Ecosystem approaches to coastal resources management: the case for investing in mangrove ecosystems

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1. Introduction

The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way (Secretariat of the Convention on Biological Diversity, 2004). It is particularly applicable to the sustainable management of mangrove forests because of their location at the land-sea interface and the close ecological links prevailing between the vegetation, soil and water and the intertidal and aquatic animal species, which together provide a wide array of valuable goods and services to millions of coastal dwellers worldwide (Aksornkoae, 1993; Macintosh and Ashton, 2002; Hogarth, 2007).

The concept of ecosystem approaches was developed in the 1960s, drawing from various disciplines, including conservation biology, ecology and the social sciences. Ecosystem-based management builds on these earlier approaches by incorporating elements of environmental planning and resource-sharing, while maintaining an explicit focus on the management of human impacts within the ecosystem (Kappel *et al*., 2006). In relation to the coastal zone, these approaches are applied collectively in the form of integrated coastal management (ICM). The Convention on Biological Diversity outlines 12 principles that form the basis for the ecosystem approach (SCBD, 2004). These principles are recommended to guide the implementation of projects and other investments in the coastal zone (see Box 1).

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BOX 1: PRINCIPLES OF THE ECOSYSTEM APPROACH

1. *The objectives of management of land, water and living resources are a matter of societal choice.*
2. *Management should be decentralized to the lowest appropriate level.*
3. *Managers should consider the effects of their activities on adjacent and other ecosystems.*
4. *Potential gains from management should be recognized; there is usually a need to understand and manage the ecosystem in an economic context.*
5. *Ecosystem structure and functioning should be conserved in order to maintain ecosystem services. This should be a priority target.*
6. *Ecosystems must be managed within the limits of their functioning.*
7. *Action should be undertaken at the appropriate spatial and temporal scales.*
8. *Objectives for ecosystem management should be set for the long term.*
9. *Management must recognize that change is inevitable.*
10. *Action should seek the appropriate balance between, and integration of, conservation and use of biological diversity.*
11. *Action should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.*
12. *The approach should involve all relevant stakeholders of society and scientific disciplines.*

The advantages of adopting an ecosystem-based approach are evident from the wide range of services, or benefits, that people obtain from ecosystems. In the case of mangroves, the Millennium Ecosystem Assessment (2005) groups these services into four categories, covering both use and non-use benefits:

1. ***Regulating services***: protection of beaches and coastlines from storm surges, waves and floods; reduction of beach and soil erosion; stabilization of land by trapping sediments; water quality maintenance; sequestration of carbon dioxide; and climate regulation.
2. ***Provisioning services***: subsistence and commercial fisheries (food, habitat and nursery ground for aquatic life); aquaculture; honey; fuelwood; building materials (timber); and traditional medicines.
3. ***Cultural services***: tourism and recreation; and spiritual appreciation.
4. ***Supporting services***: cycling of nutrients; and habitats for species.

These mangrove ecosystem goods and services are the key attributes sustaining economic activities in Asian countries, at both a commercial and subsistence level.

Policy-makers, investors and developers need to take into account the particular complexities of coastal ecosystems, especially their inter-relationship with other upstream and downstream processes, and their generally high economic value. Usually, however, investment appraisals of large infrastructure development projects do not adequately consider the economic costs/risks resulting from altering downstream river flows that can impact on mangroves and coastal fisheries. Economic valuations and investment decisions need to incorporate not only the direct costs and benefits of an intervention, but also the socio-economic consequences of other alterations or losses in terms of ecosystem services in the longer term. For example, converting a mangrove area to shrimp ponds may be financially attractive to investors in the near term to mid term, but experiences in many countries have shown that mangrove shrimp farming is not viable in the longer term because of a gradual loss of ecosystem productivity resulting from the clearance of the mangroves. Worldwide, 800 000 ha of mangrove may have been destroyed to build shrimp farms (Hogarth, 2007). This represents an enormous loss in terms of mangrove ecosystem services, since these were valued more than ten years ago at almost US$10 000/ha/annum (Costanza, *et al*., 1997).

The lack of comprehensive information about coastal ecosystems, especially the true value of mangrove forests and coral reefs, has led to past large-scale destruction or degradation of coastal resources, resulting in immense economic losses/costs. Conversely, putting new, more accurate monetary values (price tags) on coastal ecosystems and their goods and services is a powerful tool to influence decisions and policy-makers in favour of sustainable coastal development choices. Recent global estimates suggest that, in terms of a nation's economy, coral reefs and mangroves provide an annual value of US$100 000 to 600 000 and US$200 000 to 900 000 per square kilometre, respectively (UNEP-WCMC, 2006). Overall, coastal ecosystem services have been estimated to be worth over US$25 000 billion annually – "ranking them among the most economically valuable of all ecosystems." (Nellemann, 2009)

In the face of climate change, many of the regulating services of mangroves are actually becoming more necessary and valuable, especially their buffering capacity against storms and flooding. Mangroves can hold back the sea and reduce wave forces with their extensive and dense above-ground roots by an estimated 70 to 90 percent on average, or by 20 percent per 100 m in the case of mangrove green belts in Viet Nam. Mangrove forests also moderate climate extremes by providing shade and increased air-humidity, while also reducing wind velocity and soil water evaporation.

Mangroves and other coastal ecosystems, such as tidal salt marshlands and seagrass meadows, are also important global carbon sinks. These coastal wetlands are able to bury large quantities of carbon at a rapid rate (reviewed by UNEP, 2009). In the case of mangroves this is aided by their extensive root systems, which develop both above and below ground. Globally, mangroves may be accumulating between 0.009 to 0.038 Gt of carbon per year, which, when their limited area of coverage is taken into account, suggests that they sequester carbon faster than terrestrial forests. However, current patterns of use, exploitation and impacts will if left unchecked potentially lead to mangroves becoming carbon sources rather than sinks. Conversely, there are now opportunities to include mangroves in some of the emerging forest carbon marketing mechanisms, provided suitable technical and financial models can be developed.

Regarding food security and livelihoods, mangroves support and enrich coastal fish and shellfish populations vital to the nutrition and subsistence livelihoods of millions of coastal dwellers, as well as sustaining the commercial fisheries and aquaculture sectors. The ecosystem-based approach recognizes that mangroves are critical to the life cycles of many of these species, e.g. mud crabs, especially during their juvenile life stages; thus protecting mangroves helps to sustain coastal fish/shellfish stocks, even in the face of heavy fishing pressure.

This paper looks at the socio-economic benefits of applying the ecosystem approach in the coastal zone, especially in relation to mangrove forests and food security. It draws on examples and lessons learned from applying ecosystem-based and participatory approaches in sustainable coastal management projects in Southeast Asia. Four case studies are presented to demonstrate the importance of mangrove conservation to protect food security and livelihoods. From these case studies, a number of action areas and recommendations are presented highlighting research and knowledge gaps, plus emerging issues, especially the need to invest in adaptation responses to the growing threats from climate change in the coastal zone.

2. Issues

i) Mangrove ecosystems are particularly dynamic and productive, features that create both opportunities and challenges for innovative management and investment opportunities.

Many tropical coastal areas are dominated by mangrove forests and associated vegetation (e.g. nypa palm, seagrasses). This important intertidal wetland community is maintained by many ecological processes determined by the flows of water, sediments, nutrients, organic matter and animal populations that move through and within the ecosystem (Robertson and Alongi, 1992; Hogarth, 2007). Mangroves flourish best in estuaries, deltas, bays, lagoons and other sheltered coastal locations, where they are influenced by both freshwater and seawater. This makes them highly productive ecosystems providing habitat and food for many commercially important fish, crustacean and molluscan species (e.g. Robertson and Blaber, 1992), but the dynamic nature of the processes that support this productivity, especially the delicate hydrological system, make mangrove ecosystems particularly difficult to manage.

ii) Despite growing awareness of their value, mangroves are still being degraded and lost at an alarming rate across Asia.

Mangrove ecosystems have been degraded, or converted for agriculture, aquaculture, and industrial and urban development areas. The global coverage of mangroves in 1997 was 181 000 km^2 worldwide (Spalding *et al*., 1997). A more recent estimate by FAO indicates that the figure may be below 150 000 km^2 and many species are reported to face the threat of extinction because of human activities (Polidoro *et al.*, 2010). The scale of human impact on mangroves has increased dramatically in recent years, with many countries showing losses of 50 to 80 percent or more, compared to the mangrove forest cover that still existed even 50 years ago; the Philippines for example has lost 75 percent of the mangrove area that existed in the 1950s (Primavera, 2000). The livelihoods of many local coastal communities have been severely diminished or even lost as a result, and recent typhoons in India, Bangladesh and Myanmar have shown that peoples' lives and property are at much greater risk without the storm protection mangroves can provide. On an economic basis, Das (2008) estimated the value of the storm protective services of mangroves in Orissa to be US$4 335 per hectare of mangrove forest land.

iii) There has been considerable investment in planting mangroves, but not enough attention has been paid to their long term restoration and sustainable use.

The cost of planting mangroves is typically within the range of US$100 to 200 per hectare in Asia, making it a relatively low-cost and popular investment. However, this is only the direct seedling procurement and planting cost; it does not take into account the survival rate of the seedlings, which is dependent on a variety of factors, including the soil and hydrological conditions, climatic influences, and the need to protect and manage plantation areas. Because of these factors, which are sometimes compounded by poor site selection and/or choice of species, the survival rates for planted mangrove seedlings have often been very poor (see for example de Leon and White, 1999). Some practitioners have actually argued that “ecological restoration” based on natural seedling recruitment has many advantages over the widespread practice of planting mangroves (Lewis, 2001).

Technically sound and well-costed mangrove restoration, protection and sustainable use models are urgently needed, including benefit—cost analyses based on the services that restored mangroves provide. It is also important to understand how mangrove plantations compare in relation to the services provided by natural mangrove forests. In a recent study in Kenya, resource users rated natural mangroves more highly than plantations (Ronnback, Crona and Ingwall, 2007). In Thailand, it has been shown that biodiversity recovery in replanted former mangrove areas reaches levels almost comparable to the biodiversity of natural mangrove forests (Macintosh and Ashton, 2002), and plantations appear to be at least as productive as natural mangroves in terms of the fish and shellfish abundance they support (Crona and Ronnback, 2005 and 2007). This is an important conclusion because on a global basis the annual market value of mangrove-associated fishery products may average US$3 000 per hectare (Ronnback, 1999), whereas mangrove restoration costs including seedling gap-filling and plantation protection for the first five years can be as little as US$400 per hectare (data for India; Hirway and Goswami, 2004).

iv) More integrated management systems are needed for mangrove ecosystems.

Governments, development agencies and NGOs have responded to the dramatic loss of mangroves by adopting policies and projects to replant mangrove forests and introduce more sustainable management systems. However, the management aspects in particular require a radical rethink away from the traditional sectoral exploitation of mangroves towards their conservation, restoration (or rehabilitation) and “sustainable use” as defined by the CBD, or “wise use” as defined specifically for wetlands by RAMSAR (2006): “Wise use of wetlands is the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development.“

In practice, this means that both investment and management actions should follow the ecosystem-based approach, which considers mangroves to be an integral part of the coastal zone linked to other adjacent marine and freshwater/terrestrial ecosystems. This approach is more holistic and sound compared to the prevailing view that mangroves are only one isolated element of the coastal zone, or worse still are “just trees.”

v) The role that healthy mangroves can play in terms of food security and livelihood provision are commonly undervalued/overlooked, especially the ecological links between mangroves and coastal fisheries.

Some of the most important innovations needed in mangrove ecosystem investment and management are sustainable fishing and aquaculture practices which maximize mangrove food production without depleting key species or damaging the ecosystem in other ways, and which do not exclude traditional subsistence users.

vi) Investment in mangrove services has high potential, but few proven mechanisms exist.

Ecosystem services are the benefits people obtain from mangroves or other natural ecosystems, either directly (e.g. food, fuelwood, water supply) or indirectly through cultural, regulatory and supporting services. “Payment for Ecosystem Services” (PES) links the owners (or sellers) of ecosystem services to the beneficiaries (or buyers) of environmental services through financial payments. The ecosystem-based approach opens up opportunities to apply PES to mangroves. One example is REDD (Reducing Emissions from Deforestation and Forest Degradation). REDD includes a set of steps designed to use market/financial incentives in order to reduce the emissions of greenhouse gases (GHGs) from deforestation and forest degradation. The primary objective is to reduce GHGs but it can deliver "co-benefits" such as biodiversity conservation and poverty alleviation. REDD credits offer the opportunity to utilize funding from developed countries to reduce deforestation in developing countries. Mangroves have recently been included in the forest categories eligible for REDD.

3. Innovations and best practices involving mangrove ecosystems

Case study 1: Mangroves or shrimp farms – the case of Tha Po Village, Thailand

A study using partial valuation compared the net benefit from conservation of mangroves with the net benefit from their conversion to shrimp farms in Tha Po Village, Kanjanadit District, Surat Thani, located in the Gulf of Thailand. The villagers had traditionally utilized mangroves for both wood and non-timber forest products (NTFP), but excessive conversion of mangrove to shrimp farms seriously affected their livelihoods. Economic and environmental problems started to emerge, such as a drastic decline in offshore fishery yields and water pollution from farm effluent. In addition, some villagers' houses were made more vulnerable and suffered from storm surges because no mangroves were left to serve as a windbreak. From 1993 the villagers protested against the mangroves encroachment by shrimp farmers, leading to community action to protect the remaining mangroves of 2 500 rai[2] (400 ha), or about 35 percent left for traditional use (Sathirathai, 1998).

The benefits from the remaining mangroves comprised both products (wood to make fishing gear and NTFPs, mainly fish, shrimp, crab, molluscs and honey), and indirect benefits in terms of mangrove-fishery linkages and coastal protection. A valuation study (Pongthanapanich, 2008) estimated the mean annual value per household from direct use of wood and non-wood products to be US$ 1 155 (THB36 984).[3] The aggregate annual value for the entire remaining mangrove was US$ 43 919 per annum or US$ 18 per rai.[4]

The supply and demand functions of fishery products for the community were also estimated in order to measure the welfare impacts of the change in mangrove area on offshore fisheries.[5] Two different assumptions of management regimes were assumed for the valuation: 1) *open access*, i.e. first-come, first-served fishing basis assuming that the fishers sell fishery products at a price equal to average cost; and 2) *managed fisheries*, i.e. under a private/community property regime, the fishers sell the products at the price equal to marginal cost. The results showed that the economic values ranged from US$4.2 to 14/rai/year (THB133 to 441) under the open access regime, but were much more consistent for the

[2] A Thai unit of area (6.25 rai = 1 ha)
[3] The study applied an exchange rate of THB32 = US$1.
[4] The market prices were used to calculate the net benefit of wood and non-wood products. Assumptions on the households' collection of wood and non-wood products were made as a basis for calculating the benefits from the entire remaining mangrove area.
[5] The supply function was estimated based on the production function approach using a model which was applied to evaluate the offshore fishery production in which the mangrove area is included as one of the input factors.

managed fisheries regime at US$10.5/rai/year (THB333 to 335). These mangrove values represent the flow of annual income loss from offshore fisheries because of mangroves removal.

A replacement cost method was applied to assess the windbreak and shoreline stabilization functions provided by mangroves. Given a unit cost of US$1 094 per metre for constructing breakwaters to prevent erosion, a windbreak of one metre wide, and approximately 30 percent of the coastal area suffering from severe erosion, the replacement cost to protect the shoreline was US$389 rai/year. This is a proxy for the value of the coastal protection service provided by mangroves in the area. By adding the direct and indirect use values estimated above, conserving mangrove in Tha Po Village contributed an economic value in the range US$411 to 420/rai/year, or more than US$2 500/ha.

This study also evaluated the financial and economic returns from shrimp farming in the area. These were compared with the benefits from preserving the mangroves using a 20-year timeframe. The results implied that converting mangroves to shrimp farming was financially feasible, but not economically viable when the external costs of shrimp farming, i.e. cost of water pollution (calculated based on effluent treatment cost and rice production loss caused by saline water intrusion from shrimp farms) and mangrove deforestation (calculated based on costs of rehabilitating abandoned farms, replanting and maintaining mangroves) were factored into the analysis.

This study tended to underestimate the economic value of mangroves in terms of offshore fishery linkages and overestimate the coastal protection benefit. The study also overlooked other important potential economic direct use values especially those from recreation, and option values and non-use values were completely absent. However, this makes an even stronger case for the conclusion that from a societal viewpoint, it was not economically desirable to convert mangroves to shrimp farms.

The study also estimated that the local community benefited from the mangroves by almost US$44 000 annually from subsistence uses alone. It concluded that strengthening the communal property rights by applying a community forest law could be used as an effective management tool to reduce the problem of open access, thus reinforcing the community's incentive to conserve the resource.

Case Study 2: Mud crab farming, Thai Binh Province, Viet Nam

One of the most sustainable and profitable small-scale aquaculture practices is the rearing of the mangrove or mud crab (genus *Scylla*) a common mangrove crustacean throughout the Indo-West Pacific region. Mud crabs have a high economic value because of their large adult size and high meat content. In addition, gravid females (also known as "egg crabs") are highly valued in many countries, and are fished principally for the export market. Overfishing of mud crabs has been a widespread problem, whereas mud crab farming can add significantly to the value and sustainability of this resource.

Thai Binh Province is one of the coastal provinces in the southern part of the Red River Delta. Its coastline is composed of mudflats, mangroves and small sand islands located within the river mouths. Overton and Macintosh (2001) reported that about 70 percent of households in Thuy Hai Commune farm mud crabs in earthen ponds. The ponds range in size from as small as 1 200 m^2, which are artificially stocked, to huge 50 hectare ponds for extensive culture where the crabs enter naturally with the inflow water, plus some additional small crabs purchased from fishermen are added. These extensive ponds also trap and hold other aquatic products including wild shrimp, fish and are often "planted" with seaweed.

The majority of aquaculture ponds are situated in front of the main sea dyke but behind an area of mangrove trees planted in the 1990s that act as a buffer zone against typhoons. The water quality is guaranteed to be much better in front of the sea dyke particularly since a large number of the farms rely on tidal water exchange. In recent years, coastal aquaculture has become more developed and formerly large extensive ponds have been subdivided into smaller, semi-intensive operations. All the ponds have a simple sluice gate for water exchange and are surrounded by some form of fencing to prevent the crabs from escaping. This form of aquaculture is based on the mangrove ecosystem, which provides both coastal protection to the ponds and a supply of crab seed and natural food to support crab rearing. Other reasons for the success of this mangrove-aquaculture system are summarized in Box 2.

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BOX 2. Reasons for the successful development of mud crab farming in Thai Binh

Physical characteristics
The coastal mud flats within Thai Binh Province are accreting rapidly because of sedimentation from the Red River. Every five years, about 250 to 300 ha of "new coastal land" are formed. This new land is suitable for pond construction and benefits from a plentiful coastal water supply**.**

Water supply
The freshwater input from the Red River results in brackish water conditions ideal for coastal aquaculture. Moreover, the level of local water pollution is low because of lack of urbanization and agriculture in the immediate area.

Accessibility
Sea dikes not only protect local villages against storm damage, but also provide the main road system between neighbouring communities. Seed, feed and harvested aquatic products are transported without difficulty. The sea dike also serves as a focal trading point where traders, farmers and fishermen can trade mud crab.

Seed and feed supply
The mangrove protection belt provides the habitat for juvenile mud crabs as well as other aquatic species. This has resulted in an increase in juvenile mud crabs caught in stock ponds providing plentiful seed supply to support mud crab farming. Moreover, food sources for aquaculture such as low-value fish species, small mangrove crab species and molluscs, are abundant in the mangrove buffer zone.

Socio-economic factors
A strong community–based structure, along with the entrepreneurial spirit and hard working attitude of the local people, has created the opportunity for many coastal communities to benefit from crab farming. The direct beneficiaries from aquaculture tend to be to the wealthier and enterprising sectors of the community who can afford to invest in mud crab culture. However, the poorer fishers also benefit from collecting crab seed and food materials to sell to the crab farmers and by providing labour for many aspects of pond operation: building and repairing of ponds, harvesting, guarding against poachers etc. Hand collecting of juvenile mud crabs from the mangrove areas is carried out mainly by women and sometimes children. Both men and women, young and old, are involved in buying and selling crabs, either as primary or secondary dealers. These additional activities spread the economic benefit of crab production widely throughout the community.

The important features of this example of good practice are multiple. The mud crab is a natural (i.e. well adapted) mangrove species much more suited to small-scale farming than shrimp and other species that carry much higher investment risks. Juvenile crabs can also be harvested sustainably provided sufficient areas of mangrove habitat are protected and managed as a community resource. (And in this regard, "crab banks" - mangrove forest areas identified by fishing communities as key habitat to sustain the mud crab population - have proved very successful in Thailand, for example). Poor people can benefit by catching juvenile crabs or collecting natural crab food to sell to the pond owners, or by providing their labour. Local people recognize that there is a positive correlation between the area of mangroves and the quantity of wild mud crab available, thereby making it easier to convince them of the importance of conserving the mangroves as an ecosystem support service in relation to mud crab farming.

Case Study 3: Co-management of mangrove resources in the Mekong Delta, Vinh Hai Commune, Viet Nam

A further innovation in relation to food production in mangrove ecosystems is co-management, based on the principle that those who catch, collect or rear fish/shellfish (or gain any other benefits from the ecosystem) should be willing to pay towards the cost of protecting/improving the mangrove forests that their livelihood activities depend on.

In 1998 the Government of Viet Nam launched a national reforestation and forest protection programme, which provided forest protection contracts signed with individual households. But subsequent assessments showed that these contracts had not worked well. In 2007, the Au Tho B in Vinh Hai Commune was selected as a pilot site for co-management under a German-funded project (see Schmitt, 2009). This village included poor, landless people from ethnic minority groups whose livelihoods were dependent on subsistence collecting in the mangrove forests. Through community consultation, 240 mangrove user households were identified and divided into six groups based on geographical criteria. In 2009, a resource use agreement was signed between each user group and the local authority (Commune People's Committee), with the objective being "[t]o enable co-management practice to protect the forest and rationally and sustainably use natural resources within Au Tho B coastal area."

The co-management system in Au Tho B village is based on zones (land areas) where different management regimes apply, ranging from mangrove protection zones, rehabilitation zones to allow natural resources recovery, and sustainable use zones for catching/collecting fish, crabs and cockles.

Village members agree to follow the rules established for each zone, supported by regular monitoring by the authorities. Some examples of the permitted and prohibited activities in the rehabilitation zone outside the mangrove forest are as follows.

Permitted:	***Prohibited***:
- only members of co-management group can enter to catch fish; - catching juvenile crabs, elongated gobies and cockles when the tide is low and mud is visible; - catching by hand or round nets (with diameter less than 50 cm); - using long hooks to catch crabs; and - using bamboo trapping basket (chum) for *Periophthalmus schlosseri* (ca thoi loi) collection.	- non-members of co-management group entering the zone; - entering the forest when mud is not clearly visible; - damaging small trees; - using chemicals and electric fishing devices; - roundnets bigger than 50 cm in width; and - using longnets

In summary, the main benefits from this co-management approach to ecosystem based management in Soc Trang are: the effective protection of mangrove forests; livelihood improvement for the villagers; participation of community resource users in planning and decision-making; further reduction of the workload of authorities because of a decentralized/community-based management approach; and more just benefit sharing established as part of an ICM approach.

Case Study 4: Community-led ecosystem-based adaptation, inner Gulf of Thailand

Erosion is a critical problem along many coastlines in Asia. Human activities in drainage basins and on coastal plains have led to a decrease in sediment supply to the coast, caused mainly by dam construction, sand mining and irrigation, and by human-induced relative sea-level rise because of land subsidence resulting from excess groundwater extraction (Saito *et al.,* 2007). These activities, together with the destruction of mangroves and other coastal ecosystems, have resulted in severe coastal erosion in the Gulf of Thailand.

Over the past 30 to 40 years the average land recession rate has been 1.2 to 4.6 metres per year, but 11 percent of the Gulf of Thailand experiences more than five metres of erosion every year, which is equivalent to two square kilometres of coastal land loss valued at US$156 million per year (World Bank, 2007). The coastline, once covered by lush mangroves has been destroyed and replaced by shrimp farms. This has accelerated the rate of erosion and the lucrative shrimp farms are now being threatened by salt water intrusion as a result of sea-level rise caused by erosion and excessive ground water extraction to support Bangkok’s population and industries. The Samut Sakhon area is of huge economical importance to the nation because of its diverse and productive fisheries such as squid, shrimp farming and fish processing industries.

The impacts of relative sea-level rise are today highly visible, with electric poles submerged in water around the Bang Khun Thien village. A nearby village, Ban Khun Samutchin, is a coastal erosion hotspot where over the past 30 years erosion and land subsidence have decreased the shoreline by more than one kilometre. The impacts of coastal erosion have not only led to the loss of physical infrastructure such as roads, electricity systems, plus aquaculture and farm land, but have also increased the vulnerability of the villagers to storms and floods.

Community-led adaptation response

To curb or reduce the rate of coastal erosion, the national government and provincial authorities have invested in concrete wall structures and sandbags, but these investments have been costly and have had limited success. According to the figures available, one kilometre of coastal erosion works using concrete poles costs THB45 million, or about US$1.4 million; and one kilometre of sandbags is THB36 million, or US$1.125 million.

The local communities who had lost their land and livelihoods joined forces in a network, with assistance from WWF and local NGOs, to try and tackle the erosion problem by constructing bamboo fences/walls (adapted from traditional technology) supplemented by mangrove planting. Bamboo walls are natural, sustainable and more cost effective. According to a Kok Kham community leader, one kilometre of bamboo costs US$ 250 000, compared to the US$1.1-1.4 million estimated costs for rock, concrete or sandbag structures. Moreover, concerns about the potential environmental impact of soil leaching from the sandbags (the soil used to fill the bags is taken from terrestrial sources) have also been raised.

The livelihoods of fishing communities such as Kok Kham are derived mainly from squid and fish processing. From 1993 to 2007, aquaculture farmers in Bang Khun Thien village invested a total of US$117 420 to protect their farms against coastal erosion and flooding. On a per household basis, they spent more than 20 percent of their annual income on adaptation measures, e.g. in 2006 this amounted to US$3 362 on average out of a total household income of US$14 634 (Rawadee and Areeya, 2008).

4. Action areas and recommendations

The overall recommendation is that investment and management actions involving mangrove forests should follow the ecosystem-based approach, which considers mangroves to be an integral part of the coastal zone linked to other adjacent marine and freshwater/terrestrial ecosystems.

Four main action areas have been identified and specific recommendations are listed under each below. They have been derived from lessons provided by the case studies described here, and from similar experiences gained during implementation of a large number of MFF projects in six countries of the Indian Ocean region (India, Indonesia, Maldives, Seychelles, Sri Lanka and Thailand).

In considering these recommendations, reference should also be made to the 12 principles outlined by the Secretariat of the CBD on ecosystem approaches (see Box 1). Although these are not necessarily important to every management decision or investment, they are a useful checklist and the case studies illustrate the benefits of following some of these principles in practice.

i) Technical innovations:

- mangrove restoration and rehabilitation – the development of technically sound and fully costed models; and
- engineering solutions for coastal protection (against storms, flooding and erosion): combining hard (e.g. sea walls) and soft (e.g. mangroves) engineering.

Mangrove restoration/rehabilitation models, combined with other coastal protection measures, are needed particularly in relation to mangroves and climate change adaptation.

ii) New investment mechanisms:

- working systems and models for Payment for Environmental Servies (PES) in coastal areas, including mangrove ecotourism; and
- applying REDD and other carbon marketing mechanisms to mangrove forests.

PES mechanisms can benefit coastal communities by paying them to provide environmental services, but to date PES has been limited mainly to payments for local people to plant and protect mangroves.

Mangrove ecotourism has shown good potential in several Asian countries, but investment and sustainable financing mechanisms, including benefit-sharing systems for local communities, are needed.

Several forest carbon marketing mechanisms have already been developed which potentially could be applied to mangroves if viable technical and financial carbon storage and marketing models can be developed.

iii) Improved management approaches:

- community-based coastal area management plans - developing and upscaling these and seeking their endorsement by local authorities and national governments; and
- co-management models - developing and replicating successful examples.

There are a number of successful community-based management models available, backed up by a great wealth of experience of working with coastal communities. These should be scaled up through national development programmes and large projects. Co-management models, whereby community involvement in mangrove resources management is linked to PES mechanisms, are also needed as the logical next step to combine management and investment in the coastal zone.

iv) Knowledge gaps and research needs:

- integrated research combining environmental and economic studies to assess the carrying capacity of mangrove ecosystems for multiple, sustainable use, including new investment opportunities, e.g. mangrove ecotourism;
- research into economic methodologies and studies to provide better economic valuations of the goods and services supplied by mangroves and the combined values of mangroves, coral reefs and sea grasses as interrelated coastal ecosystems; and
- study of approaches and best practices which can combine scientific and traditional/local knowledge more effectively to support coastal ecosystem management and sustainable resource use.

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