Available online at www.sciencedirect.com
ScienceDirect
Ocean & Coastal Management 50 (2007) 463–480
Ocean & Coastal Management
www.elsevier.com/locate/ocecoaman

Reef fisheries management in Kenya: Preliminary approach using the driver–pressure–state–impacts–response (DPSIR) scheme of indicators

Stephen C. Mangi[a,*], Callum M. Roberts[b], Lynda D. Rodwell[c]

[a]*Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH, UK*
[b]*Environment Department, University of York, Heslington, York YO10 5DD, UK*
[c]*School of Earth, Ocean and Environmental Sciences, University of Plymouth, Drake Circus, Plymouth PL4 8AA, UK*

Available online 8 December 2006

Abstract

This paper reviews the present state of reef fishing activities in Kenya and the tropics using the driver–pressure–state–impacts–response (DPSIR) framework. It identifies appropriate indicators that would evaluate the problem of overfishing and the use of destructive fishing gear, and discusses policy considerations for the Kenyan small-scale fishery. We conclude that the DPSIR framework works well at simplifying the complexity of reef fisheries management and serves to inform policy makers, scientists and general public on the relevance of indicators to monitor changes in the status of reefs.
© 2006 Elsevier Ltd. All rights reserved.

1. Introduction

Coral reefs are complex ecosystems with interrelated processes between the physical, chemical and biological components. Their management requires information on all these aspects and an understanding of the structure and function of the whole reef system. They extend throughout the tropics and are exploited primarily by subsistence fishers, supplying food and income for millions of people [1]. Changes in the condition of the reefs, therefore,

*Corresponding author. Tel.: +44 1752 633451; fax: +44 1752 633101.
E-mail address: stcma@pml.ac.uk (S.C. Mangi).

0964-5691/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ocecoaman.2006.10.003

have a direct impact on the services that humans depend on for health and economic growth. There is an increasing amount of national and international legislation that has been produced to develop tools for the sustainable use of reefs, and help manage them to conserve biodiversity and protect habitat integrity. The paradox is that while the scientific community is mostly working on detailed and narrow aspects, managers require a holistic approach not necessarily at a very high level of detail. This calls for multi-disciplinary approaches to coral reef research and resource management. There is an increasing need in reef fisheries management to link the science of the causes of change in the status of reefs to the social, economic and legal responses by people to that change. Such a link could best be demonstrated using indicators. Indicators act as information tools [2–4] and could help characterize the status of the coral reefs and provide an objective system of information and evaluation. While both fisheries managers and coral reef ecologists have developed indicator systems to better assess change, the degree to which such efforts have been linked has been limited. Managers have mostly focused on institutional measures of programme performance, while the ecologists have worked to build indicators of the scope and scale of change in the reef system. There is a need to improve the interaction between social systems and environmental variability.

In the last decade, however, efforts to expand the understanding of these interdependencies has improved [5]. This has been achieved by using socio-economic indicators that link the changes in the environment to the social and economic drivers, and political responses. Many such indicators have been developed within the pressure–state–response (PSR) or driving forces–pressure–state–impact–response (DPSIR) models originally developed by the Organization for Economic Co-operation and Development (OECD) [6]. The objective of these frameworks has been to clarify multi-sectoral relationships and to highlight the dynamic characteristics of the ecosystems and socio-economic changes [7,8]. The DPSIR approach has become increasingly popular in studies involving the management of nutrient fluxes into marine environments [e.g. 9,10], integrated coastal management [e.g. 3,5], development in catchment areas [e.g. 11], and offshore wind power generation [e.g. 7].

The purpose of this paper is to use the DPSIR conceptual framework to analyse the socio-economic issues, environmental changes and policy responses of coastal fisheries in Kenya in order to select appropriate indicators that would evaluate the problem of overfishing and the use of destructive fishing gears. We focus on socio-economic indicators to inform decision-makers about the existing environmental problems, that could help increase the transparency of the possible trade-offs involved in specific policy issues. We then establish a broader context of tropical reefs to show that the environmental pressures in Kenya's reef fisheries are similar to those experienced in other tropical coastal regions of the world, and therefore, the same indicators can be applied.

2. Problems facing reef fisheries management

Overfishing and particularly fishing with destructive techniques are threatening the normal functioning of coral reef ecosystems [12,13]. Artisanal fisheries provide the main source of protein and employment for coastal populations of many poor tropical countries of the world. In many of these fisheries, there is almost no economic constraint on fishing effort as fishers lack alternative sources of employment, and therefore have very low opportunity cost. Increased efficiency of fishing gear in many reefs has also led to increases

in fishing mortality on stocks. Many of the fishing gears used are simple and inexpensive with many fishers making their own gears such as spear guns and basket traps. Although fish catches from most reef areas are relatively low, the low cost of gears is sufficient incentive to continue fishing. Many reef fisheries are consequently overfished.

Fisheries management in coral reef areas has for a long time relied on single species models, such as maximum sustainable yield (MSY) to determine stock abundance. MSY represents the quantity of a stock that can be extracted in perpetuity without the stock collapsing or declining [14]. It was developed for cold temperate water fisheries to manage single target species that occurred at high biomass levels. Thus controls on fishing could be highly specific to the behaviour, feeding habits, seasonal cycles and migrations of the target species. However, fish stocks involve multiple interactions between species such as competition and predator–prey dynamics. The ecological complexity of tropical reefs also present a multi-species fishery with few specific target species, most of which are at low individual biomass compared to temperate waters. Despite efforts to target one species, no fishing method is able to catch a single species alone. Though, the theoretical optimum yield is sustainable, in practice we are unable to calculate its value so as to achieve it, and therefore alternatives need to be developed.

Effective fisheries management in the tropics in general is also hampered by the amount and quality of available data. Fisheries management tools involve controls on input and output. Input controls include fishing effort restrictions such as on number of fishers, boats, type and mesh size of gears used, while output controls include total allowable catch quotas (TAC) and minimum size requirements for fish [15]. These tools require biological information for analysis and management advice. For example, in order to set efficient TACs we need to know the level of fish biomass. However accurate estimates of fish biomass are difficult to obtain [16]. Gear restrictions and minimum size regulations tend to have fewer data requirements but involve enforcement difficulties. The lack of information is exacerbated by the spatial and biological diversity of reef resources, the complexity of the fisheries and the limited capacity for data collection and analysis in tropical countries [17].

Another problem facing fisheries management is that early studies of the effects of fishing were founded simply on short-term dynamics of target fish populations [18]. No consideration was given to the health of the ecosystem that is essential to the survival of these populations. Recently, there has been growing support among marine ecologists for considering fishing effects at the ecosystem, rather than population level, and treating the ecosystem as an assessment and management unit [19]. Management practices, therefore, need to look to an ecosystem approach that recognizes the interdependence of species and the need to understand the interacting social and political structures in the reef environment.

3. The DPSIR framework for the Kenyan reef fishery

In order to make policy recommendations for the Kenyan fishery, it is first necessary to describe the present state of the fishery and its management and the impacts of current socio-economic drivers and pressures on reef resources. Once the link between drivers, pressures and impacts is clear, policy responses can be formulated that will act to reduce the pressures created by certain drivers, and the socio-economic impacts of certain pressures on reef resources.

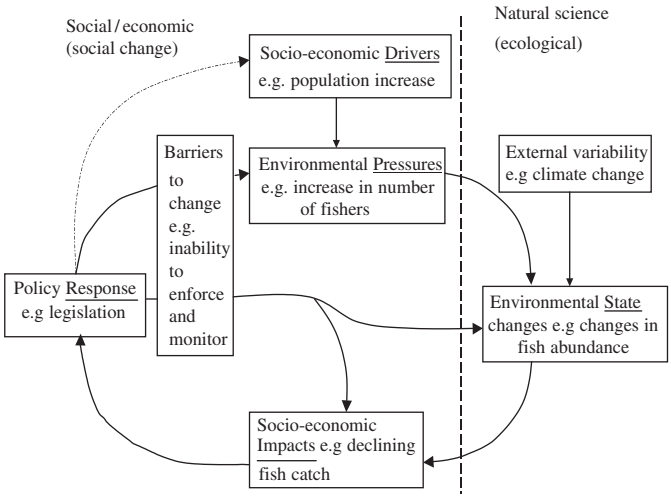

Fig. 1. The DPSIR framework (adapted for reef fisheries from [11]). Socio-economic drivers create environmental pressures. These in turn lead to changes in the state of the environment, which may result in impacts on human welfare through, e.g. declining catches. Policy responses are consequently formulated, which target one or more points in the environmental change process in order to mitigate the damage or problem, or re-orientate drivers or pressures.

The DPSIR model (Fig. 1) is a conceptual framework that embraces the process and indicator linkages of environmental functions. Under DPSIR environmental problems and solutions are simplified into variables that stress the cause and effect relationships between human activities that exert pressures on the environment, the condition of the environment, and society's response to the condition. Drivers describe large-scale socio-economic conditions and sectoral trends such as the need for fisheries to feed the rising resident coastal population. Environmental pressure builds up via these socio-economic driving forces and, augmented by natural systems variability, e.g. climate change, causes changes in environmental systems. State indicators describe observable changes in coastal environmental dynamics and in functions describing sustainable development, e.g. decrease in fish biomass. Impacts are the discretely assessed changes in social benefit values linked to environmental condition such as declines in fish catch leading to loss of household income. Response indicators can be described as the institutional responses to changes in the system, primarily driven by changes in state and impact indicators, e.g. legislation.

3.1. Socio-economic drivers

3.1.1. Population

The increase in population along the Kenyan coast represents the main driving force exerting a huge pressure on the coral reefs, through the different fishing activities. Kenya's coastal population has been on the increase due to local population growth and immigration from other parts of Kenya. In 1999, the coastal population was estimated as 2.5 million people, with an annual growth rate of 3.7% [20]. Many people are attracted to

the coast as a result of the increase in economic activity due to shipping, freight handling and tourism activities [21]. This increase in population results in increased competition for jobs in both the tourism sector and shipping industry. Many local residents who are unable to compete effectively for such jobs turn to fishing as marine resource use is largely unregulated and provides a range of livelihood opportunities that are both physically and economically accessible. The increase in coastal population not only increases the number of dependants on coral reef resources, but also increases the competition for access as the coral reef resources become exploited by increasing numbers of people. In order to be more competitive, some fishers resort to using effective fishing methods some of which are destructive to the fish habitats.

3.1.2. Unemployment

Kenya has high levels of unemployment. The 2001 estimate of unemployment for Kenya was 40% [22]. Apart from fishing, the other main occupations of local coastal residents are in tourism, factory work and farming. Many coastal residents have also ended up in self-employment through odd jobs and small businesses as a result of low levels of training. Low education standards among coastal residents hinder their ability to compete effectively in the job market. Many coastal people are also landless, or occupy lands owned by absentee landlords [23]. They therefore cannot make long-term plans and investments in farming. This coupled with a low agricultural production due to aridity of the climate makes many residents turn to fishing as an alternative livelihood.

3.1.3. Tradition and culture

Many coastal residents consider fishing as a way of life and an integral part of their social and economic existence [24,25]. They treat fishing as a traditional occupation that has been passed down from generation to generation. Many children born from fisher families are, therefore, expected to become fishers and will be encouraged to do so. Most of them are taught to use the same fishing methods as those used by the family, mainly the traditional fishing gears. However, as the youngsters separate from their relatives and start fishing alone, they usually make their own decisions on which gears to use. Most of them end up using non-traditional fishing gears, some of which are destructive to the coral reef ecosystems.

Among traditional coastal communities, coral reefs and the near-shore fisheries they support are often the focus of elaborate systems of customs and traditions. Along the Kenyan coast belief systems are prevalent and often manifest themselves in systems of customary marine tenure or traditional management [26]. Most of the small-scale fishery activities have traditionally been regulated through taboos and omens controlled by community elders. These beliefs and rules govern where and when to fish as well as how one should fish, and act to maintain social control and access to common pool resources. However, many of these traditions have decayed in the recent past due to, among other reasons, Islamization of culture [26]. The management authority for the fisheries has also shifted to the national government thereby weakening the effectiveness of traditional leaders. This has led to a loose organization of the fishers, with many young fishers choosing fishing gears that are not approved of by their elders.

3.1.4. Poverty

The deepening poverty among coastal residents in Kenya is one of the driving forces exerting huge pressures on the reefs. According to the Human Development Report 2005, 42% of the Kenyan population live below the national income poverty line [27]. Many artisanal fishers live from day to day on the protein they take home as food, and the cash earned from sales, averaging around Ksh 210-280 (US$ 3–4) per day (Fig. 2) [28]. They

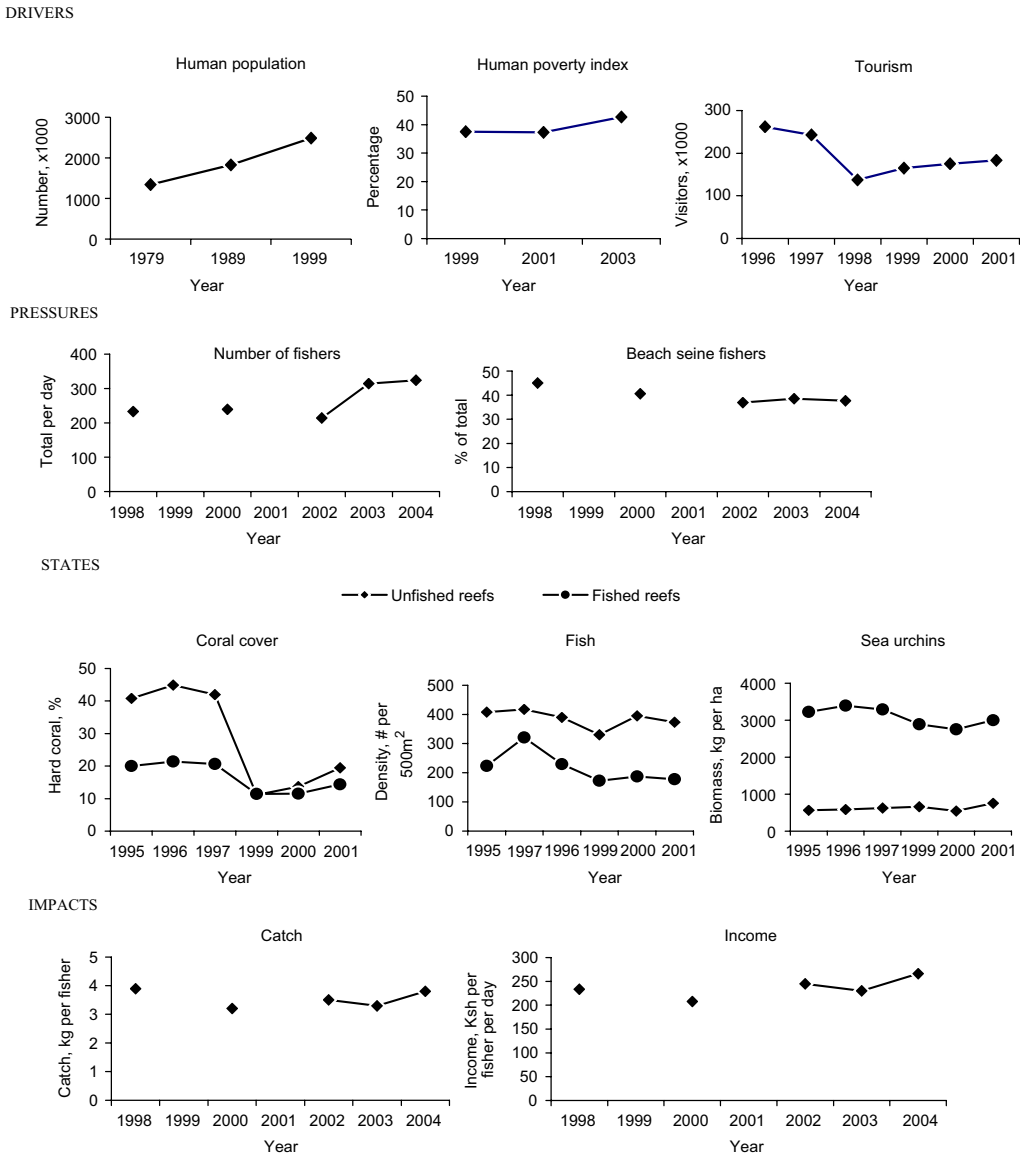

Fig. 2. Time series plots of the various indicators grouped as drivers, pressures, states or impacts. Includes a list of the various barriers to change and the laws relating to reef fisheries management in Kenya.

therefore cannot save to invest in anything else. Most of them, therefore, choose gears that are inexpensive or handmade from locally available materials and will predominantly operate from small non-mechanized craft.

3.1.5. Tourism

Tourism is frequently promoted as a highly profitable industry. Coastal areas and coral reefs are attractive for tourism development and, in many cases, the industry is promoted as a means of providing alternatives to fishery-based livelihoods and so ensure the sustainability of local reef resources. In Kenya, marine parks form the core attraction for coastal tourism, which until 1997 accounted for 70% of Kenya's tourism industry of up to 800,000 visitors annually [21]. The development of tourist resorts on beaches adjacent to marine protected areas (MPAs) has been one of the most vibrant areas of economic growth nationally. For example, on the north coast of Mombasa, the number of hotels tripled from 8 in 1971 to 25 in 1993, while their capacity increased sevenfold from 1000 to 7000 tourists during this time [21]. The tourism industry has promoted both the coastal and national economies in Kenya and has been the main earner of foreign exchange in the country. Many locals have been employed in tourist hotels, while others have relied on tourists for boat and tour operations among other benefits.

However, Kenya's coastal tourism industry fell in 1997 following political riots, and the bombing of the US Embassy in Nairobi in 1998. While statistics show a decrease of only 20% in tourism arrivals to Kenya coastal tourism plummeted, with hotels operating at less than 5–10% occupancy for 1998 and 1999 [21]. This volatility of the tourism industry has had a significant consequence on the coral reefs through the closure of hotels. Most of the people with canoes who used to take tourists to the reefs have now turned to fishing.

3.2. Pressures

3.2.1. Increase in fisher numbers

Due to the increase in population, unemployment, poverty and declining tourism (Fig. 2) many people have turned to fishing as a last resort in order to feed their families. As the barriers to outsiders who want to enter the fishery are minimal, many see the fishery as offering opportunities for those with limited financial resources. As a result, fisher numbers have greatly increased and both traditional and non-traditional fishing gears such as beach seines have been adopted.

3.2.2. Excessive exploitation

The Kenyan artisanal fishery is estimated to support between 5000 and 6500 fishers [21]. Each fisher has on average seven dependents. As the coastal population continues to increase, so does the number of dependents on the coral reef resources. Every fisher is under pressure to catch enough fish to feed their family. Consequently, there is intense competition for fish resulting in increased number of gears being deployed. Some fishers, especially those using basket traps, end up increasing the size and number of traps they use, while others have to spend more time fishing, e.g. hand line fishers. Other fishers adjust their mesh sizes to smaller ones so that they can capture as many fish as possible, e.g. fishers using beach seines. The ultimate result is that fish of all sizes are caught with adults being captured first. The small mesh size gears result in an increased exploitation of juvenile fish that leads to both growth and recruitment overfishing [12].

3.2.3. Destructive fishing gear

The demand for fishery resources has been gradually increasing following the increase in population. This has caused an increase in fishing pressure and the use of gear and techniques that are destructive. Many fishing techniques cause direct physical damage to the reef substratum and to the fish community structure [29,30], since a large number of the targeted reef fishes live in close association with structural features of the bottom [31]. Habitat degradation can have secondary effects on the standing stock of fish, decreasing fish numbers, which can lower fish catches for a long period of time. Destructive fishing gears in Kenya include beach seines and spear guns [28,32].

3.3. State change

3.3.1. Fish abundance

One of the major changes in the state of the coral reefs in Kenya is the dramatic decline in the number and individual size of finfish [33]. Fishing activities have reduced fish populations in studied reefs causing a severe decline in the species richness of the fished lagoons. A general conceptual and simulation model of the effects of fishing in Kenya is based on comparisons between protected and unprotected reef areas (Fig. 2). Results from these comparisons indicate high densities and biomass of fish in protected lagoons and less in fished ones [34].

3.3.2. Live coral cover

Both live coral cover and rugosity are linked to the condition of the coral reef ecosystem as indicators of reef health. Live corals provide food and shelter for fish and other benthic organisms. A more complex habitat, measured by rugosity, also provides more shelter and more surfaces for organisms to grow. Fishing directly and indirectly causes damage to live corals [30]. One of the ways in which this occurs is through habitat degradation and the destruction of the physical support for living communities generated by destructive fishing practices. Fishing gears that are destructive to fish habitats have accelerated the rate of decline of live coral in most of the fished reefs. Compared to the unfished reefs, fished reefs in Kenya show a half of live coral cover [35].

3.3.3. Sea urchin populations

Some fish species, such as the red-lined triggerfish *Balistapus undulatus*, prey on sea urchins providing a natural mechanism of suppressing the urchin populations. The decline in these prey species due to fishing results in high numbers of sea urchins on fished reefs. The removal of such keystone predatory fishes, and large numbers of predators and herbivores through fishing, has led to ecological release within the shallow reef lagoons of grazing sea urchin assemblages [36]. Sea urchin species like *Echinothrix diadema* and *Echinometra mathaei* are very common on the reefs now. *Echinometra mathaei*, the rock-boring sea urchin is one of the reef's major substrate eroders. Its high population numbers remain a threat to the functioning of the reef's calcium balance in many fished reefs in Kenya. Heavy grazing by sea urchins has led to the degradation of coral reef framework at fished sites, as well as inhibiting fish population recovery through competition for food [35].

3.3.4. Changes due to climatic change

Coral bleaching is one of the most dramatic environmental and ecological manifestations of global warming, and adds to the problem of overfishing in threatening reefs in many parts of the world, including Kenya [37,38]. It is caused by global climate change (carbon dioxide and other green house gases) and rising global temperatures that increase the frequency and severity of El Nino's. Coral reefs along the entire Kenyan coast suffered widespread bleaching and mortality during the first half of 1998 [37]. Sea surface temperatures rose by approximately 1.5 °C above normal values during March and April causing devastating impacts to the reefs. Live coral cover fell to between 10% and 50% of its 1997 level in most areas [38].

3.4. Socio-economic impacts

3.4.1. Declining fish catch

Artisanal fishing is the most important human activity exploiting the resources on coral reefs [1]. Fish yields decline when the reefs are heavily exploited. Declines of many marine fisheries have been attributed in large part to overfishing [12,39] and changes in the marine environment [40]. Kenya's fish stocks and catches are on the decline. A number of studies analysing fish trends show that catches declined rapidly in the 1990s [28,39]. Typical coral reef catches in Kenya vary between 3 and 4 kg/fisher/day. With a kilogram of fish selling at Ksh. 70, most fishers' daily income is between Ksh. 210 and 280 (or US$ 3–4). With such a low level of income, few fishers are able to support a family solely from their fishing income. Most, however, have little choice but to stay in fishing. Farming would be next best alternative to turn to, but due to aridity of climate agricultural production has also been low. Most fishers, therefore, end up expending greater efforts to maintain fishing. This increases the pressure on reef resources resulting to further declines of catches. As reef resources become depleted, so food security is also becoming threatened in many communities. Whilst alternative protein sources are often available, a greater number are now commercially produced and require to be purchased rather than be harvested from the wild. This places families of fishers in an increasingly difficult financial position.

3.4.2. Livelihood benefits compromise

Most of the local coastal residents are poor and for them the coral reefs represent an important resource, which contributes to many aspects of their livelihood. However, the ability of reefs to provide income and food security is being eroded by overfishing and the use of destructive fishing gears. Reef degradation is removing many of the benefits on which the fishers depend. Global climate change threatens further loss, and well-meaning policies, aimed at conserving threatened reefs often exclude fishers from access to the resources. The impact of these changes varies between different reef user groups but, in general, the fishers are finding that their livelihoods are being stressed more than most.

3.4.3. Increased conflict/exclusion

With increasing numbers of fishers competing for declining resources, it is not surprising that there is an increased conflict among fishers and other reef users. Where changes have brought about the displacement of some fishers to other fishing sites, these outsiders frequently become the focus of conflicts and disputes (i.e., local fishing communities and foreign fishers) [24]. Similarly, conflicts between local fishers and those responsible for

MPAs are common. Expanding coastal and reef tourism has also brought conflicts over access to the reef resources. As catches decline and competition and conflicts increase many of the fishers excluded and disadvantaged by the changes become increasingly disenchanted with their livelihood system. In the Diani area of Kenya, declines in fish catches and increasing conflicts with immigrant fishers, tourism and protected areas have challenged young fishers' faith in the ability of their elders to interact with spirits to ensure the health of and control access to community waters [26]. This has led to intergenerational conflicts and in some cases the total abandonment of traditional spirit appeasing ceremonies [26].

Changing resource access will often have opposing impacts on different reef users. For some, the change may be positive, leading to new or improved opportunities, while for others the change may exclude them from access to new opportunities. For many fishers faced with restrictions over gear and access to fishing grounds due to MPAs, there is no option but to continue fishing illegally. With no viable alternative to turn to, fishers typically lack the choice to alter their livelihoods in favour of conservation [26]. Furthermore the risk of punishment for breaking the law in many cases is not sufficient disincentive to stop exploiting a prohibited area or species.

3.5. Policy response

3.5.1. Legislation

Kenya has a wide variety of national, coastal and environmental legislation that relates to artisanal fishing, with parliamentary Acts on fisheries management (Cap 378, laws of Kenya), wildlife conservation and management (Cap 372, laws of Kenya) and coastal development (Act no. 20 of 1990, laws of Kenya). There are also a series of memoranda of understanding between different government departments involved in marine and coastal management, e.g. Kenya Wildlife Service and Fisheries Department, Coast Development Authority and Fisheries Department, for improved consultation amongst them. The Fisheries Act of 1991 [41] sets out the Government's plan for the development, exploitation, conservation and management of all fishery resources. The Act lists measures for the better management of the fishery including closed seasons, gear restrictions including mesh sizes of nets, and limitations on the amount, size and age of species caught. Kenya has also shown a strong commitment to protection of wildlife and natural habitats, with legislation for protection of the marine environment going back several decades. Kenya established its first MPAs in the late 1960s. Malindi and Watamu marine parks and reserves were formally established in 1968 to primarily conserve coral reefs. Kenya has a total of four marine parks namely Malindi, Watamu, Mombasa and Kisite, in which no extractive activities are allowed. Each of the four parks has a buffer zone referred to as marine reserve, where gear restrictions are imposed.

However, the level of compliance to most of these fisheries regulations by fishers has been low due to increased poverty, poor enforcement, and in some cases the rules are unknown and unclear. For instance, many fishers do not know if spear fishing is illegal, as it is not stated in the Fisheries Act. Due to poor enforcement, some of the fishing regulations have rarely led to noticeable changes in reef fisheries management, e.g. beach seining is prohibited but the practice continues. However, it is likely that if the regulations did not exist, the practices would be far more widespread than they are today.

3.5.2. Education and awareness

Education and awareness are major components of any interventions associated with preventing reef decline and are an important part of developing a better understanding of issues amongst user groups as a means of creating a willingness to change attitudes and behaviours. Education is often focused on informing user groups of the negative impact of their actions on the health of the reef and can be used as a means of informing locals of the objectives of an intervention in order to gain their support. Awareness raising programmes and local community involvement in management initiatives therefore needs to be a key part of the management plans early on before the intervention is implemented. Education and awareness on reef conservation and management issues has lagged behind in Kenya. Most MPAs and fisheries regulations have been initiated without adequate consultation and participation of the local communities [42]. This has led to a series of conflicts and slowed down implementation of management plans. However, recently education and awareness campaigns have improved with educational activities such as marine environment day and international coastal clean up taking place annually, involving school students, fishers and boat operators. Research NGOs including the Coral Reef Conservation Project (CRCP) and Coral Reef Degradation in the Indian Ocean (CORDIO), East Africa have also recently initiated annual meetings involving local fishers and Fisheries Officers where monitoring data on fish catch and other environmental data such as live coral cover, fish and sea urchin biomass are presented and discussed.

3.5.3. Planning regulations

Kenya's near-shore reef resources have been the focus of fisheries policies implemented through marine fisheries regulations, which have focused on safeguarding near-shore resources for the small-scale fishing sector. Regulations have included the protection of near-shore resources for the artisanal fisheries from large-scale commercial exploitation. e.g. trawlers. Regulations also prohibit coral mining in an attempt to prevent damage and ensure sustainability to reef and fisheries resources.

3.6. Barriers to change

3.6.1. Strong traditional and cultural attitudes

Artisanal fisheries are the focus of attention on indigenous rights by traditional reef-dependent communities. Most fishing communities would want the importance and value of their rights and knowledge to be recognized and will hold strong opinions and resist change. For example, in Diani, older fishers hold strong views about local fishing elders being able to manage their local fisheries and not Fisheries Officers. There is, therefore, a need to recognize the rights of indigenous peoples as this may confer greater participation in governmental-led policy planning and implementation.

3.6.2. Lack of detailed studies

Kenya's reef lagoons have been a magnet for research and scientific interest that has raised the profile of the reefs to global significance. As a result a number of studies focusing on artisanal fishing [e.g. 28,39], coral reef ecology [e.g. 34,35] and social dimensions of fishers [e.g. 24,26] have been conducted. A number of government departments, e.g. Kenya Marine Fisheries Research Institute and Kenya Wildlife Service, non-governmental organizations, e.g. CRCP and CORDIO, and universities, e.g. Moi and Nairobi have

offered scientific expertise to study the various aspects of the reefs. Many studies have focused on the effect of protective management on fish populations and have made comparisons based on fished and unfished areas. However, few detailed studies have been conducted on the response of catches to gear restrictions. Further, reporting of the results from most studies have targeted publications in peer-reviewed journals, theses or local project reports and have rarely been presented in a simple way for policy makers or resource users.

Management of the fisheries also requires information on the resource. In Kenya, fisheries statistics collected from most landing sites by Government Fisheries Officers are still not reliable and comprehensive enough to provide a complete picture of the status of the resources. While landing data collected by NGOs, e.g. CRCP and CORDIO East Africa is fairly good and reliable, it is mainly focused at a few landing sites. The majority of fish landing data is collected in Mombasa and Diani. Many landing sites are still not studied making accurate estimates of rates of exploitation for the reefs difficult.

3.6.3. Inability to enforce and monitor

While the existence of a reasonable legislative framework for fisheries management clearly exists, with limited funds and professional skills, implementation has been difficult and thus the potential benefits derived are minimal. The fisheries resources of Kenya are managed by the Fisheries Department and, where designated as Protected Areas, by the Kenya Wildlife Service. The Fisheries Department has scarce staff, some of whom are unskilled, and lacks resources for detailed study, monitoring and enforcement of complex multi-species multi-gear fisheries.

3.6.4. Lack of political will

The predominantly small-scale and subsistence nature of the coastal fishery means that the real benefit of the coral reef resource is often overlooked by the government. In Kenya, marine fisheries comprise less than 5% of the national fisheries production [21], dwarfed by catch from inland lakes (predominantly Lake Victoria) and rivers. As a result, despite declaring some gears illegal for many years, enforcement has been irregular, as the government has played little part in active management.

4. Measurement of indicators

The use of indicators is fundamental in the DPSIR framework as indicators provide an objective system of information and evaluation. Indicators, therefore, need to be properly selected and the methodology of their calculation specified if the dynamic parts of the fisheries management system are to be understood and appear compelling to the user communities [3,5]. A summary of the chosen indicators, units of measurement, their data sources and aggregation levels are presented in Table 1. These indicators were selected based on their relevance and priority for fisheries assessment and management. For some of them, direct measurement is difficult, e.g. lack of political will, and will therefore rely on quantification of proxies, while for others, data collection in the needed aggregation level is still lacking. Where the data are available, they are sparse and held by different organizations and institutions. A detailed analysis of the fishery using the DPSIR framework will, therefore, need to verify the quality, quantity and distribution of the

Table 1
Selection of indicators, their data sources, units of measurement and level of aggregation

Type	Indicator	Units of measurement	Data source	Level of aggregation
Drivers	Population dynamics	% rise or fall	Government census (Central Bureau of Statistics)	Province
	Unemployment	% rise or fall	Government employment figures, employment bureaus	Province
	Tradition + culture	Number using traditional methods, number actively practising beliefs and customs	Questionnaire surveys	District
	Tourism	Number of visitors per year	Government tourism statistics, Tourism Department	Province
	Poverty	% of population below poverty line	Government national income statistics	Province
Pressures	Number of fishers	No./km^2 fishing area	Fisheries Department, NGOs, KMFRI, universities	Landing site
	Excessive exploitation	Trends in total catch, kg/yr	Fisheries Department, NGOs, KMFRI, universities	Fishing ground
	Use of destructive fishing gear	Number and frequency of use, no./month	Fisheries Department, NGOs, KMFRI, universities	Fishing ground
State	Fish abundance	Biomass, kg/ha	NGOs, KMFRI, universities	Fishing ground
	Live coral cover and topographic complexity	% cover, Complexity score	NGOs, KMFRI, universities	Fishing ground
	Sea urchin populations	Density, no./m^2	NGOs, KMFRI, universities	Fishing ground
	Coral bleaching and mortality	% cover, % loss	NGOs, KMFRI, universities	Fishing ground
Impacts	Declining fish catch	Catch per unit effort, kg/fisher	Fisheries Department, NGOs, KMFRI, universities	Landing site
	Livelihood benefits compromise	% dependence on coral reef resources	CDA, NGOs, KMFRI, universities	District
	Increased exclusion/conflicts	Numbers excluded, number of conflicts	CDA, NGOs, KMFRI, KWS, universities	Fishing ground
Response	Legislation	Number of parliamentary acts. Number of MPAs, % of territorial waters under protection	Acts of Parliament	Coastal fishing
	Planning regulations		Provincial Fisheries Office, KWS wardens	Province
	Education and awareness	% of local community, literacy level	Fisheries Department and KWS local reports	District
Barriers to change	Strong traditional and cultural attitudes	% unwilling to change	Questionnaire surveys	District

Table 1 (*continued*)

Type	Indicator	Units of measurement	Data source	Level of aggregation
	Lack of detailed studies	Number and field	Reports by Fisheries Department, NGOs, KMFRI, universities	Coastal fishing
	Inability to enforce and monitor	% of population adhering to regulations	Fisheries Department, KWS reports	Coastal fishing
	Lack of political will	Fisheries management	Fisheries Department, KWS, local administration	Coastal fishing

available data and address existing gaps in data collection to achieve an appropriate evaluation of the problem.

5. The tropical reefs context

The same socio-economic drivers, pressures and impacts operate across tropical coastal regions of the world. Coastal populations in many tropical countries of the world are on the increase due to local population growth and migration. Many of these areas are also the poverty hot spots of the world. Poverty is the root of an array of fishery related and other socio-economic problems. For example, as poverty deepens, many people cannot afford to purchase gear and, therefore, end up using cheap fishing methods, which are often destructive to the fish habitats. Many reefs in tropical regions of the world are therefore under heavy pressures due to the rises in human population, unemployment, and deepening poverty. In Madagascar, for example, the number of fishers doubled between 1972 and 1988 [43]. Many fishers in the world are witnessing declines in catch per unit effort and even declines in total catches as the levels of exploitation are rising [43–46]. Despite worldwide bans in the use of many destructive fishing techniques, most of them are still practised in many reef areas of the world. The use of blasting devices on reefs such as dynamite still persist in Southeast and East Asia [47], South Pacific [48] and is becoming less common in Eastern Africa [49]. Fishing with poisons, such as cyanide, is also wide spread in Indonesia [50], Philippines, Malaysia, Thailand and Hong Kong [51]. Fishing using muro-ami, another devastating fishing method, is still common in the Philippines [52]. Many coral reefs around the world show declining long-term trends. For example, coral cover on many Caribbean reefs has declined by up to 80% over the last three decades [53].

The use of legal instruments as a means of implementing fisheries management, MPAs, integrated coastal zone management or collaborative management interventions are widespread in many tropical countries. Declining coral reef resources have also become a significant focus for concern and the target for numerous interventions. For example, when coral reefs in the Indian Ocean were devastated by the El Nino bleaching event in 1998, the Government of Sweden and the World Bank developed the CORDIO programme. Many governments have also declared MPAs and passed well-drafted legislation to protect coral

reefs, but there has been little follow-up action to manage MPAs and enforce the regulations [53].

6. Concluding remarks and policy considerations

The main purpose of this paper was to analyse the socio-economic issues, environmental changes and policy responses of reef fisheries in Kenya, and more broadly in the tropics in order to identify key indicators for the appropriate evaluation of the problem of overfishing and use of destructive fishing gears, and to develop policy and management options for these fisheries. The detailed review shows that reef fisheries in Kenya are subjected to similar socio-economic drivers and environmental pressures as those in other tropical regions of the world, and most reefs are in poor management status.

The evaluation also shows that there is a need to explain, demonstrate and illustrate the complexity of linkages between the causes and impacts of overfishing and use of destructive fishing methods to fisheries managers, politicians and resource users. This requires a broadening of the data domains and a much broader linking with other sectors and disciplines. The need for information on the state of the coral reef ecosystem, the dependence of reefs by coastal populations and the progress of management in relation to objectives impose the requirements for highly parameterized frameworks. Broad indicator systems combined with modelling of some sub-parts of the system is one effort to approach this.

Drivers, pressures, state, impacts and response indicators for evaluating overfishing and use of destructive fishing methods are proposed. These indicators are based on the practice of reef fisheries management in Kenya. The indicators are quantitative and could be routinely calculated within the annual monitoring process. Interpretation of the indicator values will be difficult due to the complexity of feedbacks involved and the general uncertainty involved in quantifying proxies [4,54,55]. Nevertheless, the indicator approach described is useful in developing policy and management options for tropical reef fisheries. In addition, it provides significant components for an adequate analysis of the problem of overfishing and the use of destructive fishing gear, and should provide a scheme for integrated environmental analysis that can be discussed, corrected and implemented. Fisheries management often requires little data, and should therefore benefit from the DPSIR approach that identifies causal links important for policy. In addition, the indicators provide an objective linkage between the causes and effects of overfishing, and should improve awareness of management failure and, ultimately, promote effective management.

Fisheries management in Kenya should consider increasing the network of marine parks to include a substantial portion of the reef system in Diani as a nonfishing area. Such a network of parks would serve as breeding and nursery grounds, where corals and fish populations would maintain natural populations undisturbed by human activities. Such areas would allow recruitment of fish to reach larger sizes before they are caught. The migrations and movement of adult fish out of these parks should enhance catches in the adjacent fishing grounds. If such a marine park were to be implemented, the 19 km square reef lagoon of Diani could be used effectively to build a viable tourism industry. Improvement of the tourism industry would provide alternative employment and remove some fishers from the reef.

Mechanisms to promote gear exchange should also be pursued involving provision of credit facilities for fishers to purchase authorized gear and compensation for owners of gears that have been declared illegal. Fishers' cooperative societies should be established or strengthened to facilitate these initiatives. Ways to reduce fishing effort should be pursued including the provision of licenses and exclusive access rights to fishing grounds. There is often a low awareness, as well as a poor understanding of conservation and resource management issues among coastal communities. Ways to change the attitudes of fishers by means of education and publicity campaigns should be pursued. The overfishing of coastal resources and use of destructive gear should be considered as a management issue of the coastal zone as a whole, which cannot be managed using simple regulatory measures. An integrated coastal zone management approach should be adopted in all areas along the coast, where local fishers and government departments consult and work together to look for alternatives acceptable to the fishing communities. Alternatives regarding fishing techniques, for those using more damaging gears, income-generating activities, alleviation of poverty, family planning schemes, improvement and enforcement of regulations and restoration of coastal habitats are some of the issues that such a collaborative management approach can address.

The DPSIR framework works well at simplifying the complexity of reef fisheries management and serves to inform policy makers, scientists and general public on the relevance of indicators to monitor changes in the status of coral reefs, assessing trends in socio-economic pressures, and appraising the effectiveness of fisheries management efforts in addressing these issues. It, however, does not give a direct proportional relationship between causes and effects, e.g. a 10% rise in coastal population does not correspond to a 10% rise in fishing pressure. The framework also lacks a component in which governance performance could be measured. For instance, one could use the number of laws relating to reef fisheries as an indicator of the government's response to fisheries management, but this does not explain how effective such laws are. Further, there are problems with the sectoral approaches to reef fisheries management, hence a higher number of laws might not necessarily be better. The DPSIR framework for reef fisheries management would therefore be more complete if it would include a methodology, which would facilitate the measurement of key indicators of governance performance, especially those focusing on outcomes rather than on processes. Such an evaluation would help decision-makers better evaluate the effectiveness of fisheries management programs.

Further work is required to validate and refine the indicators proposed here, but as proposed these socio-economic, ecological and management indicators serve as useful starters to understand and approach the problem of overfishing. Reef fisheries management should, therefore, incorporate appropriate components revealed through consideration of a DPSIR modelling effort as well as more traditional institutional performance measures. A more effective integration of social condition, environmental dynamics and institutional response will enrich the process of informed decision making on sustainable fisheries.

References

[1] Munro JL. The scope of tropical reef fisheries and their management. In: Polunin NVC, Roberts CM, editors. Reef fisheries. London: Chapman & Hall; 1996. p. 1–12.

[2] Smeets E, Weterings R. Environmental indicators: typology and overview. Copenhagen: European Environment Agency; 1999.
[3] Casazza G, Silvestri C, Spada E, Melley A. Coastal environment in Italy: preliminary approach using the DPSIR scheme of indicators. Littoral 2002: 541–9.
[4] Jennings S. Indicators to support an ecosystem approach to fisheries. Fish and Fisheries 2005;6:212–32.
[5] Bowen RE, Riley C. Socio-economic indicators and integrated coastal management. Ocean and Coastal Management 2003;46:299–312.
[6] Vandermeulen H. The development of marine indicators for coastal zone management. Ocean and Coastal Management 1998;39:63–71.
[7] Elliott M. The role of the DPSIR approach and conceptual models in marine environmental management: an example for offshore wind power. Marine Pollution Bulletin 2002;44:3–7.
[8] Belfiore S. The growth of integrated coastal management and the role of indicators in integrated coastal management: introduction to the special issue. Ocean and Coastal Management 2003;46:225–34.
[9] Turner RK, Georgiou S, Gren I, Wulff F, Barrett S, Soderqvist T, et al. Managing nutrient fluxes and pollution in the Baltic: an interdisciplinary simulation study. Ecological Economics 1999;30:333–52.
[10] Smith VH, Tilman GD, Nekola JC. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution 1999;100:179–96.
[11] Cave RR, Ledoux L, Turner K, Jickells T, Andrews JE, Davies H. The Humber catchment and its coastal area: from UK to European perspectives. The Science of the Total Environment 2003;314–316:31–52.
[12] Pauly D, Silvestre G, Smith IR. On development, fisheries and dynamite: a brief review of tropical fisheries management. Natural Resource Modeling 1989;3:307–27.
[13] McManus JW, Reyes RB, Nanola CL. Effects of some destructive fishing methods on coral cover and potential rates of recovery. Environmental Management 1997;21:69–78.
[14] Stevenson DK. Management of a tropical fish pot fishery for maximum sustainable yield. Proceedings of the Gulf and Caribbean Fisheries Institute 1978;30:95–115.
[15] Nowlis JS. Short and long-term effects of three fishery management tools on depleted fisheries. Bulletin of Marine Science 2000;66:651–62.
[16] Lauck T, Clarke C, Mangel M, Munro GR. Implementing the precautionary principle in fisheries management through marine reserves. Ecological Applications 1998;8:72–8.
[17] McManus JW. Social and economic aspects of reef fisheries and their management. In: Polunin NVC, Roberts CM, editors. Reef fisheries. London: Chapman & Hall; 1996. p. 249–81.
[18] Frank KT, Leggett W. Fisheries ecology in the context of ecological and evolutionary theory. Annual Review of Ecology and Systematics 1994;25:401–22.
[19] Jennings S. The ecosystem approach to fishery management: a significant step towards sustainable use of the marine environment? Marine Ecology Progress Series 2004;274:279–82.
[20] Anonymous. Population and housing statistics. Central Bureau of Statistics, Government of Kenya; 2003. 〈http://www.cbs.go.ke〉.
[21] Obura DO. Kenya. Marine Pollution Bulletin 2001;42:1264–78.
[22] The World Fact book. CIA 2001. 〈http://www.odci.gov/cia/publications/factbook/geos/ke.html〉.
[23] Ng'weno B. Inventing ground rules: inheritance of land among the Digo of Southern Kenya. Department of Anthropology, Stanford University; 1995.
[24] Glaesel H. Fishers, parks, and power: the socio-environmental dimensions of marine resource decline and protection on the Kenyan coast. PhD thesis, Department of Geography, University of Wisconsin, 1997.
[25] Whittingham E, Campbell J, Townsley P. Poverty and reefs. DFID-IMMIOC/UNESCO, 2003.
[26] McClanahan TR, Glaesel H, Rubens J, Kiambo R. The effects of traditional fisheries management on fisheries yields and the coral reef ecosystems of southern Kenya. Environmental Conservation 1997;24:105–20.
[27] Human Development Report. New York: United Nations Development Programme; 2005.
[28] McClanahan TR, Mangi S. The effect of a closed area and beach seine exclusion on coral reef fish catches. Fisheries Management and Ecology 2001;8:107–21.
[29] Roberts CM. Effects of fishing on the ecosystem structure of coral reefs. Conservation Biology 1995;9:988–95.
[30] Jennings S, Kaiser M. The effects of fishing on marine ecosystems. Advances in Marine Biology 1998;34:201–351.
[31] Ohman MC, Rajasuriya A. Relationships between habitat structure and fish communities on coral and sandstone reefs. Environmental Biology of Fishes 1998;53:19.

[32] Mangi SC, Roberts CM. Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. Marine Pollution Bulletin 2006.
[33] McClanahan TR. Kenyan coral reef lagoon fish: effects of fishing, substrate complexity and sea urchins. Coral Reefs 1994;13:231–41.
[34] McClanahan TR, Arthur R. The effect of marine reserves and habitat on populations of east African coral reef fishes. Ecological Applications 2001;11:559–69.
[35] McClanahan TR, Muthiga NA, Kamukuru AT, Machano H, Kiambo RW. The effects of marine parks and fishing on coral reefs of northern Tanzania. Biological Conservation 1999;89:161–82.
[36] McClanahan TR, Shafir SH. Causes and consequences of sea urchin abundance and diversity in Kenyan coral reef lagoons. Oecologia 1990;83:362–70.
[37] McClanahan TR, Muthiga N, Mangi SC. Coral and algal changes after the 1998 coral bleaching: interaction with reef management and herbivores on Kenyan reefs. Coral Reefs 2001;19:380–91.
[38] Obura DO. Kenya. In: Linden O, Sporrong N, editors. Coral reef degradation in the Indian Ocean: Status reports and project presentations. Stockholm: Sida/Sarec Marine Science Programme; 1999.
[39] Kaunda-Arara B, Rose GA, Muchiri MS, Kaka R. Long-term trends in coral reef fish yields and exploitation rates of commercial species from coastal Kenya. Western Indian Ocean Journal of Marine Science 2003;2:105–16.
[40] Coleman FC, Williams SL. Overexploiting marine ecosystem engineers: potential consequences for biodiversity. Trends in Ecology and Evolution 2002;17:40–4.
[41] Anonymous. The Fisheries Act, Chapter 378 Laws of Kenya. Nairobi: Government Printer; 1991.
[42] Muthiga NA. The effectiveness of management and the ICAM experience in marine protected areas: the Mombasa Marine Park and Reserve. Mombasa: Kenya Wildlife Service; 2001.
[43] Laroche J, Ramananarivo N. A preliminary survey of the artisanal fishery on coral reefs of the Tulear Region (southwest Madagascar). Coral Reefs 1995;14:193–200.
[44] Koslow JA, Aiken K, Auil S, Clementson A. Catch and effort analysis of the reef fisheries of Jamaica and Belize. Fishery Bulletin 1994;92:737–47.
[45] Dayaratne P, Linden O, de Silva MWRN. Puttalam Lagoon and Mundel Lake, Sri Lanka: a study of coastal resources, their utilization, environmental issues and management options. Ambio 1995;24:391–401.
[46] Maypa AP, Russ GR, Alcala AC, Calumpong HP. Long-term trends in yield and catch rates of the coral reef fishery at Apo Island, central Philippines. Marine and Freshwater Research 2002;53:207–13.
[47] Pet-Soede L, Erdmann MV. Blast fishing in SW Sulawesi, Indonesia. NAGA the ICLARM Quarterly 1998;21:4–9.
[48] Zann LP. The status of coral reefs in south western Pacific Islands. Marine Pollution Bulletin 1994;29:52–61.
[49] Verheij E, Makoloweka S, Kalombo H. Collaborative coastal management improves coral reefs and fisheries in Tanga, Tanzania. Ocean and Coastal Management 2004;47:309–20.
[50] Erdmann M. An ABC guide to coral reef fisheries in Southwest Sulawesi, Indonesia. NAGA the ICLARM Quarterly 1995;18:4–6.
[51] Cornish AS, McKeller D. A history of fishing with explosives and poisons in Hong Kong waters. NAGA the ICLARM Quarterly 1998;21:4–9.
[52] Golden F. Reef raiders: fish trappers learn to live without cyanide and dynamite while stalking America's favourite pets. Sea Frontiers 1991;37:22–9.
[53] Wilkinson C, editor. Status of coral reefs of the world 2004. Townsville: Global Coral Reef Monitoring Network and Australian Institute of Marine Science; 2004.
[54] Degnbol P. Indicators as a means of communicating knowledge. ICES Journal of Marine Science 2005;62:606–11.
[55] Garcia SM, Staples DL, Chesson J. The FAO guidelines for the development and use of indicators of sustainable development of marine capture fisheries and an Australian example of their application. Ocean and Coastal Management 2000;43:537–56.