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Coral reefs are a resource of immense importance for a large number of people, especially the coastal populations of the developing world. Available information on coral reefs in Sri Lanka and Southeast Asia has been used to evaluate the ecological services provided by coral reefs and to assess the long-term economic benefits derived from some of the ecosystem functions. The minimum economic value of coral reefs in Sri Lanka is estimated at USD 140 000–7 500 000 km^{-2} reef over a 20-yr period. The economic consequences of coral mining were investigated and economic costs (USD 110 000–7 360 000) were found to exceed net benefits (USD 750 000–1 670 000) by as much as USD 6 610 000 km^{-2} reef when analyzed over 20 years in tourism areas. The highest costs were associated with decreased tourism (USD 2–3 million) and increased erosion (USD 1–4 million). However, in rural areas there is still a strong incentive for coral mining, because coral mining in the short-term perspective provides a more profitable business compared to fishing and agriculture. The results have implications for management and show that Sri Lankan legislation banning coral mining in the coastal zone is beneficial to the country's economic development.

INTRODUCTION

Tropical coastal zones contain a variety of ecosystems such as coral reefs, mangroves, and seagrass beds, which are all utilized as resources. The coral reef is the most diversified and complex marine ecosystem. It provides humans with many benefits including food from reef fish, recreation for tourists, coastal protection and lime for the building industry. Hence, many people depend on coral reefs for their livelihood in monetary terms as a source of income as well as for subsistence. With most coral reefs situated in the developing world their importance as a resource is tremendous. However, poor management has resulted in resource depletion and most of the world's coral reefs, especially those situated in the vicinity of human settlements, are under great pressure from human activities.

Being the source of important resources it is remarkable that there are so few studies on the ecological economics of coral reefs. In a recent economic analysis of Indonesia's coral reefs, Cesar et al. (1) concluded that the cost over 25 years of destructive coral reef uses, such as coral-mining, was between USD 176 000 and USD 903 000 km^{-2} reef. Hodgson and Dixon (2) compared the benefits provided by logging and sustainable uses of coral reefs in Bacuit Bay, the Philippines and found that a logging-ban would result in 70% higher gross revenues from use of ecosystem functions than would continued logging. In addition, the carrying capacity of coral reefs, with regard to tourism use, was determined by Dixon et al. (3) for a coral reef marine sanctuary in the Caribbean. Costanza et al. (4) reviewed the available information on valuations of world ecosystem services and concluded that the quantifiable benefits of coral reefs add up to USD 607 500 km^{-2} reef yr^{-1}.

Case studies may prove useful in developing techniques for studying the ecological economics of coral reefs; if many such studies are conducted the compiled information will provide the comprehensive picture necessary for a general applicable model. Such a case study is provided by Sri Lanka. It has an easily defined coastline of some 1550 km, which supports highly productive ecosystems including coral reefs (5–7). Almost half of the 17 mill. human population lives in coastal areas and a majority of the country's economic centers are situated near the coast (8). The large population in combination with modern methods of resource utilization have resulted in considerable pressure on coastal resources (8–11). Subsequently, coral reefs have been degraded and their areal extent is continuously decreasing due to various human disturbances including destructive fishing methods, coral mining, boating (anchor damage), ornamental-fish collection, pollution, etc. (8, 10, 11).

There is reason to believe that more information about the environmental economics of Sri Lanka's reefs, and other reef areas, could generate incentives for new management strategies. The apparent resource depletion, which is probably caused by financial goals that are guided by short-term benefits such as coral mining, may be shown to result in long-term costs. This paper aims to determine a minimum estimate of the economic value of coral reefs in Sri Lanka, and to evaluate the economic loss from coral-reef destruction. We do so by looking at the coral reef as a resource and investigating the various benefits it may offer in terms of reef fishery, tourist attraction, coastal protection and coral mining.

QUANTIFIABLE ECONOMIC VALUE OF CORAL REEF FUNCTIONS

The first step in an integrated ecological-economic analysis is to define the ecosystem functions in relation to the economy (12). Ecosystem goods and services are commonly used to define the benefits derived from ecosystem functions. In this paper, we estimate some of the goods and services provided by coral reefs in economic terms. Total quantifiable economic value (TQEV) is estimated by adding the value of different compatible functions of the coral reef ecosystem. However, not all ecosystem functions can be valued in monetary terms. Therefore, the economic benefits, which are accredited to the coral reef ecosystem in this study, are a minimum estimate of the true value.

An indirect economic benefit of the coral reef is that of the physical-structure function which protects against coastal erosion. Direct economic benefits are provided through resource use, for example the fish-habitat function (through fishing or ornamental fish collection) and the tourist attraction function (through tourism). Coral mining is an example of a resource use which will provide economic benefits through the production of lime. Costs of coral mining will include labor costs (direct cost of resource use), reduction of indirect economic benefits, as a result of a reduction in the physical-structure function of the reef, and reduction of economic benefits derived from resource uses of the affected coral reef functions such as fisheries (derived from the fish-habitat function) and tourism (derived from the tourist attraction function).

Fish-Habitat Function

The economic benefits of the coral reef fish-habitat function are derived from fishing which is a resource use of considerable eco-

Fishing is the most important economic activity in the coastal zone and many communities depend on it for their livelihoods (8). The most common vessel type is the outboard motor boats, but also traditional wooden crafts as well as larger inboard engine boat are used (13). Photo: H. Berg.

nomic significance for Sri Lanka. The fish-habitat function also contributes to the economy of Sri Lanka through ornamental fish collection for the aquarium trade. However, in this analysis only the value of the food fishery is considered. Fish contribute 65% to the total animal protein consumption, and 13% of total protein consumption in the country (8). In 1990, fisheries contributed with some 2.3% of GDP (13).

A large proportion of the coastal population is critically dependent on fisheries. In 1989, the coastal fishing population numbered some 412 500 people supported by almost 100 000 fishermen of whom more than 90% had fishing as their main source of income (13). Coastal fish production peaked at 184 049 tonnes (t) in 1983, but declined later (in 1996, 149 300 t) due to civil unrest (10, 13, 14).

The proportion of the catch made up by reef-associated species is difficult to assess, but has been estimated at 15% of coastal fish landings (8). This is similar to the estimated 10–15% that coral reef fisheries contribute to total fisheries yield in the Philippines (15), but lower than the 25% coral reef fisheries contribute within other parts of the Indo-Pacific region (16) (Table1).

The value of the fish-habitat function can be estimated using the effect-on-production approach (EOP) (17). The quality of the environment determines the ecosystem productivity. This includes the output of the fish-habitat function of coral reefs, since there is a close relationship between habitat structure and fish-community composition (18). Resource uses impacting on environmental quality, e.g. habitat deformation, will affect the productivity of the ecosystem (2, 11, 19). Hence, sustainable fisheries maximizes the value of the fish-habitat function in the long term.

In this study, based on previous reports, it is assumed that maximum sustainable yield (MSY) for coral reef fisheries in Sri Lanka is 10 t km^{-2} yr^{-1} (Table 1). In the case of coral reef fisheries, MSY can be used as a proxy for maximum economic yield (MEY). Fish production data show that catches declined considerably from 1984 onwards (Table 2). This was due to the start of civil unrest in the north and east of the country, which hindered the continuous development of the fishery (13). Hence, the only data that can be used to estimate catch per boat at MSY is from 1980–1983. The vessel type most commonly used in coral reef fisheries in Sri Lanka is fiberglass boats with outboard engines (10). Catch per boat at MSY is assumed to be between 6 and 8 t $boat^{-1}yr^{-1}$ for outboard motorised crafts (Table 2). The value of food fish in 1988 prices is Rs 32.8 kg^{-1} (USD 1.0 kg^{-1}) (13). According to Joseph (13) 25% of Sri Lankan fishermen work from outboard engine boats with an average crew of 2.3 fishermen $boat^{-1}$. Traditional wood rafts are also used in Sri Lanka as well as larger 3.5 t boats with an inboard engine, which hold many fishermen. Operational costs are between Rs 181–227 day^{-1} and labor costs Rs 12 000 $fisherman^{-1}$ yr^{-1} for outboard engine boats, all assuming 240 days of fishing per year (13). Total cost of fishing using outboard engine boats is therefore Rs 71 000–82 000 $boat^{-1}$ $year^{-1}$ or Rs 31 000–35 000 man^{-1} $year^{-1}$. Thus, the total cost of fishing 10 t km^{-2} yr^{-1} would be approximately Rs 89 000 and Rs 137 000 km^{-2} reef yr^{-1} (1998 price). Hence, the net value of the coral reef fish-habitat function can be estimated to between USD 7800 and USD 9800 km^{-2} reef yr^{-1} in 1994 prices (20).

In Sri Lanka, the fish-habitat function is not only a resource in terms of food fish, it also contributes to the ornamental-fish collection industry (8, 10, 13, 21). The value of ornamental fish exports have increased from Rs 68 mill. in 1990 to Rs 273 mill. in 1995, which represents an increase in exports from 153 t to 331 t (14). Hence,

Table 1. Estimates of maximum sustainable yield (MSY) for coral reef fisheries (t = tonnes).

Location	MSY (t km^{-2} yr^{-1})	Author(s)
Fiji	10.2	Jennings and Polunin (49)
Philippines	10—20	Russ (50)
Sri Lanka	4.5	Samarakoon (51)
South Pacific	10-20	Munro (52)
Sri Lanka	22.5	Total MSY for Sri Lanka's coastal fisheries divided by proportion species dependent on coastal habitats and areal extent of coastal habitats (estimated from 8, 29, 53, 54).

Table 2. Fish yield and number of vessels for three types of fishing craft in Sri Lanka 1980–1987 (t = tonnes).

Year	Inboard motorized craft			Outboard motorized craft			Traditional craft		
	Catch per boat (t)	No. of craft	Output (t)	Catch per boat (t)	No. of craft	Output (t)	Catch per boat (t)	No. of craft	Output (t)
1980	23.8	2 305	54 825	7.2	8 020	57 432	3.4	15 722	53 007
1981	25.5	2 209	56 454	7.4	8 865	65 512	4.1	12 885	53 109
1982	18.0	3 347	60 379	6.8	9 745	66 727	3.9	14 101	55 426
1983	20.0	2 861	57 375	7.0	10 086	70 539	3.9	14 312	56 135
1984	16.7	2 781	46 625	4.5	10 800	48 660	2.9	14 404	41 357
1985	17.5	2 727	47 862	4.3	11 515	49 950	3.2	13 303	42 454
1986	17.8	2 766	49 249	4.2	11 340	47 684	3.5	13 412	47 333
1987	19.2	2 657	50 960	4.7	10 543	49 341	3.5	13 865	48 977

Data from refs 13 and 55.

the estimated USD 7800–9800 km^{-2} yr^{-1} should be taken as the minimum value of the fish-habitat function.

Tourist-Attraction Function

Coastal tourism is a mainstay of the Sri Lankan economy, and contributes about USD 200 mill. yr^{-1} to the national economy (22). The fringing reefs of Sri Lanka are close to the coast and easily accessible for tourists (8). The economic benefits from the tourist-attraction function are derived, largely through international tourism, although domestic tourism is also an important source of income in areas of recreational value (23, 24). The value of the tourist-attraction function is dependent on the level of tourism development near the coral reef. However, even if no such development is currently in place, the potential for deriving economic benefits from the tourist-attraction function exists for a large number of reef areas in Sri Lanka.

The value of the tourist-attraction function can be defined through a financial-revenue approach (FR) or through a contingent valuation approach (CV) (17). The financial revenue approach calculates the direct financial profits provided by tourism that are dependent on the coral reef, while the contingent-valuation approach investigates tourists' willingness to pay to maintain the coral reef (25). Thus, the contingent-valuation approach also includes social values, thus, these estimates could be expected to be higher than the value arrived at by the financial revenue approach.

The most developed tourist resort area in Sri Lanka is Hikkaduwa on the southwestern coast of the island. Hikkaduwa has undergone rapid development of its tourist facilities, from only one hotel in the 1960s to 9 large hotels and 125 guesthouses, 40 restaurants, 157 shops, and 5 dive stations in 1994 (8). The same year, the net financial profit from the tourism industry to the Hikkaduwa economy has been estimated to be approximately Rs 27 mill. (24).

If the financial revenue approach is applied in this area, the tourist-attraction function would be estimated to be Rs 7.6 mill. (USD 150 000 km^{-2} reef yr^{-1}). In a survey conducted in 1993, some 7% of foreign visitors stated that the fringing coral reef, which covers an area of about 25 ha, was their main reason for visiting Hikkaduwa (23). With total annual net profits of Rs 27 mill. per 25 ha (24) or USD 2 200 000 km^{-2} reef, 7% equals USD 150 000. For areas less developed than Hikkaduwa, the tourist attraction function is assumed to be 3% of this value. Although only rough, this provides a first order estimate of the tourist-attraction function in areas with only some minor tourism.

A contingent valuation survey conducted in 1994 found that foreign tourists' willingness to pay for one year's use of the Hikkaduwa reef was 256 Rs, and that more than 10 000 visitors used the reef (26). Hence, the net value of the tourist-attraction function is USD 214 000 km^{-2} reef yr^{-1}.

Hikkaduwa is one of the most popular coastal resort areas in Sri Lanka. Viewing corals from glass bottom boats is a major tourist attraction, which may cause physical damage to the reef as corals may be broken when the boats run over shallow coral patches (8).
Photo: H. Berg.

The impact of coastal erosion is most severe along Sri Lanka's western and southwestern coasts and results in damage to or loss of houses, hotels, and other coastal structures, and undermining of roads, as well as contributing to the loss or degradation of valuable land (28).
Photo: H. Berg.

Physical-Structure Function

The physical-structure function may provide people with indirect economic benefits without requiring any resource use. An actively growing coral reef is a dynamic ecosystem which is under continuous influence from both biotic and abiotic factors that may alter the reef structure. The coral reef may produce a structure that can act as a wavebreaker if the reef fringes the shore. Thus, a coral reef and the physical structure it holds may hinder coastal erosion and protect economically important constructions and land uses (1, 25, 27)

The economic benefits of the physical-structure function can be described in different ways. One procedure is through the preventive-expenditure approach (PE) which is defined by the cost of replacing the coral reef with protective constructions, e.g. groynes, revetments, and underwater wavebreakers off the coast (25). Another approach is to look at the loss of property-value (PV), which is defined by the cost of land loss (i.e. price of lost land, buildings, roads, etc.) as a result of coastal erosion plus the loss of income resulting from lost land-use opportunities (e.g. loss of agricultural land) (17).

The fringing reefs in Sri Lanka are generally about a few hundred meters in width. If the coral reefs are estimated to have a width of 200 m then, on average, 1 km^2 of coral reef protects 5 km of coastline against erosion. Coastal erosion is most severe along the western and southern coasts of Sri Lanka (28). Erosion in affected areas averages 0.4 m yr^{-1} (29). Hence, it is assumed that 1 km^2 of coral reef prohibits 2000 m^2 of erosion per year (5000 m x 0.4 m = 2000 m^2). The price of coastal land varies in Sri Lanka and is dependent on the level of infrastructure and tourism facility development. In rural areas, such as parts of the south coast of Sri Lanka, the land-use value may be defined as the value of coconut production which equals USD 0.08 m^{-2} (30). In an urban area such as Balapitiya the land price is estimated to be USD 6 m^{-2} while in an urban tourist area such as Hikkaduwa it is estimated to be USD 86 m^{-2} (31) (recalculated in 1994 prices). Hence, the property-value and land-value

Coral mining from the sea has caused coastal erosion in south and southwestern Sri Lanka. Corals are burnt in kilns to produce lime. Photo: M.C. Öhman.

approach shows that the annual cost of coastal erosion resulting from the loss of land is between USD 160 and USD 172 000 km^{-2} reef yr^{-1}, depending on land price and use.

Taking a preventive-expenditure approach it is apparent that in Sri Lanka large sums of money have been invested in the building of coastal protection structures to avoid further degradation of the coast. The average cost varies between USD 246 000 and USD 836 000 km^{-1} protected coastline (Table 3). Thus, the economic consequences for replacing the coastal protection function of a degraded reef will vary between USD 1 230 000 and USD 4 180 000 km^{-2} reef yr^{-1}, depending on the type of coastal protection structures used.

TOTAL QUANTIFIABLE ECONOMIC VALUE

Adding the abovementioned coral reef functions including the fish-habitat function, the tourist-attraction function and the physical-structure function give a minimum estimate of the total quantifiable economic value of USD 13 000–USD 4 404 000 km^{-2} reef yr^{-1} (1994 prices). Calculated over 20 years, with a discount rate of 9%, the net present value of 1 km^2 would be USD 142 000–USD 7 504 000 (Table 4). These figures should be interpreted as lower range estimates, as some of the most important values of coral reefs, such as those of future generations, and intrinsic values, cannot be quantified (1). There are also quantifiable benefits, such as ornamental-fish collection, which have not been included in the analysis due to lack of data. However, the current analysis is made to elucidate the long-term economic costs that follow from destructive use of coral reefs, such as coral mining. The continuation of these activities is often justified by their short-term financial benefits, but a more balanced assessment of the benefits and costs may provide a sufficient reason to arrest the current destruction of coral reefs in Sri Lanka (1).

FINANCIAL COSTS AND BENEFITS OF CORAL MINING

Corals are collected for ornamental purposes as well as mined for building material and lime production (27, 32, 33). Export of corals in Sri Lanka was banned following the implementation of CITES regulations (8, 11). Although illegal, mining of sea corals is still occurring and is most prevalent along the western and southern coasts where the fringing reefs are easily accessible (34–38). Where coral mining occurs it may destroy whole reefs and hence is one of the major causes of coral-reef degradation in some reef areas of Sri Lanka (8, 10). Data from coral mining in the village of Rekawa, in southern Sri Lanka, indicate that 1 km^2 of reef could be completely mined within 5 years (34, 35, 39). The reef structure is the habitat of the associated fish community. Hence, variation of the habitat, such as live coral cover and structural complexity, may influence fish abundance, fish diversity, and overall species composition (18). Thus, removal of corals and overall reef destruction may reduce the value of the fish-habitat function (40, 27), but also negatively influence the tourist-attraction function (41, 42) and the physical-structure function (43). In fact, coral mining can result in an irreversible collapse of a whole coral reef ecosystem (32).

However, in a short-term perspective coral mining may be a profitable business; coral miners may earn three times the opportunity cost of rural labor; i.e. their likely income in absence of coral mining (37). The regular kiln-worker though earns approximately the same as the opportunity cost of labor (37).

Table 3. Costs of building coastal protection structures in Sri Lanka (recalculated in 1994 year prices).

Construction/location	Length (m)	Value		
		Rs million	USD million	USD km^{-1}
Revetments[a]:				
West coast	9 100			
Southwest coast	37 900			
South coast	8 320			
Total	55 320	680	13.6	246 000
Groynes[a]:				
West coast	2 200			
Southwest coast	3 400			
South coast	1 020			
Total	6 620	166	3.3	502 000
Schemes (breakwaters, etc)[b]:				
West coast (Negombo and Moratuwa)	16 000	669	13.4	836 000

The figures may not add up due to rounding
[a] CCD (28) [b] CCD (29)

Table 4. Accumulated net present value of coral reefs in Sri lanka over 20 years (USD 1000 km^{-2} reef).

	Fish-habitat function		Tourist-attraction[2] function			Physical-structure function				Total quantifiable value	
Year	low	high	[3]FR low	[3]FR high	[4]CV	[6]PV low	[6]PV high	[5]PE low	[5]PE high	low	high
Year 1	7	9	4	148	208	0.1	158	1230	4180	12	4397
Year 5[1]	30	38	21	700	985	0.6	669	1230	4180	52	5203
Year 10[1]	50	63	39	1309	1841	1.0	1104	1230	4180	90	6084
Year 15[1]	63	79	55	1839	2587	1.3	1386	1230	4180	120	6845
Year 20[1]	71	89	69	2300	3234	1.5	1570	1230	4180	142	7504

[1] All values are discounted with a financial discount rate of 9% (cf. 22)
[2] 6% annual growth of the tourist industry (cf. 22)
[3] FR = financial revenue approach
[4] CV = contingent valuation approach
[5] PE = preventive expenditure-approach
[6] PV = property-value and land value approach

Most of the mined coral is converted to lime in kilns through burning, from calcium carbonate ($CaCO_3$) to calcium hydroxide ($Ca(OH)_2$). Theoretically, 1 kg of $CaCO_3$ should result in the production of 740 g $Ca(OH)_2$, i.e. 74% weight lime. Processing of mined corals in Tanzania has been reported to be far less efficient with only 40–50% of the coral being converted to lime (27). Therefore, as a first rough estimate, it is assumed that the efficiency of the coastal lime kilns in Sri Lanka is between 50 and 70% weight lime (34, 35, 37).

Preliminary studies of coral biomass indicate that 1 m^2 of reef containing branching corals (*Acropora* spp.) can support some 37–59 kg of live coral (U. Lindahl, unpubl. data). This represents the top 30–50 cm of the reef. In Sri Lanka, coral is collected manually and this top part of the reef is what is easily collected by coral miners (A. Rajasuriya, unpubl. data). Therefore, an actively growing reef would be estimated to contain 37 000–59 000 t km^{-2} of extractable coral, which would result in the production of between 18 500 t and 41 300 t lime; i. e. 37 000 t multiplied by 50 % and 59 000 t multiplied by 70%.

From 1 km^2 of coral reef a total of between 7400 t and 11 800 t, i. e. one fifth of 37 000 and 59 000 coral could be mined annually for 5 years. The price of lime is estimated at 4000 Rs t^{-1} (35) (recalculated in 1994 prices). The annual value of coral mining from 1 km^2 of coral reef is therefore 14.8–33 mill. rupees (i. e. 7400 x 0.5 x 4000 and 11 800 x 0.7 x 4000) or USD 296 000–661 000, for 5 years. However, there are also costs involved. The direct cost of coral mining includes the opportunity cost of labor and the cost of fuelwood to operate the kilns. The opportunity costs of labor are estimated at 22.5% of total production value (34, 37), while fuel costs make up 12.5% of the total production value (34). The annual direct cost of coral mining adds up to USD 104 000–231 000, which gives a net value of USD 192 000–430 000 km^{-2} reef yr^{-1}.

ECONOMIC COSTS OF CORAL MINING

To estimate the cost of coral mining from a decreased fish-habitat function, tourist-attraction function, and physical structure function, it is assumed that the reef would gradually degrade until it would be completely destroyed after 5 years. The value of the physical-structure function would decline in relation to the destruction of the reef and, thus, become zero after 5 years. The fish-habitat function is assumed to decrease to one fifth of the original yield within 5 years. On a reef at Mafia Island, Tanzania, it was shown that the diversity and abundance of fish on a mined site were 4 and 7 times lower, respectively, compared to an unmined site (27). After 10 years, fish yield is assumed to increase to 50% of the original MSY. It has been estimated that some 50% of the species caught in the nearshore fisheries in Sri Lanka depend directly on coral reefs for their survival (10). Recolonization and development of new "climax" coral communities, after a major disturbance, has been estimated to take 17 and 50 year for fast-growing (e.g. branching *Acropora*) and slow-growing corals, respectively (27). Since a pristine coral reef is a major attraction to tourists, it is assumed that they will switch to other destinations within 2 years after the mining has started. By that time the benefits from the tourist-attraction function have gone to zero (44).

Coral mining is assumed to be continuous and the economic consequences are analyzed on an annual basis. Therefore, the reduction in value of the fish-habitat and tourist-attraction functions is an average for each year. The same is true for the physi-

Figure 1. Accumulated net present benefits of coral mining and net present costs from reduction of coral reef function values over 20 years (USD 1000 km^{-2} reef) high estimate. Loss from the physical-structure function is estimated from property value approach (PV) and loss from tourist-attraction value from the contingent valuation approach (CV).

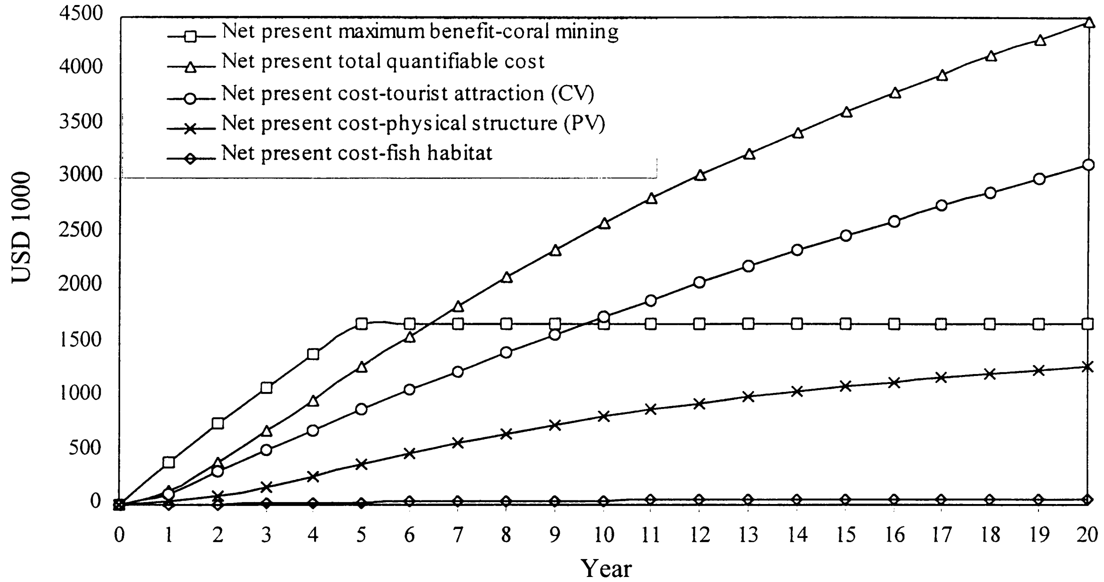

Table 5. Accumulated net present benefits from coral mining and accumulated net present costs from reduction of coral reef function values over 20 years (USD 1000 km^{-2} reef).

	Financial Benefits		Economic Costs											
	Coral mining		Fish-habitat function		Tourist-attraction function			Physical-structure function				Total quantifiable cost	
Year	low	high	low	high	¹FR low	¹FR high	²CV	³PV low	³PV high	⁴PE low	⁴PE high	low	high
Year 1	177	394	1	2	2	74	104	0.0	32	1230	4180	4	4286
Year 5	749	1671	16	20	19	626	881	0.4	378	1230	4180	35	5081
Year 10	749	1671	32	40	37	1235	1737	0.8	813	1230	4180	70	5958
Year 15	749	1671	38	48	53	1765	2482	1.0	1096	1230	4180	92	6711
Year 20	749	1671	43	53	67	2226	3130	1.2	1280	1230	4180	111	7364

[1]FR = financial-revenue approach [2]CV = contingent-valuation approach [3]PV = property-value and land value approach [4]PE = preventative-expenditure approach

cal-structure function if the property value and land-use (PV) approach is used. However, if the preventive-expenditure (PE) approach is used the preventive expenditures are not continuous, but assumed to be invested during the first year. Benefits and costs are calculated over the first 20 years and the net present values are estimated from a financial discount rate of 9% (24). The tourist-attraction value is assumed to increase annually by 6%, which is a moderate growth rate for the tourist industry in Sri Lanka (22).

In conclusion, production figures for lime production allow us to calculate the short-term financial gains from coral mining. Long-term economic costs can be estimated from decreased fisheries, tourism, and increased coastal erosion due to the destruction of the coral reef. The estimated costs and benefits are given on a per km^2 basis. The accumulated net present benefits of coral mining would be USD 749 000–1 671 000 and the accumulated economic net present costs would be USD 111 000–7 364 000 over 20 years (Table 5; Fig. 5).

DISCUSSION

The results of this study suggest that the net financial benefit from coral mining in highly developed areas is as much as USD 6 615 000 lower compared to the lost value of goods and services provided by the function of a properly managed coral reef over a 20-yr period. The high costs derive partly from the loss of valuable land, due to increased erosion. However, the loss in the physical-structure function value varies considerably depending on the type of land protected by the coral reef. In tourism areas, for example, the land value is assumed to be 1000 times higher compared to rural land. Still, the long-term value of the physical-structure function is likely to be closer to the high estimate as the possibilities of future land use disappear with erosion. In Sri Lanka, where 80% of all tourism infrastructure and the majority of the urban centers are within the coastal region (8, 22), land will probably become even more valuable in the future. This may to some extent be reflected by the fact that the estimated costs for building coastal protection constructions are higher than the estimated costs of land erosion. Furthermore, the property-value approach tends to exclude those functions, which cannot be expressed in monetary terms.

In total, USD 17 mill. have been invested to build coastal protection structures such as groynes and revetments along the west and southwest coasts of Sri Lanka (29) (recalculated in 1994 prices). Still, this provides protection to only 18–25% of erosion prone shorelines (29). Clearly, the value of coral reefs as natural breakwaters is considerable (44, 45). In this analysis, the physical-structure function emerges as one of the most valuable coral reef functions where applicable, worth up to USD 4 180 000 km^{-2} reef or USD 840 000 km^{-1} beach. In Bali and Lombok, Indonesia, accumulated expenditures to protect beaches from erosion were in the range of USD 2–3.5 mill. km^{-1} beach (44).

Thus, replacing the indirect benefits provided by coral reef functions, such as coastal protection, may be very costly. Maintaining an ecosystem intact is significantly cheaper than replacing or rehabilitating a degraded ecosystem (46). This has become apparent in Sri Lanka, where man-made structures to combat erosion with time frequently cause more problems than they solve (37).

Another major cost of coral mining, shown in this study, is the loss of income from tourism, due to the decreased tourist-attraction value of a degraded reef. Earlier estimates of the value of the tourist-attraction function, USD 300 800 km^{-2} reef yr^{-1} (4) and USD 503 000 km^{-2} reef yr^{-1} (44), are higher than the USD 150 000–214 000 km^{-2} reef yr^{-1} found in this study. An explanation for the relatively low value in this study is that direct financial profits from the tourism industry are taken into account and only a part of coastal tourism is assumed to be dependent on coral reefs.

However, the quality of reefs is a decisive factor in site selection for coastal tourism development, and reef quality significantly affects the competitiveness of an area as a tourism destination (23, 44). It has been estimated that the difference in net present value of the financial benefits from a 6% tourism growth compared to a 3% growth over 20 years in Hikkaduwa, would be some USD 4 mill. (22, 24). Decreased quality of the marine environment, including the coral reefs and the beaches, would be the main reason for the lower growth rate (22, 24). It is also likely that with a decreased environment quality tourism growth would decline or even stop in the future. The difference between no tourism growth and a maximum of 9% tourism growth over 20 years would be almost USD 13 mill. (24). If this figure is related only to the coral reef in Hikkaduwa (25 ha) the net present value over 20 years would be USD 50 mill. km^{-2}.Values of the same magnitude were found for two marine parks in Florida, where direct and gross revenues amounted to USD 15.75 m^{-2} yr^{-1} and USD 85 m^{-2} yr^{-1}, respectively (25).

Thus, intact, pristine coral reefs are of major importance for tourism development (2–4, 44–46), and the net benefits from the tourist-attraction function are most likely larger than any other functional values of coral reefs. However, the long-term benefits from the tourist-attraction function is dependent on the level of tourism that can be maintained without resulting in environmental degradation (47). Neglecting to manage coral reefs as valuable tourist attractions in Sri Lanka has led to adverse impact on corals and marine life, which in turn has affected the sustainability of the tourism business (31). In Hikkaduwa, for example, viewing the reef from glass-bottom boats has caused physical damage to corals when running over shallow patches (8). Collection of live corals as well as reef walking, which is a common practice at the Polhena reef in southern Sri Lanka, are other causes of damage to corals (7, 8). However, the value of a pristine reef can be withheld by teaching tourists how to behave when visiting the reef (3), and by ensuring that tourism establishments do not have a destructive impact (23). The results from this study make clear that it should be of major financial interest for the tourism industry itself, to keep the use of the tourist attraction- function within the working limits of a "healthy" coral reef ecosystem.

As indicated in this analysis, the tourism industry is the main beneficiary of a pristine coral reef. In Hikkaduwa, it was shown that the local tourism industry would receive 72,5% of the benefits because of the increase in tourism from conservation of the coastal resources, while the local community outside the tourism industry would only receive 2% of the quantified benefits (22). Thus, there are rarely any economic incentives for low paid or unemployed workers to give up coral mining, which generates a high income compared to many other rural occupations.

Figure 1 shows that the accumulated net present value of coral mining over 5 years is higher than the accumulated lost net present value from the tourist-attraction value during the same period of time. Coral mining directly employs about 1200 people along the southwest coast, and an additional 4700 people are directly or indirectly dependent economically on lime production (37). Some 50% of these workers are thought to be involved in the illegal industry in the coastal zone. Thus, illegal coral mining constitutes the sole livelihood for a large number of people in the coastal region, and if coral mining is to be stopped, proactive steps must be taken to provide the coral miners with alternative employment (22), otherwise this sector of the community will bear a significant portion of the costs for protecting the coral reefs. In this analysis, the net present value of opportunity cost for labor, during 5 years of coral mining was estimated to be USD 260 000–580 000 km^{-2}. This cost is lower than the lost value from the tourist-attraction function (Fig. 5; Table

5), and hence in theory, it would make economic sense for the tourist industry to pay the coral miners not to mine, or at least to provide them with alternative employment.

The most popular solution for assisting coral workers to leave the industry is that they turn to small-scale fishery or agriculture (37). In fact, many miners are already involved in these activities as they only mine corals for 4–8 months yr^{-1} (36, 37). However, as emphasized in this study, coral mining and reef fishing cannot be successfully combined in the long term. First, sustainable harvest of corals is believed to be impossible (37). Coral reefs grow much to slow and are endangered by all activities which remove more corals than are accumulated each year. Although 5 years is a conservative estimate of how long it takes to mine one km^2 reef it indicates that the reef is a nonrenewable resource that will be depleted within a very limited time scale. Second, when this time has passed the fisheries function has most likely been severely affected, and the rural worker has, if he fishes on the same reef, not only lost his income from coral mining, but also from fishing.

Despite this, coral reefs are continuously mined for lime in several nearshore areas along the southern, southwestern, and eastern coasts of Sri Lanka (8, 35, 37). This could be due to a perception problem, where the connection between an intact reef habitat and fish yields is not appreciated. However, this is unlikely because the fisherman is often aware that his activities are entirely dependent on the status of the natural environment. For example, in Madiha, a small fishing cluster in southern Sri Lanka, ornamental-fish collectors strongly opposed coral mining because it was seen as a threat to the breeding of fish (35). In the Rekawa villages, fishermen complained that increased erosion due to coral mining had deprived them of a place to berth their fishing boats (48).

The most likely explanation for the ongoing coral mining is the simple fact that the income from coral mining is much higher than, for example, small-scale fishing and agriculture (37, 39). In this study, the cost of erosion in rural areas is estimated from the lost production value of coconut plantations. Compared to the income from coral mining this cost is exceedingly low. Thus, even if the value of rural land would be orders of magnitude higher than is assumed in our analysis, this would still not provide economic incentives for giving up coral mining.

Similarly, the revenue from small-scale fisheries is low compared to coral mining. In this study it is assumed that the maximum sustainable yield from the fisheries is 10 t km^{-2} yr^{-1}, while coral miners can extract some 10 000 t of corals km^{-2} yr^{-1}, which is equivalent to approximately 6000 t of lime km^{-2} yr^{-1}. Thus, the gross profit from coral mining is at least an order of magnitude higher than that from fishing. This also indicates that the estimated yield from the coral reef fisheries does not have a major impact on the outcome of the analysis in this study.

However, as pointed out earlier there is a crucial difference between harvesting nonrenewable resources, such as corals, and renewable resources, such as fish and agricultural products. Although it has not been made explicitly clear in this analysis, renewable resources have an infinite life time and the benefits generated from these resources should be expected to accrue into perpetuity. Unfortunately, these benefits are not always accurately accounted for in environmental economic analyses, as the estimated net present value becomes less reliable as the analyzed period of time lengthens (22). This is especially true considering the debate on discounting environmental assets (47). A resource can, on the contrary, become more valuable as it becomes rarer in the future (19). An example of this is ornamental-fish collection in Sri Lanka, where the price of exported ornamental fish increased by more than 85% between 1990 and 1995 (14). Furthermore, the loss from the fishery function is analyzed over a period of 20 years, although it could take 100 years for a coral reef to regain its former coral-fish community (27). The value of the fishery function should therefore be treated with discretion.

Likewise, if only coastal protection is considered, coral mining may seem financially advantageous when the coral reef borders rural areas which are not being used for human activities of economic significance and, thus, not considered worth the construction of expensive coastal defence structures. However, as mentioned above the options of land use then become limited and will prohibit economic development in the future. At present, coastal areas sheltered by fringing reefs are valuable but limited resources. Only about 2% of the coastline in Sri Lanka has fringing coral reefs (8). In the northern parts the civil unrest diminishes the accessibility to the existing reefs, and in the southern parts many reefs have already been destroyed by coral mining and other destructive activities. Thus, the value of Sri Lankas remaining reefs is high and this value will probably increase with time, as they will become even more scarce in the future.

In accordance with the results from this study it is, therefore economically motivated to preserve the remaining coral reefs of Sri Lanka. In tourism areas the cost for preserving coral reefs is only marginal to the benefits derived through the tourist attraction function of the reef (22). However, in rural areas, proper planning and management steps must be taken by the authorities to ensure that the sustainability of reefs is not compromised for short-term benefits (47). As indicated in this study the Sri Lankan authorities acted correctly, from an economic point of view, when coral mining was banned. Clearly, the value of keeping coral reefs intact exceeds the profits of short-term resource exploitation.

CONCLUSIONS

This study shows that it is worth the effort to preserve the remaining coral reefs along Sri Lanka. The results were achieved by quantifying some of the ecological goods and services that coral reefs generate for the benefits of the local human population. The values of human activities based on these goods and services are infinite, as long as they do not degrade the coral reef ecosystem. The economic system is a part of and, thus, ultimately dependent on the ecological system (12).

Measures for coral reef protection are sometimes presumed to conflict with economic growth. This perception stems mainly from the failure to recognize that the magnitude of the present and future economic benefits from long-term sustainable use of coral reefs often, if not always, are much higher compared to individual gains from short-term destructive uses (44, 47), which is clearly seen in the case of coral mining in tourism areas.

Those who benefit from short-sighted nonsustainable resource use must therefore be identified and targeted by management action. Resource users who receive financial benefits, but do not have to bear the economic costs resulting from their resource use, are unlikely to stop nonsustainable practices. It must, therefore, be made explicitly clear that coral reefs are valuable resources that must be carefully managed to sustain economic development. Efforts must be directed towards human activities that make use of the coral reef ecosystem without severely or irreversibly degrading it. The costs of a policy of inaction are the losses in the value of the functions of coral reefs, such as sustainable fishery, food security, biodiversity, coastal protection and tourism. Only a few of these functions can be expressed in monetary terms, and some of the most important are not quantifiable. However, first order estimates of some of these costs could provide decision makers and resource users with incentives and impetus to strive towards environmental and economic sustainable management of the coral reef ecosystem.

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