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An economic analysis of blast fishing on Indonesian coral reefs

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Summary

Characteristics, impacts and economic costs and benefits of blast fishing have been little investigated and they were therefore studied in Indonesia, at the scale of individual fishing households and of Indonesian society as a whole. Although illegal and highly destructive to coral reefs, blast fishing provides income and fish to a vast number of coastal fishers who claim that they have no alternative to make a living. Crew members in small-, medium- and large-scale blast fishing operations earned net incomes per month of US$55, 146 and 197 respectively. Boat owners in the same types of operations earned US$55, 393 and 1100 respectively. These incomes were comparable to the highest incomes in the conventional coastal fisheries. At the individual household level, the differences between the three types of operations show clear incentives for scale enlargement. The cost-benefit balance at the society level was calculated with an economic model. This analysis showed a net loss after 20 years of blast fishing of US$306 800 per km^2 of coral reef where there is a high potential value of tourism and coastal protection, and US$33 900 per km^2 of coral reef where there is a low potential value. The main quantifiable costs are through loss of the coastal protection function, foregone benefits of tourism, and foregone benefits of non-destructive fisheries. The economic costs to society are four times higher than the total net private benefits from blast fishing in areas with high potential value of tourism and coastal protection. This analysis of characteristics, impact and economics of blast fishing should help to raise the political will to ban blast fishing from Indonesian waters. Moreover, it allows for an evaluation of possible management solutions, taking into account their costs and the socio-economic framework that caused coastal fishers to start using explosives.

Keywords: Indonesia, coral reefs, blast fishing, coastal management, socio-economics

Introduction

Blast fishing was introduced in the Indonesian Archipelago in the Second World War as an easy and profitable way to catch schooling reef fish (Galvez *et al.* 1989). Nowadays, due to generally declining catches in other sectors of coastal fisheries (Venema 1997), the ranks of blast fishers are joined by fishers who consider blast fishing the last opportunity to catch and earn enough to feed their families. The explosives were originally taken from old Second World War ammunition shells, which were dug up by fishers. At the present, bombs are mostly made with artificial (chemical) fertilizers such as ammonium and potassium nitrate (NH_4NO_3; KNO_3). Sometimes, dynamite obtained from police, military personnel, mining companies, or civil engineering projects is also used (Alcala & Gomez 1987; Rubec 1988; Galvez *et al*. 1989).

Blast fishers hunt specifically for schooling reef fish, so that only a few bombs will assure a relatively large catch. Because they can use visual information on the abundance of their prey, they consider this method to be very cost-effective. When there is no fish present, the fishers move their activities further down the reef without having wasted much material and time. After the charge explodes, divers enter the water to collect the fish which have been killed or stunned by the shock wave from the explosion. Many blast fishing operations use 'hookah' compressors, which supply air through hoses to divers collecting their catch from the reef.

The actual impact of destructive fishing practices on coral reef ecosystems and their functions is difficult to measure, because of other, often concurrent, effects of human-induced and natural processes such as wave-action, storms, temperature fluctuations, tectonic events, climatic disruptions, terrestrial runoff, diseases and predator outbreaks (Wells 1993; Cesar *et al*. 1997). Nevertheless, blast fishing is considered one of the most destructive anthropogenic threats to coral reef ecosystems and the damaging effects are numerous. First is the direct effect on fish and invertebrates that inhabit a reef. Not only are the preferred sizes and species killed, but also commercially unattractive organisms, species and size-classes (juveniles) fall victim to the explosion as well. Also reefs no longer function to provide food and shelter to marine organisms. Furthermore, once the reef structure is destroyed, its function in protecting coastlines cannot be sustained. Last but not least, reef-related tourism, which holds great promise for alternative income generation on reefs that are not too remote, cannot be developed in areas which are being blast-

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ed. Even sporadic blast fishing can destroy the reputation of a SCUBA-diving area.

It is especially the indirect, long-term effect of destruction of the habitat that has drawn a lot of international attention from scientists and conservationists. The background and possible causes for the introduction of this method have been described by Pauly *et al.* (1989) and Galvez *et al.* (1989). Reviews of the method and its various damaging effects have been written by Alcala and Gomez (1979, 1987), McManus *et al.* (1997) and Pet-Soede and Erdmann (1998). Some of the effects have been modelled by Young (1991) and Saila *et al.* (1993). Environmental, economic and social costs of blast fishing have been studied and described by McAllister (1988) and Cesar (1996). Enforcement measures to ban blast fishing have been suggested by Pet and Djohani (1998).

In Indonesia, awareness has increased at national as well as local levels, but this has not resulted in a reduction in the use of destructive fishing methods. Although considerable attention has been drawn to the damaging effects of blast fishing on reef habitats, a management and enforcement strategy to ban this illegal practice has yet to be developed and implemented. Even though officially forbidden by law (Badruddin & Gillet 1996) and despite the dangers to the fishers themselves, home-made bombs remain popular fishing gear in Indonesia. Enforcement of the laws in remote areas and at sea is expensive and rarely implemented effectively. Local law enforcers often lack the means and will to patrol and make arrests at sea. Galvez *et al.* (1989) point specifically at the local acceptance of blast fishing in the Lingayen Gulf area in the Philippines. Corruption is a major problem at the lower levels, usually caused by the very low salaries for government officials working in the field.

The basic problem in the fight against destructive practices currently is still the lack of interest of national authorities. Political will has to be developed at the higher levels through increased awareness of economic losses due to destructive fishing. The present paper aims to describe the economics of blast fishing, in an attempt to quantify some of the major impacts. In addition, a study of the costs and benefits at the individual household level will help managers understand the incentives for using destructive methods. Estimates of neither the actual net revenues to blast fishers nor the net economic costs to society have been presented before in the literature. Political support for restrictive management will be greater and be carried more broadly when the damage of blasting can be presented in monetary figures.

Ideally, an economic valuation for coral reefs would be based on their total economic value (TEV). This includes all direct and indirect use values as well as non-use values (Dixon & Sherman 1990). Such an attempt has recently been made for coral reefs as well as for other ecosystems in a highly publicized and criticized paper by Costanza *et al.* (1997). However, most of the reef functions, such as biodiversity, research and possible medicinal use cannot be monetized in a straightforward way. Trying to include these in the analysis, for instance through contingent valuation methods (CVM), could undermine the credibility of the study in the eyes of the policymakers who need to be convinced of the importance of reef protection. Therefore, the present study focuses on the three functions of coral reef ecosystems that can be estimated with valuation techniques based on market prices, namely fisheries, tourism and coastal protection.

Methods

Study area and characteristics of the fishery

Most of the input parameters for the model were derived from a field study of blast fishing in the Spermonde Archipelago, a coastal area in SW Sulawesi, Indonesia. This archipelago, which was first mentioned by Umbgrove (1930), comprises approximately 400 000 ha of coastal waters with submerged coral reefs, coralline islands, sandy shallows and deeper waters up to a maximum depth of 60 m. A variety of small-scale fishing gears is operated in this area, which provides food, income and coastal protection to approximately 6500 fishing households (Department of Fisheries 1995).

From May 1995 until January 1997, fishing activities in Spermonde were monitored at sea. The practice of blast fishing was studied, the number of bombs and the catch biomass were recorded, and on-site interviews were held. The size of blast impacts on the corals was estimated by direct observation under water. Between May 1995 and December 1997, all islands and major coastal villages were visited. Interviews were held with blast-fishers and their middlemen, to collect data on the number of trips that were made each month, the costs of the operations, and on profit sharing systems. During these visits, logbooks were distributed to several fishers which subsequently recorded their daily catches for two months. Fish auctions were attended to collect prices for those fish categories that were found in blast catches. Prices in Indonesian Rupiah were converted to US$ at a rate of Rp 2500 per US$1.

Three types of blast fishing operations were observed, namely small-, medium-, and large-scale. The large-scale operations used vessels 10–15 m in length with a crew typically of 15–20 men, who embarked on week-long trips to patch reefs or fringing reefs of uninhabited islands up to several hundred kilometres from their origin. Bombs were thrown from 3–4 small canoes which were launched from the mother ship. Divers used hoses from hookah compressors on the large ship to collect fishes up to a maximum depth of 40 m. These compressors were also used for the collection of sea cucumber (*Holothuria* spp.), lobsters (*Panulirus* spp.) and in cyanide-fishing for live groupers (Serranidae) (Erdmann & Pet-Soede 1996). The fishes were stored on ice and sold upon arrival at major landing places. The medium-scale operations worked similarly, but operated closer to their place of origin and often targetted schooling pelagic fish, away from the damaged reefs. They departed for day-long trips with smaller boats (8–10 m) and a maximum of five crew. Small-scale, single blast fishers used 4 m long, wooden canoes with one outrigger, with a four-HP outboard engine, and operated close to their home-islands. Fish were retrieved by free-diving with mask or goggles, and hence small-scale operations were restricted to sites which were no deeper than 10–12 m. Only small-scale operations were typically carried out within the same small area for long periods of time (over many years). Fishing on highly damaged reefs was not attractive to the medium- and large-scale operations.

The fishing methods were similar for each type of operation. Fishers looked with goggles or a mask for a school of fish from their canoes. Bombs were handmade by filling a 0.6 l beer bottle with a 1:5 mixture of kerosene and ammonium nitrate. The bottles were closed with plastic tape around a wick and a blasting cap. When a school of fish was spotted, fishers moved their boat at least 5 m from the estimated place of impact and lit the wick with a smouldering mosquito-coil, which helped control the burning speed. The bomb generally exploded after about five seconds, depending on the length of the wick. After the charge exploded, fishers entered the water to collect fish which had been killed or stunned by the shock wave from the explosion.

Model structure and parameter estimation

A model was developed to calculate the costs and benefits of blast fishing at the level of Indonesian society as a whole. This model calculated costs and benefits for a hypothetical situation on 1 km^2 of coral reef, which was in pristine condition, and which was without other concurrent threats. The general model was:

$$\mathrm{NB}_{s,t} = \mathrm{NR}_{b,t} - (\mathrm{VN} + \Delta\mathrm{VT}_t + \Delta\mathrm{VC}_t) \qquad (1)$$

where $NB_{s,t}$ = net quantifiable benefits to society in year t, $NR_{b,t}$ = net revenues of blast fishing in year t, VN = value (foregone revenues) of non-destructive fishing in a situation without blast fishing and at exploitation levels near maximum sustainable yield (constant over time), ΔVT_t = loss in value of tourism for year t, and ΔVC_t = loss in value of coastal protection for year t. The input values for the model parameters depended on the present quality of the coral reef.

The economic analysis was based on the differences in the 'with' and 'without' scenarios for blast fishing. In the 'without' scenario, only sustainable non-destructive reef fisheries take place. In the 'with' scenario, only blast fishing occurs. The losses, ΔVT_t and ΔVC_t, represent the difference between the values in the 'with' and 'without' scenarios at time t. Calculations were carried out for two cases, a 'high value' and a 'low value' scenario. In the 'high value' scenario, coastal infrastructure is well developed, there is considerable coastal construction and tourism potential is high. In the 'low value' scenario the opposite holds, which is often the case in remote rural areas.

Valuation was based on straightforward loss in added value. The economic valuation of the blast fishery through time was derived from two data points: the initial point for an intact reef at the beginning of year 1, and the final point of severe coral destruction, reached when 75% of the coral was destroyed (McAllister 1988; Rubec 1988). The economic analysis was carried out for the total time period needed to destroy 75% of the coral on a reef, and included a 10% discount rate per year. With a rate of coral destruction α, this meant that the net present values (NPV) of the individual parameters to the general model were calculated by summation of the annual totals over 75/α years with a 10% discount rate per year using the formula:

$$\mathrm{NPV} = \sum_{i=1}^{75/\alpha} \frac{value_i}{(1 + discount\ rate)^i} \qquad (2)$$

The total number of years needed to reach the final point of 75% coral destruction was calculated using the estimated annual rate of coral destruction α. This rate, or rather the average relative loss of corals on blasted reefs per year, was calculated using underwater observations on the average size of the impact area per explosion and the average number of blasts per km^2 reef per year. We assumed a circular impact with radius r and a surface area A_b that could be calculated using πr^2.

$$\alpha = \frac{A_b}{A_c} * 100\% \qquad (3)$$

where A_b = area destroyed by blast fishing per km^2 per year and A_c = area covered with coral per km^2 of reef.

The data from interviews, logbooks and personal observations were combined to calculate the four input parameters to the general model. The annual net revenue of blast fishing, $NR_{b,t}$, was calculated by subtracting the operational costs, $C_{b,t}$, and the opportunity costs of labour, $C_{l,t}$, from the total gross revenues of blast fishing, $GR_{b,t}$:

$$\mathrm{NR}_{b,t} = \mathrm{GR}_{b,t} - (\mathrm{C}_{b,t} + \mathrm{C}_{l,t}) \qquad (4)$$

For the calculations of gross revenue of blast fishing in year 1, $GR_{b,1}$, when this method was newly introduced, we used estimates of total yield per km^2 from the literature. The estimate for gross revenue of blast fishing after destruction of 75% of the reef, was based on estimates of the average number of blast operations per km^2 of coral reef, the catch (kg) per boat per day and the price (US$) per kg fish in Spermonde (Table 1). The yield of blast fishing was assumed to decrease linearly with coral destruction (Fig. 1). Fishing on highly damaged reefs was not attractive to medium- and large-scale operations; only small-scale blast fishers were observed on the reefs of Spermonde. Therefore, the average number of blast operations per km^2 was estimated by dividing the estimated total number of operations by the total surface of coral reefs with depths where small-scale blast fishers were active, ranging from 4–12 m. The density of blast fishers was assumed to be constant over time and equal to the number observed in Spermonde. The average operational costs per boat, C_b, were based on estimates of the average number of bombs used per boat per day, the amount (kg) of fish consumed, the amount (l) of fuel, and the price (US$) for fuel, boat and engine (Table 2). The average opportunity costs

Table 1 Financial data for three types of blast fishing in 1997.

	Small-scale	*Medium-scale*	*Large-scale*
No. crew/boat	1 (= owner)	4 (incl. owner)	16 (excl. owner)
No. days/trip	1	1	8
No. trips/month	20	15	2.5
Costs[1](US$/ trip)	3.25	9.5	400
Catch[2] (kg/trip)	8	75	1500
Consumed (kg/trip)	2	10	100
Subsistence[3] (%)	25	13	7
Sold (kg/trip)	6	65	1400
Price (US$/kg)	1	1	1.5
Owner share[4] (%)	100	40	40

[1]see Table 2 for calculation of costs per trip. Prices showed no variance and were considered standard in 1997. [2] Sample size (n), and standard error (SE) for small-, medium-, and large-scale respectively were n = 151, 13, 3 and SE = 0 kg, 3 kg, and 12 kg. [3] % subsistence was percentage of catch consumed. [4] Owner = single crew in 'small-scale'. Owner took both 'crew-cut' and 'owner-cut' in 'medium-scale'. Owner was not in crew in 'large-scale' (no 'crew-cut for owner'). Income was shared as follows: 3/5 (60%) for crew, 1/5 (20%) for owner, 1/5 (20%) for 'boat'. In practice this meant 40% for owner, out of which he paid all costs involved.

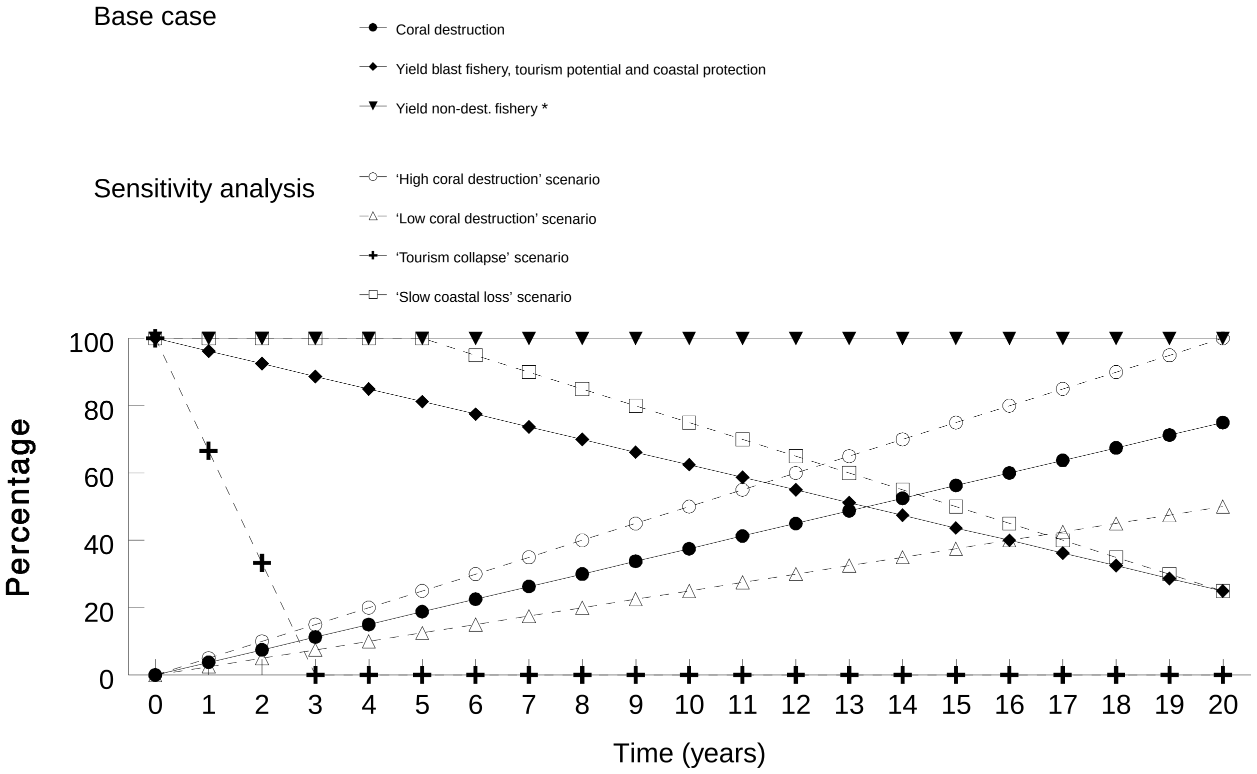

Figure 1 Model input: relative destruction of coral reefs and their functions (% of initial) during 20 years of blast fishing. Dotted lines represent sensitivity analysis scenarios. *: in a situation without blast fishing.

(US$) of labour for blast fishing, C_l, were equal to that of unskilled rural labour (World Bank 1998).

Profits of blast fishing differed between the small-, medium- and large-scale operations because of scale-specific costs and revenues. The average catch per day of a single small-scale blast fisherman was about 8 kg, a medium-scale operation caught approximately 75 kg per day and a large-scale operation caught approximately 200 kg per day or 1500 kg per 8-day trip (Table 1). The fish caught by blast fishers was typically meant for local markets because of its poor or medium quality. Prices for blast-caught fish varied from US$1.00 to US$1.50 per kg in 1997, depending on whether the fish were chilled on ice or not. The costs of fishing were not high for blast fishing operations and included bombs, fuel, depreciation costs for maintenance and repairs of the boat. Small-, medium- and large-scale blast fishing operations spent US$3.25, 9.50 and 400.00 per trip respectively (Table 2).

Table 2 Costs per trip for three types of blast fishing in spring 1997.

Type	*Depreciation time [a](yr)*	*Type of costs*	*Total amount [b] (US$)*	*Costs per trip [b] (US$)*
Small-scale	10	Boat + engine	500	0.25
		2–3 bombs		2.50
		2 l diesel fuel		0.50
Medium-scale	10	Boat + engine	3000	1.50
		2*compressor	500	0.25
		dive gear	100	0.05
		4–5 bombs		4.50
		5 l diesel fuel		1.20
		ice		2
Large-scale	10	Boat + engine	10 000	40
		6*compressor	1500	6
		dive gear	2250	9
		50 bombs		50
		225 l diesel		50
		ice		45
		food/cigarettes		100
		police 'fines'		100

[a] Depreciation for small-, medium-, and large-scale blast fishing in 10 years respectively: 2000 day-trips, 2000 day-trips, and 250 week-trips.
[b] Prices showed no variance and were considered standard in 1997.

Table 3 Estimated net income (US$/month) for crew members and boat owners from blast fishing.

	Small-scale	*Medium-scale*	*Large-scale*
Fish sold (kg)	120	975	3500
Revenue	120	975	5250
Costs	65	142	1000
Income crew	55	585[1]	3150[1]
Net income/crew member	55	146.25	197
Net income/boat owner	55	393[2]	1100[3]

[1] 60% crew cut of total (revenue-costs); [2] (40% owner cut + crew member cut) – costs per month; [3] 40% owner cut – costs per month.

The average net profits per boat owner per month in the blast fishery (Table 3) were estimated for boat owners in 1997 at US$55 for the small-scale operations (where the owner was the sole crew member), US$393 for medium-scale operations (where the owner was part of the crew) and US$1100 for large-scale operations (where the owner was not part of the crew). Crew members earned average incomes per month of US$55 in small-scale operations, US$146 in medium-scale operations and US$197 in large-scale operations (Table 3).

The annual net value of non-destructive fishing, VN, was derived by subtracting both the operational costs, C_n, and the opportunity costs for labour, C_l, from the total gross revenues for non-destructive fishing, GR_n. VN was calculated in the 'without' scenario and therefore remained constant through time (Fig. 1):

$$\mathrm{VN} = \mathrm{GR_n} - (\mathrm{C_n} + \mathrm{C_l}) \tag{5}$$

The gross revenue for non-destructive fishing, GR_n, and operational costs, C_n, were based on survey data from Eastern Indonesia and literature (Hannig 1988). In a subsistence fishery, many fishers were involved on a part-time basis and this was transformed to 10 full-time fishers per km^2 in line with estimates by McManus *et al.* (1992). Average catch per fisher was 5 kg, totalling 15 t km^{-2} yr^{-1} for 10 operations fishing 300 days per year (Russ 1991; McManus *et al.* 1992; Cesar 1996). The operational costs were estimated at US$30 per year for unmotorized fishers or US$300 per km^2 per year for 10 full-time fishers. The opportunity costs of labour for unskilled rural workers were around US$0.9 per worker per day or US$2700 per year for 10 full-time fishers per km^2 (World Bank 1998).

The annual net value of a coral reef for tourism potential, VT_t, depended on the level of coral destruction and decreased linearly with rate α from the initial value VT_0, reaching zero when no corals were left (Fig. 1).

$$\mathrm{VT_t} = \mathrm{VT_0}(1-t\alpha) \tag{6}$$

Reef-related tourism in coral reef areas encompassed diving and snorkelling and benefits differed amongst sites, depending on accessibility amongst other things.

The annual net value of a coral reef for coastal protection, VC_t, also depended on the level of coral destruction and decreased linearly with rate α from the initial value VC_0, reaching zero when no corals were left (Fig. 1).

$$\mathrm{VC_t} = \mathrm{VC_0}(1-t\alpha) \tag{7}$$

Initial values of tourism potential and coastal protection, VT_0 and VC_0, for the 'high value' and 'low value' scenarios were extracted from Cesar (1996), who combined data from Riopelle (1995), field interviews, and published market data on agricultural yields in Indonesia and used a variety of valuation techniques including the loss of productivity approach and the replacement cost approach (Dixon & Sherman 1990). The present values of tourism per km^2 of coral reef were annualized to US$55 900 representing a 'high value' and US$333 for a 'low value' situation. Similarly, the annualized values for coastal protection were US$61 100 for the 'high value' scenario and US$2800 for the 'low value' scenario.

Results

Model input

The size of the coral area destroyed by a single blast depended on the size of the bomb and the position of the explosion relative to the coral reef. Our observations showed that a beer bottle bomb shattered stony corals in an area approximately 5 m in diameter, hence the area affected per blast was 19.6 m^2. With 2–3 bombs per small-scale operation and 2 operations, 20 days per month, 10 months per year, the total number of blasts was estimated at 800–1200 yr km^{-2}. Assuming a coral cover in the target patch of 100% and an average coral cover of the entire km^2 of 50–55% in the pristine situation, the rate of coral loss α was 3.75% (points) per year. With this rate it took 20 years to destroy 75% of the coral on a reef and thus the analysis was carried out over a 20-year time period.

In year 1, when blast fishing was newly introduced, the total initial yield from blast fishing was estimated at 15 t km^{-2} yr^{-1} (Russ 1991; McManus *et al.* 1992; Cesar 1996). For year 20, total yield from blast fishing was estimated at 3.2 t km^{-2} yr^{-1} using the above-mentioned estimates of two small-scale operators per km^2 reef who fished 200 days per year (10 months times 20 trips per month) and caught an average of 8 kg fish per day (Table 1). This estimate was supported by other studies that showed maximum sustainable yields from reefs that were heavily destroyed by explosives (75% destroyed), which were 4–5 times less productive than intact reefs (McAllister 1988; Rubec 1988). Fish prices in year 1 were US$1 per kilogramme. The gross revenues for blast fishing, GR_b, were estimated at US$15 000 per km^2 in year 1 and US$3200 per km^2 in year 20. After correcting for operational costs, C_b, which were US$1300 per year, and opportunity costs of labour, C_b, which were US$360 per year, the annual net revenue of blast fishing, NR_b, was US$13 300 per km^2 in year 1 and US$1500 per km^2 in year 20.

In the scenario without blast fishing, yields from non-destructive fisheries equalled the initial total yield of blast fishing and remained constant over time at 15 t km^{-2} yr^{-1}. Again fish prices in year 1 were US$1 per kilogramme and the gross revenues, GR_n, from non-destructive fishing were estimated at US$15 000 per km^2. After correcting for the operational costs for 10 fishers, C_n, which were US$300 per year at 20% of the sales and opportunity costs, C_l of US$2700 per year, the annual net value of non-destructive fishing, V_n, was US$12 000 per km^2 per year.

Annual values of a coral reef for tourism, VT_t, decreased with rate α of 3.75% coral destruction per year from the initial value, VT_0, of US$55 900 in year 1 to US$14 000 in year 20 for the 'high value' scenario and from initial value, VT_0, of US$333 in year 1 to US$83 in year 20 for the 'low value' scenario. Similarly, the annual value of a coral reef for coastal protection, VC_t, decreased from VC_0 of US$61 100 to US$15 300 in year 20 for the 'high value' scenario and from US$2800 in year 1 to US$700 in year 20 for the 'low value' scenario.

Model output

At the level of individual fishing households, the net income per person in small-scale blast fishing operations was calculated for year 1 by dividing the annual gross revenues per km^2, GR_b, of US$15 000 over two fishers and subtracting the operational costs, C_b, of US$650 and the annual private fish consumption worth US$400 per fisher. Net income decreased in 20 years from US$6450 to US$550 (Fig. 2). The high income in year 1 when blast fishing was newly introduced formed the incentive to start blast fishing. Comparison with non-destructive fishing in an area without blast fishing, where each of 10 full-time fishers had an annual income of US$1470, showed that blast fishing in the initial years was four times more rewarding than non-destructive fishing (Fig. 2). This difference was only sustained for a short period, in the long run (more than 20 years) the income from blast fishing will reach the level of opportunity costs, C_l, of US$270. In year 20, the income from blast fishing was only one fifth of what could have been derived if blast fishing had not been introduced (Fig. 2). The motorized and well equipped medium- and large-scale operations that explore pristine reef areas find high revenues which will likely compensate their exploration costs.

At the level of the society as a whole, both the 'high value' and 'low value' scenarios showed that costs of blast fishing through loss of tourism potential and coastal protection were higher than the total net benefits from blast fishing (Fig. 3). After 20 years of blast fishing, foregone benefits from tourism totalled US$134 000 per km^2 of reef in an area with a high potential for tourism and coastal protection, and US$800 per km^2 in an area with a low potential (Table 4). Explosives fishing generated a net loss to society of US$306 800 per km^2 of reef in the 'high value' scenario and US$33 900 per km^2 in the

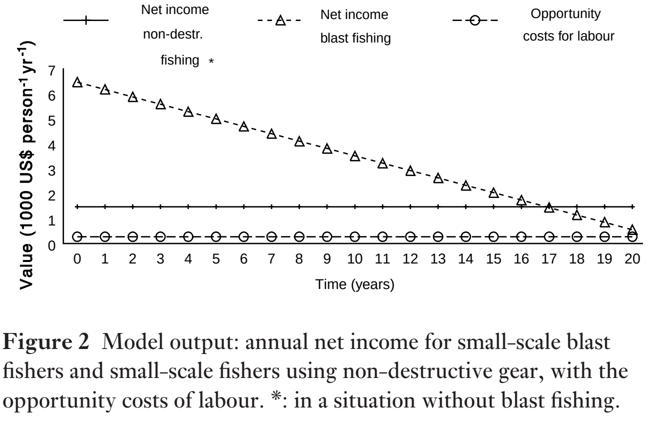

Figure 2 Model output: annual net income for small-scale blast fishers and small-scale fishers using non-destructive gear, with the opportunity costs of labour. *: in a situation without blast fishing.

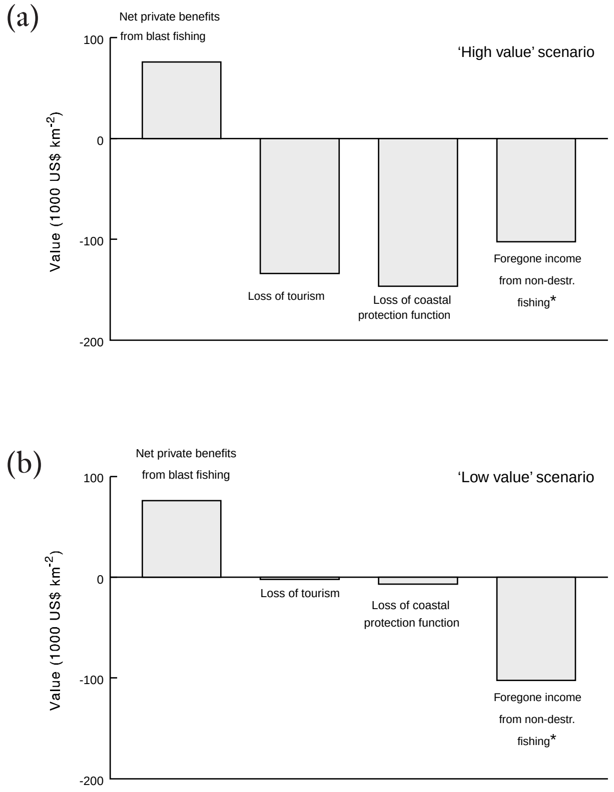

Figure 3 Model output: net present value of 20 years of blast fishing for individuals and the associated losses to society. Two scenarios are compared: (a) high and (b) low values for tourism potential and coastal protection. *: in a situation without blast fishing.

'low value' scenario (Table 4). The quantifiable costs of blast fishing in the 'high value' scenario were quite evenly distributed between the foregone net benefits of fishing, tourism, and coastal protection (Fig. 3*a*). In the 'low value' scenario, the foregone net benefits of fishing became the main costs of blast fishing (Fig. 3*b*).

Sensitivity analysis

Uncertainty surrounds the input values of the parameters in the economic analysis. To study the robustness of these numbers, a sensitivity analysis was carried out for four main assumptions. In Table 5, these calculations are presented for both the 'high value' and the 'low value' scenarios for tourism and coastal protection. First, the link between blast fishing and coral destruction was assessed. In our base scenario of severe coral destruction, 75% of the coral was destroyed after 20 years of active blasting. In the 'high' and 'low' coral destruction scenarios, 100% and 50% respectively were destroyed over the same time period as in the base scenario (Fig. 1). The resulting change in the net loss of blast fishing to society was 34% in the 'high value' scenario and around 40% in the 'low value' scenario.

The sensitivity analysis of the link between coral destruction and coral reef fishery yield shows that net losses to society differed only marginally from the base scenario. In the base scenario a value of $3.2\ \mathrm{t\,km^{-2}\,yr^{-1}}$ was used, whereas for the sensitivity analysis $3.84\ \mathrm{t\,km^{-2}\,yr^{-1}}$ was taken to represent a 'high' fishery yield. This value is approximately 20% higher than in the Spermonde base scenario and was derived by increasing the total number of day trips from 200 to 240 per year. Similarly, yield decreased by 20% to $2.56\ \mathrm{t\,km^{-2}\,yr^{-1}}$ to represent a scenario with a 'low' fishery yield. For these 'fishery yield' scenarios, the sensitivity analysis shows that the costs to society differed by approximately 1% from the base scenario in the 'high value' scenario and 6% in the 'low value' scenario (Table 5).

Third, the functional form of the relationship between tourism and coral destruction from blast fishing was altered. In the base scenario, tourism was impacted with the same rate α as coral destruction. In the 'coral collapse' scenario, tourism would rapidly break down (in 3 years) after introduction of blast fishing, due to reputation effects of blast fishing on recreational divers (Fig. 1). An alternative justification for this scenario was that future tourism potential in the eyes of investors might decline much quicker than in the base scenario after introduction of blast fishing. In the 'high

Table 4 Present value of costs and benefits of blast fishing at 10% discount rate over 20 years (US$1000 per km²). 'High value' scenario means high tourism potential and coastal infrastructure; 'low value' scenario implies low tourism potential and coastal infrastructure.

	'High Value' scenario:		*'Low Value' scenario:*	
	cost	benefit	cost	benefit
Blast fishers				
Yield		90.0		90.0
Explosives	8.5		8.5	
Other costs	2.6		2.6	
Opportunity labour	3.1		3.1	
Net private benefits blasting		75.9		75.9
Rest of society				
Foregone sustainable fisheries revenues	102.2		102.2	
Foregone tourism revenues	134.0		0.8	
Coastal protection	146.5		6.8	
Total (rest of society)		−382.7		−109.8
Net benefits of blast fishing		−306.8		−33.9

Table 5 Results of the sensitivity analysis for the economic valuation of blast fishing.

Benefits & Losses *Scenarios*	*Net private benefits from blast fishing*	*Loss of tourism revenues*	*Loss of coastal protection*	*Foregone sustainable fishery income*	*Net loss of blast fishing to society*
Scenario 'High value'					
Base scenario	75.9	−134.0	−146.5	−102.2	306.8
High coral destruction	66.1	−178.6	−195.3	−102.2	410.0
Low coral destruction	88.3	−89.3	−97.6	−102.2	200.7
High fishery yield	77.9	−134.0	−146.5	−102.2	304.7
Low fishery yield	73.8	−134.0	−146.5	−102.2	308.8
Tourism collapse	75.9	−426.5	−146.5	−102.2	599.3
Slower coastal loss	75.9	−134.0	−83.1	−102.2	243.4
Scenario 'Low value'					
Base scenario	75.9	−0.8	−6.8	−102.2	33.9
High coral destruction	66.1	−1.1	−9.0	−102.2	46.2
Low coral destruction	88.3	−0.5	−4.5	−102.2	18.9
High fishery yield	77.9	−0.8	−6.8	−102.2	31.8
Low fishery yield	73.8	−0.8	−6.8	−102.2	35.9
Tourism collapse	75.9	−3.5	−6.8	−102.2	36.6
Slower coastal loss	75.9	−0.8	−3.8	−102.2	30.9

value' scenario, the model was highly sensitive to 'tourism collapse': the net loss to society increased 95% in the 'high value' scenario, and 8% in the 'low value' scenario (Table 5).

Fourth, a time lag was introduced in the link between coral destruction and coastal protection. In this 'slower coastal loss' scenario, the coastal protection function only started to decline once a certain percentage (here: 20%) of corals were destroyed (Fig. 1). This scenario was justified in cases where the coastal protection function was still fully operational while part of the corals had been destroyed. The sensitivity analysis showed that losses to society were 21% lower in the 'high value' scenario and 9% lower in the 'low value' scenario (Table 5).

Discussion

Impact and losses

Blast fishing is destructive to the coral reef ecosystem and can lead to the collapse of coral reef fisheries (McManus *et al.* 1997). Heavily-damaged reef areas are obviously less attractive for reef-related tourism, and foregone benefits of this type of tourism form a considerable part of the economic losses due to blast fishing. The coastal protection function is also affected by this practice, as coral reefs will gradually erode through physical and biological processes. In areas with a high value of coral reefs for tourism and coastal protection, the net loss to society of blast fishing was estimated at US\$306 800 per km^2 of coral reef and the economic costs to society were four times higher than the net private benefits to blast fishers. These losses were calculated over the first 20 years after introduction of blast fishing, when tourism and the coastal protection had not yet fully declined. This means that foregone benefits in subsequent years (when there is no more tourism or coastal protection) are even larger. The model was also highly sensitive to 'tourism collapse', which resulted in a 95% increase in estimated net losses to society. Due to the difficulty of translating qualitative natural assets into quantitative monetary values, many non-quantifiable costs of blast fishing were not taken into account in the economic model. Therefore, the above estimates for economic losses are quite conservative. It can be concluded that blast fishing results in large economic losses to Indonesian society, especially when taking into account the vast areas of coral reefs that are threatened in this country.

Nevertheless, for individual fishers, the financial incentives to start blast fishing are obvious, especially in a situation with pristine coral reefs. Andersson (1995) reports that in Mafia Island, Tanzania, blast fishers catch in two days as much as other fishers catch in 20 days. A financial analysis at the individual household level also shows clear incentives for scale-enlargement. Both crew members and boat owners had the highest net income per month in the large-scale blast fishing operations with US\$197 and US\$1100 respectively. Medium-scale and large-scale operations typically work in pristine areas and therefore blast fishing will continue to spread into the most remote areas unless very firm action is taken to combat this practice. For the individual fisher involved in blast fishing, the net income is all that matters and he does not take his contribution to ecosystem damage into account.

Management options

Although the practice of fishing with explosives goes back many years, the study of its distribution and impact is of recent origin and incomplete. This results in a situation where the need to act is not yet obvious to the authorities. Awareness of the economic consequences of destructive fishing practices is lacking for most government officials. Although some blast fishers were aware that their activities destroy the habitat that the fish are dependent upon, they

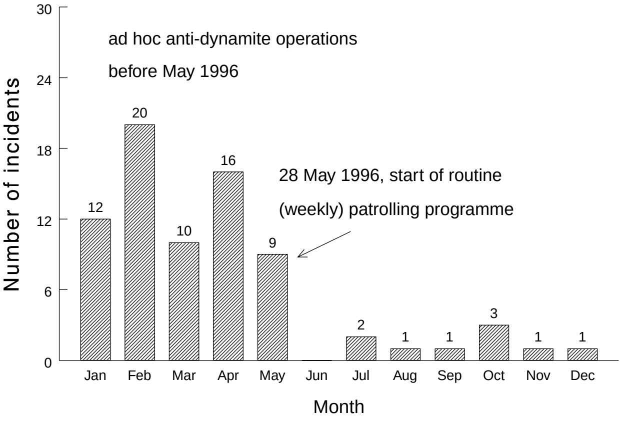

Figure 4 Trends in number of fish bombing incidents per month, Komodo National Park 1996. (Modified from Pet & Djohani 1998).

were hardly aware that their activities threatened their own existence. All fishers that were interviewed commented that their 'home-reefs' had deteriorated due to blast fishing, but they also added that there were plenty of undamaged reefs further out (Pet-Soede, unpublished data). The fishers regarded the size of their boats as limiting rather than the available resource space. A comprehensive awareness programme is therefore needed to provide fishers with information on the status of the coral reefs. In Komodo National Park, Indonesia, an awareness campaign was carried out explaining to villagers the results of a monitoring programme which showed coral mortality to range from 50–80% in badly affected areas (Pet & Djohani 1998). This campaign, combined with a rigorous enforcement programme, greatly contributed to the reduction of blast fishing in the Komodo area (Fig. 4).

Interventions to ban blast fishing must include the development of alternative livelihoods for local fishers. If and when enforcement programmes are effective in pushing the blast fishers out of the practice, other income opportunities need to be available. Many blast fishers argued that they had no alternatives, although in many coastal areas, economic activities can be developed in the fields of pelagic fisheries, mariculture and tourism. It depends on the socio-economic and cultural character of the fishing community and on other factors such as the available natural resources and infrastructure, as to which type of alternative livelihood is acceptable and feasible. Indonesia, with its many islands, long coastline and productive marine waters, has always been a fishing nation. It has been concluded, however, that most of Indonesia's coral reef resources are presently over-exploited (Venema 1997). Yet there is still sufficient scope to shift from coral reef fisheries into pelagic fisheries. Furthermore, Indonesia has a large potential for the development of mariculture. Vogt (1997) evaluated economic benefits of a protected coral area for reef-related tourism operators in the Philippines. The financial benefits of transporting tourists to resort islands were found to be substantial even to fishers using only their outrigger boats. These fishers could also sell souvenirs. Fishers' benefits exceeded the losses due to reduced catches. The income for resort owners and tour operators was found to be strongly dependent on the quality of the coral reefs. The presence of tourists also makes it harder for fishers to continue blasting without being noticed.

Although the profits and incomes in blast fishing are comparable to the highest profits and incomes in the conventional fisheries, blast fishers do not switch voluntarily to non-destructive methods. Non-blast fishers and blast fishers unanimously stated that the reason for fishing with explosives is 'to earn money the easy way' (Galvez *et al.* 1989; Pet-Soede & Erdmann 1998). Fishers occupied in blast fishing operations will have to be forced into alternative livelihoods by strong enforcement programmes. Government officials at the national level need to become more involved in the design of enforcement strategies and in the abatement of corruption. The Fisheries Law No. 9, signed on 19 June 1985 by the President of Indonesia, includes prohibition of the use of destructive fishing techniques such as explosives, poison and electrical techniques (Badruddin & Gillet 1996). The penalties upon conviction of breaking these regulations are up to 10 years in jail and/or a Rp 100 million fine. The marine police and navy, together with the fisheries service, are responsible for enforcement and control of the Indonesian waters. These authorities are occasionally involved in ad hoc enforcement of the laws against destructive fishing, but no structural plan has been implemented on national or local levels. The general lack of funds and facilities for enforcement of the fisheries law, the lack of knowledge and awareness of the responsible individuals, and the overall corruption and lack of political will at all levels, mean that enforcement of laws against destructive fishing has not yet been implemented effectively.

Indonesian fishers traditionally have a strong relationship with their middlemen. These middlemen provide credit to the fishers who, in return, must sell their catch for a set low price. This relationship usually turns out to be a life-long commitment to the middlemen who also tell the fishers what species to fish for, depending on the market prices. In this way many fishers have entered the destructive fishery even when they themselves did not intend to do so in the first place. Even when awareness about the damaging effects of blast fishing is increased at the fishers' level, fishers will not be free to stop those practices if their middlemen do not agree. Fishers will only change their ways of fishing when this is initiated by their 'bosses', or when they can be 'freed' from these middlemen by credit from more bona fide institutes. Unfortunately, corruption has made fishers very wary of government credit programmes but there is definitely scope for the development of locally managed credit systems.

Applied research in the field of coastal resources management is needed to support decision-making processes at all levels of management. Effective management is impossible without a constant flow of information on the resources and exploitation patterns. 'Local-knowledge' is important but insufficient for planning and evaluation of management interventions. Monitoring programmes need to be implemented and the systems for data collection and analysis need to be improved, especially at the local level. At present, many discussions amongst local stakeholders cannot be concluded since there is no information available and there is therefore no consensus on the status of the resource and on the patterns of resource utilization. Applied research in support of effective decision-making is also urgently needed in the fields of legislation and habitat restoration.

The role of the Government

The management of coastal and marine resources in Indonesia is heavily focused on increasing fisheries' landings. Optimization of the fisheries' output is perceived as a process which should be achieved through increasing exploitation levels rather than through protection and restriction. Indonesia's 5-year plans (*Repelita*) invariably mention how 'intensification' and 'diversification' of the fisheries should alleviate the poor coastal communities and provide the nation with more food, employment and foreign currency. With respect to destructive fishing practices, government and the fisheries sector interact over little more than the licensing of fishing vessels. The owner of a vessel has little problem in obtaining a fishing license, considering the general policy of encouraging intensification. Control of the vessel's activities hardly exists. The main worries of fisheries officials in the field are to make sure that taxes and fees for licenses are being paid for by all boat owners. This general attitude needs to be changed into a responsibility for management of coastal resources and a striving for sustainable economic development.

The traditional aim of intensification in coastal resource exploitation needs to be changed in favour of goals of conservation and sustainable use. At present, however, few if any of the stakeholders perceive the coastal resources as being overexploited. Therefore, awareness of the status of the resources must be raised at the national level before the political support for conservation can be expected to grow. Immediate investments are needed in the education and training of responsible individuals in coastal resources management. In this framework, there is also an urgent need to raise awareness amongst fisheries' managers about protected areas being potential tools to achieve optimum yields from coastal fisheries rather than just being toys for environmentalists.

The centralized and 'top-down' approach has not been successful in achieving sustainable exploitation of natural resources in Indonesia. Decentralization and involvement of the various stakeholders in a co-management system are urgently needed (Sloan & Sugandhy 1994). But to give co-management a chance, a legislative and policy framework must be established, with a place for all stakeholders involved in exploitation and conservation of fisheries' resources. As this needs to take place at the highest level, the importance of including the central government in discussions on fisheries management is indisputable (Pomeroy & Carlos 1997). The 'top-down' approach of the central government merely needs to be changed into a role of supporting co-management interventions through legislation, funding and enforcement.

The open access nature of the sea can be regarded as one of the major problems that lead to destructive fishing practices. Privatization of common property is seen as the future in natural resources management (Jentoft & McCay 1995), but this needs the imbedding of definitions of property rights in a legal framework (Pomeroy & Carlos 1997), which is a tedious process. Traditional communal property rights are usually not written down (Ruddle 1993; Zerner 1993), and have eroded during the last decades (Kendrick 1993; Zerner 1993). It is the role of the government to specify, legitimize and enforce the security of property rights to local resources. Exclusive fishing rights can only lead to improved management when actively supported by the government.

Political will

If the Indonesian government is serious about combating the destruction of its coral reefs, it should implement effective enforcement programmes, develop legislation to restrict the open access to fisheries resources, and support the development of sustainable fisheries, mariculture and tourism. It may be obvious that considerable financial resources are needed to implement the required management interventions, but the economic analysis of blast fishing and the level of the losses clearly show that investments in integrated management are fully justified. Political will needs to be generated to make these resources available. This political will can only be created by presenting the economic picture (Medley *et al*. 1993). Taking into account the economic reality, a national government striving for economic growth, low unemployment and social stability, will have to acknowledge the value of undamaged and well-managed coral reefs.

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