Western Indian Ocean J. Mar. Sci. Vol. 13. No. 2, pp. 143 - 162, 2014

Review

A Review on Kenyan Fisheries Research: 1970-2009

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Keywords: Marine fish resources; fisheries management; Kenya, artisanal fisheries, fishing methods

Abstract — Fish resources in Kenya have been exploited for centuries, mostly by artisanal fishers in inshore lagoons, on reefs and, occasionally, in deeper waters. Fish in Kenya, as in many other tropical coastal countries, constitute an important source of food and livelihood. Artisanal fisheries thus play a key role in food security and employment, and are seen as a means to poverty alleviation. We review research on the fisheries in Kenya and the usefulness of the results in fisheries management, considering information from 135 peer-reviewed publications, reports and grey literature on research undertaken over the past 40 years. Subjects covered ranged from fish surveys, species diversity and composition to marine protected areas. The research has been useful in guiding management for the sustainable use of these resources. Research gaps have been identified, emphasising the need for integrated management of Kenya's marine and coastal resources.

INTRODUCTION

Fishing in Kenya has been carried out for centuries and has been an important economic sector (Fisheries Department, 2012). Fish resources, especially reef fishes, have been exploited for many years, mostly by artisanal fishers, and constitute an important source of food and livelihood. The Fisheries Department of Kenya is vested with the management of fisheries resources in the country. The fisheries sector plays a major role in the economy of the country by providing food security, a source of employment and, hence, poverty alleviation (Fisheries Department, 2012). The annual marine fisheries production in Kenya is estimated at 7 000 tonnes, representing approximately 5% of the total catch in the country, but over 60% of the coastal and marine landings (Fisheries Department, 2012).

Information recording and reporting on marine fish resources in Kenya commenced in the 1950s (Martin, 1973) and research has, in more recent years, been conducted by various local and international research institutions and organizations. 'Frame Surveys' were conducted along the Kenyan coast by the Fisheries Department in 2004, 2006, 2008 and 2012 and are census-based, data being collected on all fishing vessels and gear (at all homeports and fishing sites) operating within a chosen context or stratum. They gather information on the number of fishers, landing sites, fishing gear and vessels, and further provide an opportunity to record supplementary information useful for management planning and implementation (e.g. fishing patterns and the seasonal use of fishing gear). They can also be used to

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provide information on the socio-economics and demography of fishing communities (Stamatopoulos, 2002). Marine fisheries in Kenya are mainly artisanal, currently comprising an estimated 13 706 participants (Fisheries Department, 2012). There are 160 fish landing sites and about 3 090 fishing craft operating within the marine artisanal fisheries sector (Fisheries Department, 2012).

While fisheries research has been ongoing in Kenya for many years, more intensive research has only been conducted in recent years. The objective of this review was to assemble this information from publications and grey literature as a baseline for future reference. Apart from serving as a one-stop source on Kenyan fisheries, it is hoped that it will be used by researchers and students to identify areas for future research, and provide information on past trends for the purposes of comparison and emphasis.

METHODS

Information for the review was gathered from the Kenya Marine and Fisheries Research Institute (KMFRI) This included peer-reviewed publications, reports and grey literature accessioned in the KMFRI Library from 1970 to 2009 on or related to the marine fish resources in Kenya. Information on the Frame Surveys conducted by the Kenya Fisheries Department was also used. Several steps were involved in compiling the review, the first involving searching for the relevant records using the following keywords: fish resources; fish surveys; impacts of fishing; overfishing and overexploitation; fish yields and catches; catch per unit effort; fish species diversity and composition; fishing methods and destructive gear; Marine Protected Areas (MPAs); predation; fish seasonality; ornamental fisheries; by-catch; fishery and habitat degradation; reproductive biology of fish species; general biology of selected fish species; age and growth; diets; spawning aggregations and homing; pollution; threatened species; genetic studies; and fisheries management. A number of records were also identified through the Internet or other sources (grey literature, books, etc.). The second step involved screening and retrieving the relevant publications and reports for review. These were then assessed for eligibility and the various topics considered were rated from those most investigated to those least studied.

REVIEW

Overview

The amount of research undertaken on Kenyan fisheries within the topics searched is reflected in the number of references on these topics (Fig. 1). Most of the research has focused on fish species diversity and composition (40 references), followed by fishing gear and fish resources in MPAs (both with 28 references), then management and yields (both with 22 references). Areas least studied included ornamental fisheries (1), habitat degradation (2), and spawning aggregations and homing (3).

A total of 207 publications were sourced from the various databases but, after screening for duplication or relevance, these were reduced to 135. The relevant publications were then reviewed under the 18 topics that follow. Note that some of the publications and reports fall under more than one topic.

Fish surveys

A number of fish resource surveys have been conducted in Kenyan waters, mainly within Food and Agriculture Organization of United Nations (FAO) projects. The first FAO survey off Malindi Bay was undertaken in 1958 and this was repeated in 1966. From these, the FAO reported that the annual catch was about 5 000 tonnes and recommended mechanization of the inshore craft with their gradual replacement by small seagoing vessels which could operate outside the reef (Martin, 1973). Bottom trawl surveys in inshore waters were conducted in the 1960s using the Kenyan research vessels *Shakwe*, *Menika II* and *Manihine* and, in 1964 and 1965, with commercial trawlers. Nansen surveys conducted in 1980-83 (Mbuga, 1984) between 10–700 m investigated the abundance and distribution of fish acoustically and by trawling. The biomass estimate was 18 000-

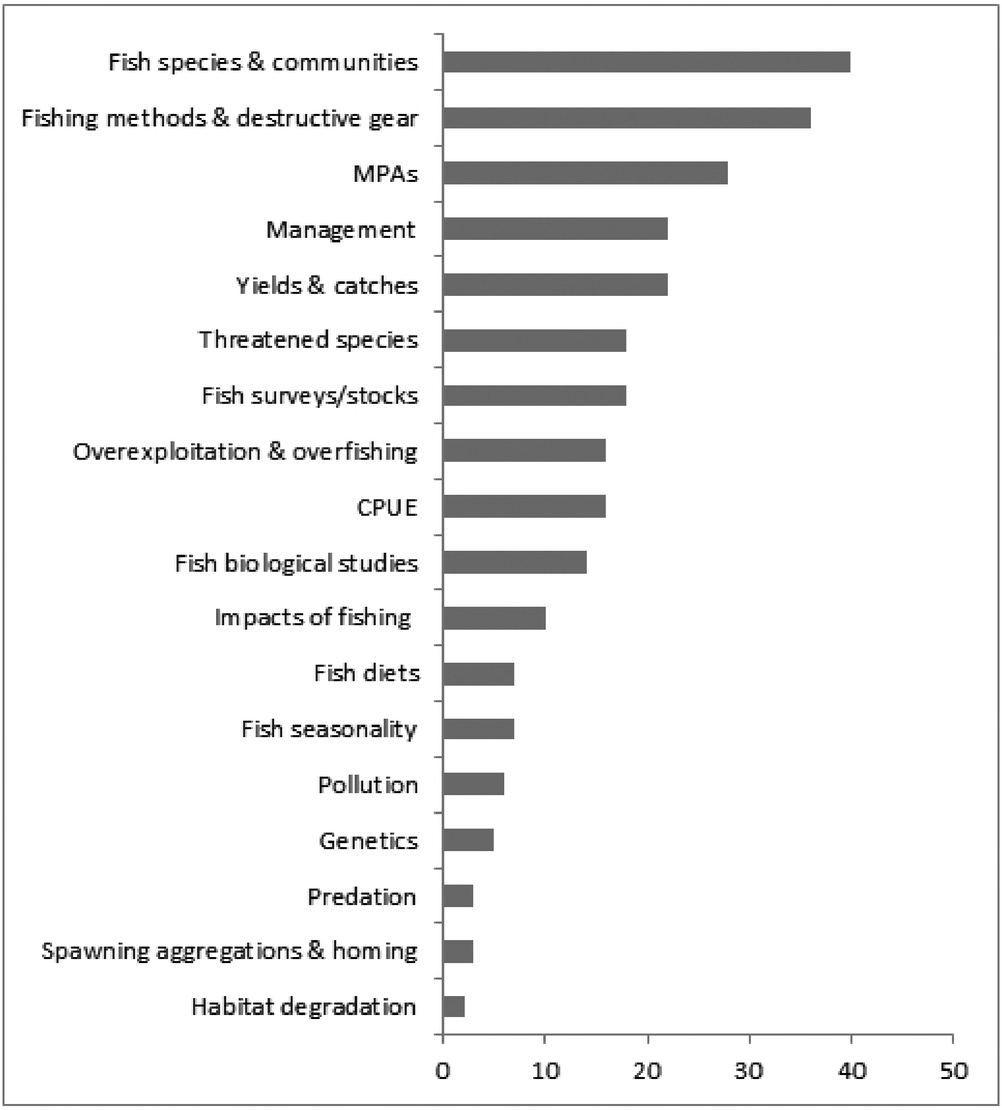

Figure 1. Research topics and the number of references on these topics considered in this review.

32 000 tonnes (Mbuga, 1984; Iversen, 1984), with a potential offshore yield of 10 000 tonnes (Mbuga, 1984). The total potential of marine fish production was estimated to be 150 000 tonnes yr^{-1} (Iversen & Myklevoll, 1984).

The Frame Surveys (2004, 2006, 2008, 2012) have also been useful in providing an overview of fisheries activities along the Kenyan coast and future surveys will be important for the management of the Kenyan marine fisheries. They have generated data and information on the status of the marine fisheries. The surveys by research vessels yielded the aforementioned potential marine fish production and yield (Iversen & Myklevoll, 1984), and form a good reference point for ongoing regional fish surveys and stock assessments. Both the Frame and fish surveys, if conducted regularly, will be important in tracking changes in the marine fisheries and provide indicators for management actions and options. Changes in fishing gear and fishing areas can be traced over time and will be crucial in future management.

Yields and catches

Annual marine catches in Kenya have fluctuated between 4 000 and 10 000 tonnes over the last two decades, with some areas reporting overfishing (Kamau *et al*., 2009). Some estimates of the fish landed annually have been greater, viz. 16 000 tonnes (Tuda *et al*., 2008). The status of fish catches and landings in Kenya has been assessed (Oduor, 1984) and analysis of long-term trends in coral reef fish catches have revealed that Kenyan reefs yield an estimated 2–4 tonnes km^{-2} yr^{-1} of demersal fish (Kaunda-Arara *et al*., 2003). The fish yield on Kilifi reef during 1982–1984, which is about 4 km2 in extent, was found to be 5.07-12.9 tonnes km^{-2}, the mean catch being 8.8 tonnes km–2 yr^{-1} (Nzioka, 1990). Studies have indicated that habitat protection in reserves can underpin fish productivity and, depending on its effects on fish movements, augment catches (Rodwell *et al*., 2003).

Catch-per-unit-effort

Catch-per-unit-effort (CPUE) - also called catch rate - is considered the single most useful index for long-term monitoring of a fishery (Stamatopoulos, 2002). Various studies have incorporated it in the assessment of fisheries and it was demonstrated that the CPUE of most species improved in traditional basket (*Dema*) trap fisheries adjacent to protected reefs in Kenya's coastal National Parks (Kaunda-Arara & Rose, 2004). A study on the influence of the 1998 coral bleaching and mortality event on coral reef ecosystems and fisheries in southern Kenya revealed a decline in total fish catches and CPUE, combined with an increase in effort, suggestive of overexploitation (McClanahan *et al*., 2002a; Maina *et al*., 2008a). It has also been observed in other studies that sites where illegal beach seining was excluded through active gear management, yielded increased catches and CPUE (McClanahan *et al*., 2008). For example, two landing sites at Diani where beach seining was prohibited for over 20 years yielded the highest per fisher catches, these being 13% greater than at sites where such fishing is allowed (McClanahan & Mangi, 2001). CPUE data collected and analysed in other studies (Mwatha & Orembo, 1998, Munywoki *et al*., 2008; Okemwa *et al*., 2008) have provided valuable results for the management of fisheries, especially in gear and effort regulation (Stamatopoulos, 2002).

Species diversity and composition

Of the 736 marine fish species recorded in Kenya according to FishBase (www.fishbase.org), 121 species are exploited commercially (pers. comm. Fisheries Department), 193 for ornamental aquaria (Okemwa *et al*., 2009) and 26 are threatened. The earliest fish checklists were compiled on the south bank of Kilifi Creek (Bock, 1975) and in the lagoon of Diani (Bock, 1972). In a fisheries survey of Kilifi Creek, the major fish groups that were harvested were Siganidae, Scaridae, Plectorhynchidae, Scombridae, Lutjanidae, Serranidae, Carangidae, Sphyraenidae and Caesionidae (Nzioka, 1990). A more recent survey of the fish fauna in the creek yielded 63 finfish species (Sigana *et al*., 2009).

An assessment of Kenyan coral reef lagoon fishes has revealed a consistent and considerable reduction in the population density and species richness of five families (Acanthuridae, Balistidae, Chaetodontidae, Pomacanthidae, and Scaridae; McClanahan, 1994a). However, protected areas have a higher abundance and species richness of commercially important triggerfish, surgeonfish, and parrotfish (McClanahan & Arthur, 2001). Studies on spillover effects have shown that this is greatest for the dominant fisheries species, viz. moderately active species like rabbitfish (Siganidae; herbivores), emperors (Lethrinidae; carnivores) and surgeonfish (Acanthuridae; herbivores) which had instantaneous emigration rates from the protected area to the fishing grounds of approximately 0.5 (McClanahan & Mangi, 2000).

Studies on the different Kenyan marine habitats have been useful to identify the fish species and communities inhabiting them (McClanahan *et al*., 1999a, 2002b; Huxham *et al*., 2008). Five taxa accounted for approximately 70% of the total fish abundance amongst juvenile fish communities associated with natural, degraded and replanted *Sonneratia alba* mangroves in Gazi Bay, the majority (65%) being reef associates, and the Gobidae and *Gerres oyena* being dominant (Crona & Rönnbäck, 2007). A total of 128 teleost fish species belonging to 50 families were identified in an earlier study of the bay (Kimani *et al*., 1996). Then the families Gerreidae, Atherinidae and Clupeidae accounted for 78.5% of the fish population and, of the species found, 44% were associated with coral reefs (Kimani *et al*., 1996). In another study, a total of 3601 fishes (>95% juveniles) were caught, comprising 75 species in 40 families (Little *et al*., 1988).

In Mida Creek further north, the most common fish landed included Siganidae, Lethrinidae, Lutjanidae, Scaridae and Nemipteridae, comprising ~80% of the catch (Mwatha & Orembo, 1998). In the mangrove area of Tudor Creek at Mombasa, 83 species of teleost fish were collected and ~90% of these were juveniles (Little *et al*., 1988).

Approximately 70% of the fish caught for the marine aquarium industry belong to four families, viz. the Pomacentridae (damselfish), Labridae (wrasses), Acanthuridae (surgeonfish) and Gobiidae (gobies) (Okemwa *et al*., 2009). Ten species made up 58% of the harvest, of which two species, *Amphiprion allardi* (10%) and *Centropyge acanthops* (9%), were the most important (Okemwa *et al*., 2009). Overall, these results show that the Kenyan coast is rich in fish species, particularly in protected areas.

Seasonality

Higher fish catches are recorded during the dry and calm northeast monsoon season along the Kenyan coast (Nzioka, 1990; Sigana *et al*., 2009; Okemwa *et al*., 2008) and it has been established that fishing activities follow the lunar cycle which affects tidal fluctuations that determine the daily fishing times (Otieno *et al*., 2001). Fishing activities are limited during the southeast monsoon period when sea conditions are rough (Nzioka, 1990).

Spawning aggregations and homing

About 24 fish species have been reported to form spawning aggregations in Kenya (Jan *et al*., 2008) and these have been studied in some species including: *Siganus sutor*; *Lutjanus sanguineus*, *L. gibbus*, *L. bohar*, *L. argentimaculatus*, *Epinephelus fuscoguttatus*, *Mulloidichthyes vanicolensis* and *Plectorhinchus* spp. (Maina *et al*., 2008b). Other studies that have investigated reef fish spawning aggregations have been conducted by Nzioka (1981b), Ntiba and Jaccarini (1990) and Jan *et al*., (2008). Reef fishes spawn during the north-east monsoon period (Novemebr-April) (Jan *et al*., 2008), while other species spawn in the two monsoon seasons (Nzioka, 1979; Ntiba & Jaccarini, 1990). The status of these spawning aggregations is poorly known and they have not been properly monitored in Kenya (Jan *et al*, 2008). Very few occur in MPAs (Jan *et al*., 2008) and, because of this, they are not adequately protected and their management should be complemented by catch and effort regulations (Jan *et al*., 2008). Marine protected areas have particular conservation potential for species (e.g. groupers) that have homing behaviour and establish home ranges (Kaunda-Arara & Rose, 2003). However, homing and site fidelity has only been studied in the greasy grouper, *Epinephelus tauvina* (Kaunda-Arara & Rose, 2003). Home ranges were found to be negatively correlated with size in this species, suggesting an ontogenetic shift in home range development (Kaunda-Arara & Rose, 2003).

Biological studies

A total of 45 species of marine fish have been studied in terms of their biology in Kenya (Table 1). These studies have included: estimates of the growth and mortality of the grunt (*Pomadasys opercularis*), thumbprint monocle bream (*Scolopsis bimaculatus*), spotted sicklefish (*Drepane punctatus*) and rabbitfish (*Siganus sutor*) (de Souza, 1986); the ecology and exploitation of yellowfin Tuna, Thunnus albacares (Hemphill, 1995);

Table 1. List of marine fish species/genera studied in Kenyan coastal waters and the aspects considered.

Species/Genera	Biology	Diet	Behaviour
1. *Lutjanus fulviflamma*	■		
2. *Pomadasys opercularis*	■		
3. *Scolopsis bimaculatus*	■		
4. *Drepane punctata*	■		
5. *Siganus sutor*	■		
6. *Lethrinus harak*	■		
7. *Thunnus albacares*	■		
8. *Plectorhincus spp.*	■		
9. *Sphaeramia orbicularis*	■		
10. *Istiophorus platypterus*	■		
11. *Anyperodon*	■		
12. *Cephalopholis*	■		
13. *Dermatolepis*	■		
14. *Epinephelus*	■		
15. *Plectropomus*	■		
16. *Variola*	■		
17. *Leptoscarus vaigiensis*	■	■	
18. *Epinephelus tauvina*			■
19. *Sardinella gibbosa*		■	
20. *Atherinomorous lacunosus*		■	
21. *Pellona ditchella*		■	
22. *Spratelloides delicatilus*		■	
23. *Gerres oyena*		■	
24. *Secutor insidiator*		■	
25. *Leiognathus equula*		■	
26. *Selar crumenopthalmus*		■	
27. *Herklotsichthys quadrimaculatus*		■	
28. *Stolephorus indicus*		■	
29. *Atherinomorus duodecimalis*		■	
30. *Apogon thermalis*		■	
31. *Fowleria aurita*		■	
32. *Paramonacanthus barnardi*		■	
33. *Mulloides flavolineatus*		■	
34. *Lutjanus argentimaculatus*		■	
35. *Gerres acinaces*		■	
36. *Bothus myriaster*		■	
37. *Fistularia commersonii*		■	
38. *Sphyraena barracuda*		■	
39. *Plotosus lineatus*		■	
40. *Cheilio inermis*		■	
41. *Apogon fragilis*		■	
42. *Apogon nigripes*		■	
43. *Lethrinus nebulosus*		■	
44. *Parascorpaena mossambica*		■	
45. *Scarus sordidus*		■	

the biology and fishery of *Plectorhinchus* spp. (Murage & Mavuti, 2001); aspects of the biology and feeding ecology of the orbiculate cardinal fish, *Sphaeramia orbicularis* (Mees *et al*., 1999), the reef fish, *Scolopsis bimaculatus* (Nzioka, 1981a, 1988); the sailfish, *Istiophorus platypterus* (Williams, 1970); some aspects of the biology and fishery of six genera of groupers (Teleostei: Serranidae), viz. *Anyperodon*, *Cephalopholis*, *Dermatolepis*, *Epinephelus*, *Plectropomus* and *Variola* (Agembe, 2008); and the morphometric relationship and condition factor of *Siganus stellatus*, *S. canaliculatus* and *S. sutor* (Wambiji *et al*., 2008).

The reproductive biology of some fish species has also been covered in several studies, including *Lutjanus fulviflamma* (Kaunda-Arara & Ntiba, 1997), *Lethrinus harak* (Kulmiye, 2002) and *S. sutor* (de Souza, 1988; Ntiba & Jaccarini, 1990, 1992). Other biological studies include the age and growth of *S. sutor* (Ntiba & Jaccarini, 1988), and the growth and survival rates of exploited coral reef fishes: the whitespotted rabbitfish, *S. sutor*, emperors (*Lethrinus* spp.), the orange-striped triggerfish, *Balistapus undulates*, the sky emperor, *Lethrinus mahsena* (Kaunda-Arara & Rose, 2006) and *Scolopsis bimaculatus* (Nzioka, 1988).

Diet

Information on the diets of fish is important in bionomic studies and in investigations of ecosystem energetics (Mavuti *et al*, 2004) and, for example, that of *Sardinella gibbosa* and *Atherinomorous lacunosus* has been elaborated (Nyunja *et al*., 2002). Eight common fish species in Mtwapa Creek, *S. gibbosa*, *Pellona ditchella*, *Spratelloides delicatilus*, *Atherinomorous lacunosus*, *Gerres oyena*, *Secutor insidiator*, *Leiognathus equula*, were shown to consume mostly copepods (Mavuti *et al*., 2004). Their feeding niches overlapped, revealing flexibility in their diets (Mavuti *et al*., 2004). The diets of various juvenile fish in Kenya have been revealed to comprise mainly plankton and benthos (Nyunja & Mavuti, 2001; De Troch, 1998; Wakwabi, 1996).

An investigation of the trophic organisation of the fish fauna in Gazi Bay revealed that they fall into four guilds: omnivores, piscivores, zooplanktivores and benthic carnivores (Wakwabi, 1999). Fourteen fish species abundant in beach seine catches from seagrass beds in the area (*Herklotsichthys quadrimaculatus*, *Stolephorus indicus*, *Atherinomorus duodecimalis*, *Apogon thermalis*, *Fowleria aurita*, *Paramonacanthus barmardi*, *Mulloides flavolineatus*, *Lutjanus fulviflamma*, *L. argentimaculatus*, *Gerres acinaces*, *Bothus myriaster*, *Fistularia commersonii*, *Sphyraena barracuda* and *Plotosus lineatus*) fell into only three trophic guilds: planktivores, benthivores and piscivores, and benthivores were dominant (De Troch, 1998).

Genetics

Molecular genetic techniques offer the ability to identify and delineate fish stock structure where it may not be apparent from phenotypic or behavioural characteristics. However, genetic studies on Kenyan marine fishes have been very limited, focusing mostly on freshwater species (Abila *et al*., 2004). The few genetic studies on marine fishes include the population genetic structure of *Lutjanus fulviflamma* (Dorenbosch *et al*., 2006), in which no clear relationship between genetic distance and geographic distance between populations was found (Dorenbosch *et al*., 2006). This suggests that populations of *Lutjanus fulviflamma* have an open structure and are possibly genetically connected on a larger geographic scale in the western Indian Ocean (Dorenbosch *et al*., 2006). The genetics of coelacanths have also been considered (Okada *et al*., 2007), revealing that the Kenyan coelacanth may be a member of an undiscovered population between Tanzania and Kenya (Okada *et al*., 2007).

Fishing methods and destructive fishing gear

Various types of fishing gear are used to fish along the Kenyan coast. These include longlines, hand-lines, trolling lines, traps (fence and basket), mono- and multi-filament gill nets (mesh size ranging from <63 to >250 mm), seine nets, beach seines, cast nets, trawl nets, ring nets, scoop nets, trammel nets prawn seines, spearguns/harpoons (Fisheries Department, 2012; Mbuga, 1984) and some traditional gear (Mwatha & Orembo 1998; Ochiewo 2004, 2008). The different fishing methods used on the Kenyan coast and the targeted catch are listed in Table 2.

The use of these gear, fishing techniques and destructive gear have been extensively studied by Crabbe and McClanahan (2005), Crona (2006), Cros and McClanahan (2003), Fulanda *et al*. (2009), Glaesel (2000), Kiszka *et al*. (2009), Mangi (2006), Mangi *et al*. (2007), McClanahan (2007), McClanahan *et al*. (1997, 2008,2005), McClanahan and Mangi (2001), McClanahan and Obura (1996), Mwaura *et al*. (2001), Tunje and Hoorweg (2003) and Samoilys (1988). Some of these studies (Glaesel 2000; Mangi 2006; Mangi *et al*., 2007) suggest that high levels of fishing effort coupled with the use of destructive gear types intensify the effects of overfishing.

Despite these studies, more are needed to ascertain the effects of each gear (especially those that are prohibited e.g. spearguns and beach seines which are still used in some areas), as well as the effects of new fishing techniques which need investigation before they are introduced. Management action is also needed based on recommendations proposed in some of the studies such as:

1. The need for enabling and enforcement by managers to achieve high user compliance (McClanahan *et al*. 2005, 2007).
2. Redress of poverty and the issue of phasing out destructive fishing gear use (McClanahan *et al*., 2005)
3. Investment geared towards the previous point should be combined with support for and enhancement of existing local ecological knowledge (Crona, 2006).
4. The provision of credit facilities for fishers to purchase authorized gear and compensation for gear that has been declared illegal, allied with facilitation and strengthening of Fishers' cooperative societies or Community Based Organizations (Mangi *et al*. 2007).

Table 2.Table 2. Fishing methods used on the Kenyan coast and the resources targeted (adapted from Samoilys *et al.*, 2010)

Capture method	Resources targeted
Basket traps	Siganidae, Scaridae, Lethrinidae
Fence traps	Clupeidae, and other shore swimming fish
Handlines/Hook and line	Lethrinidae, Lutjanidae, Serranidae, Carangidae, Scombridae
Trolling	Scombridae, Sphyraenidae, Coryphaenidae, Istiophoridae
Longlining	Scombridae, Carcharhinidae, Xiphiidae, Istiophoridae
Spearguns	Scaridae, Lutjanidae, Serranidae, Siganidae,
Spears and harpoons	Octopoda, Myliobatidae, Muraenidae
Gillnets (stationary)	Carangidae, Scombridae, Belonidae, Hemiramphidae, Lethrinidae, Siganidae, Myliobatidae, Panulirus
Gillnets (drifting)	Carcharhinidae, Scombridae,
Monofilament gillnets	Hemiramphidae, Mugilidae
Ringnets	Carangidae, Scombridae, Sphyraenidae, Lutjanidae, Clupeidae, Engraulidae
Prawn seines	Penaeid prawns
Cast nets	Clupeidae, Engraulidae, Gerreidae, Penaeid prawns
Beach seines	Scaridae, Siganidae, Lethrinidae, Atherinidae, Hemiramphidae
Reef seines	Scaridae, Siganidae, Lethrinidae, Atherinidae, Hemiramphidae
Scoopnets/handnets	Mugilidae, Clupeidae, Penaeid, Panulirus
Mosquito nets	Clupeidae, Engraulidae, Labridae, Lethrinidae, Lutjanidae
Trawling	Penaeid prawns

5. The inclusion of local fishermen in decision making on fisheries management and the provision of information on the benefits of appropriate conservation and management that result in higher fish yields (Tunje & Hoorweg, 2003).

Impacts of fishing

The effects of fishing relative to levels of protection and substratum complexity have been investigated on coral reef lagoon fish (McClanahan, 1994a, 1997a; McClanahan *et al.*, 1999b; Watson & Ormond, 1994), as well as the effects of fishing and overfishing, mainly on reef fishes (Jennings & Polunin, 1996; McClanahan, 1995a; McClanahan *et al.*, 1994; Watson & Ormond, 1994), and the factors that influence fish catches on Kenya's coral reefs (Mangi & Roberts, 2007). Several factors, including levels of fishing, protection from fishing and characteristics of reef habitat, were examined to determine the effect of these factors on the ecology of fish communities (McClanahan & Arthur, 2001). The number of fishers and live coral cover proved to be the strongest factors that determine total catches (Mangi & Roberts, 2007). The findings also showed that heavy fishing results in increased sea urchin abundance and algal turf cover, and reduced hard coral and coralline algal cover (McClanahan & Arthur, 2001). Furthermore, protected areas had greater species richness and higher abundances of some commercially important fish (ibid.).

Goñi (1998) provided an overview of the wide ecosystem effects of fishing, and the potential direct and indirect effects of the main fisheries of the world. The consequences of fishing on reef areas are reductions in coral cover, habitat and refuge for both fish and their food, and reef productivity (McClanahan, 1996). The study revealed the need for protected areas, as well as the areas that need protection, with continuous monitoring, to improve fish yields. Changes in fish populations affect reefs, since fish play important roles in reef ecology, and overfished reefs have fewer fish that are smaller. Areas which have become degraded may require restoration to achieve recovery but there have been few studies on the recovery of fish populations from heavy fishing (e.g. McClanahan, 1997b).

Habitat degradation

Loss of biodiversity, habitat degradation and the modification of mangrove and coral reef ecosystems have been identified as major concerns in Kenyan coastal areas. Anthropogenic pressures arise from overfishing and fishing-related damage, urbanization and tourism development, agriculture and industry, and damming for hydropower (Matlock, 2008). These activities alter and destroy coastal habitats with implications for marine fisheries (Brakel, 1981). Marine habitats are also damaged by natural catastrophes but, if this happens, they almost always recover (Palumbi *et al*., 2008). However, anthropogenic impacts are often the cause of permanent damage (Palumbi *et al*., 2008). Regulation of development in coastal areas and in habitat use plays an important role in the protection of fish spawning and breeding areas, their nursery grounds, and refugia (Bilkovic & Roggero, 2008). A clean environment is also important for a healthy fishery (Government of Kenya, 2009). An integrated approach to management is necessary to introduce improvements in the system with minimal and gradual changes to the activities of the human users (Government of Kenya, 2009).

Pollution

The marine environment in East Africa does not seem to be severely polluted and may be considered 'clean' when compared with the seas receiving wastes from more industrialized societies (Bliss-Guest, 1983). However, other studies have concluded that East African coral reefs are presently heavily used by fishermen and tourists, and that they experience pollution (McClanahan & Obura, 1996). Several sectors contribute to this pollution in Kenya, including coastal development, agriculture, processing industries, mining, transportation and energy (Government of Kenya, 2009). Oil spills from shipping accidents and hazardous waste from petroleum refineries and shipping activities also pose threats to the coastal and marine environment (Government of Kenya, 2009). Studies on heavy metal distribution and enrichment in Port Reitz Creek, Mombasa (Kamau, 2002) showed that fluvial input to it introduced Cd, Cu, Fe and Zn, but some Cd and Zn were also of anthropogenic origin. Other surveys have been conducted on heavy metal pollutants in sediments and fish in Port Reitz, Mtwapa and Shirazi (Muohi *et al*., 2001), and on Cd and Pb in water, sediments and selected fish species in Mombasa (Mwashote, 2002). These revealed that the levels of Pb and Cd were elevated in sediments and in some fish species, especially during the rainy season, but were generally within acceptable limits according to the FAO standards in the fish species that were analysed (Mwashote, 2002).

Such pollution studies are important in identifying hot spots and areas prone to pollution. They are important in fisheries management, especially when considering that the fish resources are harvested for human consumption, some for export.

Marine Protected Areas

Various studies related to fisheries have been conducted in Kenyan Marine Protected Areas (MPAs). They have focused largely on the role of the MPAs in enhancing local fisheries through the emigration or spill-over of recruits, the recovery of reef fish populations, and comparisons between protected and unprotected areas (Cros & McClanahan, 2003; Eklöf1 *et al*., 2009; Kaunda-Arara *et al*., 2009; McClanahan, 2007, 2008b; McClanahan *et al*., 1999b 2002b, 2006, 2007; McClanahan & Arthur, 2001; McClanahan & Graham, 2005; McClanahan & Kaunda-Arara 1996; McClanahan & Mangi, 2000, 2001; McClanahan & Shaffir, 1990; Mwatha & Orembo, 1998; Munga *et al*., 2010; Rodwell *et al*., 2003; Watson *et al*., 1997; Watson & Ormond, 1994).

Results of this research suggest that MPAs provide refugia for fish (Rodwell *et al*., 2003) and potentially protect and increase fish stocks for spawning, leading to the aforementioned spill-over. For example, the Mombasa MPA increased the catch per unit effort and per unit area adjacent to the park, decreased variation in the catches, and provided some spill-over of adults to the adjacent fishing ground (McClanahan & Kaunda-Arara 1996; McClanahan & Mangi, 2000). The catch per fisher increased by up to 75% (McClanahan & Mangi, 2000) and unfished sites had up to ten times more fish than fished areas (Watson & Ormond, 1994) . However, it was suggested that reserves needed to be older than ten years before they sustained the full diversity of fishes (McClanahan & Arthur, 2001).

Threatened species

The Kenyan coast, being rich in biodiversity, has some fish resources that have become threatened, including species such as the whale shark. Conservation efforts and studies on the distribution and abundance of the latter were undertaken by the East African Whale Shark Trust in Kenya (Bassen, 2007). Rare fish such as the coelacanth may also be threatened. An inventory of all known specimens of *Latimeria chalumnae* has thus been compiled (Bruton & Coutouvidis, 1991), as well as a bibliography (Bruton *et al*., 1991), but the first specimen was only captured in Kenya in 2001 (De Vos and Oyugi, 2002). The genetic variation between individuals from different locations was studied to determine relatedness among east African coelacanths, and it was shown that this is unexpectedly low (Schartl *et al*., 2005). There has been little research on threatened species beyond this and more studies are needed.

Management

Open-access fishing has been practiced since time immemorial in Kenya and is currently causing excessive fishing effort. The Kenyan fisheries and their management have been described by various authors, with management proposals aimed at maximizing fish production at a sustainable level, a reduction in post-harvest losses and support for local fisheries management (Allela, 1984; Barabara *et al*., 2008; Brakel, 1981; Crabbe & McClanahan, 2005; Gitonga & Achoki, 2003; Mangi, 2006; McClanahan *et al*., 1997, 1999, 2006, 2008, 2009; Munywoki *et al*., 2008; Omondi, 1995; Oluoch & Obura, 2008; Samoilys, 1988; SWIOFC, 2006). Some of the strategies and proposals for sustainable management of the fish resources in Kenya include collaborative fisheries management (Gitonga & Achoki, 2003) coupled with large, permanent closed areas to sustain ecosystem function and the associated fisheries, and protect sensitive species from overfishing (McClanahan *et al*. 2006).

DISCUSSION

This review covers the period from 1960 to 2009. Several regional and national projects were undertaken subsequent to this period or were ongoing at the time of writing, e.g. the South West Indian Ocean Fisheries Project (SWIOFP) and Kenya Coastal Development Project (KCDP); these have further addressed fisheries-related issues. While it is possible that more studies have been undertaken than those reviewed here, this article nevertheless provides a general picture of the status of Kenyan fisheries research.

Regular frame and fish surveys are proving important in tracking changes in the Kenyan marine fisheries and providing indicators for management actions and options. Changes in fishing gear and fishing areas are being tracked through these surveys, matters crucial for the management of the fisheries. Studies on fish yields have focused on different areas of the Kenyan coast, reporting varying yields depending on area, season and fishing pressure. It must be noted that estimates of Maximum Sustainable Yield (MSY) are lacking, even though they are important in fisheries management as they provide a means of establishing sustainable targets (Garcia *et al*., 1989). Fish catch rates according to boat and gear categories, often combined with data on fish size at capture, permit a large number of analyses related to gear selectivity, provide indices of exploitation and monitor economic efficiency (Stamatopoulos, 2002), all these being important indicators of fisheries management.

It is important that research plays a role in informing management regarding the various strategies for the management of marine resources. Different departments are involved in fisheries planning and management (e.g. fishing, tourism, MPAs, the port and maritime authorities, development) and need to liaise in accomplishing their task. Changes in management should be done in a manner that results in improvements to the system with minimal or gradual changes in the activities of the human users. These changes in management involve the temporal and spatial regulation of fishing, using different fishing gear and, possibly, the provision of alternatives to fishing. Such changes should increase the economic returns from fishing without damaging the ecosystem. In this regard, co-management would give people more control over their resources for a more secure living (Barabara *et al*., 2008), an approach that needs to be strengthened on the Kenyan coast. It is also essential that fisheries managers plan for change in today's rapidly changing environment rather than attempt to regulate or prevent such change.

Studies on fish species diversity, community structure and general biology have been conducted in a number of areas along the Kenyan coast, but only on a fraction of the number of marine species (736) reported in FishBase. Investigations of fish diets are also needed to understand the trophic dynamics and fisheries interactions in the ecosystem. Only one study has been undertaken on homing behaviour (Kaunda-Arara & Rose, 2003), even though such research is important to determine the likelihood of sustaining locally reproducing populations to restock adjacent areas (Kaunda-Arara & Rose, 2003); in addition such studies can be used to guide management on areas in need of protection.

Some studies have been conducted on destructive fishing gear (Crabbe & McClanahan, 2005; Crona, 2006; Cros & McClanahan, 2003; Fulanda *et al*., 2009; Glaesel, 2000; Kiszka *et al*., 2009; Mangi, 2006; Mangi *et al*., 2007; McClanahan, 2007; McClanahan *et al*., 1997, 2008, 2005; McClanahan & Mangi, 2001; McClanahan & Obura, 1996; Mwaura *et al*., 2001; Tunje & Hoorweg, 2003; Samoilys, 1988), but more studies are needed to ascertain the deleterious effects of each type of gear. Overfishing and overexploitation and the effects these have on local communities and the ecosystem have been reported in several areas (e.g. Hoorweg *et al*. 2009; McClanahan, 1994b; McClanahan *et al*., 2000; Mörk *et al*., 2009) and reveal the need for protected areas. The latter can vary from zonation to integrated management or closure to promote sustainability and health in the protected ecosystems. They are important in achieving sustainability in fisheries, since they allow enough fish to grow to maturity and produce larvae that will recruit to areas outside the MPAs. They also provide baseline information on what an unfished area should be like, and demonstrate the fishery benefits of MPAs to local communities. While they provide a useful management option, they should not be used in isolation (Jan *et al*., 2008; Munga *et al*., 2010); local communities must be included in the planning, design, establishment and management of MPAs to improve their likelihood of success in the long term (Munga *et al*., 2010; Tunje & Hoorweg, 2003).

In conclusion, most of the research reviewed here focused on specific habitats, sites or species and therefore did not cover the whole Kenyan coast. Many studies were undertaken in inshore areas and offshore studies were very few. There is evidence to suggest that overexploitation and destructive fishing have led to a decline in Kenyan marine fisheries and, in some cases, habitat degradation, especially of coral reefs. Innovative methods, incorporating the use of biomarkers, population genetics, acoustic telemetry, underwater videography and high-resolution sonic recordings, will open up opportunities to test new hypotheses on the fish resources in Kenya and in the Western Indian Ocean region. However, such research is limited in Kenya by inadequate financial and technological resources as well as expertise, and efforts must be made to meet these shortfalls.

Acknowledgements – We wish to acknowledge the Kenya Marine and Fisheries Research Institute (KMFRI) and the staff of the KMFRI Library, in particular Mr. Elijah Mokaya, Mr. Michael Mosoti, Mr. Isedorius Agolla and Mr. James Macharia, for assisting in searching for and locating the relevant documents. We thank the Fisheries Department of Kenya for making the necessary information available. We also thank the Chief Editor of Western Indian Ocean Journal of Marine Science, Professor Michael Schleyer, for comments on and improvements in this review.

References

Abila R, Barluenga M, Engelken J, Meyer A, Salzburger W (2004) Population-structure and genetic diversity in a haplochromine fish cichlid of a satellite lake of Lake Victoria. Molecular Ecology 13: 2589–2602

Agembe SW (2008) Some aspects of the biology and fishery of groupers (Teleostei: Serranidae) in the inshore waters of south coast, Kenya. MSc Thesis. Moi University, Kenya, 69 pp

Allela SO (1984) An overview of fisheries management, research and development. Aquatica Bulletin 1: 18-22

Barabara M, Nuguti S, Ndoro C (2008) Fisheries co-management through establishment of Beach Management Units Along the Kenyan Coast. Samaki News 5: 33-34

Bassen V (2007) Conservation efforts of the East African Whale Shark Trust in Kenya. In: Irvine TR, Keesing JK (eds) The First International Whale Shark Conference: Promoting International Collaboration in Whale Shark Conservation, Science and Management. Conference Overview, Abstracts and Supplementary Proceedings, pp 20-22. (Available at http://www.srfme.com.au/documents/1stInterWhaleSharkconf.pdf#page=36) Date accessed: 8 August 2011

Bilkovic DM, Roggero MM (2008) Effects of coastal development on nearshore estuarine nekton communities Marine Ecology Progress Series 358: 27–39

Bliss-Guest P (1983) Environmental stress in the East African region. Ambio, 12: 290-295

Bock, KR (1972) Preliminary checklist of lagoonal fishes of Diani, Kenya. Journal of the East Africa Natural History Society and National Museum 137: 1-6

Bock, KR (1975) Preliminary checklist of the fishes of the South Bank, Kilifi Creek, Kenya. Journal of the East Africa Natural History Society and National Museum 148: 1-6

Botsford LW, Castilla JC, Peterson CH (1997) The management of fisheries and marine ecosystems. Science 277: 509 – 515

Brakel WH (1981) Alteration and destruction of coastal habitats: Implications for marine fisheries. Proceedings of a Workshop on Aquatic Resources of Kenya, July 13-19, 1981. Kenya Marine and Fisheries Research Institute and Kenya National Academy for Advancement of Arts and Science, pp 247-255

Bruton MN, Coutouvidis SE (1991) An inventory of all known specimens of the coelacanth *Latimeria chalumnae*, with comments on trends in the catches. Environmental Biology of Fishes 32: 371-390

Bruton MN, Coutouvidis SE, Pote J (1991) Bibliography of the living coelacanth *Latimeria chalumnae*, with comments on publication trends. Environmental Biology of Fishes 32: 403-433

Crabbe M, McClanahan TR (2005) A Biosocioeconomic evaluation of shipwrecks used for fishery and dive tourism enhancement in Kenya. Western Indian Ocean Journal of Marine Science 5: 35-53.

Crona BI (2006) Supporting and enhancing development of heterogeneous ecological knowledge among resource users in a Kenyan seascape. Ecology and Society.11:32 (Available at http://www.ecologyandsociety.org/vol11/iss1/art32/) Date accessed: 18 August 2011

Crona BI, Rönnbäck P (2007) Community structure and temporal variability of juvenile fish assemblages in natural and replanted mangroves, *Sonneratia alba* Sm., of Gazi Bay, Kenya. Estuarine, Coastal and Shelf Science 74: 44–52

Cros A, McClanahan T (2003) Coral transplant damage under various management conditions in the Mombasa Marine National Park, Kenya. Western Indian Ocean Journal of Marine Science 2: 127-136

Dorenbosch M, Pollux BJA, Pustjens AZ, Rajagopal S, Nagelkerken I, van der Velde G, Moon- van der Staay SY (2006) Population structure of the dory snapper, *Lutjanus fulviflamma*, in the western Indian Ocean revealed by means of AFLP fingerprinting. Hydrobiologia 568: 43-53

de Souza T (1986) Summary of fisheries and resources information for Kenya. In: Sanders MJ, Sparre P, Venema SC (eds) Proceedings of the workshop on the assessment of the fishery resources in the Southwest Indian Ocean. FAO/UNDP: RAF/79/065/WP/41/88/E.

de Souza TF (1988) Reproduction, length-weight relationship and condition factor in *Siganus sutor* (Valenciennes, 1835) (Pisces: Siganidae) from the Kenyan waters of the western Indian Ocean. Kenya Journal of Science Series (B) 9: 89-101

De Troch M, Mees J, Wakwabi E (1998) Diets of abundant fishes from beach seine catches in seagrass beds of a tropical Bay (Gazi Bay, Kenya). Belgian Journal of Zoology 128: 135-154

De Vos L and Oyugi D (2002) First capture of a coelacanth, *Latimeria chalumnae* Smith, 1939 (Pisces: Latimeriidae), off Kenya. South African Journal of Science 98: 7-8

Eklöf1 JS, Fröcklin S, Lindvall A, Stadlinger N, Kimanthi A, Uku JN, McClanahan TR (2009) How effective are MPAs? Predation control and 'spill-in effects' in seagrass–coral reef lagoons under contrasting fishery management. Marine Ecology Progress Series 384: 83–96

Fisheries Department (2012) Marine waters fishery frame survey 2012. Frame Survey 2012 Report, 85 pp

Fratini S, Vannini M (2002) Genetic differentiation in the mud crab *Scylla serrata* (Decapoda: Portunidae) within the Indian Ocean. Journal of Experimental Marine Biology and Ecology 272: 103-116

Fulanda BM, Motong'wa H (2001) Bottom shrimp trawling in Malindi: A preliminary survey of its impact on the artisanal fishery. 2nd Western Indian Ocean Marine Science Association (WIOMSA) Scientific Symposium Dar es Salaam, Tanzania, 22-25 October, 2001, Book of Abstracts, p 37

Fulanda B (2003) Shrimp trawling in Ungwana Bay: A threat to fishery resources. Recent Advances in Coastal Ecology: Studies from Kenya 70: 233-242

Fulanda B, Munga C, Ohtomi J, Osore M, Mugo R, Hossain MY (2009) The structure and evolution of the coastal migrant fishery of Kenya. Ocean & Coastal Management 52: 459-466

Garcia S, Sparre P, Csirke J. (1989) Estimating surplus production and maximum sustainable yield from biomass data when catch and effort time series are not available. Fisheries Research 8: 13–23

Gitonga NK, Achoki R (2003) Fiscal reforms for Kenya fisheries. Paper prepared for FAO Workshop on Fiscal Reforms for Fisheries (Rome, Italy: 13-15 October 2003) (Available at http://www.fao.org/docrep/007/y5718e/y5718e04.htm) Date accessed: 31 July 2011

Glaesel H (2000) State and local resistance to the expansion of two environmentally harmful marine fishing techniques in Kenya. Society and Natural Resources 13: 321-338

Government of Kenya (2009) State of the coast report: Towards integrated management of coastal and marine resources in Kenya. National Environment Management Authority (NEMA), Nairobi, 88 pp

Goñi, R (1998) Ecosystem effects of marine fisheries: An overview. Ocean and Coastal Management 40: 37-64

Hemphill S (1995) The ecology and exploitation of yellowfin tuna, *Thunnus albacares* (Bonnaterre 1788) in the Pemba Channel, Kenya. PhD thesis. University of Wales, 269 pp

Hoorweg J, Versleijen N, Wangila B, Degen A (2009) Income diversification and fishing practices among artisanal fishers on the Malindi-Kilifi coast. In Hoorweg J, Muthiga N (eds) Advances in Coastal Ecology 20: 43-59

Huxham M, Kimani E, Augley J (2008) The fish community of an East African mangrove: Effects of turbidity and distance from the sea. Western Indian Ocean Journal of Marine Science 7:57-67

Iversen SA (1984) Kenyan marine fish resources in waters deeper than 10 m investigated by R/V "Dr. Fridtjof Nansen" In: Iversen SA, Myklevoll S (eds) The proceedings of the Norad-Kenya seminar to review the marine fish stocks and fisheries in Kenya. Mombasa, Kenya, 13–15 March 1984, 210 pp

Iversen SA, Myklevoll S (eds) (1984) The proceedings of the Norad-Kenya seminar to review the marine fish stocks and fisheries in Kenya. Mombasa, Kenya, 13–15 March 1984, 210 pp

Jan R, Melita S, Kimani P (2008) Reef fish spawning aggregations in the Western Indian Ocean: Current knowledge and implications for management. In: Obura DO, Tamelander J, Linden O (eds) Ten years after bleaching – facing the consequences of climate change in the Indian Ocean. Cordio Status Report 2008. CORDIO (Coastal Oceans Research and Development in the Indian Ocean)/ Sida-Sarec. Mombasa, Kenya, pp 263-276

Jennings S, Polunin NVC (1996) Impacts of fishing on tropical reef fishes. Ambio 25: 44-49

Kamau JN (2002) Heavy metal distribution and enrichment at Port-Reitz Creek, Mombasa. Western Indian Ocean Journal of Marine Science 1: 65-70

Kamau EC, Wamukota A, Muthiga N (2009) Promotion and management of marine fisheries in Kenya. In: Winter G. Towards sustainable fisheries law: A comparative analysis. IUCN Environmental Policy and Law Paper 74: 83-133

Kaunda-Arara B, Ntiba MJ (1997) The reproductive biology of *Lutjanus fulviflamma* (Forsskål, 1775) (Pisces: Lutjanidae) in Kenyan inshore marine waters. Hydrobiologia 353: 153-160

Kaunda-Arara B, Rose GA, Muchiri MS, Kaka R (2003) Long-term trends in coral reef fish yields and exploitation rates of commercial species from coastal Kenya. Western Indian Ocean Journal of Marine Science 2: 105-122

Kaunda-Arara B, Rose GA (2003) Homing and site fidelity in the greasy grouper *Epinephelus tauvina* (Serranidae) within a marine protected area in coastal Kenya. Marine Ecology Progress Series 277: 245-251

Kaunda Arara B, Rose GA (2004) Effects of marine reef national parks on fishery CPUE in coastal Kenya. Biological Conservation 118: 1-13

Kaunda-Arara B, Rose GA (2006) Growth and survival rates of exploited coral reef fishes in Kenyan marine parks derived from tagging and length frequency data. Western Indian Ocean Journal of Marine Science 5: 17-26

Kaunda-Arara B, Mwaluma JM, Locham GA, Øresland V, Osore MK (2009) Temporal variability in fish larval supply to Malindi Marine Park, coastal Kenya. Aquatic Conservation: Marine and Freshwater Ecosystems 19: S10–S18

Kimani EN, Mwatha GK, Wakwabi EO, Ntiba JM, Okoth BK (1996) Fishes of a shallow tropical mangrove estuary, Gazi, Kenya. Marine and Freshwater Research 47: 857-868

Kiszka J, Muir C, Poonian C, Cox TM, Amir OA, Bourjea J, Razafindrakoto Y, Wambiji N, Bristol N (2009) Marine mammal by-catch in the southwest Indian ocean: Review and need for a comprehensive status assessment. Western Indian Ocean Journal of Marine Science 7: 119–136

Kulmiye AJ (2002) Some Aspects of the reproductive biology of the thumbprint emperor, Lethrinus harak (Forsskal, 1775), in Kenyan coastal waters. Western Indian Ocean Journal of Marine Science 1: 135-144

Little MC Reay PJ, Grove SJ (1988) The fish community of an East African mangrove creek. Journal of Fish Biology 32: 729-747

Maina GW, Obura D, Alidina H, Munywoki B (2008a) Increasing catch in an over-exploited reef fishery: Diani-Chale, Kenya, from 1998 to 2006. In: Obura DO, Tamelander J, Linden O (ed) Ten years after bleaching – facing the consequences of climate change in the Indian Ocean. Cordio Status Report 2008. CORDIO (Coastal Oceans Research and Development in the Indian Ocean)/ Sida-Sarec. Mombasa, Kenya, pp 309-320

Maina GW, Obura D, Alidina HM (2008b) The importance of fish catch data in investigating reef fish spawning aggregations. Samaki News 5: 13-14

Martin BE (1973) The History of Malindi. A geographical analysis of an East African coastal town from the Portuguese period to present. East African Literature Bureau, 301 pp

Mangi SC (2006) Gear management in Kenya's coastal fisheries. PhD Thesis. University of York, 255 pp

Mangi SC, Roberts CM (2007) Factors influencing fish catch levels on Kenya's coral reefs. Fisheries Management and Ecology 14: 245 – 253

Mangi SC, CM Roberts, LD Rodwell (2007) Reef fisheries management in Kenya: Preliminary approach using the driver–pressure–state–impacts–response (DPSIR) scheme of indicators. Ocean and Coastal Management 50: 463-480

Matlock M (2008) East Africa and coastal and marine environment. Cleveland CJ (ed) Encyclopedia of Earth. (Available at http://www.eoearth.org/view/article/51cbed747896bb431f6924b3/) Date accessed: August 2011

Mavuti KM, Nyunja JA, Wakwabi EO (2004) Trophic ecology of some common juvenile fish species in Mtwapa creek, Kenya. Western Indian Ocean Journal of Marine Science 3: 179-187

Mbuga JS (1984) Fishing gears of the Kenya marine waters. In: Iversen SA, Myklevoll S (eds) The proceedings of the Norad-Kenya seminar to review the marine fish stocks and fisheries in Kenya. Mombasa, Kenya, 13–15 March 1984, 210 pp

McClanahan TR and Muthiga NA (1988) Changes in Kenyan coral reef community structure and function due to exploitation. Hydrobiologia 166: 269-276

McClanahan TR and Shaffir SH (1990) Causes and consequences of sea urchin abundance and diversity in Kenyan coral reef lagoons. Oecologia 83: 362-370

McClanahan TR (1994a) Kenyan coral reef lagoon fish: effects of fishing, substrate complexity and sea urchins. Coral Reefs 13: 189-194

McClanahan TR (1994b) Fish critical to coral reefs. Wildlife Conservation 100: 8

McClanahan TR, Nugues M, Mwachireya S (1994) Fish and sea urchin herbivory and competition in Kenyan coral reef lagoons: The role of reef management. Journal of Experimental Marine Biology and Ecology 184: 237-254

McClanahan TR (1995a) A coral reef ecosystem-fisheries model: Impacts of fishing intensity and catch selection on reef structure and processes. Ecological Modelling 80: 1-19

McClanahan TR (1995b) Fish predators and scavengers of the sea urchin *Echinometra mathaei* in Kenyan coral-reef marine parks. Environmental Biology of Fishes 43: 187-193

McClanahan TR, Obura DO (1996) Coral reefs and near shore fisheries. In: McClanahan TR and Young TP (eds) East African ecosystems and their conservation. New York, Oxford University Press, pp 67-99

McClanahan TR, Kaunda-Arara B (1996) Fishery recovery in a coral-reef marine park and its effect on the adjacent fishery. Conservation Biology 10: 1187-1199

McClanahan TR, Kamakuru AT, Muthiga NA, Yebio MG, Obura D (1996) Coral reef restoration: Effect of sea urchin reductions on algae, coral and fish assemblages. Conservation Biology 10: 136-154

McClanahan TR (1997a) Effects of fishing on East African coral reefs. Proceedings of the 8th International Coral Reef Symposium 2: 1533-1538

McClanahan TR (1997b) Recovery of fish populations from heavy fishing: Does time heal all? Proceedings of the 8th International Coral Reef Symposium 2: 2033-2038

McClanahan TR, Glaesel H, Rubensand J, Kiambo R (1997) The effects of traditional fisheries management on fisheries yields and the coral-reef ecosystems of southern Kenya. Environmental Conservation 24: 105-120

McClanahan, TR Hendrick, V Rodrigues, MJ Polunin, NVC (1999a) Varying responses of herbivorous and invertebrate-feeding fishes to macroalgal reduction on a coral reef. Coral Reefs 18: 195-203

McClanahan TR, Muthiga NA, Kamukuru AT, Machano H, Kiambo R (1999b) The effect of fishing and marine protected areas on the coral reefs of northern Tanzania. Biological Conservation 89: 161-182

McClanahan TR, Mangi S (2000) Spillover of exploitable fishes from a marine park and its effect on the adjacent fishery. Ecological Applications 10: 1792-1805

McClanahan TR, Arthur R, Kaunda-Arara B, Kiambo R, Machano H, Mangi S, Muthiga N and Rodriques M (2000) Sea urchin reduction as a restoration technique in a new marine park. Proceedings of the 9th International Coral Reef Symposium 2: 947-954

McClanahan TR and Arthur R (2001) The effect of marine reserves and habitat on populations of East African coral reef fishes. Ecological Applications 11: 559-569

McClanahan TR and Mangi S (2001) The effect of closed area and beach seine exclusion on coral reef fish catches. Fisheries Management and Ecology 8:107-121

McClanahan TR, Maina J, Pet-Soede L (2002a) Effects of the 1998 coral mortality event on Kenyan coral reefs and fisheries. Ambio 31: 543–550

McClanahan TR, Uku JN, Machano H (2002b) Effect of macroalgal reduction on coral-reef fish in the Watamu Marine National Park, Kenya. Marine and Freshwater Research 53: 223 – 231

McClanahan TR, Maina J, Davies J (2005) Perceptions of resource users and managers towards fisheries management options in Kenyan coral reefs. Fisheries Management and Ecology 12: 105 – 112

McClanahan TR, Graham NAJ (2005) Recovery trajectories of coral reef fish assemblages within Kenyan marine protected areas. Marine Ecology Progress Series 294: 241–248

McClanahan TR, Verheij E, Maina J (2006) Comparing the management effectiveness of a marine park and a multiple-use collaborative fisheries management area in East Africa. Aquatic Conservation: Marine and Freshwater Ecosystems 16: 147–165

McClanahan TR (2007) Management of area and gear in Kenyan coral reefs. In: McClanahan TR, Castilla JC (eds) Fisheries management: Progress towards sustainability. Blackwell Publishers, Oxford, pp 166-185

McClanahan TR (2008a) Establishing sustainable targets for Kenyan coral reef fisheries. Samaki News 5: 11-12

McClanahan TR (2008b) Response of the coral reef benthos and herbivory to fishery closure management and the 1998 ENSO disturbance. Oecologia 155: 169-177

McClanahan TR, Hicks CC, Darling ES (2008) Malthusian overfishing and efforts to overcome it on Kenyan coral reefs. Ecological Applications 18: 1516-1529

McClanahan TR, Castilla JC, Alan T, White A, Defeo O (2009) Healing small-scale fisheries by facilitating complex socio-ecological systems. Reviews in Fish Biology and Fisheries 19: 33–47

McClanahan TR and Hicks CC (2011) Changes in life history and ecological characteristics of coral reef fish catch composition with increasing fishery management. Fisheries Management and Ecology 18: 50–60

Mees J, Mwamsojo GU, Wakwabi EO (1999) Aspects of biology and feeding ecology of the orbiculate cardinal fish *Sphaeramia orbicularis* (Cuvier, 1828) (Teleostei: Apogonidae) in a Kenyan mangrove forest. Biology Jaarb Dodonaea 66: 134-145

Mörk E, Sjöö GL, Kautsky N and McClanahan TR (2009) Top–down and bottom–up regulation of macroalgal community structure on a Kenyan reef. Estuarine, Coastal and Shelf Science 84: 331-336

Munga CN, Mwangi S, Ong'anda H, Ruwa R, Manyala J, Groeneveld JC, Kimani, E, Vanreusel, A (2013) Species composition, distribution patterns and population structure of penaeid shrimps in Malindi-Ungwana Bay, Kenya, based on experimental bottom trawl surveys. Fisheries Research 147: 93 – 102

Munga C, Ndegwa S, Fulanda B, Manyala J, Kimani E, Ohtomi J, Vanreusel A (2012) Bottom shrimp trawling impacts on species distribution and fishery dynamics: Ungwana Bay fishery Kenya before and after the 2006 trawl ban. Fisheries Science 78: 209-219

Munga CN, Mohamed OSM, Obura DO, Vanreusel A, Dahdouh-Guebas F (2010) Resource users' perceptions on continued existence of the Mombasa Marine Park and Reserve, Kenya. Western Indian Ocean Journal of Marine Science 9: 213-225

Munywoki B, Obura D, Maina GW (2008) Development of a web-based geographic information system as a decision tool to support fisheries science and management: A case study of Diani-Chale, Kenya. In: Obura DO, Tamelander J, Linden O (eds) Ten years after bleaching – facing the consequences of climate change in the Indian Ocean. Cordio Status Report 2008. CORDIO (Coastal Oceans Research and Development in the Indian Ocean)/ Sida-Sarec. Mombasa, pp 345-351

Muohi A, Onyari J, Mavuti KM, Omondi JM (2001) Occurrence of heavy metal pollutants in sediments and fish in Port Reitz, Mtwapa and Shirazi marine tidal creeks along the Kenyan coast. 2nd Western Indian Ocean Marine Science Association (WIOMSA) Scientific Symposium Dar es Salaam, Tanzania, 22-25 October 2001, Book of Abstracts p 68

Murage DL, Mavuti KM (2001) The biology and fishery of the *Plectorhinchus* spp. along the Kenyan marine inshore waters. 2nd Western Indian Ocean Marine Science Association (WIOMSA) Scientific Symposium Dar es Salaam, Tanzania, 22-25 October 2001, Book of Abstracts pp 43-44

Mwashote BM (2002) Levels of cadmium and lead in water, sediments and selected fish species in Mombasa, Kenya. Western Indian Ocean Journal of Marine Science 1: 25-34

Mwatha GK, Orembo B (1998). The fishery in Mida creek. In: Mwatha GK , Fondo E, Uku J, Kitheka JU (eds) Biodiversity of Mida Creek: Final Technical Report pp 114-134

Mwaura JM, Wanyonyi I, Obura D (2001) Reef fisheries status and site use by fishermen in Diani, Kenya. 2nd Western Indian Ocean Marine Science Association (WIOMSA) Scientific Symposium, Dar es Salaam, Tanzania, 22-25 October 2001, Book of Abstracts pp 47-48

Ngoile MAK, Linden O (1997) Lessons learned from Eastern Africa: The development of policy on ICZM at national and regional levels. Ocean and Coastal Management 37: 295-318

Ntiba MJ, Jaccarini V (1988) Age and growth parameters of *Siganus sutor* in Kenyan marine inshore water, derived from numbers of otolith microbands and fish lengths. Journal of Fish Biology 33: 465-470

Ntiba MJ, Jaccarini V (1990) Gonad maturation and spawning times of *Siganus sutor* off the Kenya coast: Evidence for definite spawning seasons in a tropical fish. Journal of Fish Biology 37: 315-325

Ntiba MJ, Jaccarini V (1992) The effect of oocytic atresia on fecundity estimates of the rabbit fish Siganus sutor (Pisces: Siganidae) of Kenyan marine inshore waters. Hydrobiologia 247: 215-222

Nyunja JA, Mavuti KM (2001) Trophic ecology of juvenile planktivorous fishes in Tonneswapa Creek and Wasini Channel of the Kenyan coast. 2nd Western Indian Ocean Marine Science Association (WIOMSA) Scientific Symposium, Book of Abstracts p 33

Nyunja JA, Mavuti KM, Wakwabi E (2002) Trophic Ecology of *Sardinella gibbosa* (Pisces: Clupeidae) and *Atherinomorous lacunosus* (Pisces: Atherinidae) in Mtwapa Creek and Wasini Channel, Kenya. Western Indian Ocean Journal of Marine Science 1: 181-189

Nzioka, RM (1979) Observations on the spawning seasons of East African reef fishes. Journal of Fish Biology 14: 329-342

Nzioka RM (1981a) Biology and fishery of the reef fish *Scolopsis bimaculatus* Ruppel in Kenya. MSc thesis, University of Nairobi, 109 pp

Nzioka RM (1981b) Observations on the spawning seasons of East African reef fishes. Journal of Fish Biology 14: 329-342

Nzioka RM (1988) Aspects of the biology of the reef fish *Scolopsis bimaculatus* (Ruppel 1828) in Kenya: Age and growth studies. Kenya Journal of Science and Technology Series B 11: 8-14

Nzioka RM (1990) Fish yield of Kilifi coral reef in Kenya. Hydrobiologia 208: 81-84

Ochiewo J (2004) Changing fisheries practices and their socioeconomic implications in South Coast Kenya. Ocean and Coastal Management 47: 389- 408

Ochiewo J (2008) Socio-economic aspects of the Kenyan marine fisheries. Samaki News 5: 37-41

Oduor BW (1984) Status of fish catches and landings in Kenya. In: Iversen SA, Myklevoll S (eds) The proceedings of the Norad-Kenya seminar to review the marine fish stocks and fisheries in Kenya. Mombasa, Kenya, 13–15 March 1984, 210 pp

Okada N, Sasaki T, Bwathondi POJ, Ngatunga BP (2007) Population genetic analysis of western Indian coelacanths based on mitochondrial DNA. Pioneering Studies on Coelacanth, Part III: 45-47

Okemwa G, Kimani E, Fondo E, Wambiji N (2008) Spatial trends in Kenya's coastal Inshore artisanal fisheries. KMFRI Fisheries Program Technical Report 2008, 37 pp

Okemwa GM, Fulanda B, Kimani EN, Ochiewo J (2009) Exploitation of marine aquarium reef fisheries at the Kenyan Coast. In: Hoorweg J, Muthiga N (eds) Advances in Coastal Ecology 28-42

Oluoch SJ, Obura D (2008) Assessment of fisherfolk organizations and beach management units (BMU) in the management of fishery resources in Diani-Chale, Southern Kenya. In: Obura DO, Tamelander J, Linden O (eds) Ten years after bleaching – facing the consequences of climate change in the Indian Ocean. Cordio Status Report 2008. CORDIO (Coastal Oceans Research and Development in the Indian Ocean)/ Sida-Sarec. Mombasa, pp 335-343

Omondi EO (1995) Cetaceans and fisheries in Kenya coastal waters: A preliminary study. Coastal systems and sustainable development in Africa. UNESCO reports in marine science 66:124-147

Otieno AN, Mavuti KM, Wakwabi E (2001) A survey of the artisanal fisheries of Shirazi and Shimoni, South Coast, Kenya. 2nd Western Indian Ocean Marine Science Association (WIOMSA) Scientific Symposium, Dar es Salaam, Tanzania, 22-25 October 2001, Book of Abstracts pp 44

Palumbi, SR, McLeod KL, Grünbaum D (2008) Ecosystems in action: Lessons from marine ecology about recovery, resistance, and reversibility. BioScience 58: 33-42

Rodwell LD, Barbier EB, Roberts CM, McClanahan TR (2003) The importance of habitat quality for marine reserve–fishery linkages. Canadian Journal of Fisheries and Aquatic Sciences 60: 171–181

Samoilys MA (1988). Abundance and species richness of coral reef fish on the Kenyan coast: The effects of protective management and fishing. Proceedings of the 6th International Coral reef Symposium 2: 261-266

Samoilys MA, Maina GW, Osuka K (2011) Artisanal fishing gears of the Kenyan coast. CORDIO/USAID, Mombasa, 36 pp

Stamatopoulos C (2002) Sample-based fishery surveys: A technical handbook. FAO Fisheries Technical Paper 425. Rome, FAO, 132 pp

Schartl M, Hornung U, Hissmann K, Schauer J, Fricke H (2005) Genetics: Relatedness among east African coelacanths. Nature 435: 901

Sigana DO, Mavuti KM, Ruwa RK (2009) Fish species composition and distribution in Kilifi Creek. In: Hoorweg J, Muthiga N (eds). Advances in Coastal Ecology: 15-27

Souter P, Henriksson O, Olsson N, Grahn M (2009) Patterns of genetic structuring in the coral *Pocillopora damicornis* on reefs in East Africa. BMC Ecology 9: 19

SWIOFC (2006) FAO South West Indian Ocean Fisheries Commission. Report of the first session of the Scientific Committee. Dar es Salaam, Tanzania, 31 May-3 June 2006. FAO Fisheries Report No. 806. FAO, Rome, 92 pp

Tuda P, Nyaga W, Maina GW, Wanyonyi I, Obura D (2008) Estimating total fishing effort over tidal to annual periods in the Diani-Chale-Gazi reef fishery in Kenya. In: Obura DO, Tamelander J, Linden O (eds) Ten years after bleaching – facing the consequences of climate change in the Indian Ocean. Cordio Status Report 2008. CORDIO (Coastal Oceans Research and Development in the Indian Ocean)/Sida-Sarec. Mombasa, pp 321-334

Tunje JG, Hoorweg J (2003) Awareness of resource degradation among artisanal fishers in Kilifi and Lamu. Recent Advances in Coastal Ecology: Studies from Kenya. 70: 185-200

Wakwabi EO (1996) The diets of juvenile fishes in a tropical mangrove bay, Gazi Bay, Kenya. Netherlands Journal of Zoology 46: 236-252

Wakwabi EO (1999) The trophic organisation in the fish faunas of a tropical bay (Gazi Bay, Kenya). PhD thesis, Ghent Rijksuniv., Belgium, pp 157-193

Wambiji N, Ohtomi J, Fulanda B, Kimani E, Kalundu N, Hossain MY (2008) Morphometric relationship and condition factor of *Siganus stellatus*, *S. canaliculatus* and *S. sutor* (Pisces:Siganidae) from the Western Indian Ocean Waters. South Pacific Studies 29: 33-46

Watson M, Ormond RFG (1994) Effects of an artisanal fishery on the fish and urchin populations of a Kenyan coral reef. Marine Ecology Progress Series 109: 115-129

Watson M, Ormond RFG, Holliday L (1997) The role of Kenya's marine protected areas in artisanal fisheries management. Proceedings of the 8th International Coral Reef Symposium 2: 1955-1960

Williams F (1970) The sport fishery for sailfish at Malindi, Kenya, 1958-1968, with some biological notes. Bulletin of Marine Science 20: 830-852