not only from the natural resources point of view, but also because bad management decisions have led to negative environmental impacts (Cruz–Gomez et al, 1980; Chavez y Torruco, 1988 a,b; Castagna, 1987).

It is very important, in the particular case of the Eastern coast of Mexico, to think of utilising molluscs in addition to the traditionally exploited and often overfished C. virginica. Moreover, this oyster naturally belongs to an "unstable ecological environment; where it seems not very appropriate to make long term predictions" according to Yanez (1975).Thus, the approach taken must consider the present state of the whole ecosystem and the prevalent socio–economic situation of the affected area independently of the oyster population itself, otherwise there is a risk of choosing inappropriate development strategies. A good example of the latter is the Boca del Rio–Mandinga estuarine system which is described in detail in section 1.4.

1.3. Management of estuarine systems

Estuarine ecosystems are important as great producers of natural resources and areas which potentially can sustain the development of diverse human activities. They have been a focus of human settlement and consequently tend to support high population densities. For example, 74 people/km2 in the state of Veracruz, Mexico (INEGI, 1986). It is therefore necessary to establish a balance in the

human-ecosystem relationship to avoid their destruction, but these systems have been negatively affected in the past due to wrong strategies for their management or lack of management. An absence of appropriate regulations has led to issues such as overfishing of certain species or drastic environmental changes caused by physical modifications and pollution of the system (Bennet et al.,1985; Ducrotoy et al.,1985; Nobrega, 1986; Montague, 1987, Diab and Scott, 1989)
In temperate regions examples include Ducrotoy et al.(1985) who found a decrease in the diversity and number of species in a Macoma baltica community after the breaching of a sea wall in the Somme estuary. The opening of the mouth of the Bot River (South Africa) estuary affected the composition of the fish community (Bennet et al., 1985). In the tropics the negative effects on mangrove ecosystems associated with activities such as aquaculture, charcoal production and tin-mining are widely known. The mangrove forest is the environmental and energy base for a complex food web of marine organisms including valuable estuarine and nearshore fisheries and ultimately fishing communites who denpend on this food web and the income it generates (Teas, 1980; Hansa, 1984; Dixon, 1989; Saclauso, 1989). According to Saclauso (1989), using this area for aquaculture (e.g. shrimp pond culture) destroys the sanctuary of nursery and breeding grounds for countless terrestrial and aquatic fauna and the nutrient sink that supports the fisheries of contiguous coastal zones. This author also stated that, without mangrove vegetation in the coastal zone, shorelines inevitably erode with tidal action and periodic inundation, sometimes claiming lives and properties as in the province of Mindanao, Philippines in 1976.

A comparable case in the Mexican eastern coast is the Carmen- Machona system (Chavez and Toruco, 1988b). Here it was found that as a consequence of the hydraulic engineering works carried out there in 1975 to enhace the oyster fishery, the erosive process went out of control at the mouth of Panteones after this was artificially opened. It has been estimated that the mouth is widening at a rate of 96m/year and threatening to destroy the system within the next 115 years. Salinity has increased from 3 ppm up to 30 ppm, and consequently is greatly affecting the ecological structure of the lagoon.

In the summary of identified needs for production in Latin America and the Caribbean published in an FA0 report on planning for aquaculture development (Anonymous, 1989), the need to increase production through the management of coastal lagoons and estuarine systems is recognized as a main priority.

According to Kevsten, (1980), early forms of coastal lagoon management have generally had two outcomes. The first refers to the human activity which intentionally controls or modifies natural processes in order to maintain or change certain conditions in the lagoon (e.g. dredging); the second concerns profit orientated human activity in lagoons which may unintentionally alter other resources or conditions (e.g. tourism, housing development).

The management of estuaries and the effective and economic control of pollution have, in common with general management concepts five major requirements: 1) clearly defined objectives; 2) technological capability; 3) a method of measuring performance in cost–effectiveness terms; 4) a firm resolve to meet defined responsibilities in full; and 5) possession of effective executive powers (Mackay, 1985).

Middleton et al. (1985) considered that the future management of the estuarine environment is contingent on a number of factors which are applicable to the present Mexican situation, including; (a) a paucity of baseline data; (b) a lack of predictive models; (c) the difficulty of quantifying natural attributes and (d) a previous tendency to study the effects of each developmental proposal on an individual rather than cumulative basis.

However in relation to the first meaning proposed by Kevsten (1980), management approaches have been suggested for estuarine fisheries by

Kapetsky (1981) including firstly, the classical regulatory management-regulation of entry principle; and secondly restrictions on fishing gears, and fishing methods and /or on fishing areas. As a second option, non-regulatory methods, those which propose to increase fishery productivity via e.g. hydraulic engineering, predator control, stocking programmes or brush-parks. Kapetsky (1981) has a final perspective related to the second meaning mentioned previously (Kevsten, 1980) by establishing coastal management from the viewpoint of actual or potential interactions, competition or conflicts with other kind of fisheries-ethnic and socio-economic interactions, potential conflicts with aquaculture and interaction with marine nearshore and offshore fisheries. These conflicts have played an important role in the management of some coastal ecosystems (Dix, 1976; Gusman and Huser, 1984; Cormier-Salem, 1986; Le Reste, 1986; Bally, 1987).
This latter perspective coincides with the comment made by Padma (1990) that the rational use of natural resources relies on a holistic approach in examining the interactions among economic, ecological and institutional systems, as it is the totality of these determines the outcome of any activity within an ecosytem. In her study on conservation or conversion of mangroves in Fiji, she proposed the utilization of an expanded benefit-cost analysis framework to deal with three major questions related to management of these ecosystems. Under what conditions should a natural system, such as mangroves, be maintained and managed for its in situ uses of forestry and fisheries products and other environmental services? When should it be reclaimed to create land for alternative purposes? And how should one evaluate such a complex ecosytem to facilitate ecologically and economically rational decisions in the absence of a market?

Another method based on similar criteria developed by the U.S. Fish and Wildlife Service (FWS), is called the Habitat Evaluation Procedure (HEP) (Schamberger and Kumpf, 1980) and provides indices of habitat value which are based on the ability of the habitat to support fish and wildlife. The authors considered that the establishment of habitat values for estuarine habitats must occur within the perspective of three general value systems: the ability of the habitat to provide a resource such as fish, wood etc; or the relative importance society places on these resources and finally the dollar value of these resources to man. According to them, this methology should provide a mechanism to establish habitat values for fish and wildlife, establish societal weighting factors to adjust habitat and dollar values, and to allocate dollar values to these resources.

An alternative indirect method that can be used, especially in developments including aquaculture production units, is the method of risk management (Secretan and Nash, 1989). This method considers that the economic survival and strength of the aquaculture project as a whole is entirely dependent on and subordinate to the principal tasks of producing, marketing and preparing quality aquatic products profitably and without risks.

The process of managing risk is based on the individual analyses of three fundamental activities, which are taken in sequence, and subsequent synthesis of the results into a programme of management action. These three activities are:

– Identification of the risk, or discovering the source(s) from which a potential risk may arise. These risks are classified as business risks (eg. operational, technological, financial, social, market–related and consumer–related risks) and pure risks (e.g. physical risks of nature, social and political risks and liability).

– Measuring risk, or evaluating the impact on a individual or an organization in the event of a potential risk.

– Managing and controlling risk, or selecting the most effective method(s) to deal with a potential risk.

Providing the elements to supply any of the models mentioned above, and their application for management, face two main constraints; (1) poor availability of scientific data on these complex systems due to lack of financial support (Olaniya, 1981; Queen et al., 1988); (2) lack of direct participation of scientists in environmental policy making and legislation (Limburg et al, 1986; Diab and Scott, 1989).

Queen et al (1988) suggested, based on current data, that private and public expenditures on coastal industries, infrastructure, housing, office space and environmental quality will increase steadily in the USA for several decades to come. But at the same time, spending for coastal and near–shore research has not followed the trends for population or for private/public investment in coastal industries, infrastructure and environmental protection. The authors assumed the lack of funding is caused by the beliefs of government personnel that: (1) coastal science questions are not important enough to justify a higher level of public support; (2) previous research has provided an adequate data base for both science and science–based coastal policy; or (3) the development and implementation of effective coastal programmes do not require a better understanding of coastal processes.

A number of similar problems facing scientific investigators in developing countries discussed by Olaniya, (1981) are summarized as follows: (1) A need to achieve balance betweeen basic research and research related to development of natural resources; (2) the quest of policy makers for quick but not necessarily suitable solutions to problems; (3) lack of scientific manpower and the lack of dedication by scientific workers; (4) lack of financial support; and (5) role of economic development vis–a–vis ecological balance.

A good example of the situations mentioned above is provided by the Boca del Rio–Mandinga estuarine system in Mexico. As explained in the following section.

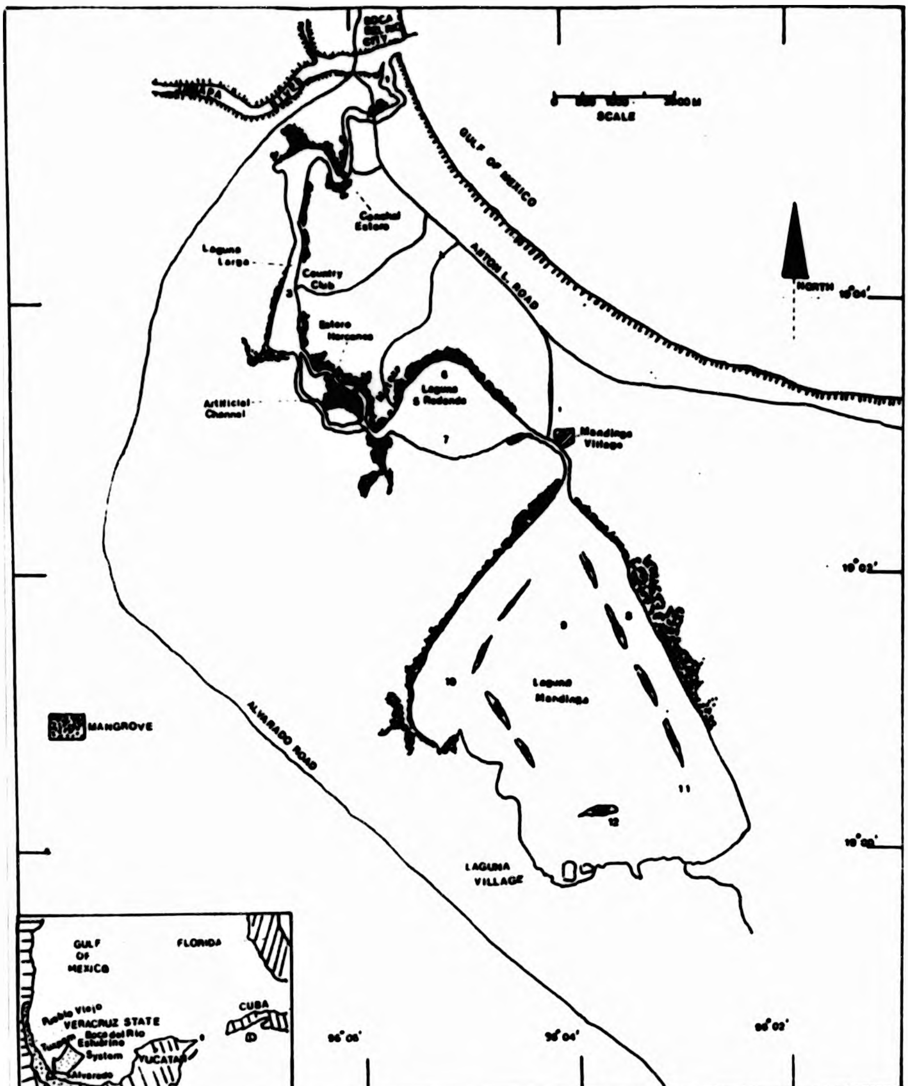


Figure 1. Boca del Rio - Mandinga estuarine system showing the sampling stations (1-12).

1.4. The Boca del Rio– Mandinga Estuarine System.

Mexico has 124 coastal lagoons and estuaries with a total area of approximately 1.6 million hectares; 84 of these covering 932,365 ha are in the Pacific coast and 40 corresponding to 667,635 ha are on the Gulf of Mexico–Caribbean Sea (Cardenas, 1969; Pedini, 1981; Baqueiro, 1984). Of the latter group, 536,310 ha representing 12 systems are the most productive from a fishery or aquaculture point of view (Chavez and Torruco, 1988a). The state of Veracruz alone has six such systems occupying 225,250 ha, making this region the foremost oyster producer with 40% of the total national yield (Aldana, 1988). The Boca del Rio–Mandinga estuarine system, with an area of 3,250 ha, is the smallest of these six systems (Fig. 1).

When Vazquez (1971) and Sanchez–Chavez (1977) described the Boca del Rio–Mandinga ecosystem, it could have been considered as a balanced multispecies production system as described in the general system evolution model of Figure 2. The original human population in the area was not very dense, being mainly involved with fishing for a diverse range of species using artisanal fishing methods. Within their normal socio-economic limitations, local people used to have the basic elements to enjoy a reasonable quality of life.

In 1979, based on the national government development programmes which emphasized proposals to increase the productivity of coastal ecosystems (Herrera, 1981; Vazquez 1986), but with "scientific" support that never produced a serious predictive environmental impact study as recommended by Valiela (1978), it was decided to dredge in different parts of the system, including a new channel parallel to Estero Horcones (Fig.1) with the intention of improving the intrusion of sea water and thus of improving ecological conditions for the oyster *Crassostrea virginica* (Gmelin) since this oyster had a great demand in the national market. Approximatelly 45 tons are produced annually on the east coast of Mexico (Chavez and Torruco, 1988a). A more detailed description of the new characteristics of the system is described in Chapter 2.

From the point of view of the general diagramatic analyses, the ecosystem was turned into a fragile monospecies production system over the period 1979–85 based on the oyster fishery (Fig.2).

The ecological changes provoked by the dredging, as described by Cruz–Gomez et al. (1980) and De la Cruz (1985), were:

Clearance of several hectares of mangrove areas;disappearance of Ruppia maritima from certain zones; an increase in to salinity by 30 % from an annual mean of 10.5 to 21.1 ppt and a decrease in dissolved oxygen by the same proportion from an annual mean of 9.5 to 5.9 mg/l; the planktonic biomass decreased by 62 % with respect to its previous mean annual biomass before the dredging; 18 species of fish present before the dredging disappeared and 26 not previously reported were recorded.

The absence of some species such Syngnathus ascovelli, Ephinephalus adsconcionis (grouper) and Eucinostomus argentus is attributed to the disapearence of the areas covered by Ruppia marina, since this plant provided a nursery ground for these species; whereas some freshwater species such as Cichlasoma and Belonosox disapeared due to the increase in salinity.

After the dredging, there was an apparent improvement environmentally from the point of view of the oyster population, chiefly the increase of salinity, but there were a number of facts that should be have been taken into account, especially for long term effects and lack of proper planning as described below.

The dredging program in the mouth of the system was supposed to be conducted periodically and for this purpose two steel fixed platforms (area approx. 400 m2) were moored on the eastern shore. In 1985 when

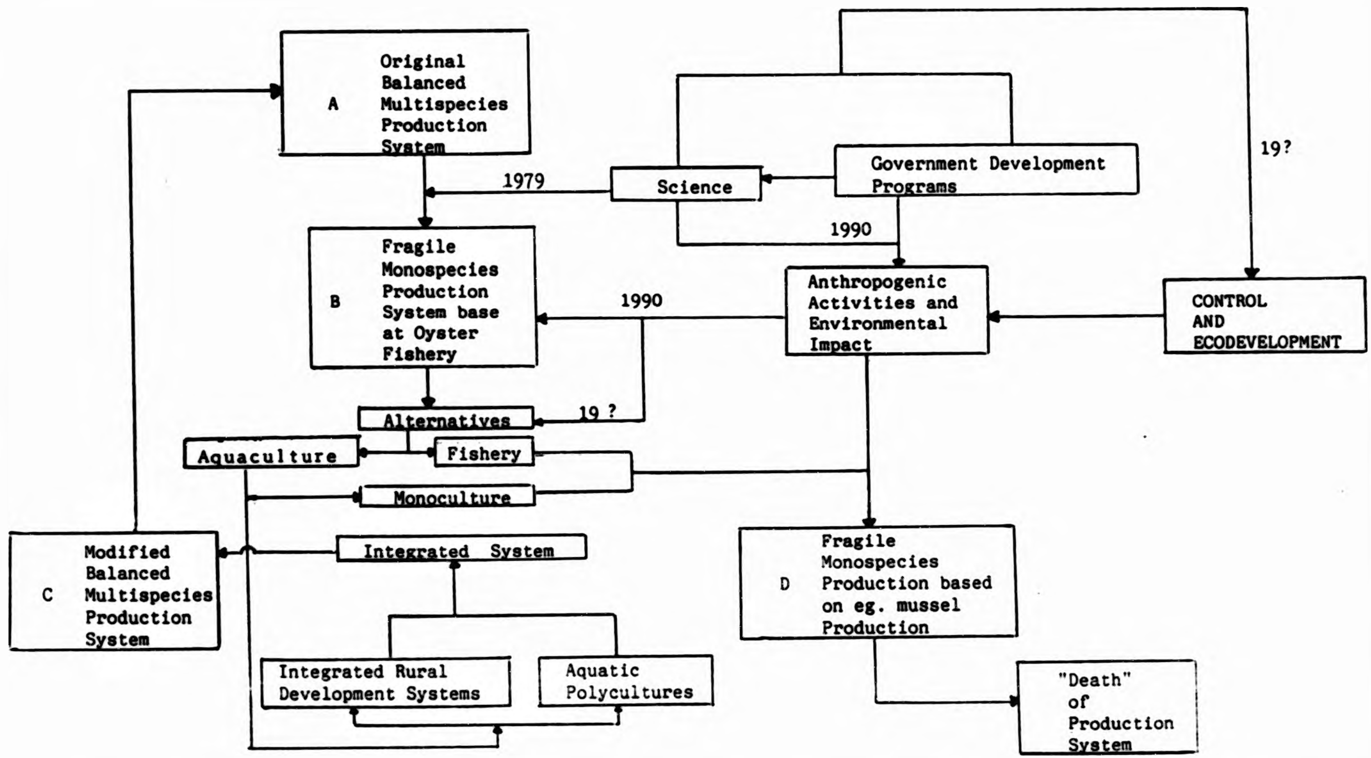


Figure 2 Diagram showing the possible aquaculture development strategies and mangement alternatives for Boca del Rio-Mandinga estuarine system.

the first Mexican economic crisis occurred, the budget for this programme was cut and the platforms were abandoned; eventually they gradually started to rust and acted as a sediment trap. By 1987 the mouth was reduced by approximately 15% of its original width of 500 m. Considering the location of these platforms they were probably also releasing metal oxides into the estuarine system at a constant rate through the tidal flows. While this may not have caused immediate massive mortalities, presumably this discharge could have been affecting larval stages of various aquatic organisms which are known to be sensitive to metal poisoning (Forstner and Wittmann, 1981; Castagna, 1987).

Furthermore, areas of several hectares adjacent to the system were cleared of mangrove trees and containment walls and jetties were constructed along the banks where new housing zones were developed, altering the flow pattern of the current.

The change in composition of the estuarine community forced the cooperative members and free fishermen that used to rely on capturing fish or shrimp, to join the oyster fishery, consequently increasing the fishing pressure on this resource.

These and other issues were presented by Farias (1987), in a local meeting with the different institutions and social sectors eg. Tourism Department, Cooperatives, Fisheries Department (SEPESCA) that directly or indirectly were involved with the estuarine system. A basic scheme of inter-relationships (Fig.3) was used to try to explain the potential magnitude of the existing problem to these groups.

Oysters, as part of the molluscan group within the estuarine ecosystem, are easily affected by different anthropogenic activities e.g. agriculture, tourism and aquaculture (Fig.3). Experience has shown that there can be direct negative effects such as overfishing or indirect caused by changes in water quality and physiography. The long term effects would eventually be perceived by humans from the health or economic points

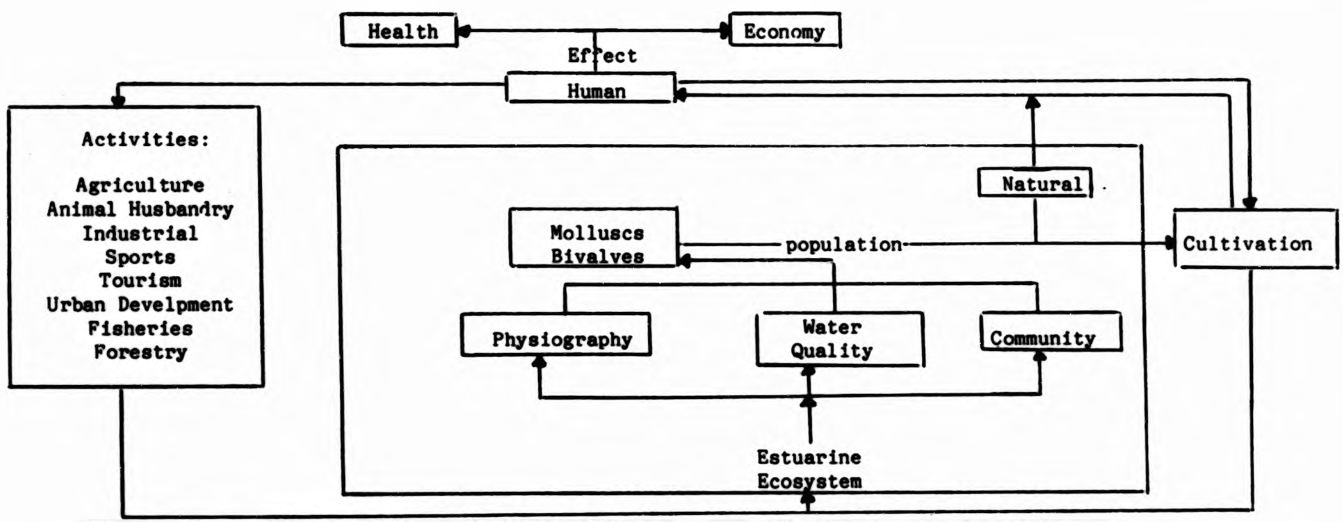


Figure 3. Anthropogenic activities and environmental impact on the estuarine system in relation to management of molluscs

of view (Fig.3).

As expected, the general response to the situation warned of by Farias (1987) up to January 1990 was practically nil and the oyster population has been greatly affected as shown by the prelimary analyses undertaken during 1986–1987 by Farias in coordination with the Instituto Tecnologico del Mar staff and students (unpublished data).
One of the indirect indicators of an overfishing problem on this population was an observed decrease in the average minimum size at capture. While waiting to convince the responsible authorities and its bureaucracy of the need to manage the oyster fishery on a scientific basis, an alternative practical solution to maintain estuarine food production was devised. This led Farias and Salinas (1986, 1987) to consider the local estuarine mussel Brachidontes recurvus as a possible future alternative species to oysters.

This study was very useful to understand the basic ecology and determine its potential for culture in this ecosystem as, will be described in more detail in section 1.5.3. , but it did not consider the general situation in terms of its consequences, in which the apparent solution would result once more in a fragile monospecies production system based this time on mussels (Fig.2). This would possibly bring the "death" of the system from the productive point of view as has been suggested for similar systems (Ardizzone et al., 1988; Chavez and Torruco, 1988b) (Fig.2).
A different alternative can be chosen which considers balanced and multispecies production, in combination with the actual socioeconomic characteristics of the locality. This alternative basically consists of attempting to reestablish a new, modified balanced multispecies production system (Fig.2). This can be achieved by operating aquatic estuarine polycultures using native and some introduced exotic species as reported for this ecosystem by Bibiano (1990), in connection with

land–based terrestrial integrated rural development systems incorporating aquaculture developed for this geographical zone (Pullin, 1982; Olguin, 1986; Farias et al., 1988) (Fig.36).
This is the approach taken in the present study, the objectives of which are detailed in the correspondent section (Objectives).

1.5. Mussel Cultivation and the *Brachidontes recurvus* mussel.

1.5.1. Mussel General Characteristics

The following describes in general terms the biological and physiological characteristics of mussels that might be useful in understanding their relationship with the surrounding environment, thereby enabling suitable culture methods to be proposed (Farias, 1988c). More detailed information on these subjects can be found in Field (1922), Barnes (1987) and Bayne (1976).

The mussels are bivalve molluscs with a gregarious nature; they have bilateral symmetry and a thin but strong external shell formed by a pair of valves jointed by a ligament. The visceral mass is located inside the mantle cavity (Barnes, 1987). Mussels have a pair of adductor muscles (anterior and posterior) and a foot which bears the byssal gland that secretes the byssal threads that are used to fix the animal to the substratum. This characteristic allows the mussel to detach and move to a new substrata. The mussels are filter feeders; they feed mainly on phytoplankton and detritus, but also on zooplankton or suspended organic matter (Dare, 1980).

The food is filtered by the gills using cillia and directed to the mouth palps. Some particles are rejected forming pseudofaeces that are expelled from the mantle cavity via the exhalant siphon. External digestion is initially carried out in the stomach and finally the food enters the digestive gland where intracellular digestion occurs and the faeces are disposed by means of a double circulation (Bayne, 1976).

Respiration is by the uptake of oxygen by ventilating water over the gill filaments (Bayne, 1976). Mussels are able to filter from 5 to 10 l per hour of water (Athree and Aubert, 1980; Dare, 1980) and can resist long periods of desiccation out of the water, since they can extract oxygen directly from the air as long their gills remain moist (Pamatnat, 1984).

The circulatory system is open with a typical pathway consisting of heart, haemocoel system, kidney and gills. The heart is composed of a ventricle and two auricles (Field, 1922).
Ionic exchange occurs across the gills; the mussel is an osmoconformer but capable of living in the salinity range of 5 to 35 ppt. The kidneys are responsible for filtering the blood and excrete mainly ammonia, amino nitrogen and uric acid (Bayne, 1973 a,b cited by Bayne, 1976). Excretion also occurs through the gills. Mussels have a rudimentary nervous system and sensory receptors are located on the border of the mantle, which can detect eg. light and dusk (Field, 1922).

In terms of reproduction, sexual maturity is reached after 6 months to one year depending on the latitude (Figueras, 1979).
They are dioecious and in the case of M. edulis it is possible to differentiate during the spawning season the males with pale yellowish gonads from the females bearing bright orange gonads (Dare, 1980). This species is a very prolific organism with a fecundity that ranges from 5 to 12 million eggs/female/year (Pares, 1987).
Fertilisation is external and spawning (shedding of gametes) depends principally on temperature, although sometimes it can be induced by chemical signals (pheromones) allowing all the population to spawn simultaneously (Breese et al., 1963).
Twenty hours after fertilisation ciliated trochophore larvae are present swimming freely in the plankton, initially feeding on the vitelline sac and then after 15 to 60 days, depending on the temperature, they finish their larval life, reaching an approximate length size of 0.25 mm. The larvae sink to the bottom looking for a suitable substratum and metamorphosis begins with the secretion of the first byssal thread. They normally settle onto filamentous alga at the primary plantigrades stage. Approximately after 4 to 5 weeks they reach a size ranging from 0.5 to 1.5 mm and detach from the first substratum and get carried by the prevailing

currents until they settle usually as secondary plantigrades onto existing mussel beds, or new, suitable rough or fibrous surfaces (Bayne, 1964; Dare, 1980).

1.5.2 General Features of Mussel Culture.

Molluscs occupy an important position in world aquaculture and fisheries statistics. Glude (1979) predicted for the year 2000 that the world mollusc demand would reach 2 million MT but the recently published figure by FAO (1990) showed that this group of organisms produced by aquaculture methods alone amounted in 1988 to 3,073,205 MT. This production represents 21% of the, current total world aquaculture production of about 16 million MT.

East Asia is the top region for mollusc culture with 68.8% of the world total, followed by Europe with 20.2%. The geographical areas relevant to Mexico (Latin and North America) produced only 5.9% (FAO, 1990).

Mussels represent an important component of this total. The world production of mussels from 1981 to 1987 ranged from 813,462 to 941,077 MT with a general average of about 891,393 MT. This represents 29% of total world mollusc production by aquaculture assuming that most of the harvested mussels came from aquaculture systems (FAO, 1987, 1990).
This assumption is based on the fact that there are several constraints associated with natural mussel beds that limit their commercial exploitation. Natural mussels have poor meat quality resulting from such factors as overcrowding and an excessive exposure to air or wave action, silty water and some other unfavourable conditions; the slow restoration of fished beds and serious problems of pollution in some coastal areas are additional limiting factors (Fujiya, 1965; Dare, 1980; Barrow, 1981; Mason and Drinkwater, 1981; Salas et al., 1983).

Another good indicator of the development of the mussel industry is the constant increase in the number of installed mussel culture production systems in different countries around the world such as Canada, USA, and New Zealand (Mason, 1969, 1971; Dare, 1980; Mason and Drinkwater, 1981; Herriott, 1984; Chalermwat and Lutz, 1989; Dijkema and Van Stralen, 1989; Figueras, 1989; Hiekman, 1989; Wilson and Fleming, 1989; Muise, 1990).

Mussel cultivation started accidentally in France during the 13th century when mussels were observed attached to wooden posts on the beach. This formed the basis of the actual cultivation method there (bouchot culture, using vertical posts). Later in the middle of 14th century, people in Holland started transfering mussel seed to zones where they could achieve better growth. At the begining of this century, Spain started to develop "floating parks" using suspended ropes for mussels from rafts which could produce up to 60 tons of mussel per hectare (Garcia and Garcia, 1987).

Based on the adaptability and hardiness of mussels three basic methods have been developed;

– On the sea bottom, as transplanted mussel beds.

– As a suspended floating culture from rafts or longlines

– As in the French method of bouchot culture in which the mussels grow attached to vertical posts, starting with spat which settle directly, or by binding seed to the posts with a tubular netting until they are firmly attached.

A detailed review of the methods used around the world is contained in Bayne (1976).

In general terms areas suitable for mussel cultivation should have: flood tidal currents of 0.17 –0.25 m/sec and 0.25–0.35 m/sec in ebb tide; phytoplankton biomass ranging from 17 to 40 mg/l and a primary productivity from 73 to 100 mg of C/m3/day (Davy and Graham, 1984).

The natural biological potential for mussel production can be threatened by meteorological phenomena and predators (Mason, 1971; Farias, 1983); by the presence of toxic algae in the water (Shumway, 1989); by parasites or infectious diseases (Andrew, 1958; Korringa, 19776; Bower and Figueras, 1989); and by pollution (Forstner and Wittmann, 1981).

Recent developments have led to more biotechnical and economically suitable methods of mussel cultivatiion under diverse environmental conditions. Whereas Dare (1980) in his summary of the mussel production in Northern and Western Europe (1970–1975), refers to different culture methods but in the case of suspended methods only mentions the use of rafts, today in countries where mussel culture is relatively new, as in Eastern Canada and New Zealand, the common practice is to use longlines (Hickman, 1989; Muise, 1990)

The interest in mussel culture in Mexico originated in the way the fishery of the natural beds of Mytilus edulis and Mytilus californianus developed on the Pacific coast of Baja California. Production started with 40 tons in 1972 and, after fluctuating, it reached a maximum of 800 tons in 1981 and then dropped drastically to only 71 tons in 1983 (Bernaldez, 1987). This was basically attributed to the intense fishing pressure exerted, especially on the most accessible inshore beds, and to the slow rate of 5 to 7 years required to complete their natural restoration process (Salas et al., 1983; Bernaldez, 1987). A similar situation with overfishing of natural beds, has motivated other countries to start culturing their local mussels, e.g. green mussel Perna canaliculus in New Zealand (Hickman, 1989).

In response to this situation the Instituto de Investigaciones

In response to this situation the Instituto de Investigaciones Oceanologicas (Universidad Autonoma de Baja California) conducted a successful series of studies on the ecology and culture of M. edulis and M. californianus on the Pacific coast of Baja California, from 1979 to 1986 (Salas and Garcia, 1987).

Based on this experience, the first Mytilus edulis commercial culture system was established in 1985 by a private enterprise (Martesano S.A de C.V.) at Ensenada B.C., with a plan of producing in each of 24 production units (rafts) an average of 50 tons/year of mussels (Garcia and Garcia, 1987). But after two years they only achieved a production 200 tons out of the 400 tons of already installed capacity.

Garcia (1987) reported as the following constraints on commercial mussel culture to explain this experience:

– Shortage of seed. Mussel seed supply generally relies on the natural spatfall. Independent of the quality of artificial seed collectors, spatfall success depends on the annual environmental conditions that influence the mussel reproductive cycle and larval development of mussels; these conditions are not necessarily good every year.

– Lack of some lifting gear and other mechanical devices to assist with the culture operations which otherwise have to be done by hand. Mussel culture in Mexico is a recent activity as mentioned previously, therefore the lack of such devices in the national market increases operating costs and limits the scale of the projects.

– Problems of commercializing of the product. The lack of tradition in mussel consumption limits the existence of and potential for expansion of a national market. The international market, represented mainly by the USA, is pratically closed since it requires high quality processed products and the certification of water quality where the product was cultivated. Although the mussel culture areas in Baja California are free of pollution, the official mechanisms to certify the water quality do not yet operate efficiently(Becerra, 1990).

– Financial problems caused by high interest rates on bank credits.

The only other commercial culture, of the M. edulis in Mexico operates on the San Martin Island, Baja California, and produced about 50 tons from 20 longlines of mussels during 1987. This operation is facing essentially the same problems cited previously for the raft culture system in the same geographical area (Gonzalez, 1987).

The production from these systems is insignificant considering that the National demand for 1987 was 6,000 tons. The potential demand for 1992 is estimated at 37,000 tons while there is an estimated cultivable area in the Baja California region of Mexico of 8000 ha with a potential yield of 80,000 tonnes annually. The total molluscs consumption per capita in Mexico 0.7 kg/annum is small compared to France with 9.6 g (Aldana,1988), so there is huge scope for expansion of the Mexican market. This has motivated new research to increase mussel production based on lists of potential species proposed by Baqueiro (1984), or as suggested by more recent revisions (Garcia–Cubas,1987).

Under this scheme, some other native mussel species have undergone preliminary investigation, but with little success in terms of applying the results on commercial or even a pilot scale. The main Pacific coast species considered have been Modiolus capax (Buckle and Farfan, 1987) and Mytella strigata (Chun,1989).Garcia–Cubas (1987) has recommended three more for the eastern Mexican coast; Geukensia demissa granosissima (Campeche and Yucatan): Brachidontes recurvus (Ischadium recurvum) and the B. exustus from the Gulf of Mexico.

This last genus, Brachidontes (Swainson, 1840), is characterised by having a radially sculptured shell with bifurcating ribs. The margins of the shell are strongly crenulated all around with strong dysidont teeth along the anterior margin. The ligament is subinternal, its resilifer forming a narrow sac about 1/2 the length of the posterior–dorsal margin; the anterior adductor muscle is absent (as in the genus

Ischadium). The lunule and anterior margin are bent inward, forming 1 or 2 toothlike ridges. The ligament is relatively short (Abbott, 1974).

The number of published papers on this genus, excluding B. recurvus, is very limited and practically none relate to its culture (Table 1). The main species reported for Europe are B. variabilis and B. marioni; for America, B. solisianus, B. darwinianus and B. exustus (Table 1).

1.5.3. The Mussel Brachidontes recurvus.

Brachidontes recurvus is an euryhaline species distributed from Cape Cod to the West Indies. It inhabits intertidal oyster reefs or attaches to aerial mangrove roots. It has, as general features a maximum length of 64 mm, a flattish and rather wide shell, with numerous wavy axial ribs. The shell is externally a dark grayish black, and internally a purplish to rosy brown with a narrow blue–gray border. At the umbonal end there are 3 or 4 extremely small elongated teeth on the edge of the shell. The anterior end of the shell is strongly hooked (Abbott, 1974; Andrews, 1975; Garcia–Cubas, 1987). The systematic classification of B. recurvus is given in section 4.9.1.

As mentioned before its systematic position has been described by Abbott (1974) who named it Ischadium recurvum and Andrews (1971) as Brachidontes recurvus; it has also been reported as Mytilus hamatus (Field, 1922).

The information related to this species is as scarce as for the rest of the genus.

Ecological studies on some United States eastern coast intertidal beds have reported its presence and the type of interactions within the community in these ecosystems (Field, 1922; Engle, 1945; Frey, 1946; Beaven, 1947; Engle, 1948; Chestnut, 1949 a,b; Morris and Rollins,

Table 1. Summary of the recent papers published on the genus *Brachidontes* or *Ischadium*

Genus	Species	Geographical Area	Type of Study	Author	Year
Branchidontes	*exustus*	Florida, USA	Ecology	Russel and Zischke	1977
B.	*mariori*	Italy	Ecology	Relini and Pisano	1977
B.	*solisianus*	Brazil	Physiology	Zuim and Mendez	1979
B.	*darwiniansus*	Brazil	Ecology	Avelar	1980
B.	*mariori*	Mediterranean	Ecology	Baudin	1980
B.	*exustus*	Brazil	Taxonomy-Ecology	Moniz-Dijck	1980
B.	*exustus*	N. Carolin (USA)	Morphometrics	Seed	1980
B.	*variabilis*	Italy	Ecology	Connto and Berdar	1981
B.	*solisianus*	Brazil	Physiology	Zuim and Mendez	1981
B.	*variabilis*	Italy	Geographical Distribution	Natale	1982
B.	*variabilis*	Suez Canal	Ecology	Aleem	1984
Ischadium	*demissum*		Physiology	Pamatmat	1984
Branchidontes	*spp*		Genetics	Singh and Green	1984
B.	*variabilis*	Red Sea - Mediterranean	Ecology	Barash and Danin	1986
B.	*solisianus*	Brazil	Ecology	Eston *et al*	1986
B.	*solisianus*	Brazil	Ecology	Petersen *et al*	1986
B.	*variabilis*		Toxicology	Unsal	1986
B.	*semilaevis*	Gulf California, Mexico	Ecology	Liucly and Raimoindi	1987
B.	*solisianus*	Brazil	Toxicology	Malagrino *et al*	1987
B.	*semilaevis*	Costa Rica (Pacific)	Ecology	Sutherland	1987
B.	*variabilis*	Hong Kong	Ecology	Morton	1988
B.	*variabilis*	Mediterranean	Ecology	Safriel and Sasson	1988

1977; Bahr and Lanier, 1981; Brown and Richardson, 1987; Frey et al., 1987).

Concerning its reproduction and larvae development, Nelson (1928 a,b) mentions B. recurvus in his studies of critical temperatures for spawning and ciliary activity in bivalves and work on the pelagic veliger behaviour of larval generarelated to Mytilus edulis. Allen (1962), described the gonad development and spawning of B. recurvus in Chesapeak Bay and Chanley (1970) described its larval development. The shell morphology, structure and mineralogy have been studied (Fuller, 1985, 1988; Fuller and Lutz, 1989). A few physiological studies report results of the influence of salinity and temperature on this species as discussed in Chapter 5 (Chanley, 1958; Allen, 1960; Nagabhushanam and Sarojini, 1965).

The papers produced in Mexico on this particular mussel are even more scarce. It has been reported in association with C. viginica oyster beds as a competitor (Leal, 1978; Camacho, 1980; Garcia, 1981; Lopez, 1985). Of possible value for the identification of B. recurvus, a genetic study on its karyotypic charaters reported that the number of bivalent chromosomes in meiosis is 15 and in mitosis there are 15 somatic chromosomes of the biarmed submetacentric type with a fundamental number of 30 (Diupotex et al., 1978).

There has been recent interest in B. recurvus as a feed for crustaceans. Anaya (1989) fed fresh mussels to the freshwater prawn Procambarus acanthourus. Villanueva (1990) used B. recurvus dry meal as part of a balanced diet to feed the freshwater prawn Macrobrachium acanthurus and Zamora (1990) tried feeding the giant freshwater prawn Macrobrachium rosenbergii with B. recurvus fresh meat as well as dry meal.

The only published studies on the settling pattern, ecology and culture of B. recurvus were carried at the Estero Horcones which is part of the Boca del Rio Mandinga estuarine system (Fig.1)(Farias and Salinas, 1986, 1987; Farias, 1988a,b). A detailed description of this locality is given in section 2.6., where this mussel is abundant in oyster beds and attached to the aerial mangrove roots. At the present moment it is unexploited and local fishermen consider it as an increasing pest associated with the oyster banks. They have to invest a great deal of time separating manually oysters from mussels and claim to notice an increasing number of B. recurvus in the oyster beds. Possibly this has been caused by changes of salinity in the system and the by the oyster fishery itself as explained in Chapter 5.

Even though the studies mentioned above were done at Estero Horcones, which represents the natural limit of the optimum hydrobiological conditions for the development of this mussel (Farias and Salinas, 1987), it was possible to establish a diagramatic model of the general B. recurvus life cycle (Fig. 4).

This cycle is similar to the general model presented by most of the mytilid mussels (Pares, 1987), but it is important to emphasise the importance of the available substratum and annual meteorogical cycles in exerting influence on general evolution of a mussel population in terms of growth pattern and survival (Fig.4).

Farias and Salinas (1986) were able to propose an explanation for the relative absence of organisms larger than 45 mm in the Boca del Rio Mandinga system on the basis of the settling pattern, in which the mussels normally settle on aerial mangrove roots, although experiments showed that they prefered oyster shell collectors to pieces of mangrove root.

Larvae are normally present during the rainy season (Lopez, 1985) and apparently float in the very surface layer of less saline water rather than the rest of the water colum. This forces the larvae to search for any

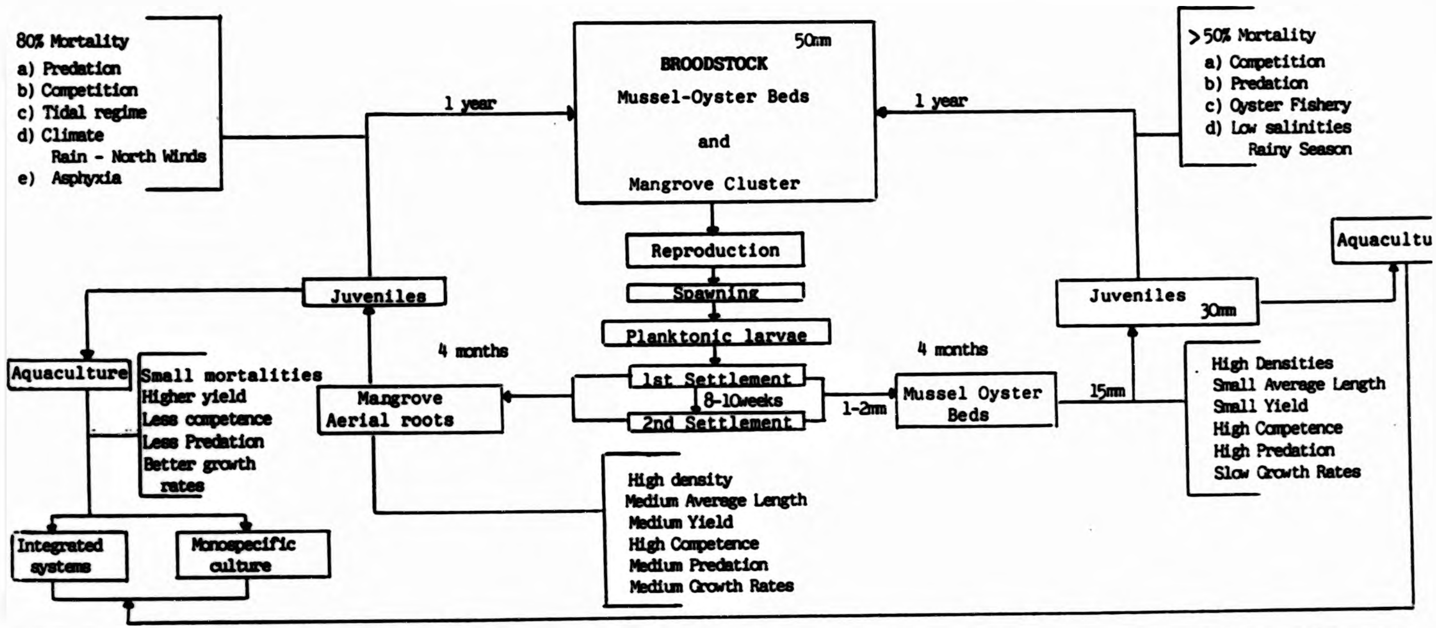


Figure 4. Simplified diagrams of the life history of the mussel Branchidontes recurvus and the alternatives for its utilisation (based on Farias and Salinas, 1987

available substratum at this depth, in which they do not have to compete with less euryhaline planktonic larvae (eg. oysters). The only suitable substratum is the Rhizophore mangle aerial roots. Within an annual cycle after the settling, the roots are subjected to the forces caused by the increase of current speeds in the rainy season and the winter North winds season. This combined with the increment of the total cluster weight and natural wood decay, causes the root with its cluster eventually to fall into the water, sinking into the soft mud bottom where most of the mussels die by asphyxia (Farias and Salinas, 1987).

In zones like Laguna Redonda and Laguna Mandinga (Fig.1), the predominant available substratum is provided by the oysterbeds. Apparently the higher salinity layer at this bottom level during the flood tides, predation and the competition for space and food with the oysters, limit the general performance and growth of the mussels.

Work to confirm and expand on the details of the life cycle of B. recurvus formed part of the objectives of the present study as described in the section of Objectives.

OBJECTIVES

General Objective

Considering the importance for Mexico of its eastern coastal estuarine ecosystems and the general lack of knowledge about their ecology, management and potential natural resources, such as the estuarine mussel Brachidontes recurvus, the present work aims to determine a suitable biotechnology to exploit this organism that could be related to a preliminary management policy for an integrated aquatic and terrestial multispecies production system.

Secondary Objectives

- Establish the basic annual hydrobiological cycle dynamic of the Boca del Rio–Mandinga estuarine system.
- Determine basic information about the biology, ecology and physiology of the estuarine mussel Brachidontes recurvus in relationship with the previously mentioned system.
- On basis of the above information conduct experimental field trials to determine the most suitable culture method for this organism.
- Test possible methods of utilisation of the mussel either for direct human consumption or as a feed for the culture of crustaceans.
- Propose a preliminary management policy designed to integrate aquatic with terrestrial polycultures, considering the environmental, economic and social characteristics of the local rural coastal community that in turn could be used as a base for the proper management of these important coastal ecosystems of the eastern coast of Mexico.

2. STUDY AREA

2.1. Location

The Boca del Rio–Mandinga estuarine system is located in the physiographic province known as the Leeward Coastal Plain.
This includes 250 km of coastline between Villa Rica Point and the San Martin Tuxtla Mountain Range. It is a flat plain which contains the lower courses of the Jamapa, Blanco and Papaloapan rivers.

The coastline is characterised by low, sandy, narrow beaches and is bordered by sandbanks and dynamic dunes (Tamayo,1962).

The Boca del Rio system is connected to the River Jamapa in the north of this coastal plain about 18 km south of the Port of Veracruz. Its limiting geographical coordinates are 19 00' and 19 06' N ; 92 02' and 92 06' W.
The system is directed North to South, whereas the adjacent coast has a Northwest–Southeast orientation (Fig.1).
The lagoons are separated from the sea to the North–East by a barrier of permanent sandbanks.

2.2. Communications.

Boca de Rio–Mandinga estuarine system is close by two main state roads; Veracruz–Anton Lizardo and Veracruz–Alvarado.
The first one goes through the city of Boca del Rio located at the mouth of the Jamapa River (Fig.1). It has a side road that leads to Mandinga Village which are of fishermen's cooperatives, is based, then to a touristic resort area and also to El Conchal Village and the Veracruz Country Club. These represent of the most important human settlements

along the shore of the various lagoons. This road runs parallel along a range of sandbanks that separate the lagoons from the sea coast.
The second road runs through Laguna Village. It is located at the south end of Laguna Mandinga, which is important for its pineapple production.
As mentioned previously the system is located 18 km south of most Mexico's important international port, Veracruz City. In January of 1990 a modern motorway was opened to connect the village of Boca del Rio to the city. Due to this innovation, urban development is expanding southwards heading towards the estuarine system, increasing the adjacent human population with inevitable environmental consequences.

2.3. Geology.

From the geological point of view, the estuarine system is included in Papaloapan Province, that forms part of the Veracruz Sedimentary Basin; it is covered mostly with recent sediments (Benavides, 1955).

The origin of the estuarine system is unknown; although considering it is a coastal lagoon, it must fit into the general scheme of coastal lagoon formation proposed by Phleger (1967), and therefore must be of recent origin.

Its sandy barrier is covered by sand dunes of considerable height. According to Zenkovick (1967) the wind can have two effects in the coast; in some cases it can produce eolic erosion and in some others, the wind can form sand dunes of different height and amplitude depending on the availability of sand at the beach. In this second case the vegetation plays an important role, fixing the sand and estabilizing the sand dunes which form.

In the zone around Mandinga, the sand banks have a maximum width of 6.27 km and a maximum height of 40 m (Vazquez–Yanes, 1971).

2.4. Climate.

The climate in the coatal zone is type A (w2") (w) (i') according to the classification proposed by Garcia (1964), i.e. hot and humid with a long dry season and summer rain. The average temperature ranges between 15 to 20 C and the annual relative humidity from 80 to 85%; atmospheric pressure is 1013.4 millibars; evaporation is 2991 mm and rainfall ranges from 1500 to 1750 mm annually.

From a general point of view there are two well marked seasons: a 'North Winds' season from September to March from when there are strong easterly and northerly winds originating in the north of the United States and Canada, reaching speeds of up to 150 km/h. These winds last from one day to one week, followed by calm extremely hot days; after one to four days of calm a new wind again hits the zone. The winds have a strong influence on the vegetation (Vazquez–Yanes, 1971). This season is characterised by low temperatures and scarce rainfall.

A second season, from April to August has abundant rainfall and high temperatures. The predominant winds are mild from the south–east or the west.

For practical purposes a third transitional season from March to June in between these main seasons can be identified; this period is characterised by a dry season lacking rainfall, an increase in temperature and a decrease in the frequency of the north winds.

2.5. Hydrography

The Boca del Rio-Mandinga system is connected to the outlet of River Jamapa (Fig.1). This river has its source in Puebla State at Pico de Orizaba volcano and receives water close to the outlet of the Cotaxtla or Atoyac river, that drains from Huatusco and part the Orizaba Valley. The total area of the basin is 3,350 km2 and it receives annually 1.895 million cubic metres of water (Tamayo, 1962).
There are no other important freshwater inlets into the estuarine system, but there is some infiltration from the sandbanks and a few summer runoffs appear mainly on the south side of Laguna Mandinga.

2.6. Description of the Estuarine System

The system consists of six parts forming a series of lagoons interconnected by relative narrow channels locally called " Esteros". This system has a total area of 3,250 ha (Chavez and Torruco, 1988a). The main components of this system are: El Conchal Estuary (Estero el Conchal), Larga Lagoon (Laguna Larga), Horcones Estuary (Estero Horcones), Redonda Lagoon (Laguna Redonda) also known as the Little Lagoon of MandingaChica (Laguna de Mandinga Chica), Mandinga Estuary (Estero Mandinga) and Great Mandinga Lagoon (Laguna de Mandinga Grande) (Fig. 1).

- Estero El Conchal. This estuary connects the system with the sea environment through the lower zone of the Jamapa River. The physical connection to the Jamapa River is a mouth approximately 100 m wide and 4 metres deep. This has become subjected to a gradual silting after the permanent dredging program was cancelled in 1985. The distance of the mouth to the sea is approximately 500 m. At the present time a sand bar has closed the direct communication to the sea, which existed according to a photograph taken during the Second World War

(Tamayo,1962).
The Estero El Conchal has a length of 3.536 km. Its average width and depth is 100 m and 2–3 m respectively.

– Laguna Larga. This lagoon starts at the the south–east of Estero El Conchal; it has a hour–glass shape and a length of 3.421 km. It reaches a width of 605 m in the north, 110 m in the central part and 577 m in the south. The average depth close to the shore is about 1m and in the central navigation channel 2 to 3 m.
Two temporary streams flow into Laguna Larga; Zavala stream in the north and Ahoga Sapos in the south.

– Estero Horcones. This estuary begins at the south–east of Laguna Larga. It has an average width of 50 m and a length of 2.695 km; the average depth in the shallow areas is 1.50 m and about 3 m in the navigation channel. It has a very sinuous shape and actually is possibly the area with less physical changes than other areas, especially in its vegetation.
In 1979 an artificial channel parallel to the natural connection was dredged to improve the communication between Laguna Larga and Laguna Redonda. The dimensions of the new channel are similar to those of Estero Horcones; being approximately 50 m wide and 2.5 km long; the depth is 3 to 4 m (Fig. 1).

– Laguna Redonda. This lagoon begins at the east of Estero Horcones.It has an ellipsoidal shape, a length of 2.134 km and a width of 1.584. The average depth is 0.80 m and 1.50 m in the central part where the navigation channel runs. On the west side there is a small permanent stream called Horconcillos, that drains the adjacent swampy areas.

– Estero Mandinga. This estuary connects Laguna Redonda with Laguna Mandinga Grande. It has a length of 1.650 km, an average width of 30 m and an average depth of 1m increasing to 4m in the navigation channel.

– Laguna Mandinga Grande. This lagoon is more or less triangular shape, being with 5.775 km wide in the south and6.490 km long. It has a uniform depth of 1.60 m and 2.5 m in the three main navigation channels (stations 8, 9, 10) (Fig. 1). After the dredging in 1979, a series of islands made up basically of dead clam shell and mangrove trees (Rhizophora mangle), emerged which run parallel to the east and west sides of the lagoon. These islands are very important habitats for migrant birds and for nesting sites of the local bird species during the late spring and early summer.

This lagoon connects with a larger number of streams including in the south the most important and permanent one called Arroyo Rosado and three smaller temporary ones: El Salazar, El Principal and El Ciruelo (Lopez, 1985).

2.7. Water Level

The water level fluctuations inside the estuarine system have not been well studied but are caused by a combination of the tides and the alternation of the rainy and north wind seasons.

The lowest mean levels are achieved during the dry season in the months of May and June; the maxima (1.2 m difference) occur in the rainy season (July to September), which can cause the adjacent areas to be flooded. This same effect can be observed as a consequence of the overflow being driven by a strong north wind. These surges can be up to 1 metre during verystrong north winds as reported for the Veracruz's neighbour state of Tabasco by Thom (1967).

According to Marmer (1954), tides in this area of the Gulf of Mexico are not a primary consideration. According to tide tables published by the

Geophysics Institute of UNAM, the absolute astronomical maximum and minimum tidal levels registered from 1953 to 1971 were 0.92m and -0.77m respectively (Anonymous, 1989). These extremes are also influenced by the time of year. Arreguin-Sanchez,(1982) reported the lowest tide in June of 1981 of - 0.27m with respect to the chart datum and the highest in December at 0.67m. The tides at Veracruz Port have been classified as mixed diurnal in pattern (Anonymous,1989).

Inside the estuarine system the fluctuation in water levels caused by the tides decreases towards the head of the system. At the seaward connection of Laguna Redonda, the phasing of tidal fluctuations occurs five hours later than at the coast and is approximately 40 % less in amplitude (Vazquez-Yanes, 1971). This author also reported that in Estero Mandinga tides only produce a change in the current direction i.e. without causing a significant variation in the water level and at Laguna Mandinga Grande there is no observable tidal fluctuation since its large volume can hardly be exchanged through the narrow and relative shallow Estero Mandinga (Fig.1). Thus the local pattern and velocity of water currents is more important to aquaculture considerations than the tidal movements themselves.

2.8. Vegetation

A very detailed description of the type and classification of the existing vegetation is given by Vazques-Yanes (1971), so only a summary of its most relevant aspects is mentioned here.

In areas such as the south of Laguna Mandinga Grande and the north of Laguna Redonda, which are subjected to periodical flooding by fresh water, it is very common to find vegetation dominated by *Pachira aquatica*. Its average height is 8 to 10 m; sometimes isolated individuals of *Avicennia germinans* and *Laguncularia racemosa* of more than 15 m can also be found (Vazquez-Yanes, loc. cit.).

Mangroves are an important element in the local vegetation. They are very typical all along the western side of the system; their composition is based on three species; an outermost zone of Rhizophora mangle and a more or less extensive platform with Avicennia germinans and less abundantly Laguncularia racemosa. The average height of the trees is 3 to 8 m. Within these mangrove areas different plants are associated depending on the the distance to the sea, such as; Rhabdaenia biflora. Batis marina. Lycium carolinianum. Spartina spartinae and Nymphaea ampla (Vazquez-Yanes,1971).

The aquatic vegetation can be divided into: emergent hydrophytes e.g. Crynum embecens: hydrophytes with floating leaves e.g. Nymphaea sp.: submerged hydrophytes eg. Ruppia maritima and free floating hydrophytes eg. Pistia stratiotes.

There are also important halophyte associations eg. Salicornia perenis in disturbed zones of Avicennia germinans. located in sandy soils mainly at the north end of Estero Conchal. Some palm trees, Sabal mexicana, can be found at the south and eastern border of Laguna Mandinga Grande (Vasquez-Yanes, loc.cit.)

2.9. Population

Boca del Rio Mandinga–Mandinga system belongs to the state of Veracruz, located on the coast of the Gulf of Mexico (Fig. 1). The population of the state in 1980 was 5, 388,000 people (8.1 % of the total Mexican population). The demographic rate of increase in population of 3.4 % per annum is above the national mean of 3.2 %. Population density is 74/ km2 compared to the National mean of 34. Amongst the most developed zones in the state are; Pueblo Viejo, Tuxpam, Boca del Rio and Alvarado (INEGI,1986). Over the last 9 years the literacy rate has been about 79% compared to the national mean of 85%.

Veracruz occupies the 21st place on a national gross product per capita basis and fourth place in terms of national fisheries production with 13 % (140,712 tonnes) of the total.

The state has 40 rivers and 116,000 ha of inland waters. It is the most important producer of oyster, blue crab, fresh water prawn and seabass in the country. Fisheries production in 1980 was 9.4% of the gross national product. The state fishing fleet represents 22% (10,479 boats) of the national total, of which 98% are used for coastal fishing. Fishermen's cooperatives own 41% of these and 60 % operate in the areas of Pueblo Viejo, Tamiahua and Alvarado (Fig.1).

In 1980, 33 % of the population received incomes less than the minimum salary of 1,500 Mexican pesos. About 1,796,000 people (51% of the state total population) were considered to be economically active.

In the Boca del Rio–Mandinga locality, the permanent population closely related to the estuarine system consists of approximately 5,000 people in La Laguna; these are mainly occupied with land farming activities. A further 3000 live in Mandinga Village and 2000 in Estero el Conchal; these are involved with fishing oyster (Crassostrea virginica), shrimp (Penaeus setiferus), blue crab (Callinectes spp.) and a few fish species. They are organized into two cooperatives with a total number of 157 official members. At the end of 1990 a new cooperative from La Laguna Village (formerly pineapple farmers) was formed and was awaiting final authorization from the Federal Fisheries Department (but already operating in practice). This has created social problems in terms of disputes over fishing grounds and environmentally it will represent a potential problem for the species exploited due to the increase in fishing effort. This situation also reflects the lack of planning in terms of the development and management of these ecosystems. These communities, especially the first two ones, lack elementary services like tarmac streets or a sewage disposal system. Thus untreated sewage is discharged directly into the estuarine system.

There are some other human settlements which are smaller in terms of population size but significant in terms of the potential or active environmental threat they represent to the whole estuarine system. The main ones are: a marina housing development located at the left (south–west) side of the connecting mouth of the system; a new housing development at Estero Horcones and the Country Club housing development at Laguna Larga (Fig.1).

All of these developments have the following in common; the people associated with them are extremely wealthy and were not born or raised near the lagoon; they have cleared extensive mangrove areas; refilled the land with clay and built retention walls or jetties; their relationship with the lagoon is based only on recreational interests e.g. water sports.

3. MATERIAL AND METHODS.

3. Material and Methods

Selection of the practical aspects of this study and choice of methods was based on the limited availability of facilities, materials and financial support provided during the two years of field work in Mexico. Due to unexpected cut-backs in the budget caused by political factors, some planned biological aspects of the work such as the filtration rate experiments with mussels, which were included in the original project proposal, had to be abandoned. It was considered that the main objectives of the project could still be achieved despite these constraints, but with less opportunity to test some of the projections concerning mussel production and economic performance used in the management model for the Boca del Rio–Mandinga System.

3.1. Preliminary Investigation.

A preliminary survey was carried out in the Boca del Rio– Mandinga system in March, 1988. To select the number and position of the sampling stations and suitable cultivation sites.

A 12 metre boat provided with a 30 hp Johnson outboard motor was used to survey the estuarine system for sites that were representative of the various hydrobiological conditions and environments where mussels occur, or which represented potential areas for mussel farming and related ecological studies.

The selection of hydrobiological sampling stations was based mainly on the following considerations:

1) The relative distance of each station from the mouth of the system. The primary aim was to establish stations in well marked salinity zones where possible, especially considering the clear influence of the seasons on salinity in this lagoon system (Arreguin, 1982).

2) The physiography of the area; as described in Chapter 2 and shown in Figure 1.

3) The proximity of human settlements such as housing developments, marinas or tourist restaurants.

4) The location of main channels and the system's general bathymetry in order to detect flow patterns of sediments, nutrients and planktonic organisms important in assessing sites suitable for studying the ecology and culture of mussels.

5) The location of the main navigation channels and water sports areas, used for water sking and fishing; these areas would have interfered with the study and were avoided.

In the case of sites for the ecological and culture studies, the following additional criteria were considered:

6) The natural distribution of mussels in the system; areas with a high relative abundance of mussels identified by Farias and Salinas (1987) were selected. Personal contact with the local oyster fishermen enabled the existence of different mussel–oyster beds to be located, especially in Laguna Redonda and Laguna Mandinga, since the study of Farias and Salinas (op. cit), was done only in Estero Horcones (Fig.1).

7) Different hydrobiological zones that could influence the presence of adult mussel populations due to their different water conditions, substrates, plankton, type of sediments, etc.

8) Areas that, due to their position in the system, lacked any important oyster beds or dense mangrove trees, but could be suitable for placing mussel collectors or suspended culture ongrowing systems, e.g. stations 8, 10 and 11 (Fig.1).

In the zones where mussels were growing naturally attached to the aerial roots of mangrove trees (Rhizophora mangle), the branches of selected trees were painted using orange oil paint so that they were easy to detect from the boat, especially in the initial stages of the work when the sites were still unfamiliar. This technique subsequently proved very useful for locating the clusters of mussels marked for study as explained in section 3.11.2.1.

These clusters were basically located in Estero Horcones and on the north west shore of Laguna Redonda. Although the surrounding vegetation in Laguna Mandinga also consists of mangrove trees (Vaquez – Yanez,1976), no mussel clusters were detected there on the aerial roots.

Most of the mussel population in Laguna Mandinga exists in the form of subtidal mussel–oyster beds. These mussels are a strong competitor for space and food with the American oyster (Crassostrea virginica) (Lopez, 1985); therefore, based on the information provided by the local fishermen, some of the important beds were marked using a mangrove pole. Later on, these were substituted by racks utilized for different culture experiments.

3.2. Sampling Stations.

Based on the criteria described in section 3.1., twelve sampling stations were selected in the system (Fig.1).

Routine physico-chemical analyses of the water were performed at all stations while the ecological and mussel culture studies were carried out at stations 4 to 12.

The main characteristics of the different stations are described below with additional imformation on why they were chosen. The water depth referred to at each station represents the low water spring tide (LWST) depth.

– Station 1. was important because of its proximity to the system's main connection with the estuarine zone of the River Jamapa. The site is subjected to gradual siltation with an approximate water depth of 4 m.

– Station 2. located in Estero del Conchal. This area is an important tourist settlement with restaurants that discharge untreated sewage directly into the system. It has been proved that this practice contaminates both the water column and oyster with faecal coliform bacteria (Farias et al, 1986). This site has one of the most important oyster beds in the system (Lopez, 1985). The depth is similar to that at station 1.

– Station 3 in Laguna Larga. This is one of the main areas which maintains a relatively good tidal flow down to the head of the system; it is also an area of good oyster settlement (Navarrete, 1989). Again the depth from the main channel is similar is to that at station 1 and 2, ie. 3–4 m.

– Station 4. Considered to be an important site according to Farias and Salinas (1987), because it marks the beginning of the system in which mussels tend to be more abundant. Based on the above report, the station was placed at the middle of the locality, where the average speed of the current and the presence of numerous clusters of mussels on the mangroves reflected apparently suitable conditions for Brachidontes. However the presence of dense mangrove vegetation bordering the estuary acts as a sediment trap, creating a very soft bottom beneath the aerial roots. This plays a very important role in regulating Brachidontes recurvus (Farias and Salinas, 1987) as explained in section 1.3.

– Station 5. This particular station was chosen for its hydrological characteristics, the existence of an important bottom mussel bed and the water current circulation pattern. The human settlement in its northeast portion is confined to four rustic restaurants, apparently limiting the degree of environmental impact compared to some other areas (e.g. stations 1, 2 and 3).

The site is connected to the main road by 4 km rural road, allowing transport of materials. The boat was kept in this locality because most of the routine work concerning the ecology and culture of the mussels took place in adjacent areas. Later, some complementary experimental trials on tilapia cage farming were performed at this station (Bibiano,1990). The sediment at this station was relatively firm and the water depth was 1.5 m.

– Station 6. This location has a soft bottom (mainly mud) and lacks bivalve beds. The station was located in a low energy zone typical of this area, but still under the influence of the prevailing ebb tidal currents. It was an important site for collecting juveniles of the shrimp, Penaeus setiferus, which were used in the nutrition experiments. The approximate water depth was 1.60 m.

– Station 7. This site provided a comparison of different conditions from the previous station, since it was located in a stronger energy zone, influenced by the proximity of the deep navigation channel that connects this lagoon with Laguna Mandinga. The site has a hard bottom mainly constituted from small pieces of oyster shell, sand and very little mud. The approximate water depth was 1.80 m.

– Stations 8, 9 and 10. All of these were in the main navigation channels of Laguna Mandinga. Stations 8 and 10 had an average depth of 1.60 m, a soft substratum and no bivalve beds. Station number 9 had a harder bottom composed of oyster shell pieces mixed with an oyster–mussel bed and very little mud. The water depth was of 2.50 m, with a strong water current, especially during ebb tide.

– Stations 11 and 12. These were important reference stations for studying hydrology and its influence on the community in the lagoon, because during the rainy season, the salinity can drop drastically to below 3 ppt (Amador, 1989; Navarrete, 1989).
Although the influence of the tide on the speed of the currents is very small, this area is exposed to dominant winds from the east during summer and to north winds later in the year; in combination with the fetch this generates strong waves (Milne, 1970). These conditions created a high energy zone at station 12, with a typical hard bottom of broken oyster shell, and scattered round oysters (Loosanoff, 1965) and a depth of approximately 2 m. At station 11, however, the depth was 1.50 m with a very soft muddy bottom, due probably to the shelter provided by small islands created after the dredging program in 1979 (De la Cruz–Aguero, 1985).

3.3. Installation of Stations.

In order to carry out the work related to the ecology and culture of Brachidontes, wooden racks were installed at stations 4 to 12. Originally the wood was obtained from trees that had were already been cut on land adjacent to the Instituto Tecnologico del Mar (ITMAR). This was convenient because there was no need to cut any trees within the lagoon system, but had the disadvantage that some of the wood rotted quickly in approximately six months.

The vertical posts of the mussel racks were 3 m long, and were driven firmly into the bottom using a mallet at a spacing of 2 m. One cross member of the same length was tied horizontally between each pair of posts (Fig.5).

There were no fixed installations for stations 1, 2 and 3 as these were only used for physico-chemical measurements. Their positions were simply fixed in relation to reference points along the shore, such as a restaurant or house.

3.4. Hydrology

3.4.1 Physico-Chemical Parameters.

Water samples were taken from the surface layer (0.5m) and from the bottom (ranging from 1.50 m to 3 m, depending on the depth of the station). These were collected monthly at stations 1 to 12, from May 1988 to September 1989, using a Van Dorn bottle. All of the measurements described below were taken in situ.

Temperature was measured using a Taylor mercury thermometer (–10 to +100 centigrade) (+ 1 C); salinity (ppt) with a portable refractometer (Erina Tokyo No.74105 NSRO) (+ 1 ppt); dissolved oxygen (mg/l), utilizing a digital oxygen meter POM 2 JENCONS; pH with a digital pH

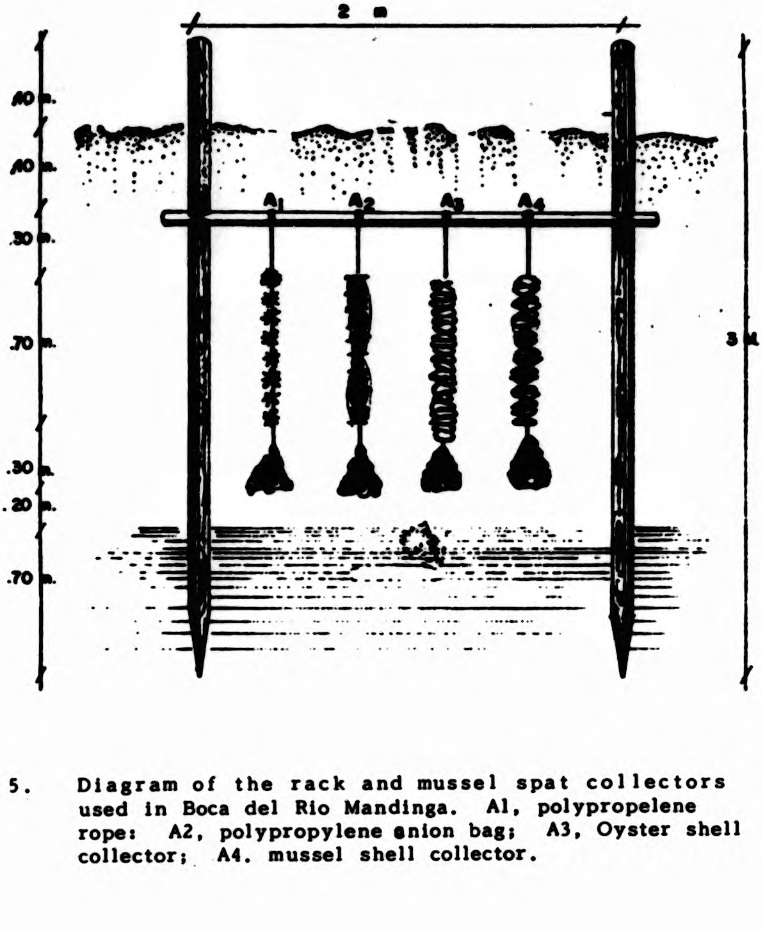


Figure 5. Diagram of the rack and mussel spat collectors used in Boca del Rio Mandinga. A1, polypropelene rope: A2, polypropylene onion bag; A3, Oyster shell collector; A4. mussel shell collector.

Meter CD 60 WPA (+ 0.1) and transparency (cms) with a Secchi disc. Sampling was normally undertaken between 9 h to 14 h and the state of the tide was noted. Logistal problems concerning the availability of the boat and the time required to sample at each of the 12 stations, made it impossible to visit each station at the same state of the tide each month. This is not considered to have affected interpretation of the data because of the weak tidal effects in the system (maximum average tidal range < 90 cm). Also the data were collected only to enable a general assessment of environmental conditions pertaining to site suitability for Brachidontes.

3.4.2. Photosynthetic Pigments

Monthly surface water samples were collected on the same dates at stations 4–12 using a 375 ml dark bottle; the sample bottles were stored in a covered box for transportation back to the laboratory.

For chlorophyll analyses, 375 ml of each sample were filtered through a Millipore filter funnel using Whatman 4.7 cm GF/C paper which had been previously incinerated in a muffle furnace at 500 C and weighed to the nearest 0.01 mg with a Mettler Analytical Balance. After filtration, the paper was rolled and placed in a test tube with 20 ml of neutralized 90% acetone, stoppered to avoid evaporation and stored in the freezer for at least 24 hours.

Once the pigments had been extracted, a sample was poured into a 7 ml capacity spectrophotometer cuvette (length 1 cm) and its absorbance measured immediatly at 665 and 750 nm in a SHIMADSU (UV–120–02) spectrophotometer, using 90% acetone in a marked reference cell.

For the determination of phaeo–pigments, two drops of diluted hydrochloric acid (1.2 M) were added and to mixed with each sample by inverting the cuvette several times with aluminium foil held over its mouth. The preparation was allowed to stand in the dark for about 10 minutes, then the absortion at 750 and 665 nm was remeasured.

Pigment concentrations were calculated based on the equations proposed in Stirling (1985).
The absorbance at 750 nm was subtracted from the corresponding absorbance at 665 nm before and after acidification, to correct the error caused by the turbidity of the sample.

Concentration of chlorophyll a in g/l=

$$26.7\,(Ao665 - Aa665) \times v2 / v1 \times L$$

Concentration of phaeo-pigments in g/l=

$$26.7\,([1.7 \times Aa665] - Ao665) \times v2/v1 \times L$$

where Ao665 and Aa665 are the corrected absorbances at 665 nm before and after the acidification, respectively.

v1 is the volume of water filtered in litres.
v2 ml is the final volume of acetone extract
L is the path length of the spectrophotometer cuvette in cm.

3.4.3. Particulate Organic and Inorganic Matter

To obtain the amount of organic matter per litre, after the chlorophyll determination, each Whatman paper was removed and placed in an oven at 85°C and left overnight. The papers were weighed to obtain the dry weight of total particulates; then placed in a muffle furnace at 510°C for 2 hours and re-weighed after cooling in a desiccator. All the weights for organic and inorganic matter determination, were measured to the nearest 0.01 mg.

The amount of organic and inorganic matter (ash) were calculated using the following formulae :

Total Particulated Matter = B – A

Particulated Inorganic Matter= C – A

Particulated Organic Matter = Total Particulated Matter (B) – Particulated Inorganic Matter (C)

where: A = initial weight of paper

B = weight of paper after drying 85°C

C = weight of paper after ashing

3.5. Sediments

Sediment analyses was conducted on samples collected from station 4 as this was considered a representative location with respect to the work on mussel ecology and cultivation.

Using a 1 litre capacity flask, soil was taken from near the mangrove aerial roots from a water depth of 1.5m, during the months of July, September and November, 1988 and January and May, 1989.

The samples were analysed at the Marine Geology Laboratory of the Veracruz Oceanography Station. The preparation and mechanical procedures applied to the samples were based on the Operative Manual of Marine Geology (1983) and the texture and type of sediments were determined using the Triangle of Shepard (Holme and McIntyre, 1984)

3.6. Detailed Study of Laguna Redonda

It was impossible to study the general dynamics of the whole Boca del Rio Mandinga system as this would have required work on its hydrological cycles, currents and bathymetry, requiring resources, manpower and funding far greater than those available. Instead one particular area, Laguna Redonda was selected for detailed hydrological study, for the following reasons:

– Amador (1989) in a study done to determine the abundance of oyster larvae (C. virginica) and availability of food in the Boca del Rio–Mandinga estuarine system, suggested that Laguna Redonda may act as a "funnel" where most of the elements that are carried by the tidal currents converge and remain for a longer period than in the rest of the system.

– The shape, bathymetry and location of the lagoon (Figs. 1, 9), makes it a suitable place to establish different aquaculture systems, such as fish cages, enclosures for crustaceans or suspended and bottom culture systems for molluscs.

– At the time of this work, there was still minimum environmental impact from human activities in Laguna Redonda.

– It was a suitable site to determine the behaviour of the tide within the whole system in terms of amplitude and delay with respect to the tidal predictions for the open coast.

– As explained in the Introduction, the government authorities were interested in dredging a deeper channel in this lagoon, so some information from work on its bathymetry and water currents was already been available.

3.6.1. Diurnal Hydrological Cycle

In order to investigate diurnal and seasonal changes in selected hydrological parameters in Laguna Redonda, two sets of measurements over 24 hours were conducted. The first, corresponding to the rainy season, started on June 19, 1989 at12:00 hrs during a spring tide. The second, was done during the north wind season, starting on November 14, 1989 at 09:00 hrs.

At the beginning of each 24 hrs cycle, a graduated post was placed vertically at the observation point so that the water changes could be measured. Every three hours the following parameters were recorded in situ: water height, temperature, salinity, dissolved oxygen and transparency; air temperature was also measured.

3.6.2 Bathymetry

Beacause of the government interest in dredging Laguna Redonda, it proved possible to arrange for a bathymetric study to be carried out with the cooperation of the Federal Electricity Commission, PEMEX and ITMAR, in May 1988.

A portable echo sounder (FERROGRAPH G580) was mounted in the boat and readings were taken between fixed reference points. In very shallow areas (< 1m) the depth was taken with a graduated pole. The position of the boat was registered using a 3 on-shore theodolites, based on points 1, 2 and 3 (Fig.9).

A detailed bathymetric profile of the south-west and the north-east connections of Laguna Redonda in relation to the rest of the estuarine system (Fig.10) was done on January, 1989. Depth was recorded every 10 m along a linear transect traversing each of these connections. In the shallower marginal zones, the depth was taken using a marked pole and in the deeper areas by means of a marked rope with a weight on the end.

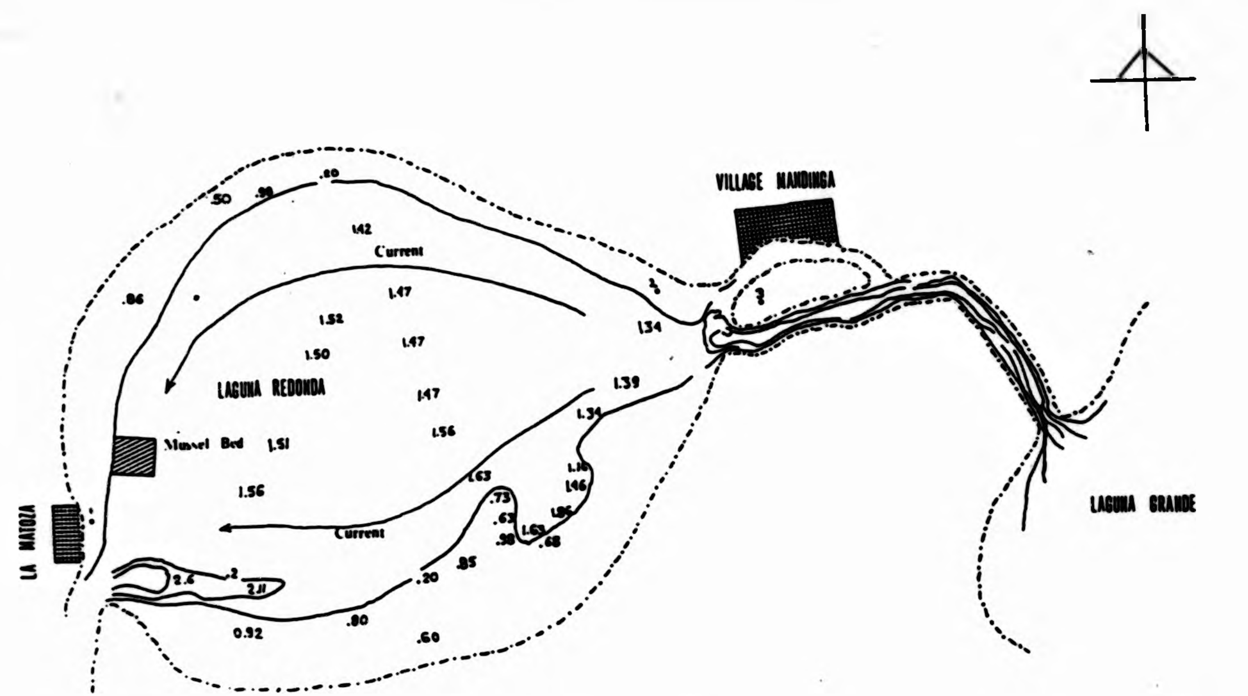


Figure 9. Bathymetry of Laguna Redondo in metres.

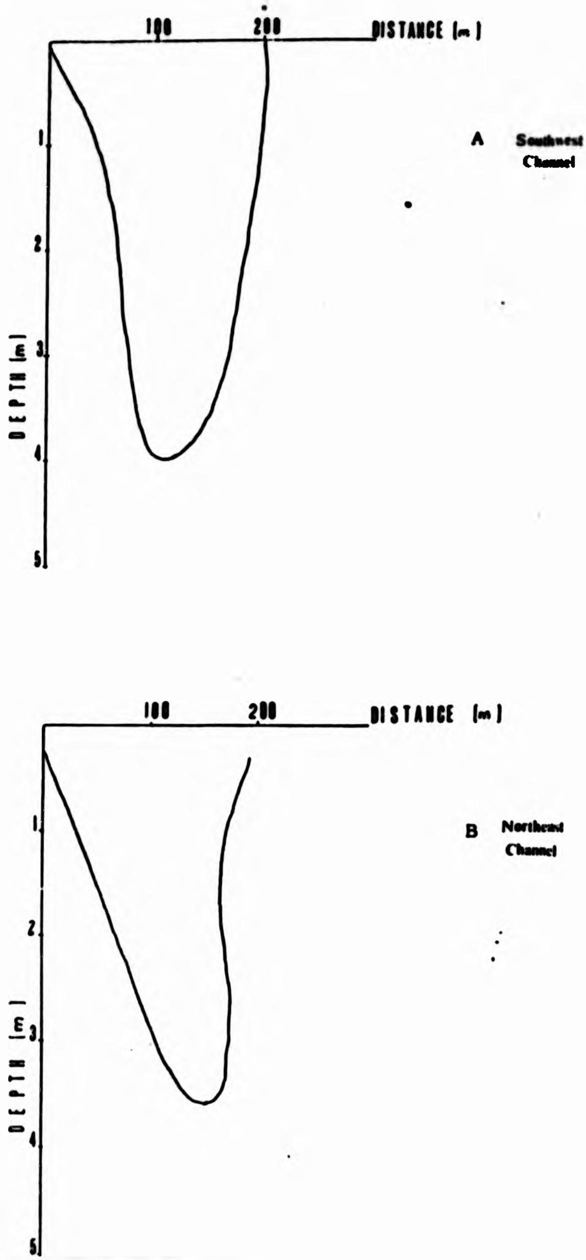


Figure 10. Laguna Redonda bathemetric profile of the south west (A) and the North-East (B) connections to the rest of the estuarine system

The measurements were done during a spring low tide.

3.6.3. Currents

This study was conducted in cooperation with the Secretaria de Marina, Direccion General de Oceanografia and Petroleos Mexicanos (PEMEX). The currents were measured at two different times of the year, the first one corresponding to the rainy season from 5 to 13 July 1988 and the second during the north wind season from 23 to 27 January 1989. The observations normally were done from 08:00 to 15:00 hrs, because the personnel who assisted in the operation were working according to this institutional time schedule. This meant that the currents were measured mainly during the morning ebb tides.

To determine the speed and direction of the currents, three drogues of different colors were released from the east side of the lagoon (19 02' 54"N and 96 04' 50"W). Their position was determined using theodolites located at points 1,2 and 3 (Fig.9). A boat with a flag remained at the side of the drogue while the position was recorded to facilitate its siting or to refloat a drogue which became stuck.

The daily wind speed and direction were provided by the Centro de Prevision del Golfo de Mexico, and the predicted tides were refered to from the tide graphic calendar edited by the Universidad Autonoma Nacional de Mexico (UNAM)(Instituto de Geofisica) (Anonymous, 1988, 1989).

3.7. Climate

The monthly measurments of air temperature, wind speed and direction, rainfall and insolation, for the period May 1988 to September 1989 were provided by the Centro de Prevision delGolfo de Mexico for the closest meteorogical station; this is located in the Port of Veracruz.

3.8. Taxonomical Identification

Twenty mussels ranging in length from approximately 15 mm to 70 mm were collected from Estero Horcones (Fig.1) and transported to the laboratory at ITMAR. Fouling organisms (eg. barnacles) were carefully removed and the shells brushed and washed. Using a scalpel, they were opened and the meat removed. The empty shells were dried in an oven at 80°C for 24 hours. The following external characteristics of the shell: size, shape, color, paleal line and the presence of teeth in the umbonal region, among others, were used to identify the organism down to species, with the assistance of various identification keys (Gonzalez, 1967; Andrews, 1971; Abbott, 1974; Leal, 1978; Garcia, 1981, 1987).

3.9. Ecology

3.9.1. Density and Distribution Pattern

For this study, only Estero Horcones and Laguna Redonda were considered. The mussel population at Laguna Mandinga is closely associated with oyster beds, and the size of this water body combined with the limitations of time and man power prevented detailed coverage. The former two localities were used as indicators of the type of distribution pattern and density associated with the two basic ways in which B. recurvus populations can be found in the system: clusters attached to the aerial roots of the mangrove tree R. mangle (i.e. living intertidally) or as a mussel bed on the bottom (i.e. living subtidally). Some additional effort was concentrated on the mangrove clusters to try to confirm the theory of the B. recurvus life cycle proposed by Farias and Salinas (1987), and because they represent the main potential source of mussel seed for semi–intensive culture.

3.9.1.1. Estero Horcones

As described in more detail in Chapter 2, this estuary looks more like a wide sinuous channel, bordered with mangrove trees (R. mangle) (Fig.1). Mussel clusters attached to the aerial roots of the mangrove trees are characteristic of this habitat.

Using painted trees as a reference, 41 aerial roots with their attached mussel clusters were collected in May, 1988 along a linear transect of approximately 1km. The mussels in each cluster were removed and counted.
A Chi square Test was applied to determine the distribution pattern of B. recurvus. The relationship between the variance and the mean of mussel

densisty was used to establish wether their distributions was random, contagious or regular (Moore and Chapman, 1986).

The average number of mussels per cluster was calculated from the 41 clusters collected and a further 17 clusters obtained from the monthly population sampling at station 4.

3.9.1.2. Laguna Redonda

The work here was concentrated on the North–west side of the lagoon at a locality called Matoza (station 5) (Fig.1). This is the only place in the lagoon where root clusters of mussels and a large mussel bed can be found together (Fig.1). This is possibly due to the currents at this location as explained in Chapter 5.

Clusters were sampled in the same way as in Horcones, except with the that only 7 clusters were collected and all the organisms were measured with a compass and a plastic ruler to the nearest 0.1 cm.

The mussel bed occupies approximately at Matoza an area of 20 x 20 m in a shallow zone (depth 0.7m) close to the shore (Fig.1).
Along a linear transect, a total of 6 samples were collected randomly every 3 metres, using a 0.25 x 0.25 m steel quadrat. The mussels were counted on board the boat. Again the analytical methodology proposed by Moore and Chapman (1988), was used to establish their distribution pattern.

3.9.2. Cluster Marking

Special attention was given to the population dynamics of the mussel clusters attached to mangrove roots, because they play an important role in the life cycle of B. recurvus (Farias and Salinas, 1987). The following studies were carried out on this subject:

– Cluster Marking. Apparently, after a certain period of time, the clusters increase in size and weight. As a result of these increases and the relatively stronger currents during the rainy and north wind seasons, the clusters tend to partially fall off or the mangrove branch breaks off and presumably most of the fallen mussels die (Farias and Salinas, 1987).

During the month of May corresponding to the dry season, 21 aerial roots with their associated clusters, were marked at Estero Horcones by tying on a stainless steel coded ring normally used to mark shrimp (placed on the base on the ocular peduncle) (Bagenal, 1978).

Using a measuring tape, the height (vertical distance between the top and the bottom of the cluster) and the circumference (distance around the hemisphere of the cluster and refered as width in Section 4.9.2.1.; Tables 7 and 8) were recorded in May 1988 and again March and August 1989. Recruitment or loss of mussels from the clusters were also monitored.

An additional 21 clusters from Estero Horcones were measured as described before.

Correlation Coefficients were calculated for the following combinations (Zar, 1984):

(1) Average individual length of the mussels in each cluster vs density of the cluster; (2) total weight of the cluster vs density of the cluster; (3) total weight of the cluster vs average individual length of the mussels in each cluster; (4) height vs width of the cluster.

3.9.3. Population Structure

Monthly samples of mussels from the natural populations in Estero Horcones, Laguna Redonda and Laguna Mandinga were collected from May 1988 to September 1989.

A cluster was taken to represent a sample at Estero Horcones (station 4); a bottom sample from the mussel bed at Laguna Redonda (station 5) and a bottom sample of the oyster–mussel bed at Laguna Mandinga (station 9).

Samples were placed in plastic bags, labelled and transported to the laboratory at ITMAR. All the mussels were removed and their lengths (maximum distance anterior to posterior) measured individually, using a metallic compass and a plastic ruler (to the nearest 0.1 cm).

From the data for each locality, a monthly length size–frequency was plotted using a 6mm length class interval.

In order to confirm the type of size distribution reported by Farias and Salinas (1987), probability paper was used to separate modes in the length–frequency distributions obtained (Cassie, 1954).

3.9.4. Growth

As reported by Farias and Salinas (1987), it was practically impossible to calculate a Von Bertalanffy growth curve for Brachidontes recurvus from analysis of the polymodal size frequencies (Cassie, 1957). This was confirmed after trying to analyse the size frequency distributions of the present work with the computer program ELEFAN KIEL (Brey et al.,1988).

The position of growth rings can be used in certain species as an alternative means to estimate growth (Bagenal, 1978; Seed, 1969b). A sample of 142 mussels obtained from a cluster ranging in length from 15 to 70 mm were individually measured as described in Section 3.9.3. and the number of rings counted. The number of rings associated with the mid value of each size interval was then calculated.

3.9.5. Reproduction

The annual reproduction cycle of B. recurvus is important to understanding the general dynamics of natural populations, and can provide basic information for the management of the resource as a fishery or for aquaculture purposes; both direct or and indirect methods can be used to help elucidate the life cycle. The former includes study of the animal's condition factor and histology, the latter the occurrence of mussel larvae in plankton samples and rate of spat settlement (Farias, 1988).

3.9.5.1. Condition Factor

The method used for measuring the condition factor of B. recurvus was based on Baird (1957). In parallel with the monthly samples for population structure, 20 mussels bigger than 45 mm were collected from each locality and taken to the laboratory. After scraping fouling organisms from each mussel shell, its total volume was measured by placing it into a 500 ml measuring cylinder, containing a known volume of water and recording the amount of water displaced. Each animal was then dried externally with absorbent paper and its length measured with a compass and a plastic ruler to the nearest 0.1 cm. The volume readings had to be taken immediately because a soon as the mussels are out of the water, a loss of internal shell cavity water occurs and sometimes they even float.

The mussels were opened using a disposable scalpel, and placed on absorbent tissue to remove the excess shell cavity water. The meat was removed from the shell and deposited in a glass container previously dried overnight at 85°C in the oven and weighed.

The total meat and shell volumes were determined by placing them separately into a 500 ml measuring cylinder, with a known volume of water, and reading the volume displaced. After measuring the volume the meat was deposited on an oven-dried and pre-weighed aluminium foil disc; this was then placed in an oven overnight at 85°C, cooled in a desiccator and reweighed.

The wet and dry weights of the meat were calculated by subtracting the weight of the container from the combined weights. The condition factor was calculated in two different ways using the following formulae (Baird, 1957):

Condition Factor 1 = Meat Volume / Shell Cavity Volume x 100

Condition Factor 2 = Meat Dry Weight / Shell Cavity Volume x 100

where

Shell Cavity Volume = Total Volume – Total Shell Volume

3.9.5.2. Gonad Histology

Coincident with the sampling for population structure, 6 mussels larger than 45 mm from each station were collected and transported to the ITMAR laboratory. They were subjected to the same cleaning procedure as described in Section 3.8., fixed with 10 % buffered formalin (one volume of tissue per 25 volumes of fixative) and stored after labelling. The formalin was changed every three months and in January 1990, the gonads of all the organisms were dissected out and stored in plastic stoppered containers for later processing at the Institute of Aquaculture, University of Stirling, Scotland.

In February 1990, all the samples for histology were processed according to the techniques described by Drury and Wallington (1980). The samples were casseted individually and left in a bowl of water to avoid drying. The samples were then processed overnight in an Automatic Tissue Processor (Histokinette 2000).
The cassettes were removed from the processor and placed in molten wax until ready to block out in a Tissue Embedding Center (Reinchert–Jung). The blocks were trimmed and sectioned at 5 micra with a microtome. The cut tissue sections were placed on slides, and dried in an oven (Windsor Incubator) at 60 C for at least one hour before staining with Harris's haematoxylin and eosin. Sections were mounted in balsam, protected with a cover–slip and labelled with a code number corresponding to the date and locality from which they were collected.
All the sections were examined with a microscope (Olympus CH), provided with 4x, 10x and 40 x objectives and the reproductive stage of the gonad was identified according to the numeric scale proposed by Seed (1975).
Using this scale, a Seed Mean Gonadic Index (S.M.G.I) can be calculated, from the following formula:

S.M.G.I. = Sum of (X)(Y)/N

where
X = Number of animals in each stage.
Y = Numerical rank associated with that stage
N = Total number in the sample

The values for numerical rank range from 0, when the gonads are immature or show no sign of reproduction, to 5 when the mussel is sexually ripe. An increase in the index, indicates sexual development and a decrease that spawning is in progress (Seed, 1975). To calculate the index males and females were included together.

To establish possible differences in the reproductive activity of mussels from the three localities (Estero Horcones, Laguna Redonda and Laguna Mandinga), the non parametric Mann–Whitney U Test (Zar, 1984) was applied to the ranks obtained from each locality.

3.9.5.3. Sex Ratio

From the observations of gonad histology the sex of each mussel was recorded and the data used to calculate the ratio of males to females in the population sampled.

3.9.5.4. Planktonic Larvae

The qualitative and quantitative presence of mussel larval stages in plankton samples is as useful indirect indication of the approximate time and the intensity of spawning by the adult mussel population (Farias, 1988).

Monthly samples of plankton were collected from May 1988 to April 1989, at stations 4 to 12 (Fig.1).

A standard plankton net (Griffin IES–22–001311 YRK–560–W), of 30 cm mouth diameter, 90 cm length and with a 0.075 mm mesh, was towed at each station from the boat for 5 minutes at a speed of 2 knots (3.6 Km/hr). The net was maintained within the upper 50 cm of the water column during towing. The samples were fixed with 10% buffered formalin and stored for later analysis.

The identification of B. recurvus larvae was done using the descriptions provided by Chanley (1970). Barnacle, oyster (C. virginica) and mussel larvae in one millilitre were counted using a Sedgwick Rafter cell (APHA,1980), after making the volume of the original sample up to 350 ml with 10% buffered formalin.

The number of organisms per cubic metre, were calculated using the following formulae (APHA, loc cit):

$$No/m3 = C \times V1 / V2 \times V3$$

C = number of organisms counted
V1 = volume of the concentrated sample (ml)
V2 = volume counted (ml)
V3 = volume of the net sample, filtered (m3)

The volume of the net (V3) sample was estimated from Stirling,(1985):

$$V = \pi r2\ d$$

where:
V = volume of the water filtered in m3
r = radius of net mouth in mm
d = distance of the trawl

3.9.6. Predation and Competition

Competition between mussels and other organisms for food and space was estimated on a semi-quantitative basis, mainly using data obtained during the study with mussel collectors (section 3.12.2.). Some qualitative observations were also recorded in the field and during the working sessions with the samples of mussels used for population structure analyses. Qualitative observations were also made on the organisms predating the mussel bed (station 5) and the mussel clusters attached on to Rhizophora trees.

3.10. Microbiology

As already stated, it is believed that Laguna Redonda acts a funnel for the whole system in terms of water exchange (Amador, 1989) so the following measurements were viewed as possibly indicative of contamination levels throughout the system. The experiments described below, had the objective of determining the concentration of coliform bacteria in the water column and in mussel meat from Laguna Redonda under different conditions.

3.10.1. Experiment 1

The concentrations of coliform bacteria in mussels held in suspension, and on the bottom, were compared between a locality close to human settlements and another zone relatively little affected by anthopogenic activities. For this purpose two different batches of mussels were placed at station 4 (Estero Horcones) and station 5 (Laguna Redonda).

A polypropylene onion bag containing 20 mussels with an average length of approximately 30 mm, were suspended at each station.

Another sample of 20 mussels was used to determine the initial concentration of coliform bacteria. Between March 15, 1988 and May 14, 1988, three more sets of analyses were conducted at 15 day intervals. A similar sampling programme was followed for mussels reared on the bottom.

The concentration of coliform bacteria, in the mussels and their

environment was estimated by the Most Probable Number (MPN) method (APHA,1970) and the quantification of mesophiles by the method of dilution and inoculation by dispersion (Cervantes, 1983).
Temperature, salinity, dissolved oxygen, transparency and pH were measured every 15 days, using the same methodology as described in the section 3.4.1.

3.10.2. Experiment 2

The concentration of coliform bacteria in the marine and coastal environment is influenced by the salinity (Barrow, 1981). Estuarine ecosystems like Boca del Rio–Mandinga are subjected to strong season salinity changes due to the influence of the rainy and dry seasons (Amador, 1989).
Two determinations of water-borne coliform bacteria were carried out at station 5 (Laguna Redonda), in the months of June 1989 and September 1989 representing conditions during the wet and dry seasons,respectively. On both occasions surface and bottom water samples were collected during ebb tide in 250 ml sterilized glass containers. Water temperature and salinity at the time of collection were registered using the methods described in Section 3.4.1.
Additional analyses were done in June on two samples of 10 mussels each, one from the bottom and one from a suspended onion bag that had been introduced one week previously. The mussel samples were taken to the Microbiology Laboratory of ITMAR and analysed using the Most Probable Number Method (MPN) (APHA, 1970).

3.11. Biochemistry

3.11.1. Proximate Composition

3.11.1.1. Natural Population

The monthly samples of mussels used to determine condition analyses (Section 3.9.5.1.), were utilized to carry out the proximal analyses in the Biochemistry Laboratory of ITMAR.

Moisture was obtained using the formulae cited by Farias (1983):

$$\% \text{ Moisture} = (A - B / A) \times 100$$

where:

A = Fresh meat weight

B = Dry meat weight

Crude protein was estimated by the Kjeldhal method (total protein = total nitrogen x 6.25) and lipids by the Soxhlet method. The total ash component was obtained after ignition of a dehydrated sample in a muffle furnace at 450°C for 12 hours (Egan et al., 1981). The percentage of carbohydrates was calculated by difference from 100% after subtracting the other fractions (AOAC, 1975).

3.11.1.2. *Penaeus Setiferus* Feeding Trial.

After obtaining the *B. recurvus* dry meal and fresh frozen meat as described in section 3.16.1.1.2., a sample of each including the commercial feedstuff, was analysed using the same methods as described in Section 3.11.1.1.

3.11.1.3. Macrobrachium rosenbergii Feeding Trial

Approximately 300 grams of dried mussel meal was obtained in August 1989 by drying fresh mussels as described in Section 3.9.5.1.. The meal was stored in a plastic stoppered container and kept in the freezer for later transportation to the Institute of Aquaculture, University of Stirling, where this feeding trial was done in February 1990.

The meal was analysed using standard procedures (AOAC, 1975).

The crude protein value was obtained by the Kjeldhal method using a KJELTC Auto 1030 Analyzer; lipids were determined by the Soxhlet method utilizing a SOXTEX System HT 1043 Extraction Unit; crude fiber was measured with a FIBERTEC System M 1020 Hot Extractor; and total ash content was estimated by ignition of a sample at 450°C (Egan et al, 1981).

3.11.2. Caloric Value

Samples of oven dried Brachidontes recurvus meal and (for comparison) oven dried and frozen flesh of Mytilus edulis obtained from Loch Etive, were analysed at the Zoology Department of the University of Glasgow. A Gallenkamp Ballistic Bomb Calorimeter (model CBB– 330 was used to process the samples in triplicate.

A calibration curve was derived using 1.4, 1.0 and 0.5 g of benzoic acid. Then, approximately 1.0 gram samples of the mussel tissue were burned in triplicate in the calorimeter bomb. All the readings were obtained using a galvanometer (Eurogalvanometer CAM Metric LTD) connected to the bomb calorimeter. On the assumption that the calorific value of benzoic acid is 24.45 kJ/ g, the values derived for the samples using the calibration curve, were transformed into kJ per gram of mussel. Finally these values were transformed into k cal/g mussel by using the relationship; lkcal = 4.18 kJ.

3.11.3. Fatty Acids

The fatty acid composition of the B. recurvus dry mussel meal was determined at the NERC Unit of Aquatic Biochemistry, School of Molecular and Biological Sciences, University of Stirling.

Total lipid was extracted from 1 gram of B. recurvus dry mussel meal by the method of Folch et al. (1957).

The fatty acid composition of the phospholipids was determined by Gas Layer Chromatography (GLC) for fatty acid methyl esters (FAME) in a Capillary Gas Chromatograph 436 with a CP Wax 51 fused capillary column (50 m x 0.032 m.m.i.d.) (Chrompack UK Ltd., London) using hydrogen as the carrier gas (Tocher and Harvie, 1988).

3.11.4. Amino Acids.

Samples of Brachidontes recurvus dry meal, Mytilus edulis dry meal and M. edulis frozen meat were analysed at the WELMET Protein Characterisation Facility, University of Edinburgh, using an Applied Biosystems 430A Amino Acid Analyser. The samples (each 1.0 mg) were first hydrolised in 500 micro litres of 0.1 % TFA.

3.12. Cultivation

3.12.1. Ongrowing

3.12.1.1. Experiment 1

In order to determine the growth performance of B. recurvus under suspended culture conditions in the different potential areas for its cultivation, 9 sections of commercial Pergolari net tubing (20 mm stretched mesh) (Bohle, 1970), each 50 cm in length, were suspended from the racks at stations 4 to 12 (Fig.1).

Mussels, ranging in length from approximately 29 to 34 mm with an average 31 mm, were collected from the natural population at station 4 after selecting them by hand using a 30 mm long mussel as a reference; each mussel was measured with a compass and plastic ruler to the nearest 0.1 cm.
Each net tube was filled with 50 mussels and placed out in the field in May 1988. After repeating the process described above, new bags were set up again in June 1988. Both attempts to rear mussels using this method failed due to heavy predation on the mussels by birds. The same problem has been encountered in mussel culture in Scotland (Farias, 1983). Based on this experience, a modified technique using polypropylene bags rather than Pergolari netting, was tried in a second experiment described below.

3.12.1.2. Experiment 2

One onion polypropylene bag (1.0 x 0.5 m), with a mesh size of 5 mm, stocked with 50 mussels with an average length of 38 mm, was suspended from the racks at each of the same stations (4 to 12). The mussels were collected, sorted and measured as described for experiment 1. The bags were placed in position in June 1988. They were recounted and measured in November 1988, and again in March and April 1989. General notes were taken on the organisms associated with the bags, and the condition of the bag material. The mussels were restocked in new bags and replaced in their original position, after each measurement.

The growth of mussels reared in experiment 2 was calculated using the specific growth rate equation (Chatterjii et al,1984):

$$G (\%) = (Ln\,L2 - Ln\,L1) / (T2 - T1) \times 100$$

where:

G = Specific Growth Rate

L2 = Length at time 2

L1 = Length at time 1

T1 = Time at time 1

T2 = Time at time 2

Ln = Natural Logarithm

Their survival was estimated by :

$$S (\%) = (No - Ntn) / No \times 100$$

where:

S= Survival

No = Initial number

Ntn = Number of organisms at a determined time.

To obtaine a condition factor for cultured Brachidontes, a subsample of 20 mussels (each larger than 45 mm), was collected from each station at the end of the experiment. The sampled mussels were analysed to derive values for conditon factor 1(CF1) and condition factor 2 (CF2) as described in section 3.9.5.1.

3.12.1.3. Experiment 3

In order to determine the average growth of mussels representing a wide range of sizes, group of mussels, juveniles obtained from experiment 2 of April, 1989, were transfered to an polypropylene onion bag was stocked with 116 mussels were stocked ranging in length from 7 mm to 37, with an average length size of 24 mm, and suspended from the rack at station 4. After 5 months (in October, 1989), the mussels remaining were counted and measured as described in Section 3.9.3.

3.12.1.4. Experiment 4

The length frequency distribution was examined and polymodal size frequency analyses was applied (Cassie, 1957) to determine whether different length (age) classes could be identified in the mussel cluster population after periods permantly suspended in the water column.
One aerial root with a cluster containing with approximately 400 juveniles of an average length of 15 mm, was introduced in May 1989, into an polypropylene onion bag and suspended from therack at station 4. The mussels were collected, counted and measured on October, 1989, as described in section 3.12.1.1.

Oysters (C. virginica) were also found to have settled by the end of experiment 4. These were also counted and the total weight of oysters and mussels was recorded.
Some qualitative observations were made during experiments 3 and 4 of the other organisms found in association with the mussel clusters. The condition of the material used to make the culture bags was also checked periodically.

3.12.2. Mussel collectors

The use of collectors is a simple technique allowing indirect monitoring of the reproductive cycle and larval activity of mussels at the moment of settling after the planktonic stage.

From the aquaculture point of view this information is very useful in managing species like [illegible], where the seed (spat) is supplied from the natural environment.

Four different materials were tested at stations 4 to 12 for their suitability as a collecting surfacefor mussel spat. Two materials, oyster shells and onion polypropylene bags were evaluated from May, 1988 to September of 1989; while two other materials, mussel shells and old nylon rope, were tested from May, 1988 to May 1989.

3.12.2.1. Preparation of collectors using different materials

(a) Oyster shell collectors were prepared according to the Japanese design (Navarrete, 1989); an average of 60 shells were perforated and threated onto a nylon rope, alternately facing up and down, and separated from each other by a 2 cm wide collar. The length of each collector was approximately 1.20 m.

(b) Mussel shell collectors were prepared by cutting material from new polypropylene bags. Three of these cut pieces were tied to a vertical nylon rope, each containing, an average of 30 shells with an average length of 40 mm. The shells were scraped clean before use.

(c) Polypropylene onion bags. These were purchased at a local market at a cost of 300 pesos each (US$ 0.16). They have an average size of 1.0 x 0.5 m and come in red,pink, green or yellow colors.

The bags were rolled up lengthwise and the ends tied up. An additional weight (a plastic bag containing a rock) was attached to one end as a mooring.

(d) Polypropylene ropes. Three groups of about 10 pieces of old rope (0.5 mm diameter and 20 cm length) were tied to a 1.20 mm other nylon line at 20 cm intervals. A similar mooring system to that for the onion bag collectors was provided.

3.12.2.2. General Operations

One set of the four different collectors was suspended from the racks at each stations (4–12). The collectors were removed each month and replaced by new ones.
The collectors were labelled after removal and transported to ITMAR, where they were hung for one week on a fence to expose them to the sun. After drying, any mussel, oyster, barnacle or polychaete settlements present were counted.

3.12.2.3. Counting procedures

(a) Oyster shell collectors. All the organisms on a random subsample of 5 shells were counted (on both faces of each shell). If there was a high number of barnacles present, the shell was carefully divided into four quadrants and only the organisms from one randomly chosen quadrant were removed and counted in order to reduce the amount of counting.

(b) Mussel shells collectors. One of the bags was randomly chosen and all the shells were analysed for settlements .

(c) Polypropylene onion bags collectors. All the organisms present in the bag were counted. The bags were shaken over a clean table to expel most of the attached organisms; the remaining ones were counted directly in the bags.

(d) Rope collectors. All the organisms on each of the three groups of ropes per collector were counted.

In the case of the oyster and mussel collectors, the total number of organisms attached was calculated by multiplying the counted average number of animals on each shell by the total number of shells making up each collector (60 oyster shells and 90 mussel shells per collector).

3.13. Effect of Salinity on Oxygen Consumption

The degree of adaptation of *B. recurvus* to estuarine salinity conditions was assessed using measurements of oxygen consumption as an indicator of its physiological tolerance to different salinities.

3.13.1. Oxygen Consumption.

In December 1989 a series of four experiments was conducted in the Biology Laboratory of ITMAR, to determine the oxygen consumption of mussels in terms of their weight specific respiratory rate (Bayne, 1976). The influence of salinity on respiration rate was compared between mussels of different sizes and between mussels inhabiting the subtidal beds and those forming clusters attached to the aerial mangrove tree roots.

3.13.1.1. Experimental Aquarium System

The measurements were conducted using 4 plastic containers (40 x 60 x 21 cm) with a capacity of 50 l. They were filled with filtered and aged marine water (35 ppt), stored in a covered tank at ITMAR and diluted to the following salinities: 32, 25, 15 and 4 ppt.
Glass containers of 250 ml capacity provided with airtight lids were used to house the mussels individually during the oyxgen consumption experiments.

3.13.1.2. General Procedure

Mussels were collected from stations 4 and 5 for the respiration experiments with mussels from mangrove clusters and subtidal beds, respectively; the in situ temperature was 19°C and the salinity 24 ppt.
They were transported to ITMAR, cleaned as described previouslys and placed in an aquarium containing clear water with salinity of 25 ppt for 24 hours prior to the experiments. Continuous aeration was provided with two electrically powered aquarium air pumps.

In each experiment, 22 mussels were introduced into an aquarium containing water adjusted to the experimental salinity for an acclimation period of two hours. The water was continuously aerated. The mussels were then numbered and introduced individually into the glass containers filled with aquarium water. These were stoppered and replaced back into the aquarium to keep them undisturbed and at the same constant temperature. The initial concentration of oxygen was recorded in the aquarium water initially and one hour later in each of the individual containers. The water temperature which was recorded with a mercury thermometer, remained constant at an average of 21°C ± 1°C during all the experiments.

The dissolved oxygen concentration and percentage saturation was measured with a BIBBY Oxygen Meter SMO1.

On completing each experiment, the mussels were measured with a compass and a plastic ruler and their dry meat weight was obtained using the same method as described for the estimation of condition factor (Section 3.9.5.1.).

3.13.1.3. Experiment 1

The objective of this preliminary experiment was simply to confirm than over one hour's duration the percentage saturation would not fall below 60 % so the organisms were respiring within their normal metabolic scope (Ross, 1987, pers. com.)

Fifteen mussels ranging in length from 35 to 48 mm, with an average size of 38 mm, were placed in the sealed containers for a total period of 4 hours while periodically measurements were made of oxygen concentration and the corresponding percentage saturation were made in the respiratory containers.

3.13.1.4. Experiment 2

The objective of this experiment was to determine the influence of three different salinities: 4, 15 and 32 ppt on the respiration rate of different sizes of animals from the mussel bed. The results obtained helped in the subsequent design of experiments 3 and 4.
One set of measurements was done at each salinity. The range and average size of the mussels used in the experiment are shown in Table 31.

3.13.1.5. Experiment 3

The objective of this experiment was to determine the influence of the above three salinities on animals of similar size from the mussel bed. The average sizes selected are shown in Table 31.

3.13.1.6. Experiment 4

In this experiment the objective was identical to that of experiment 2 exept that the mussels used were from the aerial root clusters. The range and average size of the selected mussels is shown in Table 31.

3.14. Utilisation of Brachidontes recurvus in shrimp feeds

The dramatic increase in the production of farmed crustaceans, particularly shrimps, has stimulated the search for new protein sources to be used as part of their artificial diet (Halver, 1979). Research on the cultivation of caridean and penaeid shrimps has resulted in many published papers on their nutrition (New, 1976), but very few on the utilisation of potential local native protein sources that could decrease the high cost of feed production. Two experiments using the mussel B. recurvus as a potential food for on-growing the shrimp, Penaeus setiferus and the fresh water prawn, Macrobrachium rosenbergii, were carried out. This work included an evaluation of the composition and nutritional value of B. recurvus as a possible component of balanced diets for these two cultured organisms.

3.14.1. Experiment 1. Penaeus setiferus Trial.

In these experiments Brachidontes recurvus was utilized in fresh and in dry meal forms as a feeds for juvenile Penaeus setiferus. A commercial feedstuff served as a control diet.

The experimental trial was performed at the Aquaculture Laboratory of ITMAR, Veracruz, Mexico.

The experimental system consisted of a set of three independent small recirculation units constructed using plastic containers of dimensions 40 x 60 x 21 cm and 50 l capacity. Each unit had a biological filter made up of active charcoal and 1mm nylon mesh; the water was recirculated using an airlift at a rate of 16 to 55 l/ hour allowing a total water exchange in the system from 7 to 26 times/ day.

To maintain a good permanent water flow the filters were backwashed every five days and 40% of the water in each unit was exchanged every ten days with fresh sea water.

Each holding tank was provided with 9 compartments made up with 1mm nylon mesh in order to keep the animals separated.

Room and water temperature was registered daily with a Taylor mercury thermometer; pH was measured with a digital pH meter (Camlab SA/LD014); dissolved oxygen with a digital oxygen meter (POM 2 Jencons) and salinity with a portable refractometer (Erina Tokyo 74105 NSRO). Every week ammonia was determined using the phenol–hypochlorite method for sea water (Stirling, 1985).

Three different diets were used:

– Diet 1. Frozen mussel.

– Diet 2. Oven–dried mussel meal

– Diet 3. A commercial feedstuff (Aqualine).

The mussels were collected in August 1989 from the mussel bed at station 5 (Fig.1). The meat of each mussel was removed from the shell, chopped into fine pieces and stored in a freezer. Part of the meat was weighed and placed for 24 hours in an oven at 85°C, dried in a desiccator and reweighed. The dry mussel were finely powdered with a mortar, placed into plastic stoppered containers and stored in the refrigerator.

The diets were supplied initially at 10% of the average shrimp body weight; this was reduced to 5% during final stage of the experiment.
No binder was used with the dry mussel meal and prior to its administration it was mixed with a little water to form a paste and placed into empty mussels shells which served as feeders. This facilitated recovery of any uneaten food and kept it separate from faeces voided by the shrimp.
Proximal analyses (moisture, crude protein, lipid, total ash and carbohydrate) were performed on the diets according to the methods already described in section 3.11.1.

Juvenile *Penaeus setiferus* were obtained in August in water of 13 ppt salinity and 30°C on the north–east side of Laguna Redonda (Fig.1), using a nylon cast net (10 mm mesh size) thrown from the boat by a local fisherman. The animals were picked from the bottom of the boat where they were deposited by the fisherman and placed into a plastic 50 l capacity container. This was provided with branches to reduce stress and to stop the shrimp jumping out of the container. They were immediatly transported to ITMAR and placed for 48 hours into 1000 l fiber glass tanks with brackish water at 20 ppt salinity and 27 C temperature to acclimate.

The individual length (rostrum spine to telson) of twenty seven shrimp was measured using knife-edge calipers to the nearest 0.1 cm and they were weighed to the nearest 0.01 g on a Mettler Analytical Balance (model H20). These measurements were done every 10 days starting in August and finishing in September 1989. One shrimp was randomly deposited in each chamber of the holding tanks. The shrimp were fed once daily in the afternoon.

The number of times the shrimp moulted was recorded, and the moults were removed from the chamber before being eaten.

The natural phototoperiod of approximately 13 h and 11 h darkness was used during the experiment.

During the experiment, some shrimp died in the process of moulting, and after checking the physico-chemical parameters, an analyses to determine whether these mortalities were due to the presence of Vibrio sp. and Aeromonas sp. was carried out, using the Agar BTP Teepol and Dispersion on Surface methods respectively (Cervantes, 1983). Vibrio and Aereomonas were both identified and their probable effect on the experiment is discussed in section 4.17.1.

Material to estimate digestibility in terms of assimilation efficiency was obtained by separately collecting the faeces and remaining food by siphoning the water into a 250 ml beaker. The water was filtered and the amount of organic matter was determined with the same methods described in section 3.4.3.

The following equation was used to calculate the assimilation efficiency (Conover, 1966 cited by Condrey,1972):

$$A.E. \% = (F - E)/F \times 100$$

and

$$F = PA - S$$

where:

E.A. = Assimilation Efficiency

F = Dry weight of the ingested food

E = Dry weight of the faeces

S = Dry weight of the food not consumed

PA = Dry weight of the food administered.

The Food Conversion Ratio was calculated using the formula:

$$FCR = A / B$$

where:

A = Total weight of food administered to the animals

B = Total weight gained by the animals

The specific growth rate for length and weight was calculated using the following equation (Chatterjii et al, 1984):

$$SGR \% = Ln\ A - Ln\ B / T2 - T1 \times 100$$

where:

SGR = Specific growth rate

A = Length or weight at time T2

B = Length or weight at time T1

Ln = Natural logarithm

The survival rate was estimated as:

$$S\% = (No - Ntn) / No \times 100$$

where:

S = Survival

No = Initial number of organisms

Ntn = Number of organisms at tn time.

3.14.2. Experiment 2. Macrobrachium rosenbergii Trial.

The suitability of B. recurvus as food for the giant fresh water prawn Macrobrachium rosenbergii. was tested in experiments conducted at the Prawn Unit the Institute of Aquaculture, Stirling University.

Local blue mussels, Mytilus edulis , were also tested for comparison. The mussels were prepared in the following forms; B. recurvus– dried meal; M. edulis – fresh meat, frozen meat and dried meal. The experimental system consisted of a row of eight, polythene tanks with dimensions of 39.5 x 60 x 42 cm and an average water depth of 15 cm, maintained using a swinging arm outflow pipe.

Water was supplied from a recirculating system at a flow rate ranging from 0.3 l/min to 1.2 l/min into each tank. Temperature was maintained to a constant 27°C by means of electric immersion heaters in the recirculating system. The levels of fine particulate organic matter, ammonia and nitrite levels were maintained at a low level by passing the recirlculating water through a settling tank and a biofilter.

Every three days the debris in the tanks was removed with a small hand net (0.5 mm mesh size).
Each week, water temperature and dissolved oxygen were measured with a YSI 57 Oxygen Meter; pH with a PW 9409 digital pH Meter and nitrite using a TetraTest Kit.
Each holding tank was provided with 8 cylindrical containers
18 cm high and 11 cm diameter, made up from a circular base of rigid 3 mm plastic mesh framed with a ring of PVC pipe and a 1mm mesh nylon wall, and cemented with silicon aquarium adhesive. A sheet of 0.5 mm mesh nylon sheeting was placed over the tops of the cylinders to prevent the animals from escaping.

Four different diets were used during the experiment:

– Diet 1. B. recurvus dry mussel meal.
– Diet 2. M. edulis dry mussel meal.
– Diet 3. M. edulis fresh frozen meat.
– Diet 4. M. edulis fresh meat.

The B. recurvus mussel meal was made from animals collected during late September 1989 from the subtidal beds at station 5. They were processed and stored as described in Section 3.14.1.2.
In the case of the blue mussel M. edulis, the organisms were obtained from a suspended culture system at Loch Etive (Scotland), in February 1990.

The meat was removed from the shell; part of it was finely chopped and stored in a freezer at – 10 C and the rest was dried in a oven for 8 hours at 100 C. The dry mussel meat was powdered with a mortar and stored in a refrigerator at 2 C.

The diets were administered initially at a daily rate of 15 % of the prawns's body weight; this was reduced to 10%, from the second week. Mussels from Loch Etive (M. edulis) were kept alive for the first 10–20 days in a 100 l recirculating system. To obtain fresh mussel meat, at least three mussels were killed and the meat removed from the shell and chopped before feeding.

The frozen mussel meat was taken out of the freezer one day before it was given to the prawns.

Carboxymethyl cellulose (sodium salt) was added at a rate of 2% by weight to the dry mussel meal as a binder; after adding a few drops of tap water the mixture was stirred into a moist soft paste. This last procedure was done daily to ensure that the feed was fresh and acceptable to the prawns. The diets were placed into small circular plastic dishes containers (30 mm diameter) in the experimental tanks enabling observation of feeding and retrieval of the uneaten food.

The prawns were fed once a day in the afternoon.

Proximal analysis was performed on each diet according to the methods described in section 3.11.1.

A sample of 5 M. edulis gonads from the first Loch Etieve stock were processed histologically (using the technique described in section 3.9.5.2.) in order to confirm their state of maturity as this strongly influences the nutritional value of mussels.

A total of approximately 100 juveniles of Macrobrachium rosenbergii. were chosen randomly from a stock of animals that were produced from a single brood spawned at the Prawn Unit of the Institute of Aquaculture, Stirling University. They were measured (+0.1 cm) and

weighed (± 0.01 g) using knife-edged calipers and an analytical balance (Sartorius) respectively, and deposited one at a time into one of the cylindrical containers; these were marked with a number from 1 to 64.
Two holding tanks were used for each treatment. Eight containers were introduced in each, using a table of random numbers (Zar, 1984) to select the containers.
The experiment lasted for 30 days; the prawns were measured and weighed every 10 days.
The number and date of individual moults were recorded but the moults were not removed from the containers. Animals which moulted were not fed for the 24 hours after moulting.

Food conversion ratio, specific growth rate and survival were calculated as described in Section 3.14.1.

3.15. Marketing of mussels

A preliminary investigation of the actual and potential market demand for *Brachidontes recurvus* in the area of the Port of Veracruz and its suburbs was carried out with the following objectives:

1) To identify and quantify the market for mussels and describe its main characteristics.
2) To determine the main limitations of the market related to supply and demand.
3) To enumerate the enterprises involved in trading mussels commercially.
4) To describe marketing characteristics, such as pricing, presentation of the different mussel products and labelling of brands.

Some of the information on marketing was obtained from official governmental agencies such as the Secretaria Federal de

Pesca(SEPESCA), Instituto Nacional de Geografia, Estadistica e Informatica (INEGI).These are the offices of the Federal Secretary of Fisheries and National Institute of Geography, Statistics and Information respectively.

Those involved in the interviews and a questionnaires (20 and 100 people respectively), had diverse backgrounds: members of the local scientific community, politicians, academics businessmen and others in local commerce.

The form and content of the interview and questionaire are reproduced in Appendix 1.

4. RESULTS

4.1. Climatic observations

Various climatic parameters for the port of Veracruz during 1988–89 are presented in Fig 11.

The air temperature showed a well marked seasonal fluctuation with high temperatures (29°C) from May to September and a gradual decrease (22°C) from October to February (Fig.11A).

The average monthly wind speed showed an inverse relationship with the temperature, increasing from September to February, corresponding to the north wind season, as can be seen from the predominant wind direction (Fig. 11C).

Rainfall presented a similar pattern to that of temperature with monthly maxima in June to August (500 mm) and a distinct dry season from November to May (Fig.11B).

The number of hours of insolation was not available for 1989. In September 1988 the values started to decline (Fig.11D) in parallel with the decrease in temperature (Fig.11A). The minimum daylight hours was registered in January (70 h).

4.2. Physico–Chemical Parameters.

The seasonal changes in the different hydrobiological parameters measured in Boca del Rio–Mandinga lagoon during the period from May 1988 to September 1989, are summarised on a monthly basis in Figure 6. Overall average values over 18 months at the different stations are shown in Table 2.

– Salinity. This showed a well marked cycle over the year with the lowest values from August to November and with minima of 1.6 and 2.4 ppt in September for surface and bottom salinities respectively. The highest values were observed from January to May with salinities

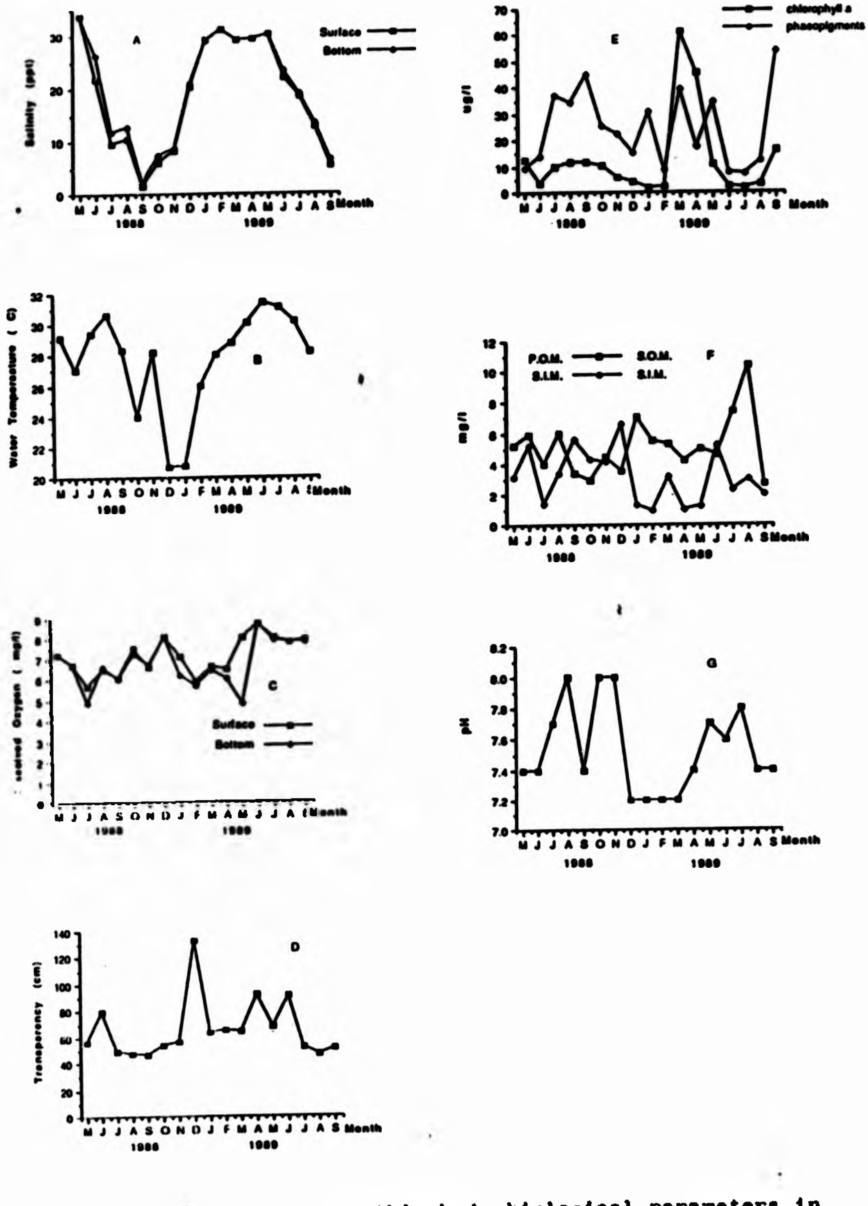


Figure 6. Average monthly hydrobiological parameters in Boca del Rio-Mandinga estuarine system over the experimental period. A, surface and bottom salinity; B, water temperature; C, surface and bottom dissolved oxygen; D, transparency; E, chloropyll a and phaeopigments; F, particulated organic matter (POM) and suspended inorganic matter (SIM); G, pH.

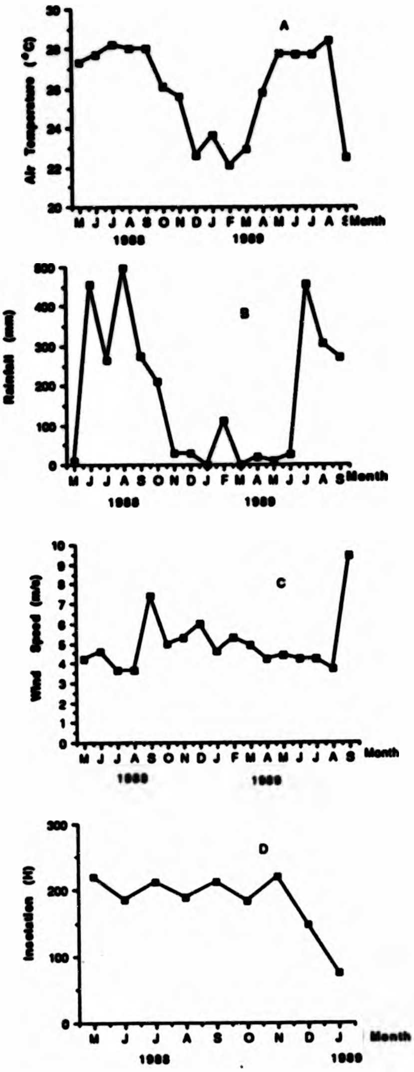


Figure 11. Monthly average climatic parameters for the Port of Veracruz over the experimental period. A, air temperature; B, rainfall; C, wind speed; D, insolation.

ranging from 31.2 to 33.8 ppt (Fig. 6A).

Significant statistical differences (Paired t Test; $p<0.01$) were found between the surface and bottom salinities.

One Way ANOVA showed no differences between the different sampling stations, although there was a tendency to find higher values and greater stratification at stations closer to the sea (Table 2).

– Temperature. This changed gradually over the year with lowest values of 20.7– 20.8 C in December–January, increasing to 30– 31 C in June–July (Fig. 6B). There was no evidence of vertical temperature stratification. Higher temperatures tended to be found at the stations located away from the sea (Table 2), but no statistical differences were observed between them ($p<0.05$).

– Oxygen. The oxygen values fluctuated irregularly with maximum a value for the surface and bottom water layers of 8.7 mg/l in June,1989 and a minimum of 5.7 mg/l in February at the bottom (Fig. 6C).

No significant statistical differences were detected between the surface and bottom readings, or between equivalent oxygen values for different stations ($p<0.05$). There was a tendency for higher values at the stations towards the head of the system (Table 2), but this was probably due more to the time of the day when the sample was taken as discussed later (Section 5.1).

– pH. The values ranged from 7.2 to 8 with a tendency to be lower during November to February when, presumably biological activity was more intense than in the remaining months (Fig 6G). No significant statistical differences in pH were found between stations (Table 2).

– Transparency (Secchi Disk). This showed well marked seasonal fluctuations, reaching its maximum values into the range from 91 to 132 cm in December, April and June; the lowest values were registered in July to September of both years, ranging from 46 to 49 cm (Fig. 6D).

Table 2. Overall averages of hydrological parameters at each station during the experimental period at Boca del Rio-Mandinga and results of One Way ANOVA and Multiple Range Test between stations (NS: not significant; S significant at $p \leq 0.05$; superscript letters indicate significant differences between station means).

Station	1	2	3	4	5	6	7	8	9	10	11	12	Mean	Anova
Parameter														
Surface Salinity (ppt)	20.7	21.7	21.3	21.	20.3	19.9	19.0	18.4	18.7	18.	15.9	17.1	19.2	N.S
Bottom Salinity (ppt)	22.7	23.3	22.2	20.5	20.7	90.1	19.6	18.3	18.7	18.8	17.0	18.3		N.S
T°C	27.4	27.6	27.7	27.6	28.1	27.8	28.1	28.0	28.5	28.8	28.2	28.1	27.9	N.S
Surface Dissolved Oxygen (mg/l)	5.9	6.5	6.9	6.7	6.7	7.1	7.1	7.1	7.5	7.5	7.4	7.3	7.06	S
Bottom Dissolved Oxygen (mg/l)	6.1	6.2	6.3	6.4	6.6	6.5	6.7	6.7	7.0	6.9	6.9	7.0		N.S
pH	7.4	7.4	7.4	7.3	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.3	7.5	N.S
Water Transparency (cm)	76.6	73.6	72.2	60.0	60.4	64.5	69.2	51.7	74.2	56.5	50.1	94.1	65.0	N.S
Chlorophyll a (µg/l)	-	-	-	12.8	9.3	12.5	12.1	12.0	14.7	12.5	12.1	11.9	12.0	N.S
Phaeopigment (µg/l)	-	-	-	25.7	23.7	31.9	21.2	2.2	28.5	22.4	28.7	23.2	24.2	N.S
Particulated Organic Matter (mg/l)	-	-	-	5.7	5.5	4.6	5.1	5.7	5.5	4.6	5.1	4.6	5.1	N.S
Inorganic Matter (mg/l)	-	-	-	3.1	3.4	3.6	3.1	4.1	3.7	3.6	3.8	3.1	3.4	N.S

Transparency at station 12 was significantly greater ($p \leq 0.05$) than measured at the othere stations because this location has coarser bottom sediments with little fine particles. There was no clear relationship between transparency and the distance of each station from the system mouth (Table 2).

4.3. Photosynthetic Pigments.

- Chlorophyll a. Two main peaks in chlorophyll a concentration were observed during the experimental period; the first one from July to September, 1988, with a maximum value of 11.7 µg/l in September anda second from March to May 1989 reaching 61.3 µg/l in March, 1989) (Fig. 6E). No significant statistical differences were observed between station means (Table 2).

- Phaeopigments. Several irregular peaks in this paramenter with some very low values, were obtained for this parameter, possibly caused by their closeness to the method's limit of detection (Fig. 6E). No significant statistical differences were found betweeen the stations means (Table 2).

4.4. Suspended Organic and Inorganic Matter

- Organic matter. The values of organic matter presented 3 irregular peaks: June 1988, January and August 1989 (Fig. 6F), but these bear no relationship to the chlorophyll a maxima observed. The average values for the stations did not show any statistical significant differences (Table 2).
- Inorganic matter. This showed five irregular peaks, during June, September and December of 1988; and June and August of 1989. A maximum of 6.6 mg/l and a minimum of 0.9 mg/l were registered in the months of December, 1988 and February, 1989 (Fig. 6F). No significant

Table 3. Particle composition and classification of the sediments analysed at Station 4

Month	Composition % by weight			Sediment Type
	Sand	Silt	Clay	
1988				
July	11.2	70.6	18.2	Silt - Clay
September	15.0	48.0	37.0	Silt - Clay
November	15.0	60.0	25.0	Silt - Clay
1989				
January	42.0	24.0	34.0	Clay - Sand
May	19.0	49.0	32.0	Silt - Clay
Average	20.3	50.3	29.3	

Sand particle size: 0.1-0.5mm, Silt 0.002-0.063mm, Clay 0.00006-0.002mm statistical differences were observed between the sampling stations (Table 2).

4.5. Sediment Particle Size

Table 3 shows that at station 4 the sediments were predominately silty–clay. Sand is a minor fraction of the sediments at this location with an average of 20 %, with an increase in the percentage of sand particles in January 1989 to 42%. The major fraction is silt (50%), while 29% is clay. The percentage of sand particles in the sediment increased in January 1989 to 42% due to an increase in current velocity which scoured away finer particles

4.6. Diurnal Hydrological Cycle

Hydrological and climatic data recorded at Laguna Redonda during two diurnal cycles are illustrated in Figures 7 and 8.

The average salinities during both 24 hour periods were similar, 22.0 and 21.3 ppt, respectively but presented a different pattern with respect to the influence of the tide (Figs. 7B, 8B). In June, the salinity did not increase as expected with the the flood tide as clearly seen in the November cycle (Fig. 7B). This was confirmed by finding a significant correlation between tidal height and salinity in November ($r=0.857$; $p \leq 0.05$) but not in June ($r= 0.098$). There was very poor correlation between tidal height and temperature or dissolved oxygen ($p \leq 0.05$).

Dissolved oxygen seemed to be more influenced by the time of the day than the tide; DO values increased during the afternoon anddecreased at night (Figs. 7C, 8C).

The pH remained fairly constant at 7.9 and transparency varied in a

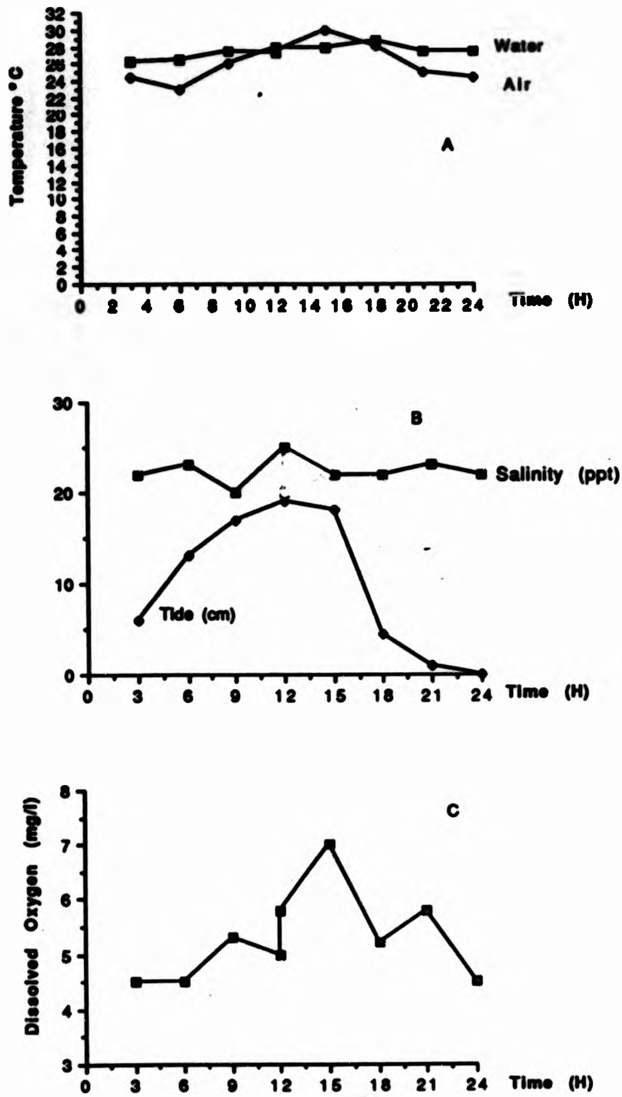


Figure 7. Physico-chemical and climatic parameters recorded at Laguna Redonda during the first diurnal cycle in June 1989. A, air and water temperature; B, salinity and tide level; C, dissolved oxygen.

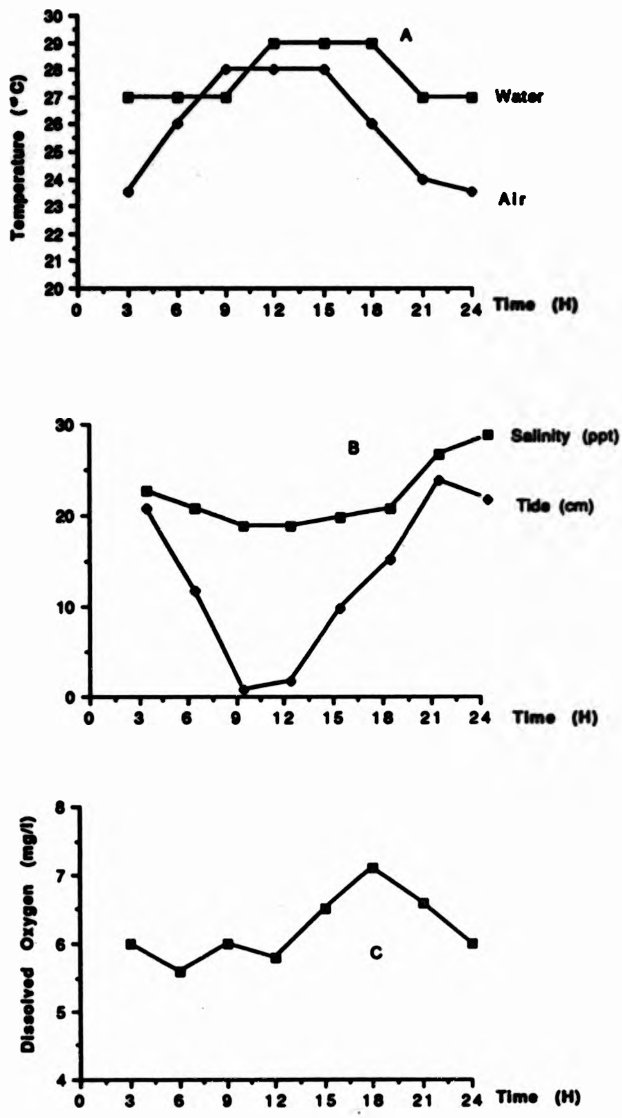


Figure 8. Physico-chemical and climatic parameters recorded at Laguna Redonda during the second diurnal cycle in November 1989. A, air and water temperature; B, salinity and tide level; C, dissolved oxygen.

random manner during the 24 hour observation periods.

The change of tide level (Table 4) was used to calculate the delay and range of the tidal oscillation at Laguna Redonda with respect to the values given in the tide tables for Veracruz Port (Anonymous, 1989a).
In the case of the June spring tide, there was a delay of 6 and 4 hours for high and low water respectively; and the tidal range was only 19 cm compared to the 75 cm predicted at Veracruz (Table 4). In November, two days after the full moon, the delay was only 3 hours at high water and 1 hour at low water. The tidal range inside the lagoon was 23 cm compared with 65 cm at Veracruz Port (Table 4).

4.7. Bathymetry

The main depth contours in Laguna Redonda are shown in Figure 16. In general, it is a shallow lagoon, where the deepest zones, ranging from 1.34 to 1.63 m, are aligned from south–west to north–east in line with the two main connections to the rest of the system. Two parallel shallow channels can be observed close to the north and south shores, separated from the rest of the lagoon by very shallow water areas (Fig. 9).
The detailed bathymetric profiles compiled for these south–west andnorth–east connecting channels reveal a similar shap in cross section; they differ mainly in maximum depth: 4 m for the first and 3.5 m the second (Fig.10).

4.8. Currents

The average speed and direction of the current drogues released during May 1988 and January 1989 are given in Table 5. The overall average speed recorded for May was 8.6 cm/ s and for January 11.2 cm/s, (at 50 cm depth).

The direction of the currents during both periods was closely related to the state of the tide, which in most cases was ebbing. Current movement was generally from north-east to south-west, except on May 13, when it had a south-east direction during the ebb tide. Speeds in January were higher in spite of weaker winds (Table 5).

The wind normally blows from a north-easterly direction during both periods, in which case the wind and tide were acting together, except on 23 January 1989 when a southerly wind prevailed.

4.9 Ecology

4.9.1. Taxonomy

According to Garcia-Cubas and Reguero (1987), *Brachidontes recurvus* is confined to the Caribbean Province in Mexico. Its systematic position is as follows (Andrews, 1971; Abbott,1974; Garcia-Cubas and Reguero, loc. cit.):

PHYLLUM : Mollusca
CLASS : Bivalvia (Pelecypoda)
SUBCLASS : Pteriomorphia
ORDER : Mytiloida
SUPERFAMILY : Mytilacea
FAMILY : Mytilidae
GENUS : *Brachidontes* (Swainson, 1840)
= GENUS : *Ischadium* (Jukes-Brown, 1905)
SPECIES : *B. recurvus* (Rafinesque, 1820)
= SPECIES : *I. recurvum* (Rafinesque, 1820)

Table 5. Average speed and direction of current drogues released at Laguna Redonda with corresponding wind information.

	Drift speed and direction (cm/s) Drogue No.				Maximum wind speed and Direction (m/s)
	1	2	3	Average	
Date (05/88)					
6	7.5 W	7.0 WSW	7.9 WSW	7.5	5.5 NNE
7	5.1 WNW	5.5 WNW	10.2 W	7.0	2.3 NNE
8	5.5 WNW	2.9 WSW	5.7 WSW	4.7	4.2 NE
9	8.5 WNW	12.9 WNW	9.9 WNW	10.4	6.0 E
10	7.0 W	6.1 SW	11.6 SW	8.2	4.6 ENE
11	12.6 W	14.0 WSW	17.4 WSW	14.7	6.1 ENE
12	7.2 WSW	8.0 S	4.8 SW	6.7	4.5 NE
13	7.8 SE	12.0 ESE	10.9 ESE	10.2	3.7 NNE
Total Average	7.7	8.5	9.7	8.6	4.5
(01/89)					
23	10.4 NW	9.7 WNW	14.0 WNW	11.4	3.3 S
24	9.0 WNW	19.4 WNW	15.0 W;ESE	15.9	3.8 ENE
25	11.1 WNW	10.4 WNW; W; WSW	12.9 W;WSW	11.5	3.3 ENE
26	8.2 WNW;W	10.3 WNW; W; WSW	10.5 WSW	9.6	3.1 ENE
27	6.0 W	8.0 W	8.5 W	7.5	3.8 NE
Total Average	8.9	12.9	12.3	11.2	3.4

4.9.2. Density and Distribution Pattern

4.9.2.1. Estero Horcones and Laguna Redonda

In both Estero Horcones and Laguna Redonda the distribution of mussels is contagious. The main ecological difference is that in the former locality the mussels grow mainly in clusters attached to aerial mangrove roots, whereas they form subtidal beds in Laguna Redonda. The average density recorded was 356 mussels per cluster in Estero Horcones and 431 mussels per cluster in Laguna Redonda. Taking all the density data obtained from the population structure study for both localities, and other records of cluster size, the overall average was 411 mussels per cluster with a maximum of 1531 and a minimum of 100. For comparison, the average density calculated for the mussel bed in Laguna Redonda was 2,320 mussels/m2, which represents for practical aquacultural purposes 5.6 times more than the average density of the mangrove root clusters.

The maximum and minimum cluster dimensions of the marked and unmarked clusters are summarised in Table 6; these ranged from 15 to 55 cm in height and from 22 to 68 cm in width.

When the cluster width was related to its height a significant correlation coefficient ($p \leq 0.05$) was obtained (Table 7). There was a significant negative correlation coefficient ($p \leq 0.05$) between mean individual length of the mussels in the cluster and the cluster density (Table 7). No significant correlation coefficients were found for the relationships between cluster density and either the mean individual length of mussels or the average cluster weight (Table 7).

The recorded changes in the dimensions of marked clusters are shown in Table 8. In general terms there was an incremental increase in either length or width of the cluster, but sometimes clusters suffered large losses of organisms due to natural causes (Table 8).

The influence of wind damage, as one example of natural damage, was

Table 6. Dimensions of marked and unmarked mussel clusters on mangrove and aerial roots in Estero Horcones and data on the mussels on the clusters

Date	Un-marked Cluster		Marked Cluster 25.05.88		Marked Cluster 01.04.89		Cluster mussel Average weight (g)	Cluster mussel Average Individual length (cm)	Cluster mussel Average Density mussel/cluster
	Height (cm)	Width (cm)	Height (cm)	Width (cm)	Height (cm)	Width (cm)			
Maximum	47	53	31	68	55	66	1.797	3.8	1531
	40	67							
Minimum	15	32	15	22	16	32	176	1.5	100
	27	32							
Total Cluster Average	27.7	46.9	30.5	46.0	29.6	43.9	1.197	2.8	411

Table 7. Correlation between dimensions of mussel clusters on mangrove aerial roots and individual mussel length (* Indicates significance at $p \leq 0.05$).

Variable x	Variable y	Correlation Coefficient (r)	Coefficient of Determination r^2	Significance
Cluster Width	Cluster Heigth	0.6165	38.02	*
Cluster density	Mean Individual Length	-0.597	35.6	*
Cluster density	Cluster Total Weight	0.2300	5.29	N.S
Mean length	Cluster Total Weight	0.5308	28.18	N.S

Table 8. Changes in height and width of 10 marked mussel clusters in Estero Marcones between May 1988 and August 1989

Age	Height (cm)			Width (cm)		
Date	25.05.88	01.04.89	11.08.89	25.05.88	01.04.89	11.08.89
Cluster No.						
1	28	30	-	64	85	-
2	17	29	-	15	22	-
3	32	31	-	55	68	-
4	29	15	-	55	25	-
5	35	31	16	43	30	32
6	32	26	-	47	39	-
7	40	30	-	67	45	-
8	32	30	55	27	39	66
9	28	56	-	32	54	-
10	32	18	22	55	32	-

Table 9. Survival of marked clusters in Estero Marcones in relation to natural events associated with mortality of the attached mussels.

Date	25.0.588	01.04.89	11.08.89
Total Marked	22	11	4
% Survival	100	50	18
Main Natural Events		Rain & Winds	Winds & Rain

determined. This caused a 50 % mortality in the marked clusters after approximately 1 year and 82 % over 15 months (Table 9). This corresponds to an instantaneous rate of natural mortality for clusters (calculated using the formula M= -(Ln S x 100/t), where S is the fraction surviving over time t (Gulland, 1983), of 6.3 % per month over 11 months from May 1988 and 25.3 % per month for four months from April 1989.

4.9.3. Population Structure

In the case of the three localities; Estero Horcones, Laguna Redonda and Laguna Mandinga, the frequency distribution of mussels was generally bimodal (Figs. 12–14), as confirmed from polymodal frequency distribution analyses (Cassie, 1957). This analysis separated in most cases two modes, the first containing an average of 83 % of the organisms, with an average length of 1.2 cm, and a second mode comprising 16 % of the organisms with 3.7 cm average length.

The monthly average length of mussels recorded from the different localities is shown in Table 10. It can be observed that in September, October and November, 1988, the values were small, ranging from 1.3 to 1.7 cm, compared to April, May and June with averages from 2.8 to 3.1 cm (Table 10). When the overall monthly length averages from each locality were compared, it was observed that mussels from Horcones were larger than those from Redonda and Mandinga (2.7, 2.6 and 2.3 cm respectively; Table 10), but the differences were not significant when tested by a one–way ANOVA ($p \leq 0.05$).

Mussels less than 6 mm in length, seem to occur in most months, in the lagoon, increasing their number in July and reaching a maximum during September, October and November (Figs. 12–14).

The average length of all mussels measured during the study period was 2.5 cm.

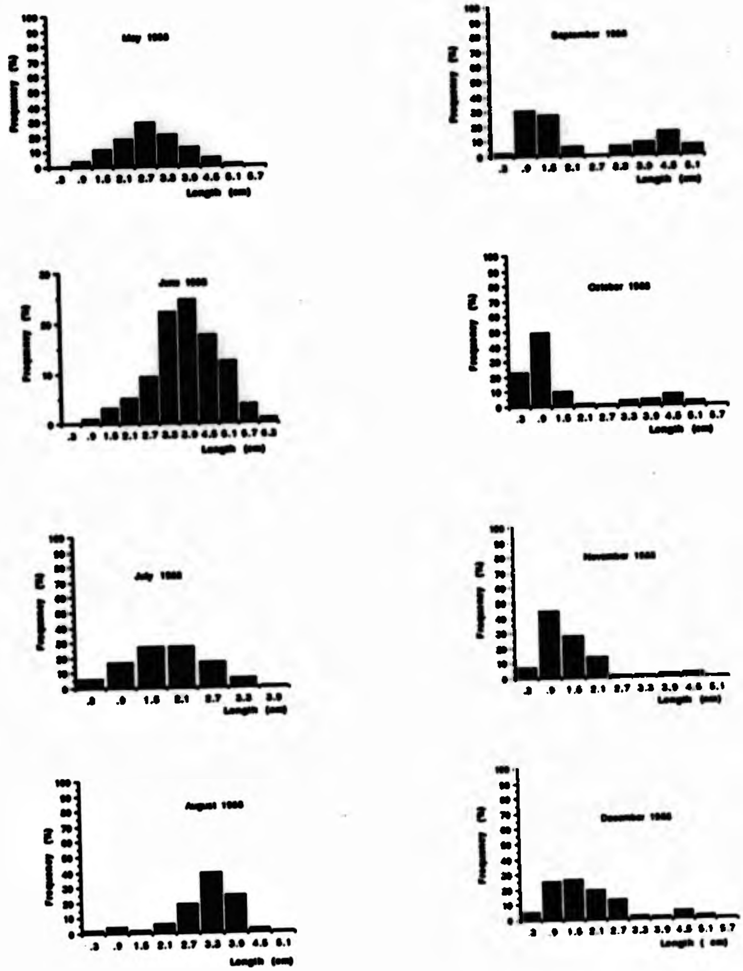


Figure 12. Monthly population structure at Estero Horcones from May 1988 to September 1989.

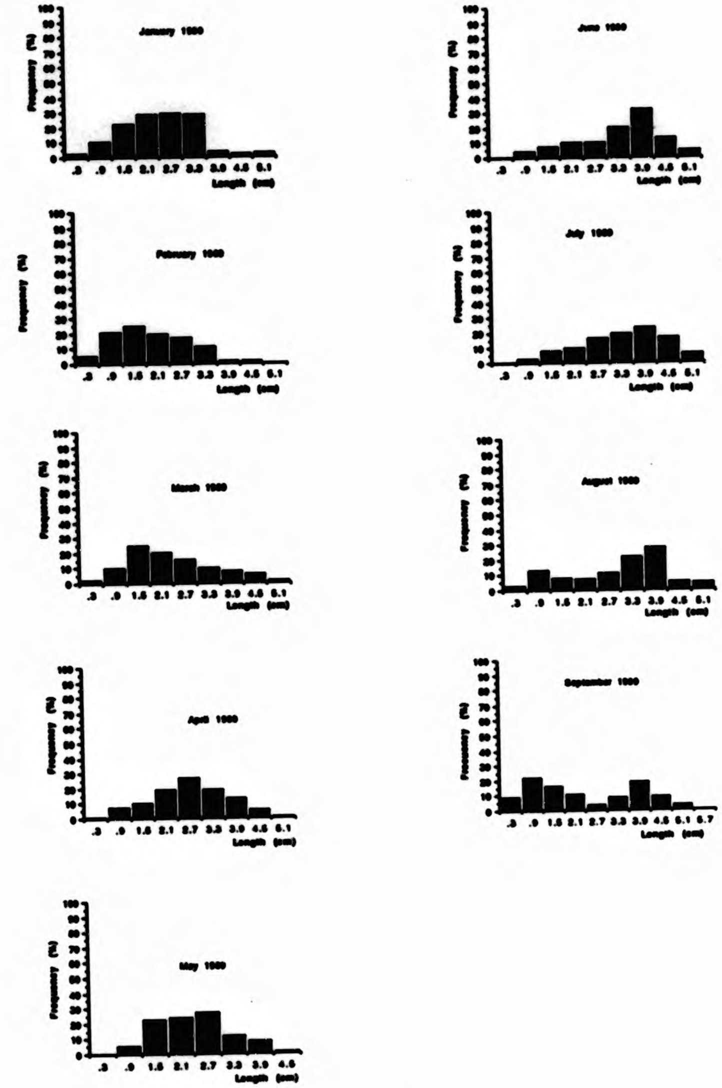


Figure 12/continued. Monthly population structure at Estère Horcones from May 1988 to September 1989.

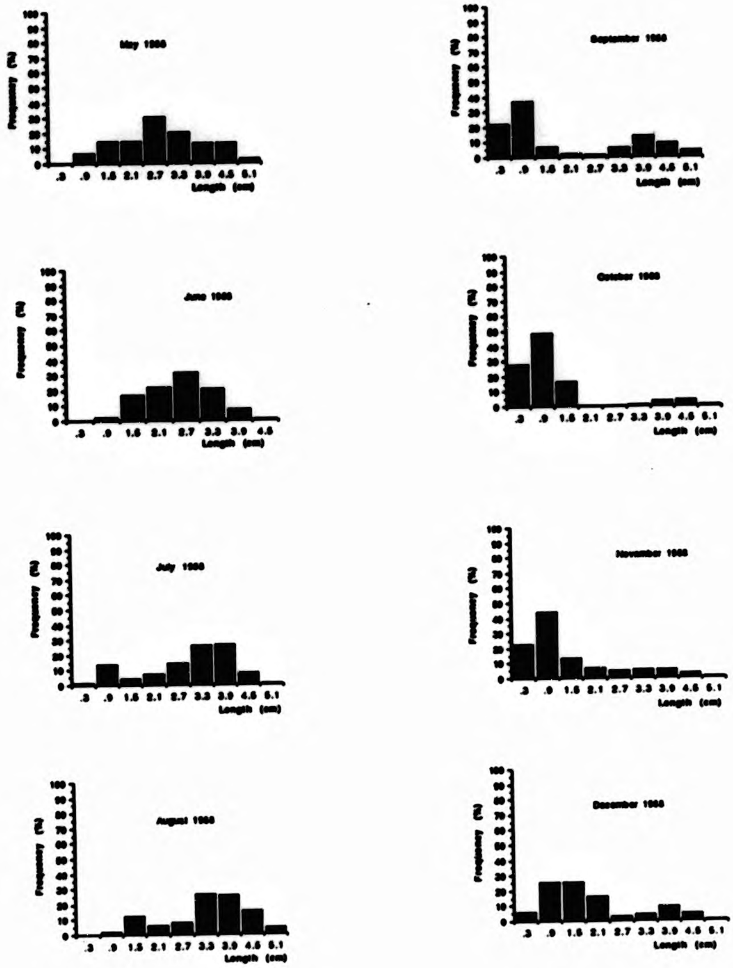


Figure 13. Monthly population structure at Laguna Redonda from May 1988 to September, 1989.

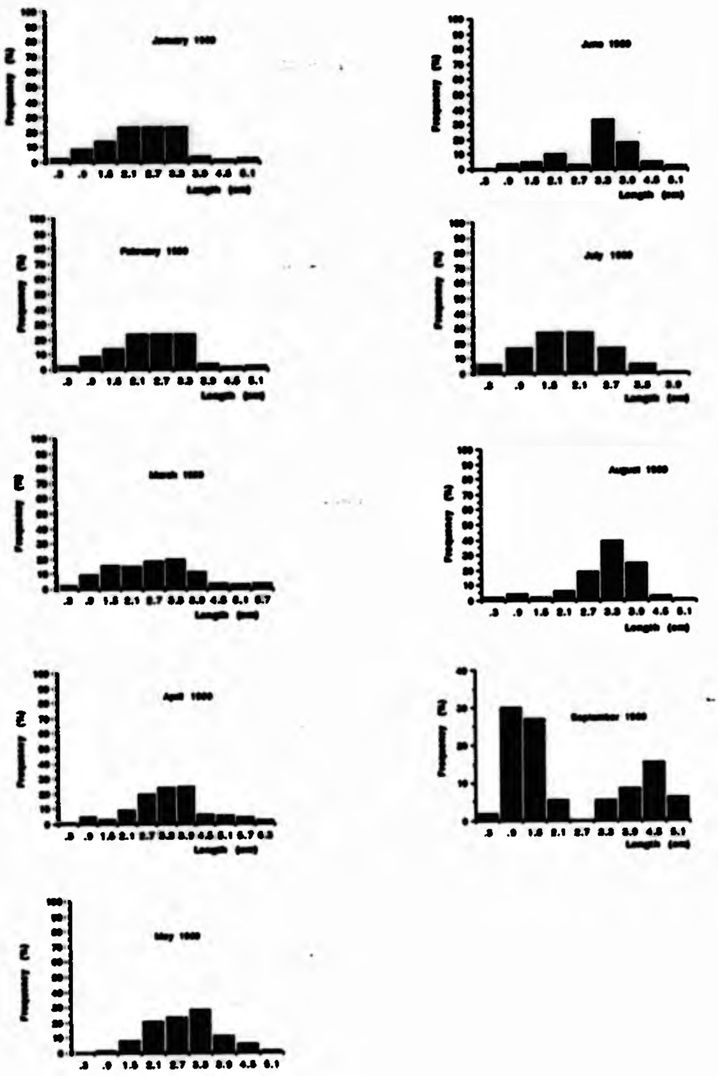


Figure 13/continued. Monthly population structure at Laguna Redonda from May 1988 to September 1989.

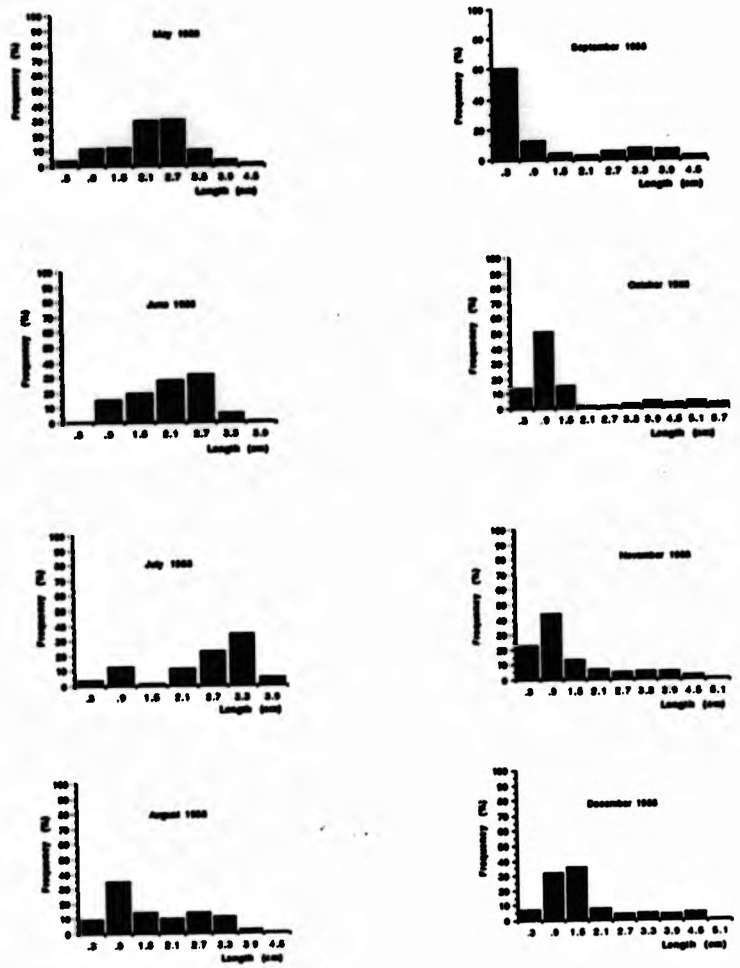


Figure 14. Monthly population structure at Laguna Mandinga from May 1988 to September 1989.

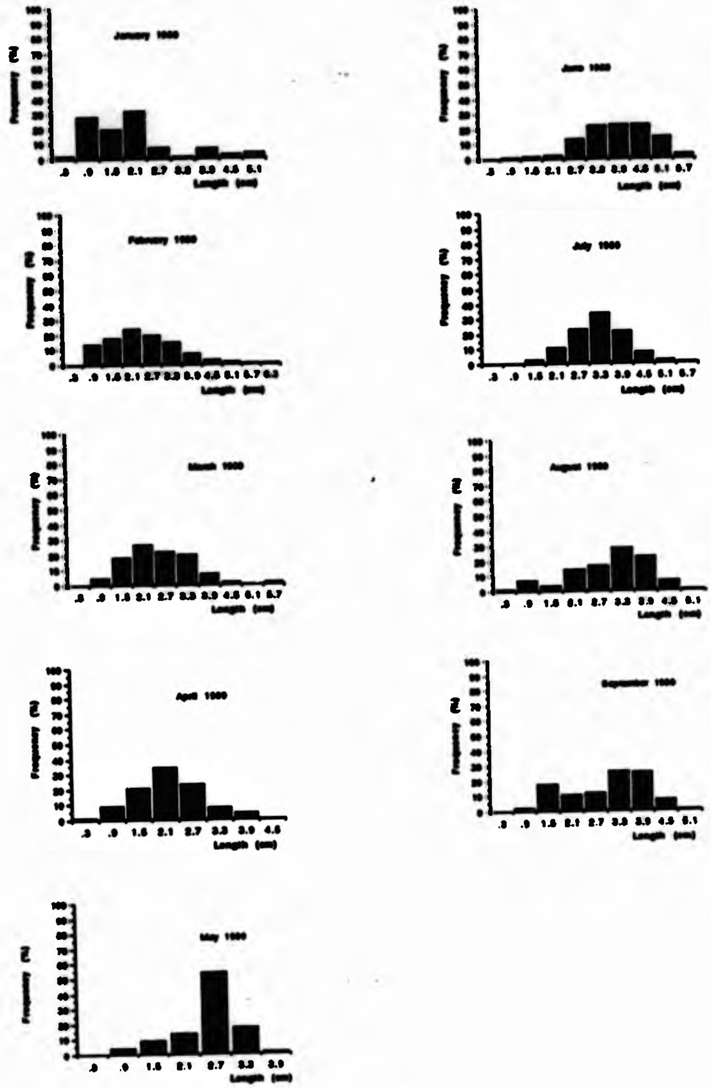


Figure 14/continued. Monthly population structure at Laguna Mandinga from May 1988 to September 1989.

Table 10. Monthly average and overall mean length of <u>Brachidontes</u> <u>recurvus</u> at three different localities of Boca del Rio-Mandinga estuarine system.

Year	1988										1989										
Month	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	$\bar{X}$	S.D.±
Locality																					
Horcones	3.2	-	2.9	3.8	3.1	3.5	2.0	1.5	1.5	2.1	2.7	2.1	2.6	3.0	2.9	3.8	3.8	3.3	2.7	2.7	0.7
Redonda	2.7	-	3.1	3.1	3.3	3.8	2.1	1.2	1.5	2.1	2.1	2.5	2.3	2.7	3.3	3.5	3.1	3.3	2.6	2.6	0.7
Mandinga	2.7	-	2.9	2.9	2.7	2.1	1.2	1.4	1.3	1.7	2.0	2.0	2.3	24.4	3.0	3.3	3.3	3.3	3.0	2.3	0.6
Average	2.7	-	2.8	3.1	3.0	3.1	1.7	1.3	1.4	2.1	2.2	2.2	2.4	2.7	3.0	3.5	3.4	3.2	2.6	2.5	
SD±	0.4	-	0.3	0.7	0.3	0.9	0.7	0.1	0.1	0.3	0.3	0.2	0.1	0.33	0.2	0.2	0.3	0.1	0.3	0.2	

4.9.4. Growth of the Natural Population

Analysis of data on the growth rings in the shells of B. recurvus revealed a wide spread in the number of rings associated with animals of different sizes (Table 11), so it was not possible to relate a fixed number of rings to a particular size. Nevertheless a highly significant correlation ($r = 0.9857$; $r2 = 97.17$ %; $p \leq 0.05$) was found for the relationship between length and number of rings (Table 11) and the following equation was derived:

$$Y = -0.566 + 1.914\,X$$

where Y is the number of rings and W the shell length in cm.

4.9.5. Reproduction

4.9.5.1. Condition Factor

Values for condition factors 1 and 2 (i.e. for meat volume and weight, respectively) are shown in Figure 15. Condition factor 1 for Estero Horcones, Laguna Redonda and Mandinga ranged from 20.7 to 63.0 %; and condition factor 2, from 2.8 to 15.4 % .

As expected, the two condition factors are significantly correlated ($r = 0.7842$; $r2 = 61.5$ %; $p \leq 0.05$). The easier of the two measurements, conditon factor 2 based on mussel meat weight, was used in the analysis of reproductive activity. Two main peaks in condition factor were detected in both 1988 and 1989, in May and October and May and August of 1989 (Fig. 15).

Estero Horcones showed higher overall average values for condition factor 2 (6.0%) followed by Laguna Mandinga (5.7%) and Laguna Redonda (5.4%), but these differences were not statistically significant

Table 11. Frequency of number of rings associated with shell length in the mussel <u>Brachidontes</u> <u>recurvus</u>.

Mid Point (cm)	Number of Rings: 0	1	2	3	4	5	6	7	8	9	10	11	12	Average No. of Rings	S.D.±
	Frequency														
1.25	1	1	2											1.5	0.5
1.75		1	7	3	1									2.4	0.9
2.25		1	2	2	4									4.0	1.1
2.75			1	6	7	1								4.5	0.7
3.25					3	7	4	3	1					6.5	1.1
3.75				4	3	8	4	2						5.8	1.2
4.25					1	9	7	6	2	2	2			7.4	1.5
4.75							7	8	7	2	2			8.3	1.2
5.25							1		2	2	2	1		9.8	1.5
5.75												3		11.0	0.0
6.25											1	1		10.5	0.7

(ANOVA, p≤0.05).

4.9.5.2. Histology

The Seed Mean Gonadic Indices calculated for Estero Horcones,Laguna Redonda and Mandinga are shown in Table 12.

The values tended to increase gradually, reaching maxima in October 1988 and March and August of 1989. The correlation between the condition factor and Seed Mean Gonadic Index was not significant.

In spite of the fluctuation in the monthly average condition factor for Brachidontes recurvus, sexually mature females and males were observed throughout the study period. No hermaphrodites were found in the sampled organisms.

A Mann–Whitney U Test did showed no statistical differences between the index values for Estero Horcones, Laguna Redonda and Mandinga, although the first locality showed a higher total average of 2.6 than the other two sites with 2.2 .

4.9.5.3. Sex Ratio

The male:female ratio calculated using all the mussels analysed from Estero Horcones, Laguna Redonda and Mandinga was 1.04:1. This is consistent with a 1.1 sex ratio (Chi2 = 0.022 with 360 d.f.).

4.9.5.4. Planktonic Larvae

The total number of all larvae per cubic metre and the relative abundance of barnacles, oyster and mussel larvae are shown inTables 13, 14.

Barnacle larvae were present in the plankton in all months of the year but

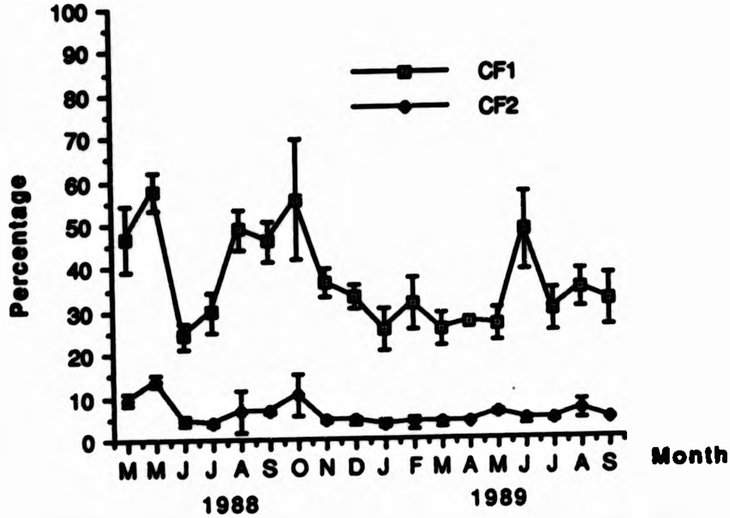


Figure 15. Total average Condition Factor 1 (CF1) and Condition Factor 2 (CF2) of <u>Brachidontes recurvus</u> during the period of study. Bars indicate ± SD.

Table 12. Seed Mean Gonadic Index values for <u>Brachidontes recurvus</u> in Horcones, Laguna Redonda and Laguna Mandinga during the study period.

(YEAR)	1988					1989							TOTAL	
(MONTH)	M	O	N	D	J	M	A	M	J	J	A	S	AVERAGE	S.D. ±
Locality	Seed Mean Gonadic Index													
Horcones	2.0	4.9	3.3	1.1	2.0	3.4	1.6	1.7	1.8	2.8	3.1	3.5	2.6	1.08
Redonda	1.7	3.8	1.7	1.4	1.1	1.9	1.6	1.5	2.0	3.7	3.0	4.0	2.2	1.09
Mandinga	1.5	2.9	1.3	1.2	2.3	1.8	2.1	1.8	3.5	3.1	4.2	2.1	2.2	0.9
Total Average	1.7	3.7	2.1	1.2	1.8	2.1	1.7	1.6	2.4	3.2	2.6	3.2		
S.D. ±	0.2	1.2	1.0	0.1	0.6	1.1	0.2	0.1	0.9	0.4	0.5	0.9		

Table 13. Monthly number of barnacle, oyster and mussel larvae in plankton during the period of study.

		1988								1989			
Organism	Mth.	M	J	J	A	S	O	N	D	J	F	M	A
							org/m						
Barnacle		313	33	328	91	104	382	115	4	33	68	12	27
Oyster		2075	172	332	498	0	10	115	0	2	4	48	12
Mussel		26	0	0	1027	0	60	21	0	4	15	5	2

were relatively more abundant in May, August and October of 1988 (Fig.16).

Oysters were less abundant and were mainly present from a peak in May through to August, 1989 (Fig.16).

Mussel larvae presented three peaks of abundance, in May, August and October 1989, and were recorded in relatively low numbers during the rest of the year (Fig.16).

In terms of spatial distribution, barnacle larvae were much more abundant at stations 4, 5 and 6 and decreased in number towards the head of the estuarine system (Fig.17). The range of values was 306 to 30.5 barnacle larvae per cubic metre (Table 14).

Oyster larvae showed a tendency to be abundant at stations 6,7,8 and 10,11,12 (Fig.17), that is in Laguna Redonda and Laguna Mandinga respectively.

The mussel larvae were more evenly distributed between stations and showed a peak of relative abundance at station 10 (Fig.17). Significant statistical differences ($p \leq 0.05$) were detected between the average monthly number of barnacle, oyster and mussel larvae according to ANOVA.

A Duncan's multiple range test ($p \leq 0.05$) showed that in the case of barnacles, abundance was higher in July and October than in other months; while for oysters and mussels May and August respectively showed significant peaks in abundance. However no statistical differences ($p \leq 0.05$) were detected when the stations were compared for each of the mentioned larvae abundance.

4.9.6. Predation and Competition

One of the most important predators of mussels observed in the Boca del Rio Mandinga estuarine system was the cormorant (*Phalacrocorax* sp.). These birds, which are abundant all year round in the system,

Table 14. Total number of planktonic larvae barnacles oyster and mussel at the different stations during the period of study.

Organism Station	4	5	6	7	8	9	10	11	12
			org/m 3						
Barnacle	301.6	220.1	184.3	124.3	64.4	114.9	32.7	44.7	30.5
Oyster	235.6	116.2	301.2	364.8	467.5	135.2	227.7	211.3	288.5
Mussel	49.7	37.9	88.8	30.7	34.4	118.2	423.7	57.2	24.1

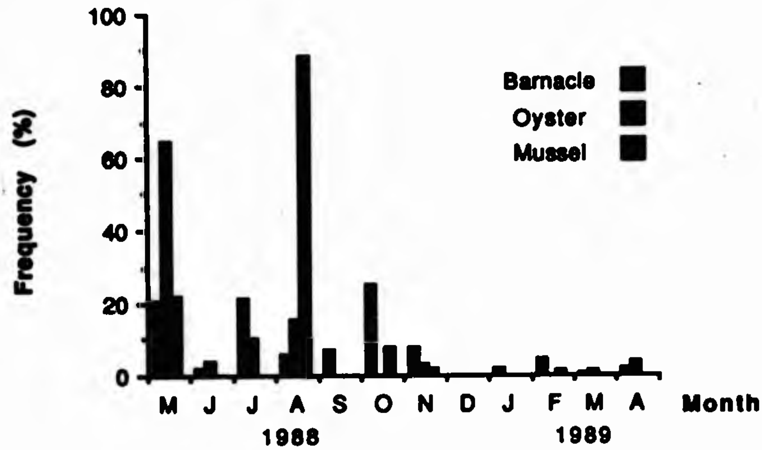


Figure 16. Temporal distribution of principal planktonic stages of fouling organisms expressed as percentage of total mean number recorded over the whole experimental period.

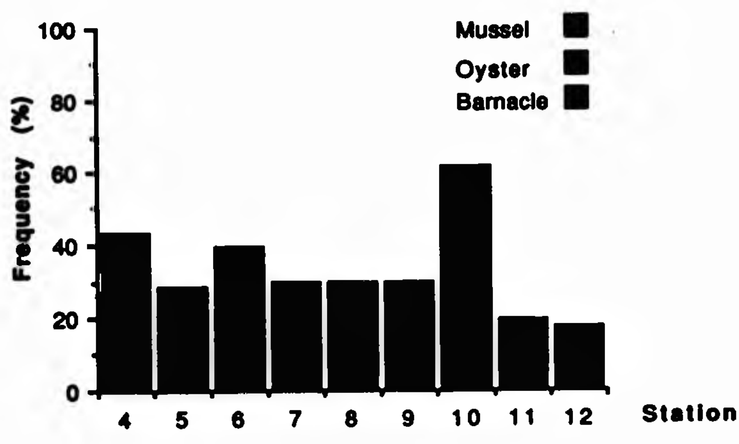


Figure 17. Spatial distribution of principal planktonic stages of fouling organisms expressed as percentage of total mean number recorded over the whole experimental period.

principally in Laguna Redonda and Mandinga, were responsible for the 100% mortality registered in the first two ongrowing experiments (May and June, 1988) involving mussels stocked in Percolari tubes.

Another important predator observed feeding on the mussel bed in Laguna Redonda was the blue crab Callinectes spp. (Table 15). A note was taken on the type of edge fracture of mussel shells of animals larger than 3.0 cm. It was very common to find this particular kind of shell damage when the samples for population structure were taken, but less frequent in the mussels collected in association with oysters from Laguna Mandinga.

Similar fractures were observed in the mussels on clusters collected in June, 1988 at Estero Horcones. In this month approximately 10.8% of the mussels were dead and out of the dead ones 71.4% had open intact shells and presumably had died as a consequence of an abrupt change of salinity in June from 35 ppt to 11 ppt (Fig.6A). The remaining 28.6%, with an average length of 2.7cm (SD+0.74), had fractured edges indicating crab damage.

In the case of competitors for space and food, it was observed that starting from the planktonic stages, barnacles play an important role since they are present all year round in the lagoon system. To a lesser extent this is also the case for oyster larvae (Fig. 16).

After settlement, organisms competing with mussels for space include not only barnacles and oysters but also polychaetes, bryozoans, ascidians, hydroids and the boring sponge Cliona spp. These were observed during different months of the year rather than showing any clear seasonal pattern in settlement. Other organisms observed to be competitors or predators of mussels during the field work period are listed in Table 15.

Table 15. Aquatic competitors (c), predators (P) and other organisms associated with the *Brachidontes recurvus* mussel population at Boca del Rio-Mandinga estuarine system.

TAXA

Porifera
- *Cliona sp.*

Mollusca
- Pelecypoda
  - *Crassostrea virginica* (c)
  - *Brachidontes exustus* (c)
  - *Rangia cuneata*
  - *Lyonsia sp.*
  - *Barnea sp.*
  - *Petricola sp.*
  - *Mya sp.*
- Gastropoda
  - *Thais sp.* (P)

Arthropoda
- Cirripedia
  - *Balanus sp.* (c)
  - *Chthamalus sp.* (c)
- Decapoda
  - *Eurypanapeus sp.* (p)
  - *Panopeus sp.* (p)
  - *Callinectes sapidus* (p)
  - *Callinectes rabthae* (p)
  - *Penaeus setiferus*
  - *Macrobrachium acanthurus*
  - *Macrobrachium olfersii*
- Amphipoda
  - *Melita sp.*
  - *Gammarus sp.*
- Isopoda
  - *Cassidinidea sp.*
  - *Idotea sp.*

Annelida
- Polychaeta
  - *Polydora websterii*
  - *Nereis sp.* (c)
  - *Sabellaria sp.* (c)

TAXA

Nemertia
- Nemertina (unidentified)

Platyhelminthes
- Turbellaria
  - Polyclad (unidentified)

Pisces
- *Bogre marinus*
- *Centropomus parallelus* (P?)
- *Mugil curema*
- *Mugil cephalus*
- *Cynoscion nebulosus*
- *Opsanus sp.*

Birds
- *Phalacrocorax sp.* (p)
- *Haematopus sp.* (p)

4.10 Microbiology

4.10.1. Experiment 1 (Bacteria in Mussels)

The concentration of coliform bacteria in Brachidontes recurvus meat ranged from 90 to more than 1100 coliforms/g and in general, the total average concentration of coliform bacteria and aerobic mesophiles in either Estero Horcones or Laguna Redonda was lower in the suspended cultivated mussels than the ones lying on the bottom (Table 16).

A Two Way ANOVA ($p<0.05$) showed no significant differences between the sites but the concentration of coliforms was significantly higher in the mussels on the bottom compared to the off bottom cultivated mussels.

The main coliform bacteria identified in both localities during the experimental period were: Escherichia coli, types I and 11; Enterobacter aerogenes, type I and Enterobacter cloacae, type VI (Table 17).

Physico-chemical data for the sampling dates are presented in Table 18.

4.10.2. Experiment 2 (Bacteria in the Water Column)

During June 1989, the concentration of coliform bacteria in the water column was found to be only 500 coliform/100 ml, whereas in September 1989 it was 3000 coliform/100 ml. The corresponding salinities where these bacterial levels were determined were 6 and 28 ppt, respectively (Table 19).

The concentration of coliform bacteria in B. recurvus meat was only recorded for July 1989 so it is possible to compare the levels of bacteria in the mussels and water directly. In July mussels from the bottom contained 20 coliform/g compared to 9 coliform/g in mussels from the suspended culture system.

Table 16 Concentration of coliform and mesophilic bacteria found in <u>Brachidontes recurvus</u> during experiment 1 from natural beds and off-bottom cultivation systems.

Date	Horcones				Redonda			
	Natural		Cultivated		Natural		Cultivated	
	MPN col/g	Mesophiles org/ml	MPN col/g	Mesophiles org/ml	MPN col/g	Mesophiles org/ml	MPN col/g	Mesophiles org/ml
2.03.88	500	*	500	-	200	*	200	-
15.03.88	>1100	+	90	+	500	*	90	*
16.04	500	*	150	+	500	*	150	*
14.05	500	*	90	-	1100	1800x10	200	*
Average	700		110		700		146.6	

\+ Present in negligible number

* Above maximum limit of countability

\- Not present

Table 17. Identification of coliform bacteria present in *Brachidontes recurvus* (experiment 1)

Date	Laguna Redonda Population Natural	Cultivated
2.03.88	-	-
15.03.88	*Escherichia coli* Type 1 (types 1)	*Escherichia coli* Type I Intermediate Type II
16.04.88	*Escherichia coli* Type I (Typical)	*Escherichia coli* - Intermediate Type I Type II
14.05.88 14.05.88	*Escherichia coli* Intermediate Type I Type II	-

Table 17 (continued)

Date	Estero Horcones Population Natural	Cultivated
2.03.88	Escherichia coli - Intermediate Type I, Type II Enterobacter aerogenes Type 1, Irregular Type 4	
	Escherichia coli	Escherichia coli
15.03.88	-Intermediate Type II Enterobacter aerogenes Type I, Type II	Intermediate Type I Type II
16.04.88	Escherichia coli Type I -Intermediate Type II	Escherichia coli Entercobacter aerogenes F. eloacae Irregular. type VI Type I Type II
14.05.88	Escherichia coli Intermediate Type I Type II Enterobecter aerogenes E. cloacae	Enterobacter aerogenes Type 1

Table 18. Average physico-chemical parameters recorded during the experimental period (experiment 1) for coliform bacteria determinations at Estero Horcones and Laguna Redonda.

Date	T°C Air	Water Surface	Bottom	PH	Transparency (cm)	O_2 mg/l	S‰
2.03.88	24.7	23	23.9	8	80	8	30.1
15.03.88	22.6	22.1	22.5	7.8	70	4.8	27.8
11.04.88	23.5	21	21	7.7	70	3.5	29.1
16.04.88	25	26	26.2	7.6	60	5.4	28.6
1.05.88	29	26.5	26.5	6.5	70	4.1	28.5
14.05.88	33	30	30	6.4	80	7.3	29.7
Average	26.3	24.7	25.1	7.3	7.1	5.5	28.9

Table 19. Physico-chemical parameters, concentration of coliform bacteria in the water column and <u>B. recurvus</u> meat during experiment 2.

Date		S%	water T °C	water MPN col./100ml	Mussel meat MPN col./g
14.06.89	Surface	28	26	500	9
	Bottom	28	26	500	20
31.09.89	Surface	5.3	28.2	3000	-
	Bottom	6.5	28.0	3000	-

4.11. Biochemistry

4.11.1 Natural Population

No statistical differences were found when the various body composition analyses values were compared for mussels from Estero Horcones, Laguna Redonda and Mandinga, but the data indicated seasonal changes in the nutritional condition of the mussel populations. Their moisture content ranged from 67.8 to 87 % with an average of 83.8 %. The values decreased during July 1988 and May 1989 (Fig.18A).

Ash values ranged from 4.4 to 11.9% with an average of 10.2%. Four peaks were observed in June, September 1989 and January, May–June of 1989 (Fig. 18B).

The body lipids content showed peaks in June and November, 1988; January and March of 1989 (Fig.18B) ranging from 2.9 to 5.9% with an average of 5%.

Average protein content was 64.2% with a minimum of 44 % and a maximum of 73%; a gradual increase in the protein levels was observed from July; this reached a peak in November, 1988 then dropped again from December to February of 1989 (Fig. 18A).

In the case of carbohydrates, there were four main peaks in May, September, 1989; January and June of 1989 (Fig. 18B). The average carbohydrate content was 8.9%, with values ranging from 2.4 to 21.1% (Fig. 18B). Carbohydrate levels tended to be high just before a rise in the mussel lipid content.

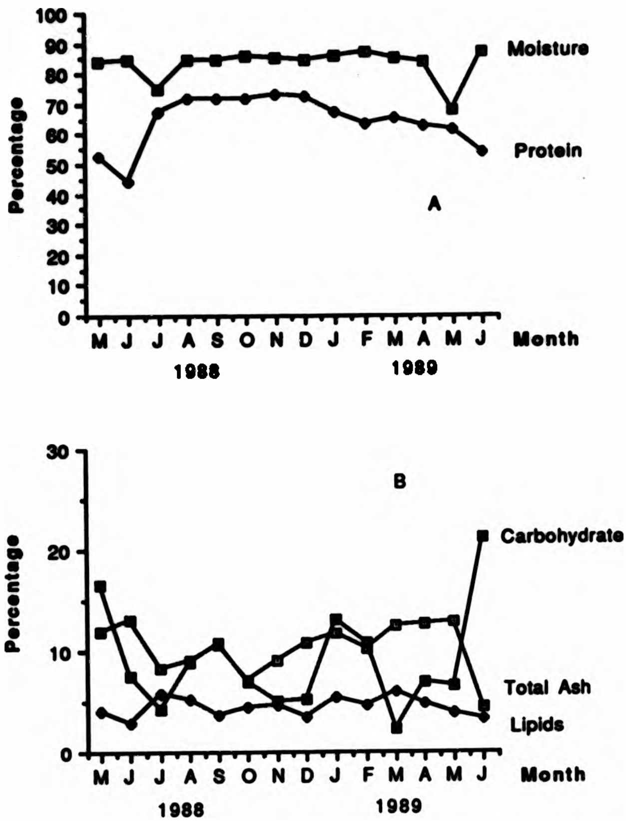


Figure 18. Proximal analysis values (% dry weight) determined for Brachidontes recurvus over the experimental period. A, moisture and protein; B, carbohydrate, lipids and total ash content.

Table 20 presents the results of correlation analyses between thevarious biochemical components and in relation to condition factor 2 (dry meat weight index). None of the correlations were significant, but some discernible trends are discussed later.

4.11.2 Penaeus setiferus and Macrobrachium rosenbergii Feeding Trials

The results of proximal analyses of the diets utilised in the feeding trials with Penaeus setiferus and Macrobrachium rosenbergii are shown in Tables 21 and 22.

4.12. Caloric Value

The caloric value of B. recurvus dry meal and M. edulis
prepared as dry meal, fresh meat and frozen meat is given in Table 22. Values ranged from 7.9 kcal/g for M. edulis dry meal to 0.7 kcal/g for the frozen meat of this mussel. The fresh meat of M. edulis and B. recurvus dry meal were intermediate in caloric value , at 1.26 kcal/g and 5.9 kcal/g respectively.

4.13. Amino Acid Content

The content of amino–acids in B. recurvus dry meal and in M. edulis dry meal and frozen meat were similar. The absence of tryptophan is due to the conditions of preparation in an acid digest. The quantitative values for each amino acid can be observed in Table 24.

Table 20. Results of statistical analysis of the relationships between mussel body composition (proximal analysis) and condition factor.

Variable		Correlation Coefficient	Coefficient of determination %
y	x	r	r2
Lipids	Protein	0.7858	23.60
Lipids	Carbohydrates	-0.394174	15.57
Protein	Carbohydrates	-0.43789	19.17
Lipids	Condition Factor 2	-0.2166	4.69
Carbo-hydrates	Condition Factor 2	-0.1873	19.75
Protein	Condition Factor 2	-0.1873	3.51

Table 21. **Proximal analyses values (%weight in feed) for the diets supplied to *Penaeus setiferus***

Diet	Moisture	Ash	Lipids	Protein %	Carbo-hydrates	Crude Fibre
I Fresh meat *Brachidontes recurvus*	8 5	2.8	1.6	18.7	1.8	-
II *B. recurvus* Dry meal	13.4	9.7	5.7	64.8	6.4	-
III Aqualine *	9.9	12.9	13.6	20.6	-	-
**	1.8	14.2	5.1	17.1	1.2	5

* Values provided by the producer

** Values calculated by Cruz and Martinez (1989)

Table 22. Proximal analyses (% weight in feed) for the diets supplied to *Macrobrachium rosenbergii.*

DIET	Moisture	Ash	Lipids	Protein	Carbonhy-drates	Crude fibre	Calories KJ/g	Calories Kcal/g
B. recurvus dry meal	13	15.9	5.06	57.9	7.7	0.5	24.8	5.9
M. edulis dry meal	5	6.4	7.88	68.9	10.6	2.0	33.1	7.9
M. edulis frozen	77.2	1.41	2.17	18.5	0.92	0.13	2.8	0.7
M. edulis fresh	84	1.07	1.34	11.4	1.78	0.33	5.2	1.26

Table 23. Fatty acid profile obtained from B. recurvus dry meal

No.	Fatty Acid	% Dry Weight
1	14.0	2.7
2	14.1	1.6
3	15.0	1.2
4	16.0	20.7
5	16.1	7.9
6	N.I.	1.0
7	N.I.	0.8
8	16.3	2.5
9	N.I.	0.6
10	N.F.	1.2
11	17.0	3.0
12	N.I.	0.6
13	150 18;0	4.4
14	18:0	5.3
15	18:1 (n-9)	1.1
16	18:1 (m-7)	7.6
17	N.I.	1.0
18	18:2 (N-6) (linoleic)	2.2
19	18.3 (N-3) (linoleic)	3.1
20	18:4 (N-3)	1.0
21	20.0	6.4
22	20:1	2.9
23	N.I.	1.4
24	20:4 (w-6)	3.6
25	20:5 (N-3)	5.2
26	N.I.	5.0
27	N.I.	1.1
28	N.I.	0.9
29	22:5 (N-3)	1.4
30	22:6 (N-3)	6.1
Total		100

N.I. Not Identified

Table 24. Amino acid content (% dry weight) of dried _B. recurvus_ and frozen and dried _M. edulis_ in comparison with values reported by FAO and required essential amino acids for shrimp.

	Brachidontes recurvus	_M. edulis_	_M.edulis_ frozen	Mussel FAO (1)	Required by (2,3) Shrimp
Aspartic Acid	4.8	11.7	9.3	11.7	
Glutamic Acid	7.7	14.9	11.6	13.0	
Serine	2.7	4.8	4.1	4.8	
Glycine	3.5	4.8	5.1	> 10.6	
Histidine	1.2	2.2	1.4	1.8	*
Arginine	3.4	6.4	5.9	5.9	*
Threonine	9.5	4.5	3.8	-	
Alanine	2.9	4.9	3.9	8.5	
Proline	2.8	3.5	3.6	3.5	
Tyrosine	0.5	1.5	1.3	2.4	
Valine	2.6	4.0	3.4	6.0	*
Methionine	0.7	2.9	2.0	2.0	*
Isoleucine	2.4	4.2	3.3	5.2	*
Leucine	3.8	6.9	5.1	7.6	*
Phenylalanine	2.3	3.6	3.0	3.8	*
Lysine	2.9	1.1	2.1	7.4	*
$\bar{X}$	2.6	4.6	3.9		
S.D.±	0.2	0.3	0.3		

1) FAO 1967

2) Cowey and Forster 1971

3) Shewlast et al 1972

Glutamic acid and Tyrosine represented the maximum and minimum values (7.7 and 0.5% respectively) in the B. recurvus dry meal. A similar distribution was observed for M. edulis in both presentations with glutamic acid maxima of 14.9 and 11.5% for dry meal and frozen meat respectively; the minimum component for the dry meal was lysine with 1.1% and in frozen meat, tyrosine at 1.3 % (Table 24).

4.14. Fatty Acid Content

The main fatty acids contained in B. recurvus dry meal are listed in Table 27; the only fatty acid present above the 8 % level was palmitic acid at 20.75%. The other fatty acids contributed between 0.6 to 7.9 per cent. Independently of quantification 33.3% remained unidentified (Table 23)

4.15. Cultivation trials with B. recurvus

4.15.1. Ongrowing

4.15.1.1. Experiment 1

The mussels were 100% predated by cormorants within two weeks in both attempts to grow them using Pergolari tubing. The birds were observed standing in the racks after the mussels were suspended. The mussels from Laguna Mandinga and Laguna Redonda were preyed on faster than the ones at Estero Horcones.

4.15.1.2. Experiment 2

Figure 19 illustrates the growth curves of experimental mussel

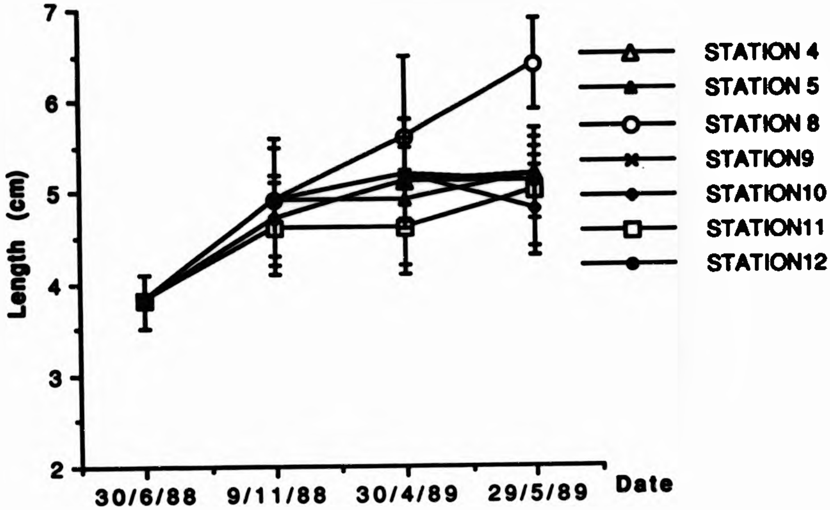


Figure 19. Growth curves of *Brachidontes recurvus* cultivated on suspension using polypropylene bags (Experiment 2). Bars indicate standard deviation for each date.

populations at stations 4 to 12. The overall average net increment was 2, 0.2 and 4 mm in the three measurement intervals. The maximum average value was observed in station 8 with 8.8 mm/month. Table 25 shows the specific growth rates for shell length which ranged from 1.1 to 13 per cent; negative growth rates were recorded at stations 9 and 10 during the last time interval due to the loss of the larger mussels.

The average specific growth rates obtained for each time period showed a decrease in the second interval followed by an increase in the third (Table 25). This plateau in size can be observed in the growth curves for most stations in Figure 19.

Statistical differences ($p \leq 0.05$) were found between the stations for the first and second length measurements. A Duncan's Multiple Range Test revealed that for November 1988, mussels at station 11 were significantly smaller from than the rest and on April 1989, the mussels at stations 8, 9 and 10 were all significantly larger than those at the other locations. However survival rates at the different stations were very variable (Fig. 20), which makes interpretation of the growth data more difficult. By April 1989 mussels at stations 4, 5, 6, 7, 11 and 12 showed the best survival while 8, 9 and 10 can be grouped as the stations with lower survival rates than the others (Fig. 20).

The final condition factor obtained in May 1989 from the harvested mussels with an average length of 5.4 cm, ranged from 2.8 to 5.2% for condition factor 2 and 23 to 32.4% for condition 1 (Table 26).

The average C.F.2 value of 3.4% (Table 26) obtained from the cultivated mussels was unexpectely low compared with the corresponding value from the natural population (5.9%) but more similar to the one recorded one month later (4.1%) (Fig. 15).

Using the values for shell length and wet and dry flesh weight recorded during this experiment, the following allometric equations were calculated (Brown et al., 1976) to relate mussel weigth to length:

$$Y1=0.0608\ X^{2.186}$$

Figure 20. Survival of Brachidontes recurvus cultivated in suspension using polypropylene bags (Experiment 2).

Table 25. Specific Growth Rate in shell length for *B. recurvus* grown using suspended polypropylene onion bags (experiment 2)

	S G R (% per month)		
Time	1	2	3
Station			
4	4.2	1.6	1.9
5	5.0	0	5.9
8	5.0	2.6	13.0
9	5.0	1.1	-1.91
10	5.0	1.1	-8
11	3.8	0	8.3
12	4.2	1.6	0
Average	4.6	1.6	* 7.2
S.D.±	0.5	0.6	4.6

* The negative increments were not considered for the average.

Table 26. Final lengths and Condition Factors 1 and 2 for the cultivated population of *B. recurvus* (experiment 2)

Station	L (cm)	FC_1 (Wet weight) %	FC_2 (Dry weight)
4	5.3	26.7	3.6
5	5.2	27.5	3.8
9	5.3	23.0	3.0
10	5.7	27.3	2.8
11	5.5	32.4	5.2
12	5.6	23.3	2.1
Average	5.4	26.7	3.4
SD±	0.1	3.4	1.0

and $Y2 = 0.0578\,X^{1.210}$

where Y1 and Y2 are the wet and dry flesh weights respectively in grams, and X is the shell length in cm. Significant correlation coefficients of 0.9500 and 0.860 ($p<0.05$) respectively, were obtained for these relationships.

Biomass production of B. recurvus in terms of flesh wet weight gain during suspended ongrowing is shown in Table 27.

Based on a maximum average wet flesh weight value of 3.7 grams for a mussel of average length (5.4 cm) it was calculated that a polypropylene onion bag stocked with 500 mussels and ongrown with 60 % survival, would produce 300 mussels weighing 3.17 kg with a flesh weight of 1.11 kg. It is assumed based on field measurements that 35% of the total mussel weight is wet flesh weight.

To produce one ton of mussels equivalent to 350 kg flesh weight, or 88 kg of dry mussel meal, would require 318 culture bags, stocked with 95,500 mussels of 5.4 cm average length. This scale of production is equivalent for mangrove root encrusted mussels to 262 clusters, with an average density of 356 mussels/cluster, and for subtidal bed mussels would be equivalent to an area of 41 m2 with an average density of 2,320 mussels/m2.

4.15.1.3. Experiment 3

This involved 116 juvenile mussels (average length 2.4 cm + SD 0.911) stocked in a polypropylene onion bag suspended at station 5. The mussels reached an average length of 4.2 cm + 0.7804 cm in five months; this was equivalent to a growth rate of 3.6 mm/month and survival was 60 %.

Table 27. Biomass production in flesh wet weight of <u>Brachidontes recurvus</u> during suspended ongrowing (experiment 2)

Date	Individual Average Length Size (mm)	Individual Average Flesh Wet Weight (g)	Biomass per Station (g) flesh wet weight: 4	5	6	7	8	9	10	11	12	Total g	Average g/bag
30.6.88	38	1.1					330					2970	330
29.5.89	54	2.7	51.3	89.1	-	-	10.8	-	45.9	37.8	121.5	356.4	77.0

4.15.1.4. Experiment 4

In this experiment a cluster with juvenile mussels of approximately 1.5 cm length were introduced into a polypropylene onion bag and suspended at station 4. These mussels were harvested in five months with an average length of 4.7 cm (SD± 0.755); their growth rate was equivalent to 6.4 mm/ month. The final harvest of mussels showed a unimodal frequency distribution, with a total gross weight of 3.1 kg. In addition there were 500 oysters weighing 1.6 kg, giving a total weight for the cluster of 4.7 kg. These oysters settled and grew during the experimental period; their average size at harvest was only 3.2.

4.15.2. Collectors

Table 28 compares the seasonal settlement of mussel spat on the various collectors tested. Statistically ($p \leq 0.05$) the best collector was the oyster shell material, while mussel shells, polypropylene ropes and polypropylene onion bags proved to be similar in efficiency. No significant differences between sampling stations were indicated in terms of mussel settlement on these four types of collectors (ANOVA $p \leq 0.05$).

A general settling pattern over the experimental period for mussels, oysters, barnacles and polychaetes was compiled by combining the monthly average settlement records for the four collectors (Fig. 21).

Mussel spat, were always present in the lagoon system except in May 1988 and April 1989, with maxima in July and September of 1989 (Fig. 21); oyster spat were absent in February, 1989 and had a maximum presence in July, September, 1988 and May 1989 (Fig. 21); barnacles

Table 28. **Total average number of mussel spat collected on the different types of collectors**

MONTH	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	$\bar{X}$	SD!
<u>Collector</u>																		
Oyster Shell	0	33.3	25.73	33.3	33.3	17.0	0	15	0	0	0	0	6.7	0	0	6.7	352.6	89.7
Mussel Shell	0	6	2.79	10.1	46.0	55	18	8	4	7	1.0	0	9	-	-	-	43.7	54
Onion Bag	0	6	157.6	13.8	19.2	16.7	4.8	0.6	1.1	1.3	0.7	0	67.6	4.8	6.7	8.8	23.3	44
Ropes	0	0	70	5.3	6.7	7.6	5.0	1.3	1.0	1.0	0.3	0	20.3	-	-	-	11.8	1

were always present, being more abundant in July and September 1988 and again in June 1989 (Fig. 21); polychaetes were always present except in June, 1989 and were most abundant in September 1988 and March 1989 (Fig. 21).

The seasonal pattern of settlement on oyster shell collectors is illustrated in Figure 22B. Mussel spat were registered most abundantly in July and September 1988 (Fig. 22B). The quantity of spat settling in July was statistically different to that recorded in the other months ($p \leq 0.05$).

Oysters spat presented maxima in virtually the same months as mussels (Fig. 21) with statistically significant peaks in May 1988 and 1989 and July 1988.

Barnacles were present throughout the experimental period, with significant peaks in abundance in June, 1988 and July, 1989 (Fig.21). Polychaetes showed a significant maximum in August, 1989 (Fig. 21).

The relative settlement of organisms at different sampling stations is shown in Figure 23B. Mussel spat were more abundant at stations 4, 9, 10 and 11; oysters presented a fairly even settlement at all stations; barnacles and polychaetes presented a similar pattern to the oysters, with slightly higher values at station 7 for barnacles and at stations 4 and 9 for polychaetes.

The seasonal pattern of settlement on mussel shell collectors is shown in Figure 22A. Mussel spatfall was statistically higher ($p \leq 0.05$) in July and September than in the other months; oysters spat showed a statistically significant ($p \leq 0.05$) peak in July, 1988 with respect to the other months, while barnacle settlement showed a significant peak in September, 1988. Polychaete settlement occurred throughout the study period with statistically significant maxima in September and October of 1988.

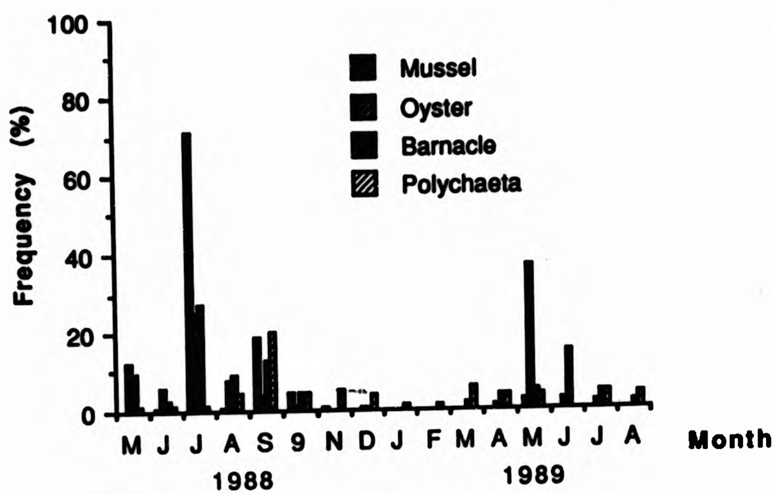
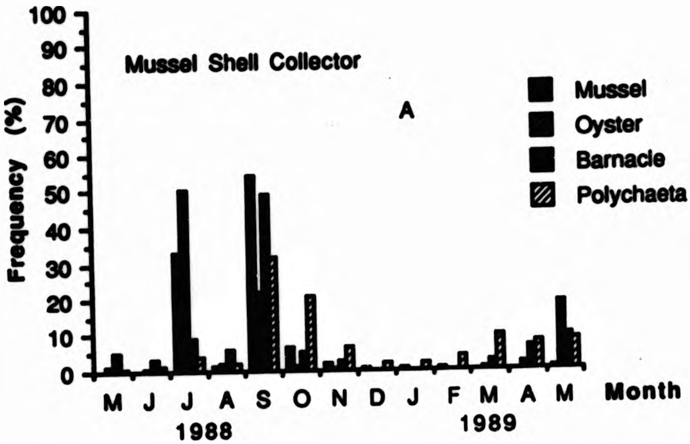


Figure 21. Monthly percentages of the total settlement of each group of fouling organisms, considering the four different collectors together.

The relative settlement of organisms on the mussel shell collectors at different sampling stations can be observed in Figure 23A. Mussels were most abundant in stations 4 and 5; whereas oysters, barnacles and polychaetes were evenly distributed in relation to all the stations.

The seasonal and spatial patterns of settlement on polypropylene onion bags are presented in Figures 22C and 22D respectively. Mussel spatfall in July 1988 was statistically higher than in from the other months. The month of July 1988 showed a significant peak ($p \leq 0.05$) for oyster settlement; barancle settlement was less abundant than on the other collectors but there was a relative peak of settlement on the onion bag collectors in June 1989; polychaetes showed a maximum level of settlement in August 1989.
Mussel spat were more abundant at stations 4–7 and 11; oysters showed a maximum settlement at station 9, while the other organisms, the abundance were evenly distributed between the stations.

Seasonal and spatial settlement on the polypropylene ropes is shown in Figures 23C and 22D. Mussel spatfall was statistically higher ($p \leq 0.05$) in July 1988; while for oysters settlement, the peak was in May 1988. The number of barnacles settling showed a statistically significant peak in May. Polychaetes were most abundant in July and August 1988 but no statistical differences in their monthly rate of settlement was detected. Mussel spat were abundant at stations 4, 5 and 8 and oysters at stations 6, 8 and 10; barnacles and polychaetes showed a more even distribution between stations, with slightly higher values at stations 6, 9 and 12 for barnacles, and at station 6 in the case of polychaetes.
Statistical differences were established using a One Way ANOVA and a Duncan's Multiple Range Test after transforming the data with an Arcsin trasformation (Zar, 1984).



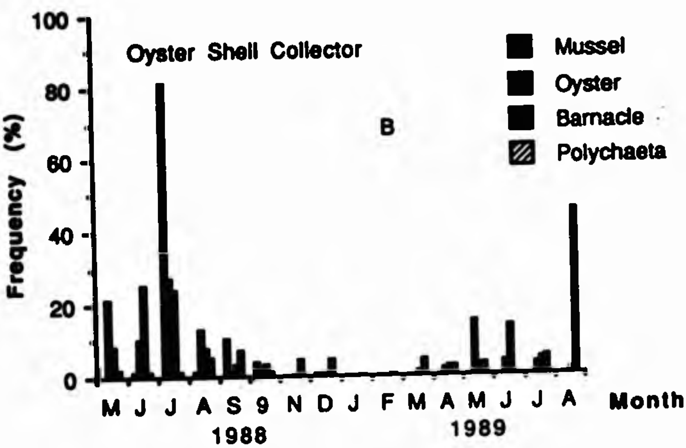


Figure 22. Seasonal pattern of settlement of fouling organisms on spat collectors as % of total numbers from all stations over the whole experimental period. A, mussel shell collector; B, oyster shell collector; C, polypropylene bag collector; D, polypropylene rope collector

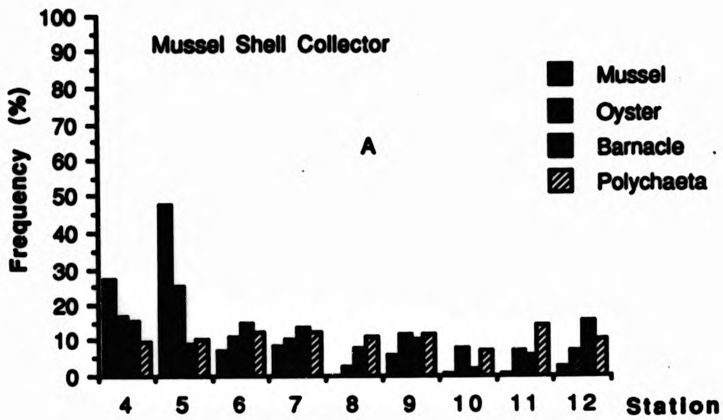
average settlement, for oyster shell, mussel shell and polypropylene rope collectors, showed the organisms to be in the following decreasing order of importance: barnacles, polychaetes, mussels and oysters (Fig. 24).
Some other organisms, such as bryozoans, ascidians, sponges, filamentous brown and green algae, were also recorded on the collectors during the experimental period. These were not quantified but some useful field notes taken during the study period are summarised below.

At station 10, brown filamentous algae were noticed on the polypropylene onion bag collectors. Some green algae were detected at the surface on ropes of the same material. At station 6, the same algae were found attached to the oyster shell collectors. In July 1988, at station 12, the oyster shell collector was covered by brown filamentous algae and a layer of fine sediment; in August, 1988 the mussel spat counted were > 1mm in length, but a great number of smaller ones were also present; at station 5 the polypropylene onion bags had filamentous brown algae. In November 1988, the mussel shell bag collector at station 12 showed approximately 95% of the total settlement on the external side of the mussel shells and bryozoans were abundant. During December, 1988 brown and green filamentous algae were observed at the same depth location on most of the different collectors; isopods and bryozoans were also abundant. Ascidians were common during April, 1989 and bryozoans were abundant in January and February of the same year.

4.16. Effect of Salinity on the Respiratory Rate of Mussels

4.16.1. Experiment 1

The result of this experiment showed that in the sealed respiratory chambers containing mussels the average oxygen percentage saturation



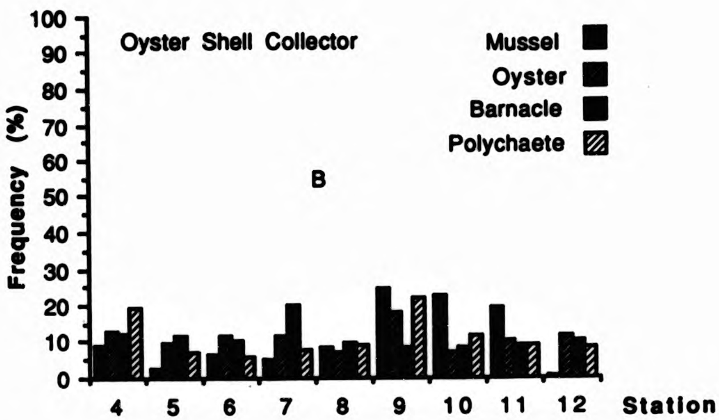
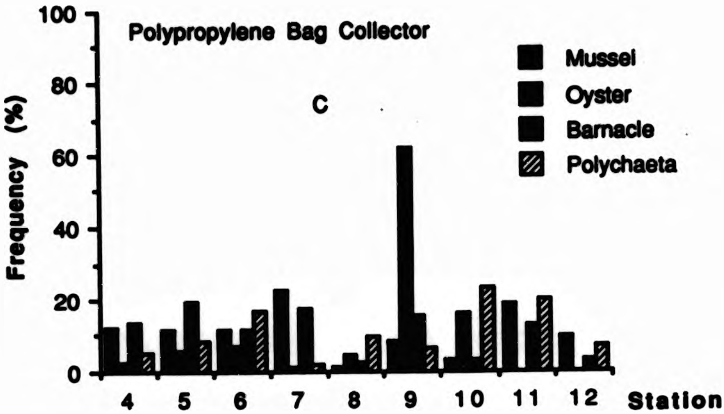


Figure 23. Spatial pattern of settlement of fouling organisms on spat collectors as % of total numbers over all months. A, mussel shell collector; B, oyster shell collector; C, polypropylene onion bag; D, polypropylene rope collector.



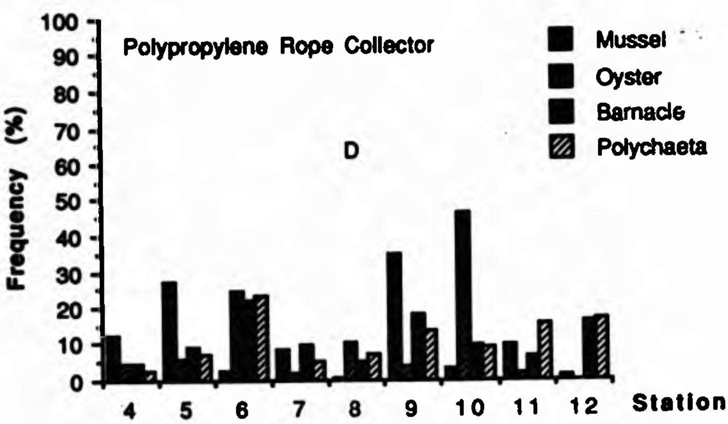


Figure.23(Continued.). Spatial pattern of settlement of fouling organisms on spat collectors as % of total numbers over all months. A, mussel shell collector; B, oyster shell collector; C, polypropylene onion bag; D, polypropylene rope collector.

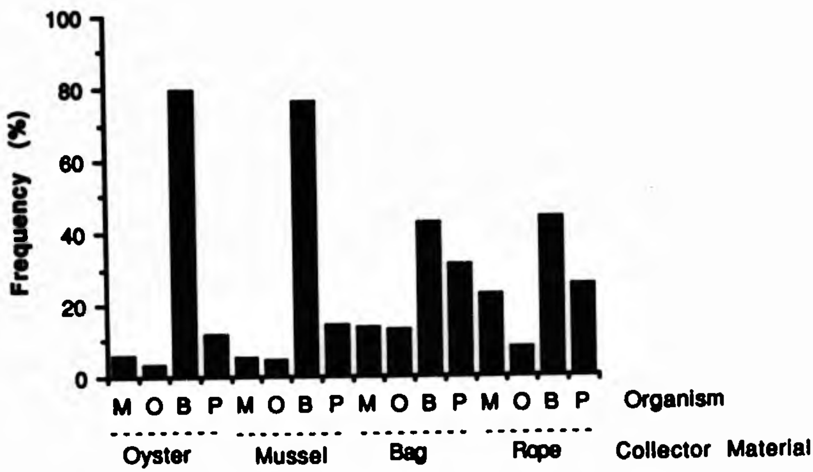


Figure 24. Relative overall average settlement of fouling organisms on the different collectors considered over the sampled months together. M. mussel spat; O. oyster spat; B. barnacles; P. polychaetes.

chambers containing mussels the average oxygen percentage saturation reached 60% two hours after the experiment was started (Fig.25).

After one hour, the standard period of time used in the subsequent experiments, the overall average percentage saturation was approximately 66 %.

The average dissolved oxygen concentration depletion during the experiment can be observed in Figure 26.

4.16.2 Experiment 2

No statistically significant differences in respiratory rate were detected between the three tested salinities. Nevertheless it can be observed that the *B. recurvus* mussel respiration rate of 13 mg/g/h at a salinity of 15 ppt was higher than the values recorded at 4 and 32 ppt (Table 29, Fig.27).

Correlation Coefficients ($p \leq 0.05$) were calculated to establish the relationship between respiration rate and mussel size, measured as length and weight (Table 30).

A significant inverse relationship was found between the specific respiration rates and the individual length and weight of the mussels tested at the experimental salinities (Table 30).

4.16.3 Experiments 3 and 4

The respiration rates of mussels of equivalent size selected from the mussel bed and aerial root clusters showed a similar pattern (Fig. 27). The highest respiratory values were recorded for the 15 ppt salinity (Table 29).

A two– way ANOVA Analysis and a Duncan's Multiple Range Test ($p \leq 0.05$) (Table 31) established a positive relationship between the salinity and the site of collection. It was determined that the mean

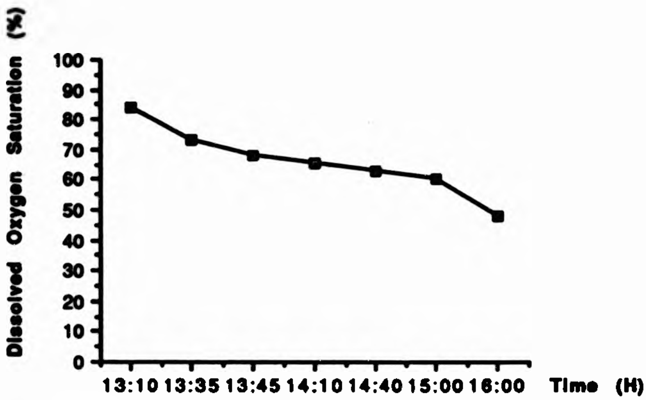


Figure 25. Average percentage saturation in the water recorded during respiration experiment 1.

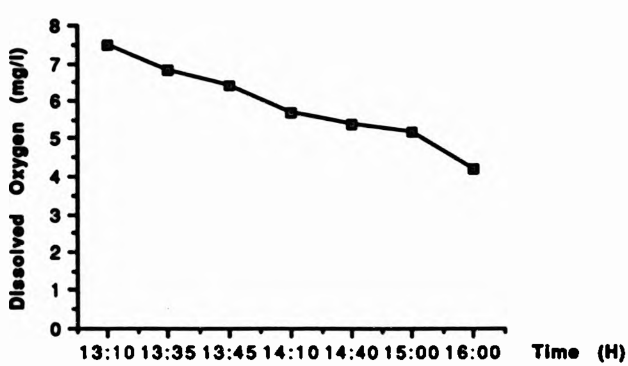


Figure 26. Average dissolved oxygen concentration during respiration experiment 1.

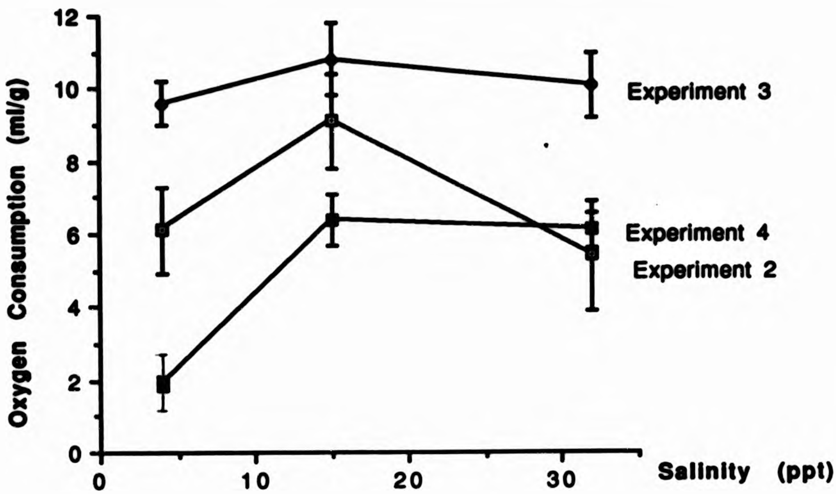


Figure 27. Weight specific respiratory rates of *Brachidontes recurvus* for experiment 2, 3 and 4; mussel bed heterogenous size, mussel bed homogenous size and cluster aerial roots (homogenous size) respectively. Bars indicate ±SE.

Table 29. Weight specific respiration rate of *Brachidontes recurvus* under different conditions of salinity, size and habitat. (B, mussel bed; C, cluster mussel).

Experiment	Salinity ppt	Length Size Range (cm)	Average Length (cm)	Habitat	Consumption O_2 mg/g/h	S.D.±	S.E.±	Consumption O_2 ml/g/h
	4	18-52	3.5	B	8.7	8.7	1.2	6.1
2	15	18-60	3.9	B	13.0	6.3	1.3	9.1
	32	17-56	3.9	B	7.8	7.3	1.5	5.4
	4	-	2.6	B	13.7	3.7	0.68	9.6
3	15	-	2.7	B	15.4	4.7	1.0	10.8
	32	-	2.5	B	14.4	4.4	0.9	10.1
	4	-	2.7	C	2.8	1.1	0.73	1.9
4	15	-	2.8	C	9.2	3.3	0.7	6.4
	32	-	2.7	C	8.8	2.6	0.5	6.1

Table 30. Correlation coefficient obtained for weight specific respiration rates with length and weight of *B. recurvus* at three salinities. * indicates significance at ($p \leq 0.05$).

Salinity ppt	Variable (x)	Variable (y)	Correlation coefficient r	r2 (%)	Significance
4	Length	Weight specific respiration rate	- 0.7199	51.8	*
	Weight		- 0.945	89.39	*
15	Length	Weight specific respiration rate	- 0.6102	37.2	*
	Weight		- 0.65	47.2	*
32	Length	Weight specific respiration rate	- 0.836	69.90	*
	Weight		-.8025	64.74	*

different to the values recorded at 15 and 32 ppt .

The respiration rates obtained at the different salinities for the two collecting site conditions (Table 29) showed the following differences:

Mussel bed   Mangrove root cluster

B C A   D E F

where the letters A,B,C and D,E,F, each correspond to the respiration rates at salinities of 4, 15 and 32 ppt respectively.

4.17. Utilisation of *Brachidontes recurvus* as a crustacean feed

4.17.1. Experiment 1.*Penaeus setiferus* feeding trial.

The average range in physico-chemical parameters measured during this experiment is summarised in Table 32. The average values were: temperature 28.3 C; pH 8; dissolved oxygen 5.2 mg/l; salinity 19 ppt; ammonia 0.01 mg/l and flow rate 42 l/h.

No statistically significant differences were found between aquaria in terms of these physico-chemical parameters.

The average daily individual length increments of shrimp reared on diets 3, 2, and 1 were 0.4, 0.2 and 0.13 mm/day, respectively (Fig. 28).

The average daily individual increment in weight ranged from 38 mg/day for diet 3 (commercial diet) to 11 mg/day for diet 1 (frozen mussel) (Fig. 28). These wieght increments were not statistically different.

Specific growth rates (total length increase) ranged from 0.73% per day for shrimp in diet 3 to 0.26% per day for those receiving diet 1. The highest daily weight specific growth rate was for diet 3 with 2.9% (Table 33). No statistical differences were obtained when these specific growth rates were compared, but the food conversion ratio (FCR) for Diet 1 was significantly higher than for the other diets (Table 33).

Table 31. Two Way Anova Analyses for the comparison between the weight specific respiration rates of cluster and bottom mussel at Estero Horcones, Laguna Redonda and Laguna Mandinga

Source of Variation	Sum of Squares	d.f.	Mean Square	F-ratio	Sig. level ($P \leq 0.05$)
MAIN EFFECTS	2240.9066	3	746.9689	66.490	.0000
level	1851.0037	1	1851.0037	164.763	.0000
salinity	389.9029	2	194.9514	17.353	.0000
2-FACTOR INTERACTIONS	193.03288	2	96.516439	8.591	.0003
level salinity	193.03288	2	96.516439	8.591	.0003
RESIDUAL	1415.5286	126	11.234354		
TOTAL (CORR.)	3849.4681	131			

Diet 1 was significantly higher than for the other diets (Table 33).

The best Assimilation Efficiency was obtained for diet 1 with a value of 82.87 %; for diets 2 and 3 the values were 75.02% and 66.63% respectively (Table 33). These were not statistically different.

The highest frequency of moulting was recorded for the shrimp fed on diet 3 (46%) and the lowest with diet 1 (25.7%) (Table 33); the organisms moulted from 0 to 4 times during the experimental period, with 1 or 2 moults being the modal frequency (Fig.30).

The survival rate of shrimp exceeded 60% for all diets, but the poorest survival occurred in the aquaria designated for diets 1 and 2 (Table 33). Water analyses detected the presence of high numbers of Vibrio spp. and Aeromonas spp. in the aquaria with shrimp fed on diets 1 and 2 (Table 34), which may explain this poor result.

4.17.2. Experiment 2. Macrobrachium rosenbergii Feeding Trial.

The physico-chemical parameters remained fairly constant throughout the experimental period with the following average values: temperature 27 C; pH 7.2; dissolved oxygen 7.1 mg/l and flow rate of 42 l/h. The concentration of nitrite was not enough to give a reaction by the colorimetric method so its concentration must have been lower than 0.002 mg/ml.

The average daily growth of Macrobrachium ranged from 0.16 mm/day (total length) diet 4 (fresh M. edulis) up to 0.24 mm/day for shrimp receiveing (diet 3) (Table 35).

The average daily weight increment presented a minimum value of 8.2 mg/day for shrimp on diet 1 and a maximum of 16.4 mg/day for thosereceiving diet 3; diets 4 and 2 resulted in similar growth increments of 10.5 and 9.6 mg/day, respectively (Table 36).

The 10 and 30 day periodic average body size and weight increments

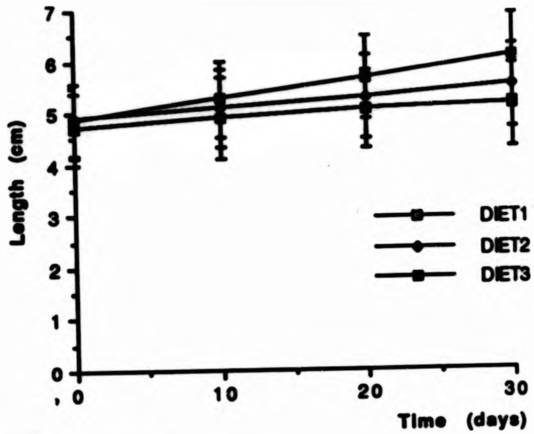


Figure 28. Average length growth curves for the *P. setiferus* feeding trial. Bars indicate ± SD. Diet 1, fresh frozen mussel; Diet 2, dry mussel meal; Diet 3, commercial balanced feedstuff.

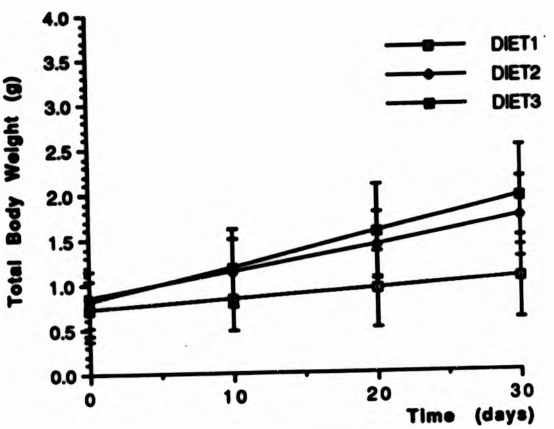


Figure 29. Average total body weight growth curves for the *P. setiferus* feeding trial. Diet 1, fresh frozen mussel; Diet 2, dry mussel meal; Diet 3, commercial balanced feedstuff.

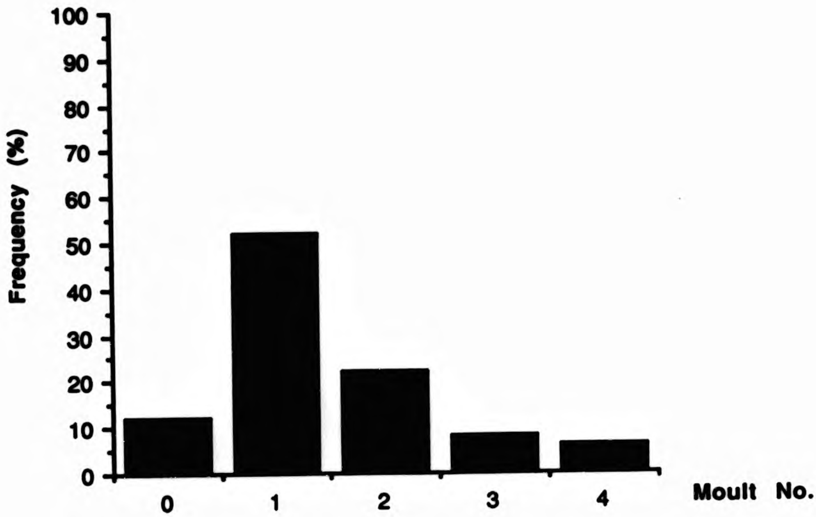


Figure 30. Distribution of total average moulting frequency of *P. setiferus* during the experimental period.

Table 32. Maxima and minima physico-chemical parameters during the *P. setiferus* feeding trial time period

Parameters	Maxima	Minima
T°C	32	26
pH	8.1	7.5
O_2 (mg/l)	68	4.5
NH_3 (mg/l)	0.0023	0.08×10^{-3}
Salinity (ppt)	20	17
Flow rate (l/h)	55	16

Table 33. General final results for the P. *setiferus* feeding trial (experiment 1).

	Diet 1	2	3
Initial length (cm)	4.78	4.88	4.86
Final length (cm)	5.17	5.48	6.06
Total length Increment (cm)	0.39	0.60	1.20
Daily length growth (mm/day)	0.13	0.20	0.40
Length Specific Growth Rate (% per day)	0.26	0.36	0.73
Initial weight (g)	0.710	0.840	0.801
Final weight (g)	1.04	1.71	1.971
Total Weight Increment	0.33	0.87	1.14
Daily Weight increment (mg/day)	0.11	0.29	0.38
Weight Specific Growth rate (% per day)	1.27	2.3	2.9
F.C.R.	12.9	6.9	5.5
Assimilation Efficiency %	82.7	75.0	62.6
Survival %	77.7	66.6	88.8
Total Percentage of moult	25.7	32.9	45

Table 34. Results of the microbiological analysis of the water in the three aquaria with the diets. *P. setiferus* trial

Aquarium No	Diet	*Vibrio* Spp	*Aeromonas* spp
		Colonies/ml	
1	1	300	600
2	2	300	100
3	3	30	10

can be observed in Figs. 50 and 51.
When the total 30 day period weight increments were compared, significant differences ($p \leq 0.05$) were established as follows:

D3 D4 D2 D1

The length and weight specific growth rates calculated for each 10 day period, and for the total 30 day experiment, are contained in Table 39. Diet 3 showed a similar pattern as described above, in which the best values of 14.4% in length and 44.9% in weight were recorded (Table 37). No statistical differences were detected for any of the specific growth rates when a one-way ANOVA was used.
The length and weight specific growth rates plotted for each 10 day interval show a general decrease after 20 days (Figs 33, 34).
This pattern was also observed in terms of the percentage of moults (Fig 35). In the first 10 days, 41 % of the moults occurred; 20.4% occured between 10 and 20 days and 38% between 20 and 30 days (Table 38).
The percentage of prawns that moulted more than once was highest for those receiving diet 1, followed by the shrimp on diets 2,, 3 and 4, respectively (Table 38). The total percentage of animals that moulted ranged from 30.6% for diet 1, to 20.7% for diet 3 (Table 38).
The shortest average intermoult time was registered for prawns receiving diet 4 (16.5 days); this compared with diet 3, 13.1 days; diet 2, 12.6 days and 12.1 days for diet 1 (Table 38).

Diet 3 showed the best food conversion ratio (FCR) with a value of 20.7 followed by diet 2, 7.3; diet 1,8.6 and diet 4 with 9 (Table 35). The survival in all the experiments was 100 %.
The gonad histological sections showed that the M. edulis mussels used

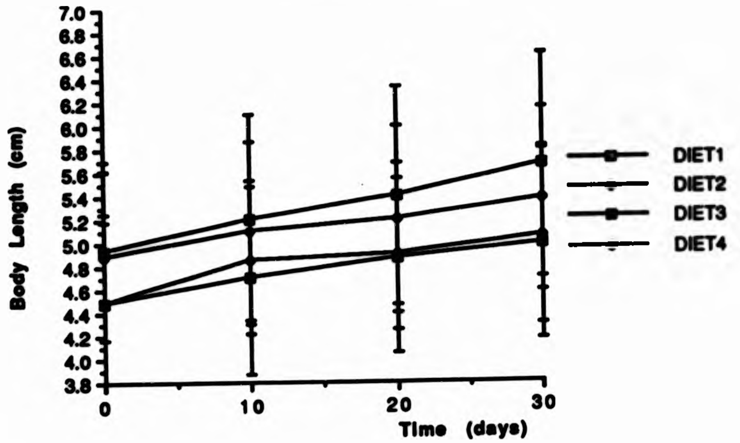


Figure 31. Average length growth curves for the *M. rosenbergii* feeding trial. Bars indicate ±SD. Diet 1, *B. recurvus* dry mussel meal; Diet 2, dry mussel meal; Diet 3, frozen meat; Diet 4, fresh meat. *M. edulis* was used in diets 2-4.

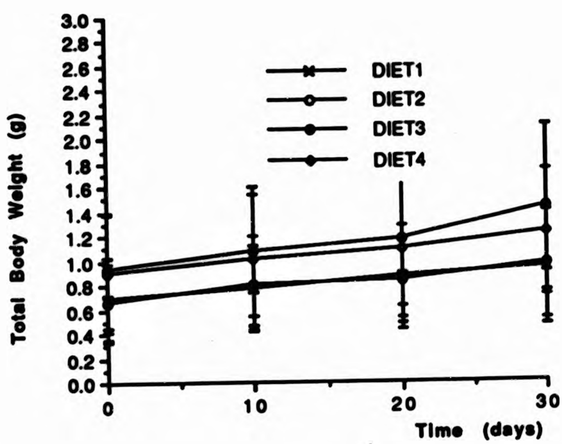


Figure 32. Average total body weight growth curves for *M. rosenbergii* during the experimental period. Bars indicate ± SD. Diet 1, *B. recurvus* dry mussel meal; Diet 2, dry mussel meal; Diet 3, frozen meat; Diet 4, fresh meat. *M. edulis* was used in diets 2-4.

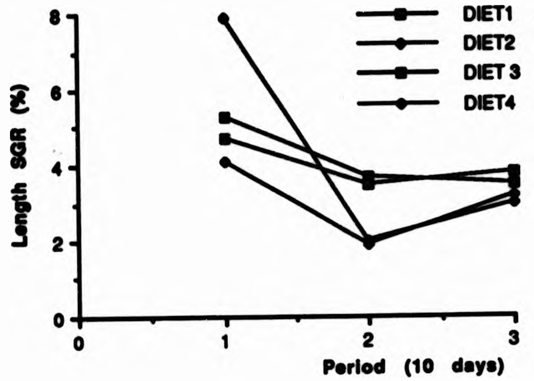


Figure 33. Average 10 day period length specific growth rates for *M. rosenbergii*. Diet 1, *B. recurvus* dry mussel meal; Diet 2, dry mussel meal; Diet 3, frozen meat; Diet 4, fresh meat. *M. edulis* was used in diets 2 - 4.

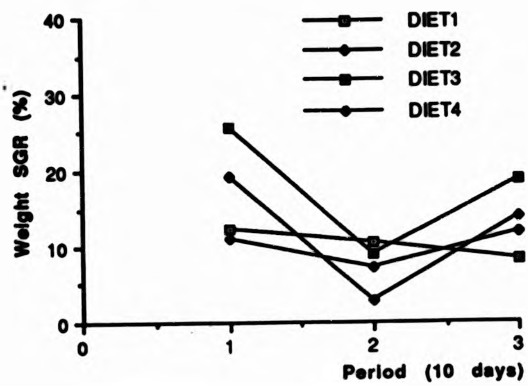


Figure 34. Average 10 day period weight specific growth rates for *M. rosenbergii*. Diet 1, *B. recurvus* dry mussel meal; Diet 2, dry mussel meal; Diet 3, frozen meat; Diet 4, fresh meat. *M. edulis* was used in diets 2 - 4.

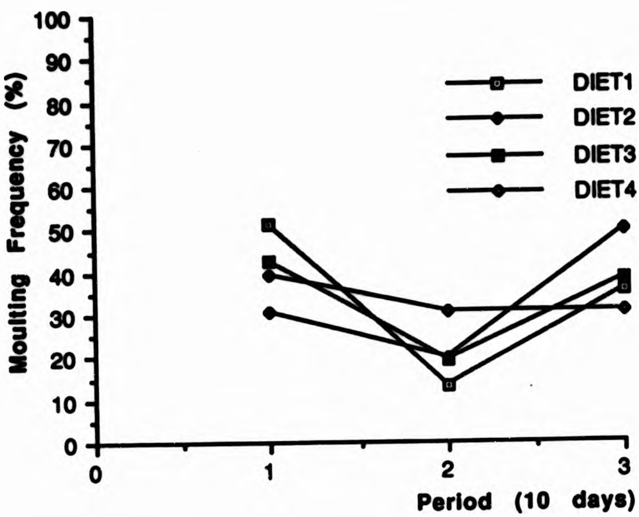


Figure 35 : Percentage of *M. rosenbergii* moulting for each 10 day period during the feeding trial. Diet 1, *B. recurvus* dry mussel meal; Diet 2, dry mussel meal; Diet 3, frozen meat; Diet 4, fresh meat. *M. edulis* was used in diets 2-4.

Table 35. Summary of final results obtained in the *M. rosenbergii* feeding trial.

Diet	1	2	3	4
		Average		
Daily length growth mm/day	0.17	0.19	0.24	0.16
Daily weight increment mg/day	8.2	9.6	016.4	10.5
Length Specific growth rate/day %	0.35	0.39	0.48	31.2
Weight Specific growth rate/day %	1.03	1.2	1.4	0.9
F C R %	8.6	7.3	5.8	9.0
Survival %	100	100	100	100
Percentage of the total prawn number moulted %	30.6	25.7	70.7	24.7

Table 36. Average length and weight of *M. rosenbergii* during the feeding trial.

Days	8	10	20	30	Average daily growth (mm/day)
Diet			Average total body length (cm)		
1	4.48	4.70	4.57	4.99	0.17
2	4.48	4.85	4.9	5.05	0.19
3	4.93	5.20	5.46	5.66	0.24
4	4.89	5.10	5.2	5.37	0.16
Total average	4.48	4.96	5.10	5.26	0.19
SD ±	0.00	0.72	0.27	0.31	0.03
			Average total body weight (g)		mg/day
1	0.6842	0.7737	0.8585	0.9329	8.2
2	0.6656	0.8080	0.8307	0.9555	9.6
3	0.9252	1.0752	1.1769	1.4193	16.4
4	0.9044	1.0105	1.085	1.2204	10.5
Total average	0.7948	0.9168	0.9877	1.0645	8.8
SD ±	0.1389	0.1485	0.1699	0.1422	3.6

Table 37. Average length and weight specific growth rates for *M. rosenbergii* feeding trial

Time	Average Specific Growth Rate (%)					
	10 day period interval			Total Average	SD±	30 day period interval
(length)	1	2	3			T_1
Diet 1	1.76	3.55	3.88	4.06	0.62	10.7
2	7.9	2.02	3.01	4.31	3.1	11.9
3	5.3	3.7	3.5	4.16	0.9	14.4
4	4.1	1.9	3.2	3.06	1.1	9.2
(weight)						
Diet 1	12.2	10.4	8.3	10.3	1.95	31.0
2	19.3	2.7	13.9	11.9	8.4	36.1
3	26.7	9.0	18.7	17.8	8.3	44.9
4	11.0	7.4	11.7	9.9	2.4	29.8

Table 38. Moulting data for _M_. _rosenbergii_ during the feeding trial period.

	1	2	3	4
Prawns moulted per diet (%)	100	81	81	87
Prawns moulted 1 time (%)	75	62.5	25.7	12.6
Percentage of moulted prawns (%)	30.6	25.7	20.7	24.7
Average intermoult time (days)	17.1	12.6	13.1	16.5

in the experiments had a Mean Seed Gonadic Index of 5, i.e. equivalent to fully sexually ripe individuals.

4.18. Marketing Survey

Fifty per cent of the respondents interviewed were between 25 and 34 years old; 22% were within the range 35 to 44 years old and the rest were a mixture of ages. The main activity for these people was house work (48% were wives); 24% were professionals; 22% were employees and the remaining 6% had other various activities.

With respect to their economy status, 96% were earning more than the minimum salary of approximately 3000 Mexican pesos/hour. About 62% normally bought their food in supermarkets and the rest in both supermarkets and normal popular markets. Fifty six per cent of the people said they normally paid by cash; 4% with credit cards; 30% with both of cash and credit cards and only 6% used other means e.g. food vouchers.

Normally 80% of the people ate marine products, but only 40% atemussels. Among the alternative answers offered in the questionair, 18% bought marine products for their flavour; 12% for their price and flavour; 8% for their nutritive characteristics and the rest for a combination of these reasons. At the time of the interviews; 44% stated that they last ate mussels more than one month previously. The others had consumed mussels one week to one month ago.

The brands of canned mussel most commonly consumed (according to the answers given) are shown in Table 39.

The most common can type, seen by 26% of the people, was oval in shape; 14% each for cylindrical and rectangular cans; 8 % for other types of containers, e.g. glass flasks.

Finally, 70% of the people answered that if they knew more about mussels, they would consume more, but they felt that knew very little about mussel products compared to other forms of seafood.

Table 39. Brands of canned mussel consumed interviewed by people in the port of Veracruz (number of interviewees = 20).

Brand	Consumer %
Ibarra	18
Marco Antonio	–
Calvo	22
Vigilante	4
Others	6
Marco Antonio and Vigilante	2
Calvo and Vigilante	2
Ibarra y Calvo	2
No consumers	12

5. DISCUSSION

5.1. Environment of the Boca del Rio Estuarine System

– Introductory definitions.

A common problem in marine science concerns the definition of coastal lagoons or estuaries (Yanez–Arancibia, 1987). The term estuary (from the Latin aestus meaning tide: Shubel, 1971), has been defined in various ways.

Geologists tend to accept the strictly physical interpretation of Pritchard (1967), who defined an estuary as "a semi–enclosed coastal body of water which has free connection with the open sea and within which sea water is measurably diluted with fresh water from the land drainage". A broader, more ecological definition, proposed by Cowardin et al (1979) is "deep–water tidal habitats and adjacent tidal wetlands which are usually semi–enclosed by land, but have open, partially obstructed, or sporadic access to the open ocean and in which ocean water is at least occasionally diluted by fresh water runoff from the land."

The Boca del Rio–Mandinga ecosystem can be described by any of these definitions except for the kind of connection it has with the sea, which in this case is located at the mouth of Jamapa River (Fig. 1). This connection determines seasonal and spatial hydrological patterns inside the estuarine ecosystem, and these are strongly influenced by the interaction of the river and the tides.

Pritchard (1967) subdivided estuarine water bodies into four geomorphological categories: drowned river valleys; fjord – type estuaries; bar built estuaries; and estuaries produced by tectonic processes. Boca del Rio–Mandinga estuarine system belongs to the first type and, as described in detail in Chapter 2, in general terms has two wide semicircular parts locally called Lagoons (Lagunas) connected by Estuaries (Esteros). These denominations are arbitrary and do not conform exactly with the definitions discussed above.

For practical purposes, and as Odum et al (1974) cited by Bahr and Lanier (1981) recommend, only those aspects of the ecosystem which most relate to ecology and culture of Brachidontes recurvus, are dealt here.

– Salinity.

Water circulation patterns are of primary significance in determining the physical and chemical conditions of the estuarine ecosystem. Water circulation strongly influences sedimentation patterns, turbidity, temperature and nutrient conditions (Bahr and Lanier, 1981). Estuaries such as Boca del Rio–Mandinga, with significant riverine sources of low salinity water are distinctly different in form and hydrographic character from those without such sources (Oertel, 1974).

Classifications of estuarine water circulation patterns are based largely on the relative magnitude of either riverine or tidal influence (Ketchum, 1951; Bowden, 1967; Pritchard, 1967, 1971) in conjuction with the estuarine geomorphology (Shubel, 1971). Usually, as in the case of Boca del Rio–Mandinga, estuaries have an elongated and rather sinuous shape (Fig.1). Estuaries with large riverine sources of freshwater have a well–defined vertical salinity stratification as shown by significant differences between the surface and bottom salinity values recorded during the present study (Fig. 6A). Fresh water overflows higher density salt water and forms an upper fresh, or brackish, layer, especially during the months with high pluvial precipitation (Fig 6A). It was found that this layer plays an important role in the settlement pattern of B. recurvus planktonic larvae as discussed in Section 5.2.

The entrainment of salt water from the lower layer into the upper fresh water layer through eddy diffusion results in the mass movement of the saline bottom layer into the estuarine basin (Shubel, 1971), creating during this season a salt–wedge type estuary (Pritchard, 1971). During the dry, north wind season with higher average salinities (Fig 6A), a partially mixed estuary occurs when the tidal flow, assisted by periodic strong north winds blowing from the sea towards the mouth of the ecosystem, is sufficient to prevent the Jamapa River from dominating the circulation pattern (Shubel, 1971). Turbulence generated by the movement of the saline bottom layer results in increased vertical mixing and moderate salinity stratification (Pritchard, 1967). Considering that this condition is present for most of the year, Boca del Rio–Mandinga estuarine ecosystem can be classified as vertically homogeneous (Pritchard, 1967, 1971; Shubel, 1971).

The water of the system can be considered in general terms as mesohaline, with wide seasonal variations and a trend of decreasing of salinity values towards the head of it (Table 2). This gradient is strongly developed during the rainy season in which two general zones can be differentiated based on the classification proposed by Ringuelet (1962); a mesohaline zone with salinities within a proposed range of 5–18 ppt from the mouth of the ecosystem to Estero Horcones, and an oligohaline zone (0.5– 5 ppt) including Laguna Redonda and Laguna Mandinga. Two different zones are defined during the dry, north wind season, including from the mouth to Laguna Larga as polyhaline (18–30 ppt) and mesohaline over the rest of the system.

The strong influence of the rain was confirmed by comparing the correlation values calculated from the diurnal variations at Laguna Redonda when tide and salinity were related. During November salinity was supposed to gradually increase with the flooding tide as in June, but the low correlation value obtained, indicated the dilution effect caused by the rain that fell during this period.

During the two years of the study (1988–89), salinities in Laguna Mandinga dropped drastically during the rainy season months (Fig 6A), causing massive oyster mortalities (Farias et al, 1987). These organisms were not able to withstand water that sometimes was practically fresh and out of the tolerance range for the species (Galtsoff, 1964). Brachidontes recurvus in this sense is better adapted than C. virginica (Chanley, 1958).

The oyster mortalities are an important indicator of the possible consequences for less euryhaline benthic estuarine species if the recent gradual decrease in salinities continues. According to Cruz–Aguero (1985) the annual average salinity in 1975–76 before the dredging was 10.5 ppt, increasing in value up to 21.1 ppt in 1982–83 after the dredging. The annual average salinity value registered in the present work was 19.2 ppt (Table 2), reflecting the effect of the gradual silting at the mouth of the system in lessening the tidal influence. This problem could become worse because of a trend in the area to build housing provided with rain drainage systems directly channelised into the estuary, plus swimming pools and general services (e.g. toilets with 50 l water capacity), all of which are releasing great extra volumes of fresh water into the system.

– Temperature.

Water temperature is an important factor in the general dynamics of the estuarine ecosystem. Annual water temperature fluctuation (Fig. 6B) is mostly influenced by the pattern of average air temperature (Fig. 11A). This is indirectly supportedby comparing the similarity of values reported by De la Cruz (1985) of 27.3 C in 1975–76 and 1982–83 with the average temperature of 27.9 C in 1990 (Table 2). There was no evidence of vertical temperature stratification in Boca del Rio–Mandinga system, hence thermal mixing of estuarine water masses occurs rapidly, and the temperatures are subjected to daily fluctuations (Oertel, 1974) as shown by the diurnal variation values at Laguna Redonda. Also there was no significant correlation between these and the tidal height. A gradient of higher temperatures towards the head of the system was detected (Table 2) where the system is shallower (Arreguin, 1982). According to Chavez and Torruco (1988a) this gradient can be important when the synergistic effect of high temperature and low solubility of dissolved oxygen on the performance of organisms living in these shallow areas. This can be stronger in spring and summer when the air temperature and the number of insolation hours is high, especially from 9 am to 6pm, as indirectly shown in the water temperature recorded during the diurnal cycles at Laguna Redonda (Fig. 7A, 8A). This effect is less important closer to the mouth of the system where lower temperature ocean waters at this time of the year have a cooling influence (Bahr and Lanier, 1981 and Table 2).

– Dissolved oxygen.

Dissolved oxygen values were significantly higher in Laguna Redonda and Laguna Mandinga where salinities tended to be lower (Table 2). This is the opposite of the expected relationship according to Bahar and Lanier (1981). Relatively low DO values, however in the inner part of the estuarine systems normally reflect the consumption of oxygen during the oxidation of organic detritus in suspension as reported by Howarth et al. (1975).

A possible explanation for this contradiction is based on the fluctuation of dissolved oxygen values found in the diurnal variations at Laguna Redonda. Statistical analysis showed that the variation in oxygen levels did not depend on the tidal height but on the time of the day, i.e. there was an increase in dissolved oxygen in the afternoon (Figs. 7C, 8C). The sampling procedure was to start at stations close to the mouth finishing normally at the head of the system in the afternoon and this would have contributed to the apparent pattern of DO values recorded (Table 2).

The average annual dissolved oxygen value of 7.4 mg/l is higher than that reported for related estuaries in the Gulf of Mexico; e.g. La Mancha, Terminos and Celestun, with average annual values ranging from 3 to 4 mg/l (Chavez and Torruco, 1988a). This condition makes Boca del Rio–Mandinga system suitable for aquatic life (Bardach et al., 1972).

In comparison to this average, DO were reported to be 9.3 mg/l before the dredging and 5.9 mg/l after it (De la Cruz, 1985) Like salinity, this can be one more indicator of the environmental changes that Boca del Rio– Mandinga system is undergoing as a result of human interference.

Even though no significant differences were detected between months, low dissolved oxygen occurred during February 1989
(North winds season), when water velocities tend to increase (Farias and Salinas, 1987), resuspending the bottom sediments as shown by the low corresponding transparency value (Fig. 6D).

Frakenberg and Westerfield (1968) reported that the dissolved oxygen levels in estuarine waters in coastal Georgia were extremely sensitive to sediment disturbance; during summer the oxygen demand of a single milliliter of disturbed sediment could deplete the dissolved oxygen contained within 986 ml of water.

This association of low oxygen with a high level of suspended matter showed the opposite relationship in December when high dissolved oxygen and transparency values were recorded (Figs 6D, C). These were similar to values reported by Arreguin (1982) for the southern part of Laguna Redonda where "transparency was total, steady waters and oyster shell and sand were present as main sedimentary components."

– Transparency and suspended matter.

Oertel (1976) described large temporal and spatial variations in turbidity in estuarine waters. These variations relate to riverine input, local resuspension of bottom sediments by tidal currents and waves, and release of trapped fine sediments in the marginal areas of the system (Shubel, 1971; Arreguin, 1982).

Transparency in Boca del Rio ecosystem showed an irregular spatial pattern, thus the zone termed by Shubel (1968) as the "turbidity maximum" was not well delimited. This zone should be clearly present when "turbidity is greater in the upper reaches of the estuarine system than either further upstream in the source river or farther seaward".

In the case of this ecosystem, spatial differences in water transparency are mainly determined by the type of bottom sediments. As a good example, stations that were close to margins in the system tended to have finer sediments (Table 3) and lower values in water transparency, as in stations 4, 8, 10 and 11. These locations were in contrast to e.g. station 12 where the subtratum consisted of a hard, broken oyster shell bottom.

According to Chavez and Torruco (1988a), when different lagoons of the Mexican coast of the Gulf of Mexico were compared on the basis of transparency, Mandinga and Celestun were the water bodies with lowest monthly average transparency, and stated the importance of transparency for all these ecosystems based on the negative correlation found, for this parameter with respect to their fisheries production.

The inorganic suspended matter maximum value found in this study was slightly lower than the figure 43 mg/l in June 1987 for Estero Horcones reported by Amador (1989) and below the optimum value reported by Winter (1975) for the feeding activity and growth of M. edulis. Considering that B. recurvus lives in association with C. virginica, it can be assumed that B. recurvus can tolerate inorganic matter concentrations at least as well as this oyster. Lund (1957) cited by Barker (1966) found that in laboratory conditions 10 mg/l of suspended matter did not affect the valve opening activity of C. virginica, and the Barker (1966) stated that this organism is able to feed in water containing up to 400 mg/l of silt. Spatial and temporal comparisons of this value, showed irregular patterns closely related to the rainy and North wind season and areas with different bottom sediments as discussed above.

These same meteorological factors seem to have a closer relationship to the levels of suspended organic matter than phytoplankton abundance, as shown by the low correlation found between chlorophyll a and suspended organic matter. Most of this organic matter comes from the mangrove trees (mainly leaves), which falls into the water as a product of biological activity by insects (Christensen, 1978), and secondary degrading processes by fungus, protozoa, microalgae and bacteria (Heald et al., 1974).

A ratio of 7:3 of inorganic: organic suspended matter, similar to that reported by Oertel (1976), was found in December 1988 but the overall average ratio showed an inverse pattern of 4:6.

– Sources of food for mussels.

Chlorophyll a is an essential constituent in phytoplankton (Jorgersen, 1966) and has been utilised as an indicator of various characteristics of the phytoplankton community in estuarine systems (Margaleff, 1964 cited by Lara and Alvarez, 1975).

High chlorophyll a values in the Boca del Rio Mandinga system were normally recorded after a sudden drop in the salinity such as in March and April 1989 when the influence of the north winds and tides had less influence on the water exchange of the system. The other case was in August and September 1988, when the salinities were low due to the rainy season (Fig. 6A).

Yanes-Arancibia and Day (1982) reported for a similar system (Terminos Lagoon) that planktonic photosynthesis, respiration, and chlorophyll were higher in turbid, low salinity, riverine influenced areas, as found for the average spatial characteristics of the present studied ecosystem (Table, 2).

In relation to the latter, although seasonal and spatial pH average values remained fairly constant (Table 3) due to the buffering capacity of marine water, it is possible that the combination of low salinities, biodegradation and respiration might have tended to decrease the values as in the month of August 1988.

The chlorophyll a annual average of 12 mg/m3 found in this study is similar to 12.7 mg/m3 (Farias et al, 1987) and 15.3 mg/m3 (Amador, 1989) reported for this same system. These averages are suitable for mussel feeding if it is considered that Galicia, Spain, one of the most productive world areas of cultivated musssels (Figueras, 1989), has a range of 19–28.5 mg/ m3 and an average of 11 mg/m3 (Korringa, 1976).

According to Pomeroy and Wiegert (1980), cited by Bahr and Lanier (1981), in a "typical" estuary in Georgia, the major phytoplankton producers were listed as pelagic diatoms and occasional benthic penate diatoms swept up from the bottom into the water column, dinoflagellates and green flagellates.

This seems to be applicable to subtropical and tropical ecosystems; Yanez-Arancibia and Day (1982) reported that for Terminos Lagoon, a tropical lagoon–estuarine system in the southern Gulf of Mexico, diatoms dominate the net phytoplankton of the ecosystem.

This fact is important as this group of algae have been shown to be nutritionally suitable for the diet of mussels and oysters (Seed, 1921; Chanley, 1958; Sivalingam, 1977; Spencer et al., 1986). Panana (1987) reported that Skeletonema sp. is very abundant in the adjacent coastal zone to Boca del Rio–Mandinga, while Amador (1989) noted that Skeletonema sp., Chaetoceros sp., Coscinodiscus sp., Rhizosolenia sp. and Ceratium sp. are present within this ecosystem. Dinoflagellates are also considered an important dietary source for mussels (Coe and Fox, 1942). Thus the conclusion is that the Boca del Rio–Mandinga ecosystem contains a suitable quantitative and qualitative source of food for molluscs in the form of phytoplankton.

The other important source of food, which is found as a significant fraction of mussel and oyster stomach contents, is fine detrital matter (Field, 1922). This finding is indirectly supported by Chavez and Torruco (1988a) who concluded, after comparing chlorophyll a concentrations and fisheries production from different coastal estuarine lagoons on the eastern Mexican coast, that although apparently this production was directly related to chlorophyll levels, the trophic structure in coastal lagoons is not simple and the energy fluxes do not depend on phytoplankton as the main energy source but mainly on detrital matter (Darnell, 1967a,b; Nixon, 1982; Batllori et al., 1986, cited by Chavez and Torruco, 1988).

Athough the values for phaeopigments (Fig. 6E) were low because of problems associated with the sensitivity of the method (Stirling, 1985), their presence in relation to chlorophyll a levels may indicate grazing activity by zooplankton in the estuarine system (Lara and Alvarez, 1985)

In these ecosytems, four groups have been related as primary producers; emergent macrophytes, phytoplankton, benthic algae and chemosynthetic bacteria (Schelske and Odum, 1962; Howard and Teal, 1979).
In terms of overall primary production for temperate estuaries
the emergent macrophytes are considered to contribute a major portion of the particulate carbon (Bahr and Lanier, 1981).
Nevertheless some arguements have been advanced by Haines (1976, 1977), that perhaps production by phytoplankton is more significant than that of macrophytes. However in ecosystems with mangrove trees, the importance of mangrove forest primary productivity is illustrated by the report of Ong et al. (1979) in which the aquatic primary productivity only represented 2% of the net mangrove forest production.
Mangrove detrital matter is more abundant in Mexican coastal systems during the rainy season and when river flow is high (Yanez-Arancibia

and Day, 1982). But litterfall is also important during the North wind season, so mangrove detritus appears to make an important contribution to the food supply for mussels and oysters throughout most of the year. Botello (1974), cited by Bravo, 1985) found that the isotopic ratio 13C:12C in the oyster C. virginica showed a great similarity to the ratio found in organic matter of terrestrial origin (e.g. mangrove material), proving that there is a large utilisation of this kind of organic matter by the oysters.

The above provides further support for the conclusion that the Boca del Rio–Mandinga estuarine system is a suitable place for natural or cultivated molluscs populations in terms of the quantitative and qualitative availability of food.

– The Sediments.

The origin of sediments in estuaries and the processes that affect their distribution and deposition have been the subject of extensive research and scientific debate for over 25 years (Guilcher, 1967). Estuarine sedimentation patterns are complex and influenced by tidal cycle, wind speed and direction, waves, seasonal riverine flooding, water storage in the estuarine system and sediment availability (Bahr and Larnier, 1981). Biological animal–sediment interactions (bioturbation) and chemical factors are also important (Howard, 1975). These factors may vary continuosly in space, time and intensity (Oertel, 1974).

Sediment texture is important for the life cycle in bivalves, whether as larvae on the moment of metamorphosis and settlement (Nybakken, 1975 cited by Carriquiriborde et al, 1981) or their general performance (Bahr and Lanier, 1981; Farias and Salinas, 1987).

The sediments found at station 4 (Estero Horcones) (Fig1), indicate that it is an area where fine sediments settle (Table 3), especially in the marginal zones where the mangrove aerial roots tend to act as a sediment trap (Arreguin, 1982).

The presence of these muddy sediments beneath the roots which normally bear mussel clusters is important in the life cycle of B. recurvus (Fig 4), because mussels which fall into the mud as a consequence of increased currents during the rainy and north wind season, as explained in more detail in Section 5.2. An indicator of the strong, indirect effect that these winds have on sediment texture can be observed from the increase is the percentage of sand recorded in January 1989 (Table 3) when winds were strong.

A similar type of coarse sediment was reported for the same locality by Arreguin (1982). This author found that in the central part of Estero Conchal and Laguna Mandinga, the sediment was formed by broken clam, mussel and oyster shells. Sandy bottoms were detected at the mouth of the system, and in the southern portion of Laguna Redonda. The rest of the system contains mainly silt and clay.

– Currents and circulation.

The distribution of the sediments in the system is directly determined by the speed of the currents. Farias et al (1987) reported water currents for Estero Conchal ranging from 21.9 to 117 cm/s with an average of 35.4 cm/s compared to 8 to 44 cm/s and 19.4 cm/s in Estero Horcones (Farias and Salinas, 1987). Current speeds higher than 60 cm/s are categorised as strong (Dare and Davies, 1975).

Water currents recorded at Laguna Redonda showed slower average speeds (Table 5). These differences are possibly determined by the physiography of the system, as the strongest recorded currents occur in the narrow straight Estero Conchal channel, decreasing in velocity in the narrow and meandering Estero Horcones and wide open areas such as Laguna Redonda.

The consequences of changes to the system's original physiography caused by human activities can be illustrated by the massive mortality registered in 1986–87 on an oyster bed located at the boundary of Estero Conchal and Laguna Larga (Fig. 1). Here mangrove was cut on the eastern margin and a containment wall was constructed as part of a housing development at this site. Subsequent to these 'developments' the water current pattern changed, eroding areas with soft sediments and, conversely, silting over regions where substrata had been, including the oysterbed which was eventually buried (pers. obs.).

The tidal cycle was found to be a more important cause of mass water movement than the wind influence. On January 23 for example the direction of the current coincided with that of the ebbing tide, yet the wind was blowing in the opposite direction (Table 5). The physiography of the system defines the general circulation pattern, as observed in Laguna Redonda where the flow was parallel to the marginal zones leading towards the northwest outlet. As explained in the methods, measurements were only taken during ebb tides, but it can be assumed that during flood tides, the same pattern occurs in the opposite direction. Considering the general shape of Laguna Redonda, the development of an eddy when the tide changes is probable during floods and ebbs is possible, with its centre in a sluggish zone (Edwards and Edelsten, 1976), but this phenomen was never clearly observed.

Tides in the system are mixed diurnal in frequency and according to Davies (1964), can be classified as microtidal (range 0–2 m). The average delay recorded of 4 hours with respect to the predicted tide at Veracruz Port is explained by the type of mouth connection and shape of the system. This lag period is less than the delay of 5 hours before dredging began as reported by Vazquez-Yanez (1971) and indicates an improvement in the sea water entrainment. Tidal amplitude ranges are small and within the maximum astronomical values for the port of

Veracruz (Anonymous, 1989); there are similar to the ranges reported by Arreguin–Sanchez (1982) (Section 2.7).

Winds do not seem to have an important influence on the water movement inside the system as discussed previously, but it was observed that the amount of seawater entering was larger during a flood tide in combination with a strong north wind, typical of a period when the river flow is not as important as in the rainy season.

This latter was clearly observed when the direction of the water current in Laguna Redonda during the ebbing tide was unexpectedly reversed on May 13, 1988 (Table 5). It was noticed at that time, that the volume of the river discharge increased suddenly with the water drained from the mountains after three days of rain. This created a "plug" of freshwater that stopped the ebb tide from flowing outwards and even pushed fresh water into the system .

Depths in Boca del Rio–Mandinga can be classified into (a) areas less than 2 m depth which correspond to most of the total area of the system, associated with fine sediments and relatively slow speed currents and (b) areas including the mouth, internal lagoons connections (Fig. 10) and navigation channels characterised by coarser sediments and high water current speeds; the average depth is 3–4 m.

The deeper waters are mainly used for water navigation, but the remaining shallower areas have proved suitable for suspended cultures and fish cages (Farias et al, 1987; Farias and Salinas, 1987; Bibiano, 1990).

5.2 Brachidontes recurvus Life Cycle and Ecology

There is a general reliable lack of means of identification for species in tropical coastal ecosystems, making it difficult to classify a particular organism properly. The mussel Brachidontes recurvus, has been partially classified down to genus (Camacho, 1980; Lopez, 1985), but sometimes confused with other species such as by Arreguin (1982) who worked in Boca del Rio–Mandinga estuarine system and classified the local mussel as Brachidontes dominguiensis. The external morphological characteristics of this species are not only similar to B. recurvus, but also to B. exustus. The main differences are the average length, which is 64 mm for B. recurvus and 38 mm for the other two. B. dominguinesis is found attached to rocks and shells in oceanic, subtidal or wave tossed areas, whereas B. exustus is abundant on rocks and pilings (Abbott, 1974; Garcia–Cubas and Reguero, 1987).

Seed (1976) has commented, based on the experience of other authors, on the difficulty of trying to use only the external shape of the shell for identification because this depends on environmental conditions and in the age of the animal. He also remarked on the possibility of finding different ecological or genetically differentiated forms. Soot–Ryen (1965), cited in the same paper, points out the importance of using the shell and soft parts of the mussel for species identification.

According to Seed (1969a), the varied distribution pattern exibited by mussels generally might be related to local differences in the physical environment. He recommends seeking an explanation for their distribution in terms of variations in sequential settlement, mortality and recolonisation occuring in different habitats. In the case of B. recurvus their spatial distribution and general performance in Boca del

Rio–Mandinga are determined by two main factors: salinity and substrata availability for settlement and growth.

This mussel is a very euryhaline organism; Chanley (1958) recorded experimentally after 50 days exposure, a 95% survival of the mussels transferred directly from 27 ppt to 2.5 ppt. In fresh water, the first mussel died after four days and all were dead within 30 days; Allen (1960) found similar results, proposing as the "probable critical value" 4.5 ppt. However, he was able to keep 50% (80 mussels) of the experimental population after 3 days and 8 mussels after 16 alive, in a salinity ranging form 0.9– 3.5 ppt. Nagabhushanam and Sarojini (1965) found that the heart rate remained fairly constant at a rate of 31–32 beats/ minute within a salinity range of 14–17 ppt indicating this to be the approximate optimum salinity range for the species. This coincides with the optimum of 15 ppt determined in the present work, based on the weight specific oxygen consumption values obtained independently of the salinities tested (Fig.27).

Remane and Schlieper (1971) found that when respiration rates of mussels from a range of environments were measured at their field–ambient salinities, they were similar throughout a range representing fully brackish to fully marine (5 to 35 ppt) conditions. This result agrees with the lack of significant differences between the specific oxygen consumption values of B. recurvus at different salinities, regardless of their generally higher consumption at 15 ppt (Table 29). Nevertheless, this coincides with the pattern found by Lange (1968), who concluded that the metabolic rate of gill tissues, like that of the whole animal, was maximal at the salinity to which the animal was adapted.

Similar results have been obtained when mussels were experimentally exposed to altered salinity over a relatively short period (Bouxin, 1931;

Remane and Shlieper, 1971). Brachidontes recurvus showed similar behaviour to M. galloprovincialis. Bouxin (1931) adapted the latter to normal sea water and measured rates of oxygen consumption at different salinities; over a range from 20-36 ppt there was little change, but with further increase or decrease in salinity the oxygen consumption was depressed.

In Nagabhushanam and Sarojini's (1965) study and in the present work experimental salinites were within the range 3.5 to 35 ppt representing the lower and upper tolerance limits for B. recurvus; in neither case were mortalities registered at this limits. Other mussels such as Mytilus edulis, can survive 48 hours exposure to 150 % seawater (Funakoshi et al., 1988).

These observations on the physiology of B. recurvus help to explain its distribution in the Boca del Rio-Mandinga system. B. recurvus starts being conspicuous from station 4 onwards towards the head (Estero Horcones), of the system where the mesohaline zone is present during the dry season, but turns oligohaline in the rainy season, as described previously.

This prevalence of mesohaline conditions gives B. recurvus an ecophysiological advantage over its closest, less euryhaline competitor, the oyster C. virginica (Lossanoff, 1952; Chanley, 1952). This physiological distribution establishes a natural distribution boundary between the two species, concentrating most of the mussel population towards the head of the system, whereas the oysters are closer to more oceanic conditions as indicated by the location of the most populated and productive oyster beds (Lopez, 1985).

The physiography of the system together with the limited water exchange between its different components restrict the transport of mussel larvae towards the mouth. It can be concluded that most of the larvae

concentrate in areas where the adult population is more abundantly distributed (Fig.17) since there is a degree of synchronicity in spawning as shown by the peaks in condition factor (Fig.15) and Breese et al (1963).
These larvae after settling on filamentous algal substrata, eventually will re-settle on the adult mussel beds (Seed, 1969a). Possibly some larvae reach and survive in zones closer to the mouth, where the mussel population density is very low (represented by small scattered groups) but where suitable substrata are available.

However, oysters and mussels coexist in the oyster beds located at the saline area nearest to the head. Apparently the well marked water stratification here in the rainy and in the dry-north wind seasons (represented by a narrow sea water layer running close to the bottom during flood tides) benefits oysters whose relative abundance is higher than that of mussels. The less than favourable conditions here for bottom mussels is reflected by the smaller average length, and lower condition factors 2 and Seed Mean Gonadic Indices found for the mussel populations at Laguna Redonda and Laguna Mandinga compared to Estero Horcones (Table 12).
The presence of B. recurvus in these oysters beds is determined by the availability of substrata in relationship to currents and salinity conditions as postulated by Farias and Salinas (1987) and confirmed by the present study.
The utilisation of shells and other hard substrata as points of attachment for settling larvae, enabling epifaunal organisms to populate soft sediment environments such as Boca del Rio-Mandinga estuarine system, is common in the fossil record, as well as the modern marine enviroment, and involves many types of materials (Morris and Rollins, 1977).
Mass Geesteranus (1942) established that mussel settlement in general

terms occurs on any substrata as long it is firm and rough with discontinuities. In the zones of Boca del Rio– Mandinga where mussels are abundant, two main substrata were identified: aerial mangrove roots and subtidal oyster–musselbeds.

The most distinctive feature of these two habitats is their position with respect to the water column and their general location in the water body. Mangroves are distributed along the marginal zone of the estuarine system (Vazquez–Yanez, 1971) and the roots are in contact with the less saline surface water layer; the beds of oyster and mussel shells are located in quite different zones of the system and are influenced by the more saline bottom water layer (Fig.6A).

As part of a preliminary study on the ecology and culture of B. recurvus. Farias and Salinas (1987) conducted an experiment to test four different materials as mussel spat collectors; oyster shells, polypropylene ropes, coconut shells and mangrove aerial root pieces; these were positioned at both ends and at the centre of Estero Horcones (Fig 1). As described in section 4.9.2.1., mussels in this locality are found attached to the aerial mangrove roots, thus a significant mussel settlement on the mangrove collectors was anticipated. However they proved to be the least effective material, setlement was recorded on the suspended oyster shell collectors.

This finding suggests that mussel larvae are strongly influenced by water level. They favour athe surface layer, where under normal conditions the only suitable substratum are the mangrove aerial roots. Only when given an artificial choice of other subtrates suspended in the surface layer as in these experiments, did they show a preference for oyster shell.

Dare (1980) showed that larvae tend to remain in the superficial layers until development of the pediveliger (Dare, 1980) and according to Bayne (1969a), cited by Bayne (1976), at this stage negative phototactism and a failure to respond to pressure stimuli should

encourage the larvae towards the bottom.
This initial surface-dwelling behaviour is perhaps caused by the fact that the upper layer has the low salinity conditions, necessary for better larval development. Under experimental conditions, Chanley (1970) was able to obtain succesful larval development of B. recurvus, using a salinities range of 18 to 20 ppt and a temperature of 25°C. These salinities are more likely to be found in the upper layers than in the bottom where possibly a 10 cm sea water layer runs during flood tide. These are typical conditions in the estuarine system during the rainy season when spawning and recruitment of B. recurvus occurs as determined by Farias and Salinas (1987) and confirmed in the present study based on condition factor (Fig. 15) and population structure analysis (Figs 12–14).

Another factor preventing larvae from swimming to the bottom to search for a better substratum is their spatial position.
At Estero Horcones the oyster shell substratum, is found at 3 m depth in the center of the navigation channel, where currents are stronger, as indicated by the coarser sediments recorded here compared to those close to the mangrove aerial roots (Table3). Although mussel larvae have the capacity of migrate vertically in the presence of tidal currents (Mileikovsky, 1973), the combination depth, water stratification and high current speeds in Estero Horcones seems to prevent them from reaching and settling on the bottom.
Farias and Salinas (1986), also determined significant differences on the total number of spat when comparing the three sampling sites and found that current speed was a determining the settling of B. recurvus mussel. Larvae prefered semi-protected zones (Chipperfield, 1953) with average speeds of 21 cm/ s coinciding with the observations of Dogson (1928).

These factors also explain the spatial distribution pattern of mussel

PLATE 2. Aerial mangrove root with a mussel cluster attached to it.

clusters at the margins of Estero Horcones, Laguna Redonda, and Laguna Mandinga found from the preliminary survey prospection (section 3.1). In these last two localities, clusters were only found on the mangroves located in a 500 m strip along the north-west shore of Laguna Redonda, which according to the rainy season current pattern is a zone where the ebb water flow converges and turns towards the connection with Estero Horcones (Fig.19).

It existence can be assumed that slower speeds prevail in the remaining marginal zones of the lagoon than the recorded average of 8.6 cm/s. Thus, although there are habitats similar to the ones found close to Laguna Mandinga shores, they arenot suitable for mussel settlement even though substrata are available.
Although these two shallower lagoons (< 2 m depth), offer oyster beds as an alternative substratum for conditions are less ideal conditions because bottom salinity and direct competition with oysters.

These distribution patterns, and the general development of B. recurvus in the system, are directly related to the two possible pathways available to complete their life cycle (Fig.4).
Sexually mature mussels are located in either the mussel-oyster beds or the mangrove root clusters (Plate 2). Spawning occurs during the rainy season (Farias and Salinas,1987) and planktonic larvae can drift with the currents from 3 weeks to 2 months until settlement (Chipperfield, 1953; Thorson, 1946; Bayne 1965; Lubet, 1969).

In the mussel-oyster community, secondary plantigrades will tend to settle on the established oyster mussel- beds (Plate 3) in Laguna Redonda and Laguna Mandinga, showing similar behavior to other mytilids (Bayne, 1964; Salas et al., 1983).

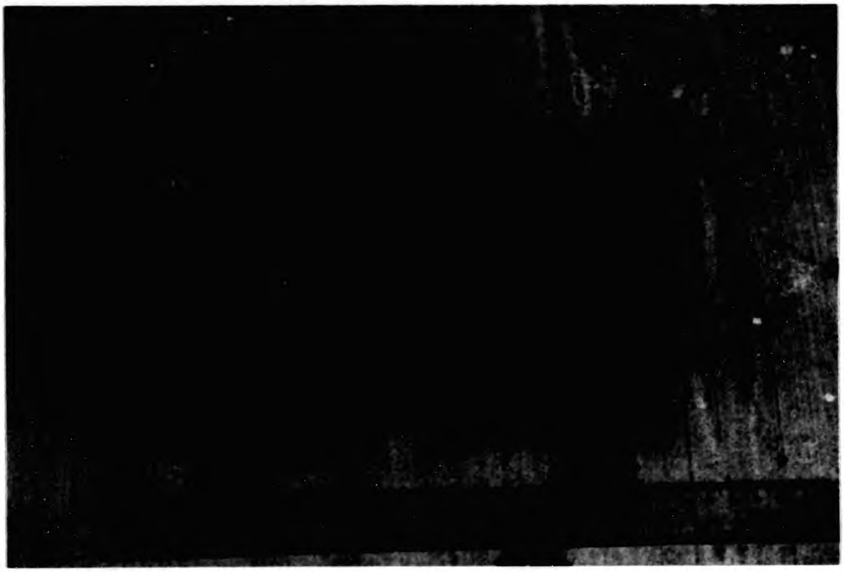


PLATE 3. Association of Brachidontes recurvus with the oyster Crassostrea virginica typical for the mussel bottom populations.

Compared to the oyster C. virginica, which needs a suitable substratum that may consist of either firm mud or clay, but not shifting sandy or extremly soft mud (Galstoff, 1964), Brachidontes recurvus is less limited due to the presence of byssal threads that enable it to attach to any hard surface (Bayne, 1976), such as dead valves and various plant and shell fragments embedded in the mud (Morris and Rollins, 1977). These same authors stated that Brachidontes sp. can settle, populate and survive in a low relief mud surface layer similar to the predominant bottoms in Laguna Redonda and to a lesser extent those in Laguna Mandinga.

Although density was not recorded for oyster–mussel beds, it can be assumed it is less than 2,320 mussels/m2 registered at the mussel bed in Laguna Redonda. Morris and Rollins (1977) reported for St. Catherines Island, in a Brachidontes–Petricola association a density of 486/m2 mussels (54% of the total epifauna) in contrast to near a peat deposit where the individuals formed a "resistant pavement" with an average density of 8,955 mussels/m2. This mussel has been reported in similar environments in association with the mussel Guekensia demissus (formerly called Modiolus) in higher densities where B. recurvus was found to be 10 times more numerous than the former, with 5028 mussels/m2. Together, these two species contributed 9.5 % of total macrofaunal biomass (112.08 g/m2) (Bahr and Lanier, 1981). Dame (1977) reported Guekensia /m2 and about 700 Brachidontes /m2 a South Carolina reef.

Very occasionally infaunal bivalves eg. Lyionsia sp. were observed associated with oyster–mussel populations at Boca delRio–Mandinga, agreeing with the postulate of Woodin (1976) that "no infaunal forms should consistently attain their highest densities among densely packed suspension– feeding bivalves", but contrary to the situation found by Morris and Rollins (1977).

These densities are far less than those reported for M. edulis beds in which up to 100,000 spat/m2 occur (Dare, 1980). But it is important to point out that although densities of M. edulis in open coasts may exceed 1000 individuals/5 cm2. Their biomass per unit of area in open coast may be low (i.e. the individuals may be very small) in comparison with mussel populations from sheltered estuaries and harbours (Seed, 1969a).

The development of mussel beds can be comparatively described to, according to the four stages proposed by Bahr and Lanier (1981) for oyster reef development. The initial colonization stage begins with the settlement and growth of single mussels and small scattered clusters. With time, additional generations of mussel larvae will settle in the area of the new bed and attach themselves to other live mussels and dead shell surfaces. This process results in the formation of distinct mussel clusters known as the clustering phase. In the case of oysters, these clusters represent a colony of three to seven generations of oysters, the majority of which are dead (Grave, 1905). The oldest and lowest mussels die from overcrowding and suffocation, but their shells remain to support the upward and outward growth of the cluster. In the accretionary stage small mussel clusters increase in size through the settlement of additional spat, to form (as in the case of oysters) massed mussel clusters (Grinnell, 1971) that comprise the true constructional nucleus of the bed. If environmental conditions remain stable the newly formed parts of the mussel bed tend to accrete laterally and vertically. Dead shell material scattered around the mussel bed aids in spreading it latteraly (Wiedmann, 1971). Finally the senescent stage described for oyster reefs is characterised by a central "flatland" with thicker accumulations of sand mud and shell debris that would be colonised by Spartina (Bahr and Lanier, 1972). This stage has been reached by oyster reefs in Laguna Mandinga which have now been colonised by Rhizophora mangle. None of the mussel beds have reached this stage yet in the Boca del Rio–Mandinga system due to their relative young age and subtidal position.

However this evolutionary process can be accelerated in the case of man–made mussel beds. This is a typical situation in Laguna Redonda and Laguna Madinga indirectly caused by the oyster fishery. The extraction is normally done by skin diving collecting and by placing oyster–mussel clusters aboard a small wooden boat. Once the boat is full, it is taken to shallow, hard bottom areas where the fishermen separate the oysters manually with a steel bar and throw the mussels outboard. These zones are regularly used for this purpose and during the period of study the fast growth of these "artificial" mussel beds was noticed.

Another indirect possible way in which this process may be contributing to a faster spread of mussel populations in these lagoons is the practice of throwing back sexually ripe individuals with broken shells. This might activate (by chemical stimulii) the spawning of the mussel bed population or induce artificial fertilization as used in some intensive culture methods (Breese et al, 1963). A similar effect has been described when attempting to erradicate the California red and purple sea urchin (Strongylocentrotus spp.) populations by puncturing or smashing their shells (Farias, 1980).

Mussel juveniles 30 mm in legth and of approximately 4–5 months of age take nearly 1 year or more to achieve a length > 60 mm and mature into active broodstock when mussels attain sexual maturity (Seed 1969a)(Fig.4). Although natural mortality in the mussel bed populations was not estimated in the present work, it is possible that it might be higher than 40 % between settlement and sexual maturation. The main causes of mortality are: predation; competition, prolongued extreme drops in salinity and oyster fishing. In comparison to the cluster and cultivated populations of mussels (see Fig. 4) these mussel beds have as general characteristics: high densities; small total average length and meat yield; slow growth rates; high competition and as reported by Dare (1980); predation.

Mussel spat that choose instead to settle on aerial mangrove roots (Fig.4), show four phases of development.
The initial colonization stage begins with the settlement and growth of single mussels on aerial mangrove roots. These roots may already support some barnacles, mussels or filamentous algae that act as extra attractants for larvae, but sometimes they are completely bare new roots that are subjected for the first time to tidal water level changes, or have scarcely any individuals left after part of a cluster has fallen into the water. The result of this process is a cluster nucleus very small in size, e.g. 15 x 32 mm (height–width) (Table 6).

During the clustering phase additional generations of new spat will settle, building up young clusters of less than one year old. If by the end of this period a cluster has not fallen or lost some of its individuals, the accretionary phase starts in which it grows rapidly, both vertically (in height) and laterally (in width) as indicated by the data analysis presented in Table 17. Growth of a cluster shows negative allometry (regression coefficient b<1) when height (X) and width (Y) are related by means of a power function of the allometric type, (Brown et al., 1976):

$$Y = 5.75\, X^{0.6340}$$

In the senescent stage the cluster reaches a maximum size after one year to two years (Table 6) and external portions of it may start falling, decreasing its size, as can be observed in the dimensional changes on Table 8. Assuming that clusters marked on 25/05/88 were approximately from 6 to 12 months and approaching the senescent phase, the decrease in total average cluster dimensions recorded 11 months later (Table 16), shows the regulatory influence of the rainy and north wind season during this period on the survival of cluster mussels.
As discussed previously, water current speed tends to increase during these seasons (Farias and Salinas, 1987) producing two basic effects; the

fall of parts of a mussel pieces or total loss of the cluster.

Table 14 shows a decreasing survival of marked clusters (total loss effect) after 15 months as an example of a general process of mortality in this type of mussel population. During the first eleven months, clusters were reaching their maximum size but were dislodged by effects of the rainy and North wind seasons.

A smaller instantaneous rate of natural mortality (6.3 %) was registered for this period than for the next 4 month period

(25.3 %), when the remaining clusters were bigger and influenced by the end of the north season and the following rainy one. Another factor that contributes to the falling of roots with clusters is the natural decaying process of mangrove wood under the influence of environmental conditions and biological wastes produced by the cluster community.

In comparison with the general characteristics mentioned for the mussel bed, the mortality in cluster populations is higher at approximately 80 % for 2 year old cluster mussels. Clusters that fall sink into the soft bottom typically present beneath the roots, and die of asphyxia (Kuenen, 1942). Apparently the mortality after falling is close to 100 %, though possibly a few organisms survive using the rest of the cluster as a support, or they mange to attach again to the base of other mangrove roots growing nearby. Old mussels (possibly 4–5 years of age) were found at spring low tide partially buried in the mud of an island close to Estero Horcones with fallen mangrove trees. The average size was >7 cm, with eroded shells and an elongated shape which is typical of old mussels (Seed, 1968, 1977). In terms of its vertical zonation, Brachidontes recurvus occupies the lower intertidal and upper subtidal ranges as described by Bahr and Lanier (1981). Thus, another source of mortality is the sudden but prolonged exposure to fresh water that forms as a surface layer on top of the denser sea water in the lagoon after a few days of heavy rain. Mortalities from this cause are estimated at 71.4% of the total mortality of mussels recorded during June 1988 (section 4.9.6.).

In relation to their remaining characteristics, mussel clusters have relatively high densities, medium average length, growth rates and meat yield; high competence and relatively small predation. The fact that they are attached to mangrove roots and therefore are exposed to periods of desiccation during low tides, means that they may experience similar conditions to mussels grown in suspension having access to more food. Because they are more isolated from predators and less prone to bombardment by silt so their growth rate is enhanced compared to that of the bottom–living mussels (Mason and Drinkwater, 1981).

Based on the above comparison of the different possible growth performance discussed, the cultivation of juveniles from these populations in suspension was proposed (Figure 4). The expected results using suspected culture are to obtain higher growth rates, survival and meat yields, by providing better environmental conditions and controlling the density and predation.

The analysis of population structure is very easy in the case of sedentary and colonial animals like mussels. It can a be useful tool to determine the dynamics of the species in terms of size frequency distribution; growth and mortality rates; recruitment and reproductive seasonality (Seed, 1968, 1969 a,b; Kautsky, 1982; Farias, 1988).

Both the bed and cluster mussel populations, showed a bimodal length frequency distribution throughout the year, with more than 80 % of the total number of individuals being 1.2 cm in average length. In the specific case of cluster mussels, recruitment was found to be continuous (Figs. 12–14), a situation balanced by the regular loss of portions of a cluster possibly containing the larger ones, as discussed previously. The low number of mussels in both the bed and cluster populations larger than the 3.7 cm average length (forming the second size frequency mode) may be attributed to the effect of overcrowding. In dense mussel clumps,growth may be slow for the majority of the individuals, especially amongst those ensnared in the byssus threads of larger ones. This phenomenon frequently results in the predominance of small individuals (Sadykhova, 1967; Reynolds, 1969; Harger, 1980) that are not necessarily young (Whedon, 1936; Bouxin; 1956; Seed, 1976).

Plots of length frequency for populations of many species are known to be polymodal and this is true of Brachidontes recurvus in Boca del Rio–Mandinga lagoon (Figs. 12–14). For some populations each mode represents individual year class and the changes of position of these modes with time often allow growth to be measured (Seed, 1969b). For this technique to be reliable the main conditions established by this author are that recruitment to the population should occur over a relative shortly period of time and individual growth rates should be relatively uniform. In the case of Boca del Rio–Mandinga mussel populations the second condition is apparently met, but recruitment occurs over most of the year and there is the further complication that parts of mussel clusters may be lost through natural causes. The effect of these factors is that growth rates tend to be rather irregular, mainly influenced by high competition and the position of mussels in the cluster in relation to water level fluctuations and exposure (Kautsky, 1982).

Smaller mussels may be competitively suppressed by larger ones, while as at the same time having to support a higher metabolic rate (Kautsky, 1982). This was observed for B. recurvus as shown by the significant inverse correlations found between the specific respiration rates and the individual length and weight of mussels, irrespective of the salinity tested (Table 30). The rate of oxygen uptake whether from routine (active condition) to standard (steady–state condition) varies with animal size, being more rapid in smaller individuals, and with season (Bayne, 1973).

According to Kautsky (1982), those mussels occupying the inner layers of the cluster may rely for their nutrition on food matter with a low energy content, such as pseudofaeces and faeces, i.e. they are confined to deposit feeding (Thiesen, 1972).

– Growth.

Several alternative methods (Seed, 1969 a,b,1976 ; Wilbur and Owen, 1964; Kautsky, 1982; Searcy and Croda de la Rosa, 1983; Martinez and Farias, 1989) have been developed for growth analyses of molluscs, of which three were used in this work, each one serving as a support to the others: (a) the use of modal length frequency analysis; (b) the use of annual or disturbance rings; (c) the measurement of marked animals .

The aspects of mussel growth discussed above explain the lack of success with the Cassie Method (Cassie, 1957) and ELEFAN KIEL computer program (Brey et al, 1988) to analyse the length size frequency distributions of mussel clusters. The only value of the first method was to calculate as proposed by Seed (1969), an approximate monthly growth rate of 3.0 mm, after calculating the mean value and displacement of the first mode from October to November 1988 (Fig.12).

Growth rings in bivalve shells are laid down when shell growth is disturbed, e.g. due to adverse temperature conditions, reproduction or variations in food availability (Seed, 1976). Seed (1969 b) reviewed the reliability of growth rings in age estimations and stated that the use of them is "somewhat tenuous".

Sometimes in molluscs several rings are formed annually (Ankar, 1980; Martinez and Farias, 1989). According to Seed (1969 b) mussels grown under fairly uniform conditions may show no well defined rings whilst those from habitats such as those found in Boca del Rio Mandinga estuarine system, with wide fluctuations in environmental conditions, may produce several rings in any one year (Table 11).

These changes in the Boca del Rio–Mandinga ecosystem are basically associated with the rainy and North wind seasons and tidal cycles as discussed previously. Thus the high variability of rings found in <u>B. recurvus</u> shells, regardless of the significant correlation obtained between length and number of rings (Table. 11), demonstrated that this method was not useful, especially considering that "if disturbance rings are to be of any value they most be distinctive, and only one ring per year must be formed" (Seed, 1969 a).

The range of ring numbers was wider in mid size mussels, in disagreement with the reports of Kautsky (1982) that in smaller organisms the growth rings were often found in close or irregular intervals. An additional problem associated with "reading" the number of rings in mussels is caused by the normal decline in growth rate with size and the occurrence of overlapping year classes (Seed, 1969b; Kautsky, 1982) hence in the distance between rings and the possibility of some rings being eroded (Seed,1976). The incorporation into the shell of radioactive materials, fluorescent chemicals or mineralogical dyes represent good alternatives (Wilbur and Owen, 1964; Searcy and Croda de la Rosa, 1983).

An alternative method to marking individuals was used by Farias and Salinas (1987) who studied growth of mussels with the same initial average length stocked into Pergolari netting tubes and suspended from a raft. A tube was removed monthly and the average length recorded. Using data collected after one year, the following growth equation based on the Von Bertalanffy Model was obtained:

$$Lt = 5.88 [1 - e^{-0.1343 (t+3.8)}]$$

whereby the shell length in cm (Lt) can be predicted for any age, t in months.

These authors calculated a monthly growth rate of 3 mm based on the directly observed field values, and a rate of 4 mm from this growth equation. These values are relatively low smaller compared to the monthly growth rates obtained for Perna viridis in natural mussel beds

(5.0 mm), and those reared in rafts (7.2 mm) and in recirculating systems (7.4 mm)(Chatterjii et al., 1984). In relation to Mexican mussel species, these values are similar to growth rates reported for Mytilus edulis in winter of 3.4 mm, but far inferior to summer growth (14.4 mm) for mussels suspended from rafts (Garcia and Monje, 1983a).

Mytilus californianus reaches a length of 9 cm in 13 months with a growth rate of 5.6 mm/month (Garcia and Monje, 1983 b). This same period was necessary for Brachidontes recurvus to reach 82 % of its asymptotic length (58.8 mm) which is already a commercial size. Thus, although the growth rate of B. recurvus is relatively slow, in terms of cultivation of this species, may be considered good.

When k and L were compared with equivalent values presented by Seed (1976), those for B. recurvus were similar to M. edulis growing in natural beds, but smaller than the values for to mussels suspended on ropes from rafts.

Thiesen (1973), has criticised the use of the Von Bertalanffy Growth Model, suggesting that it is only valid for organisms larger than one third of their maximum length such as the individuals used by Farias and Salinas (1987) which had with an initial length of 2.9 cm.

– Spawning and recruitment.

As mentioned previously, the data on mussel population structure was used to support gonad histology, condition factor and mussel larvae in plankton to determine reproductive cycle of Brachidontes recurvus.

In Figs. 12–14 constant recruitment can be observed throughout the year except in June, July, 1988 and January– February,1989.

The lack of recruitment varied depending on the locality, but it is important to point out that in Estero Horcones spatfall was recorded in January and February when mussel larvae were scarce in the plankton (Table 13 and Figure 16). During these months the presence of a suitable substratum, provided by mussel clusters that have partially lost individuals, represented a more accesible substratum than oyster–mussel beds on the bottom, especially considering the strong currents during the North wind season. This free space is presumably used with advantage since mussel adults are absent, thus decreasing interspecific competition (Dare, 1969, 1971).

The maximum number of recruits occurred during the rainy months with low salinities (September, October and November) (Figs 12–14) coinciding with the previous reports for Boca del Rio Mandinga estuarine system (Lopez, 1985; Farias and Salinas, 1986,1987; Navarrete, 1989).

The comparisons were done on a percentage basis; Seed (1969 b), however stated that this method does not give a true quantitative representation of settlement since it does not take into account the processes of mortality or growth of the size categories sampled. Evaluating mortality implies two basic problems (Seed, 1969 b): to construct life tables or survivorship curves, and to determine the major causes of mortality.

In order to construct a life table, Deevey (1947) discarded the possibility of using the shrinkage of year classes in standard population samples taken at succesive intervals of time in favour of direct observations. Sessile organisms such as mussels are particularly well suited to this alternative technique since groups of individuals can be marked and their rate of survival observed.

Nevertheless, this method was abandoned by Seed (1969 b) due to operational complications in the field.

In the Boca del Rio–Mandinga estuarine system, recruitment of B. recurvus recorded using artificial collectors presented the same temporal pattern (Table 28), with some quantitative differences related to the type of material used for the collector (see later discussion).

Two stages of the life cycle of mussels associated with reproductive activity can be identified prior to settlement: spawning and the presence of mussel larvae in the plankton (Fig. 4). Peak spawning and larval abundance can be expected within 4 to 8 weeks prior to settlement (Chipperfield, 1953; Thorson, 1946; Bayne, 1965; Lubet, 1969).

The relative abundance of Brachidontes larvae corresponded to this pattern (Fig.16), but it is possible that the total larval number shown in Table 28 was underestimated from the plankton net tow sample method used. Factors which may affect the estimate include the influence of tides on in the distribution of plankton in space and time.

For example Gowda and Panigraphy (1989) reported for Rushikulya estuary that species diversity and population density of phytoplankton increased during flood tides and decreased during ebb tides.Stearns et al. (1987) reported that these variations might be influenced by grazing activity of zooplankton. Chlorophyll a concentration revealed after short-interval sampling (1–3 h) a distinct diel fluctuation, with an afternoon peak followed by a decline, usually beginning several hours before sunset. Tidal movements and seasonal changes in freshwater flow have been observed to affect longitudinal displacement of plankton populations (Roddie et al., 1984), the vertical migration of mussel larvae (Mileikovsky, 1973) and phototaxis of larvae (Bayne, 1965). Nevertheless, these effects presumably were minimum since the mean tidal range in the estuary is small (21 cm) compared to the other ecosystems mentioned above. This small range, in combination with the physiography of Boca del Rio– Mandinga estuarine system (Guillocheau, 1988) should result in zooplankton mantaining their position during tidal exchanges, as reported for Madovi estuary by Selvakumar et al. (1986–87).

Errors could also have been caused by the preservation method for the plankton samples, possibly due to the high concentration of formalin (Carriker, 1950); and the problem of differentiating and identifying B. recurvus mussel from other bivalve larvae present. Several authors have reported useful characteristics for its identification (Chanley, 1970;

Fuller, 1988; Fuller and Lutz, 1989) but these basically relyon observation of fine structures such as the presence of dentition in the hinge line (Chanley, 1970). According Bahr and Lanier (1981) predation by filter feeding organisms, both nektonic and epibenthic, reduces the available pool of mollusc larvae and perhaps prevents overcrowding. Thus depending on the time of sampling with respect to peaks in predator abundance, it is common to underestimate larval abundance.

Another indirect means of determining the reproductive activity of mussel is to analyses of their gonadal development. It should be noted that the cycle development may be conveniently divided into initiation, control of gametogenesis, maturation and spawning (Grant and Tyler, 1983).

The simplest method is to assess paraffin sections of tissue and subjectively place them in a number of developmental stages, as done in the present work using the scale proposed by Seed (1975). However it was difficult using this method to establish the beginning of the spawning season in 1988 due to loss of samples from April–September, but based on the data for 1989 a gradual increase in the gonadal index values indicating development to sexual maturity in the months when temperature started rising and water salinity decreasing (Figs. 6A, B). However there was no a significant correlation between the Seed Mean Gonadic Index and the Condition Factor.

Histological methods have the disadvantage of requiring a large number of samples to be representative (Seed, 1969a), while the subjective estimations of developmental stages by two different people are unlikely to be exactly the same (Grant and Tyler, 1983).

Regardless of these limitations, it was possible to detect the presence of mussel gametes by histology throughout the year, coinciding with observations for the same species done by Allen (1962). This author noticed that individual follicles develop independently of each other in both sexes. Therefore gonads do not reach a high peak of maturity and immediately spawn out.

A zero value for the Seed Mean Gonadic Index was never obtained that would indicate resorption of gonad tissue following spawning as in Mercenaria (Losanoff and Davies, 1951); instead the reproductive tissue merely becomes degenerated (Allen, 1962).

Apparently species living where temperatures are relatively high during the year tend to have prolonged spawning seasons with short resting times, such as in Mytilus galloprovincialis (Hrs-Brenko, 1971 cited by Hrs- Brenko, 1973) and Brachidontes solisianus (Avelar, 1980).

Seed (1975) found for M. galloprovincialis that the gonad index never fell below two and there was a general absence of any well-marked spent phase as in B. recurvus.

The gonad histological material was also useful to determine the sex ratio in Boca del Rio-Mandinga ecosytem. This showeda 1:1 ratio and an absence of hermaphrodites, as reported by Allen (1962) for B. recurvus in Chesapeake Bay.

Seasonal changes in the gonad can also be indicated from its condition factor as discussed later, and from its biochemical composition as a result of the storage and utilization of food reserves (Daniel, 1920; Fraga, 1956; Dare and Edwards, 1975; Gabott and Bayne, 1973). The biochemical composition of B. recurvus in this ecosystem varied predictably, with loss of water and build up of reserve materials during and after food availability and spawning activity (Fraga, 1956).

A decrease of carbohydrates after spawning started can be observed in Figure 18B, e.g. March, 1988, coinciding with the pattern reported for the same species and locality by Farias and Salinas (1987). This decrease followed the non reproductive period with high carbohydrate values due to accumulation when abundant food is available (Figs. 6E,F) preceding gonad development (Gabbott, 1976). This carbohydrate has been shown to be glycogen (Gabbott and Bayne, 1973).

Lipids and protein showed an inverse correlation with carbohydrate (Table 20) agreeing with Lubet and Le Feron de Longcamp (1969) and Dare and Edwards (1975). This increase in lipid levels which is generally higher in females than in males, is presumably due to fatty reserves in the eggs (Lubet and Le Feron de Longcamp, 1969).

Biochemical changes generally showed that the main peak in spawning is associated with a rise of temperature and decrease in water salinity in line with the other reproductive indicators, but the following aspects need to be considered:

Brachidontes recurvus belongs to a tropical environment with a long spawning period, making the biochemical cycle more complex than for Spanish mussels (Fraga, 1956). The reproductive cycle varies amongst species and geographical localities, being periodical and regular in high latitudes where seasons are well– marked (Gabott and Bayne, 1973). The results obtained may be influenced by methodological errors. Manipulation of samples causes the leakage of water, affecting ash and protein level which is contained within body fluids (Fraga, 1956).

Protein values are also apparently affected when the constant of 6.25 is used (N x 6.25) and, according to several authors, due to the general high protein content in mussels a factor of 7 should be used (Fraga, 1956).

– Condition factor.

Perhaps from the practical point of view and for aquaculture purposes, the simplest method of monitoring reproductive activity by referring to the Condition Factor.

This allows the determination of two main things; spawning periods and the optimum time for harvesting mussels based on a high individual flesh weight/ total mussel weight ratio.

Two main spawning peaks were detected during 1988 and1989 (Fig.15) but these did not coincide. Nevertheless the highest values occured prior to the main recruitment periods (Fig 12–44) during low salinity in the system and coinciding with the pattern reported by Farias and Salinas (1987), although the peaks reported by these authors were registered one month later.

It seems that spawning may vary in time and intensity from year to year as reported for Mytilus edulis (Lutz et al, 1980).

The use of the condition factor to compare the effect of growing mussels in suspension (cultivated) compared to natural mussel beds resulted by chance in the determination of the exact date of the first spawning period.

Glycogen levels have been shown to be significantly lower in shore–grown mussels (M. edulis) than in raft–grown mussels (Hickman and Illingworth, 1980) and changes in body weight are mainly due to changes in carbohydrate or glycogen content (Bayne, 1976). Thus it was expected that the condition factor for cultivated mussels on 25/05/89 would be higher than for bed mussels sampled on 11/05/89, but the values were inverse and in fact similar to June 1989. This indicated that mussels at Estero Horcones spawned after 11/05/89.

Dry weight/ shell cavity volume (Condition Factor 2) was used to express condition factor fluctuations, because it is not influenced by losses of water and is therefore more accurate. An average length larger to than 50 mm corresponded to the optimum 50–60 mm recommended for this technique (Baird, 1958). Condition factor was higher in cluster mussels at Horcones compared to mussel beds at Laguna Redonda and Mandinga, contrary to the expected weakening of condition due to aerial exposure (Lutz et al, 1980). Cluster mussels possibly had more access to food which was more available in the water column than at the bottom where conditions for mussels are in general unfavourable. Thus they avoid a negative scope for growth (Warren and Davis, 1967; Bayne et al, 1976 cited by Kautsky, 1982)

Condition Factor annual mean values (CF1= 36.7, CF2= 6.0) were lower compared to reports for other species (M. edulis, M. edulis chilensis, P. perna and P. canaliculus) with ranges for Condition Factor 1 from 40-49 and Conditon Factor 2 from 7-9 (Hickman and Illingworth, 1980).

When the specific respiration rates of bottom mussels were compared with cluster mussels, the latter were significantly lower (Table 31, Fig.27) indicating a better adaptation to the intertidal environment.

Zuim and Mendez (1981) compared the influence of salinity variation on the respiratory rate of two marine mussels, Perna perna and Brachidontes solisianus. These authors observed that even in the lowest salinities used (17.9-18.7 ppt) the animals continued to respire meaning that their valves were still sufficiently open to permit gas exchange. They concluded from the reduction of oxygen consumption as dilution increased, that Brachidontes showed more resistance than Perna to falling salinity. This is in agreement with their relative zonation where Brachidontes is more exposed to rainfall and also with the fact that it can occur on the rocks of estuaries. These observations differ from Moon and Pritchard (1970) who found that the rate of oxygen consumption by M. californianus and M. edulis higher on the shore was greater by 32% than that of the individuals lower on the shore. Possibly these differences are related to the habitats in which these species live. Mytilus is normally found on oceanic, exposed and high tidal range coasts (Salas and Garcia, 1987), whereas Brachidontes is more associated with sheltered areas and estuarine conditions (Zuim and Mendez, 1981; Farias and Salinas, 1987). Exposure to air at Boca del Rio-Mandinga is not prolongued since the average mixed diurnal tidal range is < 70 cm. Bullock (1955) reported for Mytilus that individuals from high on the shore showed lower ventilation rates than mussels lower down. Two species of Mytilus exhibited a controlled response to air exposure, which results in reduced metabolic demand and the possibility of some consumption of oxygen from the air at high humidity (Bayne et al., 1976).

Taking into account the reproductive indicators discussed previously, and despite the constant reproductive activity of B. recurvus throughout the year, spawning occurs from June until November, primarly during low water salinities in summer and secondarily in early fall. This coincides with the pattern reported by Allen (1962) for the same species at Chesapeake Bay and by Farias and Salinas (1987) at Boca del Rio–Mandinga estuarine system, although differences might be expected due to latitudinal variations (Seed. 1975).

Temperature has been recognized as an important exogenous factor determining both the intensity and duration of spawning (Chipperfield, 1953). Brachidontes recurvus can be classified in relationship to temperature as an organism which breeds year round (Orton, 1920), thus it is possible that a temperature rise does not act alone as a trigger for spawning (Nelson, 1928) but that a change in salinity is also needed. The influence of this parameter has been suggested as an important factor in estuaries and tropical waters (Berner, 1935; Paul, 1942; Wisley, 1964; Baird, 1966; Kuhl, 1972; Wilson and Seed, 1975; Farias and Salinas, 1987; Navarrete, 1989).

– Predation and Competition.

Two important regulators of mussel population dynamics are predation and competition.

Predation plays an important role from an early stage being considered as a main factor to causing 99 % mortality during the free–swimming larval period (Thorson, 1946, 1950; Mileikovsky, 1971).

In estuarine systems predation is carried out by filter feeding organisms

of both nektonic and epibenthic forms (Bahr and Lanier, 1981).
At Boca del Rio–Mandinga system three animal groups were considered as main predators; crabs (e.g. Callinectes sp.), carnivorous gastropods (e.g. Thais sp.) and birds (e.g. Phalacrocorax sp.) acting on two basic situations; permanently submerged mussels and individuals periodically exposed to air during low tides. Possibly some fish species predate the mussel populations as well but only organisms that were actually observed to do so will be discussed here.

In the case of Boca del Rio–Mandinga one of the most important threats are crabs. Shore crabs have been reported by Dare (1980) to cause widespread and sometimes severe losses of small seed on both intertidal and deep water bays in many estuaries. Impact by shore crabs is difficult to assess because the larger specimens in particular migrate up and down with the tide and their density and activity are difficult to measure (Craeymeersh et al., 1986).
Estuarine systems of the Gulf of Mexican coast are characterised by a great abundance of Callinectes species (Table 15) (Chavez and Torruco, 1988a). This blue crab was observed breaking and eating small mussels. Similar fractured shells were found, representing 28.6% of the total mortality recorded in June, 1988, on a mussel cluster at Estero Horcones. It can be assumed that crabs such as Callinectes were responsible for this mortality considering that they are exceptional swimmers (pers. obs.) and the typical damage observed conformed to the type of fracture which is caused by this kind of predator (Carriquiriborde et al., 1981).
Mussel clusters are reachable by blue crabs during high tides and this is when Callinectes guts have been reported to be fullest (Ryer, 1987). This tendency to come onto the mussel beds with the incoming tide and forage for food has been reported by Seed (1969b).
Nevertheless, it can be assumed that Callinectes have a preference during

high tide to prey on the bottom (Vaughn and Fisher, 1988).

Apparently in natural populations this limitation can cause the largest mussels to be found in the high tidal zone, a habitat which, although presumably suboptimal from the point of view of feeding and growth, provides an effective spatial refuge against their predators (Seed, 1980).

Size of prey is also determined by predator size preferences. Bisker and Castagna (1988) reported that crab predation, recorded as the number of dead oyster spat/crab/day, was proportional to crab size and inversely proportional to oyster size.

These authors also reported that larger spat could be more readily preyed upon by mud crabs (Panopeus spp.) than by blue crabs (Callinectes spp.) of similar size. In their observations the largest bivalves preyed upon were 24 mm in diameter. These observations and the study of Callinectes predation on the hard clam Mercenaria mercenaria, where large blue crabs > 125 mm did not consume clams larger than 40 mm, indicate that bivalves can achieve a size immunity from the crab predation (Arnold, 1985).

Mud crabs (Panopeus spp.) seem to be responsible for predation mainly on small organisms as discussed above. Information related to this predator is scarce (Bahr and Lanier, 1982; Gibbons and Castagna, 1988; Bisker and Castagna, 1988).

Different methods can be used to control crab predation such as utilisation of fences but these are expensive to construct (Dare,1980). Considering the proposed integrated managment of Boca del Rio Mandinga estuarine system (Figure 36), a good alternative may be to use biological control. Gibbons and Castagna (1988) reported high survival of 49.2% for hard clams (Mercenaria mercenaria) grown inside cages with the toad fish Opsanus tau compared to 1.6% without it. This species is common in Boca del Rio–Mandinga system (Table 21) and can also be utilised to control predation on cultured tilapia fry. Blue crabs were observed preying on these fries during the ongrowing trials carried by

Bibiano (1990) as part of the study to evaluate the possibility of installing aquatic polyculture (Fig. 36) in Laguna Redonda.

The carnivorous gastropod Thais sp. is perhaps the most important and widely distributed littoral predator (Seed, 1969b). Six species are commonly found in the mid-tidal region and occur primarily from the southeastern United States through the Caribbean (Inham and Zischke, 1977). A small number of Brachidontes recurvus shells were found with the typical presence of a small hole drilled through the shell by the dogwelk's radula (Seed, 1969b). Brown and Richardson (1987) reported that small snails (Thais haemastoma Gray) of < 30 mm shell length could feed on small mussels (Ischadium recurvum Rafinesque) with wet weight (< 2g including shell), but had less success on large animals. In general terms these predators are excluded because of the cluster's daily exposure to the atmosphere resulting from ebb and flood tides (Bahr and Lanier, 1982).

The last group of predators are birds which proved to be very effective causing 100 % mortality of B. recurvus during the ongrowing trials using Pergolari tubes (Plate 4).

Cormorant (Phalacrocorax sp.) attacks on these cultivation systems is similar to predation exerted by eider ducks (Somateria sp.) on M. edulis suspended in Pergolari tubes off the Scottish West coast (Farias, 1983).

Predatory activity by cormorants causing heavy economic losses to fisheries and aquaculture has been widely reported (Choisy and Jones, 1983; Barlow and Bock, 1984; Alleston, 1985; Caven and Leu, 1987; Kehoe, 1987; Moerbeek, 1987; Staub, 1987; Tovar et al., 1987; Handbrink and Byrd, 1989).

Birds stayed around the ongrowing stations in the present study, but polypropylene onion bags were efficient to preventing predation (Plate 4).

PLATE 4. Pergolari tubing used in ongrowing experiment 1 showing a remaining mussel shell after predation by the bird *Phalacrocorax* sp.

Boca del Rio– Mandinga estuarine system is used by a wide variety of birds as reproductive, nursing or migratory stop over grounds, thus the potential predatory activity that could be exerted on large scale mussel culture systems needs further investigation.

Oystercatchers (Haematopus sp.) present in the same ecosystem were not observed predating mussels. Nevertheless predation by them on mussels of 30–50 mm has been reported elsewhere (Goss–Custard et al., 1984; Craemeersh,el al., 1986). The latter authors found that organisms overgrown by barnacles were hardly taken at all, and that there was a strong survival value for thick–shelled mussel.

Competition was not evaluated quantitatively, but some organisms were identified as potential competitors for space and food.

Space availability determines indirectly the degree of competition for food. Whenever space is available high densities of mussel may be present (Dare, 1980). Most invertebrates in the community associated with the mussel population are also basically filter feeders (Table 15) (Bahr and Lanier, 1982). It can be assumed, however, that due to the mussel's high capacity for filtering water (Bayne, 1976), competition for food occurs intraspecifically rather interspecfically.

Figure 21 shows the main organisms which settle on the same substratum as mussels. Apparently their presence does not create competition for space because mussel spatfall occurs at all times of the year. Regardless of the higher relative abundance of barnacles and polychaetes (Fig. 21), the byssus threads of the mussel enables them to avoid direct competition and they can even settle on these other organisms. As in the case of food, competition for space is stronger intraspecifically, especially in high density mussel beds where the growth of individuals can be drastically reduced (Kaustky, 1982).

In terms of mussel aquaculture these organisms represent a potential problem of fouling, which can be controlled by changing periodically the

bags and by carrying out a thinnig operation (Dare, 1980; Salas and Garcia, 1987).

5.3. Cultivation of Brachidontes recurvus

5.3.1. Biotechnical aspects

Two main aspects are generally considered for mussel cultivation; seed availability and the ongrowing technique (Mason, 1976; Dare, 1980; Mason and Drinkwater, 1981). It has proved feasible to produce *M. edulis* mussel seed intensively (Losanoff and Davies, 1963; Bayne, 1965; Chi and Garcia, 1987; Salas and Garcia, 1987) and to succesfully complete the larval development under laboratory conditions for *M. viridis* (Sivalingam, 1977), *Mytella strigata* (Chun,1989) and *B. recurvus* (Chanley, 1970). The cost of producing and rearing mussel larvae artificially is not economic, however, owing to the low price fetched by mussels in comparison to oysters. Thus, commercial mussel cultivation has to be based on the collection and raising of naturally settled spat (Mason, 1976).

Testing the use of different artificial spat collectors has been a common practice (Dare and Davies, 1975). Farias and Salinas (1986) tested oyster shell, coconut shell, polypropylene ropes and aerial mangrove root pieces as collecting surfaces, finding the oyster shell to be the best. Farias and Salinas (1987) noticed mussel spatfall on a suspended ongrowing system in Estero Horcones (Boca del Rio–Mandinga system) suggesting the value of adult mussel shells and polypropylene onion bags as potentially good collectors. Based on these experiences, the latter materials were further evaluated in the present work, and again oyster shell collectors were shown to be the best. Mussel shells, polypropylene ropes and onion bags showed a similar efficiency. Mass Geesteranus (1942), established that mussel larvae will settle on any rough and firm substratum. Chipperfield (1953) suggested that such surfaces stimulate secretion of byssal threads which also explains the preference for mussel shell collectors. A high preference for filamentous substrata has been mentioned by Bayne (1965), whether it is composed of natural fibers (Seed, 1976; Mason and Drinkwater, 1981) or synthetic ones (Davies, 1974).

The small number of spat collected by fibrous material in the present study (Table 28) is rather poor compared to consistent rates of 3,000–7,000 spat/m/week in the U.K. using coir ropes (Dare and Davies, 1975) or 10–20,000 spat per rope (Mason and Drinkwater, 1981). Apparently B. recurvus shows a strong preference to settle on established adult populations, as in M. californianus (Garcia, 1989 pers. comm.). But these spatfall figures do not necessarily guarantee a successful cultivation operation. A high settlement does not by itself provide enough information to adequately assess the potential of a site for mussel aquaculture (Incze et al, 1978). Also extremely high losses of young mussels occur after transfer to suspended cultivation systems, with 50% reduction in number over the first 2–4 months and less than 4% remaining after 20 months as reported by Dare and Davies (1975).

In the case of B. recurvus culture at Boca del Rio–Mandinga estuarine sytem, the utilisation of collectors is recommended as an additional source of surface for natural settlement and "seed" (average 30 mm) supply.

Considering the time consumed, the intense labour required to construct oyster shell collectors and the high fouling these attracted (Figs. 22A, 23B) (Plate 7), the ideal alternative collectors are polypropylene onion bags. These collectors should be placed at Estero Horcones, in areas where mussel clusters are conspicuous. Bags can be hung from mangrove aerial roots or wrapped around young clusters and young roots, from June to November, when recruitment is rather constant.

These spat (5–15mm) can then, be allowed to reach the "seed" length of 30 mm. After grading and stocking into polypropylene onion bags, they can be transplanted to Laguna Redonda for the ongrowing and fattening phase.

Traditional culture methods transfer mussel spat settled on ropes to suitable ongrowing areas, where after a period of time they are "thinned" to avoid overcrowding (Mason, 1976).

It is suggested that cultivation of B. recurvus in this estuarine system should be based on the life cycle in Figure 4. Mussels used for transplanting can be provided by the sources discussed previously or obtained from the oyster cleaning process performed by fishermen (Fig.36). Even if individuals within the "seed" length were slow growing older organisms, when placed in more favourable conditions, they would show greatly increased growth rates as proved by Seed (1968). These conditions are related to a good food supply. Such a capacity to grow or shrink as a function of food availability is known also from anemones, sea urchins, starfish and nudibranchs (Mead, 1901; Muscatine, 1961; Paine, 1965; Ebert, 1968; Menge, 1972 cited by Kautsky, 1982).

A way to optimize environmental conditions for mussels is to transfer the mussels from bottom beds or mussel clusters subjected to tidal water level changes to a permament position in the water column by using some form of suspension system.

Raft-grown mussels have higher growth rates than mussels in natural beds (Fig. 3)(Mason, 1971; Qasim et al, 1977), because they are freely suspended in the water column and therefore have more access to phytoplankton for food. In contrast, mussels in natural beds are overcrowded, stratified and only have access to the food in the water inmediately above them (Chatterjii et al., 1984).

Results from experiments 3 and 4 demonstrates this principle; juveniles ranging from 1.5–2.4 cm grown in suspension reached a length close to the minimum marketable size of 50 mm (Dare, 1980) in only five months. Average growth rates ranged from 3.6–6.4 mm/ month and were similar to values reported by Farias and Salinas (1987) and to the published rates discussed in section 6.2.

Experiment 2 showed the viability of using polypropylene onion bags for suspended cultures (Plate 5) and established details for managing the technique. The lack of maintenance affected the survival of mussels (Fig. 20). Overcrowding and fouling by barnacles and ascidians (Plate 6) restricted the growth performance in the initial stage as can be observed in the plateau of growth curves and specific growth rates (Table 25, Fig. 19). These tended to decrease at time 2 and had a noticeable increase at station 8 (Table 25) where the final density was very low (Table 20). This indicates the importance of thinning and maintenance of the culture system. The range in specific growth rates was similar to values reported by Farias and Salinas (1987). Negative growth rates (Table 25) were presumably caused by the loss of the larger animals in between the sampling times. Under cultivation, Brachidontes recurvus growth rates are slower than for M. viridis which can achieve 8.8 mm/month and reach its commercial size of 60–70 mm in 7–8 months (Rangarajan, 1977; Sivalingam, 1977), but much better than growth rates reported for M. edulis which requires one to three years to reach the minimum marketable size of about 60 mm (Dare, 1980; Wallace, 1980).

Despite the differences in growth found between stations for the first and second length measurements (Fig.19), the ecosystem generally provides suitable conditions for the cultivation of B. recurvus.

In summary, the mussel culture operation would consist of transplanting "seed", collected from Horcones mussel clusters, Laguna Redonda mussel beds or obtained from the oyster fishery by–catch, into polypropylene bags, followed periodically changing the bags and grading the mussels (thinning). Spat (15 mm) obtained during this operation may be kept for stocking bags for the next production cycle. Empty mussel shells can be replaced in specific areas where they can act as an additional substratum to encourage new oyster and mussel settlement, and to allow the oyster spat already settled on them to grow.

5.3.2 Economic Aspects

In order to determine the optimum size of the mussel production unit two main elements were considered: the demand of the product in relation to the potential local market and the operation of the unit as part of an integrated management proposal (Fig. 36).
These will be discussed in detail in sections 5.4.1.2,
and 5.4.2.1. respectively.
Two places were considered for establishing mussel culture: Laguna Redonda and Laguna Mandinga (Fig.1).
The latter was less suitable for the mussel cultivation unit, in spite of its suitable hydrobiological and physical characteristics, mainly due to its distance from the closest human settlement (Mandinga Village) (Fig.1) and hence the control of vandalism and increased transport costs. This also would affect its suitability as part of the integrated system approach (Fig. 36).

Thus, Laguna Redonda was considered as an ideal location due to its hydrobiological and physiographic conditions; the permanent presence of the local restaurant owners which could provide surveillance and manpower required to operate the production system; free land available to develop the landbased production subsystem (Fig.37) and good terrestrial and aquatic communications.
Laguna Redonda has an approximate area of 1 hectare. Based on the bathymetric profile, water currents, wind direction and the location of the navigation channel, it was considered that only 0.5 ha of this total would

be suitable for mariculture development.

From the biotechnical point of view this area has a potential production capacity of least 20 tonnes per year (in two production cycles), using 2 polypropelene bags/m2 with 300 mussels each. These mussel are assumed to reach a final average length of 5.4 cm and average meat weight of 3.7 g (35 % of the total individual weight).
However, it was established in general terms based on the preliminary market survey (Section 5.4.1.2.) that the potential mussel demand would be only about 1 tonne per year for consumption directly by the restaurants located at Laguna Redonda and Laguna Mandinga.
Based on this, a small production unit could be located initially in the north area of Laguna Redonda (Fig.37), consisting of two 500m rows of racks with 625 suspended polypropylene bags, with a mussel density of 300 mussel per bag.

In the Table 40 it can be observed that the capital cost of the system during the first six months of operation would be around 1,582,000 Mexican pesos (1 dollar= 2,900 Mexican pesos) which represents 43.9% of the total costs. Approximately 50.5 % of the fixed costs correspond to the materials for installing the system (wooden posts and polypropylene rope). In the following six months this cost would decrease to only a 33.3% , mainly due to the need to replace the polypropylene bags, assuming that the expected average life of the wooden post is at least two years. The other important source of costs is labour which in the first semester represents 49.3 % of the total costs. In terms of man hour costs, thinning, bag filling and rack instalation have the greatest labour requirement.

Total revenue was calculated based on two possible prices for the product: the official price for fresh landed mussels (3,000 pesos/ kg) and

Table 40 Preliminary Economic Analysis for mussel culture in Boca del Rio Mandinga estuarine system.

COST (all figures in Mexican pesos US$= Pesos 3,000)			6 MONTHS			6 MONTHS	
Capital Cost	Unit	Tot.No.	Unit Cost	Total Cost	%	Total Cost	%
Polypropylene bag	Bag	2500	300	750,000		750,000	
Monofilament string 0.70	1000m roll	2	16,400	32,800		32,800	
Polypropylene rope 3/8	kg	20	8,150	163,000		-	
Wooden post	3.5m post	318	2,000	636,000		-	
SUBTOTAL				1,581,800	43.9	482,300	33.3
Operating Cost							
A) Labour *	No. Jornales	No. People	Tot. No. Jornales	Total Cost			
Rack installement	6	3	18	288,000		-	
Seed collection	2	3	6	96,000		96,000	
Grading	3	3	2	32,000		32,000	
Bags filling and hanging	4	7	28	448,000		448,000	
Thinning and maintenance	14	4	56	896,000		896,000	
Harvesting	1	1	1	16,000		16,000	
SUBTOTAL				1,776,000	49.3	1,488,000	63.2
Other Gasoline and oil SUBTOTAL	Tank	12	20,000	240,000	6.6	80,000	3.4
TOTAL COST				3,597,800		2,350,800	
TOTAL REVENUE							
Landed mussel	kg	2,857	3,000	8,571,000		8,571,000	
Restaurant mussel	kg	2,857	6,000	11,571,000		11,571,000	
TOTAL BENEFIT							
Landed mussel				4,973,200		6,220,000	
Restaurant mussel				7,973,200		9,220,000	

* 1 Jornal = 8 hours/day at a rate of 2,000 pesos/hour; 2, 857 Kg of landed mussel = 1,000 Kg of meat.

the price it could be sold for in the locality of Boca del Rio– Mandinga. This latter figure takes account of its added value after it is cooked by the restaurants since it would be offered as a menu item there as explained in section 5.4.1.2.

For the first crop/harvest/cycle (approximately 6 months), total revenue using either market price would be a minimum of 8,000,000 pesos, providing enough money to pay the initial investment and producing a net benefit of at least 5,000, 000 pesos.

For the second crop/harvest/cycle of operation, the minimum net benefit would be about 6,000,000 pesos. Most of the costs by then, would be represented by the labour in operating the system (63.2 %) (Table 40).

After the first year of operation, operating costs would include the cost of replacing the wooden posts; this could be easily absorbed by the intermediate term revenue. Brachidontes recurvus costs and production estimates for the first production cycle are similar to equivalent the same estimates for the culture of Perna viridis in Philippines where the bamboo stake method is utilized; there bamboo plus installation represent the major operating expenses (56% of the total) followed by labourers (16 %)(Choo, 1983).

5.4. Utilisation of Brachidontes recurvus

In order to use the knowledge of the life cycle and ecology of B. recurvus (Fig.4) to assist with the integrated wetland management approach proposed in Figure 2, it is necessary to consider the following:
A) The potential of B. recurvus for commercial development as a source of food, either for human consumption (Varela, 1981; Aldana, 1988; Waterman, Torry Adv. Note) or by terrestial livestock (Davy and Graham, 1984; Farias et al., 1988) and aquatic animals (Wickins, 1972; Korringa, 1976; Beard et al., 1985; Anaya, 1989; Villanueva, 1990; Zamora, 1990). The quality and appearance of the mussels in terms of nutritional value is important for consumers (Halver, 1979; Kenneth, 1986; Baylon, 1987; De la Garza, 1987; Feder, 1987). In the case of animals, mussels and other shellfish can be used as fresh food or as a constituent of high protein dry meals (Table 21, 22).

B) Socioeconomic aspects. The scale of the mussel production system should be set according to the characteristics of the local market or the degree of integration compatible with respect to the other elements in the proposed multispecies production system (Fig. 36) as an alternative to ecosystem management along conventional sectoral lines.

C) Ecosystem management policy. Mussels live in an environment subjected to diverse human economic activities and interests (eg. fisheries, aquaculture, housing development) (Fig.1). It is important to find a balance in which all these interests produce a neutral or a less negative environmental impact
(Castagna, 1987) through appropriate planning based on predictive studies (Valiela, 1978).
D) Health considerations. Mussels are capable of filtering large volumes of water (Attree and Aubert, 1980) and storing high concentrations of

hazardous organic and inorganic waste materials (Roberts, 1972; Mackowiak et al., 1976; Hussongs et al., 1981; Unsal, 1986; Shumway, 1989). Thus they have been widely used as a traditional bioindicator of contamination (Fujiya, 1965; Phillips, 1978; Phillips, 1980; Aljebourini and Trollope, 1981; Forstner and Witmann, 1981). Damage caused to these sensitive ecosystems may be irreversible and eventually will affect the economy and health of people relying on them (Barrow, 1981; Shumway, 1989). Thus the mussel represents a vital indicator species in this respect.

5.4.1. The role of B. recurvus for commercial development at Boca del Rio Mandinga locality.

5.4.1.1. Brachidontes recurvus as a crustacean food

One of the most expensive inputs required to produce aquatic organisms by means of aquaculture is feed, especially in intensive systems where protein sources of high quality and quantity are required (New, 1976; Korringa, 1976; Halver,1979). Mussels have been succesfully used for feeding decapods such as the spot prawn Pandalus platiceros Brandt, the giant freshwater prawn Macrobrachium rosenbergii de Mann and the lobster Homarus gammarus L. (Wickins, 1972; Beard et al.,1985).

The need to promote the cultivation of native species in Mexico (Farias, 1988) and the recent expansion of activity in the commercial cultivation of marine and freshwater prawns (Wickins, 1989; Chavez and Torruco, 1988a; Anonymous, 1990) led to interest in the use of B. recurvus as a food for this group of organisms in Mexico. The Instituto Tecnologico del Mar based in the city of Boca del Rio, Veracruz, carried out experimental trials with the caridean prawns Procambarus acanthonurus, M. acanthurus and M. rosenbergii fed on B. recurvus mussel flesh and meal (Anaya, 1989; Villanueva, 1990; Zamora, 1990).

The modification in 1990 of Article 24 of the Mexican Federal Fisheries Law (Ley Federal de Pesca), released species which were formerly exclusively exploited by fishermen, since they had the exclusive right to fish these species. This has enhanced the interest by different sectors in species such as penaeid shrimps (Hatchett et al., 1990) which can be farmed.

According to the Mexican Integrated Aquaculture Development Programme, shrimp have been classified as a high yielding group and by 1994, 28 % of the total production under this category (52.6% of total national aquaculture production) should be represented by this group. It is expected that shrimp exports will produce approximately 68 % of the predicted total of 1,300 million dollars from aquaculture exports earnings (Anonymous, 1990). Associated with these production goals, it has been established that the demand for feed of high nutritional quality will increase annually by up to 67%, the requirement for shrimp feed accounting for 81 % of the total demand for all cultivated species.

Previous evaluations of the potential for semi-intensive penaeid shrimp farming in the Gulf of Mexico determined the existence of a potential area of 13,000 ha and a production capability of 500 kg/ha/crop (2 crop per year) (Chavez and Torruoco, 1988a).

With the above consideration in mind, the mussel B. recurvus was evaluated as a possible feed for the white shrimp Penaeus setiferus, which is typical of this geographical zone (Lindner and Cook, 1974) and abundant in the Boca del Rio-Mandinga estuarine system (Chavez and Torruco, 1988a).

One main concern with carrying out the P. setiferus feeding trials was ensuring that the recirculating system was efficient in terms of providing suitable environmental conditions at a low cost of construction and installation. The recirculating system used in the feeding trial was an adaptation of a similar one designed by Morales (1986) to test diets with

Procambarus clarkii. Its efficiency was indicated by the physico-chemical water quality analyses during the trial. This remained within the the tolerance ranges reported for P. setiferus (Lindner and Cook, 1974) throughout the experimental period (Table 32). And despite its low cost (49,300 Mexican pesos = 13.00), using locally available materials there was no mortality caused by cannibalism or shrimp escaping.

The statistical value of using a group of animals individually isolated inside the same aquarium to test a specific treatment in the feeding trials, as performed here with P. setiferus and M. rosenbergii, has been discussed by New (1976). In spite of the relatively small number of replicates, the utilization of single chamber for each individual, prevents mortality by cannibalism and provides standard water quality conditions.

Shrimp postlarvae and juveniles were available at Laguna Redonda in the North-East zone of the lagoon where the water is shallow (< 50 cm) with slow currents, and where the sediments are fine and rich in organic detrital matter (Fig.37). During December, March and peaks of abundance in July and August coincide with the observations of Anderson et al.,(1949) and Linder and Cook (1974). The latter authors stated that this species migrates gradually to deeper areas of the estuaries and eventually out of them. Thus the time for collecting is important if quantity and quality (size) are desired, especially in relation to the needs of the proposed integrated system (Fig.36).

Although no significant differences between diets were found for most of the different nutritional parameters, as expected, the best values, were obtained with the balanced commercial diet 3 in Table 36, except for the Assimilation Efficiency

It has been reported that due to their feeding habits, penaeid shrimp can be classified as omnivorous, with a high stomach content of detritus (80%). From this it has been assumed they could grow with a low protein diet (De la Lanza, et al., 1986).

The protein level of diet 3 reported by the producers and Cruz (1989)(Table 21) was lower than the range proposed for the species of 28–32% (Andrews and Sick, 1972), but this could possibly be compensated with the addition of some other compounds rich in fatty acids (w3) (e.g. fish oil) and carbohydrates (e.g. starch) (New, 1979). The use of diets with a relative high animal protein content (such as diets 1 and 2), does not by itself identify them as suitable feeds. Venkataramiath et al. (1975) observed experimentally in P. aztecus, an inverse effect on growth rate with 80% protein concentration. When this was reduced to 40% and mixed with vegetable matter, a high protein conversion and an increase in growth rate and survival was obtained.

Hanson and Goodwin (1977) pointed out that protein assimilation efficiency is affected by the relative proportions of lipids and carbohydrates. Lee et al. (1984) stated that one of the main aspects in P. vannamei culture is the variation of diet with age, suggesting that good results may be obtained by keeping a 1:1 proportion of animal: vegetable compounds, because this favours enzymatic efficiency.
This can be indirectly observed in the best food conversion ratio (FCR) value obtained for diet 3 (Table, 33) which is within the range reported for P. setiferus (Lindner and Cook, 1974) and other species of prawns (New, 1979).
The quality of protein and lipids in diets is important in terms of their essential amino acid and fatty acid composition, especially when planning to feed them to marine organisms (New, 1976). Essential amino acids in Brachidontes recurvus (Table 24) were the same as those found in Mytilus edulis and fulfilled the requirements for penaeid shrimp

(Cowey and Forster, 1971; Shewbart et al., 1972).

It has been postulated that fatty acids of the linolenic family (w3) are essential to diets in marine species (Korringa, 1976; Lytle et al., 1989). Shewbart and Mies (1973) reported in P. aztecus a low level of 18:3 w3 fatty acid in the stomach contents compared to that found in juvenile tissue, suggesting that diets might benefit from supplementation with linolenic acid.

The linolenic acid content found in B. recurvus (Table 23) is slightly higher than the range of 1–2 % recommended by Shewbart et al. (1973) who found that growth rates declined at 2 or 5% inclusion of this fatty acid. However, variable effects of lipid supplementation in shrimp diets has shown the specific fatty acid composition to be more important than total lipid content. High w3:w6 diets are beneficial to penaeid and caridean shrimp (New, 1976)

The highest concentration obtained was for palmitic acid (16:0) (Table 23), which was reported with other w3 polyunsaturated fatty acids as predominant in males and females of Penaeus japonicus (Guary et al., 1976).

Assimilation efficiency was apparently determined by food texture. Unfrozen mussel showed the best value, possibly due to its similarity to well–accepted semi–moist diets with less than 50 % moisture content (Gajcer and Neal, 1972) or the known preference for pasty pellets rather than dry ones (Regnault et al., 1975).

Values were were slightly higher than assimilation efficiency values reported for Procambarus clarkii (Morales ,1986) and Pacifastacus leniusculus (Moshiri and Goldman, 1969 cited by Fernandez et al., 1986) and similar to values larger than 65% reported for M. rosenbergii and M. acanthurus (Villanueva, 1990; Zamora, 1990).

Daily length growth rates achieved for P. setiferus were < 0.4 mm/day

(Table 33), which can not be considered good when compared to the ranges from 1 to 2.3 mm/day reported for this species (Gunter, 1950; Loesh, 1965). It is however important, to consider that these published growth rates were obtained from trials in ponds with balanced diets, in addition to the extra energy provided by detrital matter (Dela Lanza et., 1986). When fed formulated feeds in the laboratory, prawns are not able to grow as rapidly as when pond reared (Biddle et al., 1977).

The B. recurvus meal diet promoted a better length and weight growth than frozen mussel flesh (Figs.28,29), regardless of reports that the nutritive value of the mantle is reduced by homogenizing, drying or lyophilizing and powdering (Forster and Beard, 1975). Mussels contain a minimum of 60% moisture and during freezing the cell walls break causing loss of nutrients when thawed. Leakage of fluids is indicated in Table 21 by the moisture content differences between fresh and frozen mussel. Thus the inclusion of at least 25% fresh meat in frozen feeds has been recommended (Kitaka, 1976; Flutchercher, 1980; Grabner et al., 1981 cited by Fernandez et al., 1986).

Apparently the utilization of mussels as the only source of feed caused a weakening of the shrimp as both treatments involving only mussel as feed registered higher mortalities than diet 3 (the balanced commercial diet) (Table 33). These mortalities were presumably caused by Aeromonas and Vibrio present in larger numbers in aquaria with diets 1 and 2 than 3 (Table 34). Vibrio spp. are part of the normal microflora of shrimp (Vanderzant et al., 1971; Lightner, 1973), being oportunistic pathogens whose numbers increase whenever the hosts defenses are decreased as a consequence of stress, or they may be present as secondary invaders of wounded shrimp (Lightner, 1973).

During the experimental period no damaged shrimp were observed so the cause was possibly stress associated with moulting. Shrimp were normally found about to die, or dead early in morning with the moulted exoeskeleton present in the chamber and a whitish colour typical of organisms attacked by these bacteria (Lightner, 1973). The ecdysis process involves the uptake of large volumes of water in order to release the old exoskeleton (Reinoso and Yoong, 1983), possibly increasing the exposure time and concentration of bacteria in direct contact with the shrimp's body and combined with the normal stress caused by the moulting process. Better fed and faster growing shrimp (Diet 3) showed a higher percentage of moults and higher survival, indirectly confirming this hypothesis (Table 33)

Another group of crustacea with high commercial value in the Port of Veracruz area are caridean prawns. Research on the native fresh water prawn Macrobrachium acanthurus has been carried out (Cabrera 1976, 1980; Farias and Salinas, 1988 a,b) with a special interest in optimizing energy fluxes by integrated production and recycling of urban wastes (Farias et al., 1988; Farias and Salinas, 1988 c).
Brachidontes recurvus has been supplied as a supplementary fresh food to Procambarus acanthopurus grown experimentally in small earth ponds with acceptable results (Anaya, 1989). Villanueva (1990) used this mussel as a unique food source, and also as component of a balanced diet, to feed M. acanthurus experimentally in laboratory conditions. She concluded that the mussel is suitable as an animal protein source in balanced diets and recommeded this alternative rather than its direct use mainly because of its high cost of production.

The related species M. rosenbergii showed better growth when B. recurvus was used as a unique food source in frozen form compared to

dry meal form (Zamora, 1990).
This same freshwater prawn was used in the present work to compare dry meals prepared from B. recurvus and M. edulis and to compare fresh and frozen M. edulis flesh.

According to the final values in Table 33 M. edulis mussel meal was slightly better than B. recurvus, even though these differences were not statistically different. Apparently differences were due to the age of the Mexican musssel meal and biochemical degradation (e.g. lipid oxidation) that occured during storage. Nevertheless the essential fatty acids profile of this mussel meal (Table 23) corresponded to the requirements reported for M. rosenbergii by Sandifer and Joseph (1976).

The presence of linolenic acid (w3) in mussel meal is important nutritionally as demonstrated by these latter authors from their results after feeding fresh water prawns on a diet augmented with 3% shrimp head oil, a good source of this fatty acid. This caused a doubling of their biomass and a 15-fold increase in carotenoid pigment levels after 12 weeks when compared with animals fed a diet rich only in linoeic acid (w6).

Another possible factor was the stage of sexual maturity of the mussels used which influenced the overall biochemical composition of the feed material, resulting in high nutritional values such as protein, as discussed in section 6.3. The Mytilus edulis utilised in this feeding trial were fully ripe whereas B. recurvus were collected out of their spawning season peak.

Based on previous experiences with shrimp and lobsters, it was expected that better shrimp would be achieved growth with fresh mussel than with other presentations, but a completely opposite result was obtained (Table

33). The high Food Conversion Factor for this diet indirectly shows poor utilisation of fresh mussel by M. rosenbergii A possible explanation may be that fresh water prawns do not, unlike penaeid prawns, posses a gastric mill for crushing food particles; instead they masticate their food outside the buccal cavity with their anterior appendages (Malecha et al., 1981). In contrast frozen mussel provides a better texture and flavour (Regnault et al., 1973; New, 1976) associated with a better Food Conversion Ratio by M. rosenbergii (Table 33). It has been reported that fresh water prawns operate on a number of trophic levels in a pond ecosystem functioning as primary and secondary consumers as well as detritivores and scavengers (Nelson et al., 1977). Unfrozen organic matter immersed in water is subjected to a faster degradation by bacteria and it has been surmised that these microrganisms could have a direct role in prawn nutrition by helping to meet the amino acid requirement of prawns (Stahl and Ahearn, 1978; Farmanfarmain and Lauterio, 1979; Watanabe, 1975). These authors reported a list of essential amino acids required by M. rosenbergii, all of which are present in M.edulis and B. recurvus (Table 24).

The protein content of the diets for M. rosenbergii were either below or above from the optimum of 30-35 %. Balazs and Ross (1976) found that from a range of diets with three levels of protein, diets containing 35% resulted in the greatest growth of juveniles (0.1g) independent of the protein source. Briggs et al. (unpublished) cited by Millward (1988), demonstrated that a diet for postlarvae containing protein produced significantly better growth rate, feed conversion ratio and protein efficiency than a diet containing 44% protein. Nevertheless Millward (1988) used this level of protein in diets elaborated with copra meal and obtained a daily average length increment of 0.2 mm/day similar to that obtained in this work, but a smaller average weight daily increment of 8.4 mg/day (Table 35). A range of 20–40% protein content has been reported when using only fish meal (Ashmore et al., 1974; Farmanfarmaian and Lauterio, 1979). When values from this work (Table 35) were compared to results obtained by Zamora using the same mussel diets and fresh water prawn species the daily average weight increment (4.8 mg/day) was smaller and daily average length increment (0.22 mm/day) similar.

The contents of carbohydrate and fibre in mussel flesh were low (Table 22) in comparison to preferred levels proposed by Fair et al.,(1980) (20–30% carbohydrate). These authors suggested that dietary fibre causes a decrease in the rate of food passage through the shrimp's digestive system, thus increasing the time available for absortion of nutrients from the diet.

Moulting frequency (Table 22) was faster than the 33.3 % reported by Millward (1988) for a 74 day period. The intermoulting time period was longer (12–16 days) than the 8 days reported by him possibly due to his initial prawn size being 2.2 cm length compared to 4.4 cm (Table 36).

The idea of utilising B. recurvus as a diet in the feeding trials discussed above was to evaluate the efficiency of its nutritional characteristics in order to use it as a direct feed or to incorporate it as an element of balanced diets.

It was assumed that the performance of the mussel diet would be acceptable because it contains more than 60% protein, and being recognized as a primary source of energy which is efficiently assimilated by these crustaceans (Condrey et al., 1972; Sze, 1973).

These experiments showed that B. recurvus is a suitable source of food for successfully rearing P. setiferus juveniles although, as expected, a commercial balanced diet produced better results. However the statistically similar growth obtained by Villanueva (1990) with a comercial diet and one based on B. recurvus as a source of protein also proves that the latter is an efficient alternative.

Based on the above results two main types of dried mussel meal could be developed. Firstly, a high quality one, by drying and powdering mussel meat, which could be used as a constituent of balanced diets, or ideally as a high energy microencapsulated feed for the early larval stages of crustaceans (Meyers, 1973; Jones et al., 1974). The second option is to produce a meal including the shell to save labour. The problem with this meal would be the high calcium content; it has been reported whenever there is a higher calcium: phosphorus ratio than 1:1, growth can be inhibited and pigmentation is decreased (Kitabayashi et al., 1971). Fresh mussel appears to offer a better prospect because its nutritional efficiency did not show great differences from mussel meal; it requires less processing and it can be used directly as part of the production of integrated systems.

The constraint for mussel utilisation emerges from the production costs of extraction, transport, processing and storage (Fernandez et al., 1986). Zamora (1990), calculated that the production cost per kilogram of B. recurvus dry mussel meal pellet was 42.8 % more expensive than fresh mussel assuming a cost per kilogram of landed mussel of 3,000 Mexican pesos. And Villanueva (1990) determined that a balanced diet with 50% B. recurvus dry mussel meal producing no significant differences in growth compared to a commercial feed, was 97.4 % more expensive than the latter. Nevertheless, the final use of mussel products at a larger production scale could balance the final costs.

Among possible large-scale processing methods which may be economically viable is one which uses froth flotation as a means of protein extraction from mussels; the denser material including the shell falls to the bottom of the flotation column, leaving the protein above (Holland et al., 1983).

These alternatives remain open for the future development of intensive aquaculture in the region such as shrimp culture, but in the mean time the use of mussel is more realistic in terms of using them as part of the energy flow in terrestrial or aquatic polycultures that can be established in Laguna Redonda as discussed in section 5.4.2.1.

5.4.1.2. *B. recurvus* as Human Food.

– Nutritional value of mussels.

The Mexican National Nutrition Institution (INN), reported that approximately 90,000 children younger than 3 years old die annually as a direct consequence of malnutrition. About 50–60% of young children from the land farming areas are affected by diseases associated with nutritional deficiencies especially a lack of protein of animal origin. These are caused by lack of appropriate foods or shortage of income to buy it and ignorance by adults about different feeding alternatives to the traditional diet. Also, there is a lack of publicity concerning alternative food products such as molluscs.

Bivalves in general represent a good alternative to alleviate this animal protein supply problem because they are resistant to manipulation and transport; are highly digestible and have good nutritional value. Rapid inflation in Mexico in the last 10 years has practically stopped people from consuming traditional animal protein such as beef and chicken, so molluscs may be a good substitute. Twelve oysters are equivalent in protein to 100 g of beef meat and contain the vitamins B1, B2, C and minerals e.g. phosphorus (Aldana, 1988).

The nutritional quality of mussels is good as well: eight mussels are equivalent to 70 g of chicken meat, 90 g of beef or 175 g of milk. For every 100 g of fresh mussel flesh there is 14.4 g protein, 2.2 g fat , 3.3 g carbohydrates, 88.8 mg calcium, 236 mg phosphorus, 3.4 mg iron,015 mg iodine 0.16 mg Tiamine, 0.21 mg rivoflavine and 0.15 vitamine B2 (De la Garza, 1987). Calories range from 80 to 95 kcal/ 100 grams wet weight

(De la Garza, 1987; Waterman, Torry Advisory Note 13). Their relative high content of w3 fatty acids decreases the risk of acquiring coronary diseases (Kenneth, 1986; Feder, 1987).

– Marketing

Mussels M. edulis and M. californianus consumed in Mexico were originally obtained from the natural populations located on the coasts of Baja California and Sinaloa (Canales, 1987). Production started to decline in 1981 with 1.097 tons and decreased in 1983 to 63 % of the 1981 production. By 1984 the availability of mussels was scarce nationally. As mentioned in section 1.5.2., to compensate for this situation the commmercial culture of mussel was started in Baja California by the private company Martesano S.A. which obtained its first harvest in 1985. Athough the market indirectly determines the minimum size of a mussel production unit for culture to be considered profitable, as reflected in the high production of different countries such as France, Spain, New Zealand and Thailand (Chatermwat and Lutz, 1989; Figueras, 1989; Hickman, 1989), the size of the production system established by the Mexican company was far below the potential demand of 1200 tonnes due to the constraints explained in section 1.5.2.

Nevertheless, the 600 tons of mussels produced were canned and commercialized in the states of Baja California, Sinaloa, Sonora Nuevo Leon and Jalisco and an increasing interest in the consumption of this product developed. The subject was discussed at the Regional Meeting on Mussel Production celebrated in Ensenada, B.C., Mexico, in November of 1987, as part of the limitations for the development of a National mussel industry (Baylon, 1987; Canales, 1987; Garcia, 1987). Unfortunately Mexico never considered the incorporation in 1990 to the GATT. This opened the market to foregin products such as the Spanish mussels offered at a lower price, threatening the future of these recently formed companies.
Of the 200,000 mt of cultivated Spanish mussels marketed annually,

40% are consumed fresh (22% for export and the remaining 78% for the local market), 50% are canned and 10% are frozen. This diversity reflects a solid industry backing up the biotechnical production, which is not the case with the Mexican mussel industry – so it is unable to compete.

This situation has recently limited the establishment of commercial culture of new mussel species such as B. recurvus since the potential national market has been flooded with alternative cheaper products. Therefore their commercialization should be considered as a fresh product for the local markets. This implies other problems, as can be observed from the results of the preliminary marketing survey done in the Veracruz Port (section 4.18). This concluded that most potential consumers of mussel products acknowledge the existence of them; but the actual consumption of approximately 600 g per capita is far below the potential mussel production of more than 1000 tonnes per year from areas under present development, such as Baja California; but the product is only accessible to wealthy classes, and consumers in this zone do not have a gastronomic and culinary culture related to this organism. Thus it can be concluded that an immediate local market does not exist in the Port of Veracruz and only a small level of consumption can expected in the local restaurants of Boca del Rio–Mandinga where the product can be promoted in the form of mussel soup. It is assumed that if 10 local restaurants were to offer this new product, it is estimated that approximately 20 kilos/week would be required which can be supplied by mussel culture as part of an integrated system as explained in section 5.3.2.(Fig. 36).

5.5. Potential role of B. recurvus in an integrated ecosystem management plan

Estuarine systems are subjected to different anthropogenic activities

which affect them ecologically and eventually economically as well (Fig.3) (Cubit et al., 1987: Farias, 1988c).
According to Bahr and Lanier (1982), man–induced perturbations on bivalves including oysters or mussels can conveniently be divided into eight types as follows: (1) physical disturbances, especially sedimentation resulting from dredging or excessive boat traffic; (2) salinity changes due to freshwater diversion or local hydraulic alteration; (3) eutrophication or over–enrichment of water from organic matter sewage and/ or fertilizers; (4) toxins including pulp mill sulphites; (5) heavy metals, chlorinated hydrocarbons, organophosphates, radionucleides and petroleum hydrocarbons; (6) physical impairement of feeding structures by oil; (7) thermal loading, primarily from power plants; (8) overharvesting and wetland loss due to development.

If these perturbations are carefully analysed it can be observed that they are usually the products of powerful interests representing different socio–economic sectors. Conflicts between some of these sectors have been reported in different countries such as Italy, Mexico, Great Britain amongst others (Kapetsky, 1981; Wickins, 1986; Saclauso, 1989; Ewel, 1990).
For example, Ardizzone et al. (1982) listed the following interests interacting with fisheries and aquaculture which are also found in the Boca del Rio–Mandinga ecosystem (Farias, 1987): various types of uncontrolled fishing effort (sports fishing, small scale coastal and lagoon fishing) acting on unit fish stocks; introduction of polluting waters from human settlements often with high eutrophic loads; tourism and urban development; conservation needs with preservation of national biotopes and protection of species of particular interest. These interests, when they act together simultaneously, have a stronger impact on the ecosystems and also create social conficts betweeen the different groups of people involved such as fishermen's cooperatives, government

environmental agencies and private companies.

Management of Boca del Rio estuarine system represents a challenge for suitable exploitation, since it is already a strongly environmentally impacted ecosystem located close to a rich economic zone centered around the Port of Veracruz. Wetland loss and denudation of mangrove forest due to housing development has been intense. Several hectares of mangrove have been cleared to build five main human settlements; La Marina, El Conchal Village, Country Club, La Matoza and Mandinga Village (Fig.1). This is likely to create three main effects. As discussed by Saclauso (1989) and Wickins (1988), 1) mangrove forests are the natural nursery ground of many cultivated or captured species of fish, molluscs and crustaceans and their destruction could seriously affect many livelihoods; 2) conversion of mangroves to any other development may also encroach upon low–cost culture systems e.g. oyster and mussel farming; 3) Many poor people who depend on mangrove swamps for their livelihood could eventually be dislocated.

It is necessary, therefore to establish a management policy based on ecodevelopment theories (Ridell, 1981) using methods such as those suggested in section 1.3. Morales (1978) defined ecodevelopment as "a perspective which may allow us to guide the search for determining the equilibrium between the objectives of human development and the capacity of the environment". This has been already succesfully applied in some other similar ecosystems (Wolff, 1981), e.g. Diab and Scott (1989) proposed management strategies to alleviate the negative effects of the potential impacts on the estuarine ecology of Mgeni River, South Africa as a consequence of the Inanda Dam.

It is a conclusion from the present study that mussels can play an important role in integrated management schemes for tropical wetlands based on the concept exposed by Morales (1978). This role would have two main aspects:

1) Mussel beds serving as an exploitable natural resource that can be managed as an integrated production system (Fig.36) (Section 5.4.2.1.).
2) Mussels acting as a bioindicator of environmental impacts caused by other anthropogenic activities (Section 5.4.2.2.).

5.5.1. Utilisation of *B. recurvus* in an integrated production system

In order to incorporate mussels into an integrated production system under the ecological and socioeconomic conditions of Boca del Rio–Mandinga locality, the following two basic production subsystems need to be considered as illustrated in Figure 36; (1) Coastal Land–based production subsystem; and (2) an aquatic estuarine production subsystem. The system would be located in Laguna Redonda for the reasons discussed in section 5.3.2. concerning its suitability for mussel cultivation, and the proposed locations of the different production units are shown in Figure 37.
This production approach includes aquatic polyculture as a fundamental element in order to optimize energy flow, and to avoid the potentially harmful environmental impacts typical of monospecific production sytems. Thus the operation of this type of integrated system (Fig.36) is intended to meet two main objectives simultaneously; (a) to protect the environment; and (b) to optimize energy flow in order to benefit local underprivileged people in the Boca del Rio Mandinga region. A Subsistence Farming Model is recommended as an appropriate means of establishing the desired balance. i.e. the system of farming must be ecologically adaptive and resource sustaining, but not adequate to support a dense population, greater than 12–20 people/km2. In this way the system would sustain genuine wetland inhabitants but would not support the growth of industry or urbanisation (Ridell, 1981). However, legislation may be necessary to protect this form of eco–development from encroachment by outside interests (Limburg et al., 1986).

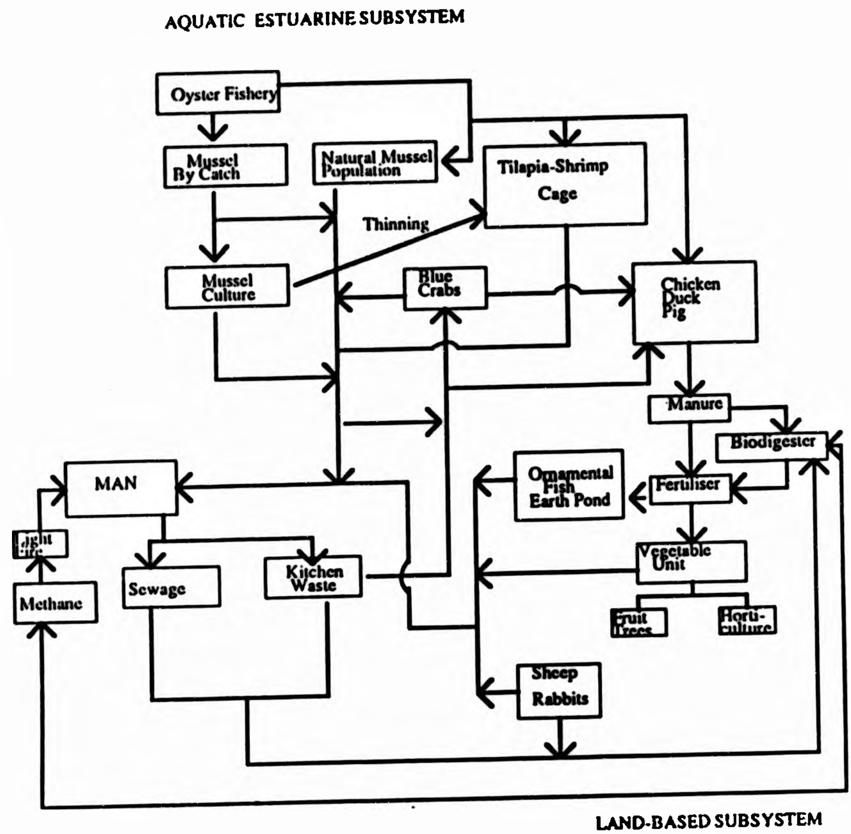


Figure 36. Diagram of estuary and land-based food production subsystems and their interrelations as proposed for integrated rural coastal development.

1) Coastal land–based production subsystem

The operation in the region of Veracruz of smallholder farming is characterised by low per capita income and per unit area productivity (relative to intensive smallholder farming in temperate areas) (Ridell, 1981). This has motivated local research institutions such as ITMAR, INIREB and CRECIDATH to direct their research to determine the ideal components for establishing integrated farms using local natural resources (Pullin, 1982; Bucheli and Reta, 1986; Olguin, 1986; Farias et al., 1988; Farias and Salinas, 1988c; Martinez, 1988). Moreover the operation of integrated systems in the area of Veracruz is not new as prehispanic cultures had similar systems which were replaced by monospecific cultivation during the Spanish Colonial period of 1521–1821 (Olguin, 1986; Siemens et al., 1988).

The main biological feature of an integrated farming system is by–product recycling; but improved space utilization, in which two subsystems occupy part or all of the space required for one subsystem, may also be an important aspect of increased productivity as proposed by Edwards et al.(1988a). These authors stated that a major socio-economic benefit of integrated farming is that inputs to the various subsystems that comprise the farming system tend to be intra–farm, with a diminished reliance on inter–farm or agro–industrial inputs.

Considering the socio–economic characteristics of the Boca del Rio–Mandinga zone, a model of an Integrated Fish Farm to be operated at a family level has been proposed by Farias et al. (1988). This should be considered as an important landbased model for better utilization of local family land. These authors established preliminary quantitative and qualitative elements for a 0.1 ha area to be operated by a family of 5 members.

The basic production units consist of: (1) small fish ponds, made impermeable at a low cost with polyethylene sheets (Farias, 1986); these are stocked with a polyculture of exotic fish species (eg.tilapias) and native species (e.g. freshwater snail); these ponds can incorporate some recycling of urban wastes (e.g. empty milk boxes as refuges for freshwater prawns) as described by Farias and Salinas (1988c) and Martinez and Farias (1989); (2) vegetable and fruit trees areas such as banana, papaya and coconut; (3) integrated livestock areas for rabbits, ducks, poultry and pigs. Similar systems have been proposed for other tropical countries such as Thailand, Panama and Kenya (Edwards, et al., 1983; Hatch and Engle, 1987; Haller, 1990).

This preliminary model was revised later by Galeana and Gonzales (1989), to include the appropriate number and type of organisms in order to establish an economically self sustainable integrated fish farm. They concluded that the monthly production costs in Mexican pesos would be $8,251, generating a revenue of $25,313 and a net benefit of $17,062. They suggested as elements: (1) a horticulture unit; (2) four chickens of the breed for cock fighting which is in high demand in the area; (3) five adult rabbits to produce rabbits for ongrowing and 3 more to keep on the farm as part of the family diet; (4) one pig, two sheep and four ducks; (5) one earth fish pond, stocked with 235 ornamental fish (goldfish, C. auratus). The value of some other food production units was not considered since these grow naturally and are mainly used for daily family consumption, such as the fruit tree unit – banana, papaya and coconut (Fig. 36). Similar projects have proved to be successful, such as in Thailand where mean fish yields of 174.7 kg/200 m2 pond/ year (extrapolated yield of 8,735 kg/ha/yr) were obtained from integration with a mean of 26.7 ducks/ 200 m2 ducks; the protein from the fish alone could supply 96% of the annual, animal protein needs of a family of five people and would alleviate widespread protein–energy malnutrition reported for those rural areas (Edwards, 1983).

Interrelations within the system proposed are illustrated in Figure 36, where animal manure is utilized to produce fresh fertilizer. In relation to re–use of pig manure in fish ponds, Edwards (1985) reported a yield of 5 tons of tilapia/ha/yr as a conservative figure for integration with 150 pigs in Thailand. Organic wastes can also be biodigested anaerobically in a biodigester to produce methane (Monroy and Viniegra, 1981). These fertilizers can then be used to enhance productivity in the vegetable units and the earth fish pond. Edwards et al.,(1988b), estimated that 60 kg of fish could be harvested annually from a 200 m2 pond loaded, with the slurry from a 6.2 m3 digester needed to produce the 1.5 m3 daily gas requrement of an average rural family of five persons. Vegetable by–products can be used as supplementary feed for the farm animals.

Three external inputs can be accomodated in this subsystem: 1) kitchen waste to feed chicken–pig–duck units or the biodigester; (2) human sewage that can be processed in the biodigester – this represents a better alternative to releasing raw sewage into the estuarine environment. The latter practice had negative environmental and health implications as discussed in section 5.4.2.1. (3) Mussels as a byproduct of the oyster fishery and naturally growing or cultivated mussels, to be used as feed for the chicken–pig–duck units. In this way the mussel constitutes an important energy link between the aquatic estuarine and coastal land–based production subsystems.

2) Aquatic estuarine subsystem

The aquatic estuarine polyculture unit and its connections with the coastal land based integrated system (Fig. 36) have still to be quantified and evaluated. Nevertheless some initial trials have been carried out (Farias and Salinas, 1986; Farias et al, 1988; Bibiano, 1990) to provide elements for a preliminary economic analyses.

The present author collaborated in the investigation reported by Bibiano (1990) in which sex reversed tilapia (O. mossambicus) were cultivated for 7 months in fish cages at Laguna Redonda. The following information relevant to the present study was obtained:

(A) It is possible to ongrow tilapia species in small fish cages (with a size of 16 x 6x 1.5 m and a density of 20 fish/m3 under estuarine environmental conditions of Boca del Rio–Mandinga, with a secondary production of shrimp (P. setiferus) and estuarine fishes that enter as fry to feed inside the cages. Tilapia reached a commercial weight of 200–250 g in a minimum of 6 months and were fed with a supplementary artificial diet at 2% total body weight per day in addition to natural productivity, showing a food conversion ratio close to 1:1. Based on this experience it can be observed in Table 41 that the capital cost of operating in the first semester one fish cage (16 x 6 x 1.5m) with 2880 fry (20 fish/m2), would be 563,380 Mexican pesos; variable costs (operational costs and others) would be 439,280 pesos, giving and a total cost of 1,002,660 pesos. If survival was 85% and fish with an average body weight of 225 g were sold at the normal market price of 3,000 pesos/kg, revenue would be 1,650,000 pesos, enough to cover the total costs after the first semester. Assuming fish would be directly harvested and sold commercially by the owner of the restaurant and fish cage as in the case of mussels unit production, the price per kilo would be increased up to 40,000 pesos (since each 200–250 g fried tilapia can be sold at 10,000 pesos) producing a revenue of 24,480,000 pesos.

(B) Shrimp (P. setiferus) grown simultaneously in the same cages can be an important element since this species was observed growing on excreta and uneaten pellets inside the mosquito net fry cages. Assuming that 4,080 shrimp juveniles were captured from the wild and were stocked into the fish cage (50 shrimp/m2), they could be fed on uneaten fish pellets, excreta and fresh whole smashed mussels provided at 20 kg/month. Shrimp production for this system is estimated to be approximately 12 kg, based on reaching a minimum commercial weight of 35 g, and if sold at the normal market value of 35,000 pesos/kg, the total revenue would be of 4,998,000 pesos. As in the case of tilapia,

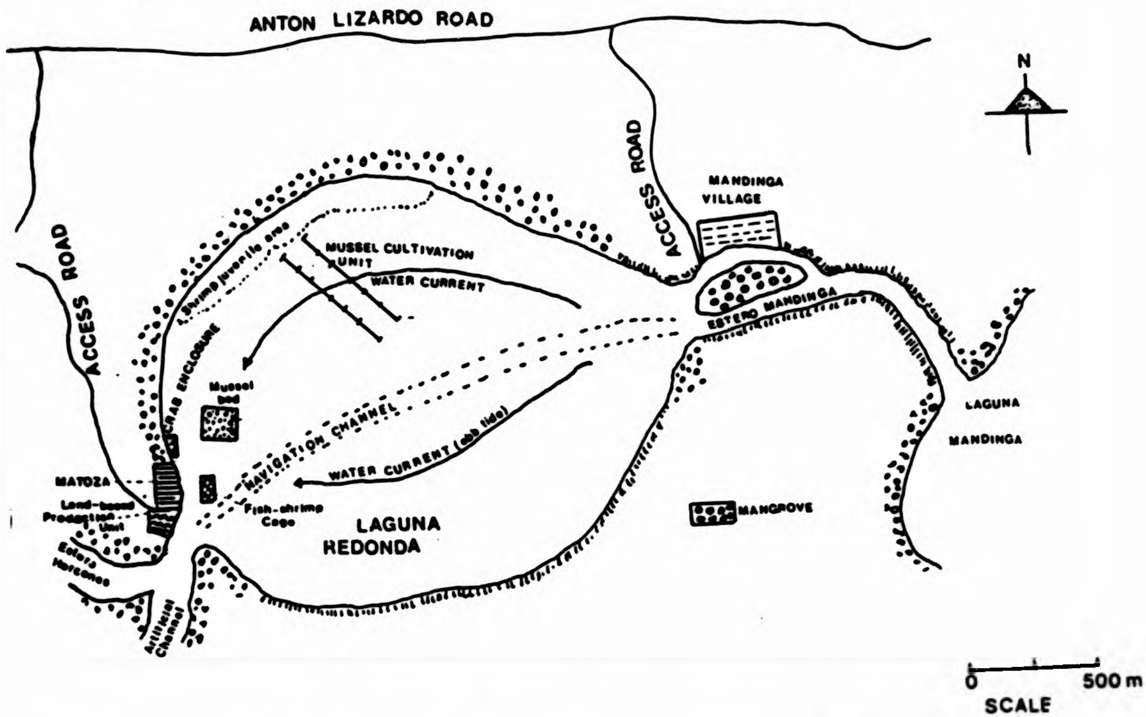


Figure 37. Diagram of the Laguna Redonda system showing the position of Lagoon based and land based food production units mentioned in the text.

shrimp would be commercialized directly by the restaurant owners increasing its value up to 50,000 pesos, resulting in a total revenue of 30,600,000 pesos (Table 41).

If the cage is considered as a single production unit and the total revenues obtained from the tilapia and shrimp are added together the total benefit would be 6,638,000 at normal market prices and 55,080,000 pesos with the added value when sold directly by the restaurant as part of the integrated mangement approach (Fig.36). Such utilisation of shrimp juveniles will however require evaluation on the dynamics of the local shrimp population in order to avoid over exploitation due to either overfishing or major changes in the nursery environment (New, 1986)

(C) The operation of fish cages can be combined with mollusc culture (eg. mussel and/or oyster). It has been proved that mussels reared close to the fish cage environment attain better growth (Sadykhova, 1967; Farias, 1983; Folke and Kautsky, 1989; Stirling, 1990). Jones and Inawa (1991) reported that the oyster C. gigas (Thunberg) grown in polyculture with chinook salmon Oncorhynchus tshawytscha showed a better growth rate and condition factor than oysters grown suspended from control stations located away from the fish cages. In the case of Laguna Redonda with the layout of estuarine units proposed in Fig. 37 and considering the direction of water currents, a permanent flow of primary production and detritus would be ensured providing constant food for mussels and other filter–feeder organisms.

(D) Other components of the aquatic subsystem.

During the tilapia ongrowing experiment large number of young blue crabs Callinectes spp. were attracted by the fish cages. These crabs can be used to stock shore enclosures (Fig. 37) similar to Mexican tapos (Pedini, 1984). Feed would be supplied by organic wastes (e.g. fish guts and waste from filleting) produced by the restaurants or families nearby and by whole smashed mussels.

Table 41 Preliminary Economic Analysis for Fish/Shrimp culture cages in Boca del Rio Mandinga estuarine system.

COST (all figures in Mexican pesos, US$1= Pesos 3,000)

Capital Cost	Unit	Total No.	Unit Cost	Total Cost
Mosquito Net 1.50	m	92	4,890	449,880
Nylon string No.9	kg	0.6	20,000	12,000
Polypropelene rope 3/8	kg	10	8,150	81,500
Wooden post	Post 3.5m	10	2,000	20,000
SUBTOTAL				563,380
Operating Cost	**No. Jornal**	**No People**	**Tot.No. Jornales**	**Total Cost**
A) Labour *				
Cage construction	1	2	2	32,000
Cage installment	1	2	2	32,000
Harvesting	1	2	2	32,000
Maintenance	6	1	6	96,000
Shrimp post-larvae	2	1	2	32,000
SUB-TOTAL				224,000
OTHER				
Tilapia food	kg	122.4	1500	183,600
Tilapia	fingerling	2,800	11	31,680
SUB-TOTAL				215,280
TOTAL COSTS				1,002,660
REVENUE				
Tilapia landed	kg	550	3,000	1,650,000
Tilapia (restaurant)	kg	550	40,000	24,480,000
Shrimp landed	kg	612	35,000	4,988,000
Shrimp (restaurant)	kg	612	50,0000	30,600,000
NET BENEFIT				
Landed				6,638,000
Restaurant				55,080,000

* 1 Jornal = 8 hours/day at a rate of 2,000 pesos/hour;

These crab enclosures can play an important role for species conservation as well as food production. During the spawning season, gravid female crab are captured bearing eggs which are stripped by hand and replaced into the water. Fishermen have the belief that this is enough for the eggs to hatch. In order to test some of these ideas author constructed a small enclosure measuring 5 x 10 m, provided with plenty of rocks and old tyres as artificial substrata to avoid cannibalism. Some gravid females were obtained from the daily catch by fishermen willing to cooperate, with the promise that they would get them back as soon as they had spawned. The crabs were kept for an average of one week, fed on restaurant wastes and then returned to the owners who added these organisms to their daily capture, thus increasing their income. A study of the population dynamic population of the crabs and biotechnical aspects of the system should be carried on to asses the potential to exploit the fishery and aquaculture resource. Similar studies have been carried on for the mangrove crab Scylla serrata by Ong (1966), Raphael (1970), Du Pleis (1971) and Hill (1975, 1975, 1979) cited by Macintosh (1982).

5.5.2. Management of the aquatic subsystem

The operation of an integrated system such as the one proposed above can result in a more efficient utilisation of the local natural resources from the environmental and economic points of view. With respect to the latter, the half-yearly total benefit (combined profits from mussel, tilapia-shrimp and land-based units total benefit) obtained from this system, based on the prices suggested from their local sale (Tables 40,41), would be approximately 63,012,473 Mexican pesos, compared to 7,830,100 pesos, 55,080,000 pesos and 102,373 pesos for each activity individually. This integrated management approach tries to balance socio-economic and environmental factors to yield on economically viable and sustainable production system above.

One of the constraints of operating mariculture units in estuarine systems is the possibility of causing negative environmental impacts (Saclauso, 1989).

Among the adverse consequences of pollution from aquaculture are changes in the composition of natural plant and animal populations brought about by eg. increased organic loading from waste feeds (such as from shrimp ponds); changes in pH or decreased dissolved oxygen concentration and increased organic sediment loads from fish cages (Gowen and Bradbury, 1987; Stirling and Day, 1990). Where exotic chemicals are used for disease or predator control these may also adversely affect adjacent natural communities (Kapetsky, 1981).

Suspended mollusc culture may also have diverse negative effects on the environment. Chesney and Iglesias (1979) found no significant differences in demersal fish biomass in mussel raft and non raft areas, although indices of diversity, species richness and even–ness indices were generally higher in the raft area. Reasons given for these results were that the demersal fishes were unable to utilize the vast epifaunal resources associated with the raft because many of the epifaunal organisms were unsuitable as food. Likewise, the benthic infauna below the rafts was adversely affected by mussel faeces and pseudofaeces and thus presumably less infauna per unit of area was available to demersal fishes than in non raft–areas. Similar effects were found by Lopez et al (1984) who detected a change of food habits of three demersal fishes from a predominantly infauna diet to one of raft epifauna.

Dahlback and Gunnarsson (1981) suggested that the increase of sedimentation under a mussel culture system should be considered. They detected a build–up of sediments rich in organic material and sulphide under the mussels. Effects may also be caused in the water column, as reported by Larsson (1985) who found that ammonium–nitrogen was doubled and the concentration of phosphate was quadrupled in the water mass that passed through a mussel culture system. These extra inputs of nutrients can cause, as in the case of fish cages, changes to the phytoplankton and periphyton (Gowen and Bradbury, 1987; Stirling and Dey, 1990), and create the possibility of toxic algal blooms (Shumway, 1989).

These effects can be avoided by installing systems operated on the basis of energy recycling (e.g. integrated fish farms). In order to achieve these without affecting the original ecosystem the qualitative and quantitative aspects of aquatic and terrestrial elements should be calculated according to their potential interactions, using techniques for environmental impact assesment (E.I.A.) such as those published by Valiela (1978), Ridell (1981), Clarke (1988) and Lawson (1989).

5.6. *B. recurvus* as bioindicator of Environmental Impact

The world wide utilisation of mussels as highly sensitive bioindicators of environmental changes is based on their capacity to filter great volumes of water and store hazardous substances such as pesticides, heavy metals and bacteria (Fujiya, 1965; Phillips, 1978, 1980; Forstner and Wittmann, 1981; Anonymous, 1983; Becerra, 1990; Gomez, 1990). Coastal water is subjected to different economic interests and activities that can cause changes in the general dynamics of coastal ecosystems, as discussed in previous sections. Chavez and Torruco (1988a) reported a total of 22 sources of pollution that may affect the estuarine systems and coastal lagoons on the eastern coast of Mexico, including wastes from the following industries; cane sugar, alcohol, wine, beer, oil, pharmacy paper, electricity and mining.

In the case of the Boca del Rio–Mandinga estuarine system, untreated sewage and occasional oil spillages in the coastal zone are apparently a serious problem at the present time. These various pollutants as well as changes in the environment caused by house development and dredging can be detected indirectly by mussels as discussed below.

– Sewage

Because of their capacity to absorb wastes mussels may not be as healthy as they seem to be when extracted from areas polluted by discharges of untreated sewage or industrial wastes. In relation with these aspects and its consequences for mollusc culture, a general review on mollusc sanitation and marketing has been published by FA0–UNDP (Anonymous, 1989c). Bivalve molluscs filter 50 to 100 litres of water daily while feeding (Athree and Aubert, 1980); in this way they trap and concentrate microorganisms, some of them pathogenic to man (Metcalf and Stiles, 1965; Cabelli and Haffernan, 1970; Hartland and Timoney, 1979; Barrow, 1981; Anonymous, 1983). Thus, in a system like Boca del Rio Mandinga where mussel collection or cultivation is technically feasible, great care must be exercised to assess the environmental and human health risks.

Bacteriological studies of the water and bivalve molluscs growing in coastal–estuarine areas near human centres such as Veracruz Port and Boca del Rio–Mandinga ecosystem show faecal pollution indices higher than 1100 coliforms per 100ml of water or 230 coliforms per gram of meat, which are the levels unacceptable to international commissions (Orozco and Segovia, 1986; Farias and Camargo, 1981; Farias et al., 1987). Because their use as human food can produce diseases like typhoid, paratyphoid fever, cholera, dysentery, poliomyelitis and hepatitis they constitute a high risk for human health (Hoff and Becker, 1968; Bendilli and Ruchi, 1969; Thompson and Thaker, 1972;

Mackowiack et al., 1976; Hussongs et al., 1981; Anonymous, 1983). The sources of pathogenic bacteria are the direct inputs of untreated sewage, and wastes from different livestock in the area (e.g. cattle) which are natural vectors of transmission (Presnell and Miescier, 1971).

Results from experiments during the present study to determine coliform bacteria in B. recurvus and the surrounding environment of Boca del Rio–Mandinga indicated that higher bacteria concentrations were present in bottom mussels than in suspended ones (Tables 16, 19; section 4.10.). This result coincided with the pattern shown by Crassostrea virginica kept experimentally on the bottom and suspended at Estero El Conchal (Fig. 1; Farias et al., 1987). Similarly Mann and Taylor (1983) reported that oysters kept suspended inside a waste recycling aquaculture system did not contain large concentrations of contaminants because these, especially heavy metals, tend to accumulate in the bottom sediments.

Mussels living on the bottom tend to register higher concentrations since it has been reported that disturbance of the sediment caused by currents and waves increase coliform bacteria and pathogenic microorganisms in shellfish (Gerba and McLeodi, 1976; Goyal et al., 1979).

Although bacterial concentrations in mussel meat were not measured during the rainy and dry seasons, the smaller bacterial levels recorded in the water column during the latter period suggested that bacterial accumulation in mussels is also lower in the dry season (Table 19). This difference may be caused by a higher survival and increase in lower salinity conditions. The New York Sea Grant Institute (1975) mentioned that in Moriches Bay, New York, faecal coliform levels in clams increased from 130 to 160,000/ 100g in the six hours after rain.

High temperatures were recorded during September (coinciding with low salinities). This too, possibly results in a faster uptake of bacteria, since in shellfish there may be a relationship between feeding activity, bacteria assimilation and increase in water temperature (Orozco and Segovia, 1986). Stefano et al. (1977), working with M. edulis, demonstrated a positive correlation between cilial activity and temperature. This causes a greater filtration rate,producing as a direct consequence a faster rate of contamination as more water flows through the gills.

Table 16 shows that bacteria concentrations found in mussels from Boca del Rio–Mandinga exceeded, in some cases, the values allowed in meat by the Mexican National Health Department of 160 coliforms/g of meat (Mendoza, 1982) and 230 coliforms/100g of meat required by the USA National Shellfish Sanitation Program (1965). A different criterion is used in the United Kingdom where counts of E. coli higher than 15 per millilitre of mussel flesh are unacceptable (Waterman, Torry Advisory Note 13).

An apparent solution to this problem may be the operation of purification or depuration plants (Camacho, 1979; Souness et al., 1979; Peranginangin et al., 1984; Reilly and Barile, 1987; Zepeda, 1987; Gomez, 1990) and the relaying which requires the transfer or trasplantation of mussels from culture grounds polluted by the water brought about by floods to clean areas (Anonymous, 1988b). This alternative does not solve the real problem (i.e. environmental contamination by sewage) and implies a relatively expensive energy input for the process of producing "safe" food, with a consequent increase in cost of production. Thus, while some depuration systems appear to be economic for higher value molluscs, particularly oysters (Gomez, 1990), they are unlikely to be economic for mussels.

To try and overcome this financial constraint, a low cost in situ mussel depuration unit has being developed in Singapore (Cheong and Beng, 1984).

Therefore a real solution would be to control sources of contamination with better management of the ecosystem. This can be achieved by involving the local government to provide drainage and water treatment services, which is unlikely to happen in the short term, or to establish biodegesters as proposed in Figure 36, to collect sewage and transform it into methane.

– Oil spills

As a drainage basin and a water body connected to the river and adjacent sea, the Boca del Rio–Mandinga system has periodically received diverse toxic substances. Oil spills due to cleaning oil tankers at Veracruz frequently lead to oil slicks, drifting towards shore and carried into the system by tidal exchange.

Gillfillan (1975), found a decline in carbon ingested and assimilated by Mytilus edulis with increasing oil concentration. This represents a sublethal form of pollution which is characterized by medium and long term effects in the mussel community. Castagna (1987) identified the way the Mytilus community is affected when he found that, although the juveniles and adults seemed to survive these levels, some of the early life stages were obviously eliminated or severly affected.

Cubit et al. (1987) reported the effects of an oil spill affecting coral reefs and mangroves on the caribbean coast of Panama. More than 50,000 barrels of medium weight crude oil were spilled causing immediate mortality of organisms living at the seward edge of the reef flats and on drying substrata above mean water level. Mangroves that showed defoliation and mortality were located on windward coasts and other areas where the oil pentrated in the sediments around the mangrove roots. Oysters and other organisms living on mangrove roots also suffered severe mortality.

– Dredging and house development

Strategies for coastal ecosystem management such as hydraulic engineering (Kapetsky, 1981) are not necessarily applicable without previous environmental impact assessment (E.I.A) (Valiela, 1978; Ridel, 1981; Clark, 1988; Lawson, 1989). Thus negative results can be expected, as observed in Carmen–Machona lagoon (Chavez and Torruco, 1988b and Cruz–Gomez et al. 1980). Changes caused by dredging, such as to the physico–chemical parameters and the water circulation patterns, may be more adverse when combined with housing development as in the case of Boca del Rio– Mandinga. The changes in this ecosystem and arose from a combination of both activities. But it is important to mention again that the change of distribution and abundance of B. recurvus can be considered as an indicator of strong alterations of environmental conditions. Thus it is important to establish a permanent monitoring programme of the mussel population in order to determine the evolution of the ecosystem.

Based on the aspects discussed in this chapter sustainable exploitation of the potential productivity of estuarine systems such as Boca del Rio–Mandinga is very promising. Further investigation, however will be necessary to determine which forms of exploitation will ensure simultaneously the health of the environment and the wellfare of the local people in Boca del Rio–Mandinga and similar lagoons, with the aim of developing and testing an appropriate multiple use management system for these important Mexican coastal water bodies. It is concluded that the mussel, Brachidontes recurvus, can play an important environmental and socio–economic role in such a multiple use management scheme, through its potential utilization as human food, food for cultured shrimp and fish, and as a bioindicator of environmental cleanliness.

CONCLUSIONS

1.– The dynamic hydrobiological characteristics of the Boca del Rio–Mandinga estuarine system are mainly determined by the interaction of tidal cycles with the rainy and north wind seasons.

2.– Temporal and spatial salinity distribution delimits zones within the system. Laguna Redonda and Laguna Mandinga are mesohaline during the dry season and oligohaline in the rainy season. A mesohaline–polyhaline zone is located towards the mouth of the system. Salinity ranges from 1.6–33.8 ppt, showing vertical stratification throughout the year. This parameter combined with temperature triggers the main spawning season of B. recurvus.

3.– Temperature changes gradually over the year, increasing in June–July (31°C). Higher temperatures tended to be found at the head of the system, possibly because of this shallowness and the limited water circulation there.

4.– Oxygen fluctuations were influenced by diurnal and climatic factors, rather than by tidal cycles. The normal diurnal range was 4.5 to 7.0 mg/l and higher values were recorded in late afternoon.

5.– Sediment distribution is determined by physiography and water currents. Soft bottom sediments were normally found closer to the system shore where mangrove roots act as sediment traps. In areas with high current speed, coarser sediment consisting of sand and shell fragments occur.

6.– The estuary system is mostly shallow (<2.0 m), with deeper areas (3–4 m) in the navigation channels.

7.– Water currents at Laguna Redonda showed overall speeds ranging from 8.6 – 11.2 cm/s, moving predominately from northeast to southwest. These currents are created by tidal flow and apparently in the same direction as the predominant winds. Although measurements were only made during ebb tides, it can be assumed that currents would reverse during flood tides.

8.– Tides in the lagoon system showed a 4 to 6 hours delay with respect to the time predicted by the tide tables for the tides at the Port of Veracruz.

9– Chlorophyll a concentrations measured in the lagoon ranged from 11.7–61.3 µg/l and 2.7– 7.4 mg/l of organic matter, indicating a good potential food supply throughout the year for cultivated as well as natural populations of Brachidontes recurvus.

10.– Brachidontes recurvus is contagiously distributed in both its habitat forms: in mussel beds and as clusters attached to aerial mangrove roots. Settling appears to be determined by salinity stratification in the water and substratum availability.

11.– Growth rings on the shells were useless for determining the age of individual mussels, although a significant positive correlation was found between their average length and the number of shell rings present.

12.– Analysis of condition factor, gonad histology (Seed Mean Gonadal Index), the abundance of planktonic mussel larvae and recruitment on spat collectors and into the natural populations indicated that Brachidontes recurvus population is reproductively activity throughout the year. The main spawning peaks were detected in August and October. The female:male sex ratio was not significantly different to 1:1.

13.– Biochemical analysis of mussel body tissues showed and expected loss of water and build up of reserve materials during and after the spawning season.

14.– Mortality was caused by prolongued extreme changes in salinity, predation by crabs (e.g. Callinectes sp.) and birds (Phalacrocorax sp.), or by asphyxia. Mussels fall from the mangrove root clusters as a result of high current speeds,sinking into the mud because of their weight. This results in more than 80% mortality by suffocation.

15.– It was determined from respiration experiments carried out at different salinities (4–32 ppt), using mussels of different sizes and from various localities, that the optimum salinity for normal metabolism is 15 ppt.

16.– Studies in the feasibility of culturing Brachidontes recurvus showed that the best material for collecting mussel spat is polypropylene onion bags. Mussel "seed" (average 30 mm) supplied by the natural population, polypropylene onion bag collectors and by-catch from the local oyster fishery industry, can be stocked in polypropylene onion bags and suspended from racks. Using this method a commercial size of 60 mm may be attained in 6 months, at an average monthly growth rate of 4 mm.

17.– Suspended cultivation of B. recurvus should be established at Laguna Redonda as part of an integrated multi-species production system. Annual minimum yields of 20 tons can be expected from a one hectare development in the most favourable zone of this lagoon, but direct human consumption would be limited by the present demand to approximately 20 kilos/week.

18.– Two potential constraints on the development of commercial mussel culture using this system are: (1) predation, particulary by cormorants (Phalacrocorax sp.) and crabs (e.g. Callinectes spp.); (2) organic pollution caused by untreated sewage discharges into the estuarine system from surrounding tourist developments and other settlements.

19.– Coliform bacteria concentrations higher than the maximum permited by different world health agencies were detected in the water column (< 1,100 coliforms/ 100 ml) and mussel flesh (< 160 coliforms/ g of mussel meat) sampled from Laguna Redonda. The highest concentrations of coliform bacteria tended to occur during low salinity periods. Escherichia coli and Enterobacter aerogenes were amongst the microrganisms identified.

20.– Cultivated mussels could be used for sale in local restaurants provided they are cooked to kill pathogenic bacteria. Based on the proximal, fatty acid and amino acid analyses, mussels can also be used succesfully as a dietary component for culturing shrimps such as Macrobrachium acanthurus and Penaeus setiferus.

21.– The potential for incorporating mussels into the food of integrated multispecies production systems in the lagoon was investigated. A preliminary approach is proposed for Laguna Redonda which includes an estuarine aquatic polyculture component (fish–molluscs–crustaceans) and an integrated fish farm operable on a family basis, using the traditional local flora and fauna. A preliminary economic analyisis indicated that returns for the first production cycle would be approximately 60,000,000 Mexican pesos ($ 1.0 U.S.= 3,000 Mexican pesos). This net benefit would be enough to cover the total costs after the first harvest (approximately 6 months). The integrated management approach would allow to balance socio–economic and environmental factors to yield an economically viable, and sustainable production system.

22.– Optimization of energy inputs can be obtained by recycling non-utilised energy produced by both sub–systems through integration.

23.– It is important to carry out environmental impact assessment (E.I.A.), and to use ecodevelopment schemes to establish an appropriate management policy for Boca del Rio–Mandinga estuarine ecosystem.

24.– It is concluded that the mussel, Brachidontes recurvus, can play an important environmental and socio–economic role in such multiple use management scheme, through its potential utilization as human food, food for cultured shrimp and fish, and as a bioindicator of environmental cleaniliness.

REFERENCES

Abbott, P.T., 1974. American Seashell. Van Nostrand, New York, 541 pp.

Aldana, A.D., 1988. Situacion actual de las pesquerias de ostras en el Golfo de Mexico y perspectivas de su maricultura. Mem.IX Congreso Nal. de Zoologia, 13–16, Octubre, Villahermosa, Tab., Mexico, 1: 8–12.

Aleem, A.A., 1984. The Suez Canal as a habitat and pathway for marine algae and seagrasss. Deep–Sea Res., 31 (6–8a): 901–918.

Aljebouri, M.M. and D.R., Trollope, 1981. The Escherichia coli content of Mytilus edulis from analysis of whole tissue or digestive tract. J. Appl. Bacteriol., 51 (1): 135–42.

Allen, J.F., 1960. Effect of low salinity on survival of the curved mussel Brachidontes recurvus. Nautilius, 74: 1–8.

Allen, J.F., 1962. Gonad development and spawning of Brachidontes recurvus in Chesapeake Bay. Nautilus, 75: 149–156. (continued) 76: 9–16.

Alleston, D.J., 1985. Observations on some piscivorous birds in a trout fishing area of Natal. Lammergeyer, 35: 41–46.

Amador del Angel, L.E., 1989. Cantidad de alimento disponible e incidencia de larvas de ostion Crassostrea virginica (Gmelin) en el sistema lagunar Boca del Rio–Mandinga, Ver. Tesis de Licenciatura, Ing. Pesquero en Acuic. ITMAR, SEP., 97 pp.

Anaya, L.J., 1989. Estudio de la fertilidad de un cultivo intensivo de Acocil (Procambarus acanthogurus) utilizando dos tipos de alimento suplementario de bajo costo, en estanques rusticos. Tesis de Licenciatura, ITMAR, SEP. Mexico, 87 pp.

Andrews, J., 1971. Sea Shells of The Texas Const. USA, University of Texas Press, 298 pp.

Andrews, J.W. and L.V., Sick, 1972. Studies on the nutritional requirements of penaeid shrimp. Proc. World Maricult. Soc., 3:403–414.

Anonymous, 1983. Cockles and Cholera. New Straits Times, Malaysia, Friday, January 7, 1983.

Anonymous, 1988a. Calendario Grafico de Mareas. Golfo de Mexico y Mar Caribe. Veracruz. Instituto de Geofisica, Universidad Nacional Autonoma de Mexico.

Anonymous, 1988b. Cleaning up the oysters. SEAFDEC Newsletter, 11(2): 11p.

Anonymous, 1989a. Calendario Grafico de Mareas. Golfo de Mexico y Mar Caribe. Veracruz. Instituto de Geofisica, Universidad Nacional Autonoma de Mexico.

Anonymous, 1989b. Planning for aquaculture development. FAO, ADCP/REP/89/33, 68 pp.

Anonymous, 1989c. Report of the workshop and study tour on mollusc sanitation and marketing. Regional seafarming development and demonstration project RAS/86/024, FAO–UNDP, 212 pp.

Anonymous, 1990. Presentacion del Programa del Desarrollo Integral de la Aquacultura. Acuavision, 19: 6–9.

Ankar, S., 1980. Growth and production of Macoma balthica (L.) in the Northern Baltic soft bottom. Ophelia Suppl., 1: 31–48.

AOAC Associaton of Official Methods Analytical Chemist, 1975. Official Methods of Analyses 12th. Ed. AOAC. Washington D.C.

APHA., 1970. Recommended procedures for the examination of sea water and shellfish 4th. Ed. A.P.H.A. New York, 203 pp.

APHA, 1980. Standard methods for the examination and wastewater. 15th. Ed. Washington D.C. American Public Health Association, 1139 pp.

Ardizone, G.D., Cataudella, S. and R., Rossi, 1988. Management of coastal lagoon fisheries and aquaculture in Italy. FAO Fish.Tech. paper, 203: 79–92.

Arnold, W.S., 1985. The effects of prey size, predator size and sediment composition on the rate of predation of the blue crab Callinectes sapidus Rathburn and the hard clam Mercenaria mercenaria (Linne). J. Shellfish Res., 5(1):31.

Arreguin, S.F., 1982. Contribucion al conocimiento de la hidrologia de las lagunas de Mandinga, Veracruz, Mexico. An. Esc. Cienc. Biol. Mex., 26: 111–134.

Ashmore, S.B., Stanley, R.W., Moore, L.B. and S.R., Malecha, 1985. Effect on growth and apparent digestibility of diets varying in grain source and protein level in Macrobrachium rosenbergii. J. World Mariculture Soc., 16: 205–216.

Attre, P. and J., Aubert, 1980. Etude de la contamination experimentale d'huitres par des bacteriophages. Rev. Int. Oceanogr. Med. LIX: 71–76.

Avelar, W.E.P., 1980. Gametogenesis annual cycle of Brachidontes recurvus darwinianus darwinianus. Rev. Nordestina Biol., 3(2): 151–177.

Avendano S.S., Campos J.C., 1983. Manual Operativo de Geologia Marina, 223 pp.

Bagenal, T.B., 1978. Methods for Assesment of Fish Production in Freshwaters. IBP Handbook No.3. Great Britain, Blackwell Scientific Publications Ltd, 213 pp.

Bahr, L.M. and W.P., Lanier, 1981. The ecology of intertidal oyster reefs of the South Atlantic Coast: A community profile. Fish and Wild Service, FSW/OBS-81/15, 105 pp.

Baird, C.H., 1958. Measurment for condition in mussel and oysters. Journal du conseil permanent international pour l'exploration de la Mer, 23: 249–257.

Baird, R.H., 1966. Factor affecting the growth and condition of mussels (Mytilus edulis). Fishery Investigations, Ministry of Agriculture, Fisheries and Food, London, Ser II, 25: 1–33.

Bally, R., 1987. Conservation problems and management options in estuaries: The Bot River estuary, South Africa, as a case–history for management of closed estuaries. Environ. Conserv., 14(1): 45–51.

Bao–Tong, H. and Y., Hua–zhu, 1984. Integrated management of fish–cum–duck farming and its economic efficiency and revenue. NACA/WP/84/14, 4pp.

Barash, A. and Z., Danin., 1986. Further additions to the knowledge of Indo–Pacific Mollusca in the Mediterranean Sea (Leseepsian migrants). Spixiana, 9(2): 117–141.

Bardach, E.J., Ryther, J.H. and W.O., McLarney., 1972. Aquaculture. The Farming and Husbandry of Fresh Waters and Marine Organisms. USA, Wiley Interscience, 868 pp.

Barlow, C.B., and K., Bock, 1984. Predation of fish in farm dams by cormorants Phalacrocorax spp. Aust. Wildl. Res., 11(3): 559–566.

Barnes, R.D., 1987. Invertebrate Zoology. USA, CBS College Publishing, 893 pp.

Barrow, G.L., 1981. Microbial pollution of coastland estuaries. The public health implications. Wat. Poll.Contr. Fed., 80(2): 221–230.

Baudin, J.P., 1980. A contribution to the ecological study of Mediterranean brackishwater system. 2. Population of the Citis Lagoon (Bouches dy Rhone). Vie Mielieu, 30 (3–4): 303–305.

Baqueiro, C.F., 1984. Status of molluscan aquaculture on the Pacific coast of Mexico. Aquaculture, 39: 83–93.

Baylon, G.O., 1987. Potencial productivo y perspectivas del mejillon en Baja California. Mem. Encuentro Regional sobre produccion de Mejillon, Ensenada, B.C., Mexico, 17–19 Nov., 1987, FONDEPESCA: 131–135.

Bayne, B.L., 1964. Primary and Secondary settlement of Mytilus edulis. Journal of Animal Ecology, 33: 513–523.

Bayne, B.L., 1965. Growth and delay of metamorphosis of the larvae of Mytilus edulis (L.) Ophelia, 2: 1–47.

Bayne, B.L., 1973. Physiological changes in Mytilus edulis L. induced by temperature and nutritive stress. Journal of Marine Biological Assoc. of the United Kingdom, 53: 39–58.

Bayne, B.L., 1976. Marine Mussels: Their Ecology and Physiology. Cambridge University Press, G.B., 506 pp.

Bayne, B.L., Thompson R.J., and J., Widdows, 1976. Physiology: I.In: Marine mussels, B.L. Bayne (Ed.), Cambridge University Press: 13–65.

Beard, T.W., Richards, P.R. and J.F., Wickins, 1985. The techniques and practibility of year–round production of lobsters, Homarus gammarus (L.), in laboratoty recirculation systems. Fisheries Research technical Report 79, 22 pp.

Beaven, G.F., 1947. Observations on the fouling of shells in the Chesapeake Bay area. Address Nat. Shellfish Assoc.: 13–15.

Becerra, W.S., 1990. Importancia de la sanidad del ostion. Acuavision, 19: 30–31.

Benavides, L., 1956. Notas sobre la geologia petrolera de Mexico. Cong. Geol. Int XX Ses. Mexico. Yac. Petrolero y Gas. T.3 America del Norte: 35–562.

Bendinelli, M. and A., Ruchi., 1969. Isolation of human enterovirus from mussels. Appl. Microbiol., 18(3): 531–532.

Bennet, B.A., Hamman, K.C.D., Branch, G.M. and S.C., Thorne, 1985. Changes in the fish fauna of the Bot River estuary in relation to opening and closure of estuary mouth.Trans. R. Soc. S. Afr., 45(3–4): 449–464.

Bernaldez, A.C., 1987. La pesqueria del mejillon en Baja California. Acuavision, 10: 30–31.

Berner, L., 1935. La reproduction des moules comestibles (Mytilus edulis et M. galloprovincialis Lmk.) et leur repartition geographique. Bulletin de l'Institute Oceanographique, Monaco, 680: 1–8.

Bibiano, L.C., 1990. Evaluacion de la adaptabilidad y crecimiento de Oreochromis mossambicus en un cultivo de jaulas situadas en la Laguna Redonda del sistema lagunar Boca del Rio–Mandinga, Mpo. de Alvarado, Veracruz. Tesis licenciatura, Ing en Acuicultura, Instituto Tec. del Mar, SEP., 72 pp.

Biddle, G.N., Joseph, J., Stahl, M. and D., Conkin, 1977. The nutrition of freshwater prawns. In: J.A. Hanson and H.L. Goodwin (Eds.) Shrimp and prawn farming in the Western Hemisphere. Dowden, Hutchinson and Roos Inc., Troudsberg, P.A. (Ed.), 8: 272–291.

Bisker, R. and M., Castagna., 1988. Predation on single spat oysters Crassostrea virginica (Gmelin) by blue crabs Callinectes sapidus and the mud crabs Panapeus herbstii Milne-Edwards. J. Shellfish Res., 7(1): 111 p.

Bohle, B. and K.E, Wiborg. 1967. Forsok Med Dyrking au Blask Sell.Fishets Gang.N.R., 53: 391–395.

Bouxin, H., 1931. Influence des variations rapides de la salinete sur la consommation d' oxygne chez Mytilus edulis var Galloprovincialis (Lmk). Bull. del L' Institute Oceanographique, 596:1–11.

Bouxin, H., 1956. Observations sur le frai de Mytilus edulis var. galloprovincialis (Lmk) dates precise de frac et facteurs provoquant l'emission de produit genitaux. Rapp. P.-V. Reun. Cons. Int. Explor. Sci. Mediterr., 143: 43–46.

Bowden, K.F., 1967. Circulation and diffusion. In.G.H. Lauff, ed. Estuaries.Am. Assoc. Adv. Sci. Publ., 83: 15–36.

Bravo, G.P.R., 1988. Determinacion de la Productividad Primaria neta del manglar en el complejo Lagunar Terminos, Campeche. Tesis Licenciatura,Instituto Tecnologico del Mar, Ver, SEP, Mexico.

Bower, S.M. and A.J., Figueras, 1989. Infectious diseases of mussels, especially pertaining to mussel transplantation. World Aquaculture, 20(4): 89–93.

Breese, W.P., Williamson, R.E. and R.E., Dimick., 1963. Stimulation of spawning in the mussels, Mytilus edulis Linnaeus and Mytilus californianus. Conrad, by kraft mill effluent. Biol. Bull., 125: 197–205.

Brey, T., Serrano, M and D., Pauly, 1988. Electronic length frequency analysis. A revised and expanded user's guide to ELEFAN 0,1 and 2 (2th edition).ICLARM, Contribution 261,ISSN 0341-8561, 31pp.

Brown, R.A., Seek, R. and J.O., Connor, 1976. A comparison of relative growth in Cerastoderma (Cardium) edule, Modiolus modiolus and Mytilus edulis (Mollusca: Bivalvia). J. Zool.Lond., 179: 297–315.

Brown, K.M. and T.D., Richardson, 1987. Foraging ecolgy of the southern oyster drill Thais haemastoma (Gray): Constraints on prey choise. J. exp. mar. biol. ecol., 114 (2–3): 123–141.

Bucheli, M.P. and J.L.M., Reta, 1986. Aprovechamiento de pequenas lagunas tropicales con fines de explotacion piscicola de Oreochromis niloticus en jaulas flotantes. Tesis Lic. Instituto Tecnologico del Mar, Ver. SEP, Mexico.

Buckle, R.F. and B.C., Farfan, 1987. Experiencias y posibilidades del cultivo de Modiolus capax en Bahia de los Angeles, Baja California, Mexico. Mem. Encuentro Regional sobre produccion de mejillon. Ensenada B.C., Mexico, 17–19 Nov., 1987, FONDEPESCA: 119–129.

Bullock, T.H., 1955. Compensation for temperature in the metabolism and activity of poikilotherm. Biol.Reviews, 30: 311–42.

Cabelli, V.J., W.P., Hefferman., 1970. Accumulation of Escherichia coli by the Northern guahaug. Appl. Microbiol., 19: 239–244.

Cabrera, C.M., 1976. Experimentacion y cultivo del camaron prieto langostino "Manos de carrizo" Macrobrachium acanthurus , en la estacion de acuacultura de los Amates, Tlacotalpan, Veracruz. Mem. Simp. Pesq. en Aguas Continentales, 3–5 Nov. Tuxtla Gutierrez, Chis., Mexico: 33–52.

Cabrera, C.M., 1980. Metodo para el cultivo comercialmente rentable del camaron prieto o langostino "Manos de Carrizo" Macrobrachium acanthurus (Wiegmann, 1936),Mem. II Simp Lat. de Aquacultura, Depto. Pesca, 13–17 Noviembre, 1: 663–718.

Camacho, E., 1980. Resultados preliminares al cultivo del ostion en las lagunas de Tamiahua, Pueblo Viejo y Tampamachoco, Ver. Men. 2 Sim. Lat. de Acuac. II: 902–942.

Canales, A., 1987. Mercado interno y externo del mejillon. Mem. Encuentro Regional sobre Produccion de Mejillon,Ensenada, B.C., Mexico, 17–19 Nov.,1987,FONDEPESCA: 363–373.

Cardenas, F.M., 1969. Pesquerias en las lagunas litorales de Mexico.Mem. Simp. Inter. Lagunas Costeras UNAM–UNESCO. Nov. 28–3–, 1967: 645–652.

Carriker, M.R., 1950. Killing and preservation of bivalve larvae in fluids. Nautilus, 64: 14–17.

Carriquiriborde, L., Farias, A., Ferrer, L., Gastelu, A. y O. Perez., 1981. Transplante experimental de almeja Pismo en Baja California, Mexico. Ciencias Marinas (Mex) 7(1): 49–66.

Cassie, R.M., 1954. Some use of probability paper in the Analyses of Size Frecuency Distributions. Aust. J. Mar. Freshwater Res., 5: 513–522.

Castagna, M., 1987. Mollusc culture for Chesapeake Bay. Contaminant problems and management of living Chesapeake Bay Resources: 210–216.

Cervantes, C.R., 1984. Manual de Practicas de Microbiologia. Instituto Tecnologico del Mar, Veracruz, SEP. Mexico.

Chanley, P., 1958. Survival of some juvenile bivalves in water of low salinity. Proc. Nat. Shellfish Ass., 48: 52–65.

Chanley, P., 1970. Larval development of the hooked mussel Brachidontes recurvus Bivalva Mytilidae including a literature review of larval characteristics of the Mytilidae. Proc. Nat. Shellfish Ass., 60: 86–94.

Chatermwat, K. and R.A., Lutz., 1989. Farming the green mussel in Thailand. World Aquaculture, 20(4): 41–48.

Chatterjii, A., Ansari, Z.A, Ingole, B.S. and A.H., Parulekar, 1984. Growth of the green mussel, Perna viridis L. in a sea water circulating system. Aquaculture, 40: 47–55.

Chavez, E.A. and D., Torruco, 1988a. Las lagunas costeras del Golfo de Mexico, caracterizacion ecologica y pesquera. Taller Regional sobre Lagunas Costeras–Pesca y Acuicultura. FAO–AQUILA, Caracas 12–16 de diciembre, 1988, 29 pp.

Chavez,E. A. and D., Torruco, 1988b. El sistema Carmen–Machona, una laguna costera del Golfo de Mexico. Taller Regional sobre Lagunas Costeras–Pesca y Acuicultura. FAO–AQUILA, Caracas,12–16 diciembre, 1988, 21 pp.

Cheong, L. and L.H., Beng, 1984. Mussel farming. SAFIS Extension Manual Series No. 5, 51 pp.

Chesney, E.J., 1979. Seasonal distribution, abundance and diversity of demersal fishes in the inner Rio de Arosa, Northwest Spain. Estuar. Coast. Mar. Sci., 8: 227–239.

Chesnut, A.F., 1949a. The oyster industry of North Caroline and some of its problems. Address. Nat. Shellfish Assoc.: 11–12.

Chestnut, A.F., 1949b .The oyster industry of North Carolina and some of its problems. Adress. Nat. Shellfish Assoc.: 39–42.

Chi, B.C. y F.P., Garcia, 1987. Obtencion de semilla de mejillon en laboratorio. Acuavision, 10: 22–24.

Chipperfield P.N.J., 1953. Observations on the breeding and settlement of Mytilus edulis (L.) in British waters. J. mar. biol. Ass., VI 32: 449–76.

Choisy, J.P. and R., Jones, 1983. Predation of the cormorant Phalacrocorax sp. on an anglerfish Lophius piscatorius. Oiseau Rev. Fr. Orinithol., 53(2): 181 p.

Choo, P.S., 1983. Mussel culture. SAFIS Estension Manual Series No.3, 17 pp.

Christensen, B., 1978. Biomass and primary production of Rhizophora apiculata B.L. in a mangrove of southern Thailand. Aquatic Botany, 4: 43–52.

Chum, J.C., 1989. Desarrollo y cultivo de larvas y juveniles de mejillon de laguna Mytella strigata (Hanley, 1943). Tesis de licenciatura, Ing. Pesq. en Acuic. SEP, ITMAR, Ver., 71 pp.

Clark, M., 1988. The Role of Environmental Impact Assessment on the Planning Process. Clarick and Harington (Eds.), Hansel, London, 203 pp.

Coe, W.R. and D.F., Fox, 1942. Biology of the California Sea Mussel (Mytilus californianus).I. Influence of temperature, food supply, sex and age on rate growth. J.Exp. Zool., 90: 30 pp.

Conato, V. and A., Bedar, 1981. The littoral pool in Ganzirri (Messina). Mem. Biol. Mar. Oceanogr., 11(2): 73–90.

Condrey, R.E., 1972. Comparison of the assimilation of different diets by Penaeus setiferus and P. aztecus. Fish. Bull., 70: 1281–1292.

Cormier-Salem, M.C., 1986. The management of aquatic space in Casamanance. L' estuarie de la Casamance: Environment, Peche, Socio-economie: 181–209.

Cowardin, L.M., Carter, V., Golet, F.C. and E.T., La Roe, 1979. Classification of wetlands and deep water habitats of the United States. U.S. Fish and Wildlife Service, Biological Services Program, Washington, D.C., FWS/OBS–79/31, 103 pp.

Cowey, C.B. and J.R.M., Forster, 1971. The essential amino-acid requirements of the prawn Palaemon serratus. The growth of prawn on diets containing proteins of different amino-acid compositions. Mar. Biol., 10: 77–81.

Craven, S.R., and E., Leu, 1987. Double-crested cormorants in the Apostle Islands Wisconsin, USA: Population trends, food habits, and fishery depredations.Colonial Waterbirds, 10(1): 64–71.

Craymeersh, J.A, Herman, P.M.J. and P.M., Meire, 1986. Secondary production of an intertidal mussel (Mytilus edulis) population in the Eastern Sheldt (S.W. Netherlands). Hidrobiologia, 133: 107–115.

Cruz-Gomez, A., Rocha-Ramirez, P. and G. De la Cruz-Aguero, 1980. El impacto del dragado sobre la hidrobiologia del sistema lagunar de Mandinga, Veracruz, Mexico. Congreso sobre problemas ambientales de Mexico, 8–12 diciembre de 1980. Mexico, D.F.

Cruz, S.S. and Martinez, R.J., 1989. Elaboracion y evaluacion de dietas, utilizando ingredientes convencionales para crecimiento de O. mossambicus en piletas de concreto en el ITMAR. Boca del Rio, Ver. Tesis Lic. ITMAR, SEP., 110 pp.

Cubit, D.J., Getter, D.C., Jackson, J.B.C., Garrity, S.D., Caffey, H.M., Thompson, C.R., Weil, E. and M.J., Marshall, 1987. An oil spill affecting coral reefs and mangroves on the caribbean coast of Panama. American Petroleum Institute Pub. No. 4452: 401–406.

Dahlaback, B. and L.A.H., Gunnarsson, 1981. Sedimentation and sulfate reduction under mussel culture. Mar.Biol., 63: 262–275.

Dame, R.F., 1979. The abundance, diversity and biomass of macrobenthos of North Inlet South Carolina, intertidal oyster reefs. Proc. Natl. Shellfish. Assoc., 69: 6–10.

Daniel, R.J., 1920. Seasonal changes in the chemical composition of the mussel Mytilus edulis. Rep.Lancashire Sea Fisheries Lab: 74–87.

Dare, P.J., 1969. The settlement, growth and survival of mussels Mytilus edulis L. in Morecombe Bay, England. International Council for the exploration of the sea, C.M. 1969/K (mimeo.), 11 pp.

Dare, P.J., 1971. Preliminary studies on the utilisation of the resources of spat mussels, Mytilus edulis L. occurring in Morecombe Bay, England. International Council for the Exploration of the Sea,C.M. 1971/K (mimeo.), 11pp.

Dare, P.J. and G., Davies, 1975. Experimental suspended culture of mussels (Mytilus edulis L.) in Wales using spat transplanted from distant settlement ground. Aquaculture, 6: 257–274.

Dare, P.J. and A.B., Edwards, 1975. Seasonal changes in flesh weight and biochemical composition fo mussels (Mytilus edulis L.) in the Conway Estuary, North Wales. J.exp.mar. Biol. Ecol., 18: 89–97.

Dare, P.J., 1980. Mussel cultivation in England and Wales. Ministry of Agriculture Fisheries and Food Directorate of Fisheries Research.Laboratory Leaflet No.50, 18 pp.

Davies, J.L., 1964. A morphological approach to world shorelines. Z.Geomorphol., 8: 127–142.

Davies, G., 1974. A method for monitoring the spatfall of mussels (Mytilus edulis L.). Journal du Conseil International pour Exploration de la Mer, 36: 27–34.

Davy, F.B. and M., Graham, 1984. Bivalve culture in Asia and Pacific. Work presented at Seminar in Singapore 16–18 February, 1982.IDCR.Asia Regional Office.Singapore 56.Ottawa, Ont. CIID.1984, 94 pp.

Day, J.W., Day, R.H., Barreiro, M.T., Ley–Low, F. and C.J., Madden, 1982. Primary production in the Laguna de Terminos, a tropical estuary in the southern Gulf of Mexico.Oceanol. Acta. Proceedings Int. Symp. on Coastal Lagoons SCOR/IABO/UNESCO, Bordeaux, France, 8-14 September 1981: 269-276.

De la Cruz-Aguero, G., 1985. Cambios Ictiofaunisticos debido al dragado en la laguna de Mandinga, Veracruz. Mem. VII Cong. Nal. de Zool., 26-30 Agosto, Saltillo Coah., Mexico.

De La Higuera, M., 1985. Fuentes de proteina y de energia alternativa en acuicultura. ASA/ Mexico, An. No. 66: 8pp.

De la Lanza, G., Rodriguez, M.M.A, and L.A., Soto, 1986. Ensayo experimental del consumo de detritos de la halofitas por camarones Peneidos Penaeus vannamei and P. stylirostris. An. Inst.Biol. Universidad Auton. de Mexico.

De la Garza, M.C., 1987. El cultivo de mejillon en Galicia, Espana. Acuavision, 10: 17-21.

Deevey, E.S., 1947. Life tables for natural populations of animals. Quart. Rev. Biol., 22: 282-314.

Diab, R.D. and D., Scott, 1989. Inanda Dam: A case study of estuarine impacts. Int. J. Environ. Stud., 3(4): 271-278.

Dijkema, R. and M., Van Stralen, 1989. The Netherlands. World Aquaculture, 20(4): 57-62.

Diupotex-Chong, M.E., 1978. Cariotipic characters of Brachidontes recurvus Rafinesque 1820. (Pelecypoda: Mytilidae). An. Cent. Cienc. del Mar y Limnol. Univ. Nal. Puton. Mex., 5(1): 55.

Dix, T.G., 1984. Accomodating commercial and recreational fishing and aquaculture in Australia estuaries. Management of Coastal Lagoon Fisheries, 1(6): 557-563.

Dixon, J.A., 1989. Valuation of mangroves. ICLARM, Tropical Coastal Area Management, 4(3): 1-11.

Dominguez, R.C.E., 1986. Perspectivas de la acuacultura en el Estado de Veracruz. Resumenes Primer. Simp. Nal. de Acuacultura, 8-12 Diciembre.,Pachuca, Hidalgo, Mexico:48 p.

Ducrotoy, J.P., Deprez, M. and J.P., Dupont, 1985. Short and long term biosedimentary evolution to two Macoma balthica communities. Estuarine management and quality assesment: 105-130.

Drury, R.A.B. and E.A., Wallington, 1980. Carleton's Histological Technique. USA, Oxford University press.

Edwards, A. and D.J., Edelsten, 1976. Marine Fish Cages. The Physical Environment. Proccedings of the Royal Society of Edinburgh (B), 75(14): 207-221.

Edwards, P., 1983. The future potential of integrated farming systems in Asia. Proc. V. WCAP, vol.1: 273-281.

Edwards, P., Kaewpaitoon, K., Meewan, A., Hamprasitkam, A. and C., Chantachaeng, 1983. A feasebility study of fish/duck integrated farming at the family level in Central and Northeast Thailand. AIT Research Report No 163, 48 pp.

Edwards, P., Pullin, R.S.V. and J.A., Gartner, 1988a. Research and education for the development of integrated crop-livestock fish farming in the tropics. ICLARM Studies and Reviews, 16, 53 pp.

Edwards, P., Polprasert, C., Rajput, V.S. and C., Pacharaprakiti, 1989b. Integrated biogas technology in the tropics. 2. Use of slurry for fish culture. Waste Management and Research, 6: 51–61.

Egan, H., Kirk, R.S., and R., Sawyer, 1981. Pearson's Chemical Analyses of foods. Eight Edition. Great Britain, pp 11–20.

Engle, J.B., 1945. The condition of the natural reefs and other public oyster bottoms of Alabama 1943 with suggestions for their improvement. Spec. Sci. Rept. no. 29. Fish wildl. Ser., U.S. Dept. Interior., 42 pp.

Engle, J.B., 1948. Investigation of the oyster reefs of Mississippi, Louisiana and Alabama following the hurricane of Sept. 19, 1947. Spec. Sci. Rept. no. 59. Fish wildl. Serv. U.S. Dept. Interior, 71 pp.

Eston, V.R., Galvez, A., Jacobini, C.M., Langevin and N.S.,1986. Tanaka. Chatamalus bisinuatus (Cirripedia) and Brachidontes solisianus (Bivalvia) spatial interactions: A Stochastic model. Ecol. Model.,34 (1–2): 93–113.

Ewen, K.C., 1990. Multiple demand of wetlands. Florida cypress swamps can serve as a case study. Bioscience, 40(9): 660–666.

Fair, P.H., Fortner, A.R., Millikin, M.R. and L.V., Sick, 1980. Effect of dietary fibre on growth, assimilation and cellulasa activity of the prawn (Macrobrachium rosenbergii). Proc.World Maric.Soc., 11: 369–81.

FAO, 1987. Provisional pattern of essential aminoacids for human nutrition.

FAO, 1987. Fishery Statistics, 64: 124 p.

FAO, 1990. Aquaculture Minutes, No 8: 4pp.

Farias, S.J.A., 1980. Observaciones preliminares sobre la ecologia de una poblacion de erizo rojo Strongylocentrotus franciscanus (Echinodermata–Echinoidea) en Baja California, Mexico. Tesis Licenciatura, Esc.Sup.Cienc.Mar.,Univ. Auton. Baja California, Mexico, 94 pp.

Farias, S.J.A. and F., Camargo, 1981. Estudio preliminar por contaminacion de bacterias coliformes en las aguascosteras del puerto de Veracruz. Mem. VII. Simp. Lat. de Oceanografia Biol.,Acapulco, Mexico, 661–674 pp.

Farias, S.J.A., 1983. Experimental trial on the growth of mussels (Mytilus edulis L.) on the ropes suspended from marine fish cages. MSc. Thesis. Institute of Aquaculture. Univ. of Stirling, Scotland. 80 pp.

Farias, S.J.A., 1986. Metodo practico para la construccion de estanques rusticos de pequenas dimensiones en zonas rurales con alta permeabilidad. Mem. Primer Simp. Nal.de Acuacultura, Pachuca, Hidalgo, Mexico, 1986.

Farias, S.J.A. y D.O., Salinas, 1986. Patron de fijacion de semilla de mejillon Brachidontes recurvus, empleando colectores de diferentes materiales en el Estero Horcones perteneciente al sistema lagunar Boca del Rio, Mandinga, Ver. Resum. Primer Cong. AMAC. Mexico 20–24. Octubre, 225 pp.

Farias, S.J.A., 1987. Primera reunion sobre el impacto ambiental, conservacion y aprovechamiento integral del sistema lagunar Boca del Rio Mandinga, Veracruz. Boletin de Acuacultura, Mexico,10: 6–7.

Farias, S.J.A., and D.O., Salinas, 1987. Observaciones preliminares sobre la ecologia y posible utilizacion en acuicultura del mejillon Brachiodontes recurvus en el estero Horcones Boca del Rio–Mandinga, Ver. Mem. 9th. Symp. Nal. de Oceanografia. Ensenada B.C. Mexico.

Farias, S.J.A., Akester, M. y D.P., Garcia, 1987. Comparacion del crecimiento del ostion Crassostrea virginica (Gmelin) cultivado en superficie y fondo en el sistema lagunar Boca del Rio Mandinga. Resumenes VII Congreso Nacional de Oceanografia, 27–31, Julio, Ensenada B.C., Mexico, 215 pp.

Farias, S.J.A., 1988a. Hooked mussel culture. Aquaculture News, 5: 5p

Farias,S.J.A., 1988b. Ecologia y cultivo del mejillon estuarino Brachidontes recurvus en el sistema lagunar Boca del Rio–Mandinga. Acuavision, 16: 16p.

Farias, S.J.A., 1988c. Consideraciones ecologicas sobre el cultivo de moluscos bivalvos en sistemas estuarinos. 3er. Congreso Nacional Acuic. AMAC 88 Xalapa, Ver.

Farias, S.J.A., Cabrera,C.M., Salinas, D., Martinez, T., Galeana, T.M. and L.V., Gonzalez, 1988. Proyecto Experimental de Granja Integral operable a nivel familiar en zonas rurales y suburbanas del Puerto de Veracruz. Primera Etapa. Tercer Congreso Nacional de Acuicultura, AMAC '88, Xalapa, Ver, 5–9, Diciembre, 1988.

Farias, S.J.A. and D.O., Salinas, 1988 a. Influencia de la luz y transparencia del agua en el patron de distribucion del langostino "manos de carrizo" Macrobrachium acanthurus. Mem. IX Congreso Nal. de Zool., 13–16 Octubre, Villahermosa, Tab., Mexico, I: 218–219.

Farias, S.J.A. and D.O., Salinas, 1988b. Colector artificial para la obtencion de juveniles de langostinos Macrobrachium acanthurus en la zona estuarina de un medio lotico. Mem. IX Congreso Nal. de Zoologia, 13–16 Oct., Villahermosa, Tab., Mexico, 1: 214–221.

Farias, S.J.A., y D.O., Salinas, 1988c. Resultados preliminares sobre el empleo de desechos urbanos como sustratos artificiales en el cultivo de Macrobrachium acanthurus (Decapoda–Palaemonida). Tercer Congreso Nacional de Acuicultura. AMAC'88, 5–9 diciembre, 1988, Xalapa.Ver., Mexico

Farias, S.J.A., 1989. Retrospectiva y perspectiva de la investigacion para el aprovechamiento de los recursos acuicolas del tropico de Mexico. Mem. Perspectivas de la investigacion sobre ei aprovechamiento del tropico humedo. Veracruz, Mexico, May, 1989 (in press).

Farmanfarmaian, A. and T., Lauteri.,1979. Amino acid supplementation of feed pellets of the giant shimp (Macrobrachium rosenbergii). Proc. World Maric. Soc., 10: 674–688.

Feder, S.M., 1987. Fatty acid of current interest ... Omega–3. Food Engineering, May: 64–66.

Fernandez R., Celada, J.D. and F., Munoz, 1986. Nutricion y alimentacion de crustaceos. Nutricion en Acuacultura. Plan de Formacion de Tec. Sup., Madrid, Espana.

Field, I.A., 1922. Biology and economic value of the sea mussel, Mytilus edulis. Bull. Bur. Fish Wash., 38: 125–259.

Figueras, A.J., 1989. Mussel Culture in Spain and France. World Aquaculture, 20(4): 8–17.

Folch, J., Lees, M. and G.H., Sloane–Stanley, 1957. J.Biol. Chem. 226: 497–509.

Folke, C. and N., Kautsky., 1989. The role of ecosystems for a sustainable development of Aquaculture. Ambio, 18(4): 234–243.

Forstner, V. and G.T.W., Wittmann, 1981. Metal Pollution in the Aquatic Enviroment. USA, Springer–Verlag, 486 pp.

Fraga, F., 1956. Variacion estacional de la comparacion quimica del mejillon (Mytilus edulis).I.Invest.Pesq., 4: 109–125.

Frey, D.G, 1946. Oyster bars of the Potomac River. Spec. Rept. No. 32. Fish. and wildlife serv., V.S. Dept. Int., 93 pp.

Frey, R.W.,Basan, P.L.B. and J.M., Smith, 1987. Reothaxis and distribution of oysters and mussels. Georgia tidal creeks and salt marshes, USA. Palaeogeog., Palaeclimatol., Palaecol., 61 (1–2): 1–16.

Fujiyama, M., 1965. Physiological Estimation of effects of Pollutants upon Aquatic Organisms. In: Advances in Water Pollution Research. Proceeding of the 2th. International Conference hold in Turkey, 1964., Vol 3 E.A. Penson (Ed.), Longman Press. Oxford.

Fuller, C.S., 1985. Structure and mineralogy of larval and postlarval shells of Mytilus edulis (Linne) and Ischadium recurvum (Rafinesque). J.Shellfish Res., 5(1): 36p.

Fuller, S.C., 1988. Comparative analysis of larval and early post–larval shell morphology in seven mytilid species. J. Shellfish Res., 7(1): 119 pp.

Fuller, S.C. and R.A., Lutz, 1989.Shell morphology of larval and post larval mytilids from the North–Western Atlantic. J. Mar. Biol. Assoc. U.K., 69(1): 181–218.

Funakoshi, S., Suzuki, T. and K., Wada., 1988. Salinity tolerances of marine bivalves. NOAA Technical Rept. NMFS, 69: 15–18.

Gabbott, P.A. and B.L., Bayne, 1973. Biochemical effects of temperature and nutritive stress on Mytilus edulis L. J.mar. biol. Ass.U.K., 53: 269–286.

Gabbott, P.A., 1976. Energy metabolism. In: Marine Mussels. B.L.Bayne (Ed.), Cambridge: Cambridge University Press: 293–355.

Galeana, T.M. and L.V., Varela, 1989. Evaluacion de una granja agropecuaria–piscicola y proposicion de un modelo cualitativo y cuantitativo de granja integral para autoconsumo operable a nivel familiar en las zonas suburbana y rural proximas al puerto de Veracruz. Tesis Licenciatura, Instituto Tecnologico del Mar, SEP, Veracruz, Mexico, 242 pp

Galstoff, P.S., 1964. The American oyster Crassostra virginica (Gmelin). U.S. Fish. Wildl. Ser. Fish. Bull., 64: 1–480.

Garcia, C.A, 1981. Moluscos de un sistema lagunar tropical en el Sur del /golfo de Mexico (Laguna de Terminos, Campeche). Inst. Cienc. del Mar y Limnol. Uni. Nal. Auton. Mex. Pub. Esp. 5

Garcia, P.L. and F., Monje, 1983a. Cultivo experimental de Mejillon Europeo Mytilus edulis en Erendira,B.C., Mexico. Resumenes VII Congreso Nal. de Zool., 4–10 Diciembre, Xalapa, Ver., Mexico.

Garcia, P.L. and F., Monje, 1983b. Experimentos iniciales de cultivo de mejillon Mytilus californianus en al costa de Baja California. Resumenes del VII Congreso Nal. de Zool., 4–10 diciembre, 1983, Xalapa, Veracruz, Mexico.

Garcia, L.P., 1987. Engorda en balsas en Ensenada,B.C. Mem. Encuentro Regional sobre Produccion de Mejillon, Ensenada,B.C., Mexico, 17–19 Noviembre, 1987. FONDEPESCA: 181–200.

Garcia, P.F. and L.P., Garcia, 1987. Cultivo comercial del mejillon en Baja California (Mytilus edulis). Acuavision, 10: 27–29.

Garcia–Cubas, A.y M., Reguero, 1987. Conocimiento actual de los Mytilidos Tropicales en Mexico. Memorias Encuentro Regional sobre Produccion de Mejillon, Ensenada, B.C. Mexico, 17–19–Nov, 1987. FONDEPESCA: 139–165.

Gerba, C.P. y J.S., Mc Leodi, 1976. Effects of sediments on the survival of Escherichia coli in marine waters. Appl. Environm. Microbiol., 32: 114–120.

Gerhardsen, G.M., 1979. Aquaculture and Integrated rural development with special reference to economic factors. Advances in Aquaculture, FAO, Fishing News Books, Ltd., England: 10–22.

Gibbons, M.C. and M., Castagna, 1985. The use of the tod fish Opsanus tau as biological control of crabs preying on juveniles of the hard clam Mercenaria mercenaria (Linne) in field cultures. J. Shellfish Res., 5 (1): 36.

Gilfillan, E.S., 1975. Decrease of net carbon flux in two species of mussel caused by extracts of crude oil. Mar. Biol., 29: 53–57.

Glode, J.B., 1979. Oyster culture–A world review. Advances in Aquaculture, Pillas, T.V.A. y W.N.A. Dill (Eds.), FAO, Fishing News Books Ltd, England: 325–332.

Gomez, R.A., 1990. Contaminacion y depuracion de moluscos bivalvos. Aquavision, 19: 10–12.

Gonzales, A.H. and S.R., Guerrero, 1987. Cultivo comercial de mejillon (Mytilus edulis L.) en la Isla San Martin, Baja California, Mexico, 1987. Mem. Encuentro Regional sobreProduccion de Mejillon, Ensenada, B.C., Mexico, 17–19 noviembre, 1987, FONDEPESCA: 167–179.

Goss–Custard, J.D., Clarke, R.T. and L., Duvell–Seal, 1984. Rates of food intake and agression of oystercatchers Haemotopus estrategus on the most and least preferred mussel Mytilus edulis beds of the Exe Estuary. J. Anim. Ecol., 53 (1): 33–245.

Goyal, S.M., CH.P., Gerba and J.L., Merlnick, 1979. Human enteroviruses in oyster and their overlying waters. Appl. Environ. Microbiol., 37: 572–581.

Gowda, R. and R., Panigraphy, 1989. Diurnal variation of phytoplankton in Rushikulya estuary, east coast of India. Indian J. Mar. Sci., 18(4): 246–250.

Gowen, R.J. and N.B., Bradbury, 1987. The ecological impact of salmonid farming in coastal waters: A review. Oceanogr. Mar. Biol. Ann. Rep., 25: 563–575.

Grajcer, D. and R. Neal, 1972. Growth of hatchery reared Penaeus aztecus on experimental diets. Proc.World Maricult. Soc.: 461–470.

Grant, A and P.A., Tyler, 1983. The analysis of data in studies of invertebrate reproduction.I. Introduction and statistical analysis of gonad indices and maturity indices. International Journal of Invertebrate Reproduction, 6: 259–269.

Grave, C., 1905. Investigation for promotion of the oyster industry of North Carolina. In. Report of the US Fish Commission for 1903.

Grinnell, A.S. Jr., 1971. Structure and development of oyster reefs on the Suwanee River Delta, Florida. PhD Dissertation, State University of New York, Binghamton, 186 pp.

Guary, J.C., Kayama, M., Murakami, Y. and H.J., Ceccaldi, 1976. The effects of fat free diet and compounded diets supplemted with various oils on moults, growth and fatty acid composition of prawn Penaeus japonicus. Aquaculture, 7: 245–254.

Guilcher, A., 1967. Origin of sediments in estuaries. In. G.H. Lauff (Ed.), Estuaries. Am. Assoc. Adv. Sci. Publ., 83: 149–157.

Guillocheau, N., 1988. Spatial distribution of Arcachon Basin phytoplankton. Univ. Aix–Marseille 2; Marseille (France): 156 pp.

Gulland, J. A., 1983. Fish Stock Assesment. A Manual of Basic Methods. U.K., John Wiley & Sons, 223 pp.

Gunter, G. 1950. Seasonal population changes and distributions as related to salinity of certain invertebrate of Texas coast including the commercial shimp. Pub. Inst. Mar. Sci. Univ. Texas, 1(2): 1–51.

Guzman, S. and V., Huser, 1984. Mediation in the estuary. Coast. Zone Manage. J., 11(4): 273–295.

Haines, E. B., 1976. Stable carbon isotope ratios in biota, soils and tidal water of tidal water of a Georgia salt marsh. Estuarine Coastal Mar. Sci., 4: 609–619.

Haines, E.B., 1977. The origin of detritus in Georgia salt marsh estuaries. Oikos, 29: 254– 260.

Halver, J.E., 1979. The nutritional requeriments of cultivated warm water fish species. Advances in Aquaculture, FAO, Fishing News Ltd., England, 574–579 pp.

Haller, D.H., 1990. Integrated aquaculture revolutionary system in Kenya. Aquaculture News, 9:10–11.

Hanebrink, E. and W., Byrd, 1989. Predatory birds in relation to aquaculture farming. Aquacult. Mag., 15 (2): 47–51.

Hansa, C., 1984. Mangrove detritus. Procceding of the workshop on productivity of the mangrove ecosystem: Management implications, Ong J.E and W.K., Gong (Eds.), University Science Malaysia, Penang, 48–59 pp.

Hanson, J.A. and L., Goodwin, 1977. Shrimp and Prawn Farming in the Western Hemisphere. Dowdson, Hutchinson and Ross, England, 439 pp.

Harger, J.R.E., 1980. Comparissons among growth characteristics of two species of sea mussels Mytilus edulis and M. californianus, Veliger, 13: 44–56.

Hartland, B.J. and J.F., Timoney, 1979. In vivo clearence of enteric bacteria from the hemolymph of the hard clam and the american oyster. Appl. Environ. Microbio., 37(3): 517–520.

Hatch, V. and C., Engle, 1987. Economic analysis of aquaculture as a component of integrated agro-aquaculture systems; some evidence from Panama. J. Aqua. Trop., 2: 93–105.

Hatchett, E., Dominguez, A. and H., Calderon, 1990. Mayor apertura en las actividades pesqueras. Aquavision, 18: 3–5.

Heald, E.J., Odum. W.E. and A.C., Taba, 1974. Mangroves in the estuarine food chain. In.Gleason, P.J. (Ed.).Environment of South Florida. Past and Present. Miami Geol. Soc. Mem., 2: 182– 189.

Herriott, N., 1984. A guide to longline mussel cultivation. Aquaculture technical bulletin, 9, Mariculture Systems Ltd., Galaway, 97pp.

Hickman, R.W. and J., Illingworth, 1980. Condition cycle of the green-lipped mussel Perna canaliculus in New Zealand. Mar. Biol., 60: 27–38.

Hiekman, R.W., 1989. Farming the green mussel in New Zealand. World Aquaculture, 20(4): 20–28.

Hoff, T.C. and R.C., Becker, 1968. The accumulation and elimination of crude and clarified poliovirus suspension by shellfish. American Journal of Epidemiology, 90(1): 53–61.

Holland, C.R., Otterburn, M.S. and P., Mc Comiskey, 1983. Froth flotation as a means of protein extraction from mussels. J. Fd. Technol., 18: 195–205.

Holme, N.A. and A.D., McIntyre, 1984. Methods for the Study of Marine Benthos. IBP Handbook No. 16, Oxford Blackwell Scientific, Oxford, 387 pp.

Howard, J.D., 1975. Estuaries of Georgia Coast USA. Sedimentology and Biology. IX.Conclusions. Senckenb. Marit., 7: 297–305.

Howard, J.D., Elders, C.A., and T.F., Heinbokel, 1975. Estuaries of the Georgia coast USA. Sedimentology and biology. V. Animal-sediment relationships in estuarine point bar deposits Ogeechee River-Ossabaw Sound, Georgia. Senckenb. Marit., 1: 181-203.

Howarth, R.W. and J.M., Teal, 1979. Sulfate reduction in New England salt marsh. Limnol. Oceanogr., 24: 999-1013.

Hrs-Brenko, M., 1973. The study of mussel larvae and their settlement in Vela Draga Bay (Pula, the Northern Adriatic Sea). Aquaculture, 2: 173-182.

Hussong, D.J.M., Damare,J. M., Weiner, R.M. and R.R., Colwell. 1981. Bacteria associated with false-positive most probable number coliforms test result for shellfish and estuaries. Applied and Enviromental Microbiology, 41(1): 35-45.

Incze, L.S., Porter, B. and R.A. Lutz, 1978. Experimental culture of Mytilus edulis (L) in a Northern estuarine gradient: Growth, survival and recruitment. Proc. World Maricult. Soc., 9: 523-541.

INEGI, 1986. Instituto Nacional de Estadistica y Geografia e Informatica, Veracruz. Cuaderno de Informacion para la planificacion, Mexico.

Ingham, E.R. and J.A., Zischke, 1977. Prey preferences of carnivorous intertidal snails in the Florida Keys. The Veliger, 20(1): 49-51.

Jones, D.A., Mumford, J.G. and P.A., Gabbott, 1974. Microcapsules as artificial food particles for aquatic filter feeders. Nature, 247: 233-235.

Jones, K.J., 1981. Phytoplankton biomass and the growth of mussels in Caol Scotnish and Saileon Mhur, Loch Sween in 1980.SMBA, internal reports, 39, 28 pp.

Jones, T.O. and G.W., Inawa, 1991. Polyculture of the Pacific oyster Crassostrea virginica (Thunberg) with chinook salmon Onchorynchus tshawytscha. Aquaculture, 92(4): 313-322.

Jorgersen, C.B., 1966. Biology of Suspension Feeding. Pergammon Press Ltd. Ecology, Division No 27.

Kapetsky, J.M., 1981. Some considerations for the management of coastal lagoon and estuarine fisheries. FAO, Fisheries Technical Paper, 218, 47 pp.

Kautsky, N., 1982. Growth and size structure in the Balthic Mytilus edulis population. Mar. Biol., 68: 117-133.

Kehoe, F.P., 1987. The effect of double crested cormorant predation on the salmon Genetics Research Program (SGRP).SGRP Tech. Rep., 66, 29 pp.

Kenneth, K.C., 1986. Biological effects of fish oils in relation to chronic diseases. Lipids, 21(12): 731–732.

Ketchum, B.H., 1951. The exchange of fresh and salt water in tidal estuaries. J. Mar. Res., 10(1) : 18–38.

Kevsten, G., 1980. Mesa Redonda sobre manejo de Lagunas Costeras. Revista Latinoamericana de Acuicultura.

Kitabashi, K., Kurata, H. and K., Shudo, 1971. Studies on formula feed for Kumura prawn. Bull. Tokai Reg. Fish. Res. Lab., 65: 91–107.

Korringa, P., 1976. Farming Marine Organisms Low in the Food Chain. Elsevier Scientific Publishing Company, 264 pp.

Kuenen, D.J., 1942. On the distribution of mussels on the intertidal flats near den Helder. Archives Neerlandaise Zoologie, 6: 117–60.

Kuhl, H., 1972. Hydrography and biology of the Elbe estuary. Oceanography and Marine Biology. Annual Reviews, 10: 225–309.

Kutty, M.N., 1980. Aquaculture in South East– Asia: some points of emphasis. Aquaculture, 20(3): 159–168.

Lara, J.R. and S.B., Alvarez, 1985. Ciclo anual de clorofilas y produccion organica primaria en Bahia San Quintin, B.C. Ciencias Marinas, 2 (1): 77–97.

Landless, P.J., 1974. An economical floating cage for marine culture. Aquaculture, 4: 323–328.

Landless, P.J. and A., Edwards, 1976. Economical ways for assessing hydrography for fish farms. Aquaculture, 8: 29–43.

Larsoon, A., 1985. Blue mussel sea farming–effects on Water Quality. Vatten, 41: 218–224.

Lawson, W.J., 1989. Environmental impact assessment: A selected bibliography. Walter J. Lawson, Brisbane, Griffith University, 198 pp.

Leal, L., 1978. Estudio taxonomico de los moluscos marinos (Gasteropoda–Pelecipoda) representativos de la region de Soto la Marina, Tamaulipas, Mexico. Tesis licenciatura en Biologia. Univ. Auton., Nuevo Leon, 175 pp.

Le Reste, L., 1986. The artisanal shrimp fishery in Casamance. L' estuarie de la Casamance: Environment, Peche, Socio–economie: 245–256.

Lee, P.G., Smith , G.G. and A.L., Lawrence, 1984. Digestive proteasa of Penaeus vanamei Boone. Aquaculture, 42: 225–239.

Lightner, D.F., 1973. A new fungus disease of the white shrimp Penaeus setiferus. Journal of Invertebrate Pathology, 22 No.I.

Limburg, K.E., Levin, S.A. and C.C., Harwell, 1986. Ecology and estuarine impact assesment: Lessons learned from Hudson River (USA) and other estuarine experiences. J. Environ. Mange., 22(3): 225–280.

Linghton, E.F., 1977. Vibrio disease of Shrimps. University of Arizona, Tucson, Arizona, USA.

Linder, M.J. and H.L., Cook, 1974. Synopsis of biological data on the white shrimp. Penaeus setiferus (L). FAO Fisheries Synopsis No 101: 1439–1469.

Lively, C.M., and P.T., Raimoindi, 1987. Dessication, predation and mussel–barnacle interactions in the northern Gulf of California. Oecologia, 74(2): 304–309.

Loesch, H., 1965. Distribution and growth of penaeid shrimp in Mibile Bay. Alabama, Pub. Fish. Wild. Serv. Wash., 251, 25p.

Losanoff, V.L. and H.C., Davies, 1951. Delayed spawning of lamellibranchs by low temperature. Journ. of Marine Research, 10: 197–202.

Losanoff, V.L., 1952. Behaviour of oysters in water of low salinities. Proc. Natl. Shellfish. Assoc.: 135– 151.

Losanoff, V.L. and H.C., Davies, 1963. Rearing of bivalve mollusks. Adv. mar. Biol., 1: 1–136.

Lopez, J., 1985. Estudio de las condiciones biologicas de C. virginica (G.) en el sistema lagunar de Boca del Rio– Mandinga, Mpo. de Alvarado en el Estado de Veracruz. Tesis licenciatura. Instituto Tecnologico del Mar, Ver.SEP, Mexico, 288 pp.

Lopez, E.J., Iglesias, J. and J.J., Otero, 1984. Contribution of infauna and mussel–raft epifauna to demersal fish diets. Mar. ecol. Prog. Ser., 15: 13– 18.

Lubet, P., 1969. Biologie et exploitation des moules.La Peche Maritime: 947–52.

Lubet, P. and D. Le Feron de Longcamp, 1969. Etude des variations annuelles des constituants lipidiques ches Mytilus edulis L de la Baie de Seine (Calvados). Compte Rendus de Seances de la Societe de Biologie, 163: 1110–12.

Lutz, A.R., Incze, L.S., Porter, B. and J.K., Slotz, 1980. Seasonal variation in the condition of raft-cultivated mussels (Mytilus edulis L). Proc. World Maricult. Soc., 11: 262–268.

Lytle, S.J., Lytle, T.F. and J.T., Ogle, 1989. Polyunsaturated Fatty Acids in the diet of Penaeus vanamei. Aquaculture: 2–20.

Mackay, D.W., 1985. Progress in estuarine water quality management: An overview. Estuarine management and quality assesment: 163–172.

Malagrino, W., Pereira, N. and A.A., Rocha, 1987. Effect of low concentrations of anionic detergents on the byssal activity of Brachidontes solisianus. Ambiente 1(1): 37–39.

Malecha, S.R., Buck, D.H., Baur, R.J. and D.R., Onizuka, 1981. Polyculture of the freshwater prawn Macrobrachium rosenbergii, Chinese and common carps in ponds enriched with swine manure.I Initial trials. Aquaculture 25(2–3): 101–116.

Macintosh, J.D., 1982. Fisheries and aquaculture significance of mangrove swamps with special reference to the Indo-West Pacific Region. In: Recent Avances in Aquaculture, Muir J.F and R. Roberts (Eds.), London; Croom Hemlin, 1: 5–85.

Mackowiak, P.A., Caraway , C.J. and B.J., Partney, 1976. Oyster associated hepatitis: Lessons from the Louisiana experience. Am.J. Epidemiol., 103: 181–191.

Mann, R. and Taylor, 1983. Public Health aspects of the culture of Japanese oyster Crassostrea gigas (Thunberg) in a waste recycling system. Aquaculture, 30: 311–327.

Margus, D. and E., Teskeredzic, 1986. Settlement of mussels (Mytilus galloprovincilis Lmck) on rope collectors in the estuary of the River Krka, Yugoslavia. Aquaculture, 55: 285-296.

Marmer, H.A., 1984. Tides and sea level in the Gulf of Mexico. In: Gulf of Mexico, Its origin, waters and marine life. U.S. Fish and Wild Serv. Fish. Bull., 89: 101–118.

Martinez, P.C.A., 1988. El potencial de las especies nativas en la Aquacultura. Mem. IX Cong. Nal. Zool., I: 13–20.

Metcalf, T.G. and W.C. Stiles, 1965. The accumulation of the enteric virus by the oyster Crassostrea virginica. Journal Infect. Dis., 115: 68–76.

Mason, J., 1969. Mussel raft trials succeed in Scotland. World Fishing, 18 (4): 22–24.

Mason, 1971. Mussel cultivation. Underwater Journal, April, 3(2): 52–59.

Mason, J., 1976. Cultivation In. Marine Mussels, B.L., Bayne (Ed.), Cambridge: Cambridge University Press, Cambridge: 13–65.

Mason, J. and J., Drinkwater, 1981. Experiment on suspended cultivation of mussels in Scotland. Scottish Fisheries Inf. Pamphlet, 4, 15 pp.

Mass Geesteranus, R.A., 1942. On the formation of banks by Mytilus edulis. Archives Neerlendaises Zoologie, 6: 283–325.

Mendoza, G.P., 1987. Estudios microbiologicos del ostion Crassostrea virginica de la Laguna Mandinga Grande. Facultad de Ciencias Quimicas. Orizaba, Ver. (Tesis de Lic.), 17 pp.

Meyers, S.P., 1973. Capsulation techniques, development of diets for larval and postlarval aquatic animals reported. Feedstuffs, 45, 35 p.

Middelton, M.J., Rimmer, M.A. and R.J., Williams, 1985. Structural flood mitigation works and estuarine mangement in New South Wales. Case study of the MacLeay River. Coast. Zone Manage. J., 13(1): 1–23.

Mileikovsky, S.A., 1971. Types of larval development in marine bottom invertebrates. Marine Biology, 16: 13–21.

Mileikovsky, S.A., 1973. Speed of active movement of pelagic larvae of marine bottom invertebrates and their ability to regulate their vertical position. Marine Biology, 23: 11–17.

Millward, R.N., 1988. The effects of copra meal on growth of postlarval Macrobrachium rosenbergii. MSc. Thesis, Institute of Aquaculture, University of Stirling, 83 pp.

Moerbeek, D.J., Van Dobben, W.H., Osieck,E.R., Boere, G.G. and C.M., Bungenberg de Jong, 1987. Cormorant damage prevention at a fish farm in the Netherlands. Biol. Conserv., 39(1): 23–38.

Moon, T.W. and A.W., Pritchard, 1970. Metabolic adaptations in vertically separated populations of Mytilus californianus Conrad. Journal of Experimental Marine Biology and Ecology, 5: 35–46.

Moore, P.H. and S.B., Chapman, 1986. Methods in Plant Ecology. London, Blackwell Scientific Publications (2nd ed.), 466–68 pp.

Monroy, D. and G., Viniegra, G., 1981. Biotecnologia para el aprovechamiento de los despercios organicos. AGT Editor, S.A., Mexico, 260 pp.

Montague, C.L., Zale, A.V. and H.F., Percival, 1987. Ecological effects of the coastal marsh impoundments. A review. Environ. Manage., 11(6): 743–756.

Morales, G.J.R., 1986. Evaluacion de la eficiencia de la utilizacion de tres dietas en el crecimiento de Procambarus clarkii en condiciones de laboratorio. Tesis Licenciatura.Instituto Tecnologico del Mar, Ver.SEP.Mexico.

Morales, H.L., 1978. La Revolucion Azul? Acuacultura y Ecodesarrollo, Mexico, (Ed.) Nueva Imagen, 159 pp.

Morton, B., 1988. The population dynamics and reproductive cycle of Brachidontes variabilis (Bivalvia: Mytilidae) in a Hong Kong mangrove. Malacol. Rev., 21 (1–2): 109–117.

Morris, B.W. and H.B., Rollins, 1977. Observations on intertidal organisms associations of St. Catherines Island Georgia, USA. Part I. General description and paleoecological implications. Bull. Am. Mus. Nat. Hist., 159 (3): 87–128.

Muise, B., 1990. Mussel Culture in Eastern Canada. World Aquaculture, 21 (2).

Muniz-Dijck, M.P., 1980. Mollusks of the north Paraiba River Estuary.1. Ilaha da Restinga. Rev. Nordestina Biol., 3 (spec. No.): 47–53.

Nagabhushanam, R. and R., Sarojini, 1965. The influence of salinity and temperature upon the heart rate in the bivalve molluscs, Brachidontes recurvus. Sci. Cult., 31: 318– 319.

Natale, A., 1982. Extra-Mediterranean species of mollusca along the southern Italian coasts. Malacologia, 22(1–2): 571–580.

National Shellfish Sanitation Program, 1965. Manual of operations. Part I. Sanitation of shellfish growing areas. Public. Health Service. Publication No 33 FDA. Washington, D.C., 32pp.

Navarrete, R.O.I., 1989. Evolucion gonadica y fijacion del ostion Crassostra virginica (Gmelin) en el sistema lagunar de Boca del Rio Mandinga, Ver. Tesis licenciatura, Instituto Tecnologico del Mar, Veracruz, Mexico, SEP, 92 pp.

Nelson, C.T., 1928. On the distribution of critical temperatures for spawning and for ciliary activity in bivalve molluscs. Science, 67(1730): 220–221.

Nelson, S.G., Li, H.W. and A.W., Knight, 1977. Calorie, carbon and nitrogen metabolism of juvenile Macrobrachium rosenbergii (De Mann) (Crustacea, Palaemonidae) with regard to trophic position. Comp. Biochem. Physiol., 38a: 319–327.

New, B.M., 1976. A review of dietary studies with shrimp and prawns. Aquaculture, 9: 101–144.

New York Sea Grant Instite, 1975. Proceedings of a workshop on the shellfish management program in New York State, 59 pp.

Nobriega, C.P., 1986. Suggestions for coastal mangement of estuaries. Arq. Cienc. Mar., 225: 77–86.

Olaniya, C.I.O., 1981. Some problems of lagoon researh in Nigeria. The coastal ecosystems of west Africa: Coastal lagoons, estuaries and mangroves. A workshop Report, Dakar, 11–15 June, 1979. UNESCO REP. MAR.SCI./RAPP. UNESCO SCI. MER., No. 17.

Olguin, P.C., 1986. Desarrollo de Tecnicas Agroacuicolas para la explotacion integral de las zonas bajas tropicales.Resumenes Primer Simp. Nal. de Acuacultura, Diciembre, 1986. Pachuca Hgo., Mexico, 59 pp.

Oertel, G.F., 1974. Hydrography and suspended matter distribution patterns at Doboy Sound estuary, Sapel, Island, Georgia. Mar.Sci. Cent. Tech. Rep. Series, 74–4: 61 pp.

Oertel, G.F., 1976. Characteristics of suspended sediments in estuaries and nearshore waters of Georgia. Southeast, Geol., 18: 107–118.

Ony, J.E., Gong, W.K. and C.H., Wong, 1979. Productivity of a managed mangrove forest in West Malaysia. Contribution to the conference on trends in applied biology in Southeast Asia. Penang Malaysia. Oct. 1979.

Orozoco, B.M.J. and J.A., Zegovia, 1986. Calidad bacteriologica del mejillon Mytilus califorinianus en la zona costera noroccidental de Baja California, Mexico, Ciencias Marinas 12(1): 7–17.

Orton, 1920. Sea temperatures, breeding and distribution in Marine animals. J.Mar. Biol. Assoc., 12: 339–66.

Padma, N.L., 1990. Conservation or conversion of mangroves in Fiji. An ecological Economic Analyses. Environmental and Policy Institute, East–West Center. Occasional Paper No. 11, 108 pp.

Palacios, F.M.R., 1987. Manual Tecnico para la operacion de centros acuicolas productores de ostion. Comite coordinador para la operacion acuicola, Secretaria de Pesca (SEPESCA).

Pamatmat, M.M., 1984. Metabolic heat flow patterns in the intertidal mussel Ischadium (Modiolus = Geukensia) demissum demissum during aerial and underwater respiration.Int. Rev. Gestamt. Hydrobiol., 69(2): 263–275.

Pares, S.G., 1987. Biologia del mejillon azul. Acuavision, 10: 25–26.

Panana, A., 1987. Estudio del plankton de Isla Verde y su posible aplicacion a trabajos en acuicultura marina.Tesis licenciatura, Instituto Tecnologico del Mar, Ver. SEP, Mexico, 158 pp.

Paul, M.D., 1942. Studies on the growth and breeding of certain sedentary organisms in Madras Harbour. Proceedings of the Indian Academy of Sciences, Sect.B,15: 1–42.

Pedini, M., 1981. The Mexican tapos shrimp fishery.ICLARM Newsletter, 4(4); 17–19.

Peranginangin, R., Putro, S., Nasran, S. and J., Tri Murtini, 1984. Studies on depuration of green mussel (Mytilus viridis L.). Badan Penelitian dan Pengembargan Pertanian Dep. Pertanian Research Report for Fishery Technology, 37:17–26.

Petersen, J.A., Sutherland, J.P. and S. Ortega, 1986. Patch dynamics of mussel beds near Sao Sebastiao (Sao Paolo) Brazil. Mar.Biol., 93 (3): 389– 393.

Phillips, D.S.H., 1978. The common mussel Mytilus edulis as an indicator of trace metal on Scandinavian waters.II. Lead, iron and manganese, Mar. Biol., 46: 147–156.

Phillips, J.H.D., 1980. Quantitative Aquatic Biological Indicators. London, Applied Science Publishers Ltd., 448 pp.

Phleger, F.B., 1969. Some general features of coastal lagoons, Mem. Simp. Intern.Lagunas Costeras. UNAM– UNESCO, Nov.,28–30, 1967. Mexico, D.F., 5–26 pp.

Pillay, T.V.R., 1979. The state of aquaculture 1976. Advances in Aquaculture, FAO. Fishing News Books, Ltd., England, 1–9 pp.

Presnell, M.W. and J.J., Miescier, 1971. Coliforms and faecal coliforms in an oyster growing area. J.Water Pollut. Control. Fed., 43 (3): 407–416.

Pritchard, D.W., 1967. Observations of circulation in coastal plain estuaries. In. G.H. Lauff, (Ed.).,Estuaries. Am. Ass. Adv. Sci. Publ., 83: 37–44.

Pritchard, D.W., 1971. Estuarine hydrography. In. J.R. Shubel, ed. The estuarine enviroment, estuaries and estuarine sedimentation. Am. Geo l. Inst. Short course lecture notes, Washington, D.C.

Pullin, R., 1982. Experimental integrated farming systems in Mexico. ICLARM Newsletter, 5(3), 11 p.

Qasim, S.Z, Parulekar, A.H., Harkantra, S.N., Ansari,Z .A., and A., Nair, 1977. Aquaculture of green mussel Mytilusviridis L. Cultivation on ropes from floating rafts, Indian. J. Mar. Sci., 6: 18–25.

Queen, W.H., Copeland, B.J. and F., Perkins, 1988. Estuarine Science: Involvement in public policy. Estuaries, 11(4): 286–287.

Rangarajan, K., 1977. Prospects of mussel culture in the estuarine environment. Indian. J. Fish., 24(1–2): 237–241.

Ravishankar, A.N. and P., Keshavanath, 1986. Growth response of Macrobrachium rosenbergii (de Man) fed on four pelleted feeds. Indian J. of Animal Sciences, 56(1): 110–115.

Regnault, M., Campillo, A. and P., Luquet, 1975. Croissange des crevettes Crangon crangon et Palaemon serratus soumises a un regime artificiel: influence du mode de presentacion et du mode de sechjage de l' aliment. Cah. Bio. Mar., 16: 1–20.

Reilly, R.J.A. and L.E., Barile, 1987. Depuration of farmed bivalves in the Philippines. INFOFISH Marketing Digest 4/87: 44–46.

Reinoso, N. and B., Yoong, 1983. Cultivo de camaron marino (Penaeus) en el Ecuador.Inst. Nal. Pesca Ecuador.

Remane, A. and C., Schlieper, 1971. Biology of Brackish water. Wiley Interscience, New York, 372 pp.

Resendes, M.A., 1979. Estudios ictiofaunisticos en las lagunas costeras del Golfo de Mexico y Mar Caribe, entre 1966 y 1978. An.Inst. Biol. Univ. Nal. Auton. Mexico, Ser. Zoologia, 1: 633–646.

Reynolds, N., 1969. The settlement and survival of young mussels in the Conway Fishery. Fish. Invest. Min. Agric.Fish. Food, London Ser. II, 26: 1–24.

Ridell, R., 1981. Ecodevelopment; Economics, Ecology and Development: An Alternative to Growth Imperative Models. Faraborough Gower, 218 pp.

Riguelet, R.A., 1962. Ecologia Acuatica Continental. Ed. Universitaria, Buenos Aires, 137 pp.

Relini, G. and E., Pisano, 1977. Preliminary observations on the fouling organisms of Orbetello Lagoon. Proceedings of the 9th Congress of the Italian Society of Marine Biology, Lacco Ameno D'Ischia,19–22, May, 1977: 351–362.

Roberts, D., 1972. The assimilation and chronic effects of sub–lethal concentrations of endosulfan on condition andspawning in the common mussel, Mytilus edulis. Marine Biology, 16: 119–25.

Roddie, B.D., Leackey, R.J.G. and A.J., Berry, 1984. Salinity–temperature tolerance and osmoregulation in Eurytemora affinis (Poppe) (Copepoda: Calanoida) in relation to its distribution in the zooplankton of the upper reaches of the Forth estuary. J. Exp. Mar. Biol. Ecol., 77(2): 191–211.

Ryer, C.H., 1987. Temporal patterns of feeding by blue crabs (Callinectes sapidus) in a tidal–marsh creek and adjacent seagrass meadow in the lower Chesapeake Bay. Estuaries 10(2): 136–140.

Saclauso, C.A., 1989. Brackishwater Aquaculture a threat to the environment. Naga, the ICLARM Quarterly,ISSN 0116–240X, 6–8 pp.

Sadykhova, I.A., 1967. Some data on the biology and growth of Mytilus grayanus Dunker in experimental cages in Peter the Great Bay. Proc. Symp. Moll., 2: 431–435.

Safril, U.N. and Z., Sasson–Frostig, 1988. Can colonizing mussel outcompete indigenous mussel? J. exp. mar. Biol. Ecol., 117(3): 211–226.

Salas, A., Garcia,L., Searcy, R, Garcia,F., Cancino, J.L. and S., Lizarraga, 1983. Cultivo experimental del mejillon Mytilus californianus y M. edulis en las costas de Baja California. Informe Anual,TomoI, Cap.I, UABC, IIO, SEP: 1–67.

Salas, G.A. and L.P., Garcia, 1987. Estudios basicos y experiencias en el cultivo del mejillon por el IIO en Baja California. Mem. Encuentro Regional sobre Produccion de Mejillon, Ensenada , B.C., Mexico, 17–19 Nov., 1987, FONDEPESCA: 69–113.

Sandifer, P.A. and J.D., Joseph, 1976. Growth responses and fatty acid composition of juvenile prawn (Macrobrachium rosenbergii) fed a prepared ration augmented with shrimp head oil. Aquaculture, 8: 129–138.

Sanchez–Chavez, J., 1977. Contribucion al conocimiento de la ictiofauna de las lagunas de Mandinga y sus pesquerias. Inf. Integr. Conoc. (Tesis Prof.)Escuela Nacional de Ciencias Biologicas IPN., Mexico, D.F.

Searcy, B.R. and A., Croda de la Rosa, 1983. Avances sobre una nueva tecnica para determinar edad en el mejillon Mytilus californianus . Resumenes de VII Congrso Nal. de Zool., 4–10 dic, 1983, Xalapa, Veracruz, Mexico.

Secretan, P.A.D., and C.E., Nash, 1989. Aquaculture and risk management. FAO, ADCP/REP/89/41.

Seed, R., 1968. Factors influencing shell shape in Mytilus edulis L. J. of Mar.Biol. Assoc of the U.K., 48: 561–84.

Seed, R., 1969a. The ecology of Mytilus edulis (Lamellibranchiata) on exposed rocky shores. I. Breeding and settlement. Oecologia, 3: 277–316.

Seed, 1969b. The ecology fo Mytilus edulis L (Lamellibranchiata) on exposed rocky shores. 2 Growth and mortality. Oecologia, 3: 317–50.

Seed, R., 1975. Reproduction in Mytilus (Mollusca: Bivalvia) in European Waters. Pubb. Stazz. Zool. Nap., 39 Sup.:317–334.

Seed, R., 1976. Ecology. In. Marine Mussels, B.L. Bayne (Ed.) Cambridge: Cambridge University Press, Cambridge, 13–65.

Seed, R., 1977. The systematics and evolution of Mytilus galloprovincialis Lmk. In. Marine Organisms, Genetics Ecology and Evolution. Battaglia and Beadmore (Eds.), 447–68.

Seed, R. 1980. A note on the relationship between shell shape and life habitats in Geukensia demissa and Brachidontes exustus (Mollusca: Bivalvia). J.Moll.Stud., 46: 293–299.

Selakumar, R.A., Goswami, S.C. and U., Goswami, 1986–87. Tidal and influence on zooplankton ocurrence in the Mandovi estuary, Goa. J. Indian Fish. Assoc., 16–17: 39–49.

Shamberger, M.L. and H.E., Kumpf, 1980. Wetland and wildlife values. A practical field approach to quantifying habitat values. Estuarine perspectives. Proccedings of the fifth biennial International Estuarine Research Conference. Jekyll Island, Georgia, October 7–12, 1979: 37–46.

ShelShelske, C.L. and E.P., Odum, 1962. Mechanisms maintaining high productivity in Georgia estuaries. Proc. Gulf Caribb. Fish. Inst. 14th Annual Session: 15–80.

Shewbart, K.L. and W.L., Mies, 1972. Identification and quantitative analysis of the amino acids present in the brown shrimp Penaeus aztecus. Mar. Biol., 16: 64–67.

Shewbart, K.L. and W.L., Mies, 1973. Studies on nutritional requirements of brown shrimp shrimp the effects of linolenic acid on growth of Peaneus aztecus. Proc. World Maricult. Soc., 4: 277–287.

Shewbart, K.L , Mies, W.L. and P.D., Ludwig, 1973. Nutritional requirements of the brown Penaeus aztecus US Dep. Commer. Rep. No. COM–73–11794. NOAA, Office of Sea Grant, Rockville, Md, 52pp.

Shubel, J.R., 1971. Sources of sediments of estuaries.In. J.R. Shubel. ed. The estuarine environment, estuaries and estuarine sedimentation. Am.Geol. Inst. Short course lecture notes, Washington, D.C.

Shubel, J.R., 1968. Turbidity maximum of the Northern Chesapeake Bay.Science, 161: 1013–1015.

Shumway, E.S., 1989. Toxic algae.A serious threat to shellfish aquaculture. World Aquaculture, 20(4): 65–74.

Singh, S.M.and R.H., Green, 1984. Excess of allozyme homozygosity in marine molluscs and its possible biological significance. Malacologia, 25(2): 569–581.

Siemens, A.H., Hebda, R.J., Navarrete, M., Piperino, D.R., Stein, J.K. and M.B., Zola, 1988. Evidence for cultivar and a chronology from patterned wetlands in Central Veracruz, Mexico. Science, 224: 105–107.

Sivalingam, P.M., 1977. Aquaculture of the green mussel Mytilus viridis Linnaeus, in Malaysia. Aquaculture, 11: 297–312.

Souness, R., Bowrey, R.G. and G.H., Fleet, 1979. Commercial depuration of the Sydney rock oyster, Crassostrea commercialis. Food Technology in Australia: 531–537.

Stahl, M.S. and G.A., Ahearn, 1978. Amino acid studies with juveniles Macrobrachium rosembergii. Proc. World Maricult. Soc., 9: 209–216.

Stefano, G.B., Catapane, E.J. and I.M., Stefano, 1977. Temperature dependent ciliary rhythmicity in Mytilus edulis and the effects of monaminegic agents on its manifestation. Biol. Bull., 153: 618–629.

Stearns, D.E., Litaker, W. and G., Rosenberg, 1987. Impacts of zooplankton grazing and excretion on short-interval fluctuations in the chlorophyll a and nitrogen concentrations in a well mixed estuary. Estuar.Coast.Shelf.Sci., 24(3): 305–325.

Stirling, H.P., 1985. Chemical and biological methods of water analysis for aquaculturists. G.Britain, Institute of Aquaculture, Univ. of Stirling, 119 pp.

Stirling, H.P., 1990. A double bill of trout and mussel. Aquaculture News, 9: 14–15.

Stirling, H. P. and T. Day, 1990. Impact of intense cage fish farming on the phytoplakton and periphyton of a Scottish freshwater loch. Hydrobiologia, 190: 195–214.

Staub, E., 1987. Cormorants and Fisheries. Schriftenr. Fish. Bundesamt Umweltshutz (Switz.), 47: 56 pp.

Sutherland, J.P., 1987. The importance of recruitment variation in a tropical intertidal community. 1987 AAAS Annual Meeting: 153rd National Meeting, Chicago, 14–18 febraury. Abstract papers: p 27.
Sze, C.P., 1973. The biochemical composition of Macrobrahium rosenbergii. Malays. Agric. J., 49: 8–10.

Tamayo, J.L., 1962. Geografia General de Mexico. 2 ed. Inst. Invest. Econ. Mexico. 5 vol.

Teas, H.J., 1980. Saline Silviculture. 2nd International Workshop on Biosaline Research: 29.

Thom, B.G., 1967. Mangrove ecology and deltaic geomorphology, Tabasco, Mexico. J. Ecol., 55: 301–343.

Thiesen, B.F., 1972. Shell cleaning and deposit feeding in Mytilus edulis L. Ophelia, 10: 49–55.

Thiesen, B.F., 1973. The growth of Mytilus edulis L. (Bivalvia) from Disko and Thule district, Greenland. Ophelia,12: 59–77.

Thompson, W.K. and C.L., Thaker, 1972. Incidence of Vibrio parahaemolyticus in shellfish from eigth Canadian Atlantic Sampling areas. J.Fish. Res. Board Canada, 2: 633–35.

Thorson, G., 1946. Reproduction and larval development of Danish marine bottom invertebrates with special reference to the planktonic larvae in the Sound (Oresund). Medd. Komm. Dan.Fisk. Hauundersog, Kbh. Series, Plankton, 4: 1–523.

Thorson, G., 1950. Reproductive and larval ecology of marine bottom invertebrates. Biological Reviews, 25: 1–45.

Tocher, D.R. and D.G., Harvie, 1988. Fish Physiol. Biochem, 5: 229–239.

Tovar, H., Guillen, V. and M.E., Nakama, 1987. Monthly population size of three guano bird species off Peru, 1953 to 1982. In: The Peruvian Anchoveta and its upwelling ecosystem: Three decades of change. ICLARM Stud. Rev., 15: 208–218.

Unsal, M., 1986. Uptake accumulation and toxicity of vanadium and tin in marine organisms. FAO/UNEP Meeting on the toxicity and bioaccumulation of selected substances in marine organisms. Rovina, Yugoslavia, 5–9 Nov.,1984, FAO Fish. Rep. No. 334: 155–161.

Valiela, D.W., 1978. Biological Environmental Impact Studies. New York, Academic Press, 157 pp.

Vanderzant, C., Nickelson, R. and P.W., Judkings, 1971. Microflora of pond reared brown shrimp (P. aztecus). Appl. Microbiol., 21: 9–16.

Varela, G., 1981. Mussel possibilties in human nutrition. Food from the sea Noell, H. (Ed.), 60–76 pp.

Vazquez–Yanez, C., 1971. La vegetacion de la Laguna de Mandinga, Veracruz. An. Inst. Biol. Univ. Nal. Auton. Mexico, Ser. Botanica, 42(1): 49–94.

Vazquez. F., Millero, J.F., Alexander, H. and H., Fernandez, 1982. Estudio de la composicion quimica del Rio Jamapa y las lagunas de Mandinga. III Congreso Nacional de Ingenieria Sanitaria y Ambiental, 22–24, Sept.,1982. Acapulco Gro.Mexico.

Vahl, O.L.A., 1972. Efficiency of particle retention in Mytilus edulis L., Ophelia,10:49–55.

Vargas, I.M., Yanez-Arancibia, A. and F., Amezcua-Linares, 1981. Ecologia y estructura de las comunidades de peces en areas de Rhizophora mangle y Thalassia testidium de la Isla del Carmen,Laguna de Terminos, Sur del Golfo de Mexico. An.Inst. Cienc. del Mar. y Limnol. Univ.Nal. Auton. Mexico, 8(1): 241-266.

Vaughn, C.C and F.M., Fisher, 1988. Vertical migration as a refuge from predation in intertidal marsh snails: A field test. J. exp. mar.Biol. Ecol., 123(2): 163-176.

Venkataramiath, A., Lankshmi, G.J. and G., Gunter, 1975. Effect of protein level and vegetable matter on growth and food conversion efficiency of brown shrimp. Aquaculture, 6: 115- 125.

Villanueva, C.G., 1990. Aprovechamiento del mejillon estuarino Brachidontes recurvus como posiblefuente de alimento para langostino Macrobrachium acanthurus. Tesis de Licenciatura, Instituto Tecnologico del Mar, Veracruz, SEP, Mexico, 61 pp.

Wallace, J.C., 1980. Growth rates of different population of the edible mussel, Mytilus edulis in north Norway. Aquaculture, 19: 303-311.

Watanabe, W.O, 1975. Identification of essential amino acids of the freshwater prawn M. rosenbergii. PhD thesis. Univ. of Hawaii, Honolulu, Hawaii.

Waterman, J.J. Processing mussel cockles and whelks. Torry Research Station. Torry Advisory Note No. 13, 11pp.

Whedon, W.F., 1936. Spawning habits of mussel Mytilus californianus with notes on the possible relation to mussel poison. University Publications in Zoology, 41: 35-44.

Wickins, J.F., 1972. Experiments on the culture of the spot prawn Pandalus platyceros Brandt and the giant freshwater prawn Mracrobrachium rosembergii (de Man).Ministry of Agriculture, Fisheries and Food Fishery Investigation, Series II, 27(5): 1-23.

Wickins, J.F., 1986. Prawn farming today: Opportunities techniques and developments. Outlook on Agriculture 15(2): 52-61.

Wiedemann, H.V., 1971. Shell deposits and shell preservation in quaternary and tertiary estuarine sediments of Georgia, USA. Sediment. Geol., 7(2): 103-125.

Wilbur, K.M. and G., Owen, 1964. Growth. In. Physiology of Mollusca. K.M., Wilbur and C.M., Yonge (Eds.), Academic Press, New York, 1, 211-242 pp.

Wilson, J.H. and R., Seed, 1975. Reproduction in Mytilus edulis L. (Mollusca, Bivalvia) in Carlingford Lough, Northern Ireland. Irish Fisheries Investigations, Dublin, Ser.B. Marine.

Wilson, J. and D., Fleming, 1989. Economics of the Maine Mussel Industry. World Aquaculture, 20(4): 49–55.

Winter, J.E., 1975. Feeding experiments with Mytilus edulis L at a small laboratory scale II. The influence of suspended silt in addition to algal suspensions on growth. Proc. 10th Europ. Symp. Mar. Biol.I.Mariculture: 383–600.

Wisely, B., 1964. Aspects of reproduction, settling and growth in the mussel Mytilus edulis planulatus. Journal of the Malacological Soc.of Australia, 8: 25–30.

Wolff, W.J., 1981. Management of estuaries in Netherlands with respect to bird populations. Estuaries 4(3): 265.

Woodin, S.A., 1976. Adult–larval interactions in dense infaunal assemblages: Pattern of abundance. J. mar. Res., 34: 25–41.

Yanez–Arancibia, A., 1975. Sobre los estudios de peces en las lagunas costeras. Nota cientifica. An.Centro Cienc. del Mar y Limnol. Univ. Nal. Auton., Mexico, 2(1): 53–60.

Yanez–Arancibia, A. and R.I. Nugent, 1977. El papel ecologico de los peces en estuarios y lagunas costeras. An.Centro Cienc. del Mar y Limnol. Univ. Nal. Auton. Mexico, 4(1): 107–114.

Yanez–Arancibia, A. and J.W., Day Jr., 1982. Ecological characterization of Terminos Lagoon, a tropical lagoon–estuarine system in the Southern Gulf of Mexico. Oceanologica Acta No. Sp., Proceedings Internationa Symposium on coastal lagoons, SCOR/IABO/UNESCO, Bordeaux, France, 8–14, September, 1981: 431– 440.

Ysanes–Arancibia, A., 1987. Lagunas costeras y estuarios: Cronologia, criteriso y conceptos para una clasificacion ecologica de sistemas costeros. Rev. de la Soc. Mexicana de Hist. Nat., 39: 35–54.

Zamora, S.L., 1990. Estudios Prelimimares de crecimiento del langostino Macrobrachium rosembergii con alimentacion a base de mejillon estuarino Brachidontes recurvus en tinas de plastico con recirculacion. Tesis de licenciatura. Instituto Tecnologico del Mar, Ver.SEP, Mexico, 64 pp.

Zar, H.J., 1984. Biostatistical Analysis. Prentice–Hall International Ed., USA, 718 pp.

Zenkovich, V.P., 1967. Process of Coastal Development.Oliver & Boyd, London, 738 pp.

Zepeda, R., 1987. Depuracion de moluscos Bivalvos. Mem. Encuentro Regional sobre produccion de mejillon. Ensenada, B.C., Mexico, 17–19 Nov., 1987, FONDEPESCA: 399–421.

Zuim, S.M.F. and E.G., Mendez, 1979. Comparison of the capacity for regulation of respiration rate in Perna perna and Brachidontes solisianus. Cienc. Cult.(Sao Paolo), 31(10): 1177.

Zuim, S.M.F., and E.G., Mendez, 1981. The influence of salinity on the respiratory rate of two mussels, Perna perna and Brachidontes solisianus (Mollusca, Bivalvia). Rev. Brasil, Biol., 41(1): 57–61.

APPENDIX 1

Translation of Questionnaire (original in Spanish)

The objective was to establish the localization and dimension of the mussel market; the physical characteristics it presents and acceptance by actual or potential consumers.

Name

Adress

Date

Age ( ) Sex

Ocupation

Average Monthly Income

Number of people living in the house

Age of members living in the house

Type of store where food is normally purchased

Do you like marine canned food? Why?

What kind of marine products do you normally purchase.

Select the most important factor that determined you to buy marine products:

Price, flavour, brand, packing method, recommended by friends, recommended by salesman, sales, nutritional properties and presentation.

When was the last time you bought mussels in any of its presentations ?

What is the most common brand of canned mussel that you find in the local markets ?

What kind of presentation have you found most commnon in the local markets ?

If you knew more about the mussel, would you like to consume it?

Why?

What is the common payment method you use ?

Appendix 1 (contd.)

Interview

The objective is essentially the same as for the questionnaire.

Name

Sex

Enterprise name

Post in the enterpirse

Profession

– Do you consider that if mussels are commercialized in this locality, it would imporve the nutritional level in the population?

– What do you think about the actual average diet in the locality ?

– Do you think that the average potential consumer would increase the adquisition of mussel products? Why ?

– Considering the nutritional value and the gastronomic characteristics, should the mussel be more consumed ? Why?

– What reasons do you think, determine the low or high demand of the product ?

– If you were a mussel producer or supplier, what kind of actions would you take to increase the demand?

– Do you think that mussels are only attractive to a certain kind of people? Why?

– Considering your post, and supposing you were a potential agent to generate a change in the alimentary conditions of the locality, what would you do to improve them in relationship with the mussel consumption ?