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Aquaculture and Environmental Protection in the Prioritary Mangrove Ecosystem of Baja California Peninsula

Magdalena Lagunas-Vazques,
Giovanni Malagrino and Alfredo Ortega-Rubio
Centro de Investigaciones Biológicas del Noroeste,
La Paz, Baja California Sur.
Mexico

1. Introduction

There are more than 123 coastal lagoons in the Mexican coastal zone covering an approximate area of 12,555 km². The length of these lagoons represents between 30 % and 35 % of the 11,543 km of the Mexican coast. Magdalena Bay, Mexico, is the largest bay in the Baja California peninsule (Fig. 1). The Bay is a lagoon system with three main areas, the northernmost called Laguna Santo Domingo, the central part Magdalena Bay, and the southernmost Almejas Bay. The lagoon system has a total length of 250 km, covering an area of 2,200 km² that includes 1,453 km² of the lagoon basin and 747 km² of mangrove forest, sand dunes, and wetlands (Malagrino, 2007).

Currently Magdalena Bay is very important for the economy of the state of Baja California Sur, 50 % of the artisan fisheries activities are established in this zone. To avoid conflicts between environmental conditions and commercial productive activities we studied and summarized the main biological, physical, chemical and socioeconomic aspects of Magdalena Bay, in order to determine where, and how, new clam culture projects must be established.

Aquaculture world production has maintained a sustained growth in several countries for the last 15 years, generating both positive and negative impacts, on social (Bayle, 1988; Primavera, 1991; Lebel *et al*., 2002), economic (Kautsky *et al*., 1997), and natural systems (Páez-Osuna, 2001; Macintosh, 1996). Mexico, being no exception, has developed these activities at similar rates going from 0 tons in 1984, to more than 62,000 tons in 2003 (SAGARPA-CONAPESCA, 2003).

Moreover, it is expected that aquaculture activities will increase explosively in the coming years. If aquaculture activities flourish, as it is foreseen in this region, there will be direct conflicts with artisan fishing activities, ecotourism and tourist activities foreseen to be carried out in the region, and with the conservation of the environment, including sand dunes and mangrove fragile ecosystems.

Magdalena Bay lagoon system is located on the occidental side of the state of Baja California Sur. This lagoon system is the most extensive and important of the whole peninsula and

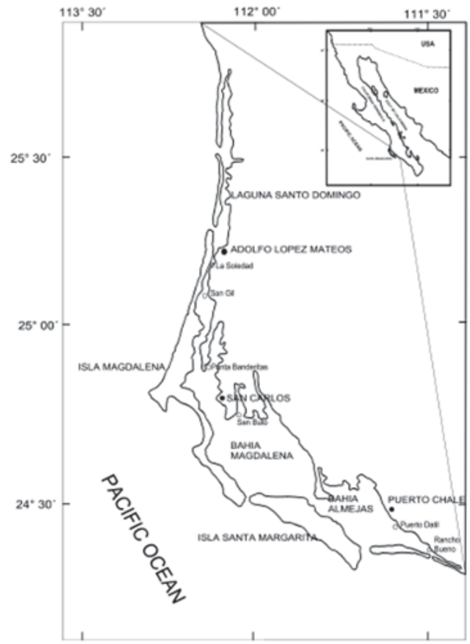

Fig. 1. Magdalena Bay location, Baja California Sur., México.

within Mexico. It is located between 24° 17´ and 25° 40´ N and 111° 30´ and 112° 15´ W. The system is made of wide areas of wetlands especially in Laguna Santo Domingo and in Almejas Bay.

Because of the physiography of the system it is regarded as a natural shelter for marine flora and fauna, and for small fishing boats. This zone is influenced by the California Current and by water that comes from the Equator, being a transition zone characterized by high productivity (Parrish et al., 1981); the climate is warm and dry, classified as a semiarid climate by Coppell system. The annual average temperature is of 20 °C, with a maximum of 41 °C in July-August, and a minimum of 4 °C in January-February. The mean total annual average temperature is of 125 mm (Rueda-Fernández, 1983). In the warm season water temperature column varies between 23 and 28 °C, while in the cold season it varies between 16 and 23.6 °C. Maximum salinity, ranging from 37.3 to 39.2 ups, is found in channels in the lagoon system, while minimum salinity, from 34.0 to 34.5 ups, is registered in channels connecting the system to the Pacific Ocean characterizing it as antiestuarine (Alvarez & Chee, 1975; Acosta-Ruiz & Lara-Lara, 1978). Tides are semi-diurnal mixed. Maximum and minimum dissolved oxygen level at the mouth of Magdalena Bay are of 6.85 and 3.68 mL/L respectively; concentration of chlorophyll a fluctuates from 1.2 to 5.1 mg/m^3; phosphates vary from 3.09 to 0.62 µm, and water velocity from 0.24 to 1 m/s (Rueda-Fernández, 1983).

2. Magdalena Bay Mangrove

Mangroves often provide a source of wood products, providing subsistence for local populations. However, logging is rarely the main cause of the loss of these trees. This is

Fig. 2. Satellite image of Magdalena Bay, Pacific Ocean, Mexico.

Fig. 3. Magdalena Bay Mangrove. (Photographer Magdalena Lagunas, 2011).

primarily due to competition for land for urban development, tourism, agriculture or construction of ponds for shrimp farming. The high rate of negative changes in the mangroves during the eighties in Asia, the Caribbean and Latin America has been caused mainly by the conversion of these areas for aquaculture and infrastructure, as many governments have opted for it with the intention of increasing security food, to stimulate national economies and improve living standards. According to FAO, in 1980 the mangroves covered a surface area of 19.8 million hectares of coastal areas of the world, for the year 2005, the same FAO report 15.2 million hectares, which means that in the past 20 years have been lost 23% of the global area. With the pressures and if the trend continues, we would be destroying one of representative ecosystems of global biodiversity (CONABIO, 2009). In Mexico, the annual loss rates calculated by comparing the mangrove areas are between 1 and 2.5%, depending on the method of analysis of the information used (INE, 2005).

Magdalena Bay is one of the largest lagoon system in Mexico. The dense mangroves of the bay represents the most extensive mangrove area of the Baja California peninsule (Enríquez-Andrade, 1998, Hastings & Fisher, 2001; Malagrino, 2007), 21, 116 has been holding 85% of mangrove state (Acosta-Velazquez & Vazquez-Lule, 2009), moreover, are of particular importance because of its isolation from other areas of its kind. Here, the mangroves are highly productive and structurally provide habitat, breeding sites and/or food for fish, crustaceans, molluscs, sea turtles (López-Mendilaharsu *et al*., 2005) and birds (Zárate, 2007). Particularly in these areas nesting a variety of both migratory and permanent residents seabirds (Hastings & Fisher, 2001).

Regarding to marine fauna, it has been reported 161 species of fish in the bay, belonging to 120 genera and 61 families and four species of sea turtles (*Caretta caretta*, *Chelonia mydas*, *Dermochelys coriacea* and *Lepidochelys olivacea*) listed as endangered in NOM-059-SEMARNAT-2001, gray whales (*Eschrichtius robustus*) under special protection and other marine mammals can also be found within the Bay (Tena, 2010). The marine flora of the lagoon system includes 279 species of macroalgae and 3 segrasses, for this reason it is considered as a bay with high vegetation species richness (Hernández-Carmona *et al*., 2007).

Magdalena Bay is defined as an area with a high level of ecological integrity, the National Commission for Biodiversity of Mexico, CONABIO recognizes the coastal area of Magdalena Bay as a priority region for conservation from the standpoint of terrestrial, marine, coastal and river basin hydrological as well as an Area of Importance for the Conservation of Birds (AICA). In recent national studies the Magdalena Bay, has been listed as a Site of Mangrove biological relevance and in need for ecological rehabilitation in the North Pacific Region, PN03 site identifier Baja California Sur, Magdalena Bay (Fig. 4), (CONABIO , 2009).

The most important plant community in the area is the mangrove. In Magdalena Bay exists three of the four Mexican mangrove species: red mangrove (*Rhizophora mangle*) which is endemic and is dominant in the area, associated with black mangrove (*Avicennia germinans*) and white mangrove (*Laguncularia racemosa*).

These species are listed under the category of special protection in the Mexican Official Standard NOM-059-SEMARNAT-2001. Mangroves are highly productive and structurally provide habitat and breeding and feeding sites for fish, crustaceans, molluscs, turtles and

Fig. 4. Magdalena Bay mangrove (CONABIO, 2009).

birds. The mangroves of the lagoon system are the largest in the Baja California peninsule (Enriquez-Andrade *et al*., 1998; Malagrino, 2007).

Recent studies on the coverage, distribution and structure of the mangroves of Magdalena Bay, indicates that the mangrove area is estimated above 17000 ha (Acosta-Velazquez & Ruiz-Luna, 2007). Mangrove class were subclassified into shrub, mixed and monospecific forest, based on field data (Acosta-Velazquez & Ruiz-Luna, 2007). The forest subclasses include *Rhizophora mangle* and *Laguncularia racemosa* species, being dominant the last species, with densities from 2339 to 5922 individuals/ha and basal area ranging from 20.6 to 58.5 m^2/ha. Shrub mangroves includes also *Avicennia germinans*, whit densities up to 30000 individuals/ha. The mangrove area diminished more than 1500 ha between 1990 and 2005, with the shrub subclass as the most disturbed, while the monospecific forest displayed a significant increase (48%). The estimated annual mean deforestation rate was 0.55, but it was lower (0.15/year) if only the mangrove forests were included (Acosta-Velazquez & Ruiz-Luna, 2007).

Aquaculture and environmental impact on mangroves

The coastal zone bears most of the ecological consequences of aquaculture development. These include habitat loss/modification, excessive harvesting of wild seed/spawners and damage to bycatch, introductions of exotic species, escapes of cultured animals, spread of diseases, interactions with wild populations, misuse of chemicals and antibiotics, release of wastes, and dependence on wild fisheries.

Globally, more than a third of mangrove forests have disappeared in the last two decades, and shrimp culture is the major human activity accounting for 35% of such decline. This

Fig. 5. Magdalena Bay Mangrove, ecosystem Desert succession (Photographer Magdalena Lagunas, 2011).

transformation results in loss of essential ecosystem services generated by mangroves, including the provision of fish/crustacean nurseries, wildlife habitat, coastal protection, flood control, sediment trapping and water treatment. Fish pens and cages also degrade nearshore habitats through their physical installations on seagrass beds and sediment communities, or through deposits of uneaten feeds (Primavera, 2006).

The shrimp aquaculture ponds are located in the most biologically productive and undervalued in the world: marshes, mangrove forests and wetlands. It is clear that the mere physical presence of ponds for aquaculture production has an impact by hindering the continued natural flow between coastal environments. Mangrove conversion to shrimp ponds is the single major factor that has contributed to the negative press received by aquaculture. Southeast Asia has 35% of the world's 18 million ha of mangrove forests, but has also suffered from the highest rates of mangrove loss, e.g., 70–80% in the Philippines and Vietnam for the last 30 years. Around half of the 279,000 ha of Philippine mangroves lost from 1951 to 1988 were developed into culture ponds; 95% of Philippine brackish water ponds in 1952–1987 were derived from mangroves (Primavera, 2006)

Prevent environmental impacts on mangroves of Magdalena Bay

Although the ecological importance of Magdalena Bay is evident there are currently no state or federal programs that regulate the lagoon complex ecological system or the area surrounding it. The gradual increase in population and alternative activities such as ecotourism will only increase the ecological pressures on the ecosystem.

An important contribution to the proper use of this lagoon system is precisely to obtain adequate rates to define the proper establishment of suitable sites for different types of aquaculture farming.

In order to consider the suitability of each potential site for the clam culture, a mathematical index was utilized. This index helped determine the ranks of suitability of each site in regards to its possible use for marine cultures. Based on the results obtained, seven sites were identified as adequate for clam culture. The one that presents the best conditions is estuary San Buto. The Methodology and Results of this work can be used in all Coastal Zone with Aquaculture potentialities.

Mangroves and aquaculture are not necessarily incompatible. For example, seaweeds, bivalves and fish (seabass, grouper) in cages can be grown in mangrove waterways. Such mangrove-friendly aquaculture technologies are amenable to small-scale, family-based operations and can be adopted in mangrove conservation and restoration sites. Brackish water culture ponds may not necessarily preclude the presence of mangroves. Dikes and tidal flats fronting early Indonesian tambak were planted with mangroves to provide firewood, fertilizers and protection from wave action. Present-day versions of integrated forestry-fisheries-aquaculture can be found in the traditional geiwai ponds in Hong Kong, mangrove-shrimp ponds in Vietnam, aquasilviculture in the Philippines, and silvofisheries in Indonesia. Alternatively, mangroves adjacent to intensive ponds can be used to process nutrients in pond effluents (Primavera, 2006).

Fig. 6. Suspension system in aquatic farming Baja California peninsula.

2.1 Methodology

From 2001 to 2003 the main characteristics of the area were determined: climate, soil, geology, orography, morphology, and hydrology; after analyzing the bibliography and the data sets of the meteorological stations of the region as well as official charts, field stages of work were developed to corroborate the information.

Marine and costal characteristic, including tide effects, morphology of the coastal zone, and accessibility for marine water intake and waste water treatment and disposal were obtained through the analysis of satellite images and field stays of work. The availability of services for each potential clam culture zone, including roads (paved and not paved), electricity, phone and internet availability, human populations and potential workers, were also established by field surveys.

In order to assess the suitability of each potential site for sustainable clam culture activities inside Magdalena Bay, we applied the modified index of Lagunas & Ortega (Lagunas, 2000):

$$CCS = \frac{ACS\ (0.1)\ +\ NMST\ (0.3)\ +\ AVD\ (0.15)\ +\ MCAS\ (0.15)\ +\ AAPD\ ((0.3)\ +\ MSK\ (0.1) x100}{2.45}$$

Where:

CCS = Clam Culture Suitability

ACS = Accessibility

NMST = Number of Months with Suitable Temperature for the Clam Culture

AVD = Average Depth

MCAS = Marine Current Average Speed

AAPD = Annual Average Phytoplankton Density

MSK = Marine Substrate Kind

The index of Lagunas & Ortega is the result of empirical field studies developed by the authors of this paper and by the careful assessment of the ecological, environmental, socioeconomic and facilities characteristics of the places where the optimal clam aquaculture activities are currently developed. In order to standardize the values obtained by this index, it is divided by the empirical value of 2.45. This way values obtained range from 0 to 100. The rank values are shown in Table 1.

3. Conclusions

After the bibliographic revision and the analysis of satellite images, which were digitalized in a GIS in which we included climate, vegetation, soil, geological, and geomorphological characteristics, 7 potential places were identified where clam culture activities could be performed with the lesser impacts and with more success probability; the sites selected were Santo Domingo, Adolfo Lopez, Estero San Buto, Estero Chisguete, Punta Cayuco, Puerto Chale, and Rancho Bueno, which are shown in Figure 7.

Variable	Characteristics	Rank value
ACS	Site without roads available and without sea connection Site only with sea connection Site only with road connection Site with roads available and with sea connection	0 1 2 3
NMST	Less than 5 months with suitable temperature Between 6 to 9 months with suitable temperature More than 10 months with suitable temperature	0 1 2
AVD	From 1 to 5 m in average From 6 to 10 m in average More than 10 m	1 2 3
MCAS	Annual average more than 31 m/s Annual average between 21 to 30 m/s Annual average between 11 to 20 m/s Annual average between 1 to 10 m/s	0 1 2 3
AAPD	From 67% to 100% of water turbidity From 34% to 66% of water turbidity From 11% to 33% of water turbidity From 1 % to 10% of water turbidity	0 1 2 3
MSK	Rocky Clay-slime Sandy	0 1 2

Table 1. Rank value used to assess clam aquaculture suitability.

After the 7 sites were selected, we performed one week field stays of work in each of them. The CCS value for each site was obtained after we analyzed all the specific characteristics of the environmental and socioeconomic features considered in the formula for each place (Table 2). As we can see the best site to develop clam culture is located in Estero San Buto where optimal conditions were found with a CCS value of 90.

According to the characterization of this site we recommend that the species to be cultured are the Catarina scallop (*Argopecten ventricosus*), the Lion paw scallop (*Nodipecten subnodosus)*, the Pen shell (*Atrina maura*), and the Chocolata clam (*Megapitaria squalida*).

We recommend to establish polyculture facilities for these local species, without intensive culture activities, thus avoiding the nourishment excess and the pollution caused by the own detritus of the cultured individuals (Fig. 4). There exist 150 ha in Estero San Buto suitable to establish this recommended polyculture, being possible to hire workers in the locality for it; an average annual harvest of 2,312 tons of the different species is estimated.

Knowing the precise biological, physicochemical and social environment, we can determine the best species to cultivate, the recommended total area to use, and the methodology to be employed to produce the lesser environmental impacts and to obtain the maximum profitability. Our methodology could be used not only to select appropriate sites for clam culture but also to assess the suitability, in a quick and accurate way, of any other aquaculture activity in coastal zones.

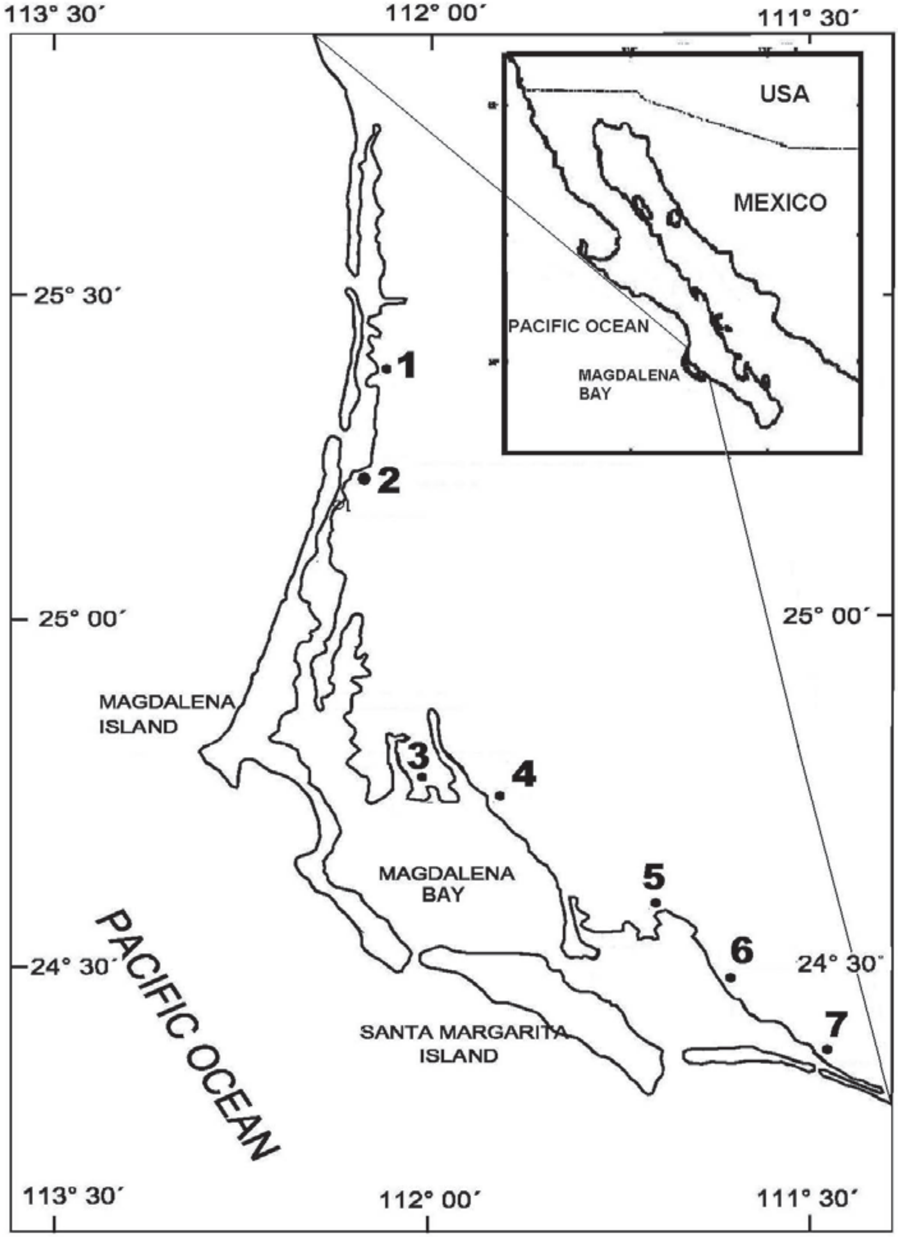

Fig. 7. Magdalena Bay location and selected clam culture sites. Sites are described in Table 2.

SITE	ACS Accessibility	NST Number of Months With Suitable Temperature for the Clam Culture	AVD Average depth	MCAS Marine Current Average Speed	AAPD Annual Average Phytoplankton Density	MSK Marine Substrate Kind	CCS Clam Culture Suitability
1 Santo Domingo	1	2	1	1	1	1	57
2 Adolfo Lopez	3	2	1	1	1	1	65
3 Estero San Buto	2	2	2	2	2	2	90
4 Estero Chisguete	2	2	3	1	1	1	73
5 Punta Cayuco	1	2	1	1	2	1	69
6 Puerto Chale	3	2	1	1	1	2	65
7 Rancho Bueno	2	2	1	1	1	2	65

Table 2. Main characteristics and CCS value obtained for each selected site.

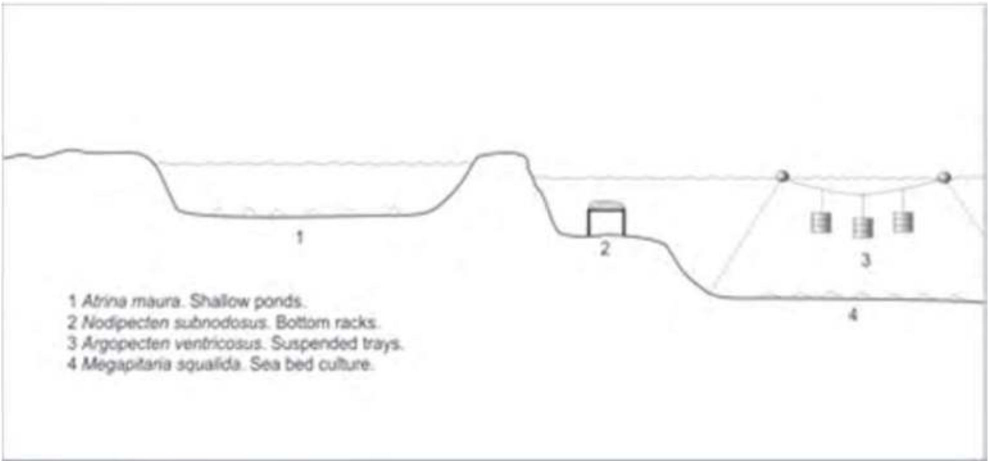

Fig. 8. Recommended polyculture.

Mangrove-friendly aquaculture technologies are amenable to small-scale, family-based operations and can be adopted in mangrove conservation and restoration sites.

Make mangrove reforestation, to consider forestry to aquaculture (eg. the traditional geiwai ponds in Hong Kong, mangrove shrimp ponds in Vietnam on aquasilviculture in the Philippines and in Indonesia silvofisheries). On the other hand, mangroves adjacent to the intensive ponds can be used to process the nutrients in pond effluents.

Magdalena Bay mangroves seems to be exposed to relatively low human impact compared whit other Mexican system of mangrove. Effective conservation programs and sustainable management plans will be required to preserve this important mangrove ecosystem, mainly related to aquaculture activities, based in scientific knowledge such as the study here presented.

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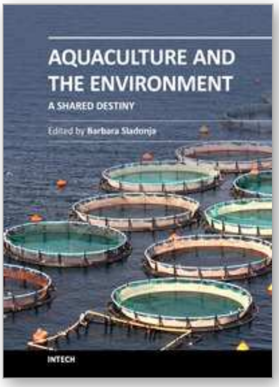

Aquaculture and the Environment - A Shared Destiny
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Aquaculture is the art, science and business of cultivating aquatic animals and plants in fresh or marine waters. It is the extension of fishing, resulted from the fact that harvests of wild sources of fish and other aquatic species cannot keep up with the increased demand of a growing human population. Expansion of aquaculture can result with less care for the environment. The first pre-requisite to sustainable aquaculture is clean wate, but bad management of aquatic species production can alter or even destroy existing wild habitat, increase local pollution levels or negatively impact local species. Aquatic managers are aware of this and together with scientists are looking for modern and more effective solutions to many issues regarding fish farming. This book presents recent research results on the interaction between aquaculture and environment, and includes several case studies all over the world with the aim of improving and performing sustainable aquaculture.