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The effect of a closed area and beach seine exclusion on coral reef fish catches

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Abstract Fish landing data from the Mombasa Marine National Park (MNP) and a marine reserve exploited by various gears were studied over a 5-yr period to determine the influence of the closed area and different gears in fisheries. The number fishing and boats per landing site was constant, but total and catch per unit effort progressively declined in all sites on an annual basis irrespective of the existence of a marine reserve, exclusion of the beach seines or use of gear. Differences between landing sites were most pronounced when analysed on a catch per area as opposed to the more standard catch per fisherman, suggesting compensation in human effort when catches decline. A marine reserve next to a closed area that excluded beach seines had the highest catch per area (5.5 kg ha^{-1} $month^{-1}$) despite having the highest density of fishermen (0.07 ± 0.02 fishermen ha^{-1} $month^{-1}$). The annual rate of decline in the catch was lower than the other sites at around 250 g day^{-1} compared with 310–400 g day^{-1} in the other sites. One landing site, which excluded beach seine landings for more than 20 yrs, had a high catch per area (~5.3 kg ha^{-1} $month^{-1}$), but after experiencing a doubling in the effort of other gears (line, speargun and trap), the catch per fisherman and area were reduced. Environmental or habitat degradation and excessive effort remain the most likely explanation for the overall declines in catch from 1995 to 1999. Closed areas and beach seine exclusion have the potential to increase catch rates, but the first often reduces the total fishing area and possibly leads to a loss of total catch, at least on a time scale of less than 10 yrs. The exclusion of beach seines can lead to an increase in other gear types that can also cause reductions in catch.

KEYWORDS: coral reef fisheries, gear conflict, Kenya, marine parks and reserves, management.

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Introduction

Most fishing in the tropical oceans is carried out by small-scale artisanal fishermen who largely use human power to generate large catches (Dalzell 1996). Tropical artisanal fishing is therefore a low expenditure and potentially high economic return activity when the resources are not overexploited. Nonetheless, heavy exploitation of fishery resources and poverty are common in the tropics and East Africa (McClanahan 2000; Muthiga, Riedmiller, Carter, van der Elst, Mann-Lang, Horrill & McClanahan 2000). As stocks decline more effective or competitive gear is used to focus on smaller or less-preferred fish, but these gears, such as blasting, poisons and drag nets, are often destructive of fish habitat and can therefore jeopardize the long-term sustainability of fish production (Pauly, Silvestre & Smith 1989; Muthiga *et al.* 2000). Poverty is pervasive among fishing societies of the world and management therefore requires the creation of inexpensive institutional interventions (NRC 1999).

Methods to prevent overexploitation, poor catches and poverty have often focused on opening new fisheries such as offshore or artificial reef or aggregation fisheries (Seaman & Sprague 1991), closed areas such as marine parks (Gubbay1995; Nowlis & Roberts 1999) or eliminating redundant or destructive gear (Pauly *et al.* 1989). Closed areas have recently received a good deal of attention as they are viewed by some scientists and policy makers as being a simple and cost-effective way to increase stocks in diverse and complicated tropical fisheries (Plan Development Team 1990; Roberts & Polunin 1991, 1993; Bohnsack 1998). Closed areas have, however, also been difficult to implement largely because of poverty, poor planning and lack of coordination (McClanahan 1999).

This study examines field data collected from landing sites in southern Kenya using two relatively inexpensive management institutions, closed areas and exclusion of destructive gear, namely beach seines. Beach seines or pull seines are a long net of ~150 m with a mesh of ~3 cm and a weighted line that is dragged across the seagrass, sand and coral reef substratum. The objective was to compare the catch on a per man and per area basis, their trends and effort in coral reef areas with these two restrictions compared with areas, without area or gear restrictions. Determining which restrictions produced the highest and most stable yields should assist decisions on appropriate low-cost fisheries restrictions for tropical reef lagoons.

Methods

Study sites

Artisanal fisheries in Kenya use various gears including hand lines, traps, gill nets, seine nets and spear guns. These gears harvest many species and may be employed from shore to the outer reef edge in waters seldom deeper than 5 m at low tide (McClanahan & Kaunda-Arara 1996), usually from small boats and throughout the year. Study sites described below were chosen for comparison because they were considered typical coral reef-based fisheries of southern Kenya and because of the different gears used or changes in use of gear over time. Landing sites are located on shore from a lagoon protected by a fringing reef where fish are caught from seagrass, sand and coral habitats. These landing sites contrast with the second common type of fish landings in southern Kenya, those located in or at the mouth of creeks where the continuous fringing reef is broken, allowing a passage to the open sea. Creek sites land fish from various habitats, are potentially more porous to migrating fish and shown to have a different tidal pattern in fish catch compared with landings behind the continuous fringing reef (McClanahan & Mangi 2000).

The history of each landing site is important for understanding the pooling of site data and subsequent analysis and results. The Mombasa Marine Park (MNP) was legally established in 1987 and was heavily fished before protective management (Fig. 1; McClanahan & Kaunda-Arara 1996; Glaesel 1997; McClanahan & Mangi 2000). When this park came under active management in 1991, 63% of the fishing ground was lost and effort also declined by 68% leaving a constant fishing density (McClanahan & Kaunda-Arara 1996). Early efforts to enforce park and reserve status resulted in physical conflicts, but by the mid-1990s negotiations, as part of an integrated coastal area management process (Coast Development Authority 1996), reached a consensus to eliminate beach seines and reduce the park size. These two management changes were implemented in October 1995. Fishermen-state relations have increasingly improved and fishermen have slowly adapted to park management rules (Glaesel 1997). Reefs to the south of the park were demarcated as a marine reserve and from 1995 only traps, gill nets and hand lines were allowed. Kenyatta beach is the only major landing site for fishing in the near shore coral reefs and seagrass beds adjacent to the park (Fig. 1).

The Diani area, until recently, had largely unregulated gear use except for two landing sites (Mvuleni and Mwanyaza in the Galu sector) where elders and fishermen have tried to eliminate the use of beach seines for over 20 yrs (McClanahan, Glaesel, Rubens & Kiambo 1997; Fig. 1). Between 1993 and 1995 a marine protected area was proposed for this area by the Kenya Wildlife Services which began meetings and negotiations with hoteliers and local people, including fishermen (McClanahan *et al.* 1997; Glaesel 1997). Implementation of the zoning plan did not begin because of conflicts among the above parties. Fishermen feared losing control of their fishing grounds and local officials, who hoped for revenue from the park, realized that revenue would more likely go to the park service and not local government (see McClanahan *et al.* 1997). Despite failure to implement the marine reserve in Diani, there were some changes in gear use that may have resulted from changing views among fishermen about appropriate gear, possibly stimulated by the above meetings. For instance, in 1996 a group of fishermen using spear guns changed to using traditional traps and some moved from their unregulated gear landing site in Kinondo to the above Galu sector, essentially doubling the trap effort in Galu, the area without beach seines (Fig. 1).

In Mwaepe, the landing to the north of Galu, leaders of fisheries began to enforce the beach seine exclusion in November 1996 by prohibiting beach seines catches to be landed or sold. There was, however, continued late-night beach seining in their fishing grounds and the catch was landed elsewhere (S. Kitema, personal communication). In March 1998, the beach seine fishermen using landing sites on the south side of Galu, Mgwani and Chale, stopped using beach seines because their large nets wore out, some were stolen and they could not afford to replace them. Some bought cheaper gill nets and fished in smaller

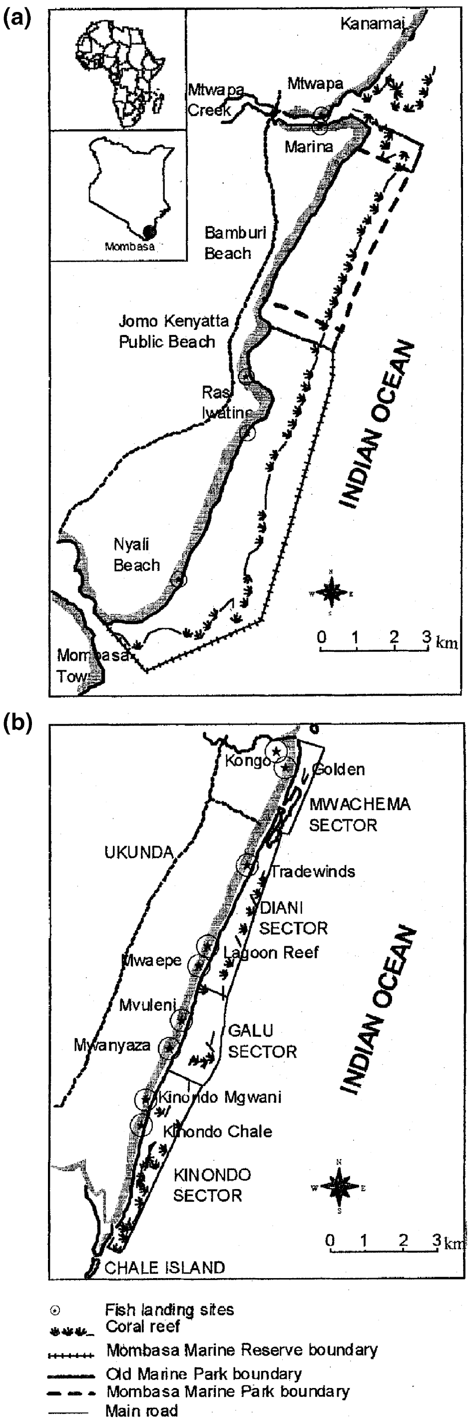

Figure 1. Map of the study area showing (a) the different management areas, border changes and the Kenyatta fish landing site and (b) the Diani-Kinondo area showing the approximate position of the fish landing sites.

groups while others moved and joined beach seine fishermen in the sites further to the north of Galu, Tradewinds and Lagoon Reef (Fig. 1). Consequently, these changes between 1995 and 1998 resulted in no beach seine use south of Galu, reduced beach seines in Mwaepe, just north of Galu and continued beach seine use in the northern end of this study area. Fishing effort also increased in Galu over this time, largely because of the movement of nonbeach seine fishermen into this fishery.

The fishing area of each landing site was estimated from maps (Fig. 1) and discussions with fishermen. Fishing ground boundaries of each landing site are clearly known and maintained by interactions among fishermen from different landing sites. There were four principal fishing grounds based on the type of management in place. (1) Kenyatta beach, adjacent to the Mombasa Marine Park, with most of the fishering carried out in the reserve next to the park (Fig. 1). Here only artisanal fishing with traps, gill nets and hooks and lines is allowed and shell collecting is also prohibited. The second management area is (2) Galu, comprising the two fish landing sites where traditional management stopped beach seines from landing their catch for over 20 yrs. Elders at these two sites have also attempted to stop spear fishing in the area, but claim the young fishermen using spears do not fully respect their authority and the use of spear guns has approximately doubled from 1995 to 1999. (3) Kinondo area is characterized by a high number of fishermen with many relying on beach seines until March 1998, when seines were largely replaced with gill nets. (4) Diani, where beach seines and all other forms of gears were used. In Diani, the average daily number of fishermen per beach seine went down from 17 to 12 from 1995 to 1999. The Mwaepe site was on the border between the Galu and Diani sectors and began to prevent beach seine fishers from landing their catch at this site, but beach seining continued at night and we, therefore, included catch from Mwaepe into the Diani rather than the Galu sector.

Fish landing studies

Fish landing data were collected from September 1995 to June 1999 in all eight landing sites. Fish landed by individuals or pairs were identified to six groups (1) octopus, (2) parrotfish (Scaridae), (3) scavengers (Lethrinidae, Lutjanidae and Haemulidae), (4) rabbitfish (Siganidae), (5) goatfish (Mullidae), and (6) a group called mixed which included either a high diversity of species or groups so mixed together that they were not easily separated into the previous five groups. The wet weights (to the nearest 0.5 kg) of each of these groups were estimated using a spring balance. Recorded data included the number fishing and types of gears used at each landing site. The total catch, fish groups and numbers that participated in fishing were recorded each sampling day. The number used here is the number recorded fishing during each sampling day. Independent total census of fishermen numbers produces a fishing population about twice the value for each sampling day because some fishermen do not report to the landing site during the regular incoming tide time or because they fished during the night. Consequently, numbers reported in this study would need to be multiplied by ~2 for comparison with total fishing number censuses (McClanahan & Kaunda-Arara 1996; McClanahan *et al.* 1997).

Discussions with fishermen revealed that fishing was carried out for 24 days a month while catch data were collected for 12 days (±4.0) for the Kenyatta landing and 3 days (±1.0) for each site in the Diani region. Catch on a per area and month basis was calculated by adjusting to 24 days and dividing by the area of the fishing ground (Table 1). These data were analysed to calculate daily, monthly and yearly averages of the catch per individual and area which were used for scatterplots, regression analysis and ANOVA statistics (Sall & Lehman 1996). To describe the fishery, each gears contribution to the catch was calculated for each fish family group. Plots and ANOVA of catch per area, annual changes and mean numbers of fishermen were used to test for differences among the landing sites based on the above management categories.

Results

Gear use and catch composition

Five main gears were employed in the near-shore fishery. There was generally a fairly even use of gears in these fisheries with all five gears contributing between 16 and 31% of the recorded landings (Table 1). Exceptions were Galu and Kenyatta, which had no beach seine landings and Mwaepe which had a small sample size for beach seines collected before the management changed. Parrotfishes (largely *Leptoscarus*), octopus, scavengers and rabbitfishes were the predominant fish groups caught, with the overall percent composition of each group varying from 15 to 25% of the total catch. There were significant differences ($P < 0.01$) between landing sites based on the fish groups, except for scavengers (Table 2).

Table 1. Details of the fishing area and number of fishermen (top) and the gear composition at the studied sites (bottom)

Landing site		Kenyatta	Galu	Kinondo	Diani	Total
Fishing area, ha		375	500	700	700	
Number fishing	mean	25.1	27.1	41.7	24.4	
	SD	10.6	9.5	13.6	10.7	
Fishermen per area	Number, ha^{-1} month^{-1}	0.07	0.05	0.06	0.04	
	SD	0.02	0.01	0.01	0.01	
Percentage catch by gear						
Spears	n =	30.8	26.3	20.5	22.9	23.3
		605	184	186	171	1167
Hand line	n =	25.1	24.7	19.9	21.3	20.3
		518	94	122	96	846
Gill net	n =	22.2	20.7	23.2	20.2	19.4
		568	23	96	57	751
Beach seine	n =			20.4	19.2	18.5
				106	105	211
Trap	n =	21.9	28.3	15.9	16.4	18.4
		606	189	177	126	1118

Table 2. Catch composition (kg day^{-1}) at each of the studied landing sites and an ANOVA comparison between landings sites

Family	Kenyatta		Galu		Kinondo		Diani		Mwaepe		Total (%)	ANOVA	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		*F*-value	*P*-value
Octopus	6.7	14.8	7.4	15.7	8.1	19.4	8.1	19.4	6.2	14.0	24.6	3.11	0.01
Parrotfish	1.8	4.0	11.4	10.6	7.8	10.8	7.8	10.8	5.6	7.9	23.2	239.26	0.00
Mixed and others	4.9	10.5	4.8	5.4	7.1	15.6	7.1	15.6	5.0	8.4	19.4	5.08	0.001
Scavengers	5.1	10.2	4.8	6.5	5.4	9.9	5.4	9.9	4.3	12.0	16.9	1.27	NS
Rabbitfish	4.0	9.3	5.5	12.1	4.9	8.8	4.9	8.8	3.2	7.2	15.2	7.06	0.001
Goatfish	0.1	0.8	0.3	0.9	0.3	1.2	0.3	1.2	0.2	0.9	0.8	5.98	0.001

Changes over time

Fishing landing data, pooling the catches from the eight landing sites and plotting variables with time from 1995 to 1999, showed a steady decline in the measures of total fish abundance (Figure 2) despite a nearly constant number of fishermen and boats (Figure 3). On an annual basis, total catch per landing sites is declining at an annual rate of 6.0 kg day^{-1} and the catch per fishermen is going down at 320 g day^{-1} (Fig. 3). Rabbitfish have the clearest annual decline ($r^2 = 0.82$) while the scavengers, goatfish and mixed/others were more variable with time ($r^2 = 0.41$–0.47). There was no relationship with time for the parrotfish (largely *Leptoscarus vaigiensis* Quoy & Gaimard) and octopus (Fig. 3).

Catch and gear use

Catch per area and per man based on the full time-series data pooled into the four management categories suggest differences in catch related to gear and closed-area management (Figure 4a). On a catch per man basis, differences between landing sites are not large (around 14% day^{-1}), but were statistically significant. Galu, the area with long-term beach seine exclusion, had the highest mean catch per man (3.7 kg man^{-1} day^{-1}) while the sites that still adopt beach seines had the lowest (3.2 kg man^{-1} day^{-1}). On a per area basis, there was a larger and statistically significant difference in mean catch. Kenyatta produced the highest yields (5.5 kg ha^{-1} month^{-1}), Galu and Kinondo had the same mean catch per area at 4.7 kg ha^{-1} month^{-1}, despite a 200-ha difference in their fishing areas (Table 1). Diani-Mwaepe had the lowest catch per area at 2.8 kg ha^{-1} month^{-1}.

The number fishing at Galu doubled over the study period to the extent that the once high catch per area of 5.3 kg ha^{-1} month^{-1} in 1995 was reduced to 4.0 kg ha^{-1} month^{-1} towards the end of the study period (Figure 5). The change in catch was greater when measured on the catch per man basis, which dropped from 4.5 to 2.5 kg man^{-1} day^{-1}. Kinondo had the highest number of fishermen using its fishing grounds (41.7 ± 9), but when the number of fishermen was divided by the fishing area, the reserve at Kenyatta had the highest numbers of individuals fishing per unit area (0.07 ± 0.02 ha^{-1}, Table 1). Plotting the catch data by management groupings over time showed the same downward

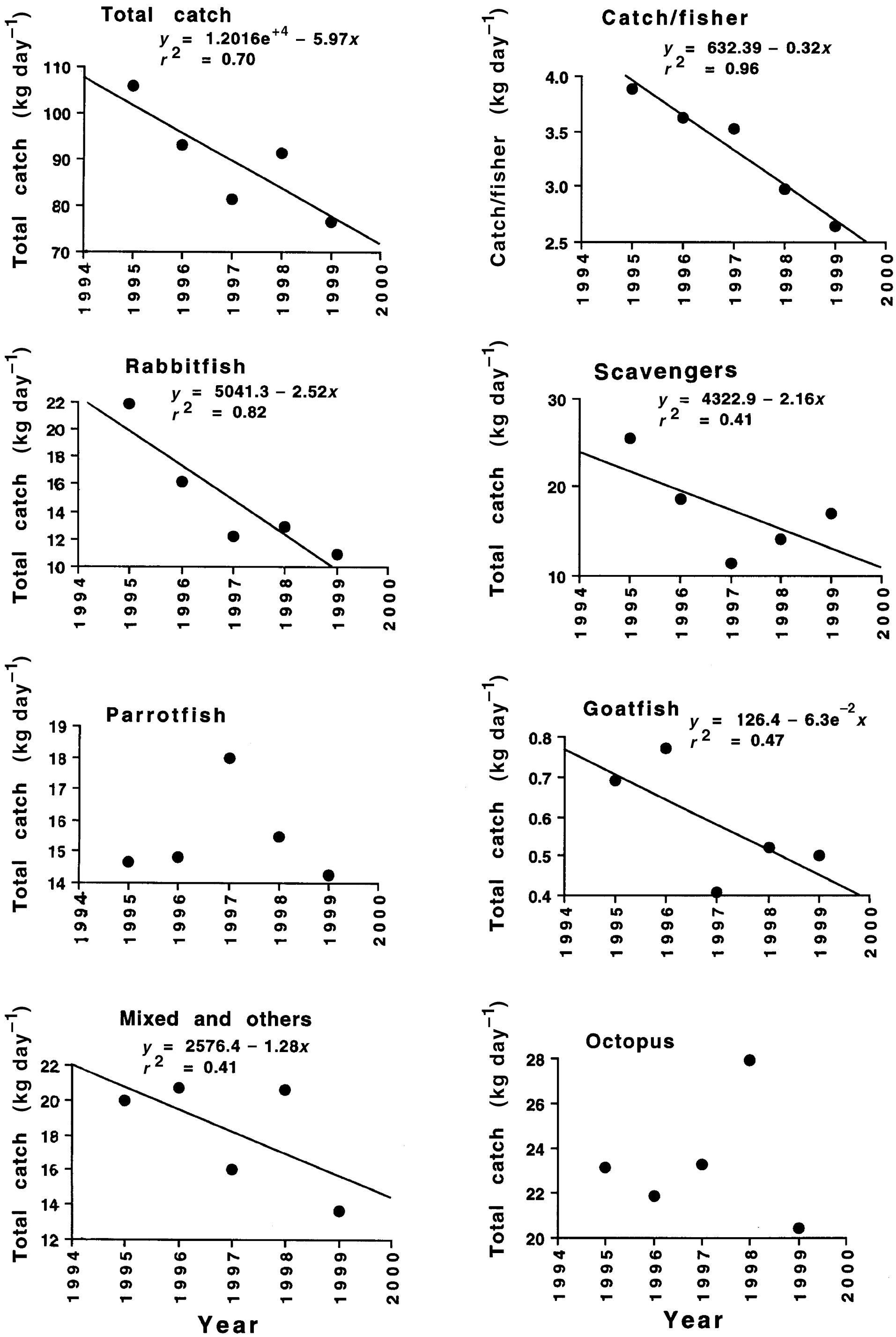

Figure 2. Scatter plots of the annual average total catch, catch per fisherman and the six measured fish categories based for all landing sites combined.

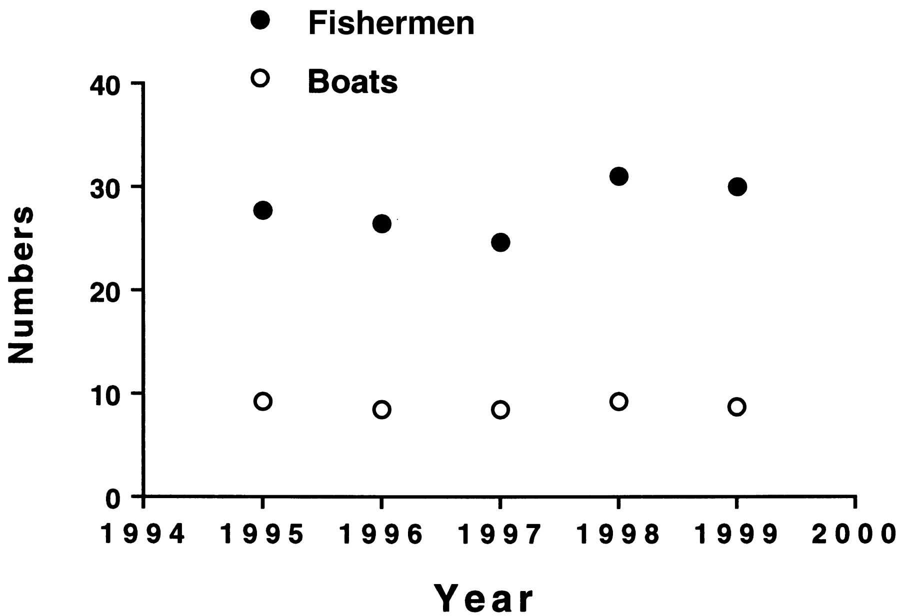

Figure 3. Plots of the average number of fishermen and boats per day on an annual basis on all landing sites combined.

trend in all fisheries management groups with the only difference being the rate at which they were declining (Table 3; Fig. 4b). Catch at the most managed site, Kenyatta Beach, declined the slowest, at 250 g day^{-1}, while the other sites were falling at a rate of 310–400 g day^{-1}, on an annual basis.

Discussion

The main fish families caught in this fishery were seagrass and coral reef-associated species reflecting where fishing is focused. The studied reef lagoons were exploited throughout the year and there was little evidence for seasonality in the demersal catch (McClanahan & Mangi 2000). Groups predominating the Kenyan coral reef fishery included rabbitfish and scavengers similar to findings in Madagascar (Laroche & Ramananarivo 1995; Laroche, Razanoelisoa & Faroux 1997) and Fiji (Jennings & Polunin 1995) and snappers, scavengers, mullets, parrotfish, jacks and groupers were reported for Papua New Guinea (Dalzell & Wright 1990). However, octopus was a large part of the fishery in Kenya, often taken from shallow waters or off the reef flat.

A variety of gears were used and each gear caught a nearly equal fraction of the catch. The lack of beach seines in two fishing areas did not result in lower, but rather higher fish catches, which suggests that this gear is competing with other gear types rather than having a unique or separate fish resource niche (McClanahan *et al.* 1997). A comparable study in northern Tanzania undertaken from 1995 to 1998 with a similar set of gears and habitats also found an overall declining catch over time (Muthiga *et al.* 2000). The Tanzanian study showed that beach seine catches increased slightly over time while all

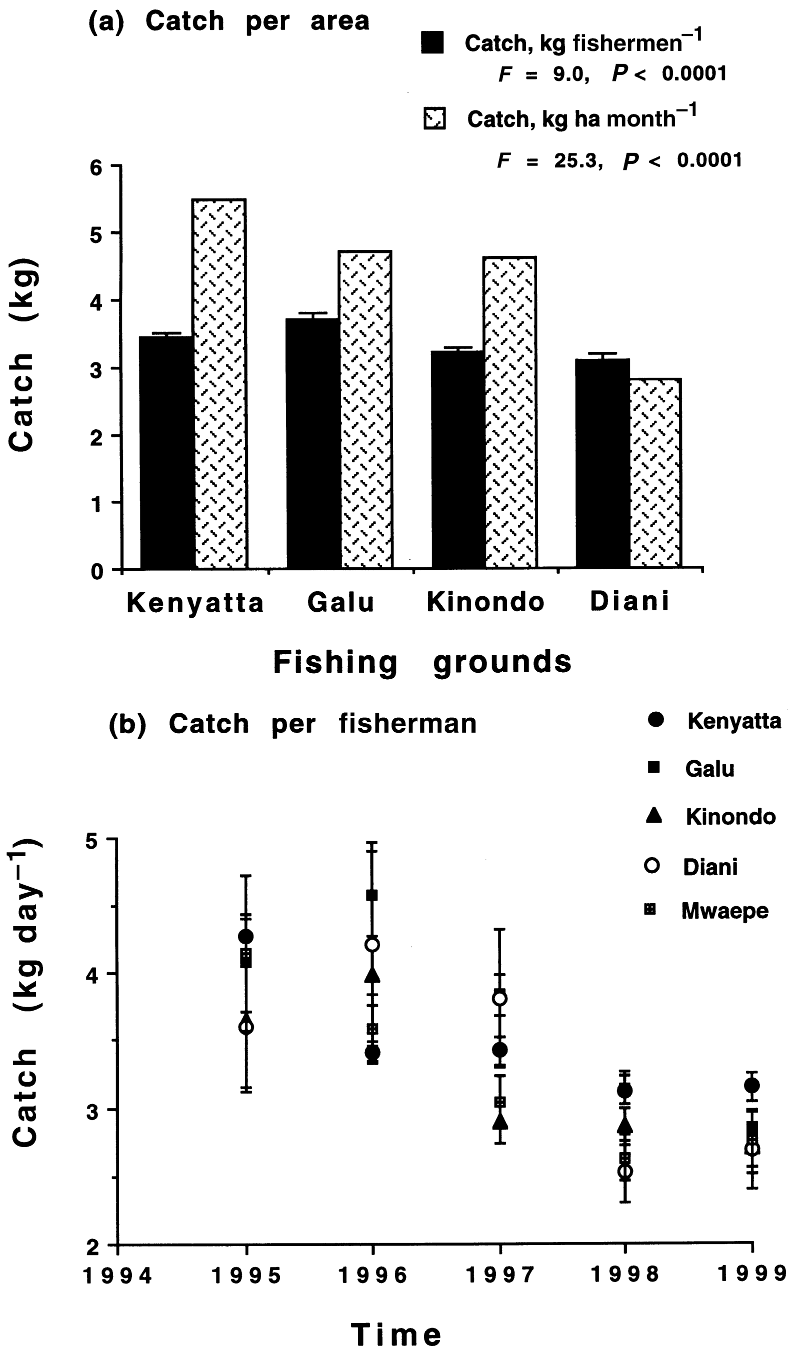

Figure 4. (a) Mean catch per fisherman and per area per month in each of the four management categories and (b) annual mean catches from 1995 to 1999. Error bars are standard errors of the mean. Regression statistics for the year vs. annual catch are given in Table 3.

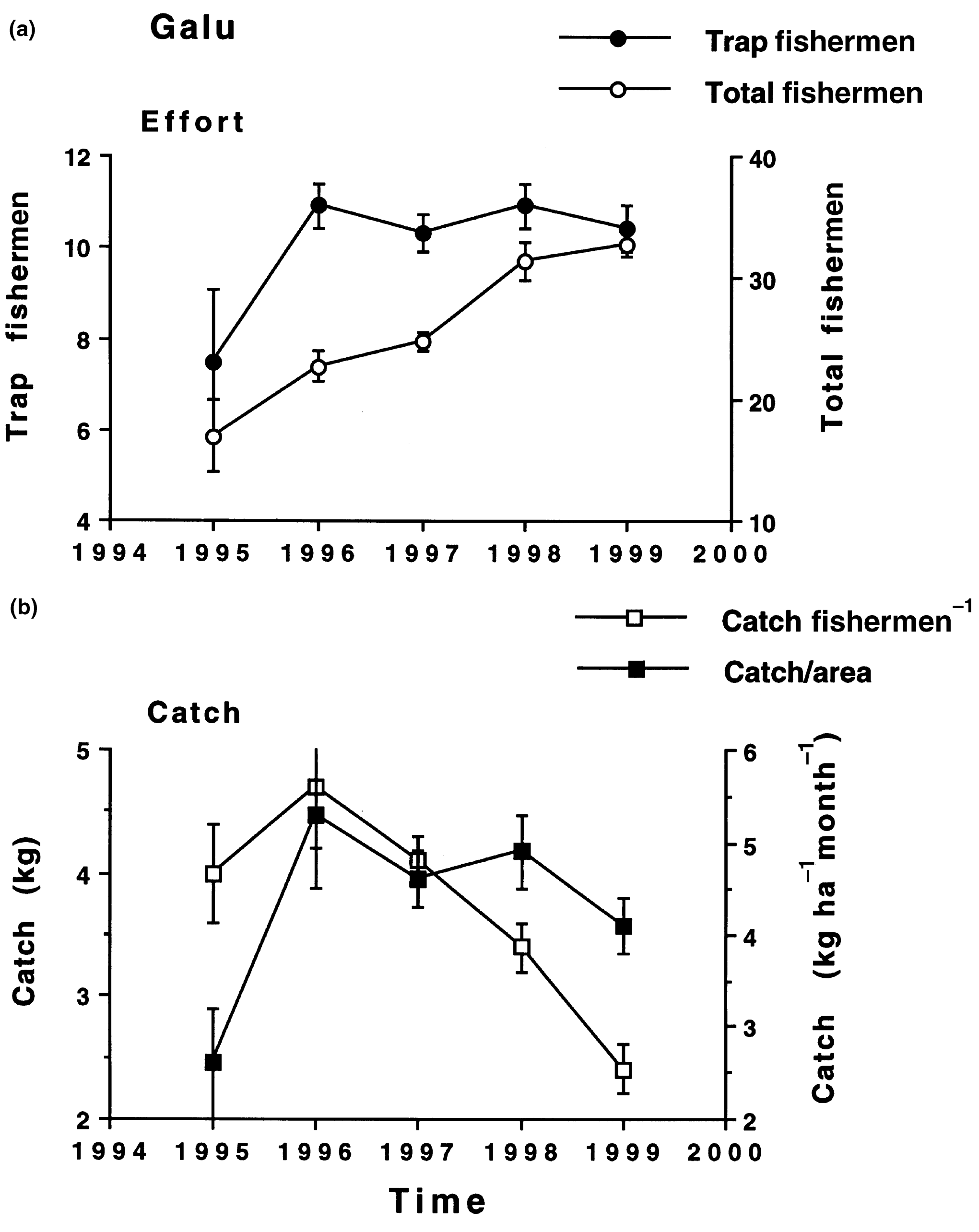

Figure 5. Time series of (a) the total number and trap fishermen and (b) the catch per man and area in the Galu sector, where beach seines have traditionally not been allowed to land their catch.

other gear type catches were declining. Again, this suggests that beach seines were outcompeting other gear for fish resources. This is not surprising given the small 3-cm mesh size of most beach seines. These changes occurred despite the fairly constant effort in the fishery as measured by the number of fishermen and boats.

Table 3. Regression statistics of catch as a fuction of time in the studied areas

Site	Equation	r^2 value	*F*-value	*P*-value
Kenyatta	$y = 28.11–0.25x$	0.73	18.0	0.0001
Galu	$y = 42.01–0.40x$	0.77	10.1	0.0001
Kinondo	$y = 32.81–0.31x$	0.72	5.5	0.002
Diani	$y = 37.32–0.35x$	0.58	3.6	0.01
Mwaepe	$y = 39.51–0.37x$	0.88	4.8	0.001

Decreasing catch at all sites, despite stable effort, suggests that either: (1) increased effort is occurring outside of these fishing grounds, such as trawlers working beyond the reef; (2) there is a long-term cycle of recruitment or environmental conditions that is driving this pattern, which may be cyclical; or (3) effort is too high despite being stable; and (4) there are some forms of environmental degradation which are reducing the fisheries productivity of these reef areas. Previous studies have shown that a significant portion of the catch from these reef lagoons comes from fish migrating in from deeper offshore areas (McClanahan & Mangi 2000). Consequently, trawling might be a factor, but most off shore trawling is restricted to river mouths that support a shrimp fishery in northern Kenya, so this explanation is not convincing. La Niña-El Niño cycles are known to influence water temperatures and other environmental conditions in this region (Cole, Dunbar, McClanahan & Muthiga 2000). This cycle has a duration of 3.5 yrs since the 1960s (Charles, Hunter & Fairbanks 1997), shorter than this 5-yr study and the time-series data do not yet reflect a pattern consistent with this cycle. A meteorological cycle of 11.8–12.3 yrs, known as the Indian Ocean dipole (Saji, Goswami, Vinayachandran & Yamagata 1999; Webster, Moore, Loschnigg & Leken 1999), might explain this pattern. The time series is not sufficiently long, however, to test the influence of this cycle and future monitoring will be required to determine its possible importance.

The importance of effort, irrespective of gear, is supported by findings from Galu where a doubling of fishing effort resulted in a halving of CPUE. Traps may be a more benign form of fish capture than beach seines, in having a larger mesh and being less destructive to the substratum, but traps also have the ability to fish beyond a maximum sustainable yield. The present level of effort and gear appears to be largely controlled by poverty or the equilibrium between high but low-cost effort and fish production (Clark 1985; Pauly *et al.* 1989). Examples of this equilibrium were reflected in decisions made by fishermen. For example, those wishing to change gears in the Kinondo fishery chose to move to Galu, where the more competitive gear, beach seines, was absent, rather than face competition with beach seines in their own fishery. Further, when the Mombasa MNP closed an area to fishing in 1991 the fishermen density in the adjacent reserve stayed the same, at $\sim$12 km^{-2}, even though $\sim$70 fishermen were excluded from fishing in the park. Most preferred to leave and fish elsewhere or search for other work rather than increase their density in the reserve and face an eventual loss in income. Overall fishing numbers in southern Kenya are not increasing as a result of the low profits obtained from fishing.

The average catch of around 3 kg person^{-1} day^{-1} probably represents the minimum existence wage (landed fish sell for $\sim$1 US\$ kg^{-1}). Fishermen may change their daily effort to obtain this minimum wage. This behaviour may explain the weak patterns found for the associations with management based on the catch per man data, where as a much stronger pattern was found for the catch per area data. It is common to hear fishermen say they fish 'until they get enough' when asked how long they fish each day. Consequently, compensation in effort may cause catch per man or per boat to be poorer measures of fish abundance and yield compared with the catch per area measure.

Studies of fish populations inside the Mombasa Park showed a large increase in fish biomass with the elimination of fishing (McClanahan & Kaunda-Arara 1996). This increase in biomass and its dispersion into the adjacent fishery is probably why the reserve has the slowest decline in catch rate and maintains higher catch per man and area than found before the park (McClanahan & Mangi 2000). These findings confirm some predictions of previous models and field studies (Alcala & Russ 1990; DeMartini 1993; Russ & Alcala 1996; Nowlis & Roberts 1999), but they do not confirm the prediction of increasing total fish catch in areas adjacent to closed areas. Further, if the area of the park had been included in calculations of catch per area, the benefits of the closed area would be further reduced. Nonetheless, this and a previous study (McClanahan & Mangi 2000) found increased number of fish species caught and reduced monthly variation in fish catch (McClanahan & Mangi 2000). Even if closed areas do not increase catches they are likely to make the catch more diverse, sustainable and less vulnerable to collapse. There are also other indirect effects of closed areas. For example, increased cover of coral and topographic complexity have been measured inside the park as fishing exclusion (McClanahan & Mutere 1994) as well the increased income to the area from park entrance and boat fees (McClanahan & Kaunda-Arara 1996). This is in contrast to the Diani and Galu reefs, which have low levels of coral cover, substratum complexity and species diversity and poor income from tourism, largely because of insecurity (McClanahan *et al.* 1997).

It was concluded that closed areas, gear, effort and environmental degradation influence fish catches in Kenya's coral reef lagoons. Beach seines appear to be competing for fisheries resources rather than exploiting a unique fish resource. Reducing effort, through either closed areas or employment alternatives and destructive gear would appear to be two relatively inexpensive ways to increase fish stocks and their sustainable extraction. Despite constant effort and the existence of marine parks (4 closed areas totaling $\sim$35 km^2), Kenya's coral reef fisheries appear to be declining such that fishermen are, on average, losing $\sim$\$125 annual income per year. This study suggests the need for further closed areas, the elimination of destructive gear and reduced fishing effort. Appropriate incentives and comanagement between park, fisheries department personnel and fishers are needed to obtain further closed areas and the development of alternative resources and employment.

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