1 Land and Water Management in Coastal Zones: Dealing with Agriculture–Aquaculture–Fishery Conflicts

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Abstract

The coastal environment has undergone rapid change in recent times. Change in the state of the environment is multifaceted, but a key concern is the way that natural habitats – principally mangrove forests and salt marshes – have been extensively cleared and converted to shrimp farming and other uses. The expansion of shrimp farming has also encroached onto agricultural lands. Coastal shrimp farming has been practised for a very long time in some countries as part of the traditional livelihood system, but recent strong demand in global markets, together with technological advances, has fuelled rapid expansion. These rapid, and generally unplanned changes, have provoked conflicts among the three dominant resource-dependent livelihoods in the inland coastal zone: agriculture, shrimp farming and fishing.

The coastal zone is characterized by ambiguities of resource ownership and a complex web of interactions among people, resources and ecosystems. Conflicts exist between the drive for short-term financial gain and the desire for long-term sustainable development. Conflicts exist between the priorities of people who derive their livelihoods from aquaculture and those who depend upon agriculture. Conflicts exist between the needs of people who may gain from intensification of land use for agriculture and/or aquaculture and other people (e.g. fisherfolk), whose livelihoods may be adversely affected by environmental impacts. This synthesis chapter presents a discussion of trends, problems and approaches to managing change in the inland coastal zone. We identify key messages from previous research and development experience and consider the supporting evidence for these messages.

Introduction

Coastal zones are home to 40% of the world's population and support much of the world's food production and industrial, transportation and recreation needs, while also delivering vitally important ecosystem services. The coastal environment is under pressure and has undergone rapid change in recent times. The scale of the stresses imposed on this environment poses a threat to the resilience of both natural and human systems. Driving forces are demographic, economic, institutional and technological. These build up environmental pressure through land-use change, intensification of resource exploitation, urbanization, industrial development, tourism and recreational demand. Changes occurring in the state of the environment include altered nutrient, sediment and water fluxes; degradation of habitats and loss of biodiversity; and pollution of soils, groundwater and surface water. These in turn affect human welfare through their effects on productivity, health and amenity.

One of the key issues is land-use change, in particular the rapid growth of shrimp aquaculture. Change in the state of the environment is multifaceted, but a key concern is the way that natural habitats – principally mangrove forests and salt marshes – have been extensively cleared and converted to shrimp farming and other uses. The reduction in area occupied by mangrove forest is well documented and has provoked widespread concerns over environmental and social impacts. However, it is important to recognize that recent expansion of shrimp farming has also encroached onto agricultural lands (Karim, Chapter 5, this volume; Szuster, Chapter 7, this volume). This is the second key issue in the coastal zone, but it is important to see both in the context of the range of conflicting demands of the different stakeholders who live within and depend upon the resource base in this environment.

In this synthesis chapter, we discuss trends, conditions, responses and scenarios for the coastal zone. A problem analysis follows in which we examine the main environmental and social impacts of change. We then identify key messages from previous research and development experience and provide supporting evidence for these messages. Crucial to the achievement of a more sustainable approach is the adoption of appropriate evidence-based policy for which we identify knowledge gaps.

Land-use Change in Coastal Zones

Shrimp-farming trends

Extensive shrimp farming has been practised for a very long time in some countries as part of the traditional livelihood system, but recent strong demand in global markets together with technological advances has fuelled rapid expansion and intensification. The annual percentage rate of growth at 17% between 1970 and 2000 was considerably higher than that of other food production sectors. However, the double-digit growth rates of 23% in the 1970s and 25% in the 1980s slowed to 7% in the 1990s (FAO, 2003). To some commentators (e.g. Fegan, 1999) this is seen as a success story, having developed from a cottage industry based upon a backyard production system to a global industry in little more than 30 years; to others (e.g. EJF, 2003), this rapid growth is associated with serious negative environmental and social impacts.

In 2000, brackish-water aquaculture comprised 4.6% by weight of total aquaculture production but 15.7% by farm-gate value. Since 1970, shrimp farming has emerged as a major source of foreign earnings and an important source of income and employment. Estimates for the main shrimp-producing countries put the total employment generated by shrimp farming at around 2 million people. The top 25 producer countries are listed in Table 1.1. Of these, the top ten account for 90% of world production.

Shrimp-farming methods are classified according to the level of technology adopted, stocking density and yield. Terminology varies between sources and countries, but we can recognize the following types:

Extensive: traditional methods rely on natural recruitment of shrimp postlarvae from wild sources and natural productivity of the ecosystem; built-in intertidal areas with water exchange by tidal action; pond size typically >10 ha; trap and hold wild shrimp at a density of 1–3/m^2; yield typically less than 200 kg/ha/year.

Semi-intensive: the first stage of development usually involves some stocking of shrimp postlarvae from a hatchery; natural productivity may be enhanced by fertilizers and occasionally some use of feeds; pond size 2–10 ha; water exchange usually provided mainly by tidal action, supplemented by low-lift axial-flow pumps; stocking density of 3–10/m^2; yield typically 1000–2500 kg/ha/year.

Table 1.1. The top 25 producers of farmed shrimp in 2000 by weight and value (from FAO, 2003).

No.	Country	Production (mt)	Production (000 US$)
1	Thailand	299,700	2,125,384
2	China	217,994	1,307,964
3	Indonesia	138,023	847,429
4	India	52,771	393,938
5	Vietnam	69,433	319,392
6	Ecuador	50,110	300,660
7	Philippines	41,811	271,385
8	Bangladesh	58,183	199,901
9	Mexico	33,480	194,184
10	Brazil	25,000	175,000
11	Malaysia	15,895	124,577
12	Colombia	11,390	91,120
13	Sri Lanka	6,970	78,342
14	Taiwan	7,237	60,483
15	Honduras	8,500	59,500
16	Venezuela	8,200	34,030
17	Australia	2,799	27,557
18	Madagascar	4,800	24,000
19	Nicaragua	5,411	17,423
20	USA	2,163	14,513
21	Belize	2,648	12,710
22	New Caledonia	1,723	12,061
23	Costa Rica	1,350	11,475
24	Panama	1,212	6,399
25	Peru	512	3,741

mt = metric tonnes

Intensive: progression to advanced production systems relies on artificial stocking at high density (>10/m^2) in small ponds (1–2 ha) with heavy feeding rate; involves mechanical aeration; sometimes incorporates water recirculation and/or treatment; generally above high-tide level to allow drainage and drying of pond bottom between crops; yield of over 7500 kg/ha/year possible with multiple cropping, but 5000 kg/ha/year is typical.

Mangrove trends

Mangrove forests occupy intertidal areas along tropical and subtropical coasts, especially where large river systems deposit alluvial sediment and salinity is moderated by high freshwater discharge. They therefore represent a dominant natural ecosystem of tropical and some temperate coastal zones. The global extent of mangroves has been estimated at 181,077 km^2 (Spalding *et al.*, 1997), but this represents a much reduced area compared with their undisturbed extent. Historically, they have been exploited for forest products or converted to various alternative forms of land use (salt pans, aquaculture ponds, agriculture, urbanization and industrial development). In some countries, the reduction exceeds 50% (Table 1.2).

Shrimp farming has no doubt contributed to the overall loss of mangroves, as documented in some countries, but it is by no means the only factor. For example, mangrove loss in Thailand over the last two decades has been exacerbated by the expansion of shrimp farming (see Szuster, Chapter 7, this volume). In Chakoria, Bangladesh, shrimp areas expanded from 10,000 ha to 75,000 ha between 1967 and 1988, at the expense of a decrease in mangrove area from

Table 1.2. Estimated loss, in % of the original forest cover, of mangrove area in selected countries (from WRI, 2000).

	Loss (%)
Asia	
Brunei	20
Indonesia	55
Malaysia	74
Myanmar	75
Pakistan	78
Philippines	67
Thailand	84
Vietnam	37
Africa	
Angola	50
Côte d'Ivoire	60
Gabon	50
Guinea Bissau	70
Tanzania	60
Latin America	
Costa Rica	0
El Salvador	8
Guatemala	31
Mexico	30
Panama	67
Peru	25

70,000 ha to 7,000 ha (see Islam, Chapter 18, this volume). Many commentators (e.g. Gujja and Finger-Stich, 1996; Janssen and Padilla, 1999; Nickerson, 1999; EJF, 2003) have attributed much of the global loss to the expansion of shrimp farming, but the evidence for this assertion is not always strong because the unavailability or unreliability of data prevents the assessment of the true extent of the link worldwide. In-depth studies of the history of mangrove exploitation are few (see, for example, Walters, 2003).

The relationship between the decline of mangrove and expansion of shrimp farming is examined by Lewis *et al*. (2003), who showed that in Thailand half of the mangrove area present in 1960 had been lost before the shrimp boom in the 1980s. Elsewhere in South-east Asia, conversion for salt production, urbanization and agriculture has removed large areas. Within southern Asia, mangroves in India and Bangladesh have been heavily exploited for timber, fuelwood and other forest products for centuries, and population pressure has led to serious forest degradation. These countries also show evidence that before the expansion of shrimp farming large tracts of mangrove had already been converted to rice farming. In Africa, it is apparent from Table 1.2 that the extent of mangrove destruction is comparable with that in Asia even though coastal aquaculture in general, and shrimp farming in particular, is not widespread. A comprehensive survey of 5000 shrimp farms in Asia (ADB/NACA, 1997) showed that less than 20% of the area occupied by intensive and semi-intensive farms was former mangrove. Most of the shrimp farms on former mangrove land were extensive ponds. The estimated total of 400,000 ha of ponds on former mangrove land represents only 5% of the mangrove resource. In an analysis conducted for the World Wide Fund for Nature, Clay (1996) concluded that '… the extent of mangrove destruction worldwide resulting from shrimp farming is only a tiny fraction of the total lost to date …'. Nevertheless, conflicts do exist between shrimp farmers and mangrove resource users.

Conversion of rice farms

Coastal rice lands in tropical regions often suffer from saline intrusion that prevents crop production in the dry season. This is a natural phenomenon in deltaic and estuarine environments because of seasonally varying freshwater input; however, it may be aggravated by upstream river basin management (see Atapattu and Molden, Chapter 22, this volume). Agricultural lands in the brackish-water zone generally have lower productivity than those in the freshwater zone. As demand for shrimp increased, many farmers found that shrimp farming could bring them higher income than agriculture and they converted their rice fields into shrimp ponds. It is difficult to estimate the extent to which brackish-water shrimp farming has encroached on to agricultural land worldwide, but available data from a few countries illustrate the significance of the trend.

A large number of rice farmers in central Thailand converted irrigated paddy fields into shrimp ponds during the latter half of the 1990s (Szuster *et al*., 2003). Surveys conducted by the Thai Department of Land Development and the Department of Fisheries suggested that shrimp farms operating within freshwater areas could have accounted for as much as 40% (or approximately 100,000 t) of Thailand's total farmed shrimp output in 1998 (Limsuwan and Chanratchakool, 1998). In Bangladesh, because of commercial interests of shrimp, many coastal polders constructed since the 1960s to protect agricultural land from inundation of salt water were turned into large shrimp culture *ghers* (ponds) during the 1990s. Shrimp area expanded from 51,812 ha in 1983 to 137,996 ha in 1994 and to 141,353 ha in 2002 (DoF, 1995, 2003). In the coastal zone of the Mekong River Delta of Vietnam, rice area decreased from 970,000 ha in 2000 to 800,000 ha in 2002, whereas shrimp area increased from 230,000 ha to 390,000 ha in the same period (MNRE, 2002, unpublished).

Problem Analysis

Coastal zones support three distinct types of resource-dependent livelihood: agriculture, shrimp farming and fishing (and/or extraction of other common-property resources). There are many cautionary tales about environmental and social problems arising from the impacts of land-use change (see Table 1.3). In order to promote evidence-based policy, a worthwhile problem analysis depends upon recognizing and evaluating interactions (and trade-offs) among agriculture, aquaculture and fisheries in this environment. While the focus here is necessarily on negative impacts of change, this is not inevitable and the aim is to identify possibilities for co-existence and win-win scenarios for future resource use.

Bailey and Pomeroy (1996) argue that the complexity and high natural productivity of the environment provide many niches for these different activities, but sustainable development depends upon their co-existence rather than specialization. Lewis *et al.* (2003) similarly argue that the promotion of coastal aquaculture in an environmentally (and socially) responsible manner requires 'adopting the principles of co-existence of mangroves and aquaculture'. They note that 'implying co-existence is possible and documenting its actual occurrence are two different things'.

Environmental impacts

Aquaculture's effects on mangrove resources include cutting trees and clearing land, hydrological changes due to the construction of canals and roads, and the spread of disease to wild shrimp (Lewis *et al.*, 2003). Other environmental impacts related to the development of extensive shrimp culture in mangrove forests include coastal erosion, saline intrusion into agricultural lands, decrease in shrimp postlarvae and mud crab, increased malarial incidence in coastal areas and acidification of soils and waters (Boyd and Clay, 1998; GESAMP, 1991; Paez-Osuna, 2001). Several authors have pointed out the irony that mangrove destruction itself is sometimes the main reason for the unsustainability of shrimp farming because of erosion, loss of natural productivity, water acidity and contamination. As a consequence, some extensive shrimp farm developments have been abandoned (Dierberg and Kiattisimkul 1996) and environmental activists have criticized such occurrences, calling them 'slash-and-burn' exploitation or 'swidden aquaculture'.

Table 1.3. Common environmental and human impacts of aquaculture development in the coastal zone.

Environmental problems	Human problems
Destruction of mangrove, wetlands and other sensitive aquatic habitats	Restricted access to common-property resources
Water pollution resulting from pond effluents, excessive use of bio-active chemicals in aquaculture ponds, excessive use of pesticides and fertilizers in agriculture	Loss of land because of indebtedness or coercion
Salinization of land and water by drainage and seepage from ponds	Reduced employment opportunities for landless people
Acidification arising from development of acid sulphate soils	Loss of subsistence fishery
Spread of aquatic animal diseases to native populations	Increased vulnerability as a result of less diverse sources of income
Negative effects on biodiversity caused by exploitation of wild shrimp larvae/ brood-stock and destruction of habitat	Health and social impacts arising from degraded domestic water supply
Negative impact on vegetation cover and terrestrial livestock	Higher economic values but increased inequity and social unrest

Where shrimp ponds have expanded into rice farms, salinization of soil and water is a major concern (Szuster and Flaherty, 2002). This is particularly detrimental when shrimp farms encroach on to the originally freshwater area as in Thailand, where rice farmers realized that the potentially high profits derived from shrimp production could easily offset the costs associated with trucking salt water to their land. Seepage and percolation from shrimp ponds can salinize adjacent rice fields and the long-term build-up of salt threatens the sustainability of agriculture on neighbouring farms. This is not the case where shrimp farms are located in the brackish-water zone, where salinity intrusion is a natural seasonal phenomenon, such as in the Mekong Delta of Vietnam (Phong *et al.*, 2003).

The adoption of shrimp–rice production systems in the brackish-water zone may also lead to the encroachment of shrimp ponds onto homestead lands. Karim (Chapter 5, this volume) reports that in Bangladesh before 1975 most shrimp farms (>80%) were located further than 500 m from homestead areas, but, in 1999, 46% of the shrimp ponds were found within 10 m of homestead land. Fruit trees and many plant species have gradually decreased because of salinity and the shrinking of homestead areas. Similarly, grazing land and its vegetation cover also declined.

One of the key concerns is the effect of the periodic discharge of shrimp-pond water that contains high concentrations of suspended solids, nutrients and bio-active chemicals. This occurs as natural drainage after heavy rain, when ponds are emptied at the end of the season, and when water is exchanged during the season. The discharge of high loads of nutrients and suspended solids has the potential to have adverse effects on the receiving waters, including the stimulation of algal blooms and the creation of anoxic conditions (Naylor *et al.*, 1998). Graslund and Bengtsson (2001) provide a comprehensive review of chemicals used in shrimp farming and the potentially adverse effects of discharges into the environment, but in general their impact on coastal waters is poorly documented in rigorous scientific studies. The characteristics of shrimp-farm discharges are qualitatively different from agricultural and urban effluents. The resulting discharge water has high concentrations of inorganic particles, phytoplankton, particulate and dissolved organic compounds, and ammonium derived from feeds. Burford *et al.* (2003) linked ecological processes in intensive shrimp ponds with impacts downstream, but it should be noted that extensive and low-level semi-intensive shrimp farms do not cause appreciable chemical discharge pollution.

Just as shrimp ponds may pollute their environment and provoke downstream problems, they may also suffer from poor water quality due to upstream users. There is much debate about this as an issue affecting decisions about the appropriate intensity of shrimp-farm development in a given area (i.e. carrying capacity), but the wider issue of land use within the river basin merits consideration. A case study from Honduras (Dewalt *et al.*, 1996) is illustrative in that it examines the dispute between shrimp producers and other people from coastal communities (farmers and fishermen), which has led to serious confrontations. Their study demonstrates the importance of a wider perspective in that growing population and increased intensity of farming, especially in upstream hillside communities, is seen to have contributed to increased sediment and pesticide loads in the coastal environment. Environmental change in the coastal zone may be the result of actions farther up the river basin.

The development of acid sulphate soils (ASS) for both aquaculture and agriculture also merits consideration. Such soils are associated with inland coastal zones (salt marshes, mangrove forests and other estuarine wetlands) and when oxidized these pyrite (FeS_2)-rich sediments generate sulphuric acid. On-site impacts affect shrimp ponds (Sammut, 1999) and agricultural fields (Minh *et al.*, 1998) because of low pH and high concentrations of aluminium and iron. Cultural practices developed to reclaim these soils depend upon liming and leaching of toxic substances. Leaching results in the transfer of acidity to the surroundings, leading to severe acidification of the local aquatic environment (Minh *et al.*, 1997). Acid can also be exported farther into tidal creeks and estuarine waters, where mass mortalities of fish have been recorded, and there is evidence of chronic long-term effects on coastal habitats (Sammut *et al.*, 1996; Wilson *et al.*, 1999; see also Macdonald *et al.*, Chapter 8, this volume).

Human impacts

Socio-economic impacts associated with change in resource-dependent livelihoods have often been underestimated or oversimplified. This can perhaps be explained in part by failures to recognize off-site effects, which occur when the boundaries of the system under consideration are not properly defined (Phillips *et al.*, 2001). The nature and extent of impacts inevitably differ between countries, but general lessons do emerge.

In Bangladesh, shrimp farming has become a major export industry, but concern has grown about negative socio-economic impacts (Deb, 1998). Shrimp farming itself is less labour-intensive than rice cultivation (Deb (1998) estimates a 75% reduction), thus giving rise to concern for impact on poor people whose livelihoods depend on selling labour. However, the overall labour requirement of the shrimp industry is higher than that of rice production because of the level of employment in ancillary activities. In 1990, total on-farm and off-farm labour requirements were 22.6 million person-days, and the corresponding figure for 2005 was projected to be 60 million. It is logical to assume that the shrimp industry should absorb the surplus rural labour force in coastal areas, but in reality benefits to local people are less because many shrimp producers prefer hiring labour from outside. Social tension arises because of this and also because of coercive methods (seizure and intimidation) adopted by investors wishing to gain access to land for conversion into shrimp ponds (see also Karim, Chapter 5, this volume).

The social impact of shrimp farming in India was assessed by Patil and Krishnan (1997), who surveyed 26 coastal villages in Andhra Pradesh. Respondents were asked to rank the degree of severity of specific factors arising in shrimp development areas. For fishing communities, blocked access to the beach and saline well water were scored as the most severe problems. Salinization of land and shortages of fodder and fuelwood were the main problems identified in farming communities, together with the problem of saline well water. Similar issues have been identified in Bangladesh.

The social unrest arising from the socio-economic impacts reported in Bangladesh and India is less evident in Vietnam, but similar underlying problems have been reported (EJF, 2003; Hoanh *et al.*, 2003). Results from a study involving ecosystem changes from agriculture to aquaculture in Quang Ninh Province of Vietnam (Adger *et al.*, 2000) demonstrate that conversion of part of a mangrove forest for agriculture and aquaculture affects property rights and imposes additional stress on local livelihoods. There is evidence of increased inequality since poorer people are more dependent on common-property resources that are degraded or made less accessible. It appears that common-property management of the remaining mangrove and fishing areas is also undermined by the changes in property rights and inequitable benefits derived from enclosure and conversion (see also Luttrell, Chapter 2, this volume, and Ocampo-Thomason, Chapter 11, this volume).

In spite of widely reported environmental and social impacts, the potential for substantial profits attracts both local farmers and outside entrepreneurs, and shrimp farming continues to expand and to dominate the debate on land use in the coastal zone. The debate has tended to polarize between those who emphasize the economic benefits and those who emphasize negative impacts. Planning for sustainable development requires consideration of both perspectives and trade-offs between them (GESAMP, 2001). The starting point should be the recognition that private and social benefits often diverge. Be *et al.* (1999) outlined this conflict in the context of an analysis of alternative land uses (shrimp monocrop, rice monocrop and rice–shrimp) for the Mekong Delta in

Vietnam. They identified the critical policy issue that farmers have not received appropriate signals about the cost of externalities associated with private investment decisions. This point has been echoed by many commentators on the shrimp–mangrove conflict (e.g. Janssen and Padilla, 1999; Huitric *et al.*, 2002). It is sometimes argued (e.g. Fegan, 1999) that this has resulted from the 'goldrush mentality' associated with the early stages of an immature industry. The challenge therefore is to move quickly to put in place the measures necessary to develop a sustainable industry.

Approaches to Managing Change

Regulating farm operations

Governments have responded mainly with specific regulations relating to shrimp-farm operation (such as effluent limits, design standards, best management practices and codes of conduct). Many tropical nations (e.g. Belize, Brazil, Ecuador, India, Mexico, Thailand and Venezuela) have made aquaculture effluent regulations, which are designed to prevent effluents from causing negative impacts on receiving waters. These farm-level measures have often been ineffective. Some non-government organizations have also proposed effluent standards for aquaculture. Among them, the Global Aquaculture Alliance (GAA) has suggested that members adopt environmentally responsible culture methods to comply with effluent standards. These standards consist of initial, rather lenient, limits, and stricter target limits with which the members should comply within 5 years (Boyd and Gautier, 2000).

A large number of producer associations, governmental fishery agencies, international development organizations, environmental non-government organizations and others have formulated codes of conduct for aquaculture (Boyd *et al.*, 2002). A code of conduct in its most basic form is a set of guiding principles consisting of broad statements about how management and other operational activities should be conducted. Most aquaculture codes reference the Code of Conduct for Responsible Fisheries presented by the Food and Agriculture Organization (FAO) of the United Nations (FAO, 1995, 1997) and the general principles of the codes usually reflect those of the FAO code. Most codes do not have any legal authority, and adoption is usually voluntary.

Given that tens of thousands of small farms are operated by individuals with relatively little technical knowledge, it is virtually impossible to effectively regulate aquaculture effluents by applying traditional water quality standards. An alternative is to require the application of specific practices called best management practices (BMPs). A BMP is the best available and practical means of preventing a particular environmental impact while still allowing production to be economically efficient. The best inducement is when adoption of BMPs clearly increases profit. Thus, BMPs should be related back to farm economic performance. For example, suppose that the BMPs are to lower stocking rates and use better feed management. The lower stocking rates and lower feed inputs will result in better water quality, less stress, faster growth, better feed conversion ratios and less waste produced. This scenario will also increase efficiency and profits. Another example is the storage of rainfall in ponds to avoid overflow. Less overflow means that less water will need to be pumped into ponds to maintain water levels. A reduction in pump operation will reduce costs and increase profits.

The main disadvantages of relying on codes of practice are summarized below:

- Adoption is voluntary, so some producers may not follow codes of conduct despite promotional efforts.
- Producers who adopt a code of conduct may selectively adopt BMPs and avoid those that are expensive or difficult to implement.
- There are many obstacles to effective self-evaluation and third-party verification.
- Small producers may lack technical knowledge for using BMPs, and education and training will be difficult and expensive.

- Implementation of programmes could be slow and result in substantial costs to farmers.
- Effectiveness of BMPs in codes of conduct is assumed, but monitoring is needed to verify this assumption.
- Unless all stakeholders are involved in preparing codes of conduct, the BMPs may not address significant socio-economic issues.

Because of the necessity of preserving mangroves and recycling aquaculture wastes, some researchers have proposed integrated shrimp–mangrove systems (Robertson and Phillips 1995; Dierberg and Kiattisimkul, 1996). Expected benefits of integrated systems include enhancement of coastal fisheries, minimization of contamination of the coastal environment and provision of a higher-quality water supply for shrimp farming. Integrated mangrove–shrimp farming systems have the advantage of combining mangrove conservation with the high-income potential of aquaculture (Macintosh, 1998). One approach is to transform current extensive shrimp farming into 'silvo-fishery' systems (Macintosh, 1998). The Indonesian *tambak* is a traditional form of integrated system in which extensive aquaculture is sustained by mangrove productivity (Hambrey, 1996; Macintosh, 1998). Binh *et al*. (1997) demonstrated that integrated mangrove–shrimp farms (mangrove covering 30–50% of the pond area) in Vietnam have higher economic returns than farms where mangrove had been cleared. Johnston *et al*. (1999) investigated yields of shrimp and wood from mixed systems in Vietnam, but raised concerns over their sustainability.

Another way of integrating shrimp ponds and mangrove areas is to discharge pond effluents into a mangrove wetland, which is used as a biofilter to remove suspended solids, lower BOD[1] and absorb nutrients in order to limit the risk of eutrophication of the adjacent waters (Twilley, 1992; Robertson and Phillips, 1995; Rivera-Monroy *et al*., 1999). How mangrove forests work as sinks for phosphorus and nitrogen is poorly understood, but Corredor and Morell (1994) reported their effectiveness in removing nutrients from effluents. However, it is not possible to make any general recommendation about an appropriate ratio of mangrove–shrimp pond area while the nutrient assimilation capacity of different kinds of sediments and plants remains unknown (Gautier, 2002).

Integrated coastal zone management

Although some problems can be addressed at the farm level, many problems require strategic intervention at a wider landscape or basin scale and call for collective action (see also Szuster, Chapter 7, this volume). In many ways, what we have is a classic example of why integrated coastal zone management (ICZM) is needed:

- Coastal aquaculture commonly straddles the boundary between land and sea.
- Resource (land, water) ownership or rights allocation, and related administration, is often complex or ambiguous in prime aquaculture locations.
- Aquaculture may be seriously affected by water quality and habitat degradation caused by other activities.
- Aquaculture itself may affect environmental quality and the interests of other users through conversion of natural habitat; through pollution of recipient waters with nutrients, organic substances and potentially toxic (hazardous) chemicals; and through the spread of disease.
- Poorly planned aquaculture may result in negative feedback and self-pollution.

Unfortunately, there are few clear examples of the successful integration of aquaculture into comprehensive ICZM. It is arguable that this is because there have been very few genuinely integrated initiatives, where aquaculture has been assessed alongside the full range of existing or potential activities in the coastal zone using consistent and rational assessment criteria, agreed upon across a

[1] BOD, biochemical oxygen demand.

range of interests and agencies. To do this thoroughly takes time, however, and this poses a dilemma in many developing-country situations where aquaculture is developing very rapidly. The case of Ecuador, where population pressure, industrial development and shrimp farming have had significant negative impacts on estuarine resources throughout a period in which a long-term ICZM project was under way, is particularly notable (GESAMP, 2001). Also, shrimp farming has developed uncontrollably in Sri Lanka, with adverse environmental consequences and self-pollution, despite a strong ICZM awareness and a variety of initiatives in place (Nichols, 1999).

Based on a review of experience, GESAMP (2001) concluded that comprehensive ICZM may be effective as a starting point where coastal aquaculture is in the early stages of development, where institutions for resource management are flexible or undeveloped and where appropriate legal and institutional frameworks are in place or can be developed rapidly. The available scientific and technical capacity is often a constraint and there is a need to develop appropriate planning tools (see Trung *et al.* and Baran *et al.*, Chapters 14 and 16, respectively, this volume, for examples). However, technical competence does not guarantee success, since institutional inertia may mean that planning authorities do not respond quickly to rapidly changing circumstances (Hoanh *et al.*, 2003). Also, well-laid plans are often undermined by the strength of economic and political interests. Evidence from Thailand (GESAMP, 2001) suggests that more locally focused initiatives (e.g. relating to an estuary or lagoon system) may offer the most practical starting point, since they retain the benefits of integration but at a smaller scale.

An integrated strategy for sustainable development might include

- zones with development and environmental objectives specifically related to aquaculture and other compatible activities, and
- allocation of environmental capacity, in terms of waste production/emission limits, for aquaculture and other activities within these zones.

Zoning (an *allocation of space)* implies bringing together the criteria for locating aquaculture and other activities in order to define broad zones suitable for different activities or mixes of activities. Geographic information systems (GIS) are particularly well suited to facilitating this task (see Kam *et al.*, Chapter 15, this volume). Zoning may be used either as a source of information for potential developers (for example, by identifying those areas most suited to a particular activity) or as a planning and regulating tool, in which different zones are identified and characterized as meeting certain objectives. Zoning of land (and water) for certain types of aquaculture development may

- help to control environmental deterioration at the farm level,
- reduce adverse social and environmental interactions,
- serve as a focus for estimates of environmental capacity and
- serve as a framework for providing or improving infrastructure to small-scale farmers.

The strength of zoning lies in its simplicity, its clarity and its potential in terms of streamlining procedures (see Islam, Chapter 18, this volume). For example, once a zone is established and objectives defined, then developments that meet the objectives and general conditions for the zone may need no further assessment (such as an environmental impact assessment). What is allowed and what is not allowed is clear, and developers can plan accordingly. Any monitoring required can be applied to the whole zone rather than to individual farms. Its weakness lies in its rigidity, and farmers must adapt to the situation within the zone. No zone is perfect, land/water capability assessment may have been inadequate, boundaries are frequently arbitrary and conditions may change. Flexibility and farmer choice are limited by the zone criteria. On the other hand, the task of catering to highly diverse needs is also quite difficult, and can break down. There may be small pockets of land or water of high potential for aquaculture that were not recognized in the resource-assessment process. Exclusion of these lands from an aquaculture zone could prevent appropriate development, subject it to inappropriate regulation or restrict access of poor people to opportunities for aquaculture development. Furthermore, zoning may actually be undesirable for encouraging a concentration of aquaculture because of the associated environmental and social impacts.

Environmental capacity measures the resilience of the natural environment in the face of impact from human activities. Some assessment of environmental capacity is desirable and is of particular relevance to the problem of cumulative effects. It has been argued (GESAMP, 2001) that environmental capacity must be assessed, even if only at the most elementary level, if sustainable development is to have any practical meaning. Environmental capacity (otherwise referred to as assimilative capacity) is 'a property of the environment and its ability to accommodate a particular activity or rate of an activity … without unacceptable impact' and must be measured against some established standard of environmental quality. In the case of aquaculture, it will be applied to a specified area (e.g. a bay, lagoon or estuary) and might be interpreted as

- the rate at which nutrients can be added without triggering eutrophication,
- the rate of organic flux to the benthos without major disruption to natural benthic processes and
- the rate of dissolved oxygen depletion that can be accommodated without causing mortality of the indigenous biota.

A set of planning interventions in the form of incentives and constraints (planning regulations) will be required to implement the strategy and ensure that objectives are met, standards are not breached and environmental capacity is not exceeded. These might apply to

- location of aquaculture development,
- waste emissions,
- the quantity or quality of inputs used (e.g. food, chemicals) and
- design, technology and management practices.

Given the nature of coastal aquaculture as a mainly small-scale activity, the implementation of recommendations may be difficult for farmers, and the enforcement of regulations difficult for authorities (see, for example, Murthy, 1997). This may be made more effective if responsibility for design, implementation and enforcement is located at the proper administrative level, and full use is made of self-management and self-enforcement capacity by industry and farmers' associations (see White *et al.*, Chapter 9, this volume).

Incentives, on the other hand, do not suffer from problems of evasion and non-compliance, and in some cases can be used to stimulate innovation leading to more environmentally friendly technologies. The use of economic instruments to influence both siting and operation holds considerable promise. Although some positive incentives may be costly, it should be possible to pay for them with negative incentives (e.g. taxes on undesirable locations, activities, technologies). However, incentives may need to be underpinned or reinforced through complementary regulation.

Environmental impact assessment (EIA) is a standard planning tool for evaluating the potential consequences of development decisions, and has been used widely in coastal management. Strategic environmental assessment (SEA) is a relatively recent tool that has been developed to evaluate the environmental effects of policies, plans, programmes and other strategic actions. The likely environmental and social impacts of a range of technologies or development options in different locations can be compared, and planning interventions to minimize environmental impact can be devised. Alongside EIA and SEA, properly informed planning requires consideration of the impact of development decisions on the livelihoods of people who depend upon the natural resource base. Luttrell, Ocampo-Thomason, Saint-Paul and Campbell *et al.* (Chapters 2, 11, 12 and 21, respectively, this volume) provide insights from experiences in different countries. They demonstrate the dependence of poor people on open-access resources as, for example, in mangrove forests. The failure to detect and respond to this adverse impact may be due in part to a lack of capacity among decision-makers to engage with and understand the perceptions of stakeholders (Le Tissier and Hills, Chapter 19, this volume). The explanation may also be due in part to the inherent difficulty of detecting impacts and attributing changes to causes (van Zwieten *et al.*, Chapter 17, this volume).

Conclusions

The coastal zone is home to 40% of the world's population and supports much of the world's food production, while also delivering important ecosystem services. But it is under increasing pressure that threatens the resilience of both natural and human systems. The problem is multifaceted, but contributions to this publication have focused in particular on land-use change within the tropical coastal zone.

Among the diverse environments that make up the coastal zone, the land-use issue considered here is most pertinent to river deltas and estuaries, which are characterized by a gradual and seasonally varying land-water interface. The various contributors to this publication have presented evidence from different countries, but in each case we can recognize common features:

1. The aquatic environment is subject to seasonally varying salinity.
2. The terrestrial environment is vulnerable to both tidal and riverine flooding.
3. The natural resource base supports agriculture, aquaculture and fisheries.

The critical land-use issue has been shown to be the expansion and intensification of brackish-water shrimp production. This activity takes place in ponds that may have been developed by clearing natural habitats (principally mangrove forest and salt marsh) or by converting agricultural land (notably rice farms). Extensive shrimp farming has been a part of the traditional livelihood system, but recent strong demand in global markets, together with technological advances, has provided the impetus for rapid and generally unplanned change.

The potential for quick profits from shrimp production attracts both local farmers and outside entrepreneurs, but questions are raised about short-term risk and long-term sustainability. The debate has tended to polarize between those who see increased productivity of land and water resources and others who emphasize the negative impacts. Policymakers, planners and others concerned with environmental protection face a real dilemma in making development decisions. The widely reported problems can be attributed in part to the 'gold-rush mentality' associated with the early stages of an immature industry. This has been exacerbated by institutional weaknesses that have allowed unplanned and unregulated development, leading to environmental stresses that in turn affect human welfare. It is often only at this late stage that policy responses are triggered. The question that this publication has sought to answer is: Can we achieve socially and environmentally sustainable development?

The complexity and high natural productivity of the environment lead us to believe that co-existence of alternative natural resource–based livelihoods is the key to sustainable development. However, implying that co-existence is desirable and making it happen are two different things. Zoning can be seen as an essential element of planned development, but no zone is perfect and livelihood choice will inevitably be limited within any zone. Seasonal zoning may provide the best compromise as, for example, in a rice–shrimp rotation system with alternate freshwater and brackish-water conditions. The spatial scale at which zoning occurs also merits careful consideration, with an assumption in favour of smaller units allowing more flexibility. Creation of a buffer zone around homesteads will be necessary to prevent close encroachment of shrimp ponds and the resulting salinity problems that affect the daily living environment of farmers.

One advantage of more localized zoning is that adoption of a participatory approach becomes more feasible. This should ensure better-informed decisions and greater likelihood of compliance. There is a need to develop appropriate planning tools and, in particular, tools for proper assessment of both environmental capacity and the value of ecosystem services. Improved knowledge should in time allow for the establishment of economic instruments to incentivize appropriate use of the natural resource base (e.g. through resource-use charges or environmental capacity charging). However, in the short term, control will depend upon establishing a regulatory framework and imposing penalties for any infringement.

Regulation is required both to control land use within any zone and to exercise control over the nature of production activities. However, given that there are many thousands of small-scale producers, it will be very difficult to effectively regulate on-farm activities. Promotion of best management practices and codes of conduct should be seen as a priority for all concerned institutions. Investment is needed in capacity building within local extension services and in creating effective farmers' organizations to empower community participation in natural resource management. A key issue here is the control over intensification and, in particular, the intensity of shrimp production. The progression from extensive to intensive systems brings trade-offs between economic benefit on the one hand and environmental and social impact on the other. Many cases have shown clearly that intensive shrimp farming is not sustainable.

A priority issue that emerges from the case studies presented in this publication is the impact of change on poor people. There is evidence of an increasing gap between the rich and the poor. Spending of public resources on coastal zone infrastructure (e.g. tidal sluices and polders) has been shown to deliver economic benefit while still causing relative poverty to increase. The livelihoods of poor people depend upon open-access resources, which include, but are not limited to, fisheries. Any development decision that aims to enhance production from aquaculture and/or agriculture is likely to impact adversely on access to and productivity of these resources. Planners and decision-makers should recognize this conflict and ensure that they have adequate information on the importance and value of open-access resources.

In spite of frequent calls for integrated water resource management, the coastal zone is generally considered in isolation from the river basins to which it is linked. The coastal zone sits at the tail-end of river systems and suffers the impact of upstream river basin development. Changed flow regimes, sediment yields and pollution loads all add to the direct local pressure on the coastal zone. Arguably, the health of the coastal zone can be seen as an indicator of river basin health. Improved river basin management will seek to increase water productivity and manage multiple uses while delivering essential environmental flows. Institutional barriers between those concerned with river basin management and those responsible for coastal zone management must not be allowed to threaten the sustainable development of this vital resource base and the livelihoods of those who depend on it.

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