ELSEVIER

Ecological Economics 25 (1998) 323–346

ECOLOGICAL ECONOMICS

ANALYSIS

Use of environmental functions to communicate the values of a mangrove ecosystem under different management regimes

Alison J. Gilbert *, Ron Janssen

Institute for Environmental Studies, Vrije Universiteit, De Boelelaan 1115, 1081 HV Amsterdam, The Netherlands

Received 25 August 1996; received in revised form 17 April 1997; accepted 25 April 1997

Abstract

Mangroves are part of rich ecosystems providing a variety of environmental goods and services. Underestimation of their value and of the impacts of human activities is a major factor contributing to the widespread loss and degradation of ecosystems. Economists frequently receive the blame for such environmental ills, but it can also be argued that ecologists communicate inadequately their knowledge to decision makers and therefore have limited influence. This article links information supplied by ecologists to the information required for effective and efficient mangrove management. A key problem which ecologists face is the high degree of interconnectedness within and between ecosystems. This makes it difficult to predict what is going to happen, let alone understand what is going on. The concept of 'environmental function' is used in combination with system diagrams to address this problem. System diagrams are used to identify and assess goods and services produced by the system under different management regimes. These goods and services are then valued to enable assessment of the economic efficiency of the management regimes.

Keywords: Mangrove management; Environmental functions; Valuation; Sustainability

1. Introduction

Mangroves are salt-tolerant trees or shrubs found along low-energy, tidal shorelines between latitudes in tropical and subtropical areas (approximately between 30°N and 30°S). They colonise newly formed tidal flats in the wind and wave shadows of promontories and islands, and behind wave-absorbing sand bars and seagrass beds (Carter, 1988). As much as 75% of low-lying tropical coastlines with freshwater drainage support mangrove ecosystems (WRI and IUCN, 1986). Mangroves provide the basis for complex

* Corresponding author. Tel.: +31 20 4449555; fax: +31 20 4449553; e-mail: alison.gilbert@ivm.vu.nl

0921-8009/98/$19.00
PII S0921-8009(97)00064-5

and extensive ecosystems at the interface of terrestrial, freshwater and marine ecosystems (Mann, 1982; Robertson and Alongi, 1992).

The exploitation of mangrove resources in traditional subsistence economies is usually not intensive. Increased market integration and the modernising of traditional economies in recent decades have led to more intensive mangrove exploitation and even to their removal. This has been observed in the Philippines where mangrove cover was reduced from 288035 ha in 1970 to 123400 ha in 1993, largely as a result of aquaculture development (WRI and IUCN, 1986; Zamora, 1989). Mangrove ecosystems provide a variety of environmental goods and services. Underestimation of their total value and of the impacts of human activities are major factors contributing to the widespread loss and degradation of mangrove (and other) ecosystems. Economists frequently receive the blame for such environmental ills, but it can also be argued that ecologists poorly communicate their knowledge to decision makers and therefore have limited influence on environmental management.

A key problem which ecologists face is the high degree of interconnectedness within and between ecosystems. This makes it difficult to predict what is going to happen, let alone understand what is going on. The concept of 'environmental function' is used in combination with systems diagrams to address this problem. System diagrams are used to identify and assess goods and services produced by the system under different management regimes. These goods and services are then valued to enable assessment of the economic efficiency of the management regimes. This article aims to demonstrate that linking environmental functions through systems diagrams with goods and services makes it possible to integrate physical performance of the ecosystem as studied by ecologists with economic efficiency of the system as studied by economists.The structure of this article is as follows:

- Description of the study site (Section 2).
- Specification of environmental functions (Section 3).
- Description of feedbacks and linkages using systems diagrams to identify and value goods and services produced by the mangrove forest (Section 4).
- Specification and valuation of management alternatives assuming sustainability (Section 5).
- Assessment of the changes in these values should sustainability conditions fail (Section 6).
- Conclusions and recommendations (Section 7).

2. The Pagbilao mangroves

The municipality of Pagbilao is located in the southern part of Quezon Province on the island of Luzon, the Philippines. It has an area of 15820 ha, a population of 41635 (1990) and an annual population growth rate of 2.77%. The original area of mangroves in Pagbilao is not known but can be deduced from the existing area of mangroves and brackish water fishponds. In 1984 the total area of mangrove forest was around 693 ha. Of this, 396 ha were within public forest lands while 297 ha were owned privately. At present 110.7 ha of public forest land remain—the Pagbilao mangroves—and have been declared an experimental forest under the jurisdiction of the Department of Environment and Natural Resources. The legal basis of the experimental forest is Presidential Proclamations 2151 and 2152 which, as of 1981, declared certain parts of the Philippines to be wilderness areas. The primary purpose of these proclamations was to preserve remaining mangrove ecosystems.

Fig. 1 shows Pagbilao Bay. The island of Pagbilao Grande and coral reefs separate the bay from the larger Tayabas Bay which, together with Pagbilao Bay, is listed among the most seriously threatened wetlands in Asia (Scott and Poole, 1989). The Pagbilao mangroves occupy the delta of the Palsabangan River and are almost surrounded by fishponds. The forest is second growth with an average age of 20 years. Comprising 19 species (56% of all true mangroves) it has the largest number of mangrove species of any stand in the Philippines and, in terms of the number of tree species, associates and variations in topography and substrate, it is the also the most diverse (NRMC, 1980; Bennagen and Cabahug, 1992).

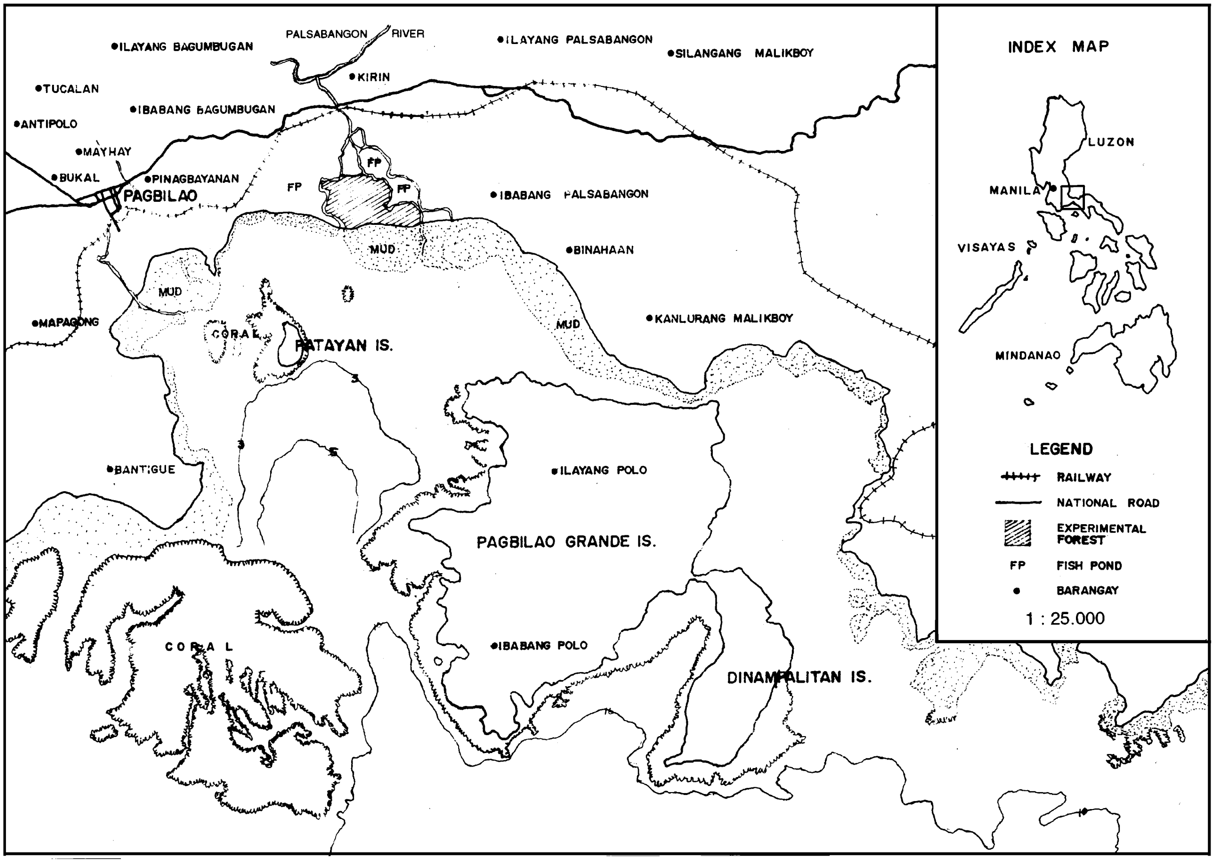

Fig. 1. The Pagbilao region.

Pagbilao Bay is one of the richest, natural marine areas in southern Luzon (Pinto, 1985, 1988). Dolphins and small cetaceans may still be sighted in the bay. Various sources, such as Davies et al. (1990), Dickinson et al. (1990) and IESM (1993), suggest the following picture with regards to terrestrial wildlife populations. Shore birds are the most apparent wildlife species. Around 20 species may be seen feeding in drained and disused fishponds, on mudflats at low tide, or roosting in the mangroves at high tide. Piscivores, such as kingfishers, are common and supplement their diet from the fishponds. The mangroves are a crucial stepping stone in bird migration paths through the Philippines, e.g. the Brahminy kite (*Haliastur indus*). Their loss could be expected to cause increased stress and mortality in these populations (Ong, 1996 (private communication). Few mammal populations remain.

The mangroves have traditionally been exploited by local communities for minor mangrove products. In the 1970s the mangroves were cut for commercial fuel wood and charcoal, and this was a major cause of degradation. These uses have been prohibited since 1981, although illegal cutting of pole-sized trees is still evident (Carandang and Padilla, 1996). The coastal villages of Pagbilao are dependent on fishery resources which include mud crabs and gastropods (found in and near the mangroves—collection of these products is permitted), marine crabs, fish and prawns (taken from the bay). Commercial trawling is prohibited in the bay, and so the catch is taken using artisanal techniques—corrals, traps, bottom set gill nets, and hooks and lines.

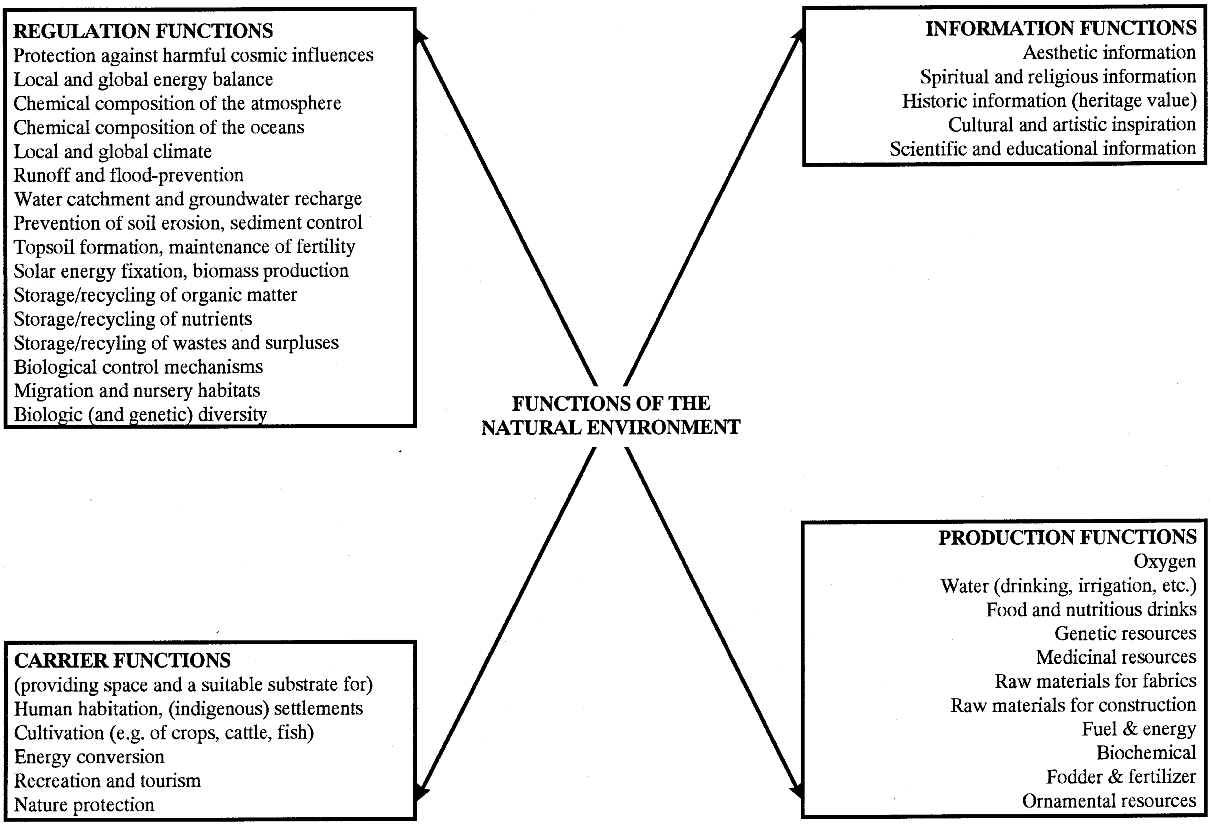

Fig. 2. Functions of the natural environment (adapted from de Groot, 1993).

Fishpond development in the 1980s concentrated on degraded mangrove sites. Mangrove strips were kept to stabilise the dykes and embankments surrounding the ponds. Aquaculture in the study area is exclusively monoculture of milkfish (*Chanos chanos*) by extensive or semi-intensive means (Padilla and Tanael, 1996a). Fishponds are owned by wealthy individuals (a general and an ambassador own fishponds in the study area) who neither live in the municipality nor employ local residents to manage them.

3. Environmental functions of the Pagbilao mangroves

The purpose of this section is to specify the environmental functions of the Pagbilao mangroves. Environmental function has been defined as the provision of environmental goods and/or services by the natural environment for human use (Braat et al., 1979; de Groot, 1993). de Groot (1993) may also be credited with giving the term form by devising a lucid terminology and classification (Fig. 2).

Mangroves perform most of the functions in Fig. 2, but there is much interconnection, e.g. most of the production functions are dependent on the 'fixation of solar energy and biomass production', 'storage and recycling of organic matter' and 'storage and recycling of nutrients'. While a long list of environmental functions supports the argument that mangroves are valuable, interdependencies among functions lead to confusion. This is exacerbated if two or more functions lead to the provision of only one environmental good or service. This article defines environmental function as: 'a set of ecological processes responsible for providing an environmental good or service.' This definition links any good or service to only one environmental function; identification of environmental functions is driven by the goods or services provided. The following discussion identifies the environmental functions of the Pagbilao mangroves, and draws on similar discussions in IUCN (1983), Fisilier (1990), James (1991a,b), Ruitenbeek (1992), Groombridge (1992), Hirsch and Mauser (1992) and Larsson et al. (1993).

Environmental goods are supplied both directly and indirectly by the Pagbilao mangroves. Directly-produced goods include crabs, gastropods, resources for traditional medicines, and raw materials such as wood (also used as a fuel), leaves, *Nipa* shingles, and tannins. Mangrove propagules are collected for (government-sponsored) reafforestation and afforestation programs. Offshore fish and shellfish which use the mangrove ecosystem as a nursery comprise indirectly-produced goods. Mangrove ecosystems are widely held to be primary nursery areas for commercially important species (e.g. MacNae, 1974; Christensen, 1982; WRI and IUCN, 1986) and may contribute to offshore productivity via the outwelling of detritus (Carter, 1988). These paradigms have come into question in recent years (Robertson and Duke, 1987; Parish, 1989; Thollot et al., 1991) and it would appear that the picture is much more complicated. However, some part of the catch from Pagbilao Bay can be attributed to the mangroves (NMC, 1982).

Mangrove ecosystems also provide environmental services. Mangroves stand in sediments which are frequently waterlogged and anoxic. The problem of supplying air to the roots is solved by above-ground root systems which, in turn, determine the physical structure of this ecosystem. The root systems retard water flow. Resistance to water flow serves to dissipate the energy of floodwaters, of particular service during typhoons. It also creates a quiet environment which encourages sedimentation and inhibits resuspension. Sediment stabilisation by mangroves protects shorelines and shore-based activities. Mangrove ecosystems can function as a sink for dissolved and suspended substances removed from through-flowing water by sedimentation as well as uptake by organisms attached to the roots. Fertilizer and pesticide surpluses, industrial wastes and sewage may be removed, and so mangrove ecosystems can perform a waste disposal service. Fishponds adjacent to the study site are, in part, dependent on this service. Fixation of carbon dioxide is also identified as a service but not dealt with further.

Indirect interest in species found in mangrove ecosystems stems from an appreciation of the diversity of life and/or individual species. This may be expressed passively or actively (ecotourism). At present there is no ecotourism in the study area, although migratory species may contribute to ecotourism elesewhere and even in other countries. Carrier functions are central to the management issue for this mangrove stand, but are treated in the development of management alternatives. Mangroves provide services which are associated with knowledge, e.g. the Pagbilao mangroves are frequently visited by students and scientists. Finally mangroves also perform disservices, the most economically significant of which is the support of disease vectors. This disservice is not relevant for the Pagbilao mangroves as there is no malaria in the area.

As shown in Table 1, the Pagbilao mangroves supply a variety of environmental goods and services. The production of water (for use by fishponds) is, for the sake of simplicity, accredited to the mangroves whereas it is more a product of the environment which mangroves occupy. Key ecological processes associated with these environmental functions are also identified. Table 1 also lists current and potential users of the natural mangrove forest.

4. Feedbacks and linkages in mangrove use

Table 1 shows that some ecological processes are common to more than one environmental function, clearly showing interconnectedness within the ecosystem. Should common processes be compromised, the repercussions could be felt over a wide range of users. Evaluation of alternative management strategies should take into account this wider picture of economic-ecological interaction. The systems diagrams presented in

Table 1
Environmental functions of the Pagbilao mangroves

Ecological processes	Environmental function	Good/service	User
Hydrological cycle	Production of water	Water	Aquaculture adjacent to mangrove forest
Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients Maintenance of nursery and migration habits	Production of food and nutritious drink	Offshore fish and shellfish On-site crabs	Artisanal fisheries
Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients	Production of other biotic resources	Medicinal resources	Local communities
Fixation of solar energy and biomass production	Production of raw materials for building, construction and industry	Wood, leaves, tannins, *Nipa* shingles	Local communities
Storage/recycling of organic matter and nutrients			Aquaculture adjacent to mangrove forest
Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients	Production of fuel and energy	Wood, charcoal	Local communities
Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients Maintenance of nursery and migration habitats	Production of juveniles for cultivation	Mangrove propagules	Government (afforestation and reafforestation programs)
Sediment control	Regulation of environmental quality	Disposal of wastes and surplus	Aquaculture adjacent to mangrove forest
Fixation of solar energy and biomass production Storage/recycling of wastes and surpluses		Uptake of carbon dioxide	Global population
Sediment control Buffering of storms	Prevention of soil erosion	Shoreline protection	Local communities Aquaculture adjacent to mangrove forest
Buffering of storms	Flood mitigation	Flood mitigation	Local communities Aquaculture adjacent to mangrove forest
Fixation of solar energy and biomass production Storage/recycling of organic matter and nutrients Maintenance of nursery and migration habitats	Maintenance of biodiversity	Biodiversity	Global population On-site ecotourism Off-site ecotourism
All ecological processes	Scientific and educational information	Knowledge	Scientific and educational community

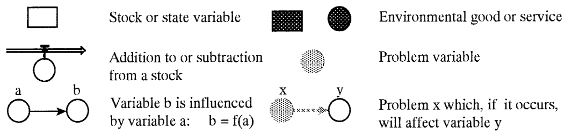

Fig. 3. Explanation of symbols used.

this section offer such an integrated approach. The result is a qualitative model which structures reasoning. The meanings of the various symbols are shown in Fig. 3. The diagrams make use of the basic building blocks of systems analysis, viz. stocks, flows and other variables. Added to these are environmental goods and services and problem variables (Fig. 3).

The system diagrams are presented in Figs. 5–9; Fig. 4 shows how the diagrams are linked. The quality of mangrove cover drives the ecological processes (Fig. 5) which control the performance of environmental functions and so the supply of environmental goods and services (Figs. 6 and 7). Use of these goods and services contributes value to the users (Figs. 8 and 9). An environmental 'problem' develops with overuse where demand for any good or service exceeds its supply. A problem may trigger feedbacks within the ecosystem, or generate costs via linkages between the ecological and the economic systems.

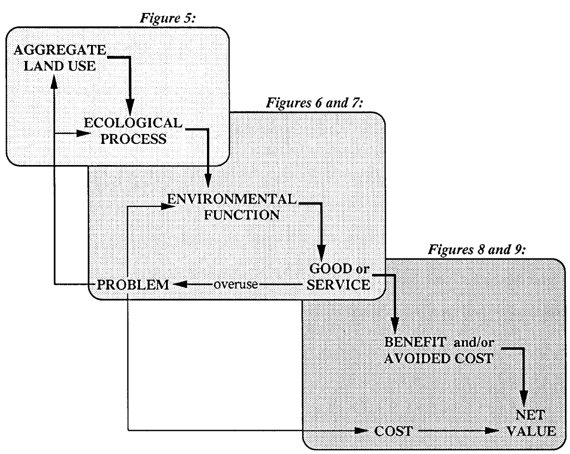

Fig. 4. Structure of the systems diagrams.

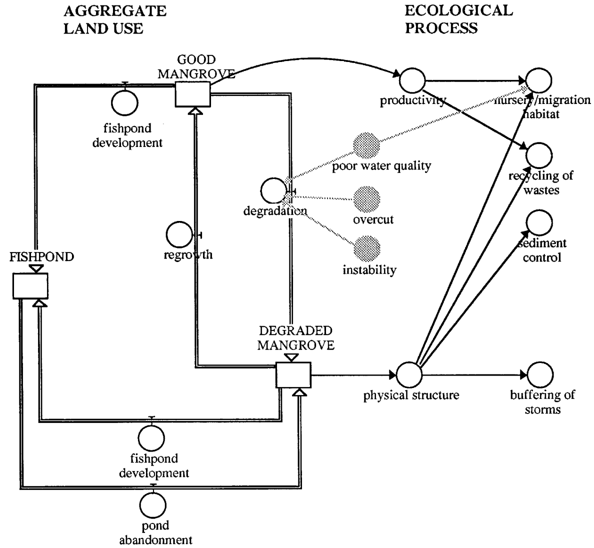

Fig. 5. Aggregate dynamics and ecological processes.

4.1. Aggregate land use and ecological processes

Two mangrove quality categories—good and degraded—are identified in Fig. 5, with degradation and regrowth generating dynamics between them. Mangroves are removed with fishpond development. Historically, this has concentrated on degraded sites. Current information on the profitability of fish farming suggests that the costs incurred in removing mangroves no longer constrain pond development. Fishpond development on sites with good mangrove cover is now possible.

It is assumed that the better the mangrove cover, the better the performance of ecological processes and so of environmental functions. The quality of mangrove cover has a direct influence on two key variables—productivity and physical structure—which direct other ecological processes. The variable 'productivity' is an aggregate of stocks and flows associated with the fixation of carbon and the storage and recycling of carbon and nutrients. Mangrove ecosystems are believed to be highly productive (e.g. WRI and IUCN, 1986). 'Productivity' influences two ecological processes. Firstly, mangrove ecosystems offer a habitat with abundant food for temporary residents such as juvenile aquatic species. Secondly,

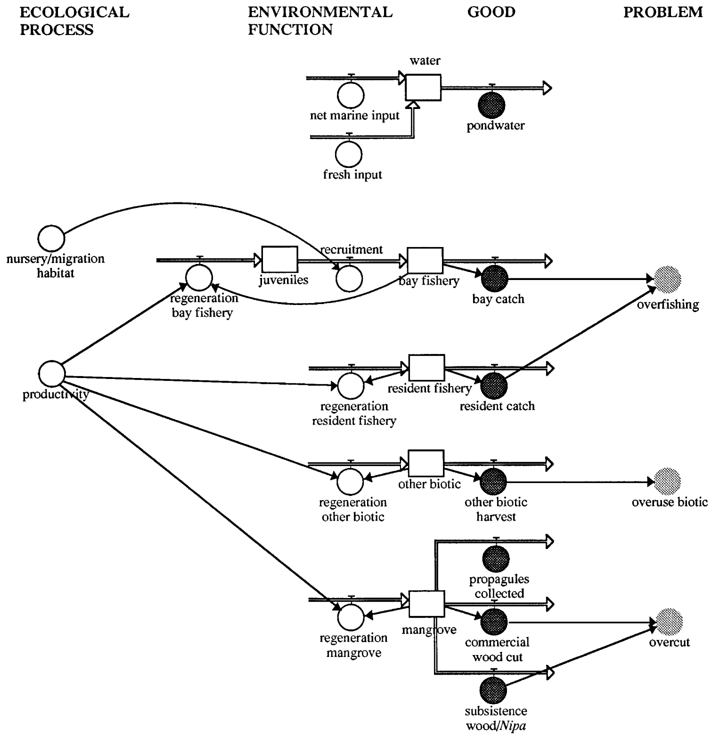

Fig. 6. Production of environmental goods by the Pagbilao mangroves.

by extracting substances from through-flowing waters, mangrove ecosystems serve to process and recycle wastes and surpluses from adjacent fishponds.

The physical structure of mangroves is largely determined by their above-ground root systems and this contributes to four ecological processes. The quiet environment contributes to habitat, particularly for juvenile aquatic species. The exposure of through-flowing waters to organisms fixed onto the roots assists in the recycling of wastes. The retardation of water flow, as well as the roots themselves, facilitate sediment control. The physical structure also mitigates against flooding. Three problem variables are also shown in Fig. 5. These are defined in Figs. 6 and 7. Degradation will be stimulated should these environmental problems occur. Poor water quality also has a direct negative effect on nursery/migration habitat.

The figure implies a smooth transition between all combinations of good and degraded mangrove cover and fishpond development, as well as essentially linear relationships between cover and ecological processes. The real possibility of irreversibilities or discontinuities has not been considered. A key question here is: what is the minimum forest size which could maintain a viable ecosystem? In the absence of information on this point, it is assumed that the current stand is capable of maintaining itself. If such an assumption was unrealistic, then preservation of the Pagbilao mangroves would not be a serious management option.

4.2. *Production of environmental goods and services*

Figs. 6 and 7 describe the production of environmental goods and services by the Pagbilao mangroves. The figures use a common format moving from left to right: ecological process, environmental function, environmental good or service, and environmental problem. Environmental functions and the goods and services they provide

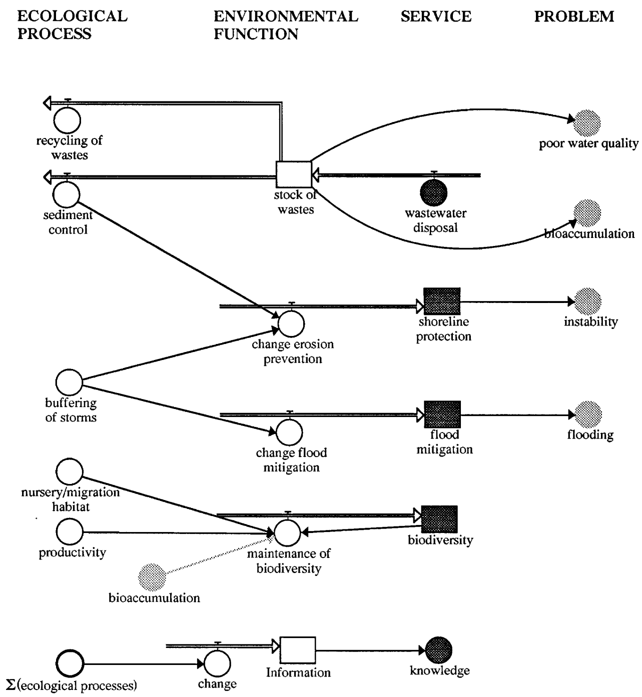

Fig. 7. Provision of environmental services by the Pagbilao mangroves.

are presented as stock-and-flow combinations. The production of environmental goods is straightforward being, in most cases, based on simple population dynamics with harvesting. No distinction is made between the production of wood for construction purposes or for fuel and energy purposes. Overextraction of environmental goods leads to three problems which, should they occur, trigger costs for users by requiring greater harvesting effort (Fig. 8). 'Overcut' also feeds back to Fig. 5, stimulating ecosystem degradation.

The products of fishponds are not environmental goods and so do not appear in Fig. 6. While they may be species, they are still economic goods derived from man-made capital; environmental goods are derived form natural capital. A fish farm is a fish factory, no different from a power plant occupying space once covered by ecosystems and using water in its production process.

Ecological processes in the mangrove ecosystem may affect the structure of waterways, but beyond this they have little influence on water volumes and flows. Water is used to flush fishponds, releasing contaminated water to the environment. Some portion of these wastes and surpluses enters the mangrove ecosystem where they may be taken up by organisms. The problem variable 'poor water quality' develops if the waste load exceeds the system's capacity for removal. Poor water quality feeds back to Fig. 5 by stimulating degradation and adversely affecting habitat. It also triggers costs for aquaculture by killing or retarding the growth of the cultured stock (Figs. 8 and 9). Chemically persistent pesticides, antibiotics, etc. may accumulate in sediments, have direct toxic effects on species, and/or bioaccumulate in food chains. These may lead to adverse effects on biodiversity.

The services 'shoreline protection', 'flood mitigation' and 'biodiversity' are treated similarly. It is assumed that there is a capacity for supplying these services as a result of the quality of mangrove cover. This capacity is represented by a stock. Changes in the quality of cover filters through various ecological processes to cause a change in this capacity. The environmental prob-

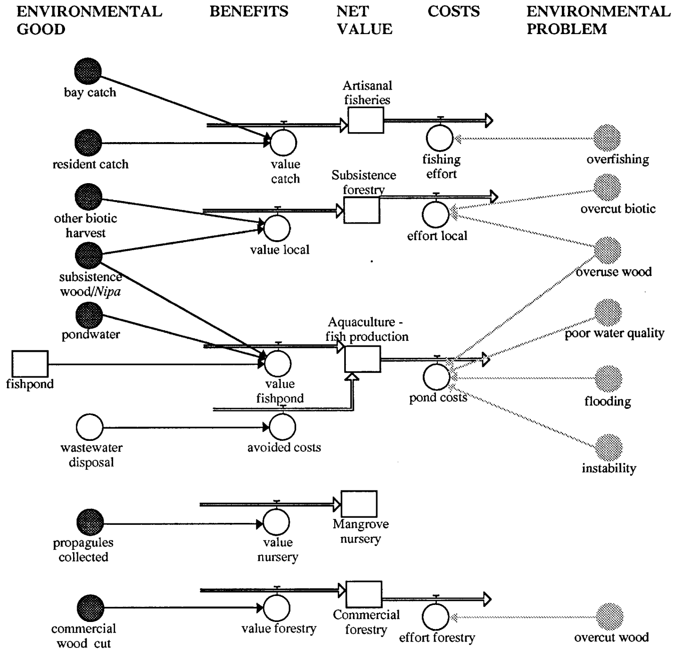

Fig. 8. Values of environmental goods provided by the Pagbilao mangroves.

lems 'sediment instability' and 'flooding' occur if the quality of mangrove cover declines such that insufficient capacity in relation to conditions in the bay remains. Both problems are linked to economic consequences (Figs. 8 and 9) while sediment instability also feeds back to stimulate ecosystem degradation (Fig. 5). No problem variable is associated with biodiversity. Feedbacks from a decline in biodiversity are uncertain, probably long term, and so have been ignored. Rather, biodiversity is viewed as the ultimate indicator of ecosystem quality. Its decline does not trigger costs, merely a reduction in the values derived from this service.

The information content of the ecosystem is assumed to be related directly to the quality of mangrove cover and the performance of ecological processes, and subject to changes in cover and performance. The service provided is knowledge which is a subset of the total information contained. No problem variable is identified, essentially for the same reasons as with a decline in biodiversity.

4.3. Value of goods and services provided by the mangrove forest

Figs. 8 and 9 attempt to capture environmental-economic aspects of using the Pagbilao mangroves. Nine sectors are specified. The approach taken is to imply a net value per sector but considering only 'environmental' benefits and costs. The figures show an annual value derived from using environmental goods and services (flows) accumulating in a net value per sector (stocks). The catch of fish, crabs and shellfish contributes value to the artisanal fisheries. Mud crabs caught on-site comprise about 95% of the value of fisheries. Various goods, mainly for medicines and construction purposes, may be taken by locals from the mangrove ecosystem and so contribute to the value of the subsistence forestry sector. Should the problem variables 'overfishing', 'overcut' and 'overuse biotic' be triggered, costs to these two sectors will rise with increased effort required to harvest these environmental goods.

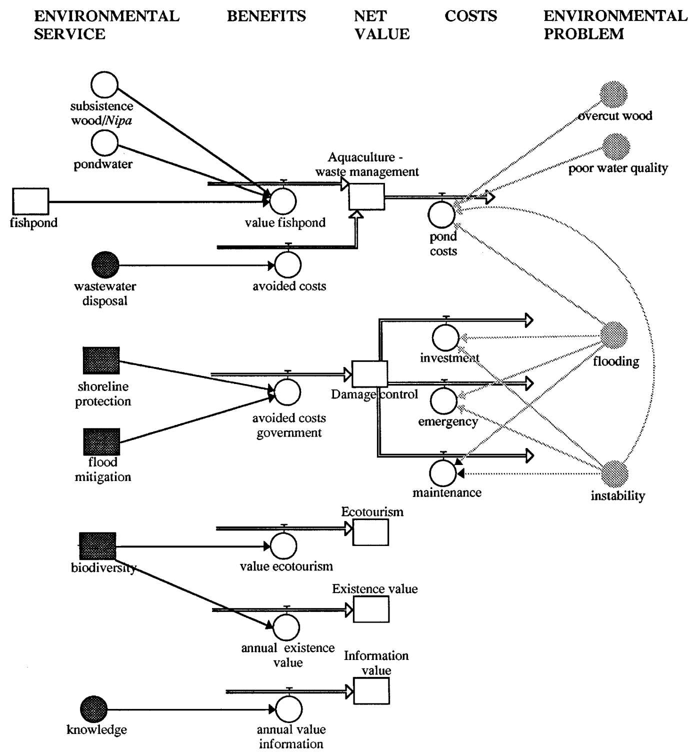

Fig. 9. Values of environmental services provided by the Pagbilao mangroves.

Aquaculture appears in both figures, its activities split into ‘Aquaculture-fish production’ which emphasizes environmental goods, and ‘Aquaculture-waste management’ which emphasizes environmental services. Value accruing to this sector is a function of the area of fishponds (currently zero), water used to flush the ponds, wood used in and around the ponds, and costs avoided by releasing contaminated water into the ecosystem. Costs are incurred should the mangroves be overused as a source of wood; should water quality decline and the stock be killed or its growth retarded; should the ponds be flooded and the stock escape (this occurred during the typhoon in November 1995); and/or should the dykes enclosing the ponds be breached, resulting in the escape of the stock and the need to reconstruct ponds.

The mangrove nursery derives value from the collection of mangrove propagules. It is assumed in the diagrams that sufficient propagules are available. Commercial forestry derives value from cut wood. Costs are incurred should the problem variable ‘overcut’ be triggered.

The shoreline protection and flood mitigation services of mangrove ecosystems help governments and private individuals to avoid the costs of constructing, say, dykes to limit storm and erosion damage. Should the frequency and/or severity of flooding increase or erosion of the shoreline occur, the damage control sector would incur costs: repair of existing infrastructure, investment in new infrastructure, and emergency costs if the local population is endangered by extreme weather events. Biodiversity provides an annual value to two sectors, ecotourism and existence value. Migratory bird species which use the Pagbilao mangroves may contribute to ecotourism in, say, Australia. The knowledge gained from the information content of the ecosystem contributes value to the scientific and educational community.

5. Evaluation of management alternatives

Preservation is the current management strategy of the Pagbilao mangrove forest. Only the cutting of mangrove branches for fuel wood and poles and the collection of resident fish, crabs and gastropods is allowed. However there is continuous pressure to convert part or all of the ecosystem to fishponds. An attempt to develop a fishpond without formal approval is now under litigation. Evaluation of different management alternatives for the site of the forest is performed in the following steps:

- Specification of management alternatives;
- Assessment of goods and services produced for all management alternatives;
- Valuation of goods and services produced for all management alternatives;
- Evaluation of management alternatives.

Comparison of preservation with other management alternatives puts the benefits and cost of preservation into perspective and gives insight into the pressures for change to other types of use. All alternatives involve management regimes that can be considered sustainable under certain conditions. The costs of unsustainability, when these conditions are not met, are analyzed in the next section.

5.1. Management alternatives

Eight management alternatives have been formulated and are described below. The conditions under which the alternative may be considered sustainable are also specified. A condition for all alternatives is that poaching is effectively prevented.

5.1.1. Preservation

Extraction of forest products (wood, *Nipa* shingles, biotic resources for medicines etc.) is not allowed, while the gathering of gastropods and crabs from the ecosystem is. Based on past recovery of the ecosystem under its current management regime, it is reasonable to assume that the ecosystem is capable of further recovery under this alternative. This alternative is essentially continuation of the status quo but with effective prevention of poaching.

5.1.2. Subsistence forestry

This management alternative recognises the dependence of coastal communities on the mangroves for forest products such as fuel wood, charcoal and poles (timber) for fences and posts. Management of the forest will be in the hands of the communities themselves. To sustain the benefits derived from the mangroves, a maximum allowable cut must be imposed and held constant despite projected increases in the demand for forest products. This alternative is sustainable under the following four conditions: (a) the maximum allowable cut takes into account system-wide effects of use; (b) since the maximum allowable cut is less than current estimated demand for forest products, the shortfall can and will be met by increased imports from mountain areas; (c) information on how the allowed cut should best be taken can be communicated to and implemented by the forest users; and (d) entry into this sector is controlled.

5.1.3. Commercial forestry

This alternative provides for exploitation of the mangroves by commercial forestry where a specified commercial volume can be harvested. High value products are to be harvested, primarily timber with incidental fuel wood from tree branches. Various techniques will be applied to encourage regeneration of the forest. Associated sustainability conditions are: the maximum allowable cut takes into account system-wide effects of use and information on how the allowed cut should best be taken can be communicated to and implemented by the foresters.

The following alternatives incorporate aquaculture to varying degrees. A condition for all of these alternatives is the retention of a mangrove strip (buffer zone) of at least 50 m between ponds and the sea, and at least 20 m between ponds and waterways. This conforms to current requirements for pond development. It is estimated that the buffer zones will limit storm damage to loss of the stock once every five years on average. Exploitation of this buffer zone will not be permitted.

5.1.4. Aqua-silviculture

Excluding the buffer zone, approximately one-third of the mangroves will be converted to fishponds. The culturing technique will be based on the semi-intensive monoculture of milkfish. The remaining mangroves will be contained within the ponds. Litter falling from the mangroves will be captured by the ponds in the hope that this will reduce dependency on artificial feeds. The forest will be harvested sustainably by the fishpond owners for their own needs but may also supplement incomes. The following three sustainability conditions must be met: (1) the buffer zone is sufficient for shoreline stabilisation and flood mitigation; (2) the buffer zone is not exploited; and (3) wastes released by the ponds into the nearby environment do not overload the system's capacity for self-purification and so good water quality is maintained.

5.1.5. Semi-intensive aquaculture

This alternative converts the forest to fishponds and their water distribution system, with the only remaining mangroves in the buffer zones. Ponds will be stocked with milkfish at around 6000 fingerlings/ha per crop and managed using semi-intensive techniques. Sustainability conditions are the same as for Aqua-silviculture.

5.1.6. Intensive aquaculture

This alternative also converts the mangrove stand to fishponds, but management of the ponds is on a more intensive basis (higher cropping densities, more frequent cropping and greater use of food supplements and chemicals). The recommended intensive technology is alternation of intensive prawn farming with extensive or semi-intensive milkfish farming. Sustainability conditions are the same as for Aqua-silviculture.

5.1.7. Commercial forestry/intensive aquaculture

This alternative is a mixture of alternatives Section 5.1.3 and Section 5.1.6. Excluding the buffer zones, approximately one-third of the mangroves will be converted to fishponds for intensive aquaculture and the remainder will be exploited by commercial forestry. The two activities are separate. Sustainability conditions from alternatives Section 5.1.3 and Section 5.1.6 apply.

5.1.8. Subsistence forestry/intensive aquaculture

This alternative is the same as alternative Section 5.1.7 except that the remaining forest, excluding the buffer zones, is exploited sustainably for subsistence forestry products. Sustainability conditions from alternatives Section 5.1.2 and Section 5.1.6 apply.

5.2. Effects on goods and services

System diagrams as presented in Section 4 were used to identify the effects which each management alternative would have on the production of goods and services. Field surveys were then undertaken to assess current production and changes in production resulting from alternative management regimes (Janssen and Padilla, 1996, 1997). The effects on shore protection, biodiversity and ecotourism linked to the different alternatives could not be quantified. A forestry expert, a marine biology expert and a zoology expert were invited to provide expert judgement on the relative performance of the alternatives with regards to these three effects (Carandang, 1996 (private communication), Guarin, 1996 (private communication), Ong, 1996 (private communication), Janssen, 1992). Table 2 shows the results. Consumption or negative production could occur if an ecosystem drained resources from other systems, for example, through export of pollutants or import of clean water. This is not the case for the study site.

5.2.1. Production of goods

Resident and transient fish species were sampled to assess fisheries productivity of the mangrove reserve. The fisheries component of this study (Ong and Padilla, 1996) also updated information from more thorough studies conducted in previous years (De la Paz and Aragones, 1985; Pinto, 1985, 1988; Fortes, 1994). The experimental forest supports both on-site (resident species) and off-site (transient species) fisheries. The estimation of sustainable harvest of fishery resources presented difficulties as the fisheries surveys for this study, as well as previous studies, did not cover stock assessment. Simplifying assumptions were made to arrive at some measure of abun-

Table 2
Annual production of goods and provision of services under different management alternatives

	Unit	A	B	C	D	E	F	G	H
Goods									
Pond water	—/+++	0	0	0	++	+++	+++	++	++
Bay catch	kg/ha per year	1264	1230	1230	950	63	63	189	189
Residential catch	crabs/year	714	694	694	536	71	71	178	178
Other biotic	—/+++	0	+++	+++	+	+	+	+	++
Propagules	—/+++	+++	+++	+++	0	0	0	+	+
Commercial wood	m^3/year	0	0	317	176	0	0	169	0
Subsistence wood	m^3/year	0	307	0	0	0	0	0	170
Nipa shingles	'000/year	0	45	45	0	0	0	23	23
Fishponds: milkfish	tons/year	0	0	0	161	537	59	22	22
Fishponds: prawns	tons/year	0	0	0	0	0	158	58	58
Services									
Wastewater disposal	tons/year	0	0	0	21	41	100	50	50
Shoreline protection	—/+++	+++	+++	+++	++	+	+	++	++
Flood mitigation	—/+++	+++	+++	+++	++	+	+	++	++
Biodiversity	—/+++	+++	++	+	+	0	0	+	+
Knowledge	—/+++	+++	++	+	+	0	0	+	+

A, Preservation; B, Subsistence forestry; C, Commercial forestry; D, Aqua-silviculture; E, Semi-intensive aquaculture; F, Intensive aquaculture; G, Commercial forestry/intensive aquaculture; H, Subsistence forestry/intensive aquaculture.
+++, large production; ++, moderate production; +, small production; 0, no production.

dance and productivity. The results show that the experimental forest supports a small on-site fishery and contributes minimally to off-site fisheries. Use of a production function would have provided a more precise approach to assess the impacts of the management alternatives on the value of off-site fisheries. Limited knowledge on the complex interactions involved, and total lack data on the size of stocks of fish over time prevented such an approach (Spaninks and Beukering, 1997).

Fuel wood, timber and *Nipa* shingles are the primary forest products to be derived from the Pagbilao mangrove reserve. Subsistence forestry yields goods demanded by coastal communities, mostly fuel wood, charcoal and poles (timber) for fences and posts. The quantification and valuation of goods and services proceeded from field surveys of the mangrove reserve in 1995. Three zones or ecotones were identified: landward, middleward and seaward. Sample plots were established in each ecotone and tree density, tree dimensions and subsequently wood volume were measured or computed. Litter traps were set to estimate litter fall and to determine nutrient content. Projected timber yield was estimated over time using an empirical equation for the Philippines with age of stand and site index as explanatory variables. Subsistence forestry is estimated to produce about 262 m^3 of wood products compared to 272 m^3/year by commercial forestry; commercial forestry is therefore the more efficient (Carandang and Padilla, 1996).

The performance of aquaculture ponds converted from mangroves was also assessed (Padilla and Tanael, 1996a,b). Several studies were compared to assess the long-term prospects of aquaculture operations in the mangrove reserve. The primary objective was to identify the appropriate (sustainable) aquaculture technology and the corresponding production levels. Conversion of the mangrove forest to fishponds results in high production levels. For semi-intensive aquaculture production was estimated to exceed 597 tons/year of milkfish; for intensive aquaculture of prawns alternating with extensive culture of milkfish, estimates of 66 tons/year of milkfish combined with 175 tons of prawns were derived (Padilla and Tanael, 1996a,b).

5.2.2. Production of services

Waste water disposal is an environmental service used only by aquaculture. Padilla and Tanael (1996a) and Padilla and Tanael (1996b) were able to quantify use of this service for the various aquaculture alternatives. Intensive aquaculture is the highest user due to higher stocking rates and the use of artificial feeds, pesticides and fertilisers. For non-aquaculture alternatives it is assumed that no use is being made of the waste processing capacity of the mangrove forest. Use of the remaining services is estimated qualitatively. While the buffer zones are intended to secure the coastal plain from erosion and from flooding, their capacity in this regard is still less than that of an intact ecosystem, or of one which is only two-thirds its original size. Biodiversity and knowledge services are most abundant in the Preservation alternative (Section 5.1.1) and non-existent for Semi-intensive and Intensive aquaculture (Section 5.1.5 and Section 5.1.6). Of the remaining alternatives, subsistence forestry with its softer intervention into the ecosystem is considered to perform best with regards to these services.

5.3. Valuation of goods and services

Market prices and shadow prices of substitutes were used to value goods. Market prices of fish observed at local markets during the field surveys were used to value fisheries. It is estimated that 87.75% of the landed price of fish covers the costs of harvesting, the remainder is the value of the fish in-situ (NSCB, 1996). The use value of the forest products derived from the mangroves by subsistence forestry is net of gathering cost. When households are denied access to mangrove forest resources, the shadow price attached to the forest products is equivalent to the cost they incur in obtaining alternative products. Such a cost is equal to the market price of the alternative product plus the transport cost from the market to the point of use. Shadow prices for fuelwood and other goods not traded on the market were linked to the cheapest substitute. For commercial forestry net value is calculated using market prices of the timber products less the costs of transport, extraction and related costs incurred in managing the forest. Net value of aquaculture is calculated using data on production, market prices and operating costs of existing fishponds in the vicinity of the study site.

Net value of the management alternatives can be estimated using these results and is shown in Table 3. In this table values are combined to show the values produced according to economic sectors in the local economy: bay and residential catch are combined into fisheries, *Nipa* is included in subsistence and commercial forestry, and milkfish and prawns are combined into aquaculture. Net values linked to other biotic resources and propagules are considered marginal and therefore ignored. Values shown are annual values for the entire study area. Since alternatives are assumed to be sustainable, the time horizon can be assumed to be indefinite. With regards to aquaculture, the long life of ponds in the vicinity, some around 40 years old, lends support to this assumption. Development costs and other capital costs are valued according to the borrowing rate for capital in real terms. Typhoon damage through flooding of the ponds or breaching of the dykes is included as a 10% reduction of the annual harvest, based on two crops per year and loss of one crop once every 5 years (Janssen and Padilla, 1996, 1997).

For the five alternatives which permit harvesting of forest products, the highest value is generated by Commercial forestry (Section 5.1.3). Aquaculture alternatives perform better than the forestry (Section 5.1.2/Section 5.1.3) and preservation (Section 5.1.1) alternatives in terms of the value of goods produced. Semi-intensive aquaculture (Section 5.1.5) performs better than intensive aquaculture (Section 5.1.6) due to high development costs linked for the latter and to constraints set by sustainable management of the ponds. However the performance of both alternatives is very sensitive to changes in prices. Milkfish are produced for the local market and their price level is relatively stable. The price of prawns is determined on the world market and shows strong fluctuations. In this study a price of 185 pesos/kg is used for prawns. Should this price increase above 214 pesos/kg the value of goods produced by intensive aquaculture will be higher than those

Table 3
Net annual value of goods and services under different management alternatives.

	Unit	A	B	C	D	E	F	G	H
Goods									
Fisheries	'000 pesos	165	161	161	124	8	8	40	40
Subsistence forestry	'000 pesos	0	349	0	0	0	0	0	189
Commercial forestry	'000 pesos	0	0	416	218	0	0	229	0
Aquaculture: fish	'000 pesos	0	0	0	5648	18801	13577	4992	4992
Mangrove nursery	0/+++	+	+	+	0	0	0	0	0
Total goods	'000 pesos	165	510	577	5990	18809	13585	5261	5221
Services									
Aquaculture: waste	0/+++	0	0	0	+	++	+++	++	++
Damage control	0/+++	+++	+++	+++	++	+	+	++	++
Ecotourism	0/+++	+++	++	0	0	0	0	0	+
Existence value	0/+++	+++	++	++	+	0	0	+	+
Information value	0/+++	+++	+++	++	+	0	0	+	+
Total services	0/+++	+++	+++	++	+	+	+	+	+

A, Preservation; B, Subsistence forestry; C, Commercial forestry; D, Aqua-silviculture; E, Semi-intensive aquaculture; F, Intensive aquaculture; G, Commercial forestry/intensive aquaculture; H, Subsistence forestry/intensive aquaculture.
+++, large contribution to value; ++, moderate contribution to value; +, small contribution to value; 0, no contribution to value.

produced by semi-intensive aquaculture. Aqua-silviculture performs better than the alternatives combining forestry and aquaculture. Note that the mangrove nursery is unlikely to survive the conversion to fish farming.

Services are valued only qualitatively in Table 3 and an attempt is made to aggregate these sources of value. The improvements to the ecosystem which preservation (Section 5.1.1) provides is felt across all users permitted by this alternative. The main gains are felt by damage control (avoided costs), fisheries, the mangrove nursery, and existence and scientific values. No use is made of the ecosystem's capacity to process wastes, and so this service scores a zero. However, such a capacity exists. The total value from services is considered a maximum for this alternative. Subsistence forestry (Section 5.1.2) also scores a maximum, even though this alternative scores somewhat lower with regards to the ecotourism and existence value sectors: harvesting of forest products is assumed to affect biodiversity adversely. Commercial forestry's (Section 5.1.2) aggregate score is lower than alternatives Section 5.1.1 and Section 5.1.2. This alternative precludes contributions to ecotourism as well as reducing biodiversity and information values. As with subsistence forestry, the forest remains intact and so its capacity to mitigate against flooding and prevent erosion is high.

The aquaculture alternatives (Section 5.1.4–Section 5.1.8) score poorly with regards to the system's capacity to provide services for use. While the waste disposal capacity of the system is used in these alternatives, the buffer zones supply only a minimal capacity for damage control. Where more of the stand is kept, this capacity is larger. All alternatives, except that including subsistence forestry (Section 5.1.8), preclude any contribution to ecotourism. Some existence and information values remain in alternatives where more mangroves than just the buffer zone are retained.

5.4. Comparison with other studies

A literature survey was conducted to compare results from the Pagbilao study with other mangrove studies (Spaninks and Beukering, 1997). Table 4 shows the results from this study (last

Table 4
A comparison of net annual benefits of goods and services provided by mangrove forests

	Thailand, Christensen (1982)	Fiji, Lal (1990)	Indonesia, Ruitenbeek (1992)	Pagbilao, (1996)
Forestry	30	6	67	151
Fisheries	130	100	117	60
Agriculture	165	52		
Aquaculture	−2106			−7124
Erosion			3	
Biodiversity			15	
Local uses	230		33	
Waste disposal		5820		

All values in US $/ha per year, 1US $ = 25 pesos.

column) compared with results from studies in Thailand, Fiji and Indonesia. To facilitate comparison all results are presented in US $/ha. Please note that these values relate to different years. No data were available to adjust for inflation rates and changes in exchange rates in the different countries. The values for forestry and fisheries are similar to those derived in the other studies. The value of aquaculture is listed as a negative value since this value represents the foregone benefits of not converting the forest to fishponds and can therefore be considered as an incremental cost of preservation. The value used by Lal (1990) for purification involves construction of a sewage treatment plant. Since water pollution is not a problem in Pagbilao this value cannot be attributed to waste disposal in Pagbilao (see also Dixon and Lal, 1994).

5.5. Ranking of management alternatives

Based on the value of total goods semi-intensive aquaculture (Section 5.1.5) is the most preferred alternative followed by intensive aquaculture (Section 5.1.6). Preservation (Section 5.1.1) and also the forestry alternatives (Section 5.1.2 and Section 5.1.3) generate substantially less value in terms of goods. Based on total services, however, preservation (Section 5.1.1) and subsistence forestry rank higher and the aquaculture alternatives much lower.

Because the provision of services could not be valued it proved impossible to calculate total value of the alternatives. This raises the question of whether the value of the services provided by preservation (Section 5.1.1) will be large enough to offset its lower value of goods. The difference in total goods between the two alternatives as shown in Table 3 is more than 18 million pesos, almost US $6500/ha per year (Table 4). Using the other studies presented in Table 4 to derive a very rough indication of the value of services, the preservation alternative (Section 5.1.1) would seem unlikely to generate total values higher than Semi-intensive aquaculture (Section 5.1.5). Therefore is can be concluded that, on the basis of valuation, semi-intensive aquaculture (Section 5.1.5) is the most preferred alternative.

It is important to note that valuation has its limitations. Distribution of income is a central political issue, especially in developing countries. Benefits from fisheries are received by local, usually poor, fishermen. Benefits from fishponds, due to their high investment costs, accrue to distant, rich investors. Conversion of mangroves to fishponds therefore results in an unfavourable change in income distribution which is not reflected in total value. It also creates areas that are no longer accessible by the local population. A second limitation of valuation is that it assumes the possibility of substitution between human and natural capital. This creates serious difficulties if irreversible effects, such as the loss of biodiversity, are to be included.

Table 5
Problem variables triggered by failure of management conditions

Condition	A	B and C	D	E	F	G and H
Failure of buffer zones			Instability, flooding	Instability, flooding	Instability, flooding	Instability, flooding
Excessive wood harvest		Overcut				Overcut
Poaching of wood products	Overcut, instability	Overcut, instability	Instability, flooding	Instability, flooding	Instability, flooding	Overcut, instability, flooding
Overloading of natural waste management			Poor water quality	Poor water quality	Poor water quality, bio-accumulation	Poor water quality, bio-accumulation

A, Preservation; B, Subsistence forestry; C, Commercial forestry; D, Aqua-silviculture; E, Semi-intensive aquaculture; F, Intensive aquaculture; G, Commercial forestry/intensive aquaculture; H, Subsistence forestry/intensive aquaculture.

Table 6
Change in net annual value if all sustainability conditions are violated simultaneously.

	A	B	C	D	E	F	G	H
Goods								
Fisheries	↓	↓	↓	↓↓	↓↓	↓↓	↓↓	↓↓
Subsistence forestry	-	↓↓	-	-	-	-	-	↓↓
Commercial forestry	-	-	↓↓	-	-	-	↓↓	-
Aquaculture	-	-	-	↓	↓↓↓	↓↓↓	↓↓	↓↓
Mangrove nursery	↓	↓	↓	-	-	-	-	-
A: total goods (min)	111	227	249	4044	3	3	1789	1775
B: total goods (max)	165	395	440	5949	6398	4622	3525	3498
C: total goods (sust.)	165	510	577	5990	18 809	13 585	5261	5221
Services								
Aquaculture	-	-	-	-	↓↓	↓↓↓	↓	↓
Damage control	↓	↓	↓	↓↓	↓↓↓	↓↓↓	↓↓	↓↓
Ecotourism	↓	↓	-	-	-	-	-	↓
Existence value	↓	↓	↓	↓↓	-	-	↓↓↓	↓↓↓
Information value	↓	↓	↓	↓↓	-	-	↓↓↓	↓↓↓
A: total services (min)	++	++	+	0	0	0	0	0
B: total services (max)	+++	+++	++	+	0	0	0	+
C: total services (sust.)	+++	+++	++	+	+	+	+	+

A, Preservation; B, Subsistence forestry; C, Commercial forestry; D, Aqua-silviculture; E, Semi-intensive aquaculture; F, Intensive aquaculture; G, Commercial forestry/intensive aquaculture; H, Subsistence forestry/intensive aquaculture.
↓↓↓, large reduction in value (67-100%); ↓↓, moderate reduction in value (33-67%); ↓, small reduction in value (0-33%); -, no reduction in value.

6. Costs of unsustainability

The values of each management alternative were estimated in the previous section. The management alternatives are designed to be sustainable, with sustainability holding under a number of conditions. Failure of these conditions generates costs and/or reductions of benefits. The purpose of this section is to assess what could happen if certain conditions do not hold and the management alternatives fail in being sustainable (see also Parks and Bonifaz, 1994). Because sustainability is the norm, the effect of failure to meet this norm may be labelled the 'costs of unsustainability'. Four conditions are tested in this section:
1. Failure of the buffer zones to mitigate against flooding and stabilizing the shore;
2. Excessive extraction of wood;
3. Poaching of wood products cannot be prevented;
4. Overloading of natural waste management to process and remove wastes and surpluses.

Effects may be traced through Figs. 5–9 by linking failure of a condition with the problem variable triggered and subsequent effects on the supply of environmental goods and services. The link between condition and problem variable is presented in Table 5 for each management alternative. Table 6 presents total (monetary) value and effects on the provision of environmental services when all sustainability conditions fail simultaneously. The discussion below explains how this table is derived.

6.1. Failure of the buffer zones

An essential condition in all alternatives including aquaculture (Section 5.1.5–Section 5.1.8) is the retention of buffer zones which will ensure sediment stability and mitigate against flooding. If buffer zones are inadequate for these purposes, the problem variables 'instability' and 'flooding' will be triggered (Fig. 7). 'Instability' stimulates ecosystem degradation (Fig. 5) and will lead to the poorer performance of all environmental functions.

Both ‘instability’ and ‘flooding’ cause direct costs to users (Figs. 8 and 9). The bulk of these costs will be borne by aquaculture which will lose its stock more frequently. Aquaculture alternatives (4, 7 and 8), where more mangrove cover than just the buffer zones is retained, will be less vulnerable to sediment instability and flooding and the impacts of these problems are more likely to remain small-scale. There is the risk with Semi-intensive and Intensive aquaculture (5 and 6) that sediment instability could spread beyond the study site and/or that flood waters could penetrate further inland. Damage would then be incurred by more economic activities, with costs borne by the damage control sector.

6.2. Excessive extraction of wood

Management alternatives 2, 3, 7 and 8 are based on the sustainable extraction of forest products. A condition with Subsistence forestry (2 and 8) is that entry into the sector can be controlled so that extraction will not exceed a maximum allowable cut. Local demand for wood products already exceeds this maximum (Carandang and Padilla, 1996) and will only increase with population growth. It is highly unlikely that agreements between government and local communities to limit entry into the subsistence forestry sector will be effective under such pressure, and so over-extraction is inevitable. Similar controls are required for Commercial forestry (3 and 7) to limit harvest to a maximum allowable cut. Given pressure for short-term profit maximization, this condition is also likely to fail.

Excessive extraction of wood triggers the problem variable ‘overcut’ (Fig. 6) in all alternatives containing forestry. This in turn, stimulates ecosystem degradation (Fig. 5) and poorer performance of environmental functions, with all mangrove users being worse-off. The forestry sectors, now with a limited lifetime of activities, will bear the brunt of the costs of unsustainability.

6.3. Poaching of wood products

A key condition for sustainable management is the effective prevention of poaching. Under the current management regime, wood is poached by local residents for construction purposes and fuel, and by fishpond managers who use wood for fencing, reinforcing dykes, delivery of feeding supplements and construction purposes. Given the local demand for wood and the difficulties in limiting access to the mangrove ecosystem, it is highly unlikely that poaching can be prevented. Two possible effects of wood poaching are identified.

Firstly, poaching would cause wood harvesting in all forestry alternatives to exceed the maximum allowable cut. It could also lead to a level of illegal wood extraction above the ecosystem’s capacity for regeneration within the preservation (Section 5.1.1) alternative given the growing demand for wood products and their increasing availability within the mangrove ecosystem. The problem variable ‘overcut’ (Fig. 6) would then be triggered. As discussed above, this would stimulate ecosystem-wide degradation (Fig. 5) and reduce performance of all environmental functions.

Secondly, poaching will be concentrated in areas of easy access and particularly along the edges of waterways. This may cause bank erosion and even trigger the problem variable ‘instability’ (Fig. 7). ‘Instability’ has implications for degradation (Fig. 5). In alternatives excluding aquaculture, the impacts of poaching are likely to remain localized. However in alternatives incorporating aquaculture poaching could compromise the buffer zones, with impacts and costs which have been discussed above.

6.4. Overloading of natural waste management

All alternatives including aquaculture depend on the natural system’s capacity to remove and process wastes and surpluses released into the natural environment. Semi-intensive and extensive aquaculture in Pagbilao Bay have not yet overloaded this capacity, although the possibility exists that even more aquaculture could exceed a threshold and so cause water quality problems to develop. The likelihood of this is greatest with intensive aquaculture techniques which use high stocking rates, chemicals to control pests and diseases, and feeding supplements.

'Poor water quality' is one of two problem variables which could be triggered (Fig. 7). This not only stimulates degradation, it also has direct impacts on the mangrove habitat (Fig. 5). Poor water quality causes costs to aquaculture and, if it is persistent, these activities will become uneconomic. This is most likely for intensive aquaculture (Section 5.1.6) and possible for semi-intensive aquaculture (Section 5.1.5). Alternatives Section 5.1.7 and Section 5.1.8, which comprise some intensive aquaculture could experience periodic problems with water quality. It is assumed that this would reduce, but not compromise, the profitability of these activities.

The second problem variable, 'bioaccumulation', would be triggered only by intensive aquaculture through the use of chemicals (Fig. 7). Bioaccumulation of persistent micropollutants could have an adverse effect on biodiversity, and so on dependent activities (viz. ecotourism, existence value and information value). However these effects are relevant only for aquaculture/forestry alternatives (Section 5.1.7 and Section 5.1.8) since insufficient biodiversity and information remain with intensive aquaculture (Section 5.1.6).

6.5. Changes in the ranking of alternatives if all sustainability conditions fail

Failure of the sustainability conditions are not independent events. For example, inadequate enforcement of environmental regulations can result in inadequate buffer zones, excessive extraction, poaching and unauthorized emissions of wastes. Table 6 shows for each good and service the range of expected change in value if all sustainability conditions fail simultaneously.

These ranges are combined with the values of goods and services (Table 3) to calculate the value of total goods and services. The table provides: (A) total goods and services (min) representing the pessimistic end of the ranges (↓, ↓↓ and ↓↓↓ = −33, −66 and −100%); (B) total goods and services (max) representing the optimistic end of the ranges (↓, ↓↓ and ↓↓↓ = −0, −33 and −66%); and (C) total goods and services (sust.) representing sustainable conditions as listed in Table 3.

From Table 6 it can be concluded that violating the sustainability conditions results in a lose-lose situation—the total value of all alternatives decline. Preservation shows a decline because of ecosystem degradation. The forestry alternatives show a decline in long-term wood production combined with a decline in the provision of most services. The aquaculture alternatives face a loss in long-term fish production. Although the pattern of changes differs considerably between alternatives the ranking of alternatives is relatively insensitive to failure of these sustainability conditions. The rankings associated with total goods (max) are the same as the ranking under sustainability; with semi-intensive (Section 5.1.5) on the first position and preservation (Section 5.1.1) on the last. However if the pessimistic values (total goods (min)) are compared with the ranking under sustainability, semi-intensive aquaculture (Section 5.1.5) and intensive aquaculture (Section 5.1.6) shifted to last position. This is the disaster scenario for both alternatives where pollution prevents operations completely. The most likely position between these extremes is difficult to predict. Uncertainty centres on two questions: how much waste can the system manage without water quality declining and at what stage are the effects of declining water quality irreversible? In general, semi-intensive aquaculture runs fewer risks than intensive aquaculture, as does partial conversion to aquaculture compared to conversion of the whole mangrove stand.

7. Conclusions and recommendations

In this study ecological and economic information are combined to support the evaluation of management alternatives for the Pagbilao mangrove forest. A key problem which ecologists face is the high degree of interconnectedness within and between ecosystems. This makes it difficult to predict what is going to happen, let alone understand what is going on. The concept of 'environmental function' is used in combination with systems diagrams to address this problem. System diagrams are used to identify and assess goods and services produced by the ecosystem under different management regimes. These goods and services are then valued to assess the economic efficiency of the management regimes. This final section assesses the usefulness of the concept of environmental function, summarizes the results of the study and offers recommendations for further research.

Mangroves are complex systems which provide a variety of goods and services for human use. The high degree of interconnectedness within such ecosystems leads to uncertainty and unpredictability. In particular it means that environmental goods and services are rarely produced independently. The concept of environmental function was used in this study to communicate the environmental values of the Pagbilao mangroves. The interface between environmental supply and societal demand for goods and services from the mangroves could then be detailed. This was effective in demonstrating the complexity of ecosystem performance to non-ecologists, and in particular the multiple interdependencies involved in providing environmental goods and services. Systems diagrams were used to envisage ecosystem performance and to 'think through' what the alternative management options and their associated conditions meant in terms of future supply of mangrove goods and services. In combination with valuation of selected products, the evaluation of alternative management regimes was then based on the integration of ecological and economic information.

This study assessed the conversion of the 110.7 ha of protected mangrove forest in Pagbilao, Philippines into aquaculture, forestry and combined uses. Considerable effort was invested in data collection and modelling. Despite this effort results have to be used with care. This holds especially for the results linked to off-site fisheries. It proved to be very difficult to establish a clear link between the size of the mangrove forest and the value of off-site fisheries. A production function approach proved not to be feasible. Further most services could not be valued and so could only be included qualitatively. Given these limitations the following can be concluded:

- For the Pagbilao mangrove forest semi-intensive aquaculture is the policy alternative with the highest economic value. If sustainability conditions are not met total values of all alternatives are reduced. However, semi-intensive aquaculture still produces the largest total value except under extreme conditions.
- Environmental services, such as biodiversity, shore protection and flood mitigation, need to be priced very high to make Preservation the alternative with the highest value. If it is accepted that preservation of the mangrove forest is in the interest of the world community, it is not reasonable to make the Philippines pay the price of preservation. The Global Environmental Facility should then be prepared to pay the incremental costs if preservation of the forest is considered worthwhile.

Although biodiversity is considered crucial to the decision to preserve the forest, it proved impossible to put a monetary value on changes in biodiversity. This raises questions regarding the limitations of valuation. Is it possible to value irreversible effects such as the loss of life, the loss of ecosystems, the loss of species, the loss of works of art, etc. Another crucial issue in the case of Pagbilao is the distribution of wealth. The income from the fish ponds is earned by distant investors. Also conversion to fishponds creates areas inaccessible to the local population. Equity issues cannot be addressed adequately using net value as a decision criterion.

7.1. Further research

- Further research on ecological linkages both within mangrove ecosystems as between mangrove and other coastal ecosystems is essential.
- Assessment of production functions between mangroves and mangrove-related products, such as fisheries, can be seen as an extension of these efforts. However, it is questionable whether assessment of production is feasible in applications such as Pagbilao.

- Further research on approaches for valuing environmental services such as biodiversity is necessary. This should include an appraisal of the appropriateness of valuation to support decisions including this type of environmental values.

Acknowledgements

This article presents results from the project 'Economic valuation of mangrove-fish pond interactions'. This project is part of the program for 'Collaborative Research in the Economics of Environment and Development (CREED)' which is funded by the Directorate of International Co-operation of the Dutch Ministry of Foreign Affairs. The authors would like to thank Dr Jose E. Padilla, Dr M.S. delos Angeles, Dr A. Carandang, Dr P. Ong and M. Tanael from Resources, Environment and Economics Centre for studies Inc., Pasig City, Philippines, for their contributions to the project, and the three anonymous referees for their thorough review of the manuscript and their suggestions for improvement.

References

Bennagen, E., Cabahug, D., 1992. Mangrove forest accounting: physical accounts (Technical Appendices). The Philippine Natural Resources Accounting Project (NRAP Phase 1), Manila.

Braat, L.C., van der Ploeg, S.W.F., Bouma, F., 1979. Functions of the natural environment and economic-ecological analysis. Institute for Environmental Studies publication no. 79-9, Institute for Environmental Studies, Vrije Universiteit, Amsterdam, in co-operation with the World Wildlife Fund.

Carandang, A., Padilla, J.E., 1996. Assessment of forest resources of the Pagbilao mangrove forest. In: Janssen, R., Padilla, J.E. (Eds.), 1997. Mangroves or Fishponds? Valuation and Evaluation of Management Alternatives for the Pagbilao Mangrove Forest (Final report), Resources, Environment and Economics Centre for Studies Inc., Pasig City, Philippines / Institute for Environmental Studies (IVM), Vrije Universiteit, Amsterdam, The Netherlands.

Carter, R.W.G., 1988. Coastal Environments: An Introduction to the Physical, Ecological and Cultural Systems of Coastlines. Academic Press, London.

Christensen, B., 1982. Management and utilisation of mangroves in Asia and the Pacific. FAO Environment Paper No. 3. FAO, Rome.

Davies, J.P., Magsalay, P.M., Rigor, R., Mapalo, A., Gonzales, H., 1990. A Directory of Philippine Wetlands. Vol. 1. AWBPFI, Cebu City, the Philippines.

De la Paz, R., Aragones, N., 1985. Mangrove fishes of Pagbilao (Quezon Province, Luzon Island), with notes on their abundance and seasonality. Nat. Appl. Sci. Bull. 37 (2), 171–190.

Dickinson, E.C., Kennedy, R.S., Parkes, K.C., 1990. The Birds of the Philippines. BOU Checklist No. 12. Dorset Press, Dorchester, UK.

Dixon, J.A., Lal, P.N., 1994. The management of coastal wetlands: economic analysis of combined ecological-economic systems. In: Environment and Emerging Development Issues. Partha Dasgupta and Karl-Göran Mäler, Oxford, Clarendon Press.

Fisilier, J.L., 1990. Living off the Tides: strategies for the integration of conservation and sustainable resource utilization along mangrove coasts. Report of the Environmental Database on Wetland Interventions (EDWIN), Leiden, the Netherlands.

Fortes, M.D., 1994. Mangrove resource valuation project: marine ecology component (final report). Philippine Institute for Development Studies, Makati City, Philippines.

Groombridge, B. (Ed.), 1992. Global Biodiversity: Status of the Earth's Living Resources. Chapman and Hall, London.

de Groot, R., 1993. Functions of Nature: Evaluation of Nature in Environmental Planning, Management and Decision making. Wolters-Noordhoff, Groningen, the Netherlands.

Hirsch, D., Mauser, A., 1992. The economic value of mangroves. Two case studies: Mida Creek and Funzi Bay. School of Environmental Studies, Eldoret, Kenya, University of Amsterdam, The Netherlands.

Institute for Environmental Studies and Management. 1993. An environmental impact statement for the Quezon coal-fired thermal power plant project in Grande Island, Pagbilao, Quezon.

International Union for Conservation of Nature and Natural Resources. 1983. Global Status of Mangrove Ecosystem. IUCN Commission on Ecology Papers No. 3.

James, R.F., 1991a. The Valuation of Wetlands: approaches, methods and issues. PHPA/AWP. Sumatra Wetland Project Report No. 29, Asian Wetland Bureau, Bogor, Indonesia.

James, R.F., 1991b. Wetland Valuation: guidelines and techniques. PHPA/AWP. Sumatra Wetland Project Report No. 31, Asian Wetland Bureau, Bogor, Indonesia.

Janssen, R., 1992. Multiobjective Decision Support for Environmental Management. Kluwer, Dordrecht p. 232.

Janssen, R., Padilla, J.E., 1996. Valuation and evaluation of management alternatives for the Pagbilao mangrove forest. CREED Working Paper Series, International Institute for Environment and Development (IIED), London/Institute for Environmental Studies (IVM), Vrije Universiteit, Amsterdam, The Netherlands.

Janssen, R., Padilla, J.E. (Eds.), 1997. Mangroves or fishponds? Valuation and evaluation of management alternatives for the Pagbilao mangrove forest (Final report), Resources, Environment and Economics Centre for Studies Inc., Pasig City, Philippines/Institute for Environmental Studies (IVM), Vrije Universiteit, Amsterdam, The Netherlands.

Lal, P.N., 1990. Conservation or Conversion of Mangroves in Fiji. Occasional Papers of the East-West Environment and Policy Institute, paper No. 11.

Larsson, J., Folke, C., Kautsky, N., 1993. Ecological limitations and appropriation of ecosystem support by shrimp farming in Columbia. Beijer Discussion Paper Series, No. 29.

MacNae, W., 1974. Mangrove Forests and Fisheries. Indian Ocean Fishery Commission IOFC/DEV/74/34. Food and Agriculture Organisation and United Nations Development Programme, Rome. 35pp.

Mann, K.H., 1992. Ecology of Coastal Waters. Blackwell, Oxford.

National Mangrove Committee, 1982. Initial findings: an assessment of mangrove areas as spawning grounds for fishes and crustaceans. Bakawan 2 (2), 3.

Natural Resources Management Centre, 1980. Mangrove inventory of the Philippines using LANDSAT data. Bakawan 1(1).

National Statistical Coordination Board, 1996. A case study on natural resource accounting: Philippine marine fishery resources, National Statistical Coordination Board, Philippines.

Ong, P., Padilla, J.E., 1996. Assessment of fisheries-related functions of the Pagbilao mangrove forest. In: Mangroves or fishponds? Valuation and evaluation of management alternatives for the Pagbilao mangrove forest (Final report), Resources, Environment and Economics Centre for Studies Inc., Pasig City, Philippines/Institute for Environmental Studies (IVM), Vrije Universiteit, Amsterdam, The Netherlands.

Padilla, J.E., Tanael, M., 1996a. Assessment of milkfish and prawn culture in brackish water ponds. In: Mangroves or fishponds? Valuation and evaluation of management alternatives for the Pagbilao mangrove forest (Final report), Resources, Environment and Economics Centre for Studies Inc., Pasig City, Philippines/Institute for Environmental Studies (IVM), Vrije Universiteit, Amsterdam, The Netherlands.

Padilla, J.E., Tanael, M., 1996b. Evaluation of integrated aquaculture and silviculture. In: Mangroves or fishponds? Valuation and evaluation of management alternatives for the Pagbilao mangrove forest (Final report), Resources, Environment and Economics Centre for Studies Inc., Pasig City, Philippines/Institute for Environmental Studies (IVM), Vrije Universiteit, Amsterdam, The Netherlands.

Parish, J.D., 1989. Fish communities of interacting shallow-water habitats in tropical oceanic regions. Mar. Ecol. Prog. Ser. 58, 143–160.

Parks, P., Bonifaz, M., 1994. Non sustainable use of renewable resources: mangrove deforestation and mariculture in Ecuador. Mar. Resource Econ. 9, 1–18.

Pinto, L., 1985. Community structure and population dynamics of mangrove fishes of Pagbilao, Quezon, Philippines. Ph.D. thesis, University of the Philippines, Diliman, Quezon City, 170 pp.

Pinto, L., 1988. Population dynamics and community structure of fish in the mangroves of Pagbilao. Philippines. J. Fish Biol. 33 (Supplement A), 35–43.

Robertson, A.I., Alongi, D.M. (Eds.), 1992. Tropical Mangrove Ecosystems. American Geophysical Union. Washington D.C.

Robertson, A.I., Duke, N.C., 1987. Mangroves as nursery sites: comparison of the abundance and species composition of fish and crustaceans in mangroves and other near-shore habitats in tropical Australia. Mar. Biol. 96, 63–90.

Ruitenbeek, H.J., 1992. Mangrove management: an economic analysis of management options with a focus on Bintuni Bay, Irian Jaya. Environmental Management Development in Indonesia a Project (EMDI) Environmental Reports, 8. (ISSN 1181-6457;8) Jakarta and Halifax, Indonesia.

Scott, D.A., Poole, C.M. 1989. A Status Overview of Asian Wetlands. No. 53 AWB, Kuala Lumpur, Malaysia.

Spaninks F., van Beukering, P. 1997. Economic valuation of mangroves: a review of techniques and case studies with special attention to the production function approach. CREED Working Paper Series, International Institute for Environment and Development (IIED), London/Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands.

Thollot, P., Kulbicki, M., Wantiez, L. 1991. Temporal patterns of species composition in three habitats of the St. Vincent Bay (New Caledonia): coral reefs, soft bottoms and mangroves. In: M. Ricard (Ed.) Proceedings ISRS Congress, Noumea, New Caledonia. pp. 127-136.

World Resources Institute and the International Union the Conservation of Nature, 1986. World Resource 1986. Basic Book, Inc., New York.

Zamora, P.M., 1989. Philippine mangroves: their depletion, conversion and decreasing productivity. Wallaceana 58, 1–5.