Trouble on the reef: the imperative for managing vulnerable and valuable fisheries

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Abstract

Reef fishes are significant socially, nutritionally and economically, yet biologically they are vulnerable to both over-exploitation and degradation of their habitat. Their importance in the tropics for living conditions, human health, food security and economic development is enormous, with millions of people and hundreds of thousands of communities directly dependent, and many more indirectly so. Reef fish fisheries are also critical safety valves in times of economic or social hardship or disturbance, and are more efficient, less wasteful and support far more livelihoods per tonne produced than industrial scale fisheries. Yet, relative to other fisheries globally, those associated with coral reefs are under-managed, under-funded, under-monitored, and as a consequence, poorly understood or little regarded by national governments. Even among non-governmental organizations, which are increasingly active in tropical marine issues, there is typically little focus on reef-associated resources, the interest being more on biodiversity *per se* or protection of coral reef habitat. This essay explores the background and history to this situation, examines fishery trends over the last 30 years, and charts a possible way forward given the current realities of funding, capacity, development patterns and scientific understanding of coral reef ecosystems. The luxury live reef food-fish trade is used throughout as a case study because it exemplifies many of the problems and challenges of attaining sustainable use of coral reef-associated resources. The thesis developed is that sustaining reef fish fisheries and conserving biodiversity can be complementary, rather than contradictory, in terms of yield from reef systems. I identify changes in perspectives needed to move forward, suggest that we must be cautious of 'fashionable' solutions or apparent 'quick fixes', and argue that fundamental decisions must be made concerning the short and long-term values of coral reef-associated resources, particularly fish, for food and cash and regarding alternative sources of protein. Not to address the problems will inevitably lead to growing poverty, hardship and social unrest in many areas.

Keywords biodiversity, conservation, live fish trade, management, reef fish fisheries

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Introduction

Reef fish fisheries have long sustained coastal communities throughout the tropics as an important, sometimes sole, source of protein and livelihood. In the last few decades, with the development of the economy, technological improvements in fishing gear, growing coastal populations, globalization of trade and rising life-style aspirations, these fisheries have widely come under threat. Rapid modernization has led to problems unimagined even a generation ago.

Let's take the islands of Fiji to illustrate some of the major problems. James Hornell, based in Fiji in the 1930s, could not have envisaged what would happen once the desires (Hornell's wording) of the modern world were awakened, as can be seen from his unmistakably industrialized-world lament: ''So few and so simple are their (those who by right of heritage are native Fijians and own the sea) wants, that a minimum of effort suffices to supply them. Money of itself furnishes no incentive. Therefore, until they come to value money as a means to the attainment of wants at present not desired, we cannot expect them to awaken from their present apathy and indifference to the riches which the sea offers to their grasp at the expense of regular and sustained effort'' (Hornell 1940).

Less than 50 years after Hornell's publication, fishing effort had become so sustained and focused on material riches, cash needs for schools, commodities and the Church that what the sea can provide has come under threat (A. Batibasaga, Fiji Fisheries, personal communication). Had he had the chance to rewrite his words, with hindsight, Hornell might well have qualified them, in the recognition that reef-associated resources are far from certain means to unlimited wealth. It is to Hornell's credit that he also proposed the establishment of a fishery division now struggling actively to deal with the consequences of awakened desires.

In Fiji, reef fish catches are on the decline, with far-reaching consequences for health, human communities and target species, a pattern repeated in much of the tropics. Fresh fish is increasingly marketed for cash or exported, rather than going to the dinner table, while cheaper, imported, canned mackerel or inexpensive frozen fish are a regular part of the diet (A. Batibasaga, personal communication). Aspirations within some communities are frustrated because of declining catches and incomes, and there are increasingly unwelcome incursions by outside interests into areas of local Customary Marine Tenure (CMT) known as 'qoliqolis' (Y. Sadovy, unpublished data based on fisher interviews conducted in Fiji in 2003). Fishers must travel further than before, with less working time within their communities, and possibly increasing the workload on women who take up some of the slack. In urban areas, or where there is extensive coastal development, damage to reefs exacerbates decline due to overfishing, while in remote communities there are few alternatives to gaining a living from the sea. Formerly important or culturally significant species in Fiji and elsewhere, have all but disappeared, such as the bumphead parrotfish (*Bolbometopon muricatum*, Scaridae) and humphead wrasse (*Cheilinus undulatus*, Labridae) (Dulvy *et al.* 2003; Sadovy *et al.* 2003a). Yet there is little incentive for government action because the value of subsistence catches is typically not factored into economic valuations of the resource. For example, in the mid-1990s commercial landings were estimated at 6653 tonnes and subsistence at 16 600 tonnes, annually, yet only commercial landings were assigned a monetary value and officially considered an economically beneficial activity; elsewhere in the Pacific the pattern is the same (Gillett and Lightfoot 2001).

A situation similar to that in Fiji occur throughout the tropics. There is growing recognition that reef fish fisheries need substantially more attention at local, national and international levels to prevent further declines and to ensure that they continue to play a critical role in providing coastal communities with food (Whittingham *et al.* 2003; Sadovy et al. 2003b; Bellwood *et al.* 2004). Easy access to fishing is particularly important in times of economic hardship where fishing may be one of few remaining livelihood options, not just in developing but also in developed areas. For example, in Hong Kong during the SARS (severe acute respiratory syndrome) crisis when unemployment increased due to an economic downturn, fishing remained an important option for food or income (Y. Sadovy, personal observation). In the Pacific island of Niue following cutbacks in government sector jobs, in times of hardship in coastal Mozambique, or in Indonesia following a decline in clove prices, fishing as a source of income became critically important for food and livelihoods (Whittingham *et al.* 2003; I. Harkes and I. Novaczek, unpublished data). Indeed, in many cases fisheries provide the ultimate alternative livelihood.

This paper explores key reasons as to why management is so poorly developed for most tropical reef fisheries, with a focus on fish species because of their critical importance for sustenance, examines why it is so important to address the issues from economic, social and biological perspectives, and considers options for change. It is argued that many reef fishes are by their nature particularly susceptible to over-exploitation and that important factors impeding progress in their management are perceptions of low economic value, a poor understanding of their biology and response to fishing, a lack of effective local, national or international management measures, misdirected non-governmental organization (NGO) initiatives, and the relatively recent dual pressure on fisheries important both for local consumption as well as for generating cash in local and international markets. I do not consider other important aspects of coral reefs, such as their role in shoreline protection or biogeochemical services as these are well-covered elsewhere, and further strengthen the case for action (e.g. Moberg and Folke 1999). As a case study, throughout, I refer to the luxury international trade in live reef fish for food because it is relatively well understood, epitomizes many of the general problems and has cast a much-needed spotlight on key issues.

Recent history and current condition of coral reef-associated fisheries

Overview

Reef-associated fisheries officially make up about 10% of total world marine fishery landings, according to the UN Food and Agriculture Organisation (FAO) statistics. In the eyes of governments, donors, aid agencies and the general public, this misleadingly low figure all but obscures their true significance. In so doing, it distracts much-needed attention from their assessment, funding and management. Reef fish fisheries provide food, livelihoods and incomes for tens of millions of people in the tropics and subtropics; 20–25% of all reef fishes taken globally are caught in developing countries (Cesar *et al.* 1997; Moberg and Folke 1999). In South-east Asia alone over 20 000 000 people are employed in fishery and related sectors (Cesar *et al.* 1997; World Resources Institute 2005). In the Philippines, reef fishes are estimated to comprise 15–30% of total national municipal fisheries production from the small-scale sector (Alino *et al.* 2004), while a study from the island of Lombok, Indonesia, showed that >35% of the catch from small-scale fishermen came from coral reefs (Spalding *et al.* 2001). Many communities in thousands of small islands depend almost exclusively on the sea for livelihood. In Pacific island nations, subsistence landings are up to 10 times higher than commercial coastal landings (Gillett and Lightfoot 2001), and overall about 80% of the coastal fishery landings do not enter the economy (FAO 1997). Finally, in a world that increasingly has to be aware of efficiency and wastefulness, it is important to recognize that small-scale fisheries are more efficient, less wasteful and support far more livelihoods per tonne produced than industrial scale fisheries (Thompson 1989).

A major obstacle to assessing trends and volumes in reef fish production in a way that reflects their true value, history and condition is the poor quality (in terms of species resolution and coverage) of official, country-level, data on landings and number of fishers, year to year. At the international level, this information is supplied to the FAO, of the United Nations, and typically lumps different categories of small-scale fishers. These are combined into one group as commercial and subsistence fishers in marine, brackish and freshwaters who fish in non-covered boats or have no boat, together with fish culturists. Also combined into single categories are landings that comprise a diverse mix of coastal pelagic and reef species. Species or species groups are either amalgamated at various taxonomic levels or may not even appear in statistics for fisheries as diverse as baitfish, aquarium fish or for fishes used solely for subsistence or for local barter (Y. Sadovy, personal observation). Therefore, it is difficult to assess the national social and economic importance of reef fish fisheries relative to other activities, the trends in catch rates, the status of fished species, or fisher numbers. Nonetheless, understanding such trends and patterns is essential for pushing for change, assigning conservation and management priorities, obtaining funding, focusing development and responding to changes in human demographics.

Despite the many and largely inevitable shortcomings in data collection from multispecies and multigear fisheries in hundreds of thousands of small fishing communities, judicious selection of FAO data on small-scale fisheries can provide some useful general indications of trends over time, and across countries, especially if cross-checked with independent local studies. To identify general trends, catch-per-unit effort (CPUE) (tonnes per fisher per year) and productivity (or yield) (tonnes per km^2 reef per year) were calculated. Information was collected from FAO data on marine fish landings, numbers of ‘commercial and subsistence’ fishers between 1970 and 2000 (constrained to 1970, 1980, 1990, 1995/96 and 2000 by data availability), and estimates of coral reef areas (Spalding *et al.* 2001). Trends over time within countries were made assuming no major changes in the way in which data had been collected and reported, and no major shifts in effort between fishing sectors, for example between coastal pelagic and reef fish sectors. Comparisons across countries were made where appropriate.

Analysis

In an attempt to incorporate only those data sets that largely reflect reef-associated fisheries, several criteria were applied to country selection and all countries meeting the criteria were included in the analyses (see Table 1 footnotes). Data were obtained from FAO fisheries statistics databases and personal communications with FAO staff, and from the World Resources Institute (2005) online database. Sixteen countries met all the criteria applied (Tables 1, 2).

Trends from 1970 to 2000 for 16 tropical countries were examined for (i) number of fishers over time, (ii) annual landings over time, (iii) annual catch in tonnes per fisher over time (catch rate), (iv) tonnes produced annually per km^2 of coral reef (i.e. productivity) against time, and (v) productivity against number of fishers. Over the 30-year period, the most notable trends were:

1 within countries, the number of fishers increased, especially in Indonesia, Jamaica and the Bahamas (Table 1);

2 within countries, annual landings increased steadily in Indonesia, and the Bahamas and decreased in Jamaica (Table 2);

3 within countries, annual catches in tonnes per fisher (a crude measure of CPUE) increased in the Maldives and St Lucia, and decreased in Fiji, Jamaica, Aruba, Indonesia and in the Bahamas (Fig. 1a,b);

4 across countries, productivity (yield per km^2) varied considerably (Figs 1c,d and 2);

5 annual catches in tonnes per fisher (CPUE) showed an inverse curvilinear relationship; in areas with high numbers of fishers, catch rates are low (1–2 t $fisher^{-1}$ $year^{-1}$) irrespective of natural levels of productivity; at low fisher numbers, annual catch volumes per fisher are highly variable reflecting natural differences in productivity across countries included in the analysis (Fig. 2).

The data suggest that several countries among the 16 examined have declining catch rates and that many, such as the Bahamas, Jamaica, Indonesia and the Philippines, may have reached or exceeded maximum sustainable yields. These trends, albeit based on a limited data set, are, nonetheless, consistent with other studies over the last 30 years, suggesting that small-scale fishing effort and landings are increasing and that many

Table 1 Numbers of fishers (small-scale) from Food and Agriculture Organization fisheries statistics division and World Resources database for 1970, 1980, 1990, mid-1990s (either 1995 or 1996 according to availability) and 2000. First column shows reef areas (Spalding *et al.* 2001).

Country	Reef area (km^2)	1970	1980	1990	1995/96	2000
Aruba	<50	360	360	410	610	884
Bahamas	3150	1750	585	4000	12 600	12 600
Barbados	<100	2014	3000	3000	2995	2995
Fiji	10 020	2000	3000	4583	3826	16 059
Indonesia	51 020	841 627	2 190 352	3 146 645	4 062 500	5 129 215
Jamaica	1240	7000	10 400	16 900	8150	23 465
Maldives	8920	20 932	24 330	21 725	21 932	19 108
Martinique	240	1549	1200	806	2772	886
New Caledonia	5920	273	270	670	790	793
Papua New Guinea	13 840	500	2515	10 400	16 000	16 000
Philippines	25 060	1 047 441	781 500	898 000	990 872	990 872
Puerto Rico	480	2000	1447	1332	1758	1758
Samoa	490	6300	7860	6030	8272	13 904
Solomon Islands	5750	600	115 447	51 546	51 250	51 250
St Lucia	160	2600	2600	1802	1766	2046
Tonga	1500	1800	5950	5900	2501	3500

Criteria for selection of countries in analyses, and definitions:

(a) Small to large islands for which is was assumed that a significant proportion of the 'marine' landings recorded come from coral reef areas in local waters (continental areas, on the other hand, often have a large non-reef component in reported marine small-scale landings).

(b) Countries for which 'subsistence and commercial' fisher numbers are best reflected in the marine and non-aquaculture environment (but see notes below on Indonesia).

(c) Selection was bounded by 30° latitude that generally defines the limits of coral reef growth.

(d) Independent cross-checks were made where possible with existing literature (e.g. landings data and fisher numbers from annual fishery reports, wherever available).

(e) Landings data include significant quantities, or are entirely composed of, reef associated fish for all or part of the life cycle. For all countries except the Philippines and Indonesia, landings are mainly of reef fishes. For Philippines and Indonesia, approximately 15–35% of marine landings given in the table are likely to be reef species.

(f) 'Fishers' refers to 'small-scale' fishers as defined by FAO. However, in Indonesia during 1980 and later, 'inland' fishers were removed from the small-scale fishers sector but 'aquatic-life cultivators' have not been removed as these include fishers that grow-out some wild caught reef fish, use wild caught feed for culture activities, and sometimes fish. This subclass of small-scale fishers comprises approximately 40% of the sub-class.

fisheries have already reached or possibly exceeded maximal sustainable yield (Pauly 1994, 1997; Dalzell 1996; Barut *et al.* 1997; Hunt 2003). Highest rates of small-scale landings reach approximately 60 t km^{-2} $year^{-1}$ in the Philippines and Indonesia, the two countries for which total small-scale landings include significant non-reef coastal species. Assuming that 15–30 % of these are reef fishes, this suggests a maximum of about 10–20 t km^{-2} $year^{-1}$ for reef fish production. This level is close to the maximum reef fish production rates predicted by published models and theory and strongly suggests that both countries may be close to peak maximum long-term yields (Dalzell 1996; Polunin *et al.* 1996), with every prospect of increased fishing pressure and declining landings, in the near future.

Without interventions and a change in attitude towards management, it appears inescapable that important reef fish fisheries will continue to, or will soon, yield less per fisher and less overall per km^2 of reef. This problem will intensify by continuing degradation of reefs from natural and anthropogenic factors, growing human populations, increasing national and international pressure for exports, technological improvements, and growing economic development in the developing world (Ruddle 1996; Spalding *et al.* 2001; Hunt 2003; Bellwood *et al.* 2004). Further threats to vulnerable species are inevitable (Sadovy *et al.* 2003a).

Table 2 Landings (in tonnes) from Food and Agriculture Organization fisheries statistics division and World Resources database for 1970, 1980, 1990, mid-1990s (either 1995 or 1996 according to availability) and 2000.

Landings	1970	1980	1990	1995/96	2000
Aruba	400	770	420	140	163
Bahamas	2100	5026	7531	10 035	11 191
Barbados	2300	4255	3018	3581	3100
Fiji	3600	19 124	24 247	19 171	26 632
Indonesia	731 500	1 209 095	1 98 7421	2 724 923	3 316 355
Jamaica	8500	9600	7000	7300	4664
Maldives	37 273	38 624	84 220	118 811	132 427
Martinique	4000	4521	3372	5175	5200
New Caledonia	400	659	3383	2103	2729
Papua New Guinea	14 828	35 469	11 480	24 550	80 914
Philippines	851 300	1 042 371	1 497 816	1 521 937	1 613 621
Puerto Rico	1900	3074	1677	2146	2179
Samoa	900	1910	568	2489	11 152
Solomon Is	8000	33 932	40 663	61 795	24 853
St Lucia	1419	867	924	1161	1790
Tonga	400	1993	1639	2497	3572

See footnotes to Table 1.

Status and productivity of coral reef ecosystems and fish species

Status and change

Heavy exploitation pressure has caused moderate to severe declines in valuable tropical marine invertebrates and vertebrates, as well as ecosystem shifts. We know most about species of high commercial, structural or cultural value because of the greater attention and interest they tend to attract; interestingly, until recently these have tended to be non-fish species. For example, in many places in the Pacific, fishing has markedly reduced sea cucumber (beche-de-mer or trepang), species of the family Holothuridae, such as *Holothuria nobilis*, the black teatfish, and trochus, or topshell, (*Trochus niloticus*,family Trochidae), and extirpated the giant clam (*Tridacna gigas*, family Tridachnidae) from several areas (Villanoy *et al.* 1988; Foale 1998; J. Veitayaki personal communication). Caribbean coastal ecosystems were probably degraded centuries ago for large vertebrates such as hawksbill turtle (*Eretmochelys imbricata*, family Cheloniidae), and manatee (*Trichechus manatus manatus*, family Trichechidae), while the Caribbean monk seal (*Monachus tropicalis*, family Phocidae) was largely decimated by about 1800, and is now extinct (Jackson 1997; Jackson *et al.* 2001).

For reef fishes, severe declines began to attract attention more recently, although changes in mean size evidently occurred centuries ago. Archaeological remains suggest that mean fish body lengths declined markedly for several exploited and strongly reef-associated food fish families in the Caribbean 500–2000 years ago (Mace and Hudson 1999; Wing and Wing 2001). In the last 10–20 years, increasing fishing pressure has resulted in marked declines in several species, ranging from groupers in the tropical western Atlantic, to the bumphead parrotfish and humphead wrasse (Musick *et al.* 2000; Sadovy *et al.* 2003a; Aswani and Hamilton 2004). About 50 coral reef fishes are listed as threatened, and these make up 60% of all marine fish species assessed according to current IUCN (World Conservation Union) criteria (IUCN 2004), most the result of exploitation (Dulvy *et al.* 2003). The humphead wrasse was listed in October 2004 in Appendix II of Convention on International Trade in Endangered Species (CITES) because of declines due to demand from the live reef food-fish trade. Declining catches and the increasing distances of source countries from demand centres (Fig. 3) are symptomatic of growing fishing pressure on many coral reef species (Sadovy *et al.* 2003b).

Many of the more desired and valuable reef fish species also happen to be particularly vulnerable to overfishing because of their biology, especially their natural rarity, longevity compared with fish species that have supported industrial scale fisheries in the past, and associated suite of life-history characteristics such as late sexual maturation (Jennings *et al.* 1998, 1999). Other biological attributes such as complex mating systems, limited geographical

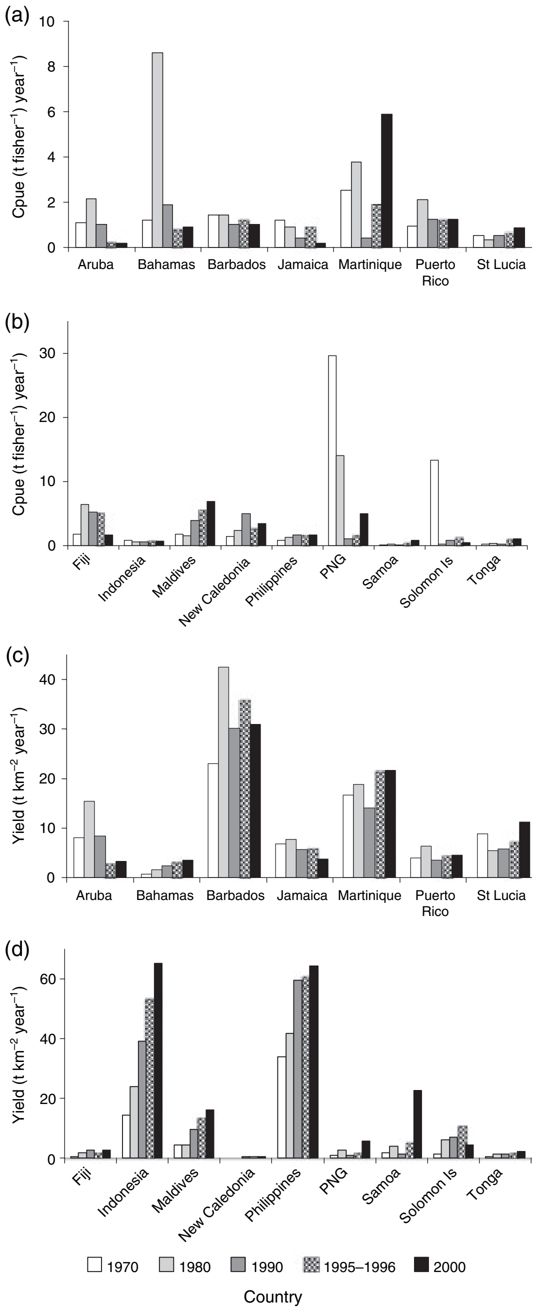

Figure 1 (a) Catch-per-unit effort (CPUE) as tonnes per fisher per year for selected tropical western Atlantic and Caribbean countries from 1970 to 2000; (b) CPUE for selected tropical countries in the western Pacific and South-east Asia from 1970 to 2000; (c) yield in tonnes per km^2 per year for reef areas in selected tropical western Atlantic and Caribbean countries from 1970 to 2000; (d) yield in tonnes per km^2 per year for reef areas in selected countries in the western Pacific and South-east Asia from 1970 to 2000. See footnotes to Table 1 for details of data sources.

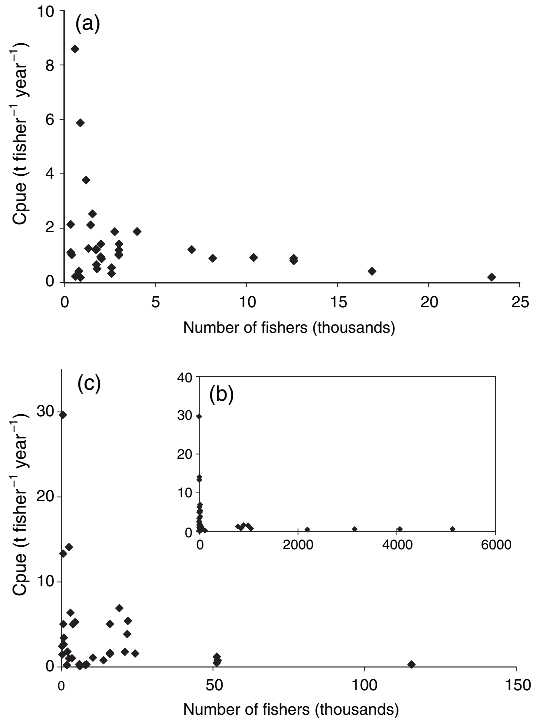

Figure 2 Catch-per-unit effort (CPUE) as tonnes per fisher per year against number of fishers for each of five time periods (1970, 1980, 1990, 1995/96 and 2000 – therefore each country is represented by five data points) for (a) tropical western Atlantic and Caribbean and (b) and (c) western Pacific and South-east Asia. Graph (c) is a subset of graph (b) to show details at lower numbers of fishers; all graphs have same *x* and *y* axes. For data and countries included see Tables 1 and 2.

distribution, reliance on specific nursery areas or the existence of spawning aggregations that are few in number, concentrated or predictable in temporal and spatial location, can make species particularly susceptible to disturbance or exploitation (Vincent and Sadovy 1998; Roberts and Hawkins 1999; Reynolds *et al.* 2001; Mumby *et al.* 2004; Sadovy and Domeier 2005). Examples include many larger reef fishes marketed live and chilled for food, and some marine ornamentals (Sadovy and Vincent 2002).

Although no marine fish is known to have gone globally extinct from exploitation, there are many pressures that threaten species that might be susceptible to extirpation. Examples include growing pressure on vulnerable species, disruptions to reef communities and damage to the reef habitat by destructive fishing and land-based activities, that

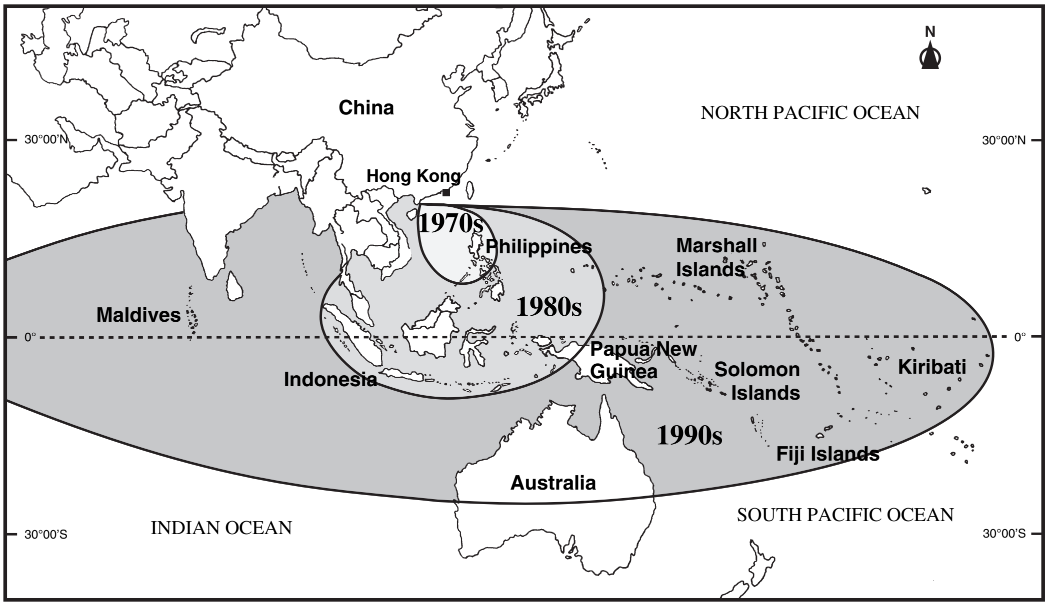

Figure 3 The expansion of the live reef food-fish trade into both the Pacific and Indian oceans over the last three decades. Note that Vietnam is an exception since trade did not begin until the 1990s. The increasing number of source countries involved reflects declining stocks in South-east Asia, growing demand for live reef fish, the high prices paid for live fish which enable expensive transport, and improvements in transport (boat and plane) capacity and routings. From Sadovy *et al.* (2003b), with permission.

reduce biodiversity and compromise recovery from natural and man-induced events (Jennings and Lock 1996; Russ and Alcala 1999; Spalding *et al.* 2001; Dulvy *et al.* 2003). Globally, more than 40% of coral reefs are degraded, many in areas where fisheries are particularly crucial to coastal communities and have high species diversity. For example, in Indonesia extensive Coral Reef Rehabilitation and Management Programme (COREMAP) surveys conducted since 1994 show that >60% of reefs have <50% of living coral cover, and that in much of Southeast Asia reefs are in poor condition (Bryant *et al.* 1998; Spalding *et al.* 2001). Not only are reefs essential habitat for most reef-associated fishes, approximately two-thirds of all coastal species, including many that live offshore as adults, also depend for part of their life cycle on reefs habitats. Such changes and impacts can have far-reaching effects on both biodiversity and productivity in fished populations.

Extracting species selectively and beyond their regenerative capacity from coral reef communities can have direct and indirect effects. While the direct effects of fishing on certain high visibility species, or damage to coral reefs by a range of factors, are often obvious, indirect fish community or reef ecosystem disruptions are much less well understood and can have unexpected and far-reaching outcomes on species diversity and fishery yields. Such effects are likely to be highly variable depending on species targeted and gears used (Jennings and Lock 1996). Typically, over-fishing leads to the progressive loss of larger individuals, shifts in dominant species and declines in catch rates (Koslow *et al.* 1988; Birkeland 1997). For example, reduction and disappearance of grazers can lead to shifts from coral to macro-algal dominance and reductions in fish diversity. This is because fish diversity is positively correlated with hard coral and coralline algal cover and negatively associated with algal turf and sea urchins (Hughes 1994; Jackson 1997; McClanahan and Arthur 2001). Degradation in coral condition and reduction in coral cover can lower yields of reef fishes (Bryant *et al.* 1998), especially in the case of obligate corallivores (Sano 2004). In some cases, damage to reefs has been associated with higher localized incidence of ciguatoxic fishes, apparently because damaged surfaces are particularly appropriate for settlement of the causative dinoflagellate(s), posing a serious problem for food supply and fish trade from affected areas (Kohler and Kohler 1992; Lewis and Holmes 1993; de Sylva 1994).

When dominant species are lost from ecosystems, the outcomes are far from predictable; much depends on which species are lost and the functional redundancy in the system. One might reasonably predict, for example, that piscivores are the most significant consumers of fish biomass and that their removal, by fishing, might lead to ecological release of an abundance of prey fish and increased catches through species replacements. While such 'compensatory' type changes have been reported for non-reef fishes, there is only limited evidence for this in reef fishes (Lock 1986; Koslow *et al.* 1988; Dulvy *et al.* 2004). Other studies report little or no evidence for such compensatory responses in a range of fisheries (Jennings and Polunin 1995; Pauly *et al.* 2002; Graham *et al.* 2005). Jennings and Polunin explained their finding by suggesting that increases in prey populations among reef fish species are likely to be less marked and less consistent than decreases in predator populations in such complex systems. Graham *et al.* (2005) found that, in areas under different fishing pressure in Fiji, heavy fishing resulted in declines in size spectra because of the loss of larger fishes with no detectable increase (compensation) in smaller fishes, despite a general low functional redundancy in coastal fish assemblages (Bellwood *et al.* 2004; Micheli and Halpern 2005). As many gears are often in use in reef fish fisheries targeting a wide range of species, life-history stages and size classes, even if prey release were to occur compensatory responses could be difficult to detect. If areas are also nutrient limited or reefs degraded, there may be no possibility of such response (Polunin *et al.* 1996). Understanding the direct and indirect effects of fishing and habitat condition of fish yields, and the degree and nature of functional redundancy, is a key part of managing for sustainable fisheries and of recognizing the full effects of fishing and habitat loss.

Productivity

From the above analyses of FAO data as well as from existing literature (Dalzell 1996) there can be a 100-fold difference in reef productivity between areas, according to a range of biological and zoogeographical conditions, as well as prevailing fishing pressure and reef circumstances. Despite such variability, several patterns relevant to both management and conservation of reef fishes and coral reef-associated resources are clear. These patterns relate to the relationships between biological diversity, productivity, and reef condition and area, and help us understand what happens to communities and yields when species are removed, or habitat is degraded. Understanding such interrelationships allows for decisions and predictions to be made regarding sustainable levels of catch, and should assist in developing meaningful and practical indicators of the effects of fishing and management (Johannes 1998; Graham *et al.* 2005).

One particularly interesting study in the Pacific shows a positive relationship between biodiversity, measured as the number of fish species per transect using underwater visual census, and fish biomass, measured as g m^{-2}, at different levels of fishing pressure and ranging from high to very low. The results of this, and other, work suggest that biodiversity and biomass can be positively and significantly related and that an increase in fishing pressure results in lower biomass per unit area for the same species diversity (Koslow *et al.* 1988; Kulbicki *et al.* 2004) (Fig. 4). As many studies also suggest that increased fishing pressure is likely to reduce biodiversity by removing, first, long-lived, late maturing, vulnerable species, then increasing fishing pressure is expected to reduce overall yield both directly, and indirectly. Conversely, protecting biomass and diversity in marine protected areas (MPAs) can result in increase in biodiversity, fish size and fish biomass (Roberts 1995; Russ 2002). This does not mean that MPAs will necessarily restore fisheries, as the effects of protection are mainly demonstrated to occur within the protected areas, conserving biodiversity unless MPAs are large enough and well-managed. However, it does point to the need for maintaining species diversity and suggests that judicious spatial protection is one important aspect of fishery management in areas where their implementation is economically and socially feasible (e.g. Sale *et al.* 2005).

An example of the implications of an unmanaged high-value fishery on a few selected target fish species unable to withstand heavy fishing pressure is the live reef food fish. Major demand centres for live fish are in Chinese communities for a luxury high-end restaurant trade. Supplies of fish come from South-east Asia, the western Pacific, and, for Chinese communities in North America, from the east coast of the USA (Summers 2001; Sadovy *et al.* 2003a). Most species involved are groupers that tend to be vulnerable to overfishing because of their biology; most are long-lived and many spawn in aggregations that are targeted (Sadovy *et al.* 2003b;

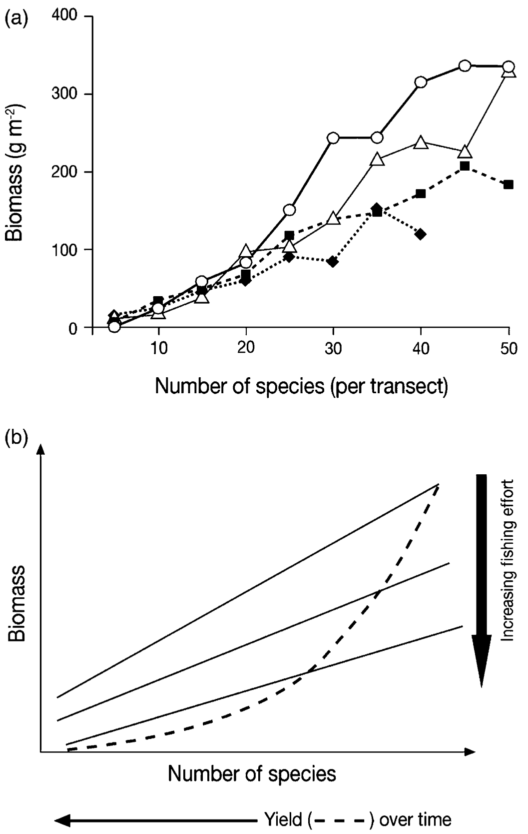

Figure 4 (a) Biomass against number of species per transect (i.e. fish species diversity) at different levels of fishing effort in locations of the western and south Pacific; (b) graphical representation of (a), the solid straight lines being different levels of fishing effort and the dashed curved line indicating the decline in yield over time as fishing pressure increases, reducing biomass, and biodiversity decreases due to the effects of fishing. Black diamond, high fishing effort; black square, medium fishing effort; white triangle, low fishing effort; white circle, very low fishing effort. From Kulbicki *et al.* (2004), with permission.

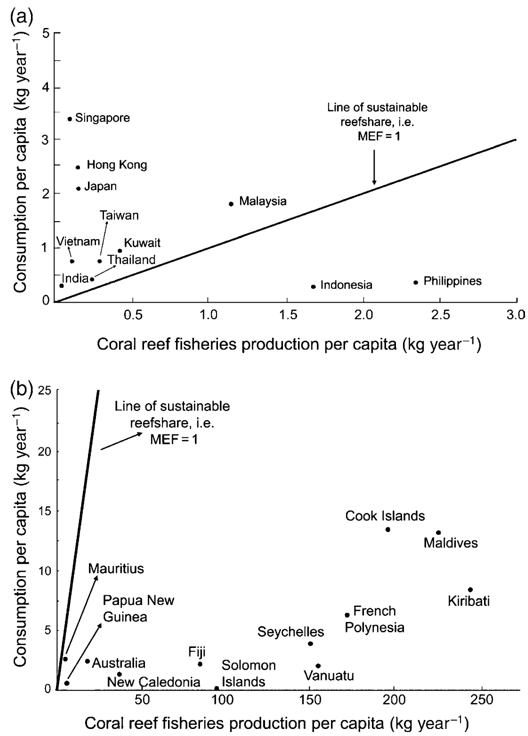

Figure 5 Estimates of individual country or city coral reef fishery biocapacities and marine ecological footprints (MEF) in South-east Asia and the Indo-Pacific. Positions above the line of MEF = 1 indicate where coral reef seafood consumption exceeds the local coral reef biocapacity, while below the line there is self-sufficiency; (a) and (b) represent different sets of countries showing a wide range in demand and supply. The consumption indicated in the *y*-axis refers to coral reef fish consumption. From Warren-Rhodes *et al.* (2003), with permission.

Sadovy and Domeier 2005). Profits are particularly high at the retail end of the trade, while the fishers themselves may not be demanding high enough prices for their fish because they do not have good market information (Sadovy *et al.* 2003b). Rapid expansion of the fishery has occurred in some places, and, where pressure has been particularly high, a boom and bust pattern of exploitation on target species has resulted, with serial resource depletions. In some areas, new fishing practices, such as the use of poisons and hookah (surface supply of compressed air to diver), introduced for the live fish trade, remained after this business had moved on, causing further resource depletions (Sadovy *et al.* 2003b). A typical pattern of fishing operations involves removal of target species of preferred market size and targeting of spawning aggregations. As the fishery continues, subadult fish are retained and grown-out (i.e. placed in net cages and fattened up) in captivity to reach market size. Ultimately this undermines the resource base because both reproductive adults and subadults are heavily targeted (Sadovy *et al.* 2003b). The demand for live fish from key demand centres exerts a massive ecological footprint on preferred species, taking a substantial proportion of the estimated sustainable yield available to the fishery (Warren-Rhodes *et al.* 2003) (Fig. 5). This type of unmanaged fishery leads to loss of important resources and removal of important functional groups (Bellwood *et al.* 2004). However, managed by controls on effort, as this fishery is in Australia (Sadovy *et al.* 2003b), gives potential for a lucrative and sustainable fishery.

To summarize, the full effects of fishing and management depend heavily on the temporal and spatial scales, as well as the species and type of fishery involved. However, our growing understanding of the complexity and species interrelationships within coral reef ecosystems suggests four important areas that merit wider discussion and need to be considered when developing management and conservation initiatives. The first is that the positive relationship between biodiversity and productivity means that conservation and management for productive use can be complementary rather than conflicting. However, high biodiversity areas (commonly termed 'hotspots') do not necessarily require the greatest protection as low biodiversity areas may have less functional redundancy and be more vulnerable following species losses (Bellwood *et al.* 2004). The second is that fishing a multispecies fishery may be best practiced by ensuring a balanced removal across species and size ranges to ensure maintenance of biodiversity, while avoiding loss of functional groups, rather than focusing heavily on a few valuable species (Jennings and Polunin 1996; Halpern 2003; Bellwood *et al.* 2004; Kulbicki *et al.* 2004). The third is that protected areas should encompass important life-history phases or bottlenecks such as nursery and spawning sites in efforts to maintain species diversity and productivity, but that protection alone is likely to be insufficient. Effort reduction must be an integral aspect of most management. In many areas, MPAs are too small or unmanaged to be effective and are often not a solution that is socially or politically acceptable or feasible. Finally, high value fisheries need special attention because of the potential for boom and bust types of operations that could undermine the resource base if uncontrolled.

Moving from inaction to action

The importance of perception

The impetus to act, or recognition of the need to do so, either comes from identifying a problem and being able, needing, or wanting to respond, or being forced to do so; it also depends much on perceptions and the time and spatial scales involved. Fisheries associated with coral reefs, with few exceptions, have little formal history of exploitation and its consequences as few have been documented over significant periods. For most economically important species there is often no biological information, while catch data, if any, are typically sporadically collected, available for only short time frames, or sorted crudely by genus or family such that species-level data are not distinguishable. Many major fishing nations like China do not publish reef fish data (even if collected it is considered to be sensitive given the reef areas involved, Y. Sadovy, personal observation), while it was only since the early 1980s that the USA separated important reef-associated families into species. Even when data are collected in a country such as Indonesia, where reef-associated fisheries are so important, fisheries officers may have problems integrating the information into patterns of catch and effort at an ecological spatial scale relevant to management because of the wide area from which data are gathered. Local fishers, on the other hand, cannot perceive of an area larger than that of immediate relevance to their own experience and, hence, have no means of generalizing. If overly optimistic stock assessments are then applied, the combined differences in perspectives and expectations create uncertainties that paralyse action and defy understanding (Dudley and Harris 1987; Pet-Soede 2000).

For fishers in many fishing communities, local history and traditional knowledge may provide little clue to the possibility, or likely consequences, of overfishing. In the eyes of many, fish have always been a mainstay, plentiful and readily available, an apparently self-replenishing resource (personal observation). Until recently, human population levels in most places in the tropics where fishing has long been a major activity, at least within living memory, were typically too low to cause obvious or serious declines in fish numbers. A wide range of species was taken, fishing methods were often selective for certain species and seasons, and there was no 'cash economy' to focus intense interest on a few valuable species. Exceptions to this were a few invertebrate species (see above), but because these were not taken for local sustenance, the oftentimes boom and bust nature of their intensive fisheries was of no direct consequence for food supply. Even if declines in certain species did occur, natural year-to-year variations, the diverse range of gears used and the typical seasonality of many species easily masked all but the most obvious or culturally significant, changes. Such variability over time and across space combined with the subtle ‘shifting of baselines’ across generations seriously undermines incentives to change the *status quo* (Pauly 1995; Bohnsack 2003).

The considerations discussed so far do not mean that that there have never been controls on fishing in tropical reef-associated fisheries. There are cases when politics, social systems, colonialism or other outside influences exerted controls. In parts of the Pacific and South-east Asia, for example, CMT systems gave considerable power to communities, or community leaders, over marine resources through control of access, and allocation of fishing rights (Ruddle 1996). Topshell, sea cucumber or similar highly valued ‘cash crops’ were often viewed as a garden, or ‘farm’, with interspersed fallow and harvest periods, or protected in specific areas where controlled periodic harvesting for export or other commercial use was regulated (Ruddle 1996; Foale 1998). Controls on certain culturally important species confined their capture and consumption to specified individuals (e.g. turtle, humphead wrasse) (Ruddle 1996; Sadovy *et al.* 2003a). Some colonial or CMT systems imposed heavy penalties to maintain control over local fisheries. For example, public shaming, caning, confiscation of boat/gear/catch, compensation/fines, even capital punishment were strong disincentives for defying such authority (Ruddle 1996).

So, although controls on reef-associated fisheries have been implemented under certain circumstances, increasing market and population pressures make controls much harder to introduce today. A key impediment to progress with coral reef resource management is the serious underestimation of overall economic and social worth of reef-associated fisheries. Few economic analyses have been conducted and these typically do not incorporate a monetary value for livelihood importance, or assign market value to subsistence catches. In one of the few economic projections of the value of coral reefs and reef-associated resources under different fishing scenarios, Cesar *et al.* (1997) estimated that the social costs far outweigh the short-term private gains over the 25-year time scale of the analysis. Cesar *et al.* (1997) considered fishing with and without the use of destructive methods, such as blast and cyanide, overfishing, sedimentation and coral mining. In the Pacific, the inshore fishery contribution to the GDP of most countries is greatly underestimated because of reliance on dated surveys and weak indicators and methods (Gillett and Lightfoot 2001). These authors identify the need for better liaison between fisheries and statistics agencies to improve estimates of small-scale fisheries production. In the case of exports, the underestimation of coral reef derived ‘products’ is probably worse than for any other trade sector in the Pacific (Gillett and Lightfoot 2001), and source fishing communities often do not benefit substantially from high-value, luxury, fisheries in the long term; indeed, the opposite may be true (Sadovy *et al.* 2003b). The association of short-term financial gains with long-term losses in intensive high-value fisheries is often not appreciated by key decision-makers and government officials who seldom understand the current condition or capacity of their fisheries. M. Connell (unpublished data) captured an important element of impediment to sustainable fishery development when commenting: ‘‘It is not necessary for everyone to fully appreciate the significance of any activity in the economy. However, when the lack of appreciation extends to policy-makers, planners and development agencies, it can mean that fisheries development receives lower priority than it deserves’’. And, unlike in many more developed countries, there are few ‘champions’ to push the issues forward in the communities or with government (Gillett and Lightfoot 2001).

A framework for action

Even where problems are identified and clearly need addressing, there is often little political will, community resolve, institutional capacity, understanding of the resource, funding or enforcement capacity to act effectively. In many places, fisheries departments were not in place until the latter half of the 20th century and then were more often associated with agriculture than with fisheries. In the Pacific, where coastal fisheries are so important for coastal communities, an extensive study revealed that only 25% of fisheries agency staff spent time on coastal management matters; in the 10 years preceding the study, only 40% of villages surveyed had been visited by officials to discuss coastal resource management (World Bank 2000). In a series of hundreds of interviews in South-east Asia and the western Pacific, which involved visits to local fishery departments and nearby communities, there were clearly large disparities between the perceived and actual state of local fisheries between government officials and community members; moreover, there was little government support for local-level management efforts (Society for the Conservation of Reef Fish Aggregations 2005). Few coral reef fish fisheries fall under the purview of regional fisheries management authorities, national laws are often outdated, corruption is common, and the judiciary tends not to take fisheries violations seriously, further undermining enforcement attempts. Even for major commercial species biological understanding is poor. Readily available literature on coral reef fisheries is scant compared with what is available on the large industrial-scale fisheries of temperate regions (Pauly 1994).

A range of approaches is now being explored, advocated, promoted or imposed as alternatives or complements to conventional forms of management; alternative livelihoods, mariculture, artificial reefs (ARs), restocking and MPAs. Most promise more than they currently deliver and considerably more focused research and development are needed before they become viable options for reducing pressure on wild resources. Irrespective of future successes, considerably more focus is needed on the control of fishing effort.

Large sums of money are spent on developing alternative livelihoods to remove pressure from natural resources, or initiatives introduced to add value to resources formally little regarded. Such potentially important activities need careful planning and long-term commitment to improve chances of success. One example is ecotourism. Although the introduction of ecotourism initiatives can potentially offer a means of alternative or additional income, there are few examples in developing countries of tourist operations where significant benefits have gone directly back to affected communities. Such initiatives often benefit outside developers with little advantage to those displaced from fishing areas. Gaining a higher value for a given resource is another alternative that should be incentive for better management and control of effort. However experience to date has shown that, without careful management, intense activity associated with luxury markets can lead to long-term resource degradation and a range of social and environmental abuses. These include community disputes, poaching, corruption and destructive fishing. The use of cyanide and hookah to increase catches in the live reef food-fish trade, for example, introduces gears into an area which can damage reefs, make accessible new (deeper) fishing areas to intensive fishing and can incur considerable social costs through paralysis from diving accidents (Johannes and Reipen 1995; Sadovy and Vincent 2002; Sadovy *et al.* 2003b).

Mariculture, the aquaculture of marine species, is widely proposed as a significant alternative to wild capture, and, according to FAO figures the growth rate of the aquaculture sector is rapidly increasing. In tropical reef environments, South-east Asia has a very active aquaculture sector, and the Pacific can claim a long heritage of mariculture initiatives. From the Pacific, mariculture projects over the past 30 years have largely been disappointing with the possible exception of seaweed culture (R. Gillett, unpublished data). In South-east Asia, some forms of mariculture with extensive hatchery production of young, such as for milkfish, *Chanos chanos* (Chanidae), have successfully provided livelihoods and a cheap source of protein for millions of people. Others, such as the culture of ‘luxury market’ grouper species, however, have placed further pressure on wild populations and do not address basic food needs (Sadovy and Vincent 2002). Although some groupers are hatchery produced, a significant proportion of the culture of such species relies on juveniles taken from in the wild and fattened up to market size in captivity (Sadovy and Lau 2002). Practiced in this way, such activities do not take pressure off wild populations and can cause conflicts among users who target different life-history stages.

Artificial reefs are widely assumed to ‘enhance’ fisheries and/or restore damaged habitats and have been extensively deployed in South-east Asia in response to declining fish landings. Millions of dollars have been spent on such programmes, yet there are few follow-up studies, long-term monitoring is rare, and they are often fished after deployment. At best, there is little understanding of the relevance or significance of ARs for reef fish restoration; at worse, ARs exacerbate overfishing. This is particularly likely for reef fishes which are considered to be largely recruitment-(rather than habitat-)-limited especially where overfishing has severely reduced adult spawning stock. The few success stories with ARs, such as enhanced survivorship in lobster and octopus, were the result of detailed studies and require quite specific AR form and configuration (Polovina and Sakai 1989; Eggleston *et al.* 1992). ARs are an unfortunate example of so-called ‘enhancement’ activities being spurred by technological advances without demonstration of success and it has yet to be determined whether they attract or improve fisheries, especially as they are often not managed for fishing effort (e.g. Bohnsack 1996; Pickering and Whitmarsh 1997).

Restocking is an approach used in some areas in South-east Asia as an attempt to restore overexploited reef fish and invertebrate populations. Mostly these initiatives involve the release of hatchery produced or small wild-caught fish, with little follow-up work; tropical marine reef-associated species include grouper (Serranidae), rockfish (Scorpaenidae) and snapper (Lutjanidae). However, the effectiveness of restocking in restoration is largely unknown (e.g. Bohnsack 1996; Liao 1997; Molony *et al.* 2003). Effective restocking will require careful research and studies to determine appropriate species, timing and location of release and follow-up monitoring. Currently, restocking operations in the tropics are most effective as public relations exercises and are not a proven stock restoration or species protection methods.

Marine protected areas are widely advocated as a particularly appropriate fishery management tool for coral reef-associated fisheries (Gell and Roberts 2003). While showing promise, there is still much to learn about effective MPA design and placement and MPA suitability for more mobile species, which include some of the more valuable and vulnerable fishes. At present, MPA spatial scales of implementation best address biodiversity conservation and habitat protection; much less is known of their roles in fishery enhancement and spillover (Hilborn *et al.* 2004; Sale *et al.* 2005). Moreover, the introduction of large no-take areas is not socially or politically acceptable in many areas where fishing pressure is high and there are no alternatives. Nonetheless, at a small scale MPAs can be important for protecting important life-history bottlenecks of commercial species, such as spawning and nursery areas, but would usually be used together with other measures such as fishing effort reduction.

While governments and intergovernmental organizations have a key role to play in fishery management, NGOs could play a much larger part in funding, education and capacity building. Very few NGOs, however, yet address a fisheries agenda. In the tropics, the major NGO focus tends to be on coral reef habitat protection or biodiversity conservation (Table 3). To be effective, programmes or initiatives could be developed with target country needs in mind rather than primarily to address conservation agendas, and should incorporate strong educational components. Donors need to oversee project progress and outcomes in the short and long terms, and ensure that key issues are being effectively addressed. As just one example, a programme developed to reduce cyanide fishing by introducing alternative gears to catch fish in the Philippines in the 1990s did not address the primary problem, initially unrecognized, of overfishing (Y. Sadovy personal observation).

Concluding comments

Fisheries associated with coral reefs have supported, support and must continue to support millions of people. This can only be achieved by tackling the many and increasing pressures on reef-associated resources that come from growth in human populations, transmigration, export markets, cash economies and economic development, as well as the impacts of land-based activities that affect reef habitat, from pollution to global warming. Given that reef ecosystems and many reef-associated species cannot withstand high levels of fishing pressure, the challenge of recent changes cannot be met simply by increasing catches or improving technology. An altogether different approach is needed, and not one that relies on unproven 'solutions' to overfishing, such as restocking, ARs, mariculture or tourism, unless clear evidence demonstrates their effectiveness. The consequences of failing will lead to massive negative social, biological and economic consequences, given the connections between ecological systems and human health, economy, social justice and national security (Lubchenco 1998).

A more holistic approach would embrace a range of issues, including educational programmes, market information and economic analyses, monitoring programmes, long-term planning, and international instruments and efforts that promote sustainable resource use. Educational programmes are needed at all levels from governments, to communities, schools and other groups, while NGOs who work on marine issues in the tropics are well-placed to facilitate outreach initiatives. Without an appreciation and understanding of the issues, the public will not support changes and governments will not legislate for management. Traditional ecological knowledge can be useful as long as every attempt

Table 3 Principal activities or focus of international organizations working on coral reef and coral reef resources associated issues.

Organization*	Coral reef habitat	Bio-diversity	MPAs and/or ecosystem management	Tourism development	Sustainable fisheries	Education and/or data compilation	Monitoring and/or resource assesment	Coordination and collaboration
Caribbean Regional Fisheries Mechanism (1)			X		X	X		
World Fish Centre (4)					X	X		
South Pacific Regional Environmental Programme (1)			X		X			X
Secretariat for the Pacific Community (1)					X	X	X	
ICRAN, ICRI, GCRM, CORAL, CORDIO (3)	XX	X	XX	X	X	X	XX	XX
Food and Agriculture Organization (United Nations) including regional fishery management authorities (2)					X	X	X	X
United Nations Environmental Programme (2)				X			X	
Coral Reef Rehabilitation and Management Programme (COREMAP) (1)	X				X	X		X
World Resources Institute (4)						X		
Worldwide Fund for Nature (4)	X	X	X			X		
The Nature Conservancy and Conservation International (4)	X	X	X					

*Type of organization: (1) local or governmental (regional); (2) intergovernmental (global); (3) collaborative network of specialist activities, including academic; (4) not-for-profit organization.
ICRAN, International Coral Reef Action Network; ICRI, International Coral Reef Initiative; GCRM, Global Coral Reef Monitoring Network; CORAL, Coral Reef Alliance; CORDIO, Coral Reef Degradation in the Indian Ocean (double XX signifies greater cumulative focus across programmes included on the row).

is made to validate the information (Foale 1998; Aswani and Hamilton 2004). Economic analyses would be useful to demonstrate the short and long-term advantages of well-managed fisheries, and market price information would enable fishing communities to obtain a better value for their fish. The formation of cooperatives could help and would better position communities to deal with the fickleness of luxury markets and to demand better prices for their fish.

Fisheries development and management needs to be based on clear objectives that address both food production and ecosystem maintenance aspects. Balanced species removals by multispecies cropping across all trophic levels could reduce the risk of ecosystem shifts brought about by extremely selective removals (Adams 1996; Dalzell *et al.* 1996). Innovative low-intensity data collection methods are needed to assess fisheries, while ongoing monitoring is an integral part of effective and adaptive management. Management systems in some countries could complement and strengthen existing customary marine tenure, although government assistance is needed to ensure enforcement and foster management over a larger spatial scale than most CMT systems operate (Foale and Macintyre 2000; Johannes 2002). The resulting management unit is likely to be more ecologically meaningful if not based only on socially determined boundaries. International organizations such as CITES can assist in moving towards the sustainable use of particularly vulnerable and internationally traded species, and regional management authorities could be created to oversee and promote regional level initiatives in management and production.

Although lagging badly behind industrial-scale fisheries in recognizing the need to acknowledge natural limits to yields, there is finally a growing recognition that we must work within these limits for reef fish fisheries. An appreciation of the serious consequences of not doing so is beginning to emerge, as we see in Jamaica, the Philippines and Indonesia. While there is still a long way to go, we have at least moved past the paradigm of ‘it is not possible to overexploit natural marine resources’ to ‘it is not acceptable to overexploit natural marine resources’ (Mace 2001). As human populations grow and pressures on the sea increase, small-scale, multispecies fisheries become so much more appealing as more efficient and less wasteful producers of protein. We will certainly need to become more adept at feeding ourselves from the sea, particularly in regions where the sea is one of the only options available, and be more creative about seeking sources on land.

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References

Adams, T.J.H. (1996) Modern institutional framework for reef fisheries management. In: *Reef Fisheries* (eds N.V.C. Polunin and C.M. Roberts). Chapman and Hall, London, pp. 337–360.

Alino, P.M., Naŏla, C., Capmos, W., Hilomen, V., Uychiaoco, A. and Mamauag, S. (2004) Philippine coral reef fisheries: diversity in adversity. In: *In turbulent seas: the status of Philippine marine fisheries*. (ed. DA-BFAR – Department of Agriculture-Bureau of Fisheries and Aquatic Resources), Coastal Resource Management Project, Cebu City, Philippines, pp. 65–69.

Aswani, S. and Hamilton, R.J. (2004) Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. *Environmental Conservation* **31**, 69–83.

Barut, N.C., Santos, M.D. and Garces, L.R. (1997) Overview of Philippine marine fisheries. In: *Status and Management of Tropical Coastal Fisheries in Asia* (ICLARM Conference Proceedings) (eds G. Silvestre and D. Pauly), Vol. 53. ICLARM, Manila, pp. 62–71.

Bellwood, D.R., Hughes, T.P., Folke, C. and Nystrom, M. (2004) Confronting the coral reef crisis. *Nature* **429**, 827–833.

Birkeland, C. (1997) Symbiosis, fisheries and economic development on coral reefs. *Trends in Ecology and Evolution* **12**, 364–367.

Bohnsack, J.A. (1996) Maintenance and recovery of reef fishery productivity. In: *Reef Fisheries* (eds N.V.C. Polunin and C.M. Roberts). Chapman & Hall, London, pp. 283–313.

Bohnsack, J.A. (2003) Shifting baselines, marine reserves, and Leopold’s biotic ethic. *Gulf and Caribbean Research* **14**, 1–7.

Bryant, D., Burke, L., McManus, J. and Spalding, M. (1998) *Reefs at Risk: A Map-Based Indicator of Threats to the World's Coral Reefs*. World Resources Institute, Washington, DC, International Center for Living Aquatic Resources Management, Manila, Philippines and UNEP World Conservation Monitoring Centre, Oxford.

Cesar, H., Lundin, C.G., Bettencourt, S. and Dixon, J. (1997) Indonesian coral reefs - an economic analysis of a precious but threatened resources. *Ambio* **26**, 345–350.

Dalzell, P. (1996) Catch rates, selectivity and yields of reef fishing. In: *Reef Fisheries* (eds N.V.C. Polunin and C.M. Roberts). Chapman & Hall, London, pp. 161–192.

Dalzell, P., Adams, T.J.H. and Polunin, N.V.C. (1996) Coastal fisheries in the Pacific Islands. *Oceanography and Marine Biology: an Annual Review* **34**, 395–531.

Dudley, R.G. and Harris, K.C. (1987) The fisheries statistics system of Java, Indonesia: operational realities in a developing country. *Aquaculture and Fisheries Management* **18**, 365–374.

Dulvy, N.K., Sadovy, Y. and Reynolds, J.D. (2003) Extinction vulnerability in marine populations. *Fish and Fisheries* **4**, 25–64.

Dulvy, N.K., Polunin, N.V.C., Mill, A.C. and Graham, N.A.J. (2004) Size structural change in lightly exploited coral reef fish communities: evidence for weak indirect effects. *Canadian Journal of Fisheries and Aquatic Science* **61**:466–475.

Eggleston, D.B., Lipcius, R.N. and Miller, D.L. (1992) Artificial shelters and the survival of juvenile Caribbean spiny lobster *Panulirus argus*: spatial, habitat and lobster size effects. *Fishery Bulletin* **90**, 691–702.

FAO (1997) Review of the state of world fishery resources: marine fisheries.. FAO Fisheries Circular No. 920 FIRM/C920.

Foale, S. (1998) Assessment and management of the trochus fishery at West Nggela, Solomon Islands: an interdisciplinary approach. *Ocean and Coastal Management* **40**, 187–205.

Foale, S. and Macintyre, M. (2000) Dynamic and flexible aspects of land and marine tenure at west Nggela: implications for marine resource management. *Oceania* **71**, 30–45.

Gell, F.R. and Roberts, C.M. (2003) Benefits beyond boundaries: the fishery effects of marine reserves. *Trends in Ecology and Evolution* **18**, 448–454.

Gillett, R. and Lightfoot, C. (2001) *The Contribution of Fisheries to the Economies of the Pacific Island Countries*. A report prepared for the Asian Development Bank, the Forum Fisheries Agency, and the World Bank, 217 pp.

Graham, N.A.J, Dulvy, N.K, Jennings, S. and Polunin, N.V.C. (2005) Size-spectra as indicators of the effects of fishing on coral reef fish assemblages. *Coral Reefs* **24**, 118–124.

Halpern, B.S. (2003) The impact of marine reserves: do reserves work and does reserve size matter? *Ecological Applications* **13** S117–137.

Hilborn, R., Stokes, K. and Maguire, J.J. (2004) When can marine reserves improve fisheries management? *Ocean and Coastal Management* **47**, 197–205.

Hornell, J. 1940. *Report on the Fisheries of Fiji*. Government Printer, Suva, Fiji.

Hughes, T.P. (1994) Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. *Science* **265**, 1547–1551.

Hunt, C. (2003) Economic globalisation impacts on Pacific marine resources. *Marine Policy* **27**, 79–85.

IUCN (2004) IUCN Red List of threatened species. Available at: http://www.redlist.org/. Accessed in January 2005.

Jackson, J.B.C. (1997) Reefs since Colombus. *Coral Reefs* **16** (Suppl.), S23–S32.

Jackson, J.B.C, Kirby, M.X., Berger, W.H. et al. (2001) Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**, 629–638.

Jennings, S. and Lock, J.M. (1996) Population and ecosystem effects of reef fishing. In: *Reef Fisheries* (eds N.V.C. Polunin and C.M. Roberts). Chapman & Hall, London, pp. 193–218.

Jennings, S. and Polunin, N.V.C. (1995) Relationships between catch and effort in Fijian multispecies reef fisheries subject to different levels of exploitation. *Fisheries Management and Ecology* **2**, 89–101.

Jennings, S. and Polunin, N.V.C. (1996) Impacts of fishing on tropical reef ecosystems. *Ambio* **25**, 44–49.

Jennings, S., Reynolds, J.D. and Mills, S.C. (1998) Life history correlates of responses to fisheries exploitation. *Proceedings of the Royal Society-Biological Sciences* **265**, 333–339.

Jennings, S., Reynolds, J.D. and Polunin, N.V.C. (1999) Predicting the vulnerability of tropical reef fishes to exploitation with phylogenies and life histories. *Conservation Biology* **13**, 1466–1475.

Johannes, R.E. (1998) The case for data-less marine resource management: examples from tropical near-shore finfisheries. *Trends in Ecology and Evolution* **13**, 243–246.

Johannes, R.E. (2002) The renaissance of community-based marine resource management in Oceania. *Annual Review of Ecology and Systematics* **33**, 317–340.

Johannes, R.E. and Reipen, M. (1995) Environmental, economic, and social implications of the live reef fish trade in Asia and the western Pacific. Report to The Nature Conservancy and the Forum Fisheries Agency, 82 pp.

Kohler, S.T. and Kohler, C.C. (1992) Dead bleached coral provides new surfaces for dinoflagellates implicated in ciguatera fish poisonings. *Environmental Biology of Fishes* **35**, 413–416.

Koslow, J.A., Hanely, F. and Wicklund, R. (1988) Effects of fishing on reef fish communities at Pedro Bank and Port Royal cays, Jamaica. *Marine Ecology-Progress Series* **43**, 201–212.

Kulbicki, M., Labrosse, P. and Ferraris, J. (2004) Basic principles underlying research projects on the links between the ecology and the uses of coral reef fishes in the Pacific. In: *Challenging Coasts. Transdisciplinary Excursions into Integrated Coastal Zone Development* (ed. L.E. Visser). Amsterdam University Press, Amsterdam, pp. 119–158.

Lewis, R.J. and Holmes, M.J. (1993) Origin and transfer of toxins involved in ciguatera. *Comparative Biochemistry and Physiology* **106C**, 615–628.

Liao, I.C. (1997) Status, problems and prospects of stock enhancement in Taiwan. *Hydrobiologia* **352**, 167–180.

Lock, J.M. (1986) Effects of fishing pressure on the fish resources of the Port Moresby Barrier and fringing reefs. *Techical Report of Fisheries Division* No. 86/3, Department of Primary Ind., Port Moresby, Papua New Guinea, 31 pp.

Lubchenco, J. (1998) Entering the century of the environment: a new social contract for science. *Science* **279**, 491–497.

Mace, P.M. (2001) A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish and Fisheries* **2**, 2–32.

Mace, G.M. and Hudson, E.J. (1999) Attitudes toward sustainability and extinction. *Conservation Biology* **13**, 242–246.

McClanahan, T.R. and Arthur, R. (2001) The effect of marine reserves and habitat on populations of east African coral reef fishes. *Ecological Applications* **11**, 559–569.

Micheli, F. and Halpern, B.S. (2005) Low functional redundancy in coastal marine assemblages. *Ecology Letters* **8**, 391–400.

Moberg, F. and Folke, C. (1999) Ecological goods and services of coral reef ecosystems. *Ecological Economics* **29**, 215–233.

Molony, B.W., Lenanton, R., Jackson, G. and Norriss, J. (2003) Stock enhancement as a fisheries management tool. *Reviews in Fish Biology and Fisheries* **13**, 409–432.

Mumby, P.J., Mumby, P.J.; Edwards, A.J. et al. (2004) Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature* **427**, 533–536.

Musick, J.A., Harbin, M.M., Berkeley, S.A. et al. (2000) Marine, estuarine, and diadromous fish stocks at risk of extinction in North America (exclusive of Pacific Salmonids). *Fisheries* **25**, 6–30.

Pauly, D. (1994) *On the Sex of Fish and the Gender of Scientists*, 1st edn (Fish and Fisheries, 14). Chapman Hall, London, 250 pp.

Pauly, D. (1995) Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology and Evolution* **10**, 430.

Pauly, D. (1997) Small-scale fisheries in the tropics: marginality, marginalization and some implications for fisheries management. In: *Global Trends: Fisheries Management* (eds E.K. Pikitch, D.D. Huppert and M.P. Sissenwine). American Fisheries Society Symposium 20, Bethesda, MD, pp. 40–49.

Pauly, D., Christensen, V., Guenette, S. et al. (2002) Towards sustainability in world fisheries. *Nature* **418**, 689–695.

Pet-Soede, C. (2000) *Options for Co-management of an Indonesian Coastal Fishery*. PhD thesis, Wageningen University, AG Wageningen, The Netherlands, 135 pp.

Pickering, H. and Whitmarsh, D. (1997) Artificial reefs and fisheries exploitation: a review of the 'attraction versus production' debate, the influence of design and its significance for policy. *Fisheries Research* **31**, 39–59.

Polovina, J.J. and Sakai, I. (1989) Impacts of artificial reefs on fishery production in Shimamaki. *Japanese Bulletin of Marine Science* **44**, 997–1003.

Polunin, N.V.C., Roberts, C.M. and Pauly, D. (1996) Developments in tropical reef fisheries science and management. In: *Reef Fisheries* (eds N.V.C. Polunin and C.M. Roberts). Chapman & Hall, London, pp. 361–377.

Reynolds, N.K., Jennings, S. and Dulvy, N.K. (2001) Life histories of fishes and population responses to exploitation. In: *Conservation of Exploited Species* (eds J.D. Reynolds, G.M. Mace, K.H. Redford and J.G. Robinson). Cambridge University Press, Cambridge, pp. 147–168.

Roberts, C.M. (1995) Rapid buildup of fish biomass in a Caribbean marine reserve. *Conservation Biology* **9**, 815–826.

Roberts, C.M. and Hawkins, J.P. (1999) Extinction risk in the sea. *Trends in Ecology and Evolution* **14**, 241–246.

Ruddle, K. (1996) Traditional management of reef fishing. In: *Reef Fisheries* (eds N.V.C. Polunin and C.M. Roberts). Chapman and Hall, London, pp. 137–160.

Russ, G.R. (2002) Yet another review of marine reserves as reef fisheries management tools. In: *Coral Reef Fishes Dynamics and Diversity in a Complex Ecosystem* (ed. P.F. Sale). USA Academic Press, San Diego, CA, pp. 421–443.

Russ, G.R. and Alcala, A.C. (1999) Management histories of Sumilon and Apo marine reserves, Philippines, and their influence on national marine resource policy. *Coral Reefs* **18**, 307–319.

Sadovy, Y.J. and Domeier, M.L. (2005) Are aggregation fisheries sustainable: reef fish fisheries as a case study? *Coral Reefs* **24**, 254–262.

Sadovy, Y.J. and Lau, P.P.F. (2002) Prospects and problems for mariculture in Hong Kong associated with wild-caught seed and feed. *Aquaculture Economics and Management* **6**, 177–190.

Sadovy, Y.J. and Vincent, A.C.J. (2002) Ecological issues and the trades in live reef fishes. In: *Coral Reef Fishes Dynamics and Diversity in a Complex Ecosystem* (ed. P.F. Sale). Academic Press, San Diego, CA, pp. 391–420.

Sadovy, Y.[J.], Kulbicki, M., Labrosse, P., Letourneur, Y., Lokani, P. and Donaldson, T.J. (2003a) The humphead wrasse, *Cheilinus undulatus*: synopsis of a threatened and poorly known giant coral reef fish. *Reviews in Fish Biology and Fisheries* **13**, 327–364.

Sadovy, Y.J., Donaldson, T.J. Graham, T.R. et al. (2003b) *The Live Reef Food Fish Trade While Stocks Last*. Asian Development Bank, Manila, 147 pp.

Sale, P.F., Cowen, R.K., Danilowicz, B.S. et al. (2005) Critical science gaps impede use of no-take fishery reserves. *Trends in Ecology and Evolution* **20**, 74–80.

Sano, M. (2004) Short-term effects of a mass coral bleaching event on a reef fish assemblage at Iriomote Island, Japan. *Fisheries Science* **70**, 41–46.

Society for the Conservation of Reef Fish Aggregations (2005) Available at: http://www.scrfa.org. Accessed in January 2005.

Spalding, M.D., Ravilious, C. and Green, E.P. (2001) *World Atlas of Coral Reefs*. University of California Press, Berkeley, CA, 424 pp.

Summers, C. (2001) Live fish business grows. *Pacific Fisher* **October**, 35–38.

de Sylva, D.P. (1994) Distribution and ecology of ciguatera fish poisoning in Florida, with emphasis on the Florida Keys. *Bulletin of Marine Science* **54**, 944–954.

Thompson, D. (1989) Graph on duality of large and small-scale fishers. *Naga* **11**, 17.

Villanoy, C.L., Juinio, A.R. and Menez, L.A. (1988) Fishing mortality rates of giant clams (Family Tridacnidae) from the Sulu Archipelago and Southern Palawan, Philippines. *Coral Reefs* **7**, 1–5.

Vincent, A.C.J. and Sadovy, Y. (1998) Reproductive ecology in the conservation and management of fishes. In: *Behavioural Ecology and Conservation Biology* (ed. T. Caro). Oxford University Press, New York, pp. 209–245.

Warren-Rhodes, K. Sadovy, Y.J. and Cesar, H. (2003) Marine ecosystem appropriation in the Indo-Pacific: a case study of the live reef fish food trade. *Ambio* **32**, 481–488.

Whittingham, E., Campbell, J. and Townsley, P. (2003) *Poverty and Reefs*. DFID-IMM-IOC-UNESCO, Exeter, UK, 260 pp.

Wing, S.R. and Wing, E.S. (2001) Prehistoric fisheries in the Caribbean. *Coral Reefs* **20**, 1–8.

World Bank (2000) *Voices from the village: a comparative study of coastal resource management in the Pacific Islands. Pacific Islands Discussion No. 9*. A World Bank Final Report, March 2000, Washington D.C., 104 pp.

World Resources Institute (2005) Available at: http://www.wri.org/. Accessed in January 2005.