Catch rates and income are associated with fisheries management restrictions and not an environmental disturbance, in a heavily exploited tropical fishery

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ABSTRACT: We evaluated and compared the influence of the largest temperature anomaly in recent history, the 1997–1998 El Niño–Indian Ocean Dipole anomaly that killed half of the corals in the Indian Ocean, with a nearly coincident increase in fisheries management restrictions on coral reef fisheries in southern Kenya. Seawater temperatures, benthic primary producers, and fishing effort and catch rate and income time series collected over the 1993–2012 period were evaluated using time series and variable cointegration methods. An observed decline and subsequent increase in catch rates was closely associated with the implementation of increasing fisheries restrictions and was not predictably cointegrated with the temperature or the primary producer's time series. This may have occurred because the disturbance was pulsed with a limited 6 yr impact on the primary producers and the fishery was heavily utilized and composed of fast-growing generalist species with broad diet and habitat needs. Consequently, under these conditions, promoting fisheries restrictions is expected to attenuate the predicted declines in fish catches projected by global warming.

KEY WORDS: Adaptive management · BACI design · Food security · Global change · Granger causation · Poverty alleviation · Sustainable fisheries

INTRODUCTION

Climate and fishing disturbance have the potential to undermine the sustainability of tropical coral reef fisheries and the associated food security of millions of people living in tropical climates (Cheung et al. 2010, 2013). A divisive societal debate concerns the extent to which efforts at increasing human adaptive capacity in poor nations and associated natural resource management can counter the detrimental effects of global warming-induced disturbances (McKibben 2012). In the marine environment, increasing demand for resources combined with the effects of global climate change will challenge the future maintenance of fisheries production in tropical coun-

tries (Worm & Branch 2012). Losses of habitat, fisheries production, and biodiversity are expected to increase and the potential to counter these losses with management solutions remains poorly investigated (Pratchett et al. 2008). Millions of people in tropical countries depend on natural coastal habitats, such as coral reefs and associated seagrass beds, for seafood; yet, coral reefs are sensitive to human and climate impacts and have been degrading globally in many regions over the past 3 decades (Gardner et al. 2003, Bruno & Selig 2007, Ateweberhan et al. 2011). Consequently, it is imperative to determine if and what increased management efforts have the potential to attenuate the effects of environmental degradation that arise from the strong and large-scale dis-

turbances expected to occur at an increasing frequency in the coming decades.

Studies of coral–fish–fisheries interactions and impacts of coral loss have found that the loss of corals most frequently reduces the abundance of small and coral-dependent fish, and could potentially lead to extinction of the most vulnerable species (Pratchett et al. 2008, Graham et al. 2011). Nevertheless, the subsequent effects on the fisheries have been less clear and difficult to study because of the expected time lag responses between losses of smaller and prey species on the larger and predatory fish and their potential interactions with fisheries management (Graham et al. 2007, 2008, Karkarey et al. 2014). Further, management restrictions might improve the outcomes and hide the full effects of environmental degradation expected from climate change. Given the extent and high dependence of tropical countries on coral reef resources, it is prudent to investigate and develop management systems that can potentially attenuate the predicted increasing severity of climate impacts.

Here, we examined time series of water temperatures, benthic cover of calcifying and non-calcifying primary producers, and fisheries catches to evaluate the evidence for a coupling of these environmental factors with catch rates of reef fishes. Specifically, we investigated whether the warm temperature anomalies that cause losses in coral and calcifying organisms also lead to declines in reef fish catch rates. This was contrasted with an alternative: that improved fisheries management can counter the predicated losses. In Kenya, the near simultaneous before and after nature of a thermal disturbance and increased fisheries restrictions made it possible to compare these 2 predictions, that is, that catch per unit effort (CPUE) should (1) decrease with the thermal disturbance and (2) increase with increased fisheries restrictions. We used a combination of variable cointegration and before and after, control and impact (BACI) methods to detect the possible cause and response variables and to test the 2 alternative predictions (MacNeil 2008).

MATERIALS AND METHODS

Management experimental design

A forum of fishers, non-governmental organizations, and government agencies ('Kenya's Fisher's Forum') developed a co-management program that collected and used fisheries and ecological data as a basis for making management decisions (McClanahan 2007).

This forum was established in 1994 to evaluate the status, changes, and management needs of the southern Kenya fishery. A measured steady catch rates decline in the landing sites from 1995 to 2000 led to discussions that eventually resulted in implementation of gear restrictions and community closures at selected sites. In the more southerly sites, where small-meshed beach seines were seen as the main fisheries problem, the co-management program led to their slow elimination between 2001 and 2004 (Fig. 1, Table 1). In sites where seine nets had not been used or had been removed, smaller community closures of <0.5 km^2 were established throughout the mid to late 2000s. These management restrictions were closely coincidental with the 1997–1998 El Niño–Indian Ocean Dipole warm temperature anomaly that caused a large and widespread loss of coral cover and changes in the benthic cover in the fishing grounds (McClanahan et al. 2001, Ateweberhan et al. 2011).
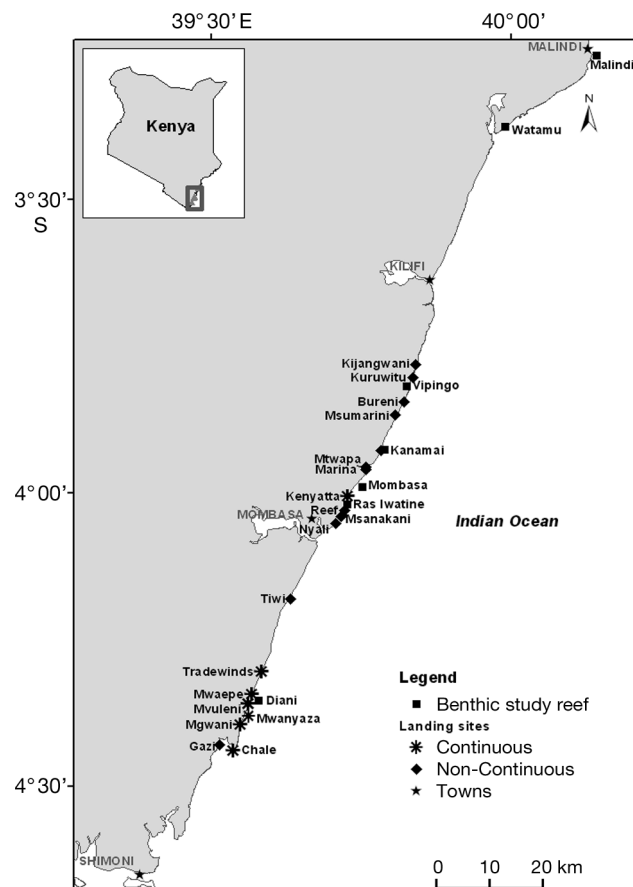

Fig. 1. Distribution of the study sites in southern Kenya. These include benthic cover and *in situ* temperature monitoring sites, and fish landing sites that were sampled over the whole study period; and those added later in the sampling period (excluded from the full time series analyses but shown in Fig. 3)

Table 1. Summary of fisheries management restrictions used at each of the studied landing sites, the time at which sampling began, and the use of data collection in the 2 analyses. Sites are organized from oldest to youngest in terms of data collection, but see Fig. 1 for their spatial locations

Sites	Management type	Beginning of sampling period	Used in full time series	Used in partial analyses
Kenyatta beach	Gear restriction and a national closure	1995	X	
Tradewinds	Gear restriction	1996	X	
Mwaepe	Gear restriction	1996	X	
Mvuleni	Gear restriction	1996	X	
Mwanyaza	Gear restriction	1996	X	
Mgwani	Gear restriction	1996	X	
Chale	Gear restriction	1996	X	
Nyali	No restriction, mixed gear	2001		X
Marina	No restriction, mixed gear	2001		X
Mtwapa	No restriction, mixed gear	2001		X
Kanamai	Community closure with gear restriction (no beach seine)	2005		X
Kuruwitu	Community closure with gear restriction (no beach seine)	2005		X
Kijangwani	Community closure with gear restriction (no beach seine)	2005		X
Msanakani	Beach seine	2005		X
Nyali (Reef)	Beach seine	2005		X
Bureni	Community closure with gear restriction (no beach seine)	2009		X

Study sites

Kenya's southern coast (3° to 4° S) is fringed by ~250 km coral reef located ~1 km offshore and has a fairly uniform reef lagoon containing a mixture of corals, sand, and seagrass and an outer reef edge that drops into a sand plain at ~10 to 15 m depth (Fig. 1, Table 1). This lagoon and the immediate reef edge are ecologically similar between sites in terms of the habitats and gross benthic and fish composition, but differ in the abundance of fishers (~5 to 20 fishers km^{-2}) and the types of fishing gear that they use (McClanahan et al. 2008). These gears include traditional basket traps, nets, lines, spearguns, and various types of stationary nets and dragnets (McClanahan et al. 2008). Fishers travel to their fishing grounds by foot, canoes, and small sailing boats, while motorized boats are seldom used in the fishery. For this study, we selected fish landing sites for their gross ecological similarity, but their differences in gear and closure management.

We began fisheries catch surveys in most sites from 1995, but additional landing sites were added until 2009 (Table 1). In the southern study region, the sites of Tradewinds, Mwaepe, Mvuleni, Mwanyaza, Mgwani, and Chale were sampled from 1996 and these sites used a mix of gear dominated by small-meshed beach seines that were eventually removed by a co-management project between 2001 and 2004 (McClanahan 2007). Prior to this study, a national government closure (Mombasa Marine National Park — 6 km^2) was enforced adjacent to the Kenyatta

landing site in 1991 and restriction on small-meshed nets near the closure began in late 1994 prior to this study. Kenyatta Beach was therefore considered a positive management intervention control site. In 2001, we also added 3 nearby landing sites that used beach seines, namely Nyali, Marina, and Mtwapa, to act as negative management intervention controls. Further, between 2005 and 2009, 6 additional and similar reef lagoon landing sites in the areas of Bureni, Kanamai, Kuruwitu, Kijangwani, Nyali (Reef), and Msanakani sites were added. These sites acted as management experiments or their controls to evaluate the emerging influence of community-level fisheries closures established in the northern region. In 2009, 2 of the larger landing sites, Kenyatta Beach and Mwaepe, were each given a motorboat as part of a donor aid program (USAID) to improve fisheries catches. The boats frequently travelled and fished beyond the reef and the usual reef fishing grounds, but landed their catch at these sites. The catch rates increased, but so did the operating costs, and these boats were abandoned and no longer present at the landing sites after 2010. Therefore, to make direct comparisons of the catch in our reef lagoon and treatments over time, the catch rates for 2009 were excluded from the time series analyses.

Ecological studies

Reef lagoon temperature data and benthic cover data were part of a coral reef monitoring program

that included 14 sites in 7 reefs maintained in shallow (1 to 4 m at low tide) Kenyan back reef lagoons from 1991 to 2012 (Fig. 1). These ecological study sites were back reefs near the fishing landing sites and frequented by the fishers who landed catch at the above landing sites. Automated temperature gauges (HoboTemp, OnSet) were established in 7 of these benthic monitoring reef lagoons starting in 1996 (Fig. 1). Gauges were placed beneath corals and set to collect temperature measurements every 1 to 3 h and the analyses are based on annual means from a total of ~250 000 measurements. While some gauges were periodically broken or missing, the differences in mean values among these sites were small, and periodic losses were not expected to influence the mean temperatures used in the analyses (Carreiro-Silva & McClanahan 2012).

Benthic cover was estimated by the line-intercept method, where ~1000 m of line transect was completed in each of the 14 sites within the 7 reef lagoons as described in McClanahan & Shafir (1990). Benthic cover categories included turf, red coralline, green calcareous, and erect fleshy algae; and sponge, soft and hard coral, and seagrass. We pooled the calcifying (red and green coralline algae and hard coral) and non-calcifying (turf and erect algae, seagrass, sponge, and soft coral) to test the potential role of these 2 groups and their associated primary production and calcification effects on the fish catch rates. Non-calcifying algae have high organic primary production while calcifying taxa have lower organic production because they contribute more to inorganic carbon reef production (calcium carbonate). Consequently, a decline in calcification and an increase in non-calcifying algae could increase reef benthic and fisheries production. Nevertheless, the opposite is the most frequent prediction among reef ecologists who commonly view reef habitat as critical to fish biomass and production (Pratchett et al. 2008). The response may, however, depend on the diet and habitat requirements of the fish and their subsequent importance in the reef catch (McClanahan et al. 2002, Wilson et al. 2006, Sebastian & McClanahan 2013).

Fisheries studies

The main fishing gears catch mostly benthic or coral reef- and seagrass-associated fish species (Hicks & McClanahan 2012). The occasional or seasonally large catches of pelagic or invertebrate taxa, such as anchovies, sea cucumbers, and lobsters were recorded but not included in the analyses. Two methodologies were used to sample fish catches at the 17 landing sites. The longest and most frequently used method was to weigh fish in the dominant, widespread, and common taxa, which were naturally pooled by fishers into groups based on their markets and prices. These groups include scavengers, rabbitfish, parrotfish, goatfish, octopus, and a 'mixed group' of diverse coral reef fishes of low market values. The benthic catch was not combined with pelagic species in the catch or in the measurements and subsequent analyses. Fish landing sites were visited 2 to 3 times per month on haphazardly selected days and the weights of the above groups taken to the nearest 0.5 kg along with the numbers of boats, fishers, and their gear use associated with the catch recorded.

The second method periodically measured standard fish lengths at the genus or species level between 1998 and 2012. Fish were identified, their names recorded, and their lengths measured to the nearest millimeter. When catches were small to modest, every individual fish landed was measured. When catches were large, care was taken to sample the different species in proportion to their numbers and sizes caught. The fish length data were pooled by family, all taxa combined, and management type, and tested for a predicted increase in mean lengths with increased fisheries restrictions. This study presents analyses for the 7 continuously sampled landing sites based on 6257 fish length measurements and the full sample of all sites and times based on 8695 measurements.

The prices of each of the above fish groups were recorded and average annual values calculated to estimate revenues of the fishers for the analyses. This fishery is largely part of Kenya's informal economy of subsistence-livers and we, therefore, did not adjust prices by a national inflation rate, which may not reflect well the price values or temporal dynamics of these local markets.

Data analyses

The main goal of the analyses was to test the theoretical predictions of fisheries management and disturbance ecology by evaluating evidence for a coupling between temperature, benthic cover, and fish catch rates. The measurements above allowed for a test of the influences and potential coupling between catch metrics and fisheries management and temperature disturbance and benthic response variables. Calculations of these data included changes in catch

rates (CPUE), effort (yield; kg) and fisher numbers (km^{-2} d^{-1}); the income of fishers (Kenya shillings where US\$1 ≈ 70–80 KSh), and standard body lengths (cm). For this primary analysis, we used only the original 7 fish landing sites and the corresponding full coral reef benthic and temperature monitoring data to avoid the confounding effects of adding new fish landing sites during the time series (Table 1). These analyses were based on a total record of 36 367 fish catch measurements.

We used cointegration and Granger causation analyses, commonly used by economists to test for the coupling of variables, prices, and products in economic markets (EViews 7 software; Griffiths et al. 2008). All variables were tested by the Augmented Dickey Fuller test statistic for stationarity and found not to be stationary in level and therefore appropriate for cointegration using both trace and maximum-eigenvalue statistics. Using these variables, we tested for causative relationships between temperature and the benthic variables to test the null hypothesis that the catch rates were controlled by the temperature or 2 benthic cover variables (organic and inorganic primary producer cover) rather than fishing effort and management. Acceptance and presentation of appropriate lag selection was based on evaluation of Akaike's information criterion of different realistic time lags.

The full data set of all 17 sites is presented in time series graphs, where we used the full set of 51 690 fish catch weight measurements. The more recently added landing sites and shorter time series information are presented in separate figures to augment findings from the longer time series and cointegration analyses. In our analyses, we pooled landing site data by the gear and management categories based on a cluster analysis of the gear used (McClanahan et al. 2008). We distinguished 5 management groups, which included sites with gear restrictions, gear restriction and a national closure, beach seine sites (where beach seines were the dominant gear in use), no restriction (a mixture of gear where beach seine were used but other gears were also common), and landing sites with a small community closure with no beach seines. All catch analyses were based only on benthic-associated species that feed in the nearshore coral reef, sand, and seagrass habitats.

Detrended correspondence analysis (DCA) was used to analyze catch composition to determine whether there were indications of permanent directional change in the fish catch rates for either the family or genus–species level data. DCA is a multivariate statistical technique widely used to find associations in large and species-rich data sets that typify ecological community data. We tested for outliers and present the main 2 DCA axes after removing outliers using JMP statistical software (Sall et al. 2001).

RESULTS

The global-scale temperature anomaly in 1998 and increased management efforts beginning in 1990s were the main temporal characteristics of the environmental and fisheries time series (Figs. 2 & 3). The unusual rise in mean annual *in situ* seawater temperature measured in the reefs from 1997 to 1998 was followed by a decline and subsequent smaller and more gradual rise from 2005 until the end of the time series in 2011 (Fig. 2). The 1997–1998 temperature rise was followed by a rapid change in the benthic cover with a rapid decline in hard corals and other calcifying benthic cover (red and green calcifying algae) and an increase in non-calcifying benthic cover (turf and fleshy algae) (Fig. 2). Subsequent to the rapid decline, calcifying benthic cover increased and non-calcifying cover declined for about 6 yr before stabilizing.

We found that sea surface temperature (SST) and catch rates were not cointegrated or 'Granger caused', which suggest no cause and effect relationships between catch rates and *in situ* SST for the fisheries taxa over this period (Table 2). While the organic and inorganic cover variables were cointegrated with catch rates, the Granger analysis did not find any spectral correlations for the expectation that their cover change preceded catch rate changes. Consequently, the significant cointegration was a result of the ecologically unlikely cause and effect implication that the catch rates 'Granger caused' the benthic cover changes. The massive observed change in benthic cover was, however, caused by the 1997–1998 temperature anomaly (Fig. 2).

In contrast, the catch rates and income increases were partially associated with declining daily fishing effort — associated with an increase in gear restrictions (Figs. 3 & 4). The increase in catch rates occurred 2 yr after the 1997–1998 temperature anomaly and continued to increase after the recovery of the benthos. Further, there was generally higher catch rates during the reversal rather than the initial increase in fishing effort. Fish body lengths rose steadily and by ~6 cm overall for the dominant catch species (Fig. 5a) and also when pooled into the management systems (Fig. 5b). The high catch rates in 2009 were associated with the supply of 2 motorboats
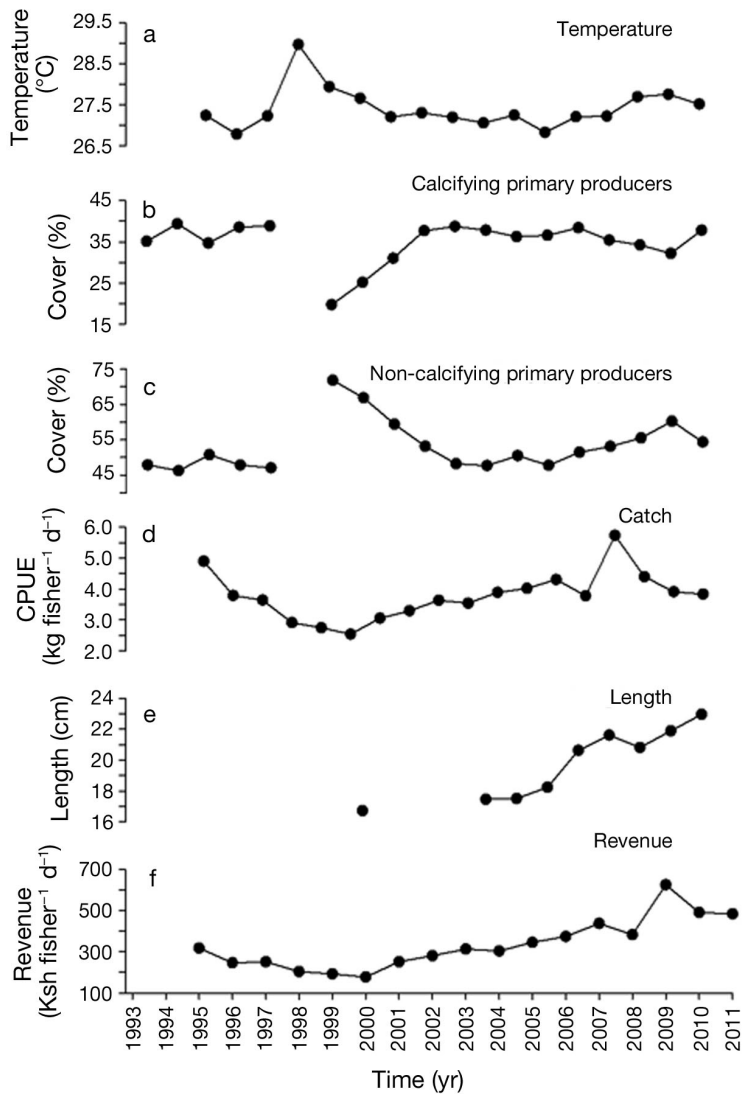
Fig. 2. Time series of Kenyan nearshore variables showing (a) reef lagoon water temperature, (b,c) the gross benthic cover categories of (b) calcifying (hard coral and calcifying algae) and (c) non-calcifying (sponge, soft coral, and non-calcifying algae) taxa, (d) catch per unit effort (CPUE), (e) fish body lengths, and (f) fishers' daily revenue in southern Kenya. Catch data are based on the 7 landing sites where data were collected across the full study period. Additional catch data for other landings sites are presented in Fig. 3. The 'missing' sample of benthic cover in 2008 is an artifact of a change in the monthly sampling in that year (moved from November to December to January to February). Ksh: Kenya shillings
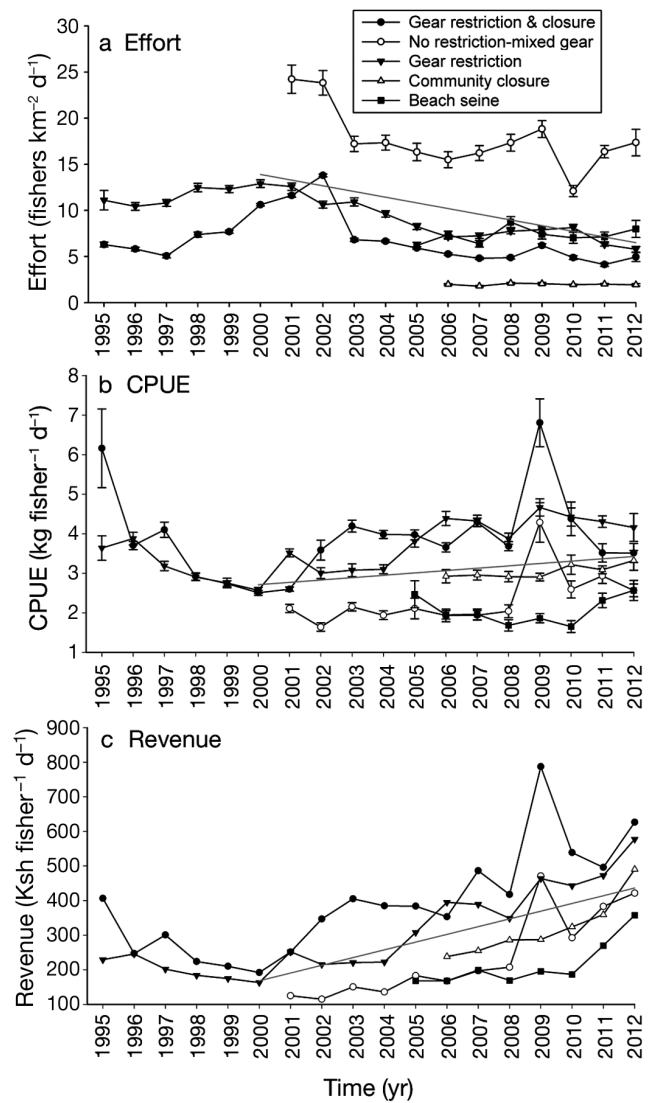

Fig. 3. Time series of the catch pooled by the different management systems showing (a) fishing effort, (b) catch per unit effort (CPUE), and (c) fishers' daily gross revenue. This figure includes other landing sites added during the study period from 2001 to 2009. Error bars are SE; grey lines are best-fit regression lines for all sites combined from 2000. Ksh: Kenya shillings

(none existed prior to this point) by an international donor.

The possibility that the increase in catch rates was caused by a change in fish catch composition was examined for both the family-level and the more resolved but less frequently collected genus-to-species-level data. Multivariate analysis of the catch composition did not, however, indicate any clear or permanent directional change in the fish catch rates for either the family-level (1995 to 2013; Fig. 6a) or the genus–species-level data (1998 to 2013; Fig. 6b). Years both before and after 1998 were associated with the major family groups, with the exception of a period from 2004 to 2008 where higher dominance of goatfish and mixed catch were recorded. The genus–species-level data exhibited shifts among the different taxa, mostly among herbivores and micro-invertivores, but without any clear association for a particular functional group at any time.

Table 2. Cointegration and Granger analyses results of the full time series of the 7 reefs for associations between reef lagoon water temperature, pooled benthic cover categories, and catch per unit effort. The Granger output presented here is the test for a 1 yr time lag, which is reasonable given the high growth and turnover of the fisheries species. The tests that catch rates cause benthic cover or temperature change are not shown. NS = not significant and S = significant

| Variable | Cointegration tests | | |
	Trace and maximum eigen statistic	Critical values, trace and eigen value $p < 0.05$	Probability and decision
Temperature	2.99, 9.12	3.84, 14.26	0.28, NS
Non-calcifiers	3.69, 15.16	3.84, 14.26	0.04, S[a]
Calcifiers	8.86, 14.34	3.84, 14.26	0.05, S[b]
	Granger causation test		
	F-statistic	p	
Temperature	0.99	0.34	NS
Non-calcifiers	0.001	0.97	NS
Calcifiers	0.69	0.43	NS

[a]Vector error correction model (VECM) found a significant speed of adjustment to the long run equilibrium of 27% ($t = -2.87$, $p < 0.02$)
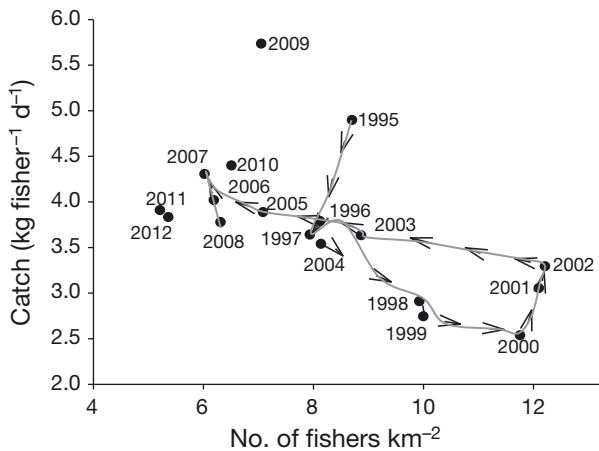[b]VECM did not find a significant adjustment to the long run equilibrium ($t = 1.51$, $p = 0.16$)

Fig. 4. Annual average daily catch rates as a function of fishing effort. Data shows a declining catch rate with increasing effort as measured by fishers per area per day from 1995 to 2000 and then a reversal of this pattern after 2002, but with higher catch rates after than before the management restrictions. Arrows represent direction of time. The unusually high catch rates in 2009 were associated with the supply of 2 motorboats by a donor, which were abandoned by 2010 due to high operating costs

DISCUSSION

Based on the lack of ecologically meaningful cointegration between the temperature and the 2 primary producer variables, we concluded that there was not a strong coupling between the environment and the fish catch. The increase in mean body lengths and the lack of directional change in the taxonomic composition further collaborates the dominant role of changing management in causing the observed changes. An increase in body size is one of the primary expectations of increased fisheries restrictions. Consequently, reduced fishing intensity and gear use restrictions were the likely causes for the rise in catch rates and fisher's revenues. These findings indicate the important role that management may play in attenuating the predicted detrimental effects of climate change on some tropical fisheries (Cheung et al. 2010, Worm & Branch 2012).

If there was an impact of the 1997–1998 temperature anomaly on the fish catch community, it was difficult to detect in this catch time series data. Seawater temperatures in East Africa have been shown to potentially influence total fish catches (Jury et al. 2010). Higher total catches have been associated with cooler offshore temperatures, but this finding is not specific to coral reefs and includes all caught fish, including pelagic and offshore catches (Jury et al. 2010). In contrast, the findings here support previous visual census studies reporting declines for only coral-dependent and small-bodied species, which are species infrequently taken in the fishery (Graham et al. 2008, 2011). Therefore, the current consensus is that the impact of lost calcifying cover on reef fisheries requires a 5 to 10 yr lag after the climate disturbance before negatively influencing the fishery (Graham et al. 2007, 2008, 2011, Pratchett et al. 2008).

Here, we extended a fisheries study in a coral reef lagoon beyond this 10 yr horizon and yet failed to find detectable coupling that might implicate catch losses due to the 1997–1998 disturbance. In contrast, a study of catch rates in the remote Aldabra islands of the Seychelles that captured only large-bodied, top-level predators found catch rate declines in some grouper taxa ~5 yr after the 1997–1998 disturbance, which they attributed to declining prey caused by degradation of the reef (Pistorius & Taylor 2009). Some of these small-bodied prey species are typically dependent on hard coral cover for recruitment, survival, and growth and are therefore sensitive to losses in coral cover (Graham et al. 2007, 2011).
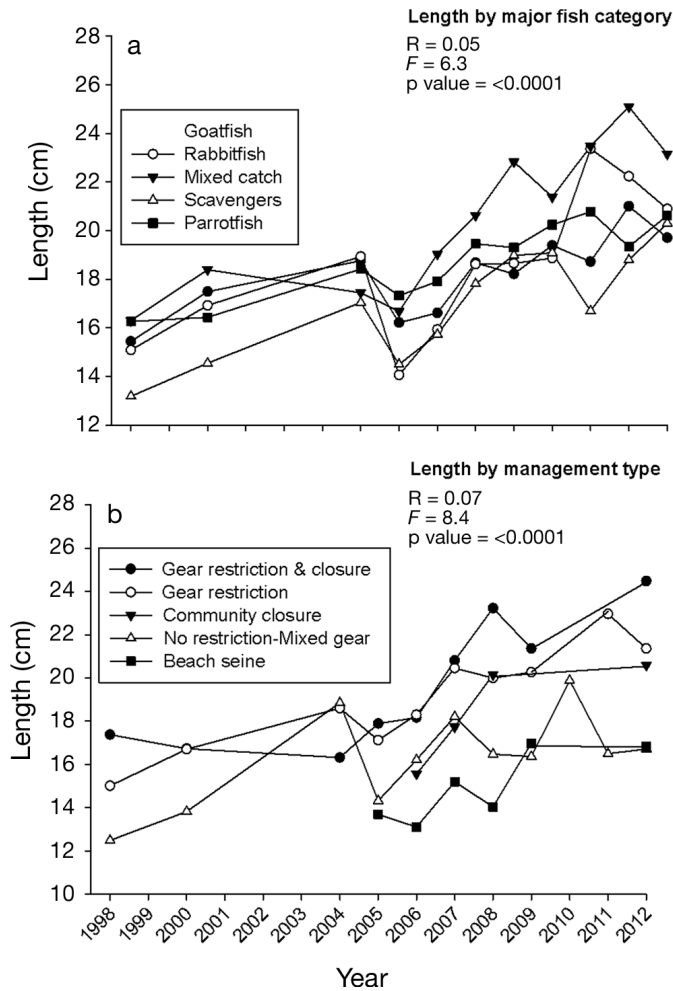
Fig. 5. Changes in the mean length of captured fish in Kenya by (a) fish family and mixed catch, and (b) the type of management restrictions in place at the landing site. Data are based on periodic sampling of fish lengths at the landing sites and pooled by the year of sampling, and fish catch and management categories
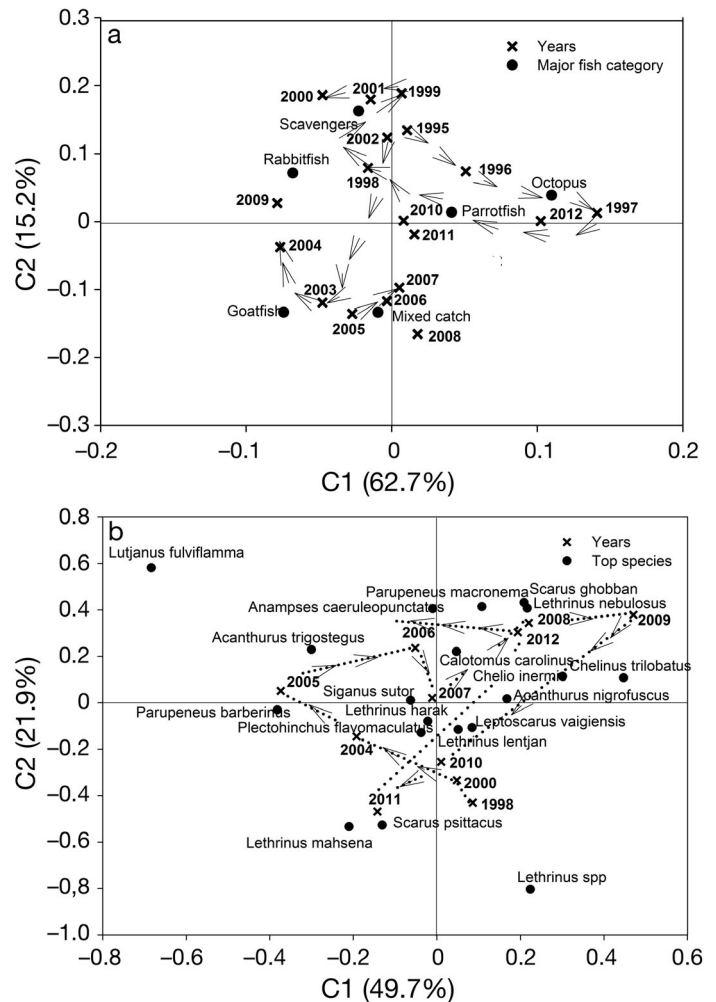

Fig. 6. Multivariate analyses (detrended correspondence analysis) of the fish catch time series by (a) annually collected fish families and mixed catch, and (b) the less frequently collected genus–species-level catch data collected for length–frequency analysis

Karkarey et al. (2014) showed that grouper numbers declined on reefs where structural complexity was lost after coral mortality, which is likely due to a loss in their coral-dependent prey. Consequently, the issues of what species are caught in the fishery, their reliance on coral reefs and prey, and the extent of the disturbance may all play a role in the outcomes of the disturbance on the fishery.

Differences in the fisheries responses between Kenya and the remote Seychelles islands are likely to reflect local differences in the fisheries and habitats. First, the Kenyan fishery has been heavily fished and groupers and other top-level benthic predators have largely been extirpated from the fishery (Kaunda-Arara et al. 2003, McClanahan et al. 2008). The dominant catch in Kenya is largely generalist herbivores,

microinvertivores, and mid-trophic-level carnivores that appear tolerant of intense levels of fishing (Hicks & McClanahan 2012). Second, Kenya's catch comes from coral reefs that also include large areas of seagrass and sand habitats that are promoted by the strong tidal movement (4 m range). These alternative habitats and sources of food and productivity are likely to promote considerable resilience to coral reef disturbances, particularly for generalist and rapidly growing species. Third, heavy fishing is expected to reduce diversity and homogenize the coral fish community and habitats, and promote disturbance-tolerant species (McClanahan et al. 2008, Hicks & McClanahan 2012). This ecological state may have a number of negative consequences yet still have high production and resilience to synergistic disturbances,

such as climate and fishing impacts. Finally, it may be that coral devastation was worse and recovery poorer in the Seychelles than in Kenya (Darling et al. 2013, Chong-Seng et al. 2014). Possibly, a permanent ecological phase shift is required to produce a large decline in reef fish catches. Consequently, while we predicted more coupling than observed, the larger literature indicates habitat context- or disturbance-dependent responses of fisheries to thermal anomalies and some resilience for moderate disturbances in already modified fisheries.

Global warming and associated climate disturbances are becoming a potential detrimental force influencing tropical fisheries by influencing productivity, habitats, species composition, and body sizes — mostly with negative and often lagging consequences (Ateweberhan et al. 2011, Cheung et al. 2013). Nevertheless, using a summary of life history characteristics to evaluate the 2 factors of climate disturbances and fishing indicated greater potential for resilience to climate disturbance among reef fish than hard corals (McClanahan et al. 2014). This occurs, in principle, because many of the reef species caught in high abundance are less sensitive to reef conditions than fishing mortality (Graham et al. 2011). An empirical test is challenging, however, because simultaneous stressors and associated responses can be difficult to distinguish. It was possible in the case presented here due to the BACI design, cointegration methods, opposing predictions, and near-coincident reduction in fishing pressure and thermal stress. Consequently, the positive response of catch rates to increased restrictions during a time of climate impact is an indication of the value of fisheries management for attenuating climate change impacts. It suggests that efforts to increase restrictions and the adaptive capacity and management of tropical fisheries can have an immediate positive influence that can, in part, counter the theorized negative effects of climate change.

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