The Economics of Worldwide Coral Reef Degradation

Herman Cesar Lauretta Burke Lida Pet-Soede

Background Information

Acknowledgements

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Abbreviations

NPV	=	Net Present Value
DFP	=	Destructive Fishing Practice
NOAA	=	National Oceanic and Atmospheric Administration
GDP	=	Gross Domestic Product

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Summary and Conclusions

Coral reefs are an incredibly valuable ecosystem. Not only are they very important for nature, but they represent a very high value for humankind, supporting millions of people whose lives depend on these natural resources for a source of food and income. Estimates in this report show that coral reefs provide each year nearly US$ 30 billion in net benefits in goods and services to world economies, including, tourism, fisheries and coastal protection (Table 1).

Yet coral reefs are under heavy pressure. Already, 27% is permanently lost and with current trends, a further 30% is at risk of being lost in the coming thirty years. With such devastating levels of destruction, the social and economic implications for the millions of people who depend on coral reefs are of great concern. Over 39% of the world population now live within 100 kilometres of the coast and many people in these areas depend on reefs. Reefs protect coastlines and reef fish provide a source of nutrition and income. Poverty increases and food security decreases as fish stocks are depleted. This drives fishers further toward the use of destructive methods to catch what little there is left.

Key causes of coral reef decline have been the over-development of the coastal area and the over-use of coral reef resources. Migration to coastal areas has created a surge in land development leading to clearance of important coastal ecosystems such as mangroves and seagrass beds. Unregulated coastal construction, such as hotels, factories and desalination plants, has increased sedimentation in the coastal waters and is destroying reefs worldwide as light levels in the water column are reduced and reefs are smothered. Untreated sewage and chemical agriculture run-off (e.g. pesticides, herbicides and fertilizers) have caused nutrient loading into coral reef waters, leading to algal blooms and eutrophication. Overfishing and destructive fishing practices have decimated coral reef fish populations and their habitats. In addition, increases in sea surface temperatures associated with global climate change are causing ever more frequent bleaching events.

Countries with coral reefs attract millions of SCUBA divers every year, yielding significant economic benefits to the host country. Globally, tourism is estimated to provide US$ 9.6 billion in annual net benefits and a multiple of this amount in tourism spending (Table 1). These revenue streams in coral reef areas are being threatened by the deterioration of coral reefs. Damage to the reefs has often been caused by the increase in tourism itself, through direct damage by careless tourists and through the unregulated construction and the irresponsible operation of tourist related facilities. Mass tourism poses a threat to reefs and to the income that coral reefs provide to the local population. Sustainable tourism, on the other hand, is a source of income to people in reef areas. It even forms an alternative to destructive fishing practices.

Table 1: Potential net benefit streams per year and net present value (NPV) of the world's coral reefs (in billion US$)

Good/service	Amount
Fisheries	**5.7**
Coastal protection	**9.0**
Tourism/recreation	**9.6**
Biodiversity value	**5.5**
Total	**29.8**
NPV (50 year; 3%)	**797.4**

Source: authors' own calculations

Reef fisheries provide nutrition and necessary incomes to millions of people in developing countries. Potential reef fishing benefits are estimated at US$ 5.7 billion annually. However, increases in fishing effort, driven by rising populations and more effective fishing technology, have led to overfishing, such that the obtained economic value of coral reef fisheries is now close to zero in many developing countries. With fewer fish on the reefs many fishermen have resorted to more efficient yet highly damaging methods, such as bomb and cyanide fishing. Because enforcement of these illegal operations is difficult, the financial incentive to fishers in the short run is high. However, the ecological impact causes a net loss to society. For instance, in areas of Indonesia with high potential value of tourism and coastal protection, the socio-economic costs have been estimated to be four times higher than the total net private benefits from blast fishing. The cost of 'inaction' on blast fishing has been estimated at US$ 3.8 billion in Indonesia over the last 25 years. These figures would have justified enforcement expenditures of around US$ 400 million annually.

Land-based pollution is another major threat to coral reefs as untreated sewage from urban areas and runoff from chemicals used in agriculture cause sedimentation and mass algal growth. Currently 22% of the world's coral reefs are under medium to high risk from these land-based sources of pollution. As a result, investment to decrease the flow of sediments and excess nutrients into coastal waters is often justified despite high upfront costs. For example, a proposed wastewater treatment plant in the Florida Keys requires around US$ 60-70 million in investment costs and around US$ 4 million annually in operation and mainetance costs. However, in the long-term, the benefits to the local population are much higher, estimated at around US$ 700 million in Net Present Value (NPV) terms. Additional side benefits such as reduction in water-borne diseases provide further arguments in favour of these investments. To be cost-effective, river basin management should be linked with coastal zone management. This is the essence of the H2O Partnership (from Hilltop to Ocean) launched at the World Summit on Sustainable Development in Johannesburg, August 2002.

Global climate change and related coral bleaching pose a final set of threats to coral reefs. In 1998, 75% of reefs worldwide were affected by bleaching and 16% suffered mortality. Recent studies predict that bleaching could become an annual event within the next 25 to 50 years. The study here calculates the net present value of future losses over the next 50 years at a 3% discount rate. The losses in the case of the 'severe' coral bleaching scenario with mass coral mortality are estimated around US$ 83 billion. For the 'moderate' scenario, where bleaching leads to less mortality, costs are estimated at around US$ 21 billion. Other associated impacts of global climate change also have adverse effects on coral reefs, such as increased frequencies of storms and hurricanes. A recent study estimates that climate change will cause losses of US$ 109.9 million in the Caribbean due to increased sea-surface temperatures, sea-level rise and loss of species, among others. This is equal to 13.8% of the total GDP in the region. Reduction of other stressors to reefs such as those mentioned above, in combination with climate change adaptation measures, could help to decrease the impacts of climate change and coral bleaching on reefs.

Without even attempting to measure their intrinsic value, it is clear that coral reefs contribute enormously to food, income and various other quantifiable benefits, if properly managed. Net potential benefits are estimated at US$ 30 billion per year. With current trends of reef degradation, revenues will decrease, in some cases by as much as 75% with increasing costs. This will imperil the lives of millions of people who rely on reefs for food and income, especially in developing countries. Good reef management is costly, but the losses will be much higher if we fail to take action now. The choice is ours.

Reefs in Peril

Status of coral Reefs

Coral reefs are productive and biologically diverse ecosystems covering only 0.2% of the ocean floor, yet supporting an estimated 25% of all marine life [1]. However, coral reefs face worldwide degradation, such that today we have already lost 27% of the world's reefs through a combination of natural and, more importantly, human impacts [2]. If present rates of destruction are allowed to continue, 60% of the world's coral reefs will be destroyed over the next 30 years (Figure 1).

Runoff, pollution, tourism overuse, destructive fishing and coral bleaching among others are all contributing to these trends (see next page). Figure 2 shows, for instance, the decrease in live coral cover over the last five years in the highly valued tourist/dived areas in the Sharm-el-Sheikh area of the Egyptian Sinai coast: live hard coral cover fell from nearly 40% in 1997 to only 10% in 2002 due to mass tourism expansion [3].

Aside from the local and regional human impacts, global climate change is posing a serious long-term threat to the world's coral reefs. Mean sea-surface temperatures have increased by 0.3-0.6°C. With increased sea temperatures it is predicted that frequency and magnitude of hurricanes will increase.

The combined effect of hurricanes and warm waters can have a devastating effect which has already been experienced in some areas. Belize witnessed a 50% reduction in live coral cover in 1997-98 due in part to sedimentation from rainfall linked to hurricane Mitch and to the 1998 coral bleaching event [3].

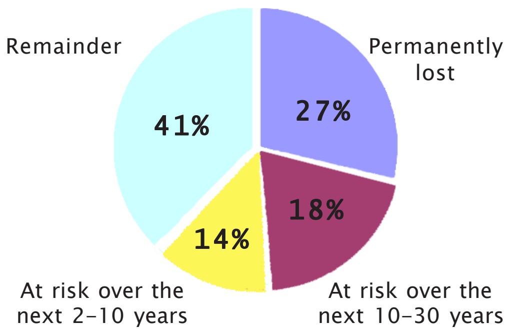

Figure 1: Percentage of Coral Reefs under Threat World-wide [2]

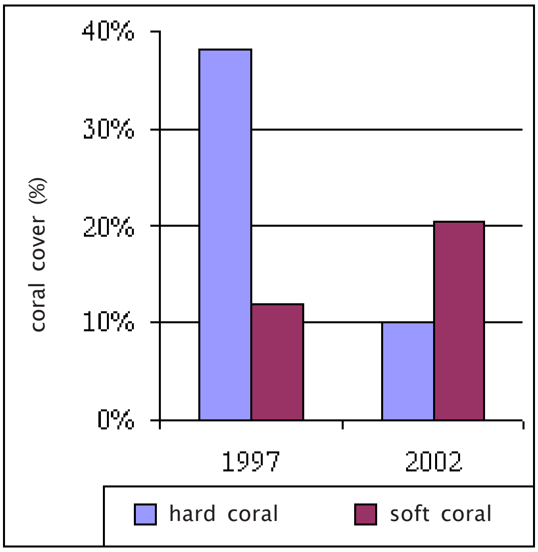

Figure 2: Change over time of hard and soft coral cover along the Sinai coast (Egypt); Source: [3])

Photo: reef degredation

Causes of Reef Decline

Reef decline is due to a host of stresses in coral reef areas. Four specific causes will be highlighted in this report. Ecological aspects of these causes are discussed here, while the economic implications are discussed later.

Tourism overuse has had disastrous impacts on precisely the coral reefs on which the tourism industry depends. The main human impacts related to mass tourism development include sedimentation and loss of habitat by land reclamation, dust, and disposal of solid waste, sewage and sludge. This has, among other things, increased turbidity thereby reducing the levels of light needed for growth and survival. Alongside this, careless practices have direct impacts on coral reef ecosystems, as corals are damaged and killed by contact with fins, hands, knees and also boat or anchor damage.

Destructive fishing practices result in damage to either the fished habitat or the primary habitat-structuring organisms in that habitat, and include such well-known problems as blast and cyanide fishing and muro-ami drive nets[1] . The explosion in blast fishing shatters the stony corals and kills fish and invertebrates in a large surrounding area. Over time, blast fishing damages the whole reef and thereby destroys the resource base of many subsistence fishers. Poison fishing uses cyanide in concentrations that are not meant to kill but only tranquillise the fish, facilitating their capture. The cyanide is squirted into the reef cavities, often breaking branching coral to get to hiding fish. In the process, corals come under severe stress from the cyanide with many smaller reef organisms often dying from overdoses. Corals that are repetitively subjected to cyanide die.

Runoff and **land-based pollution** from effluent discharge of industrial waste, domestic waste, agricultural sources and logging practices do great harm to corals. Sedimentation from dredging and runoff smothers corals, thus preventing the coral from exposure to sunlight and capturing plankton, their primary sources of energy and nutrition. In comparison to the acute stress caused by destructive fishing practices, the chronic stress of sedimentation leads to slow and gradual decline of reef health. This, in turn, impedes growth and makes corals more susceptible to disease and death. Nutrient enrichment can introduce imbalance to the reef ecosystem due to stimulated phytoplankton growth. Moreover, it may bring about proliferation of seaweeds, which rapidly outgrow the slow-growing corals that are adapted to the low-nutrient concentrations typical of tropical seas.

Climate change, and in particular its associated effect of **coral bleaching,** is a key threat to the future of coral reefs. Corals and many other reef organisms depend for survival on symbiotic algae living in the polyps as these algae provide up to 95% of the coral's energy for growth, reproduction, and feeding. These algae, zooxanthellae, also give the coral their beautiful colour and when the corals become stressed, the loss of the zooxanthellae from the coral colony leaves a bare white skeleton or 'bleached' appearance. If conditions improve and the source of stresses is removed affected corals may recover, with zooxanthellae returning but this depends on the duration and severity of the environmental disturbance [4]. A prolonged period of stress increases the likelihood of coral death. The coral bleaching event of 1998 was by far the worst on record and also the most widespread as 16% of coral reefs were effectively destroyed throughout the world [3]. This episode coincided with prolonged periods of drought and higher than average sea surface temperatures linked with the 1998 El Niño event.

Impacts on Biodiversity

Coral reefs have been evolving for the last 240 million years and scientists estimate that, in total, more than 1 million plant and animal species are associated with the coral reef ecosystem. These important natural resources provide a home, shelter and food for nearly one quarter of all known marine species, including over 4,000 species of fish, 700 species of coral, and thousands of other forms of plant and animal life. However, studies show that populations of a variety of marine and coastal species have declined by 30% in the period 1970-95 [5].

With some 60% of the world's coral reefs 'seriously at risk' from human activities [6], it is likely that certain species will disappear before they have been identified. These species may have contained bio-active components that held cures for cancer, HIV and other diseases. Now, more than half of all new cancer drug research focuses on marine organisms. Compounds that have been extracted from a Caribbean reef sponge form the basis of AZT, a treatment for people with HIV infections. Alongside the extinction of unknown species, commercially important species are being wiped out which are critical to maintaining the natural balance of the coral reef ecosystem.

Some important findings from recent research paint a clear picture of the plight of coral reefs[2]:

- o reefs subject to land-based pollution showed a reduction of 30-50% in diversity at a 3 m depth, and a 40-60% reduction in diversity at a 10 m depth compared to unpolluted reefs at similar sites in Indonesia [7].
- o commercial reef fish favoured by tourists for eating may be facing extinction in the near future [8]. For example:
  - *Nassau Groupers were absent from 82% of shallow Caribbean reefs*
  - *Baramundi Cod were absent from 95% of Indo-Pacific reefs*
  - *Bumphead Parrotfish were absent from 89% of Indo-Pacific reefs*
  - *Humphead wrasse were absent from 88% of Indo-Pacific reefs.*
- o Important and highly-valued seafood such as spiny lobster and triton shells are also close to being extinguished. Moray eels were not recorded on 81% of reefs, and in the Indo-Pacific there were no groupers larger than 30 cm recorded at 48% of reefs surveyed [8]. This may indicate for some grouper species mass overfishing and removal of fish before they have had a chance to reproduce.
- o There was also a decrease in the global mean number of butterfly fish – widely considered to be an indicator species for reef health and diversity - from 1997 to 2001 (Figure 3) [8]. This could be an indication of overfishing and destructive fishing methods as well as a decline in general reef health.

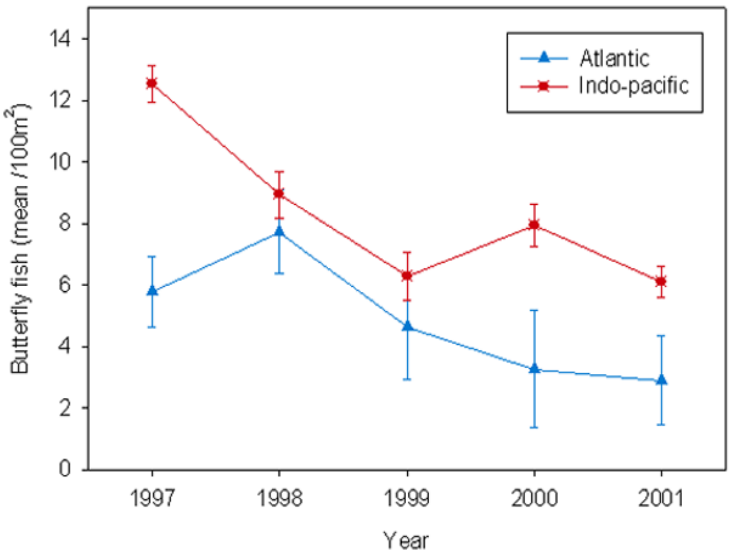

Figure 3: Mean Abundance of butterfly fish per 100 m² (1997-2001) on Indo-pacific and Atlantic reefs. Source:[8]

Impacts on People

The 2002 World Summit on Sustainable Development highlighted the importance of alleviation of poverty amongst the millions of people whose lives depend on coral reefs. Almost two-fifth of the world's population live less than 100 kilometres from the ocean [9] and most of these are in developing countries. As human populations continue to grow, coastal communities become increasingly dependent on healthy fish stocks. Reef-associated fisheries are an important component of this. See also Appendix on Poverty trap.

A combination of high levels of fishing pressure and habitat destructive harvesting methods, results in declining catches and reduces stock sizes to levels insufficient to ensure reproduction. Table 2 indicates perceived changes in fish stocks since 10 years by fishers throughout Indonesia.

Table 2: Indonesian fishers' perceptions on current status of reef fish stocks measured in daily catch compared with 10 years ago and reasons for change. Note difference between MPA sites and non-protected sites.

Site	Respondents	Decreasing catch	Reason for decrease: Over-fishing	Reason for decrease: Habitat destruction
Derawan	259	74%	55%	8%
Spermonde[a]	225	73%	71%	16%
Bunaken MPA	216	56%	No data	No data
Riung MPA	160	42%	34%	2%

Source: [10]; The Spermonde data (a) come from [11]

A second example is the artisanal reef-dependent fishery which is crucial to approximately 23,000 fishers in Zanzibar, contributing over 60% of protein consumption to local communities [12]. Along the reef strewn coastline of Eastern Africa, some 50% of about 100,000 full-time fishers and several hundred thousand part-time fishers risk losing their livelihoods if over-fishing continues [13].

Overfishing in reef areas and coastal habitat destruction can often a result in continued and increased poverty. The open access character of coral reef fisheries increases fishing effort resulting in locally decreased catches, particularly in marginal fisheries . In a spiral of diminishing returns, other family members then need to partake in securing daily food, often through reef gleaning such as harverting octopus and sea cucumbers at low tide. Associated reef trampling with this activity puts yet another irreversible stress on the corals. Additionally, (by)-catch of other (often endangered) marine organisms such as whales and manta rays provide a welcome, if unsustainable, contribution to fishers' incomes or simply to the families' dietary requirements for protein. Figure 4 shows involvement of women in fisheries in Bunaken National Park sampled in 16 villages, indicating the dependence of entire families on the Park's reefs [14].

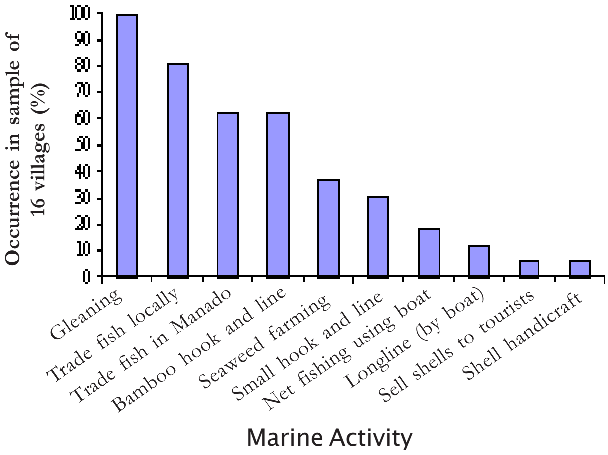

Figure 4: Summary of Marine Activities by Women in Bunaken National Park, Indonesia; (Source [14])

Economic Valuation of Coral Reef Decline

Potential Economic Value of Coral Reefs

The fact that coral reefs have tremendous value often seems to elude policy and decision makers. If these decision makers were more aware of the amount of capital that healthy reefs can bring to the economy in terms of tourism, fisheries, coastal protection and biodiversity, a more concerted and united management effort would be possible. Economic valuation can help to ensure that coral reefs are properly taken into account in public decision-making and that financial resources – both locally and globally – are made available for their management and conservation. In addition, economic valuation enables the assessment of monetary losses to the economy when reefs are damaged as a result of human activities (e.g. ship groundings, oil spills). Below, new estimates are given of the reef value in monetary terms.

Reefs provide a variety of goods and services, which create economic benefits to society. These economic benefits are often taken for granted, yet if these goods and services were taken away or destroyed, we would be forced to provide other methods to supply these benefits at significant costs. Table 3 illustrates the potential net benefit streams for the world in the order of US$ 30 billion per year if coral reefs were well managed and intact, based on new calculations[3]. The corresponding global asset value of coral reefs is estimated at nearly US$ 800 billion, calculated at a 3% discount rate and a 50 year timeframe.

Potential net benefits from fisheries are estimated at US$ 5.7 billion a year. Yet, overfishing and destructive fishing have taken their toll and reef fishery benefits in most places in the developing world are now close to zero – fishers merely fish to stay alive without making any profits. The aesthetic beauty of coral reefs attracts millions of tourists worldwide who come to dive and snorkel amongst these natural treasures. Reef tourism is growing rapidly and is estimated to provide potential annual net benefits of US$ 9.6 billion. Coral reefs also act as natural sea walls by providing a buffer to protect inshore areas from the pounding of ocean waves. This protective function of reefs is estimated to be valued at US$ 9.0 billion per year. Finally, reef biodiversity has a high research and conservation value, as well as a non-use value, estimated together at US$ 5.5 billion annually. In addition to these quantified values, reefs have drawn a mass of medical and pharmaceutical research interest in the pursuit of finding cures for human diseases. These estimates provide new data on how much reefs can be worth in economic terms and give insight into the costs to society if these reefs are lost.

Table 3: Potential net benefit streams per year and net present value (NPV) of coral reefs per region (in US$ million) [see note 3 for supporting calculations]

	Southeast Asia	Caribbean (ex. USA)	Indian Ocean	Pacific (ex USA)	Japan	USA	Australia	World
Reef area (km²)	89,000	19,000	54,000	67,000	3,000	3,000	49,000	284,000
Fisheries	2,281	391	969	1,060	89	70	858	5,718
Coastal protection	5,047	720	1,595	579	268	172	629	9,009
Tourism/recreation	4,872	663	1,408	269	779	483	1,147	9,621
Biodiversity value	458	79	199	172	529	401	3,645	5,483
Total	12,658	1,853	4,171	2,079	1,665	1,126	6,278	29,830
NPV (at 3%)	338,348	49,527	111,484	55,584	44,500	30,097	167,819	797,359

Tourism Overuse

Tourism is the world's largest industry, employing 199 million people and contributing US$3,500 billion (10%) to world GDP in 2002 [15]. Globally, tourism is one of the top five sources of foreign exchange for 83% of countries. Moreover, it is the fastest expanding industry, growing annually at 4.6% in the year 2000 [16]. Reef-related tourism is increasing even more rapidly with dive tourism growing at a rate of 20% per year [17]. The Caribbean, for instance, attracts about 57% of the world's 10 million active SCUBA divers and it has been estimated that by the year 2005, diving will generate about $1.2 billion annually [18]. Figure 5 shows the spread of dive centres and tourism as percentage of GDP.

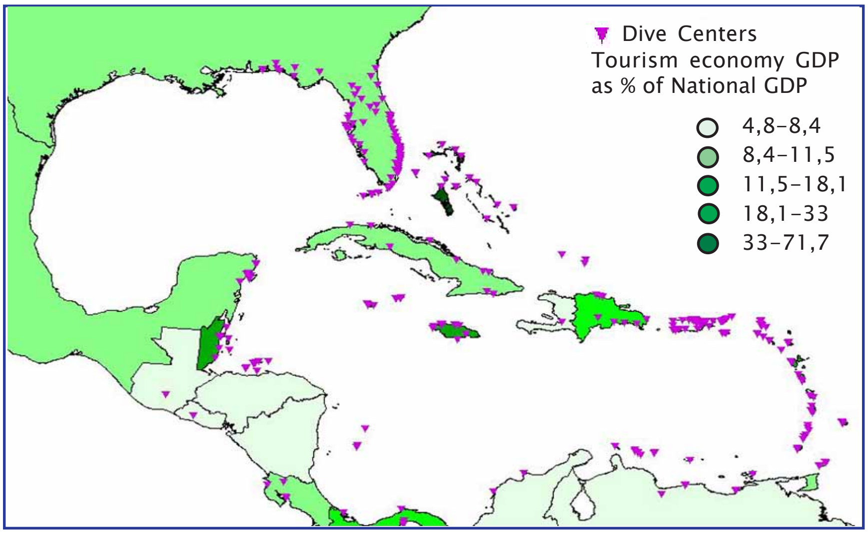

Figure 5: Dive Centers and Tourism Economy as percentage of GDP in the Caribbean
Source: Preliminary data from Reefs at Risk in the Caribbean project, WRI (unpublished), based on [15] and UNEP-WCMC dive centers.

However, coastal tourism has in many places been a mixed blessing. The rapidly expanding mass tourism industry in the Caribbean has required large investments in coastal development to cater for the high influx of tourists, as there is an increasing demand for hotels, marinas, harbours, shops, sports facilities, etc. These rapid developments have had major impacts on the coral reefs, on which the tourism industry depends, with 32% of Caribbean coral reefs estimated to be threatened by coastal development [6]. Sewage from coastal developments, including tourist resorts, is the largest form of pollution in the Caribbean as 80-90% of the sewage generated is disposed of in near-shore coastal waters without adequate treatment [19]. Additionally, in many areas the sheer numbers of dive and snorkel tourists cause direct damage to coral reefs, often through careless behaviour including contact with fins and hands, as well as boat or anchor damage.

In a further illustration, in 1993 the Cayman Islands generated about US$ 280 million from general tourism. Of this, US$ 84 million was spent by divers for diving and non-diving related activities [17]. Nearly 375,000 logged dives were recorded and some dive sites attracted 15,000 dives in one year. The Grand Cayman office of tourism considers that dive sites can support between 4,500 to 5,000 dives per year before the reefs become seriously degraded [17]. A recent ecological study in Grand Cayman [20] found significantly lower overall hard coral cover at high intensity sites compared with low intensity and undived sites. High intensity sites were also found to have greater incidences of total dead coral and coral rubble [20]. Current levels of diving pressure are thus unsustainable and all reefs in the Caymans are now at serious risk.

Diving is also important for the economy of Bonaire, Netherlands Antilles. Diving rates on this island have increased from about 20,000 total dives per year in 1991 to about 26,000 in 2001. Diver impacts were analysed for Bonaire in the early 1990s [21]. This study found that diver impact becomes quickly apparent when use exceeds a level of 4,000-6,000 divers on a single dive site per year. Thanks to effective management, current levels of diving are still largely within these limits. This has enabled Bonaire to maintain itself as one of the best dive sites in the world.

A recent study in Hurghada estimated the percentage of coral damage in correlation with the number of dives per year [22]. The results (Figure 6) show coral impacts in heavily dived sites. (see also Box 2).

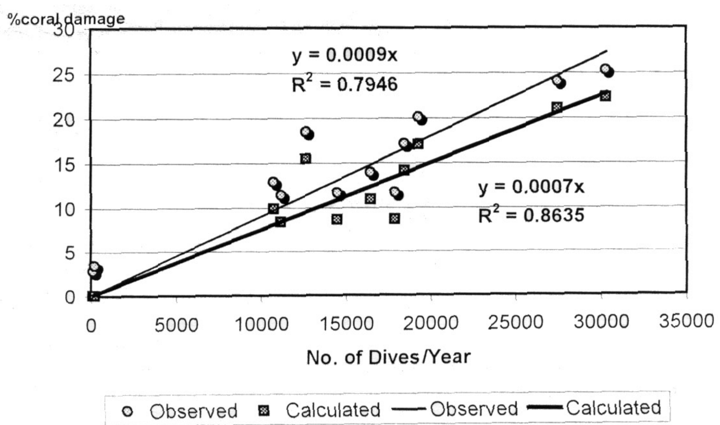

Figure 6: The correllation between the number of dives per year and the observed and calclutated percentage of coral damage recorded from the examined sites around Hurgada, Egypt [22].

Photo: Tourism trampling on coral (by Marc Kochzius)

It is likely that the notion of carrying capacity is elastic rather than fixed [23] and depends on other factors, such as the level of diver education and briefing [24], or adverse impacts from tourism development practices in general and construction in particular.

Tourism clearly brings substantial benefits to countries with reefs, estimated here at US$ 9.6 billion annually. However, the income derived from tourism is threatened by reef degradation, often the result of mass tourism development. The challenge for policy makers and the private sector is to develop a high value sustainable tourism industry that maintains healthy reefs over time.

Box 1: Dive toursim in Egypt: where do we go?

Egypt offers 1,800 km of coastline and 3,800 km² of reef in the tropical waters of the Red Sea coast and in the Gulf of Aqaba [1]. Live coral cover is relatively high in Egypt, varying on reef slopes from 2% to 62% and along reef walls from 12% to 85% [2]. Reefs are of particular importance to the Egyptian economy due to their close proximity to the millions of tourists from Europe. Around 2.5 million visitors a year enjoy the tropical coastal areas of Egypt, of which 23% come specifically to dive and a further 33% participate in snorkeling activities [25].

In recent years, anthropogenic impacts have reduced coral cover in many places by 30% [2], both through direct contact (fins and trampling) as well as through land reclamation, artificial beach construction and hotel sewage. Around 61% of the country's coral reefs are estimated to be at serious risk from human impacts [6]. A recent study has shown that in areas where the number of divers far exceeds the diver carrying capacity, coral cover is gradually declining over time [22] and that an upper limit of around 10,000 divers annually per dive site seems to prevent serious degradation. Some of the most popular dive sites in Hurghada, however, are now hosting well above 100,000 divers a year. In such sites, the percentage live coral ranges from 29-34% in such sites versus 69-75% in non-diving control sites around Hurghada (Figure 7) [22].

Preliminary results from a USAID-funded study on the economic value of dive tourism in Egypt highlight positive and negative impacts of diving [25]. Two scenarios are described with a 50-year timeframe period: the 'business-as-usual' scenario and the 'towards sustainability' scenario.

In Hurghada, where tourism has developed since the 1980s, the impacts of tourist activities have already caused a significant decline in the value of coral reefs. The annual net benefits will decrease over time in the 'business-as-usual' scenario as reefs continue to be exploited at the current levels. In the 'towards sustainability' scenario, the number of divers decline to carrying capacity levels and net benefits will stabilize after an initial drop (Figure 7). In Marsa Alam, where tourism only took off 2-3 years ago, there is less of a threat at present from human impacts and both scenarios show increasing net benefits over time over the coming 10-15 years. However, this is reached in two very different ways. While tourism numbers are stabilized in the 'towards sustainability' case with higher value added per tourist, the 'business as usual' scenario shows increasing numbers of tourists and decreasing value per tourist over time. After 2020, the difference in approach starts to show off: net benefits in the 'towards sustainability' case keep increasing over time, while dive benefits of the 'business-as-usual' case start to diminish (Figure 7).

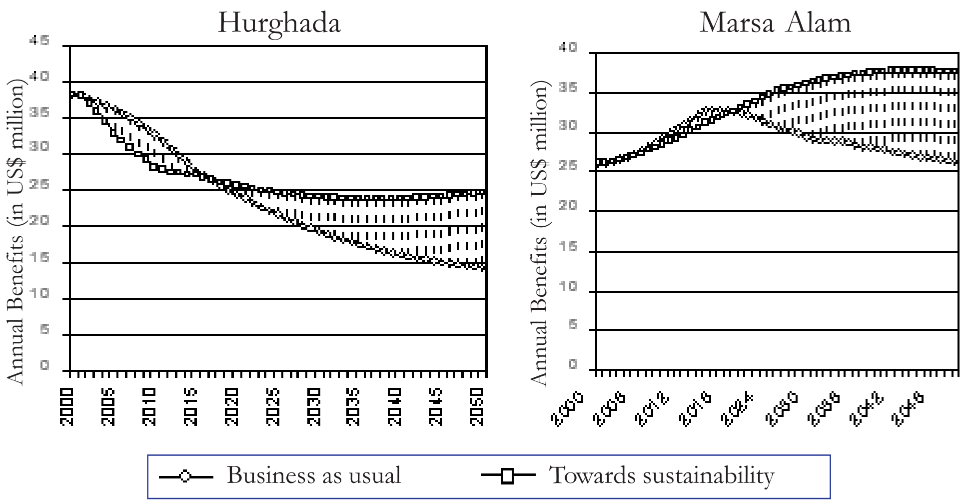

Figure 7: Change in annual benefits over time in Hurghada and Marsa Alam (Source: [25])

Destructive Fishing

Destructive fishing practices (DFPs) include well-known problems such as blast and cyanide fishing and muro-ami nets[1] . DFPs result in direct damage to the fisheries habitat or to habitat-structuring organisms, such as hard coral communities [26]. Blast fishing occurs in the Caribbean, East Africa and Southeast Asia. Cyanide fishing and muro-ami are largely restricted to Asia and parts of the Pacific. Figure 8 indicates high threat levels for major parts of Sulawesi (Indonesia), the Philippines and Vietnam [27].

Photo: Blast fishers in Indonesia (by Lida Pet-Soede)

Economics drive the use of DFPs but sooner rather than later the reefs will have been destroyed having broad socio-economic impacts on coastal communities and society as a whole. Estimates from Indonesia show that costs of blast fishing to society, can be as much as 4 times higher than the benefits to fishers, resulting in a net loss after 20 years of blast fishing of over US$ 300,000 per km^2 of coral reef in areas with a high potential value of tourism and coastal protection, and US$33,900 per km^2 where there is low potential value [28]. The main quantifiable costs are through loss of the coastal protection function, and the foregone benefits of tourism and non-destructive fisheries. Based on these figures, the foregone benefits to Indonesia of blast fishing during the last 25 years could be estimated at US$ 3.8 billion [29]. Bombs were originally made from World War II ammunition, but now chemical fertilizers are used at very low cost (US$ 1-2). Income from blast fishing compares to the highest incomes in conventional fisheries. Three types of blast fishing occur in Indonesia: small-, medium- and large-scale. At individual household level, differences between the three show incentives for scale enlargement (Table 4).

Cyanide fishing is popular amongst the younger generation of fishers who perceive available resources opportunistically, and join the ranks of divers roaming reefs for groupers and elusive angelfish. Cyanide fishing is both used for the aquarium trade [Box 2] as well as the live food fish trade. The latter emerged from Hong Kong, Taiwan and mainland-China [30], where customers are willing to pay US$ 100 and more per serving, especially for specific species of groupers (especially *Plectropomus spp.* and *Cromileptes altivelis*) and Napoleon wrasse *(Cheilinus undulatus)*. The high prices allow Indonesian traders and middlemen to employ skilled divers and use relatively advanced methods, yet sizes of cyanide operations vary from single outboard engine canoes to large-scale mother ships with several dinghies and 20 crew. Profits and incomes are higher than in any type of conventional fishery (Table 4).

Table 4: Midpoint estimates of monthly average income in US $ for crew and owners of destructive fishing operations in Indonesia (Source: [29]).

Destructive Activity	Small-scale	Medium-scale	Large-scale
Blast fishing ('97):			
- Crew	**55**	**146**	**179**
- Owner	**55**	**393**	**1100**
Cyanide fishing:			
**** Food fish ('97)***			
- Crew	**100**	**252**	**400**
- Owner	**100**	**413**	**35000**
**** Aquarium fish ('02)***			
- Crew	**120**	**253**	**114**

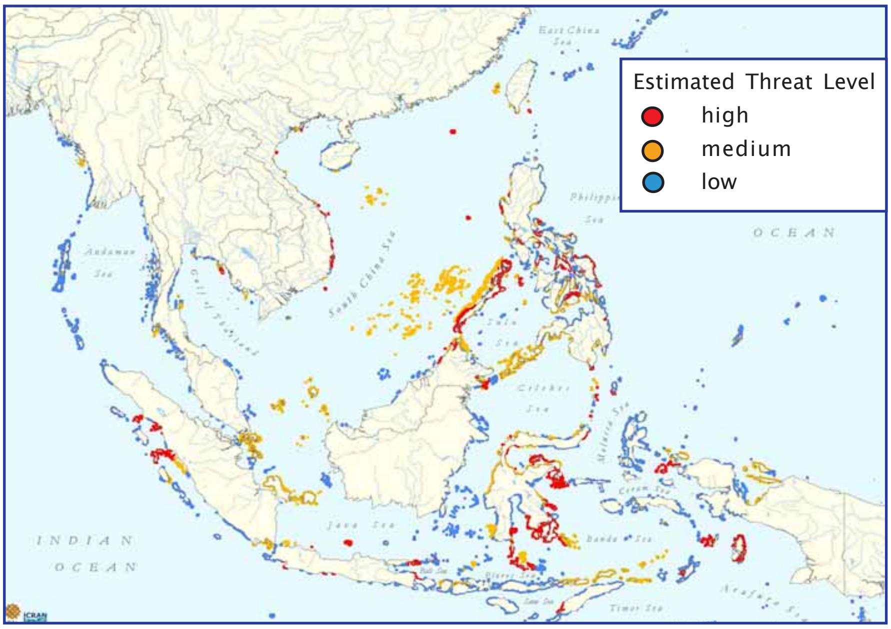

Figure 8: Occurrence of destructive fishing in Southeast Asia (blast and cyanide fishing) [27]

Individual fishers often seem locked into their destructive practices although their combined actions exhaust the resources that form the basis of their income. Management of the vast ocean waters poses serious logistical challenges, particularly where enforcement authorities have low wages and are thus susceptible to corruption. Yet the projected losses would seem to justify substantially increased enforcement efforts to halt the destructive practices and reverse the downward spiral of poverty and resource degradation.

Box 2: Aquarium Trade

The global marine aquarium trade involves some 1000 fish species, 2000 coral species, live rock and other reef invertebrates such as clams, worms and sea feathers. Indonesia is a major exporter and its importance is rising yet the potential negative impact of international trade on the country's wild populations is high. In 1997 Indonesia was the main supplier of marine aquarium fish to the EU, providing 217.1 tonnes (44%). The volume shows a 60% increase compared to 1996 (132.5 tonnes) and 150% compared to 1991 [32]. In 1996, EU Member States importing most of Indonesia's marine ornamental fish were: the Netherlands, United Kingdom, France and Germany, [32]. Compared to other Indonesian fisheries, the ornamental trade is a small but lucrative sector. Unfortunately destructive techniques are used and the trade experiences high losses during transportation from bad handling. In response, the Marine Aquarium Council (MAC) has launched an effort to reform the trade through the establishment of a certification system which would allow hobbyists the choice of fish caught and transported using sustainable methods.

Runoff and Land-based Pollution

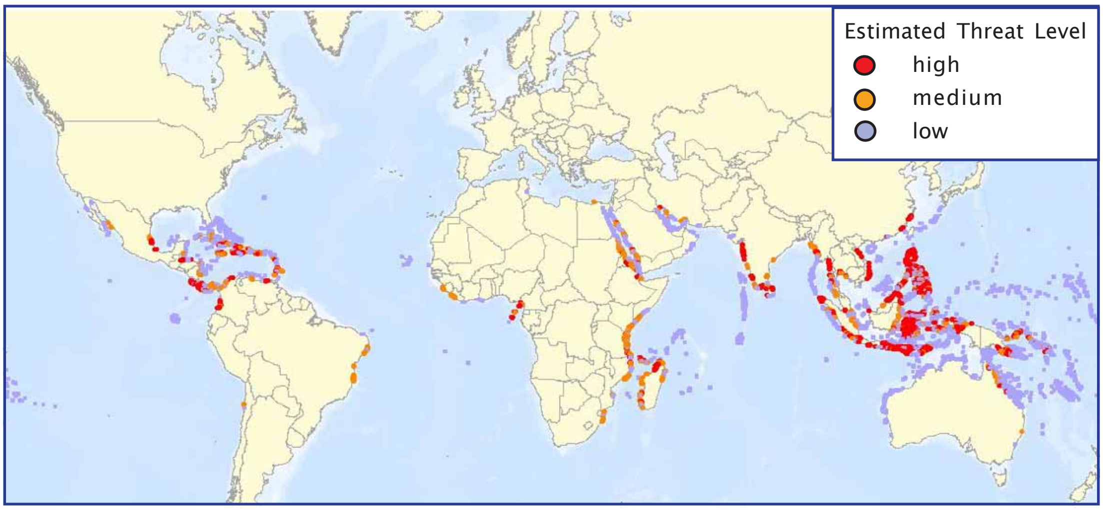

Figure 9: Sedimentation from inland sources [6]

Land-based sources of pollution and sediment are a significant threat to coral reefs, both through smothering coral with sediments and through increased nutrients and other pollutants, which create favourable conditions for algae and disease. Some sediment and pollution come from activities near the coast, while others originate far inland and are transported by rivers to the coast. Land clearing and agricultural activities contribute to this threat. A 1998 study by the World Resources Institute estimates that 22% of the world's reefs are under medium to high threat from inland sources of pollution and sediment [6], sometimes with large economic consequences (Figure 9).

Economic valuation of runoff and land-based pollution is nearly impossible as often there are multiple sources of pollution, having site-specific and seasonal dispersal, and a variety of economic impacts (water-borne diseases, lower fisheries productivity, reduced amenity, etc.). A possible exception is logging, where a specific activity leads to erosion and the consequences are restricted to one or two major impacts. An example is the logging versus fisheries and tourism case in El Nido, Palawan (Philippines) summarised in Table 5 [32].

There are two options to address logging: a logging ban (1) versus a continuation of logging (2). Gross revenues are estimated for each sector under both options for 1987-1996. Reults are striking as gross revenue under option 1 more than doubles that under option 2 even when logging revenue

Table 5: Tourism, fisheries and logging industries: ten-year sum of gross revenue ('000 US$) under 2 scenario's: Logging ban (option 1) and continued logging (option 2) (Source: [32].

Gross Revenue	Ban on logging (1)	Continued logging (2)	Option 1-2
Tourism	47,415	8,178	39,237
Fisheries	28,070	12,844	15,226
Logging	0	12,844	-12,884
Total	***75,485***	***33,906***	***41,579***

Box 3: Cost benefit Analysis for Wastewater Treatment Plant in Florida Keys [33]

The Florida Keys contain extensive coral reefs and are a popular destination for water sports enthusiasts. Given their isolated position, fresh water availability and wastewater issues have long been a management challenge. Pollution from wastewater in the Keys contributes to eutrophication of the coastal waters and degradation of local marine communities. A treatment plant would reduce wastewater entering this environment, yet it would require around US$ 60-70 million in investment costs and around US$ 4 million annually in operational costs. However, in the long-term the benefits with respect to the welfare gains of tourists are much higher, around US$ 700 million in NPV terms. Hence, the wastewater treatment plant is economically fully justified in this ecologically sensitive area.

under option 1 is nil since fisheries and tourism, generate large and continuing benefits. In contrast, continued logging generates smaller and decreasing benefits as after five years, both the logs and a significant part of the tourism and fisheries sectors will be depleted. The modest logging revenue generated under option 2 is easily offset by the decreased income from tourism and fisheries. This study helped convince the provincial government to withdraw this specific logging licence [32].

Photo: sedimentation (by Ross Jones)

These and other studies have shown the benefits of reduction in runoff and pollution. In developing countries policy makers that are challenged to achieve economic progress are not easily convinced of the benefit of investing in waste treatment and run-off reduction. Costs of wastewater treatment is indeed high, but the costs can be supported by even greater economic benefits (Box 3).

At the World Summit on Sustainable Development, the H2O Partnership (from Hilltop to Ocean) was launched, promoting ocean protection from land based activities. Linking river basins with coastal zone management can reduce negative external effects of sedimentation on reefs. In this sense, this partnership is a modern institutional version of the traditional Hawaiian ahapu'ua system whereby the entire watershed from hilltop to reef and beyond is seen as one area to be managed by one clan. This ensures that any impacts of land-based activities on coral reefs are taken into account.

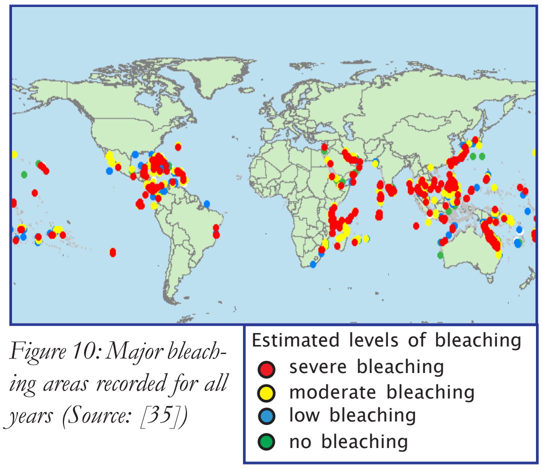

Figure 10: Major bleaching areas recorded for all years (Source: [35])

Global coral bleaching episodes and subsequent coral mortality are likely to result in serious socio-economic impacts. A study on the 1998 massive bleaching event estimated a loss of US$ 700 – 8,200 million in net present value terms for the Indian Ocean [34]. Evidence suggests that the cause of these bleaching events is El Niño-related changes in sea-surface temperatures [34] (Figure 10). It is difficult to establish this link with scientific certainty but it is important, nonetheless, to estimate likely losses over time due to future changes in sea surface temperature.

Recent work on "hotspot frequencies" show a weak link with bleaching events. Figure 11 shows the cumulative number of hotspots over 16 years, between 1985-2000. The data are based on climatological mean 5-day maximum temperatures[4]. A hotspot is recorded whenever the temperature in a grid cell exceeds the mean maximum temperature in that cell by one degree Celsius. The map illustrates that there is a wide geographical variation in where hotspots are experienced. Note that a high frequency of hotspots does not indicate a high correlation with a high incidence of coral bleaching (Figure 10): corals can bleach in places where hotspots are infrequent and may even be less tolerant to hotspots than in areas that experience frequent hotspots.

There is little biophysical and ecological knowledge of the impacts of large-scale coral mortality on ecosystem services [37]. This makes it even harder to estimate socio-economic impacts of large scale bleaching and related mortality. With these caveats in mind, new estimates on tourism, fisheries and biodiversity impacts are presented here, by region and by ecosystem function.

Current estimates suggest a likely increase in the frequency of bleaching as a result of climate change and predict that bleaching could become an annual event in the next 25-50 years [38]. Given the uncertainties discussed above, a scenario-analysis is used to estimate possible economic costs of these predictions. In the 'moderate' bleaching scenario – corals would bleach but mortality is limited - it is assumed that fisheries, tourism and

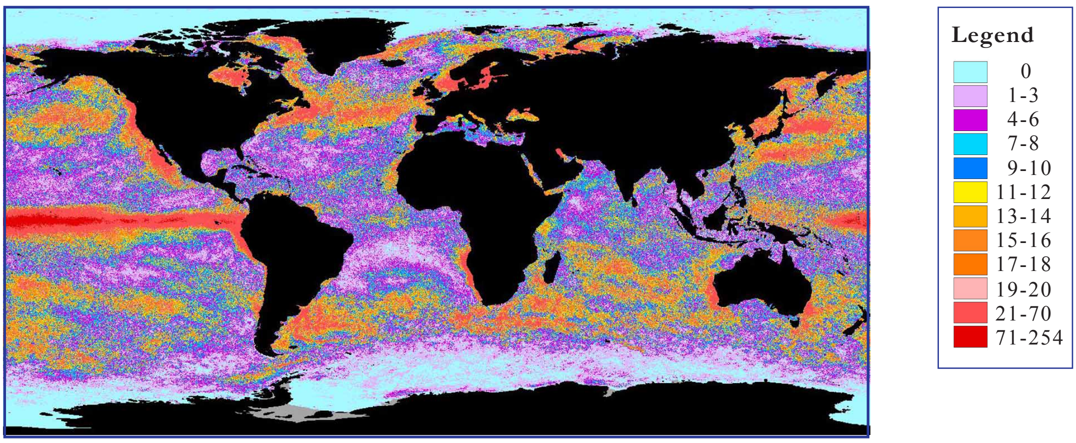

Figure 11: Cumulative Number of Hotspots over 16 years (1985-2000) (NOAA data through Ken Kassem, WWF-US)

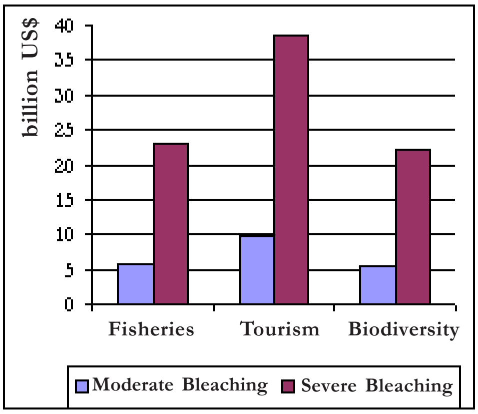

Figure 12: Costs of bleaching distributed among sectors (in billion US$)

biodiversity values will decline gradually over time to 90% of their current level. In the 'severe' bleaching scenario with mass coral mortality, it is assumed that these values will decline to 50% of current value. Current values are based on calculations presented in Table 3. Total costs of bleaching over a 50 year time horizon with a 3% discount rate are estimated at over US$ 84 billion in net present value. For moderate bleaching, this number is US$ 20 billion. The tourism value is highest with nearly US$ 40 billion in the 'severe' bleaching case, followed by fisheries (US$ 23 billion) and biodiversity (US$ 22 billion) (Figure 12). The regional distribution is given in Table 6 and shows that the main costs of bleaching are in Australia (US$ 28.4 billion) and Southeast Asia (US$ 38.3 billion).

In addition to bleaching, there are other associated impacts of climate change which will have adverse impacts on coral reefs and their economic value. It has been projected that the sea-surface temperature in the Caribbean could lead to about 40% more hurricane activity in the area [39]. Hurricanes have the potential to destroy large areas of coral reef on a national and regional scale. Between 1997 and 1998 there was a 50% reduction in live coral cover in Belize, mainly attributed to hurricane Mitch and the coral bleaching event of 1998 [3]. These events and subsequent impacts simply add to the overall economic costs to society. Overall, in the Caribbean, climate change is predicted to cause a loss of US$ 109.9 million in terms of increased sea-surface temperatures, sea-level rise and loss of species among others, which equates to 13.8% of the total GDP [40].

The question is what short term measures are available to address coral bleaching, in addition to the promotion of global efforts to curb emissions from burning fossil fuels. It may be possible to avoid the predictions of the 'severe' bleaching scenarios and remain at the level of the 'moderate' bleaching predictions. For example, it is possible that impacts of sea surface temperature changes on corals can be reduced by lowering the overall stress level on coral reefs through concerted efforts by all stakeholders ind more mainstream parts of international funding agencies' activities in the Caribbean and the Pacific. A concerted effort is required to ensure that these efforts are extended more widely to other regions of the worlds and that progress in addressing global climate change is made.

Table 6: Regional allocation of costs of severe bleaching (in billion US$)

	Severe bleaching
Australia	**28.4**
Southeast Asia (excl. Japan)	**38.3**
Caribbean (excl. USA)	**5.7**
Indian Ocean (incl. Red Sea)	**13.0**
Pacific (excl. Hawaii)	**7.6**
USA (excl. overseas territories)	**4.8**
Japan	**7.0**
Total	***104.8***

Note: Calculated in Net Present Value (NPV) with 50 year time horizon at a 3% discount rate.

References

[1] Spalding, M.D., Ravilious, C., Green, E.P. (2001) World Atlas of Coral Reefs. Prepared by the UNEP-World Conservation Monitoring Centre. University of California Press, Berkeley, USA

[2] Wilkinson, C. (2000) Status of Coral Reefs of the World 2000, Australian Institute of Marine Science (AIMS), Global Coral Reef Monitoring Network (GCRMN), Townsville, Australia

[3] Wilkinson, C. (2002) Status of Coral Reefs of the World 2002, Australian Institute of Marine Science (AIMS), Global Coral Reef Monitoring Network (GCRMN), Townsville, Australia

[4] Hoegh Guldberg, O. (1999) Climate Change, Coral Bleaching and the Future of the World's Coral Reefs, Report for Greenpeace, Australia

[5] Groombridge, B., Jenkins M.D. (2000) Global Biodiversity: Earth's Living Resources in the 21st Century,The World Conservation Press, Cambridge, UK

[6] Bryant, D., Burke, L., McManus, J., Spalding, M. (1998) Reefs at Risk – A Map Based Indicator of Threats to the World's Coral Reefs, WRI/ICLARM/WCMC/UNEP

[7] Edinger E.N., Jompa J., Limmon G.V., Widjatmoko W., Risk M.J. (1998) Reef Degradation and Coral Biodiversity in Indonesia: Effects of Land-Based Pollution, Destructive Fishing Practices and Changes over Time, Marine Pollution Bulletin 36:617-630

[8] Hodgson, G., J. Liebeler (2002) The Global Coral Reef Crisis: Trends and Solutions1997-2001, Reef Check, University California Los Angeles (UCLA), Los Angeles, USA

[9] Burke, L., Kura, Y., Kassem, K., Revenga, C., Spalding, M., McAllister, D. (2001) Pilot Analysis of Global Ecosystems: Coastal Ecosystems, WRI, Washington, DC

[10] WWF- Indonesia Wallacea Fisheries Program Document, unpublished 2002.

[11] Pet-Soede, C., 2000. Options for co-management of an Indonesian coastal fishery. PhD Thesis, Wageningen Agricultural University

[12] Jiddawi N.S. (1997) The reef dependent fisheries of Zanzibar. In Johnstone R.W, Francis, J. Muhando, C.A. (eds.) Proceedings of the National Conference on Coral Reefs, Zanzibar, 2-4th Dec. 1997:22-35

[13] Moffat, D., Ngoile, M.N., Linden, O., Francis J. (1998) The Reality of the Stomach: Coastal Management at the Local Level in Eastern Africa, Ambio 26:590-598

[14] Gallop, K. (2001) The impact of the Bunaken National Park management plan on women's access to and utilization of marine resources, North Sulawesi, Indonesia. MSc Thesis. WWF Wallacea Fisheries Program.

[15] World Travel and Tourism Council (2002), End of Year Update, TSA Research Summary and Highlights (also: www.wttc.org)

[16] World Tourism Organisation (1998) http://www.world-tourism.org

[17] Madigan Pratt & Associates (1995) Diving in the Cayman Islands: Economic Impact & Requirements for Maintaining Its Premier Status, Prepared for the Cayman Islands Department of Tourism. Cited in Caribbean Environment Programme and United Nations Environment Programme, 1997, Coastal Tourism in the Wider Caribbean – Impacts and Best Management Practices, Technical Report No.38.

[18] Caribbean Latin American Action. (1998) Caribbean Basin Profile, Caribbean Pro Publishing Ltd. Grand Cayman Island

[19] Simmons & Associates (1994) The Impact of Tourism on the Marine Environment of the Caribbean, Prepared for the Caribbean Tourism Organisation, cited in Caribbean Environment Programme and United Nations Environment Programme, 1997, Coastal Tourism in the Wider Caribbean – Impacts and Best Management Practices, Technical Report No. 38

[20] Tratalos, J.A., Austin T.J. (2001) Impacts of recreational SCUBA diving on Coral Communities of the Caribbean Island of Grand Cayman, Biological Conservation 102:67-75

[21] Dixon, J.F., Scura, L.F., Van't Hof, T. (1993) Meeting Ecological and Economic Goals: Marine Parks in the Caribbean, Ambio 22:117-125

[22] Abou Zaid. M. (2002) Impact of Diving Activities on the Coral Reefs along the Red Sea Coast of Hurghada, mimeo Marine Biology and Fish Science Section, Zoology Department, Al-Azhar University, Cairo

[23] Hawkins, J.P., Roberts, C.M. (1997) Estimating the Carrying Capacity of Coral Reefs for Recreational Scuba Diving, In: Proc. 8th Int. Coral Reef Symp. 2:1923-26

[24] Medio, D., Ormond, R. F. G. , Pearson, M. (1997) Effects of briefings on rates of damage to corals by scuba divers. Biological Conservation 79: 91-95

[25] Cesar, H. (2003) Economic valuation of the coral reefs of Egypt. Report prepared for the MVE-unit of EEPP, funded by USAID. Preliminary version, January 2003 (mimeo)

[26] Erdmann, M., Pet-Soede, L, N. Cabanban, A. (2002). Destructive Fishing Practices in: Best, B.A., Pomeroy, R.S. and Balboa, C.M. (Eds.), Implications for Coral Reef Management and Policy – Relevent Findings from the 9th international Coral Reef Symposium, pag 78-81, US-AID/WRI/CI/ISRS

[27] Burke, L., Selig, E., Spalding, M. (2002) Reefs at Risk in Southeast Asia, World Resources Institute, Washington DC

[28] Pet-Soede, L., Cesar, H., Pet, J. (1999) An Eco-

nomic Analysis of Blast Fishing on Indonesian Coral Reefs, Environmental Conservation 26: 83-93
[29] Pet-Soede, L., Cesar, H., Pet, J. (2000). Blasting Away: The Economics of Blast Fishing on Indonesian Coral Reefs, in Cesar H. (ed.) Collected Essays on the Economics of Coral Reefs, CORDIO, Kalmar University, Kalmar, Sweden
[30] Johannes, R.E., Riepen, M. (1995) Environmental, Economic and Social Implications of the Live Reef Fish Trade in the Asia and the Western Pacific, The Nature Conservancy, Jakarta.
[31] Raymakers, C. (1998) Unpublished fact sheet TRAFFIC and WWF-Netherlands, Zeist.
[32] Hodgson, G. Dixon, J.A. (1988) Logging Versus Fisheries and Tourism in Palawan: an Environmental and Economic Analysis. East-West Environment and Policy Institute. Occasional Paper No. 7
[33] Wiley P. (1999) Cost Benefit Analysis for Wastewater Treatment Plant in Florida Keys. unpublished, NOAA, Silver Spring (MD), USA
[34] Wilkinson, C. Linden, O., Cesar, H., Hodgson, G. Rubens, J. Strong, A.E. (1999) Ecological and Socioeconomic Impacts of 1998 Coral Mortality in the Indian Ocean: An ENSO Impact and a Warning of Future Change? AMBIO 26: 188-196
[35] Reefbase (2003) Bleaching Map, www.reefbase.org/reefgis/mapper.asp
[36] Kassem, K. (2003) Hotspot Frequency Images (mimeo), WWF-US, Washington D.C.
[37] Hoegh-Guldberg, O., Hoegh-Guldberg, H., Stout, D.K., Cesar, H., Timmerman, A. (2000) Pacific in Peril. Biological, Economic and Social Impacts of Climate Change on Pacific Coral Reefs, Greenpeace Australia
[38] Hoegh-Guldberg, O. (1999) Climate Change, Coral Bleaching and the Future of the World's Coral Reefs, Greenpeace Australia.
[39] Gray, W.M., Landsea, C.W., Mielke P., Berry, K. (1993) Predicting Atlantic basin seasonal tropical cyclone activity by 1 August, Weather Forecasting 8:73-86
[40] Tol, R.S.J. (1997) A Decision-Analytic Treatise of the Enhanced Greenhouse Effect. PhD Thesis, Vrije Universiteit Amsterdam, the Netherlands.
[41] Cesar, H., van Beukering,P., Pintz, S., Dierking, J. (2002) Economic Valuation of the Coral Reefs of Hawaii, Hawaii Coral Reefs Initiative, University of Hawaii, Hawaii, US.

Notes

1 The muro-ami technique involves setting bottom nets and then driving reef fish out of their hiding places and into the nets by walking (or swimming) along the substrate and beating the reef with sticks and other hard implements. This practice is highly unsustainable as the reefs are destroyed from trampling and beating of sticks by the fishermen

2 Site selection of the Reef Check study is not random, among other things and therefore, the results of the study should be considered as indications rather than proofs over certain trends.

3 Potential values for are taken from a recent economic valuation study in Hawaii [41]. These values were used for Australia, the US and Japan. For all other countries, potential values presented in the Reefs at Risk Report for South East Asia are used [27]. Both publications give value ranges. Reefs at Risk data for coastal development and overexploitation were used to calculate the weighted averages. Low values for fisheries were used for areas with high levels of overexploitation, while high values of fisheries were used for areas with low and medium levels of overexploitation. This was also used for the biodiversity value. For coastal protection and tourism, high and medium levels of coastal development were used for the upper limit of the range, while low levels of coastal development were used for the lower limit of the range. An exception was made for the Pacific, where only areas with high coastal development were linked to the high tourism and coastal protection value.

4 From the 9km AVHRR Pathfinder database.

5 Our estimates of average expenses include depreciation costs for boats and gear and operational costs for fuel and food for crew if applicable (multi-day-trips) and estimates of average catches. Maximum catches are very different and on a good trip the income can be a multitude of our estimates for average net incomes. Furthermore, our estimates may vary from fishers' estimates as these often not include depreciation of boat, engine and gear yet merely relate to gross income.

6 Multi-day trips.

Appendix: Poverty Trap Case Study

The poverty trap is a vicious circle of poverty, resource degradation and further impoverishment.Poverty is an important root cause for biodiversity loss and unsustainable resource use resulting in an intertwining of poverty relief and sustainability. In addition, unsustainable use of resources also introduces poverty when the very base to the natural resources disappears. This persistence of poverty is illustrated in the village of Lamakera in the Solor and Alor region of Indonesia. The region is a biodiversity hotspot for whales and other large marine life, including manta rays, marine turtles, billfish, tuna, ocean sunfish and other pelagics, mainly because of the region's function as migratory bottleneck with its productive currents and up-welling of nutrient-rich waters. However, the concentration of marine resources and lack of marine protected areas also makes the region highly vulnerable to increasingly modern fisheries pressures often arriving in the area from the more crowded and fished-out parts of western Indonesia. Destructive practices such as blast fishing and cyanide fishing are common, but impoverished local communities such as those in Lamakera, have turned to harvesting nearby manta ray populations.

The general economic situation in the Solor and Alor region is similar to other regions in eastern Indonesia and must be considered in the light of dominating agricultural and service sector contributions to regional economic production. During the recent economic crisis the islands were also hit by a severe drought giving the younger generation further impetus to leave the area. Already significant numbers of the area's inhabitants work in Malaysia as plantation, construction, or domestic workers. Aside from some minor government support projects that include small-scale seaweed farming, provision of some fish attracting devices and boats and engines, the general fishery is small-scale, focussing on resources nearby. Locals mention difficulties related to market access and education levels are low.

Not all coastal communities are full-time fishers and many supplement their income through farming. Farming serves subsistence purposes but also allows minor cash gains from selling nuts, corn and copra. Infrastructure supporting the local fishery is inadequate (e.g. there are no ice facilities) limiting the access to distant markets; and most fish must then be sold locally. On the large island of Lembata 80% of the roads are either unpaved or in bad condition from landslides. Access to the islands is limited to small ferries from Larantuka on the eastern tip of Flores. As a result very few products are sold out of the area such as sea cucumbers, shark fins, and manta ray skin, meat and gills.

Photo: Dried manta skin for sale (by Lida Pet-Soede)

The average income of fishing operations is dependent on the scale of the operations and on gross revenue of catches (Table 7). Catches are calculated on the basis of fish prices which depends on size and species, but is generally low pending local demand. Fishers relate decreasing tuna catches in nearshore waters to large, long-line fleets operating efficiently in deeper offshore waters. Reef fish are also said to be less abundant than 5 years ago due to reef destruction by outside and local fishers using bombs and cyanide.

Lamakera, situated on Solor has a whaling background, but increasingly fishers buy motorboats and use spear guns for catching manta rays. During the past five years this village has modernized its fishing fleet where all traditional whaling boats were sold 2-3 years ago and have been replaced by smaller boats

Table 7. Estimated mean benefits (US$) for fisheries in Alor and Solor region (1 US$ = Rp 10.000). Sorted by net monthly income per crewmember. [a]: Seasonal [5] ;[b]: 50/50 benefit share.

Gear type	Average catch/trip	Trips /month	Gross income /boat	Net income /person	Target species	Scale
Purse seine	300 kg	20	1000	55	Scads, squid	Medium crew[b]
Hook & line	3.5 kg	25	35-100	65	Reef fish	Small 1 crew
Traps	25 kg	25	100	90	Reef	Small 1 crew
Manta spear[a]	1 manta	15	120	95	Manta	Medium 6 crew
Trolling	5 kg	25	120	100	Tuna	Small 1 crew
Long line	1 kg fins dry	3[6]	1200	110	Sharks	Medium 4 crew[b]
Trolling	10	25	360-480	120	Tuna	Medium 3 crew
Spear + snorkel	5 kg fish + 1 kg teripang	25	120-230	120	Reef fish + teripang	Small 1 crew

powered with 15 horse power outboard engines (some subsidized through a poverty alleviation scheme). It was at this point that whale hunters switched to spearing manta rays. This was likely fuelled by the new revenue streams offered by buyers of manta skin, sold as leather to Jakarta and the brachial filter plates removed from the gills, sold as traditional medicine in Hong Kong. Exporting cartilage for inclusion the export shark fin industry is also being considered. Traditional hook and line fishers who have seen their reef catches dwindle and their resulting economic situation has forced them to join the manta crews.

Fishermen now focus on manta rays (Manta birostris), locally known as belelang, bou (Mobula tarapacana) and moku (Mobula sp.). Where once most of the manta was utilized in the village, now the vast majority is sold and the harvest has transformed into a commercial venture. Dried gill plates from one large manta bring between US$ 35-140, dried skins US$ 6/kg. Even the meat, which was once consumed in the village, is now sold locally. A bundle of 20 dried meat rings sell for US$ 3.5-4. This new market for skin and gill plates has resulted from an increase in effort. The new boats have dramatically reduced travel time to fishing grounds from 4 days to 1 day, allowing the same number of trips per month as was previously possible in 6 months. The total effort also expanded from 18 to more than 30 boats thereby increasing the local fishing pressure by almost an order of magnitude in only 5 years.

The total manta harvest per season (May-October) includes an average catch estimated to be 25-50 per boat per season, with an average take for the village of 60-90 per week. The total catch over the six-month season is estimated at 1,500 mantas (ranging between 1050-2400 individuals), which represents a considerable increase over historic levels that were normally 200-300 per season. Even if effects of over-fishing are not yet apparent, it is highly unlikely that the harvest can continue at the current rate. Whereas shark populations are understood to be highly susceptible to fishing pressure, the closely related manta rays are at even greater risk. Manta rays normally give birth to only one offspring at a time. The gestation period is thought to be nine months and it is not known whether females give birth every year. Mantas are also a long-lived species and likely reach sexual maturity only after 4 to 5 years, although this remains to be verified. For long-lived species with low reproductive rates commercial harvests have repeatedly resulted in the collapse of populations. There is no reason to think the mantas will be any different.

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