Conservation Biology

Contributed Paper

Effects of Fisheries Closures and Gear Restrictions on Fishing Income in a Kenyan Coral Reef

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Abstract: *The adoption of fisheries closures and gear restrictions in the conservation of coral reefs may be limited by poor understanding of the economic profitability of competing economic uses of marine resources. Over the past 12 years, I evaluated the effects of gear regulation and fisheries closures on per person and per area incomes from fishing in coral reefs of Kenya. In two of my study areas, the use of small-meshed beach seines was stopped after 6 years; one of these areas was next to a fishery closure. In my third study area, fishing was unregulated. Fishing yields on per capita daily wet weight basis were 20% higher after seine-net fishing was stopped. The per person daily fishing income adjacent to the closed areas was 14 and 22% higher than the fishing income at areas with only gear restrictions before and after the seine-net restriction, respectively. Incomes differed because larger fish were captured next to the closed area and the price per weight (kilograms) increased as fish size increased and because catches adjacent to the closure contained fish species of higher market value. Per capita incomes were 41 and 135% higher for those who fished in gear-restricted areas and near-closed areas, respectively, compared with those who fished areas with no restrictions. On a per unit area basis (square kilometers), differences in fishing income among the three areas were not large because fishing effort increased as the number of restrictions decreased. Changes in catch were, however, larger and often in the opposite direction expected from changes in effort alone. For example, effort declined 21% but nominal profits per square kilometer (not accounting for inflation) increased 29% near the area with gear restrictions. Gear restrictions also reduced the cost of fishing and increased the proportion of self-employed fishers.*

Keywords: coral reef, cost-benefit analyses, economic incentives, Indian Ocean, Kenya, marine protected areas, spillover, valuation of closures

Efectos del Cierre de Pesquerías y de Restricciones de Equipo sobre el Ingreso de Pescadores en un Arrecife de Coral Keniano

Resumen: *La adopción de cierres de pesquerías y restricciones de equipo en la conservación de arrecifes de coral puede estar limitada por el poco entendimiento de la rentabilidad económica del uso económico de recursos marinos competidores. A lo largo de 12 años, evalué los efectos de la regulación de equipo y el cierre de pesquerías sobre los ingresos por pesca por persona y por área en arrecifes de coral en Kenia. En 2 de mis áreas de estudio, el uso de chinchorros playeros de malla pequeña fue suspendido después de 6 años; una de esas áreas estaba a un lado de un cierre de pesquería. En mi tercera área de estudio, la pesca no estaba regulada. Las producciones de pesca de peso húmedo per cápita diaria fueron 20% más altas después de que se detuvo la pesca con chinchorro. El ingreso diario por persona en sitios adyacentes a las áreas cerradas fue 14% y 22% más alto que el ingreso por pesca en áreas sólo con restricciones de área antes y después de la restricción de chinchorros, respectivamente. Los ingresos difirieron porque se capturaban peces más grandes cerca del área cerrada y el precio por peso (kilogramos) incrementaba a medida que incrementaba el tamaño de los peces y porque las capturas adyacentes al cierre contenían especies de peces de mayor valor de mercado. Los ingresos per cápita fueron 41% y 135% mayores para quienes pescaron en áreas con restricción de equipo y cerca de áreas cerradas a la pesca, respectivamente, en comparación con quienes pescaron en áreas sin restricciones. Considerando una base por unidad de área (kilómetros cuadrados), las diferencias*

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Paper submitted September 17, 2009; revised manuscript accepted January 24, 2010.

Conservation Biology, Volume **, No. **, ***–***

DOI: 10.1111/j.1523-1739.2010.01530.x

en el ingreso por pesca entre las 3 áreas no fueron grandes porque el esfuerzo de pesca incrementó a medida que decrecieron las restricciones. Sin embargo, los cambios en la captura fueron mayores y a menudo en la dirección opuesta a la esperada solo por los cambios en el esfuerzo. Por ejemplo, el esfuerzo declinó 21% pero las ganancias nominales por kilómetro cuadrado (sin considerar la inflación) incrementaron 29% cerca del área con restricciones de equipo. Las restricciones de equipo también redujeron el costo de la pesca e incrementaron la proporción de pescadores auto-empleados.

Palabras Clave: análisis de costo-beneficio, áreas marinas protegidas, arrecifes de coral, excedentes, incentivos económicos, Kenia, Océano Índico, valoración de cierres

Introduction

Closing off areas of the sea from fishing (fisheries closures) is a controversial management option for sustaining fisheries and fishing incomes (Hart & Sissenwine 2009), regardless of the growing evidence of their ability to increase the size, biomass, and number of exploited species (Lester et al. 2009). And, despite considerable effort by resource management and conservation organizations to increase the area of the sea covered by closures, the total is only 0.2% of the area under national jurisdictions and 0.08% of the world's oceans, which is considerably less than the 11.6% area established as protected from uncontrolled hunting on land (Wood et al. 2008). Resistance to the concept of restricted access, time lags in the accruement of benefits, and perceived losses of fishing income are among the major impediments to the large-scale adoption and use of fishery closures (Ludwig et al. 1993; Pauly 2009). These impediments are particularly prevalent in poor, small-scale fisheries where nearshore resources are under intense use and their use may be ultimately guided by a desire to maximize employment and short-term profitability and by competition among alternative uses (McClanahan 1999; Beddington et al. 2007).

Short-term studies conducted near recently closed fisheries have focused on fishery yields (Worm et al. 2006), and the results of some of these studies show gains in catch per unit effort associated with the dispersion from or spillover of adult fishes from closed areas (Roberts et al. 2001; Kaunda-Arara & Rose 2004; Stobart et al. 2009). These gains are, however, seldom able to compensate quickly for the lost catches associated with lost access to fishing grounds and may not occur unless closures are combined with other fisheries regulations (McClanahan & Mangi 2000; Smith et al. 2006). More significantly, compensatory increases in catch could take decades because fished populations recover slowly after fishing is stopped (Sladek Nowlis & Roberts 1999; Rodwell et al. 2002; McClanahan et al. 2007). Nearly all population models suggest that the benefits of fishery closures to the fishery are not evident unless a fishery is exploited beyond the maximum sustained yield and that, in many cases, managing for these yields with restrictions other than closures may be more socially realistic (Beddington et al. 2007; McClanahan et al. 2009*a*).

Those who favor expansion of areas closed to fishing frequently cite indirect or non-monetary values of these areas (Pikitch et al. 2004; Worm et al. 2006; Levin & Lubchenco 2008). In poor and subsistence-based societies, where food or provisioning ecosystem services and associated income are frequently most valued, the potential to receive indirect benefits may seldom stimulate support for area closures (McClanahan et al. 2005; Cinner et al. 2009). Profitability, therefore, remains a leading incentive for fisheries management and, yet, its empirical measurement has eluded researchers.

Profitability of fishing equals total revenue minus total costs, and total revenue equals price times the quantity of catch summed across all price groups. Prices are a function of supply and demand and are influenced by fish size, species, consumer preferences and fish quality, and the catch quantity-demand function (Grafton et al. 2006; Hart & Sissenwine 2009). Costs include the capital costs of boats and gear, their replacement rates, and operational expenditures associated with time, labor, and fuel. Calculations of closure profitability need to include these variables. Instead, the number of fish caught has been a frequent metric for evaluating the success of closures (Hastings & Botsford 1999; White et al. 2008). Prices are more difficult to model and track than catch because they depend on the above factors, local or fine-scale fishing effort and demand for fish, and other, often subtle, changes in local and larger economies over time (Whitmarsh et al. 2000). Thus, prices are seldom included among the criteria used to measure the success of fisheries closures.

Here, this gap has been bridged by analyzing fish catches, prices, revenues, and costs over a 12-year period when gear restrictions increased in areas with and without a closure. Fish catches were evaluated for responses of per person and per area annual yields, size of fish, and catch composition to elucidate the influence of these management options on the resource (McClanahan et al. 2008). Here, I extend these finding by focusing on fishing revenue, quantity of catch by price category, cost of different artisanal fishing methods, and profits produced by gear restrictions and fishery closures. I examined trends in prices by their taxonomic or commodity price groupings and by the relation of body length to price to estimate the profits to fishers under gear restrictions, gear and area restrictions, and no restrictions.

Methods

Study Sites and Sampling Design

Data on fish catch were collected at these same southern Kenya study sites described by McClanahan et al. (2008), and here I describe a parallel survey of fish prices and fisher expenses and incomes and additional years of data collection undertaken between 1996 and 2007. I present a brief description of the study; consult McClanahan et al. (2008) for more details on sampling design and measurements.

The fisheries of southern Kenya are typified by an artisanal fishery in which multiple gear types (e.g., hand lines, spear guns, traps, beach seines, fence nets, and gill nets) are used and a high number of species are caught in shallow coral reefs and seagrass within a few kilometers of shore. Fishers congregate at landing sites to sell their catch, and prices were sampled at these sites. Ten of the busiest fish-landing sites along a 75-km stretch of coastline were sampled during a time when pull-seine nets were prohibited. In 2001 most seine nets were disallowed; a few were used illegally in 2002 and 2003 in the south coast fishery, but were again prohibited in 2004.

Landing sites were pooled into three distinct management treatments based on a multivariate analysis of the fish catch and gear use (McClanahan et al. 2008). The three management treatments were designated Kenyatta Beach, south coast, and north coast. Kenyatta Beach was the most intensively managed. It was adjacent a 6-km^2 area closed to fishing, where small-mesh seine nets were prohibited in 2001. South coast was moderately managed and had six landing sites that were >30 km from an area closed to fishing. Most seine nets were prohibited in 2001 and all seine nets were eliminated in 2004. The north coast had three landing sites, there were no restrictions on gear, seine nets were the dominant gear, and sites were 1–10 km from an area closed to fishing. Data were collected at north coast sites beginning in 2001 and the area acted as a control for the implementation of gear restrictions in the two other management treatments. The elimination of seine nets and design of this study allowed for a direct and simultaneous before and after comparison of gear restrictions effects with and without a closure, which is the strongest part of the before-after-control and impact (BACI) design (Stewart-Oaten 2008; MacNeil 2008).

Sampling of Fish Landing Sites

Between 2 and 10 days/month, the number of gear used and the number of fishers and boats were recorded at each landing site. Landed fish were weighed to the nearest 0.5 kg. Fishes were categorized by the six taxonomic groups used locally to price and sell fish: goatfish (Mullidae; carnivores), parrotfish (Scaridae; herbivores and detritivores), rabbitfish (Siganidae, nearly all *Siganus sutor;* herbivores), scavengers (Lethrinidae, Lutjanidae, and Haemulidae; carnivores), octopus, and "rest of catch," (a category of mixed-feeding species common in the catch but not easily classified or not willingly separated into groups by fishers or marketers). An average monthly price per kilogram of fish in each category was recorded. More detailed but less frequent studies of fish lengths at the genus or species level were sampled during five intervals across this 12-year study period. Landed fish were counted and identified to the genus or species level (Smith & Heemstra 1986; Lieske & Myers 1994) and their standard lengths (tip of snout to end of last vertebra) were measured (McClanahan & Mangi 2004). More than 27,000 fish among 152 taxa caught with five gear types were sampled and data were pooled into commodity-price groupings by landing site and year for the analyses.

The capital investment and operational costs of fishing with different gear were evaluated at the beginning and end of this survey, and the average costs from these two surveys were used to estimate fishing costs (Mangi & Roberts 2006). Gears were often a mix of nonmarket and purchased materials, but only costs of purchased materials were included in the evaluation. Engines or fuel were not used in the fishery and time spent fishing is determined by the tidal cycle, varying from 3 to 5 hours/person/day during low-daylight tides. Consequently, daily per person fishing effort was assumed to be relatively constant and was not evaluated further for individual fishers or gears.

Ownership and cost of gear and canoes were estimated from discussions with fishers and by confirming prices from the main retail supplier in Mombasa. Life spans of gear and boats were determined from these discussions and costs converted to an annual basis. The numbers of fishers using specific gear differed from one for spear guns to more than 15 for a beach seine, and the numbers of boats in use ranged from none for spear guns to two for beach seines. Therefore, to simplify the calculation of the costs of fishing that were difficult to compare on a per person basis for the different fishing systems, the total number of gear and boats used in each of the three management systems was determined from the landing data (number of gear and boats divided by total area fished) and costs were estimated on a per area per year basis. The costs and profits of investors and self-employed fishers were estimated by calculating the density of the gear per unit area in the three management systems before and after 2001. Only self-employed fishers used spear guns, handlines, and fence traps, whereas investors who employed fishing crews owned nearly all beach seines and 60% of the gill nets (C. Abunge, personal communication).

Data Analyses

The average yearly price was multiplied by the yearly mean catch per unit effort (CPUE) of each catch group to estimate income for each catch category and all categories combined. Price data frequently passed tests of normality; therefore, analysis of variance (ANOVA) and post hoc Tukey tests were used to test for differences in the commodity groups among the three management groups and over time (Sall et al. 2001). Prices of fish on a per kilogram basis were most influenced by their size compared with local market demand, local inflation, and nearness to markets; therefore, I did not adjust landing-site prices for national-level inflation or nearness to markets. Inflation at the national level is considerable but because I focused on relative differences in profits over time, I did not adjust the data for inflation. I present prices in Kenya shillings (Ksh) because the ratio of Ksh to U.S. dollars ($) was highly variable (approximately 55–80 Ksh/$) within years and over the 12 years of study and did not appear to influence or reflect local fish prices.

Length of fish influences prices per kilogram because willingness-to-pay differs among marketers (commercial dealers, tourists, and small-scale buyers). Therefore, I pooled data on fish length by management treatment and price for each catch category, year, and management treatment. The relation between standard length and price per kilogram among management categories was tested with logarithmic, exponential, and linear regression models. I considered the best-fit models those with the highest R^2 values. I calculated gross revenue, expenditures and net profits per area for the three management systems from the mean daily density of fishers, their daily incomes, and results of the cost calculations. Daily visits to landing sites showed that fishing occurred on all days except Friday and during extreme weather. Therefore, I multiplied daily catch values at a landing site by 306 fishing days per year to determine annual income per area. The product of this calculation is larger than individual fishers' annual daily fishing expenditures (McClanahan & Mangi 2000) because catches at the landing sites are the sum of individual fishers' behavior.

I used the following equations to calculate the fishing costs, revenues, and profits: cost = sum for gear (range $\sum_{g=1}^{n}$) (gear investment/life span + boat cost/life span + annual maintenance) × number of gear/km^2; revenue = fisher income days × landing days/year × fishers/km^2; fisher income = sum fish price categories (range $\sum_{pc=1}^{n}$) (price per category × quantity of catch); profits = revenue − cost where g = gear and pc = price category.

Results

Over time fish prices rose slowly and differed significantly between price categories. Prices paid for fish, with the exception of the rest-of-catch group category, differed significantly among management treatments (Supporting Information, Table 1). Rabbitfish, scavengers, and goatfish were the most valuable fishes, whereas parrotfish, rest-of-catch, and octopus were the least valuable groups per kilogram. Prices were more influenced by fish size and management treatment than by species composition (Fig. 1, Table 2).

Annual average lengths of caught fish ranged from 10 to 23 cm. Prices per kilogram were sensitive to small changes in length; a 10-cm increase in fish length often tripled the price. The log models fit goatfish, parrotfish, scavenger, and rest of catch best, which suggest a decline in the rate of price increase with fish length (Fig. 1). The rabbitfish length-price relation fits a linear model best, which suggests no decline in the rate of price increase per kilogram for this group for sizes measured. Mean sizes of fish among the three management groups differed for goatfish, parrotfish, scavengers, and rabbitfish, but not for rest of catch (Table 2). Goatfish and parrotfish were longer in Kenyatta and south than north coasts, but there were no length differences in rest of catch among treatments.

The CPUE in Kenyatta and south coast increased 20% after the elimination of the beach seines. Prior to beach-seine elimination, CPUE was 3.2 (SE 0.3) and 3.0 (0.2) in Kenyatta and South coast, respectively. After beach-seine elimination, CPUE increased to 3.8 (0.2) and 3.7 (0.2) kg/person/day, respectively (Fig. 2). Per capita revenue increased 60–67% from 224 (41) to 374 (30) and 191 (12) to 306 (19) Ksh/person/day in Kenyatta and south

Table 1. Summary of mean prices in Kenya shillings (US$1 = approximately 75 Kenya shillings) for the different fishing-management treatments and commodity-catch price groups and two-way analysis of variance (ANOVA) for tests of significance for times and fishing treatments.[*]

	Location *Kenyatta*		*South coast*		*North coast*		*ANOVA*	
Family	*mean*	*SE*	*mean*	*SE*	*mean*	*SE*	*time* F, p	*management* F, p
Goatfish	112a	9.70	84b	5.61	78b	12.41	15.3, <0.0008	11.9, <0.004
Parrotfish	77a	5.48	84a	5.61	55b	7.35	18.4, <0.0004	27.8, <0.0002
Rabbitfish	112a	9.70	84b	5.61	78b	12.41	15.3, <0.0008	11.9, <0.004
Rest of catch	68a	3.74	59a	7.84	58a	11.22	8.7, <0.005	0.34, <0.72
Scavengers	112a	9.70	84b	5.61	78b	12.41	15.3, <0.0008	11.9, <0.004

[*]*Letters indicate differences in post hoc Tukey test results for comparisons of fishing treatments. Fishing treatments with different letters are statistically different from each other. Sampling periods are pooled but are based on continuous monthly sampling. Management treatments are arranged from most managed (Kenyatta) to least managed (north coast).*

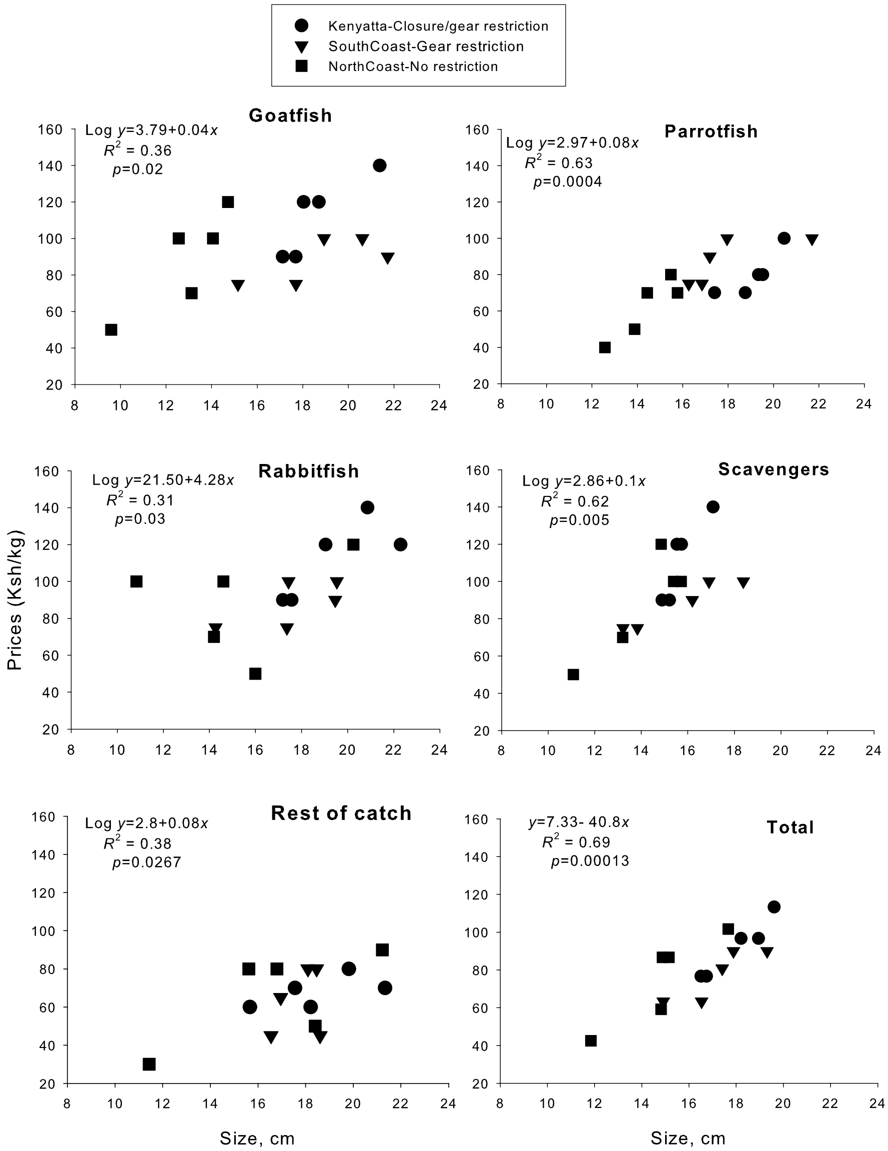

Figure 1. Relation of the average standard length of fish species pooled into each commodity category and the mean price per kilogram (Ksh, Kenya shilling) for that category during that sampling interval. Best-fit models from comparison of linear, log, and exponential options are presented.

coast, respectively. The CPUE in north coast control sites was 2.0 (0.1) kg/person/day and revenue was 159 (11) Ksh/person/day for 2002–2007. Fisher revenue in south coast and Kenyatta was 41 and 135% higher, respectively, than the north coast control sites after the beach-seine elimination.

Catch composition among management treatments and between gear-restricted areas differed significantly

Table 2. Summary of the mean fish length (cm) for the different fishing-management treatments and commodity-catch price groups and two-way analysis of variance (ANOVA) statistics for tests of significance for times and sectors.*

	Location *Kenyatta*		*South coast*		*North coast*		*ANOVA*	
Family	*mean*	*SEM*	*Mean*	*SEM*	*mean*	*SEM*	*time* F, p	*management* F, p
Goatfish	18.59a	0.74	18.82a	1.15	12.81b	0.89	5.1, <0.02	31.0, <0.0002
Parrotfish	19.10b	0.51	17.99a	0.96	14.42b	0.58	5.1, <0.02	27.8, <0.0002
Rabbitfish	19.39a	0.97	17.61b	0.96	15.18ab	1.53	1.4, <0.32	3.6, <0.08
Rest of catch	18.52a	0.97	17.73a	0.42	16.70a	1.62	1.9, <0.21	0.9, <0.46
Scavengers	15.69a	0.38	15.71a	0.96	14.05a	0.86	6.7, <0.01	4.4, <0.05

**Letters indicate post hoc Tukey test differences between fishing treatments. Sectors with different letters are statistically different from each other (SEM, standard error of the mean). Sampling periods are pooled but based on five periods: 1998, 2000, 2005, 2006, 2007. Sectors organized from most managed (Kenyatta) to least managed (north coast).*

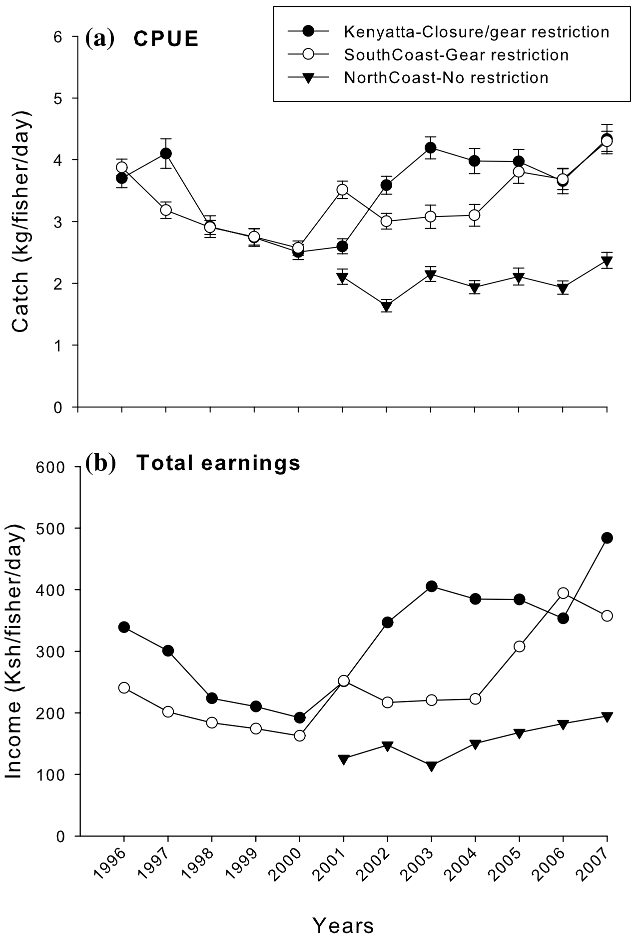

Figure 2. Catch per unit effort (CPUE) and total earnings per person in the three management treatment groups (Ksh, Kenya shilling). Incomes for all categories of catch commodities were pooled after gear management was undertaken in 2001.

(Fig. 3). Catches differed significantly among all taxonomic groups, except for octopus and rest of catch, over time and with time × management interactions. The slow elimination of seine nets in the south coast was associated with a rapid drop in catches of parrotfish and a slow increase in catches of goatfish, octopus, and particularly the rest of catch group. Catches of goatfish, parrotfish, rabbitfish, and scavengers increased in Kenyatta over time, but this increase was in progress before the elimination of seine nets. Conversely, octopus catches were declining prior to seine-net restrictions but then increased after implementation of restrictions. Control sites in the north coast had high catches of parrotfish (nearly all were seagrass-feeding *Leptoscarus vaigensis*). Control sites exhibited little change in catches over time, with the exception of a small decline in rabbitfish catches.

Over time there were small differences in per area (square kilometers) revenue among management treatments. These differences were partially attributable to the inverse relationship between number of fishers and their per capita income (Table 3). Number of fishers and the direction of change in revenue were, however, often the opposite of expectations based on effort alone. For example, there was no appreciable change over time in number of fishers in Kenyatta, but there was a 69% increase in gross and an 85% increase in net per area revenue after elimination of seine nets (Table 4). Furthermore, after 2001 the number of fishers in south coast declined 22%, gross per area revenue increased by 25%, and costs declined 21%, which resulted in a 29% increase in net income/km^2.

Annual costs of fishing were between 4 and 16% of the gross revenue. The highest costs were in Kenyatta before elimination of seine nets because fishers were accruing the combined costs of traps and seine nets. Annual costs were equally low in south and north coast and declined by 12 and 21% in south coast and Kenyatta, respectively, after elimination of seine nets in 2001 (Table 4). Net income was somewhat higher in south coast after net restrictions (US$12,000/km^2) than in Kenyatta and north coast (both approximately US$10,200/km^2). Net per area income increased 85% in Kenyatta after the gear restriction was implemented, but there was no change in fishing effort. The percentage of self-employed fishers who purchased their own gear increased when seine nets were restricted in Kenyatta and south coast. Percentage of self-employed fishers was lowest in north coast.

Discussion

This study is the first to examine empirically the effects of fisheries closures and gear restrictions on the long-term profitability of fishing. My results show that prices of fish can be critical to evaluations of fisheries closures and strongly influence profits and also closures combined with gear restrictions can increase profits. Profits increased because under gear restrictions and area closures larger fish were caught and larger fish fetched higher per weight prices. Closures increased the catch of valuable fish and this further enhanced per person profits, such that when both gear and closures were enacted together, profits increased further.

Population and economic models of fisheries closures, despite their sophistication, overlook critical aspects of closure profitability. Previous evaluations focused on management costs and benefits, opportunity costs, fish production and spillover, catch-price relations, source-sink population dynamics, indirect values, and ecosystem services associated with increased biodiversity in closures (Balmford et al. 2004; Grafton et al. 2006; Sanchirico et al. 2006; Hicks et al. 2009). Nevertheless, my study shows that fisher profits can increase with closure and gear restrictions despite heavy fishing, diverse gear and

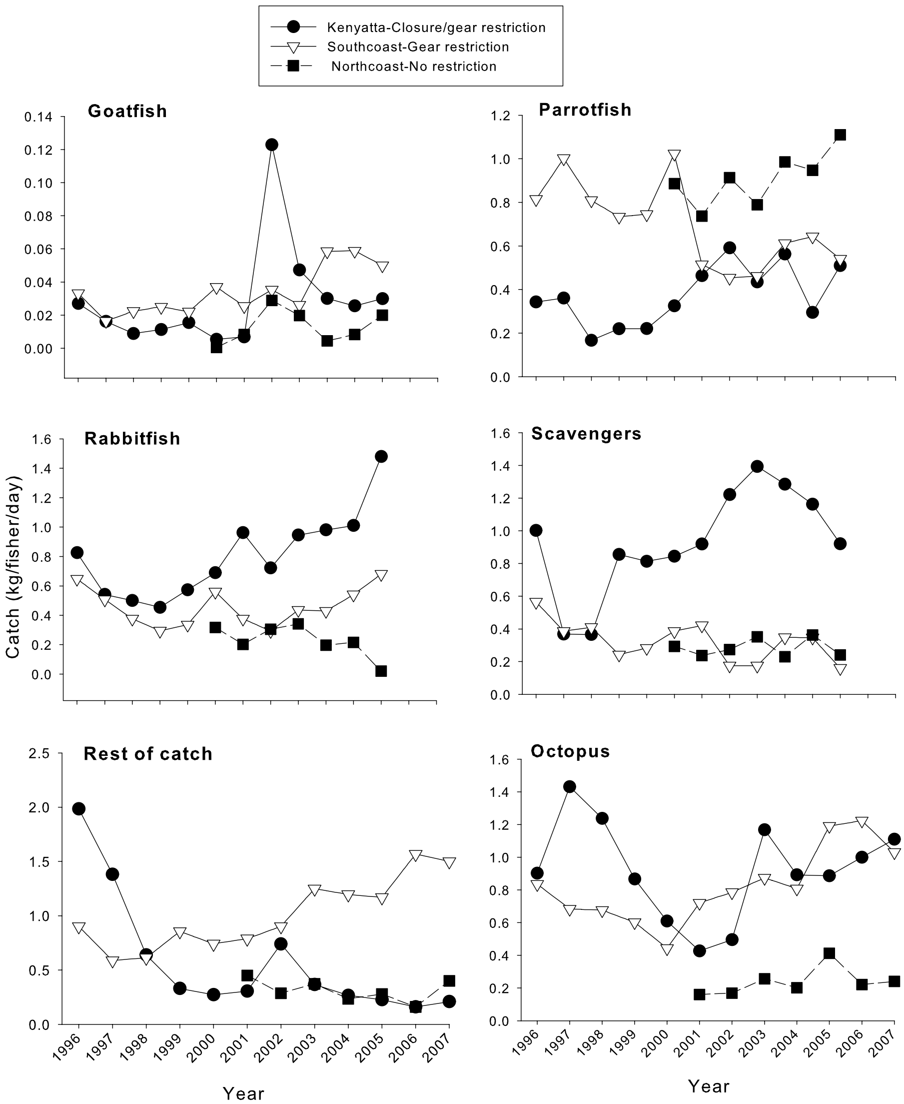

Figure 3. Catch per unit effort for the categories of catch commodity in the three management treatment groups in which gear management was undertaken in 2001. Scales on y-axes differ.

catch, poverty, and unregulated markets. In addition, increases in fishery CPUE after the elimination of the use of seine nets were more rapid adjacent to the closed area than in the area with only gear restrictions. This response is probably due to spillover or net outward migration of the accumulated biomass inside the closed area (McClanahan et al. 2007), but the slower and incomplete elimination of seine net use in south coast may have influenced the strength of this comparison.

Closures combined with gear restrictions were associated with increases in the abundance of rabbitfish and scavengers, which are among the most valuable nearshore species in the region. The price of rabbitfish and scavengers increased as very modest increases in length were achieved. In south coast the number of fish caught in the rest-of-catch category increased in gear-restricted areas. Fishes in this category are a mix of coral reef species, are of low monetary value, and are considered “trash fish” in some fisheries. Seine nets frequently catch a large number of seagrass-feeding parrotfish and other species of low value (McClanahan & Mangi 2004). Elimination of seine-net use led to a rapid drop in parrotfish catch, but it was more than compensated for by increased catches of other taxa of low value.

Early models of population closure simulated the abundance of key species under various configurations of closure age and size and used captured individuals and biomass as key output metrics (DeMartini 1993; Sladek Nowlis & Roberts 1999; Rodwell et al. 2002). Simple density-dependent models of larval and adult spillover have been enhanced by including theoretical predator–prey and behavioral responses to area closures, which indicate the potential for complex and possibly unexpected outcomes from closures (Rodwell et al. 2003; Micheli et al. 2004; Baskett et al. 2007). The field data presented here indicates generalist carnivore and herbivore catches increased next to the closure; numbers of carnivorous scavengers increased and leveled off faster than

Table 3. Costs (Kenya shilling per square kilometer) associated with fishing by gears and by location.

Cost factor	*Area*	*Gear type* *spear gun*	*handline*	*traps*	*gill net*	*fence trap*	*beach seine*
Gear							
gear, price		625	970	2,055	27,600	19,350	150,540
boat, price		0	19,500	19,500	19,500	19,500	190,000
gear, lifespan (years)		1	1.3	1.5	7.5	1.9	11.5
boat, lifespan (years)			13	13	13	13	13
maintenance costs		600	600	600	2,400	600	4,800
gear/year		500	776	1,370	3,680	10,459	13,090
boat/year		0	1,560	1,560	1,560	1,560	15,200
total yearly costs		1,100	2,936	3,530	7,640	12,619	33,090
investors (%)		0.00	0.00	0.00	60	0.00	100
Location*							
before 2001							
Kenyatta	3.6	3,854	4,466	46,161	7,852	0	18,384
south coast	15.9	8,224	1,947	35,623	3,077	0	7,455
after 2001							
Kenyatta	3.6	4,596	3,792	51,314	10,726	0	0
south coast	15.9	9,534	2,359	27,825	3,180	0	1,056
north coast	7.8	2,066	1,212	8,235	776	1,084	20,609

**All years before and after 2001 pooled on the basis of the number of gear used per area. There are no data for the north coast before 2001.*

the herbivorous rabbitfish. I expect rabbitfish catches to increase further over time because their catch had not leveled off by the end of the study. Long-term studies of Kenyan areas closed to fishing show that even after 37 years of closure, rabbitfish numbers inside closures and some other taxa had not recovered fully (McClanahan et al. 2007).

Restrictions on gear, mesh size, and fishing area increase the time to capture. Kaunda-Arara and Rose (2006) found that a number of the common fisheries species considered here grow at approximately 10 cm/year. Therefore, a 1-year delay in harvesting can nearly double fish sizes and prices. The sizes of fish caught in this fishery were small relative to those caught in less heavily fished reefs (Cinner & McClanahan 2006), and this may be responsible for the strong size-price relations observed here. Consequently, if prices respond strongly to increased sizes, then this high marginal-utility effect can greatly promote fisheries profitability even with small restrictions in heavily fished ecosystems.

In addition to affecting the size of fish caught, closures increased catches of valuable species. Whether this finding is serendipitous, a regionally specific characteristic of the fish fauna, or a common attribute of closures is unknown. Regardless of the mechanism, models that evaluate closure benefits and profitability can be improved by including species and size-price differentials, which are critical measures for evaluating and potentially adopting closures (Hart & Sissenwine 2009).

Gear and the organization of labor were different among the three management treatments. Capital investments, annual recurrent costs, and associated revenue distribution were the most notable differences. Ownership of gear played a large role in the organization of labor and income distributions; beach seines and large gill nets were owned infrequently by fishers. In Kenya gear

Table 4. Cost-benefit (per square kilometer) analyses of the three systems of fishing management on the basis of all gears combined.*

Location	*Fishers/ km²/ day*	*Revenue/ fisher/ day*	*Costs (Ksh/km²/ year)*	*Revenue (Ksh/km²/ year)*	*Costs/ revenue (%)*	*Net income (Ksh/km²/ year)*	*US$/ km²/ year*	*Self-employed (%) costs*	*Self-employed (%) profits*
Before 2001									
Kenyatta	7.2	229	80,716	493,517	16.4	412,800	5,504	71.4	50
south coast	12.9	191	56,327	753,953	7.5	697,626	9,302	83.5	73
north coast									
After 2001									
Kenyatta	7.3	374	70,428	835,441	8.4	765,014	10,200	90.9	75.6
south coast	10.1	306	43,954	945,724	4.6	901,769	12,024	93.3	88.2
north coast	16.5	159	33,982	802,791	4.2	768,809	10,251	38.0	28.1

**Values are in Kenya shillings (Ksh) unless otherwise stated (US$1 = 75 Ksh).*

owners make most of the gear investments, employ fishers, and divide the daily income, half of which is kept by the owner and half of which is divided among the crew. Area was the unit of evaluation of costs and incomes; therefore, the profit of crews was not evaluated, which underestimates the income disparity in this open-access fishery. Gear owners also frequently market the fish and supply nets to fishers as part of their seafood-product businesses, which increases the value of fish and profits to owners (Fulanda et al. 2009). In contrast, self-employed fishers used primarily gear with either lower capital outlay or recurrent costs, but these types of gear can have shorter life spans. In most cases self-employed fishers reduce the costs of fishing and can influence net profits, although costs were always <15% of gross incomes. One exception was the use of traps, which have a low capital cost and a short life span. The use of traps in the Kenyatta fishery resulted in high operational costs, particularly when they were used in combination with seine nets. Restrictions on gear can influence investment, gear longevity, and the ratio of investors to self-employed people and associated economies. Decisions on gear restriction will affect income equity and, therefore, could influence the political process.

Many marine scientists consider fisheries closures the cornerstone of marine ecosystem management (Pikitch et al. 2004; Sandin et al. 2008). Resource users whose incomes are directly affected by closures are, however, less supportive (McClanahan et al. 2009*a*). Resource users object to the potential loss of fishing area, yield, and income and question the overreliance on poorly tested harvesting models, uncertainty in the environment, and the weak empirical basis for claims of long-term gains (Ludwig et al. 1993; Crowder et al. 2000). The scientific uncertainty of the outcomes of closures and gear restrictions and the potential temporary loss of income has led to controversy and slow or reluctant adoption of closures. This conflict cannot be resolved without knowledge from long-term empirical studies (Hilborn et al. 2004; Pauly 2009; Worm et al. 2009). Net profitability of closures depends on the balance of revenue, costs of fishing, and lost fishing area for different closure sizes and configurations (McClanahan & Mangi 2000; Gerber et al. 2003). Nonetheless, my results indicate fisheries profitability can increase when small- to moderate-sized closures are implemented adjacent to areas with gear restrictions.

The closure I examined was specifically created to increase tourism revenue in a popular tourist destination. The total economic value of the closed area, primarily from recreation, was estimated at US$3.5 million/km^2/year (Hicks et al. 2009), which is about 350 times the value of the fishery. This value dwarfs the fishery value, but once gear restrictions were in effect, the closure also modestly increased fisher incomes. Increasing fisher incomes can assuage the unsupportive groups of resource users who do not directly benefit from recreational uses. Given the important role high-compliance fisheries closures play in the protection of species in this region (McClanahan et al. 2007; 2009*b*), navigating this political passage with information from empirical and long-term case studies is likely to improve the chances for adoption of and compliance with closed areas.

Acknowledgments

The Wildlife Conservation Society supported research through the assistance of Kenya Wildlife Services and Kenya's Fisheries Department and financial assistance from the Tiffany Foundation. I greatly appreciate the assistance of C. Abunge, C. Hicks, S. Kitema, S. Mangi, P. Mutisya, J. Omukoto with collection of field data and C. Abunge and P. Thoya with graphs and tables. J. Cinner and C. McClennen made valuable suggestions on a draft of the paper. Fisheries leaders and Kenya's Fisheries Department assistance with establishing and maintaining this management system created this unique opportunity to evaluate management.

Supporting Information

Prices of the fish commodity categories by management treatment are available as part of the online article (Appendix S1). The author is responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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