Fish catch responses to Covid-19 disease curfews dependent on compliance, fisheries management, and environmental contexts

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Abstract

The responses of small-scale coastal fisheries to pauses in effort and trade are an important test of natural resource management theories with implications for the many challenges of managing common-pool resources. Three Covid-19 curfews provided a natural experiment to evaluate fisheries responses adjacent a marine reserve and in a small-mesh net gear-restricted management system. Daily catch weights in ten fish landings were compared before and after the curfew period to test the catch-only hypothesis that the curfew would reduce effort and increase catch per unit effort, per area yields, and incomes. Interviews with key informants indicated that fisheries effort and trade were disrupted but less so in the gear-restricted rural district than the more urbanized reserve landings. The expected increase in catches and incomes was evident in some sites adjacent the reserve but not the rural gear restricted fisheries. Differences in compliance and effort initiated by the curfew, changes in gear, and various negative environmental conditions are among the explanations for the variable catch responses. Rates of change over longer periods in CPUE were stable among marine reserve adjacent landing sites but declined faster in the gear-restricted fisheries. Two landing sites nearest the southern end of the reserve displayed a daily 45% increase in CPUE, 25-30% increase in CPUA, and a 45-56% increase in incomes. Results suggest that recovering stocks will succeed where authorities can enforce restrictions, near marine reserves, and fisheries lacking additional environmental stresses.

1.0 Introduction

A concern for fisheries resource management is the ability to predict the outcomes of acute or catastrophic changes in access and subsequent changes in effort on the resources and associated food security outcomes. This is particularly acute in nations highly dependent on natural resources, such as fisheries in Africa (Hicks 2011; Selig et al. 2018). Therefore, it is important to determine if there are specific management decisions that can exacerbate or attenuate unplanned and episodic changes in human behavior. In the case of fisheries, two of the most common options for management are no-fishing closures or marine reserves and gear restrictions, each expected to produce different responses to changes in access to fishing grounds and markets (Cinner et al. 2016, 2018). How then might these two systems differ in their responses to a period of enforced decline in access to fishing grounds and markets?

Marine reserves protect stocks and increase production and yields when stock biomass in surrounding areas are reduced below maximum sustained yield (MSY) (Nowlis and Roberts 1999; Sladek-Nowlis 2000; O'Leary et al. 2016). Fisheries reserves should enhance the recovery of reproductive adults over time, thereby preventing recruitment overfishing (Kerwath et al. 2013; Keppeler et al. 2020; McClanahan 2021). Increased production stimulated by reserves could potentially compensate for the lost area, especially when fishing drives stocks below levels required to produce MSY (Lenihan et al. 2021). In contrast, well managed gear restricted areas may be able to maintain all stocks closer to MSY levels and maximize the area in production (McClanahan et al. 2015). If stocks are below biomass MSY (B_{msy}), the higher stock biomass and spillover of excess production and reproduction from reserves is expected to produce a faster and larger response to reductions in fishing effort compared to gear restricted fisheries with lower fish stocks. Alternatively, other fisher behaviors, local management and environmental factors could influence and override the expected rebounding fish populations (Hallwass et al. 2020; Keppeler et al. 2020).

The emergence of Covid-19 (covid) led to a global lockdown that affected human health and reduced access to resources and transportation. The peak curfew and lockdown began March-

April 2020 and, depending on the policies and practices of specific jurisdictions, persisted well into 2021. This epidemic disease prompted changes in human behavior, which had several effects on resource user's livelihoods and affected nature (Bates et al. 2021). This has led to anecdotal reports of changes in wildlife behavior or populations rebounding in the absence of human influences. However, the response in fisheries has been variable and less predictable. For example, there are reports of increases in fishing pressures in commercial inland fisheries but declines in recreational fisheries (Stokes et al. 2020; Pita et al. 2021). In Indonesia, marine catches reported a rapid decline of fishing effort, traders, and fish prices, but many fishers returned, caught more fish, and maintained their incomes (Campbell et al. 2021). The degree of reliance on local versus imported food and sharing among households influenced the social resilience to curfews in Pacific fisheries (Bennett et al. 2020; Ferguson et al. 2022). Some artisanal fisheries in Africa showed low compliance to government curfews and high crowding at local landing sites (Okyere et al. 2021; Fiorella et al. 2021). Others turned to fishing in the absence of commercial employment options or sold rather than ate fish to make up for lost revenue (Fiorella et al. 2021). Therefore, there are many potential variables and responses influenced by local laws, enforcement, compliance, management context, markets, and other responses to the combined travel, night, and gathering curfews.

Here, we explore the responses of coral reef fisheries to national curfew regulations to evaluate effort and yield responses to curfew and existing fisheries laws. We evaluated a marine reserve and gear-restricted management system that represented the dominant management system in two coastal Kenyan county jurisdictions (Fig. 1). The two management systems had similar fish stocks below MSY (B<Bmsy) but higher stocks were reported inside the the reserve (McClanahan 2021). Therefore, we hypothesized that reduced access and effort during the covid curfews would increase fish stocks, catch-per-unit-effort (CPUE), and fishers' revenue. Moreover, that the response in marine reserve would be greater than the gear-restricted landing sites. Consequently, we asked how fishers responded to the curfews rules and how a potential pulsed decline and recovery of effort provided by the "covid Anthropause" influenced fisheries metrics of effort, CPUE, per area yield (CPUA), and daily revenue (Young et al. 2021).

1.1 Study location context
Marine resource management in the northern Kilifi/Mombasa counties relies largely on a marine reserve. Kwale county relies on gear management, largely the elimination of small mesh nets dragged by a large crew, locally known as beach seines (McClanahan 2010; Fig. 1). The Mombasa Marine National Park (MMNP) closure (6-km^2) ends at the border between the smaller urban Mombasa County and the more peri-urban Kilifi county to the north. The MMNP was implemented in 1991 and after some initial conflicts has been regularly patrolled by the park service and has largely restricted fishing in the closure from the mid 1990s. In contrast, a national effort to create a similar Marine Protected Area (MPA) ~60 km south coast in the more rural Kwale county failed due to unresolvable conflicts between fishers and park service employees in 1994 (McClanahan 2007). Thereafter, the Kwale fisheries stakeholders focused management on restricting the use of beach seines (McClanahan 2010). Studies showed that stock biomasses in these areas were similar in the fished areas (~25 tons/km^2) but differed in that the reserve contained a higher biomass (~100 tons/km^2) or twice the level of the approximated MSY biomass of ~50 tons/km^2 (McClanahan 2018, 2021).
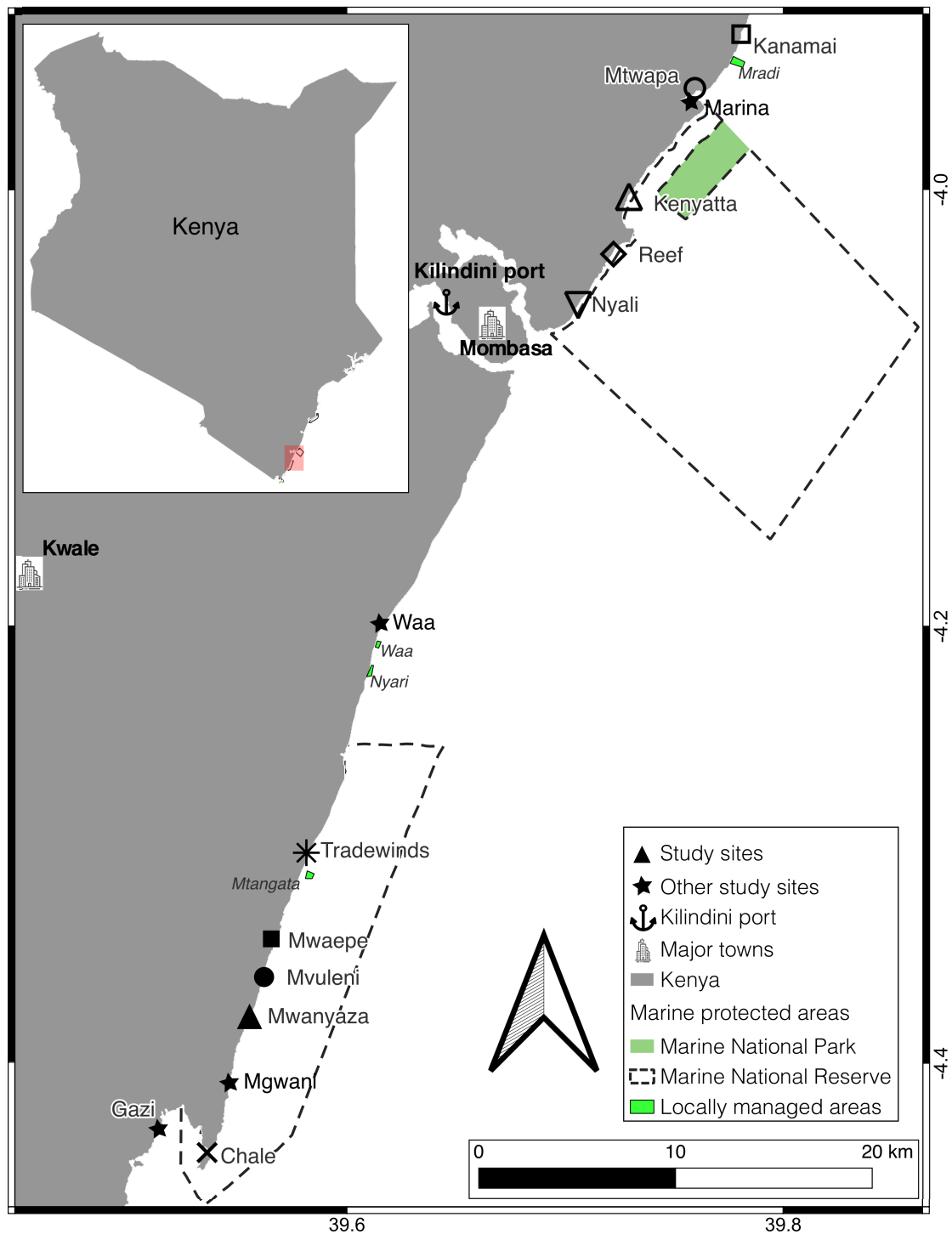
Figure 1. Map of the two fisheries management study areas and landing sites located in southern Kenya.

Fishing in these reefs is generally restricted close to shore during the strong monsoons and shorter distances beyond the reef in the calm season (Thoya and Daw 2019). Consequently, most fishing grounds were small and ranged from 2.2 to 4.2 km² and dominated by mixed gears, including lines, traps, spears, and set and drag nets. The catch in these reefs is largely composed of moderate size, fast-growing taxa, such as rabbitfish (Siganidae), marbled parrotfish (Scaridae), various species of emperors (Lethrinidae, Haemulidae, and Lutjanidae), and a diverse mix

of coral reef species (Mbaru et al. 2020). Since landings have been measured, there has been some modest changes in gear use and effort and some evidence for increased spear gun and reduction of traditional traps usage (McClanahan and Kosgei 2018, 2019). Responses to specific environmental disturbances and management interventions suggest overfishing relative to the production potential and associated difficult trade-offs arising from management decisions (McClanahan and Kosgei 2018, 2019; McClanahan 2021).

The national response to covid in Kenya was to initiate travel, gathering, and night curfews (7 and 9PM to 4AM) beginning in March 2020 (Brand et al. 2021). The travel and gathering curfews stayed in effect until March 2021 while the night curfew ended on October 20th, 2021. These curfews led to various fisheries responses but often reported as restricted access, trade, markets, fishing effort, times, and fishing gears (Lau et al. 2021) (Table 1). Information about curfew timings and enforcement were available from government of Kenya website (https://www.health.go.ke/#1621662557097-37ed30fd-e577). It was expected that fishing effort was reduced during the curfew period and was likely to have increased once the travel and gathering curfews ended.

2.0 Materials and Methods

2.1 Fish catch monitoring
There are a number of long-term artisanal fisheries landing sites with regular fish catch monitoring of shallow-water species inhabiting nearshore seagrass and coral ecosystems that is supported by the Wildlife Conservation Society – Kenyan Marine Program office. The effect of covid for the fish monitoring program was that curfews prevented the measurement of fish catch between April 2020 and November 2020. Thus, we examined catch data in ten landing sites for a period of 13 months prior to and including March 2020 (before period). Post-curfew catches were evaluated for 10 months (November 2020 to August 2021) after the final curfew was lifted (after period). Given measurements were not made for 7 months, we relied on a mixture of interviews with fisheries leaders and some fishers to qualitatively evaluate fisher and trader responses. We tested for differences in catch statistics between the more urbanized northern marine reserve (Kilifi/Mombasa counties) and more rural southern gear-restricted management systems (Kwale county) between the before and after time periods for a 23-month period of data collection with a 7-month curfew hiatus. Additionally, the post-curfew time series rates of change were than compared to longer-term catch statistics collected from January 2005.

These landing sites were monitored for catches and revenue 2 to 3 days per month from 1995 to 2021 using the same trained observers (McClanahan and Azali 2020). During each visit, the numbers of fishers and boats landing fish were counted and the wet weight of fish in 5 different demersal finfish catch group categories were measured to the nearest 0.1 kg. Price data per kg were collected monthly for each catch group during sampling period and were used to estimate revenues of fishers based on their daily catch rates (McClanahan and Kosgei 2018, 2019).

Table 1 Summary of (a) reporting of notable events in north coast (n=23) and south coast (n=28) provided by key informants in Kenya as monthly observations during the 7-month gathering, night, and travel curfew (Supplementary Table 1). The percentage of the total events is given for each of the 16 total responses. The (b) resource users and landing site leaders suggesting causes of the changes in north coast (n=55) and south coast (n=50) before and after the covid curfew period based on a video presenting catch result. Specific numbers and summary percentage responses [n (%)] for reasons for the observed catch trends after viewing a video describing the changes in catch. Sites ordered from north to south while descriptions and responses ordered by overall percentages.

a) Events during covid curfew in north and south coast sites	North coast						South coast						All sites combined n (%)
	Kana mai	Mtw apa	Ken yatta	Re ef	Ny ali	North n (%)	Trade winds	Mvu leni	Mwan yaza	Mwa epe	Ch ale	South n (%)	
Reduced fishing effort		√	√	√	√	4 (17)	√	√	√	√	√	5 (17)	9 (17)
Dusk to dawn curfew		√	√	√	√	4 (17)	√		√	√	√	4 (13)	8 (15)
Sand harvesting						0 (0)	√		√	√	√	5 (17)	5 (9)
Changes in market	√	√	√			3 (13)		√				1 (3)	4 (8)
Government enforcement (license & gear)		√		√		2 (9)		√	√			2 (7)	4 (8)
Reduced number of traders					√	1 (4)	√	√			√	3 (10)	4 (8)
Strong currents		√				1 (4)		√	√			2 (7)	3 (6)
Reduced catch		√	√			2 (9)	√					1 (3)	3 (6)
Reduced fish price		√				1 (4)		√	√			2 (7)	3 (6)
Lack of transport	√					1 (4)	√					1 (3)	4 (8)
Increased patrolling		√	√			2 (9)						0 (0)	4 (8)
Reduced water visibility						0 (0)		√	√			2 (7)	4 (8)
Gear conflict					√	1 (4)						0 (0)	1 (2)
Law enforcement from Kenya Wildlife Service			√			1 (4)						0 (0)	1 (2)
Increased cold water						0 (0)		√				1 (3)	1 (2)
County lock down						0 (0)		√				1 (3)	1 (2)
Total reported events (n)						23 (45)						28 (55)	51 (100)
b) Reasons given for changes in fish catch trends													

Fishing effort did not change	2		4	2	2	10 (18)	9	2	7	6	3	27 (54)	37 (35)
Usual seasonal changes		2		4	4	10 (18)		3	2			5 (10)	15 (14)
Market constraints	4			2	2	8 (15)	1	2			3	6 (12)	14 (13)
Fishing effort declined	2	2	4		4	12 (22)		1				1 (2)	13 (12)
Some gears were restricted and confiscated		5		1		6 (11)						0 (0)	6 (6)
Changes in long-term climate						0 (0)	2	3	1			6 (12)	6 (6)
Improved environmental condition				3		3 (5)						0 (0)	3 (3)
Increased illegal fishing						0 (0)	1				1	2 (4)	2 (2)
Restrict night fishing				1		1 (2)			1			1 (2)	2 (2)
Reduced non-fishing human activities (tourists and associated pollution)			2			2 (4)						0 (0)	2 (2)
Not beneficiary of government cushion fund						0 (0)		1				1 (2)	1 (1)
Increased effort of local fishers						0 (0)		1				1 (2)	1 (1)
Reduced effort of non-resident fishers			1			1 (2)						0 (0)	1 (1)
Political influence to allow fishing		1				1 (2)						0 (0)	1 (1)
Don't know				1		1 (2)						0 (0)	1 (1)
Total causes of changes (n)						55 (52)						50 (48)	105 (100)

Landing site information on changes in curfew were obtained through key informants, fishers, fish traders, tour operators and beach management unit leaders (Supplementary table 1). This was a two-step process where key informants were first asked to describe the notable changes monthly during the curfew without knowledge of the fishing landing results. The responses are presented as checklist of 17 unique descriptions summarized as percentages of identified forces of change by region and pooled (Table 1a). Secondly, after the catch monitoring results were completed, we presented a recorded video clip of the key results to 72 fishers at the 10 studied landing sites and requested their explanation for the causes of the reported compliance with curfew laws and changes in yield using specific questions requiring yes or no responses (Supplementary table 2). We received 105 yes responses that we broadly categorized into 15 unique grouping presented as percentages of total responses (Table 1b). Given that the catch responses were different between the north and south coast, the wording was changed to allow respondents to explain the either negative or positive changes in fish catch. We also asked for other possibilities not contained in the specific questions.

2.2 Data analyses

Prior to analyzing fisheries catch data, we evaluated 14 fish landing sites in both Kwale and Kilifi/Mombasa counties for their similarities in fisheries inputs and outputs from the above data collection process to select comparable sites adjacent marine reserve and gear-restricted management systems. The selection of sites was based mostly on the inputs of effort and gear use but also by considering similarities in fish catch categories (McClanahan and Kosgei 2019). Five landing sites in Kwale were similar in temporal completeness of sampling, effort, and gear use with the 5 catch monitored sites < 10 km from the Mombasa MNP's fisheries closure. Therefore, the design of this study was to compare these 10 similar landing sites, evenly divided between two management "treatments", for before and after changes in common catch statistics relative to the national curfew closure dates.

Fishing effort was analyzed on a per person per day basis and catch weight on a per fisher (CPUE = catch per fisher per day) and per unit area (CPUA = catch per km^2 per day) of the fishing grounds. The areas of fishing grounds were previously estimated through a participatory mapping process (McClanahan and Kosgei 2019). Fishing effort, CPUE, CPUA, and revenue (Kenya shillings (Ksh per fisher per day, where 105 Ksh ~ US$1) were not normally distributed and therefore tested for before and after differences by Kruskal-Wallis tests for each individual fishing gear, and combining all gears at a landing site. Catches of fish type categories (rabbitfish (Siganidae), scavengers (Lutjanidae, Lethrinidae, Haemulidae), parrotfish (largely *Leptoscarus vaigensis*), mixed catch or others (many taxa), and octopus were also not normally distributed and therefore tested for differences between study periods by Kruskal-Wallis tests. The Kruskal-Wallis tests were adjusted for multiple hypothesis testing using the Benjamini-Hochberg method to control the false discovery rate (Benjamini and Hochberg 1995). Statistical significance was evaluated at 10% level to reduce Type 2 errors that might arise from the large-scale but low replication of this study. Landing site prices per category per month were multiplied by daily catches per category and summed to estimate the fisher's daily revenue.

The mean fishing effort, CPUE, CPUA, and revenue at each landing site and the management treatment was averaged and plotted as a continuous 23 monthly time series with a 7-month gap when no data were collected. Linear regression of monthly averages was undertaken to test for trends in the 30-month time series in the two management categories. Mean before and after time periods for the two-management treatments of fishing restrictions with effort versus CPUE, CPUA, and revenue were plotted. Relationships were tested for significance and fit using a General Additive Model (GAMS) with 3 knots (k) and restricted maximum likelihood

(REML) to prevent overfitting. The interactions between management and time period were tested by comparing the GAMS best-fit smooths. To specifically test the predictions of the catch-only model, changes in mean fishing effort before and after the curfew were derived by subtracting the before from the after-curfew effort and plotted against the before and after change in CPUE, CPUA, and revenue for each landing site. The expectation was that the magnitude of the declines in effort would be associated with increases in CPUE and revenue.

Long-term catch dataset comprising 173 months (beginning in January 2005) prior to March 2020 and covid curfews was compared to 10 months period after the March 2020 curfew hiatus to test for changes in rates or trends in effort, CPUE, and CPUA provoked by the curfew. Slopes of the best-fit lines before and after the curfew periods were tested for differences in each county using Welch's t-test of significance, which accounts for the unequal variances between the two time periods (Welch 1938).

3.0 Results

3.1 Stakeholder's descriptions of curfew impacts

Key informants in the 10 landing sites reported similar changes in behavior shortly after the curfews (Table 1a, Supplementary table 1). These included reduced access to landing sites, reduced travel, time for marketing, and reduced fishing effort. Northern marine reserve-associated landing sites differed from south coast gear-restricted sites in that there was more involvement by the national park services in enforcing the restrictions on beach seine and monofilament gears consequently reducing fishing effort (Table 1b). Also, Kenya Maritime Authority was involved in informing and enforcing their maritime regulations of fishing licenses, buoyancy jackets, water, and first-aid kits. Police were reported to enforce the gathering restrictions by limiting shoreline access to fish landing sites. Gear-restricted landing sites reported more weather and poor visibility conditions than reserve sites and majority of fishers reported low compliance with curfew regulations (Table 1b). There was dredging and sand mining reported north of the Kwale landing sites but also some dredging in the Mombasa harbor near the reserve.

The curfews did not stop fishing, but more likely patchily reduced fishing effort through a combination of access restrictions, enforcement, and lowered demand from traders and markets. Low water visibility may have restricted some types of gear, such as spearguns. Some of the enforcement appears to have been delayed or ineffective in the Kwale relative to the Mombasa/Kilifi sites. Resource users responses to question about the decline in CPUE in Kwale, indicated it was caused by low compliance with curfew regulations. A total of 64% of responses in Kwale indicated fishers continued with the usual fishing behavior and seasonal changes during curfews (Table 1b). Additionally, 24% of these responses considered climate change or market constraints as equal contributions to declining catch trends in Kwale county. There were fewer responses among fishers suggesting limited increase in illegal gear use, increased night fishing, increased effort from local resident fishers, and not receiving government covid compensation as causes of a decline in effort, CPUE, and revenue in Kwale.

In Mombasa/Kilifi counties, 18% said fishing effort did not change but 22% mentioned effort declines, 15% listed market constraints, and 11% noted confiscated gear as causes for the increase in CPUE (Table 1b). This suggests patchy but overall increased curfew and law enforcement and gear confiscations to comply with national fisheries regulation. Other responses for

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increased catch trends in Mombasa/Kilifi included improved environmental conditions from the lack of beach and hotel pollution. Key stakeholders responded that some fishing, trader, and markets increased from July 2020 but did not fully resume in all landing sites until October 2021; after which, our catch measurements resumed. The full return of fishing efforts and traders was likely to have varied between landing sites and the two counties.

3.2 Changes in effort

Recorded fishing effort did not differ statistically between management treatments despite southern gear restricted landing sites in Kwale recording higher effort (5.4 ± 0.6 (SEM) fishers/km^2/day) than the northern reserve landing sites in Mombasa/Kilifi (3.9 ± 0.4 fishers/km^2/day) (Table 1b, Fig. 2a).
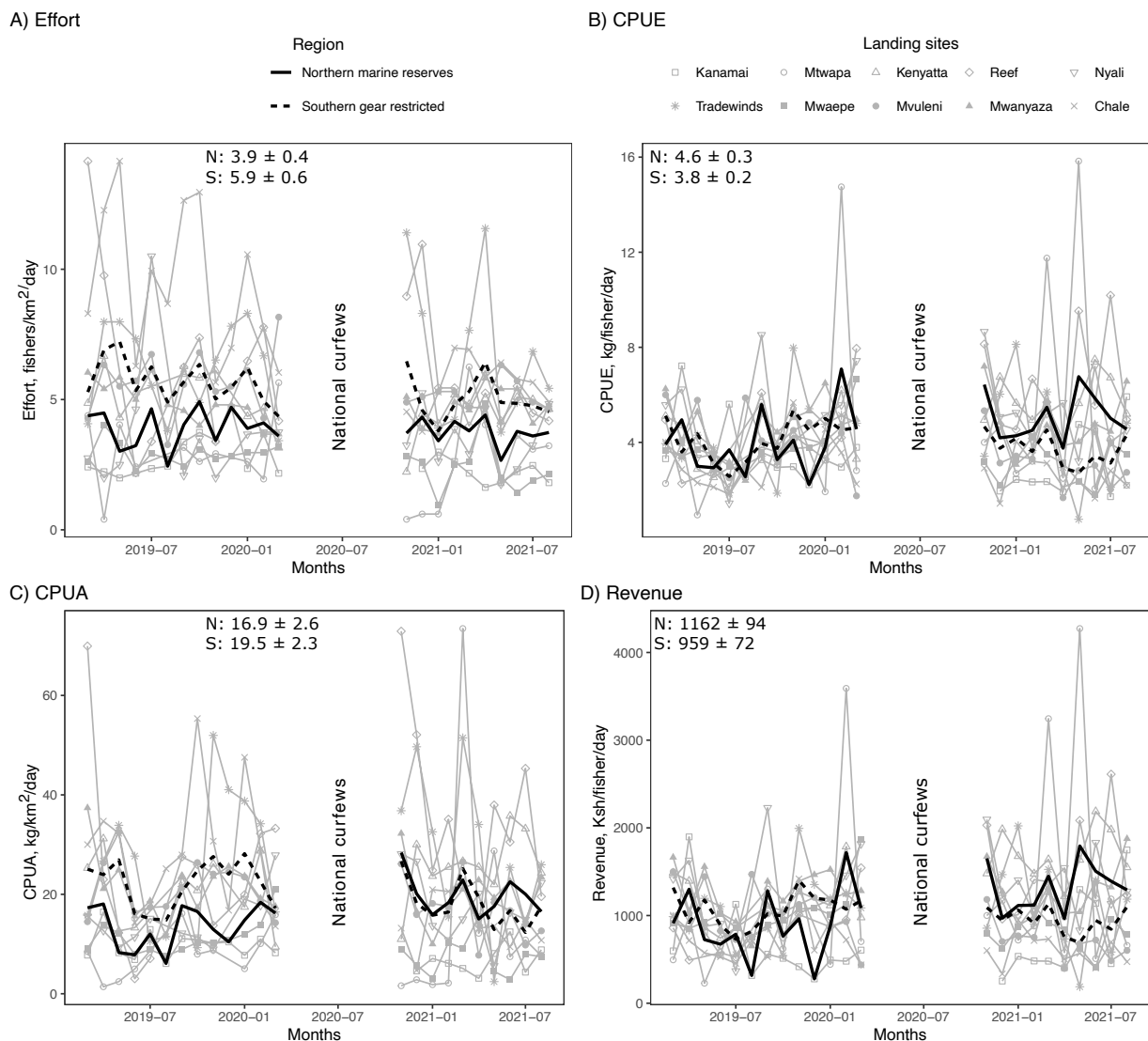
Figure 2. Time series of the relationship between fishing efforts and (a) fishing effort (number of fishers/km^2), (b) CPUE (kg/fisher/day), (c) CPUA (kg/km^2/day), and fisher revenue (Ksh./fisher/day) in the 10 studied landing sites for before and after and marine and gear management effects.

The trend from the linear regression over the 30-month study period indicated no change in effort adjacent reserves. However, in gear-restricted sites there was a significant -0.04

fisher/day linear decline (evaluated on a per month basis) (Table 2a). Over all 10 sites combined, the before and after decline comparison was from 5.0 ± 0.7 to 4.3 ±_0.5 fishers/km^2/day but not statistically significant.

Among marine reserve sites, differences in fishing effort when comparing the before and after times were not statistically different at the individual landing sites. Beach seines were eliminated in Nyali and reduced marginally in Reef during the after-curfew period (Supplementary table 3a). Among gear-restricted sites, there were more changes in effort at specific landing sites for the before and after periods. Evaluating all gears, indicated that Mwaepe and Chale experienced declines in fishing effort (Fig. 3a). These effort declines could be attributed to reduced handline and spear use in Mwaepe and Chale that were not equally compensated for by an increase in net use in Chale. Mvuleni experienced modest declines in spear and trap effort, but the overall effort with all gears combined was not statistically different.
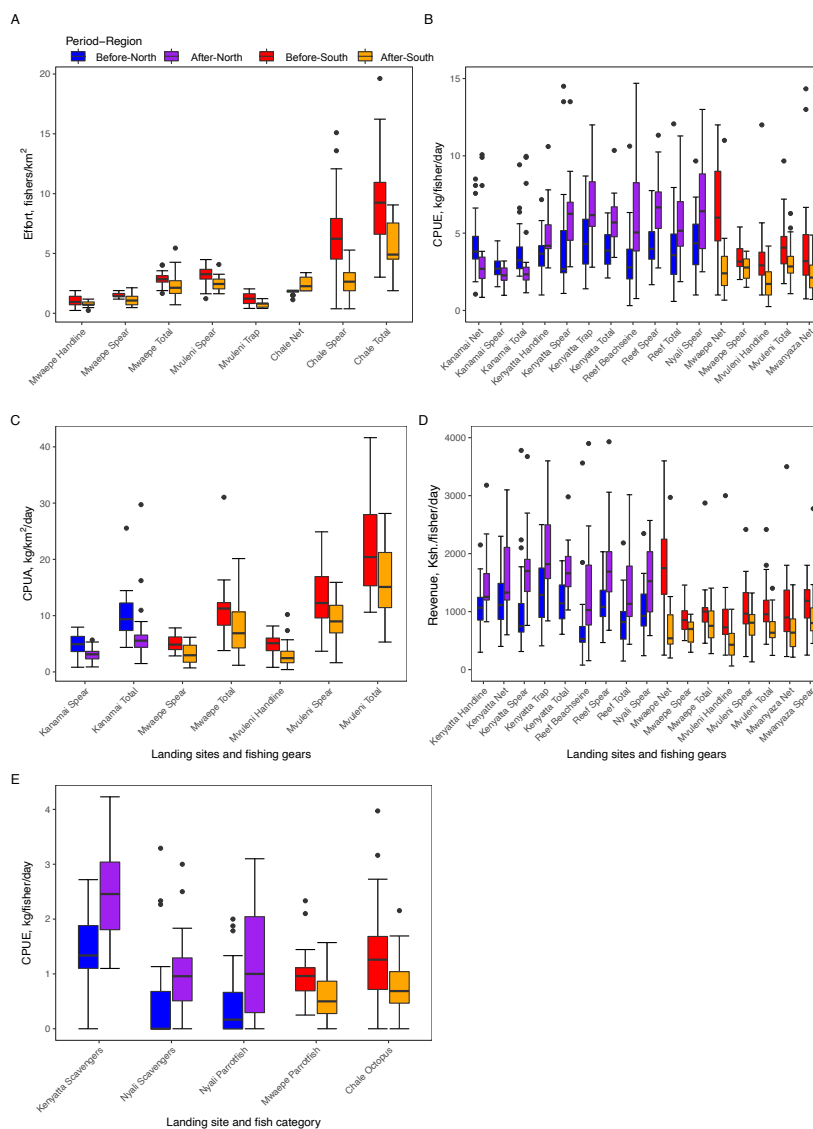
Figure 3. Boxplots showing comparisons of significant ($p < 0.10$) Kruskal-Wallis tests of (a) total and by-gear fishing effort (fishers/km^2/day), (b) CPUE (catch, kg/fisher/day), (c) CPUA (catch, kg/km^2/day), (d) revenue (Ksh/fisher/day), and (e) fish catch categories before and after the covid curfew in the studied landing sites in the north (fisheries closure management) and south (gear restriction management). P-values were adjusted for multiple hypothesis testing following methods by Benjamini and Hochberg (1995) to control for false discovery rates. Full tests of all comparisons are provided in supplementary table 3.

3.3 Changes in catch-per-unit effort (CPUE)

CPUE reported at landing sites was lower (p<0.04) in gear-restricted (3.8 ± 0.2 (SEM) kg/fishers/day) than marine reserve landing sites (4.6 ± 0.3 fishers/km^2/day) (Fig. 2b). Overall linear trends over this 30-month period indicate a non-significant CPUE decline in gear-restricted sites but a significant increase of 0.06 kg/fisher/day (on a monthly basis) adjacent reserves sites (Table 2b). Evaluating all sites combined, found no change in CPUE over the 30-month study period.

Among specific marine reserve sites there were increases in CPUE in 2, no change in 2, and a decline in 1 site for before and after curfew comparisons. Kanamai was the 1 site with the small overall decline (~0.4 kg/fisher/day) (Fig. 3b, Supplemental table 3b). The decline of nets and spear CPUE were the cause of the over loss in Kanamai. Kenyatta and Reef both had similar increases of ~1.8 kg/fisher/day over time. In Kenyatta, CPUE increased among all fishing gears. There were notable CPUE increases for spears in both Reef and Nyali and in beach seines in Reef landing sites. Among specific gear-restricted sites, there were fewer overall changes in CPUE except for a decline of ~1.1 kg/fisher/day in Mvuleni due to a decline in handlines. CPUE declined in Mwaepe for net and spear catches, and for nets in Mwanyaza.

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Table 2. Time series regressions of fishing effort, catch-per unit-effort (CPUE), catch per unit area (CPUA) and revenue of the northern marine reserve and southern gear restricted sites across 30 months period before and after the COVID 19 restrictions. Replication is the average of sites per month for each management treatment. Ksh = Kenyan shilling, which was ~105 Ksh/US$.

Variable	Region	term	Estimate (SE)	t ratio	P value	R²	P value
a) Effort, fishers/km^2/day	Northern reserve	Intercept	3.96 (0.23)	17.12	<0.0001	0.02	NS
		Time, month	-0.01 (0.01)	-0.60	NS		
	Southern gear restricted	Intercept	5.97 (0.29)	20.82	<0.0001	0.22	0.03
		Time, month	-0.04 (0.02)	-2.41	0.03		
b) CPUE, kg/fisher/day	Northern reserve	Intercept	3.63 (0.42)	8.57	<0.0001	0.22	0.03
		Time, month	0.06 (0.03)	2.41	0.03		
	Southern	Intercept	4.18 (0.28)	14.80	<0.0001	0.05	NS

	gear restricted	Time, month	-0.02 (0.02)	-1.01	NS		
c) CPUA, kg/km²/day	Northern reserve	Intercept	12.28 (1.55)	7.92	<0.0001	0.32	0.005
		Time, month	0.30 (0.09)	3.16	0.005		
	Southern gear restricted	Intercept	23.32 (1.67)	13.96	<0.0001	0.19	0.04
		Time, month	-0.22 (0.1)	-2.19	0.04		
d) Revenue, Ksh/fisher/day	Northern reserve	Intercept	774.99 (122.66)	6.32	<0.0001	0.31	0.005
		Time, month	23.31 (7.52)	3.10	0.005		
	Southern gear restricted	Intercept	1089.26 (64.58)	16.87	<0.0001	0.09	NS
		Time, month	-5.53 (3.96)	-1.40	NS		

3.4 Changes in per-area yield (CPUA)

Per area yield or CPUA was not significantly different between the marine reserve and gear-restricted landing sites (Fig. 2c). There was no changes across the curfew period in the site averaged CPUA with mean values being ~18 kg/km²/day, which was estimated to be ~ 4 tons/km² on an annual yield basis when accounting for non-fishing days. Nevertheless, linear trends in slopes over this 30-month period indicate an increase of 0.3 kg/km²/day (on a monthly basis) in CPUA adjacent the reserve and a significant -0.2 kg/km²/day decline in gear-restricted sites (Table 2c).

Among specific reserve sites, there were no changes in CPUA in 4, and a decline in 1 site for before and after curfew comparisons. Kanamai was the 1 and most distant from reserve site with the overall decline (~2.9 kg/km²/day) (Fig. 3c, Supplementary table 3c). All other sites showed increases in CPUA but none were statistically different and not clearly related to the per gear CPUA. Among specific gear-restricted sites, there were declines in CPUA in 2 of the sites. This change was mostly strongly associated with declines in CPUA by spearguns in addition to handlines in the Mvuleni site.

3.5 Changes in revenue

Daily revenue was significantly lower in the gear restricted (959 ± 72 Ksh/fishers/day) than marine reserve landing sites (1162 ± 94 Ksh/fishers/day) (Fig. 2d). Overall linear trends over this 30-month period indicate a non-significant -5.5 Ksh/fisher/day decline in gear-restricted sites and a 23.3 Ksh/fisher/day increase (on a monthly basis) adjacent reserve sites (Table 2).

Evaluating all sites combined, found no difference in the before and after revenue, which was ~1050 Ksh/fisher/day (~ 2200 US$ per year).

Among specific marine reserve sites, the largest increases in revenue were in Kenyatta and Reef whereas the other sites displayed smaller and non-significant increases, including Kanamai (Fig. 3d, Supplementary table 3d). Increases in revenue in Kenyatta were found for all gears. Most of the increase in revenue in Reef was attributable to spears and beach seines. Among gear-restricted individual landing sites, incomes declined in Mvuleni attributable to handlines and spears and also nets and spears in Mwanyaza.

3.6 Changes in fish catch categories

The specific catch categories indicated a decreases in CPUE in the gear-restricted sites for parrotfish in Mwaepe and octopus in Chale (Fig. 3e, Supplementary table 4). Increased CPUE adjacent the reserve management were found for scavengers in Kenyatta and parrotfish in Nyali.

3.7 Effort – benefits response models

Relationships between fishing effort and CPUE, CPUA, and revenue fitted to the GAMS model indicated a significant best fit for the effort – CPUA relationship (Fig. 4). This relationship explained 93% of the variance and found significant differences when comparing the reference or marine reserves with gear-restricted sites after the curfew (Table 3). The smooth terms indicate significant changes in the best-fit models for effort-CPUA but not for CPUE or income, which both had high variance. The change in the effort-CPUA relationship was due to higher reserve, Kenyatta and Reef. Kanamai fisheries, the site furthest to the reserve, did not respond to the curfews and maintained low yields despite low fishing effort.

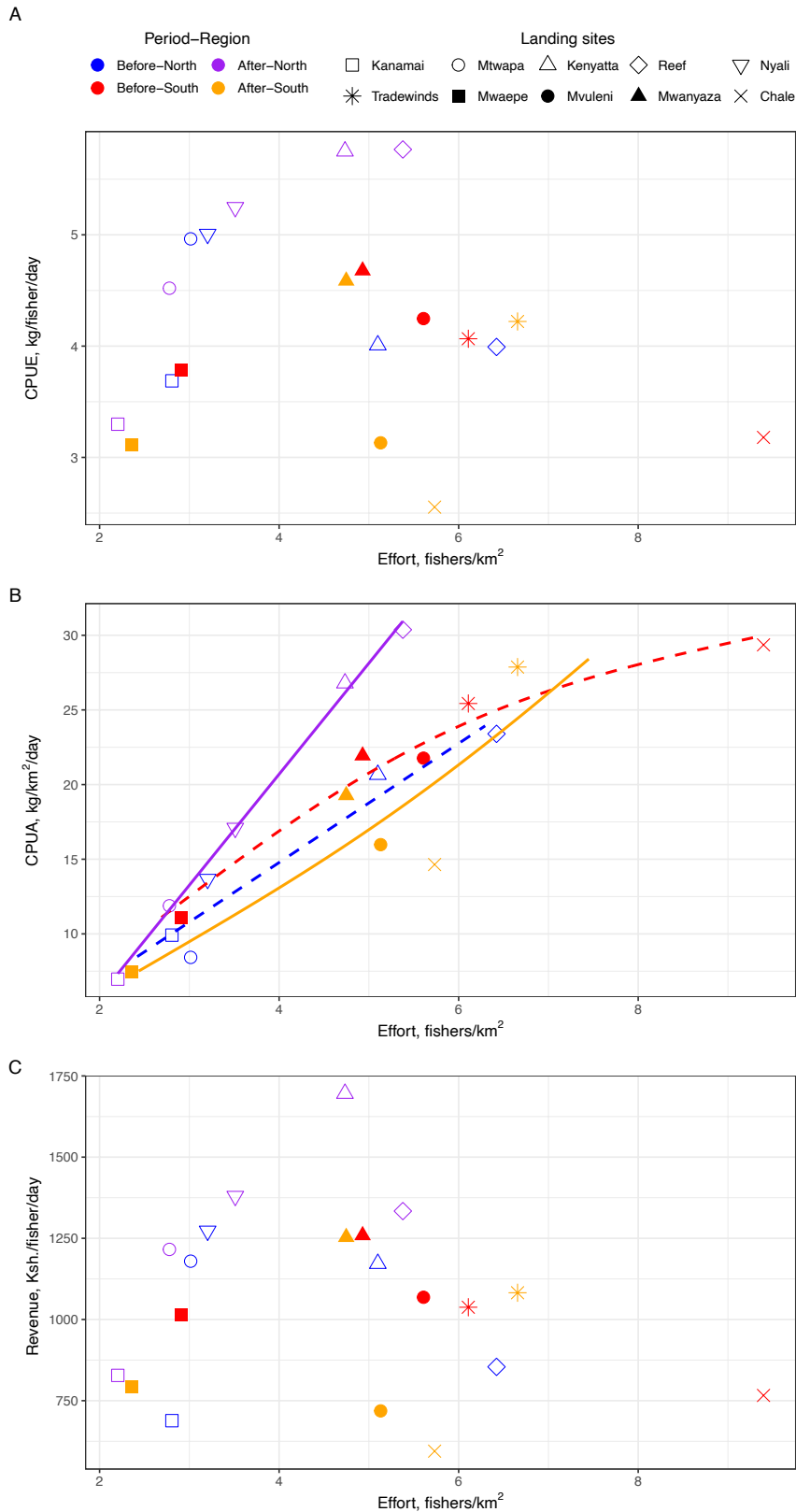Figure 4. Scatterplots of the relationships between fishing effort and (a) CPUE, (b) CPUA and (c) revenue for the before and after curfews in landing sites adjacent the northern marine reserve and in the southern gear management location (see figure 1). Models results presented in table 3 and shown here are fits only to those best-fit models that were statistically different than zero or the null hypotheses.

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Table 3. Statistical results of General Additive Models (GAM) testing for relationships between (a) CPUE, (b) CPUA and (c) revenue against fishing effort. Models include a period-region interaction term and are fitted with restricted maximum likelihood (REML), knots are limited to three to prevent overfitting (k=3).

a) CPUE, kg/fisher/day

Predictors	Estimates	SEM	t-ratio comparison differences	p	R^2	Deviance explained, %
Intercept	5.26	0.65	8.13	**<0.001**	**0.46**	**67.4**
After-Northcoast	Reference					
Before-Northcoast	-1.01	0.72	-1.41	0.19		
After-Southcoast	-1.77	0.71	-2.49	**0.03**		
Before-Southcoast	-1.14	0.73	-1.57	0.14		
			F-ratio comparison of smooth terms			
s(Effort_mn):After-Northcoast			4.07	0.13		
s(Effort_mn):Before-Northcoast			0.57	0.47		
s(Effort_mn):After-Southcoast			0.33	0.58		
s(Effort_mn):Before-Southcoast			1.06	0.50		

b) CPUA, kg/fisher/km²

Predictors	Estimates	SEM	t-ratio comparison differences	p	R^2	Deviance explained, %
(Intercept)	25.43	1.48	17.17	**<0.001**	**0.88**	**93.0**
After-Northcoast	Reference					
Before-Northcoast	-8.11	1.94	-4.18	**0.002**		
After-Southcoast	-9.34	1.92	-4.86	**0.001**		
Before-Southcoast	-6.94	2.01	-3.46	**0.005**		
			F-ratio comparison of smooth terms			
s(Effort_mn):After-Northcoast			56.47	**<0.001**		
s(Effort_mn):Before-			23.29	**0.001**		

Northcoast

	Estimate	Std. Error	Statistic	p-value		
s(Effort_mn):After-Southcoast			13.75	**0.001**		
s(Effort_mn):Before-Southcoast			12.57	**0.001**		

c) Revenue, Ksh/fisher/day

	Estimate	Std. Error	Statistic	p-value		
(Intercept)	1036.67	325.02	3.19	**0.009**	0.33	61.3
After-Northcoast	*Reference*					
Before-Northcoast	-54.00	345.84	-0.16	0.88		
After-Southcoast	-155.07	341.48	-0.45	0.66		
Before-Southcoast	50.51	345.47	0.15	0.89		
		F-ratio comparison of smooth terms				
s(Effort_mn):After-Northcoast			2.44	0.10		
s(Effort_mn):Before-Northcoast			0.26	0.66		
s(Effort_mn):After-Southcoast			0.11	0.75		
s(Effort_mn):Before-Southcoast			1.06	0.33		

Fits of effort- CPUE suggest changes in relationships in gear-restricted sites after the curfew associated with declining effort but also declining CPUE. Gear-restricted sites did not indicate the predicted increase in CPUE if effort declined. Effort-revenue relationships showed high scatter and lacked significant relational changes. Plotting changes in effort with changes in CPUE, CPUA, and revenue indicated the greater importance of the two locations or management systems rather than the before and after curfew changes in effort (Fig. 5).
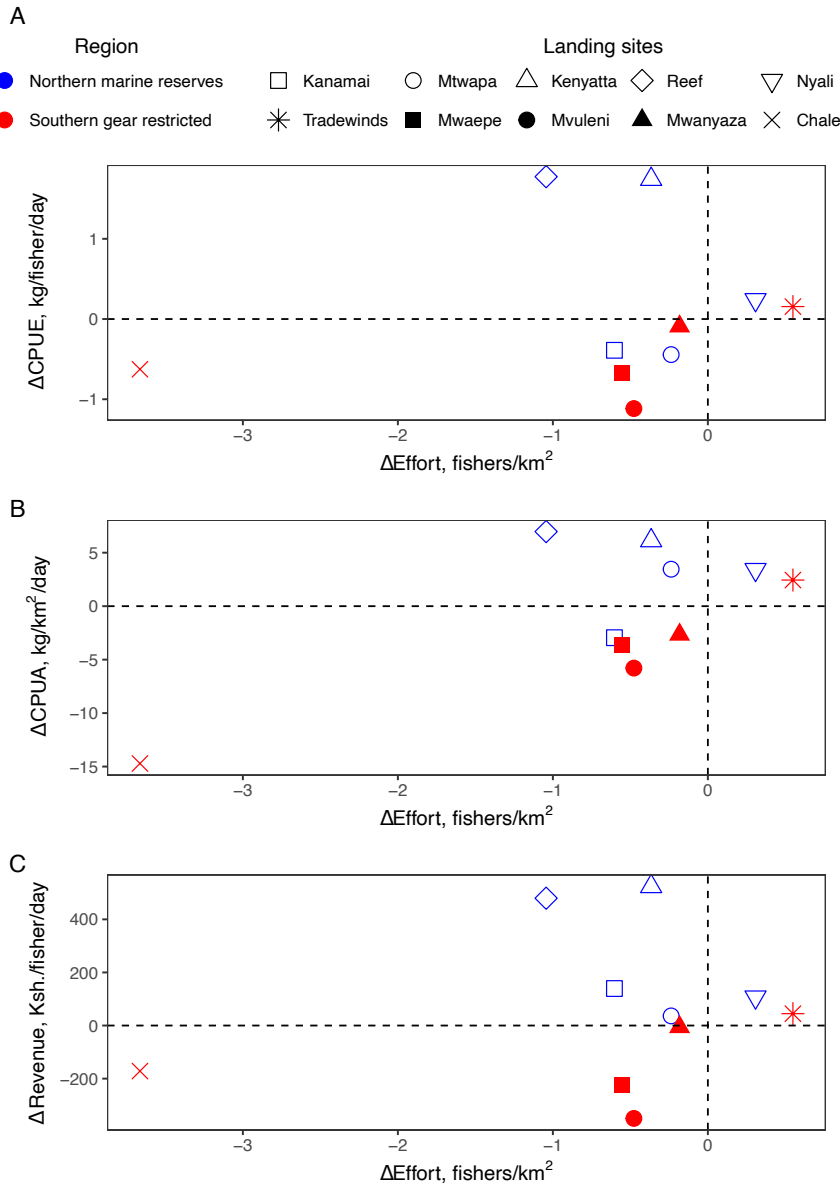
A

Figure 5. Scatterplots of the relationships between fishing the change in effort (after – before covid curfews) and changes in (a) CPUE, (b) CPUA and (c) revenue at the 10 studied fish landing sites divided equally between marine reserve and gear-restricted landing sites. See map for site and management locations.

3.8 Changes from long-term trends

Multi-annual trends for fishing effort showed moderate variability over time in both marine reserve and gear-restricted landing sites (Fig. 6). Overall, long-term effort declined in both counties. Specifically, prior to the curfew marine reserve landing sites showed a 69% reduction in effort over 173 months whereas gear-restricted landing sites displayed a 37% decline (Fig. 6a). Comparing mean before and after curfew effort indicated a 79% reduction in marine reserve and a 39% reduction in gear-restricted sites. Comparing rates of change in effort or the slopes of best-fit lines 173 months before and 10 months after the curfews indicated no significant change with time for both fisheries systems (Welch's t-test of slopes). CPUE changes over the 173 months prior to the curfew, displayed a 26% increase in marine reserve and an 18% decline in gear-restricted sites (Fig.

6b). Comparing mean CPUE before and after the curfew indicated a 25% increase in marine reserves and a 9% loss in the gear-restricted landing sites. Moreover, the monthly rate of change in CPUE declined significantly in the gear-restricted landing sites after the curfew but no change in slope was detected in the marine reserves. CPUA changes over the 173 months prior to the curfew, displayed a 29% decline in marine reserve sites and a 66% decline in gear-restricted sites (Fig. 6c). Comparing mean CPUA before and after curfew indicated a 17% decrease in marine reserves and a 57% decrease in the gear-restricted landing sites. The monthly rate of change in CPUA was not different before and after the curfew.

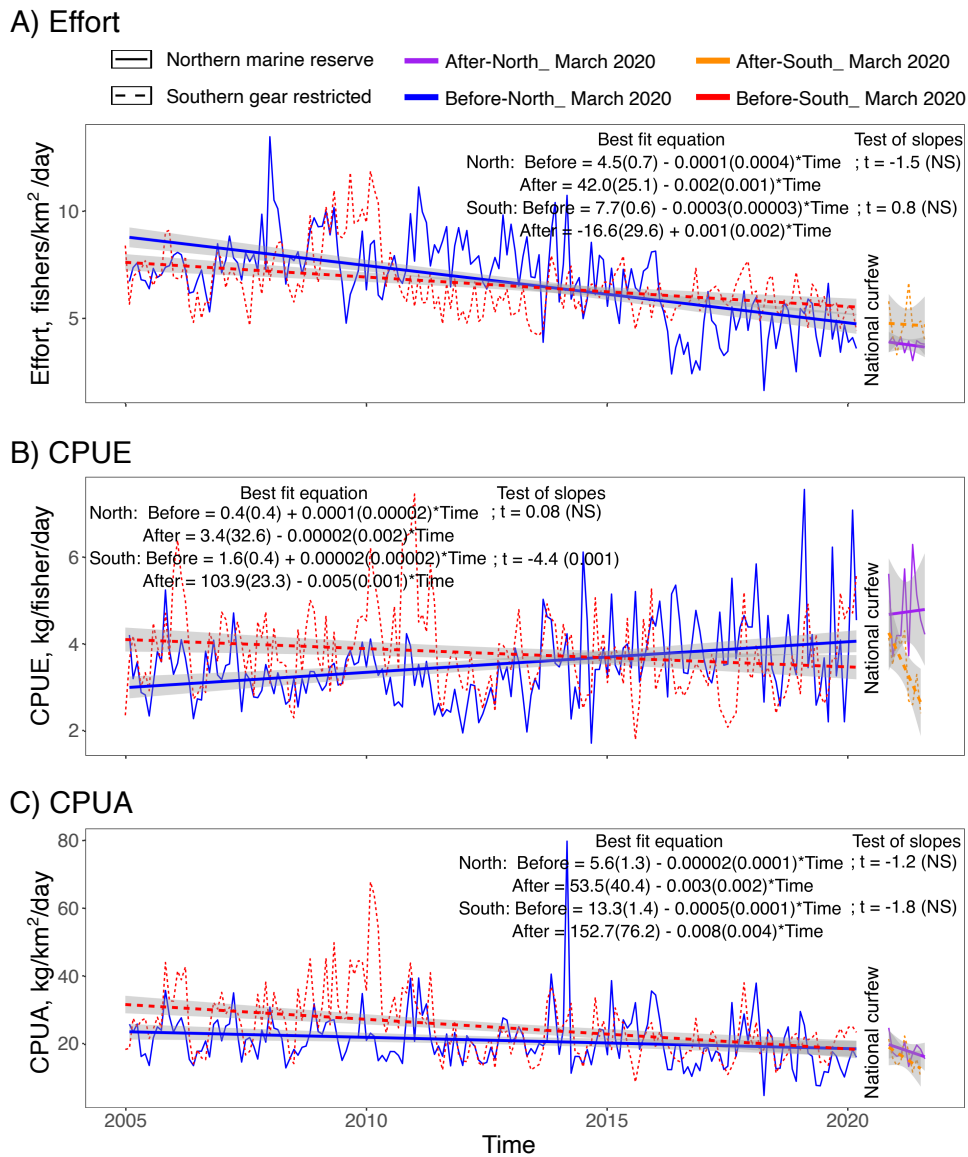Figure 6. Time series of (a) fishing effort, (b) CPUE, and (c) total per area yields (CPUA) in the 10 studied landing sites for 173 months before and 10 months after (2020 March – 2021 August) the covid curfews in the northern marine reserve and southern gear restricted managements. Best-fit linear relationships presented as well as a test of significance of the slopes before and after covid.

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4.0 Discussion

The curfew-induced disruption in fisher and trader efforts in Kenya appeared to cause several changes that interacted with geographic, environmental, and management factors. Responses did not support the overall catch-only fisheries management predictions of increasing CPUE and revenue after the hiatus (Ovando et al. 2021). Rather, there were some overriding contextual factors including fisheries management systems and enforcement and compliance with fisheries and curfew regulations that were possibly further influenced by environmental changes. The catch-only model predictions would be for an increase CPUE and revenue, at least temporarily, in all studied sites. However, support for this prediction was largely restricted to a few sites adjacent the marine reserve. High variability and a reversal of this prediction was evident in most of the gear-restricted sites. Some changes were discrete in terms of the before and after curfew comparisons while others appeared to be part of longer-term responses. Thus, the 7-month curfew hiatus was influenced by slower changes recorded during the previous ~20-30 years of fisheries management (McClanahan 2010, 2021).

The covid curfew responses were complex and complicated by site variability. Moreover, the modest site replication added to the difficulties of making strong conclusions. Large-scale opportunistic social change experiments in fisheries will inherently have challenges that can hide impact signals from noise (Kerr et al. 2019). Enforcement of laws was also not uniform and fully effective but appeared more effective adjacent the marine reserve. Most significantly in the reduction and confiscation of beach seine or drag nets. Mombasa Park and Reserve, being peri-urban and having employed national government personnel nearby in Mombasa city may have promoted a stronger curfew enforcement response. Drag nets are illegal in Kenya but persist due to political arrangements that protect users against full enforcement. This political process appeared to have waned or be temporarily overridden in some sites by national enforcement agencies enacting covid and other laws. Where beach seines were not fully eliminated, as in Reef, the catch and incomes increased as predicted. Beach seines in Reef may have been a barrier to fish movements but distance from the reserve and dredging near the harbor may have influenced the lower catches in sites more distant from reserve site, such as Kanamai and Nyali. Therefore, catches recorded in Nyali did not change and seine nets were replaced by increased set or gill nets, and total catch compensated for by an increase in speargun CPUE. The largest increases were recorded in Kenyatta, which was a site immediately adjacent the reserve and with longer-term effective enforcement of gear restrictions. Both Kenyatta and Reef sites on the southern border of the closure displayed a daily 45% increase in CPUE, 25-30% increase in CPUA, and a 45-56% increase in incomes after the curfews were lifted.

Landings north of the park were more variable and displayed less catch recovery. Mtwapa experienced an increase in CPUA but without a statistically measurable changes in effort, CPUE, and revenue. Kanamai had low fishing effort but experienced a loss of CPUA associated with a small decline in effort, CPUE, and CPUA. Catches in Kanamai were the lowest among northern sites. Some combination of distance from the reserve, a shallow and degraded habitat dominated by sea urchins, and low stocks may explain these results. Mtwapa was also highly influenced by a tidal creek and has low water visibility during spring tides and rainy periods. The mouth of the Mtwapa creek also has an episodic use of the illegal seine nets. Consistently measuring their catch was, however, not possible due to the difficulties of sampling illegal gear during a time of

increased enforcement. The impact of illegal gear and potential compliance with the curfew remains one of the unknown influences on catches. The increase in CPUA in this creek site does, however, suggest a positive effect on catch by their reduction or removal near a reserve. Consequently, some combination of factors of water quality, habitat, illegal gear, and low stocks observed north of the reserve may have prevented the expected catch-only changes.

The rural gear-restricted sites in Kwale did not display the predicted response to the curfew regulations. However, long term trends show general changes of reduced fishing effort for both locations. The most likely explanations were the absence of a reserve of protected stocks, poor and variable compliance with the curfew, poor water quality issues associated with dredging, poor habitat quality, and issuance of approved mesh-regulated fishing nets by Kwale county government (McClanahan and Kosgei 2019). All these factors combined were likely to lead to poor recovery rates of catches and the continued long-term losses. Key informants in these sites mentioned the effects of reduced water visibility due to dredging and winds but many fishers believed there was little change in effort. Dredging, for example, largely stopped before the curfews began, so should not have directly affected the water quality and catch during the early post-covid period. Spear use declined and set nets increased in several sites over the curfew and this may have been a response to poor visibility but can also be influenced by employment opportunities for youth.

A degraded habitat has also been well documented for these gear-restricted sites (Uku 1995; McClanahan et al. 1997). Habitat has been degraded by a high abundances of sea urchins in coral reefs and seagrass beds associated with low predator and fish stock abundance (Eklof et al. 2008; McClanahan and Muthiga 2016). Increases in turbidity should add to this degradation and add to longer-term detrimental consequences. Interviewed fishers were more likely than key informants to admit there was poor compliance with curfew regulations and attributed the accelerating loss due effort and some environmental factors. Thus, I suggest that the lack of a positive catch response to the curfew was largely due to the combined detrimental effects of poor compliance, low water quality, habitat degradation, gear subsidies, and low stocks. Thus, adding to the long-term decline in the catch metrics. The cumulative effect partially seen here and over the longer term has been a slow exiting of fishers associated with declining CPUE and CPUA (McClanahan 2021).

The implications of the findings are that responses to curfew-induced fishing effort hiatus were contextual and appeared to be overridden by a mixture of enforcement success, destructive gear, poor water quality, and habitat degradation. The predicted positive responses were evident only in the presence of a marine reserve that had recovered stocks (~100 tons/km^2) (McClanahan 2021). These stocks were, however, not able to override what may be an effect of excess effort and environmental and habitat degradation observed around the urbanized Mtwapa creek and Kilindini Harbor.

In the gear-restricted fisheries, a mixture of compliance and environmental issues prevented any recovery or reversal of declines. The initial response to gear restrictions after the 2001 to 2004 implementation period was positive (McClanahan 2010). However, other changes including the purchase of nets by Kwale county initiated in 2014 accelerated the slow decline that emerged after a pulsed recovery after 2004 (McClanahan and Kosgei 2017). A reported 24-year decline in catch

in gear-restricted sites was 0.01 kg/km^2/day (annual basis) is slower than the decline over the 30-months reported here at 0.22 kg/km^2/day (monthly basis) (McClanahan 2021). Thus, the evidence that the covid curfew would reduce the rate of decline was also not supported by rates of change comparisons. In Africa, where the covid epidemic was not as lethal as elsewhere and where people are highly reliant on fisheries resources, the expected reduced effort and rebound in fish populations was only patchily evident (Okyere et al. 2021; Fiorella et al. 2021).

The duration and intensity of catastrophic climate events in marine environments is increasing (Cheng et al. 2019; Skirving et al. 2019). The interactions between natural habitat losses, contact with wild animals, and global connectivity of humans also suggests a continued and persistent rapid spread of communicable diseases, such as covid (El-Sayed and Kammel 2020). This has caused considerable speculation about the influences on natural populations of animals and particularly fisheries (Knight et al. 2020; Bates et al. 2021). As shown here, the response was not a universal rebounding of fish populations and subsequent improvement of individual catches and incomes. Rather, variable management, low compliance, reductions in other environmental stresses, and protection of both habitat and fish stocks would appear to play important modifying roles. In order to avoid additive and synergistic detrimental influences, natural resources management needs policy foresight to prepare for these kinds of system-level social-ecological shocks. Marine reserves appear to play an important role in increasing fish stocks in these overfished coastal fisheries and therefore the ability to increase resilience to social-ecological shocks (Maypa et al. 2002; O'Leary et al. 2016).

References
Bates, A. E., R. B. Primack, C. M. Duarte, and P.-E. W. Group. 2021. Global COVID-19 lockdown highlights humans as both threats and custodians of the environment. Biological Conservation:109175.

Bennett, N. J., E. C. Finkbeiner, N. C. Ban, D. Belhabib, S. D. Jupiter, J. N. Kittinger, S. Mangubhai, J. Scholtens, D. Gill, and P. Christie. 2020. The COVID-19 Pandemic, small-scale fisheries and coastal fishing communities. Coastal Management: DOI: 10.1080/08920753.08922020.01766937.

Brand, S. P. C., J. Ojal, R. Aziza, V. Were, E. Okiro, I. Kombe, C. Mburu, M. Ogero, A. Agweyu, G. M. Warimwe, J. Nyagwange, H. Karanja, J. N. Gitonga, D. Mugo, S. Uyoga, I. M. O. Adetifa, J. A. G. Scott, E. Otieno, N. Murunga, M. Otiende, L. I. Ochola-Oyier, C. I. Agoti, G. Githinji, K. Kasera, P. Amoth, M. Mwangangi, R. Aman, W. Ng'ang'a, B. Tsofa, P. Bejon, M. J. Keeling, J. D. Nokes, and E. Barasa. 2021. Covid-19 transmission dynamics underlying epidemic waves in Kenya. Science **374**:989 - 994.

Campbell, S. J., R. Jakub, A. Valdivia, H. Setiawan, A. Setiawan, C. Cox, A. Kiyo, L. F. Djafar, E. de la Rosa, and W. Suherfian. 2021. Immediate impact of COVID-19 across tropical small-scale fishing communities. Ocean & Coastal Management **200**:105485.

Cheng, L., J. Abraham, Z. Hausfather, and K. E. Trenberth. 2019. How fast are the oceans warming? Science **363**:128-129.

Cinner, J. E., M. L. Barnes, G. G. Gurney, S. Lockie, and C. Rojas. 2021. Markets and the crowding out of conservation-relevant behavior. Conservation Biology **35**:816-823.

Cinner, J. E., C. Huchery, M. A. MacNeil, N. A. Graham, T. R. McClanahan, J. Maina, E. Maire, J. N. Kittinger, C. C. Hicks, C. Mora, E. H. Allison, S. D'Agata, A. Hoey, D. A. Feary, L. Crowder, I. D. Williams, M. Kulbicki, L. Vigliola, L. Wantiez, G. Edgar, R. D. Stuart-Smith, S. A. Sandin, A. L. Green, M. J. Hardt, M. Beger, A. Friedlander, S. J. Campbell, K. E. Holmes, S. K. Wilson, E. Brokovich, A. J. Brooks, J. J. Cruz-Motta, D. J. Booth, P. Chabanet, C. Gough, M. Tupper, S. C. A. Ferse, R. U. Sumaila, and D. Mouillot. 2016. Bright spots among the world's coral reefs. Nature **535**:416-419.

Cinner, J. E., E. Maire, C. Huchery, M. A. MacNeil, N. A. Graham, C. Mora, T. R. McClanahan, M. L. Barnes, J. N. Kittinger, C. C. Hicks, S. D'Agata, A. Hoey, S. , G. Gurney, G. , D. Feary, A. , I. Williams, D. , M. Kulbicki, L. Vigliola, L. Wantiez, G. J. Edgar, R. D. Stuart-Smith, S. A. Sandin, G. Alison, M. J. Hardt, M. Beger, A. M. Friedlander, S. K. Wilson, E. B., A. J. Brooks, J. J. Cruz-Motta, D. J. Booth, P. Chabanet, C. Gough, M. Tupper, S. C. A. Ferse, U. Sumaila, S. Pardede, and D. Mouillot. 2018. Gravity of human impacts mediates coral reef conservation gains. Proceedings of the National Academy of Sciences **115**: E6116 - E6125.

Eklöf, J. S., M. de la Torre-Castro, M. Gullström, J. Uku, N. Muthiga, T. Lyimo, and S. O. Bandeira. 2008. Sea urchin overgrazing of seagrasses: A review of current knowledge on causes, consequences, and management. Estuarine, Coastal and Shelf Science **79**:569-580.

El-Sayed, A., and M. Kamel. 2020. Climatic changes and their role in emergence and re-emergence of diseases. Environmental Science and Pollution Research **27**:22336-22352.

Ferguson, C. E., T. Tuxson, S. Mangubhai, S. Jupiter, H. Govan, V. Bonito, S. Alefaio, M. Anjiga, J. Booth, and T. Boslogo. 2022. Local practices and production confer resilience to rural Pacific food systems during the COVID-19 pandemic. Marine Policy **137**:104954.

Fiorella, K. J., E. R. Bageant, L. Mojica, J. A. Obuya, J. Ochieng, P. Olela, P. W. Otuo, H. O. Onyango, C. M. Aura, and H. Okronipa. 2021. Small-scale fishing households facing COVID-19: The case of Lake Victoria, Kenya. Fisheries Research **237**:105856.

Hallwass, G., P. F. M. Lopes, A. A. Juras, and R. A. M. Silvano. 2013. Behavioral and environmental influences on fishing rewards and the outcomes of alternative management scenarios for large tropical rivers. Journal of Environmental Management **128**:274-282.

Hicks, C. C. 2011. How do we value our reefs? Risks and tradeoffs across scales in "biomass-based" economies. Coastal Management **39**:358-376.

Keppeler, F. W., G. Hallwass, F. C. Santos, L. H. T. da Silva, and R. A. M. Silvano. 2020. What makes a good catch? Effects of variables from individual to regional scales on tropical small-scale fisheries. Fisheries Research **229**:105571.

Kerr, L. A., J. P. Kritzer, and S. X. Cadrin. 2019. Strengths and limitations of before–after–control–impact analysis for testing the effects of marine protected areas on managed populations. ICES Journal of Marine Science **76**:1039-1051.

Kerwath, S. E., H. Winker, A. Götz, and C. G. Attwood. 2013. Marine protected area improves yield without disadvantaging fishers. Nature Communications **4**:2347.

Knight, C. J., T. L. U. Burnham, E. J. Mansfield, L. B. Crowder, and F. Micheli. 2020. COVID-19 reveals vulnerability of small-scale fisheries to global market systems. The Lancet Planetary Health **4**: e219.

Lau, J., S. Sutcliffe, M. Barnes, E. Mbaru, I. Muly, N. Muthiga, S. Wanyonyi, and J. E. Cinner. 2021. COVID-19 impacts on coastal communities in Kenya. Marine Policy **134**:104803.

Lenihan, H. S., J. P. Gallagher, J. R. Peters, A. C. Stier, J. K. K. Hofmeister, and D. C. Reed. 2021. Evidence that spillover from Marine Protected Areas benefits the spiny lobster (Panulirus interruptus) fishery in southern California. Scientific Reports **11**:1-9.

Maypa, A. P., G. R. Russ, A. C. Alcala, and H. P. Calumpong. 2002. Long-term trends in yield and catch rates of the coral reef fishery at Apo Island, central Philippines. Marine and Freshwater Research **53**:207-213.

Mbaru, E. K., N. A. J. Graham, T. R. McClanahan, and J. E. Cinner. 2020. Functional traits illuminate the selective impacts of different fishing gears on coral reefs. Journal of Applied Ecology **57**:241-252.

McClanahan, T. R. 2007. Management of area and gear in Kenyan coral reefs. Pages 166-185 *in* T. R. McClanahan and J. C. Castilla, editors. Fisheries Management: Progress towards Sustainability. Blackwell Press, London.

McClanahan, T. R. 2010. Effects of fisheries closures and gear restrictions on fishing revenue in a Kenyan coral reef. Conservation Biology **24**:1519-1528.

McClanahan, T. R. 2018. Community biomass and life history benchmarks for coral reef fisheries. Fish and Fisheries **19**:471-488.

McClanahan, T. R. 2021. Marine reserve more sustainable than gear restriction in maintaining long-term coral reef fisheries yields. Marine Policy **128**:104478.

McClanahan, T. R., and M. K. Azali. 2020. Improving sustainable yield estimates for tropical reef fisheries. Fish and Fisheries **21**:683 - 699.

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

McClanahan, T. R., N. A. J. Graham, M. A. MacNeil, and J. E. Cinner. 2015. Biomass-based targets and the management of multispecies coral reef fisheries. Conservation Biology **29**:409-417.

McClanahan, T. R., and J. K. Kosgei. 2018. Redistribution of benefits but not detection in a fisheries bycatch-reduction management initiative. Conservation Biology **32**:159-170.

McClanahan, T. R., and J. K. Kosgei. 2019. Outcomes of gear and closure subsidies in artisanal coral reef fisheries. Conservation Science and Practice **1**: e114.

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

McClanahan, T. R., and N. A. Muthiga. 2016. Similar impacts of fishing and environmental stress on calcifying organisms in Indian Ocean coral reefs. Marine Ecology Progress Series **560**:87-103.

Nowlis, J. S., and C. M. Roberts. 1999. Fisheries benefits and optimal design of marine reserves. Fishery Bulletin **97**:604-616.

O'Leary, B. C., M. Winther-Janson, J. M. Bainbridge, J. Aitken, J. P. Hawkins, and C. M. Roberts. 2016. Effective coverage targets for ocean protection. Conservation Letters **9**:398-404.

Okyere, I., E. O. Chuku, B. Ekumah, D. B. Angnuureng, J. K. Boakye-Appiah, D. J. Mills, R. Babanawo, N. K. Asare, D. W. Aheto, and B. Crawford. 2020. Physical distancing and risk of COVID-19 in small-scale fisheries: A remote sensing assessment in coastal Ghana. Scientific Reports **10**:1-13.

Ovando, D., C. M. Free, O. P. Jensen, and R. Hilborn. 2021. A history and evaluation of catch-only stock assessment models. Fish and Fisheries.

Pita, P., G. B. Ainsworth, B. Alba, A. B. Anderson, M. Antelo, J. Alós, I. Artetxe, J. Baudrier , J. J. Castro, B. Chicharro, K. Erzini, K. Ferter, M. Freitas, L. García-de-la-Fuente, J. A. García-Charton, M. Giménez-Casalduero, A. M. Grau, H. Diogo, A. Gordoa, F. Henriques, K. Hyder, D. Jiménez-Alvarado, P. K. Karachle, J. Lloret, M. Laporta, A. M. Lejk, A. L. Dedeu, P. Martín-Sosa, L. Martínez, A. M. Mira, B. Morales-Nin, E. Mugerza, H. J. Olesen, A. Papadopoulos, J. Pontes, J. J. Pascual-Fernández, A. Purroy, M. Ramires, M. Rangel, J. A. Reis-Filho, J. L. Sánchez-Lizaso, V. Sandoval, V. Sbragaglia, L. Silva, C. Skov, I. Sola, H. V. Strehlow, M. A. Torres, D. Ustups, T. van der Hammen, P. Veiga, L. A. Venerus, T. Verleye, S. Villasante, M. S. Weltersbach, and L. Zarauz. 2021. First assessment of the impacts of the covid-19 pandemic on global marine recreational fisheries. Frontiers in Marine Science **8**: Doi:10.3389/fmars.2021.735741.

Selig, E. R., D. G. Hole, E. H. Allison, K. K. Arkema, M. C. McKinnon, J. Chu, A. de Sherbinin, J. C. Ingram, N. S. Rao, R. B. Russell, T. Srebotnjak, L. C. L. Teh, S. Troëng, W. R. Turner, and A. Zvoleff. 2019. Mapping global human dependence on marine ecosystems. Conservation Letters **12**: e12617.

Skirving, W. J., S. F. Heron, B. L. Marsh, G. Liu, J. L. De La Cour, E. F. Geiger, and C. M. Eakin. 2019. The relentless march of mass coral bleaching: A global perspective of changing heat stress. Coral Reefs **38**:547 - 557.

Sladek-Nowlis, J. S. 2000. Short and long term effects of three fisehry management tools on depleted fisheries. Bulletin of Marine Science **66**:651-662.

Stokes, G. L., A. J. Lynch, B. S. Lowe, S. Funge-Smith, J. Valbo-Jørgensen, and S. J. Smidt. 2020. COVID-19 pandemic impacts on global inland fisheries. Proceedings of the National Academy of Sciences **117**:29419-29421.

Thoya, P., and T. M. Daw. 2019. Effects of assets and weather on small-scale coastal fishers' access to space, catches and profits. Fisheries Research **212**:146-153.

Truchet, D. M., N. S. Buzzi, and M. B. Noceti. 2021. A "new normality" for small-scale artisanal Fishers? The case of unregulated fisheries during the COVID-19 pandemic in the Bahía Blanca estuary (SW Atlantic Ocean). Ocean & Coastal Management **206**:105585.

Uku, J. N. 1995. An Ecological Assessment of Littoral Seagrass Communities in Diani and Galu Coastal Beaches, Kenya. Master of Science (Biology of Conservation). University of Nairobi, Nairobi, Kenya.

Young, N., A. N. Kadykalo, C. Beaudoin, D. M. Hackenburg, and S. J. Cooke. 2021. Is the Anthropause a useful symbol and metaphor for raising environmental awareness and promoting reform? Environmental Conservation **48**:274-277.

Supplement table 1. Questions administered to resource users in north and south coast for validation of trends in catches before and after covid curfews

North coast	South coast
- The environmental conditions improved during curfew as there was no sand harvest	The environemental conditions deteroriated during curfew due to sand harvest
- Normal fishing effort did not change during curfew. Explain if it decreased following government restrictions or increased secretly	Normal fishing effort changed during curfew. Explain if it increased following government restrictions or it increased secretly
- Fishing effort from distant visiting fishers reduced during curfew	Fishing effort from distant visiting fishers increased during curfew
- Fishing effort of illegal gears declined during curfew	Fishing effort from illegl gears increased duirng curfew
- Fishing effort at night declined during curfew	Fishing effort at night increased during curfew
- Fishing was stopped during curfew	Fishing effort at night increased during curfew
- Fishing gears were changed during the curfew to improve target catches	Fishing gears were changed during the curfew which depleted catches
- Explain if there is another reason(s)	Explain if there is another reason(s)
- Marine closure such as Mombasa Park helped in increasing fish catches coupled with reduced effort during curfew	

Supplementary table 2. Comparisons of the mean ($\pm$ 95CI) (a) total and by-gear fishing effort (fishers/km^2/day), (b) CPUE (catch, kg/fisher/day), (c) CPUA (catch, kg/km^2/day), and (d) income (Ksh/fisher/day) before and after the covid curfew in the studied landing sites in the north (fisheries closure management) and south (gear restriction management). Kruskal Wallis tests were conducted, **bolded** values show significant differences ($P < 0.10$) in the period before and after covid. P-values were adjusted following methods by Benjamini and Hochberg (1995) to control for false discovery rates. LS = low sample size ($N \leq 10$), blanks = no observations.

	Beachseine		Handline		Net		Spear		Trap		Total catch	
Site	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
a) Effort, fishers/km^2/day												
Kanamai			LS	LS	1.2 ± 0.3	0.9 ± 0.3	1.8 ± 0.2	1.4 ± 0.3			2.8 ± 0.3	2.2 ± 0.3
Mtwapa			0.5 ± 0.1	0.5 ± 0.1	3.5 ± 0.8	3.4 ± 1.1	LS	LS	0.3 ± 0.1	0.4 ± 0.1	3.0 ± 1.0	2.8 ± 1.0

Kenyatta			1.7 ± 0.4	1.5 ± 0.3	1.6 ± 0.4	1.7 ± 0.4	1.2 ± 0.2	0.9 ± 0.1	1.4 ± 0.1	1.2 ± 0.1	5.1 ± 0.8	4.7 ± 0.5
Reef	6.6 ± 2.2	3.9 ± 0.6	LS	LS	LS	LS	1.2 ± 0.2	1.1 ± 0.2	LS	LS	6.4 ± 2.0	5.4 ± 0.8
Nyali	LS	LS	0.6 ± 0.2	0.5 ± 0.2	1.2 ± 0.2	1.7 ± 0.5	1.2 ± 0.3	1.2 ± 0.3	0.5 ± 0.1	0.7 ± 0.7	3.2 ± 0.9	3.5 ± 0.8
Northern re-serve			0.6 ± 0.8	0.7 ± 0.5	1.7 ± 1.3	1.7 ± 1.3	1.2 ± 0.5	1.0 ± 0.4	0.6 ± 0.8	0.6 ± 0.7	4.1 ± 2.0	3.7 ± 1.7
Tradewinds			LS	LS	4.7 ± 0.6	5.5 ± 1.1	1.9 ± 0.3	1.4 ± 0.2	LS	LS	6.1 ± 0.7	6.7 ± 1.4
Mwaepe			**1.1 ± 0.2**	**0.8 ± 0.2**	0.5 ± 0.1	0.9 ± 0.6	**1.5 ± 0.1**	**1.1 ± 0.2**	LS	LS	**2.9 ± 0.2**	**2.4 ± 0.5**
Mvuleni			1.7 ± 0.3	1.7 ± 0.3	LS	LS	**3.1 ± 0.3**	**2.6 ± 0.3**	**1.2 ± 0.2**	**0.7 ± 0.1**	5.6 ± 0.6	5.1 ± 0.4
Mwanyaza			1.9 ± 0.3	1.4 ± 0.2	2.7 ± 0.3	2.9 ± 0.2	2.8 ± 0.5	2.9 ± 0.3	1.3 ± 0.2	1.4 ± 0.2	4.9 ± 0.5	4.7 ± 0.6
Chale			LS	LS	**1.8 ± 0.1**	**2.4 ± 0.4**	**6.4 ± 1.3**	2.6 ± 0.6	1.7 ± 0.2	1.7 ± 0.3	**9.4 ± 1.4**	**5.7 ± 0.9**
Southern gear restricted			1.4 ± 0.8	1.3 ± 0.7	2.2 ± 2.0	2.7 ± 2.2	3.1 ± 2.5	2.1 ± 1.0	1.2 ± 0.7	1.2 ± 0.9	5.8 ± 2.9	4.9 ± 2.0
b) CPUE, kg/fisher/day												
Kanamai			LS	LS	**4.6 ± 1.0**	**4.2 ± 1.9**	**2.9 ± 0.3**	**2.3 ± 0.3**			**3.7 ± 0.5**	**3.3 ± 1.2**
Mtwapa			10.4 ± 12.3	4.7 ± 1.1	2.4 ± 1.4	4.3 ± 3.9	LS	LS	3.9 ± 1.4	3.3 ± 0.9	5.0 ± 3.2	4.5 ± 1.9
Kenyatta			**3.7 ± 0.7**	**5.1 ± 0.8**	4.3 ± 1.0	5.5 ± 1.1	**4.4 ± 1.8**	**6.2 ± 1.1**	**4.4 ± 0.8**	**6.8 ± 1.0**	**4.0 ± 0.5**	**5.8 ± 0.6**
Reef	**4.8 ± 3.1**	**6.0 ± 1.6**	LS	LS	LS	LS	**4.3 ± 0.7**	**7.1 ± 1.5**	LS	LS	**4.0 ± 1.1**	**5.8 ± 1.1**
Nyali	LS	LS	4.8 ± 2.2	5.1 ± 3.2	4.7 ± 2.1	6.0 ± 4.7	**4.4 ± 0.9**	**6.6 ± 1.4**	8.2 ± 2.4	8.6 ± 2.4	5.0 ± 1.0	5.2 ± 0.9
Northern re-serve			4.8 ± 4.1	3.9 ± 1.8	4.6 ± 2.0	4.9 ± 1.0	4.5 ± 1.8	6.1 ± 2.8	4.7 ± 3.9	5.6 ± 4.1	4.3 ± 0.8	4.9 ± 1.3
Tradewinds			LS	LS	4.1 ± 1.4	4.2 ± 1.4	3.7 ± 0.5	3.3 ± 0.6	LS	LS	4.1 ± 0.9	4.2 ± 1.0
Mwaepe			3.7 ± 1.3	2.6 ± 1.2	**6.5 ± 1.8**	**3.2 ± 1.9**	**3.4 ± 0.3**	**2.8 ± 0.4**	LS	LS	3.8 ± 0.6	3.1 ± 0.6
Mvuleni			**3.3 ± 1.0**	**1.8 ± 0.5**	LS	LS	4.3 ± 0.8	3.6 ± 0.6	5.0 ± 1.2	7.7 ± 3.1	**4.2 ± 0.7**	**3.1 ± 0.6**
Mwanyaza			4.0 ± 0.6	3.7 ± 0.6	**4.1 ± 1.2**	**2.3 ± 0.5**	4.4 ± 0.5	4.0 ± 1.0	6.2 ± 1.3	9.1 ± 2.7	4.7 ± 0.5	4.6 ± 0.9
Chale			LS	LS	3.2 ± 1.0	2.2 ± 0.8	3.4 ± 0.9	2.7 ± 0.6	2.7 ± 0.8	2.8 ± 0.7	3.2 ± 0.5	2.6 ± 0.5
Southern gear restricted			4.0 ± 1.7	2.8 ± 2.3	3.8 ± 2.3	2.6 ± 1.5	3.9 ± 0.5	3.3 ± 0.7	4.5 ± 1.7	6.4 ± 3.0	4.0 ± 0.7	3.5 ± 1.1

c) CPUA kg/km²/day

Kanamai			LS	LS	5.5 ± 1.7	4.5 ± 3.2	**5.0 ± 0.7**	**3.1 ± 0.6**			**9.9 ± 1.4**	**7.0 ± 2.7**
Mtwapa			3.6 ± 2.4	2.3 ± 0.8	6.8 ± 3.2	14.3 ± 14.1	LS	LS	1.2 ± 0.6	1.4 ± 0.7	8.4 ± 2.9	11.9 ± 8.5
Kenyatta			6.5 ± 1.8	6.9 ± 1.3	6.5 ± 2.1	8.8 ± 2.4	4.5 ± 1.2	5.7 ± 1.3	6.2 ± 1.5	8.3 ± 1.3	20.7 ± 4.4	26.8 ± 3.7
Reef	22.5 ± 8.3	22.2 ± 5.7	LS	LS	LS	LS	5.5 ± 1.5	7.0 ± 1.1	LS	LS	23.4 ± 8.0	30.4 ± 6.7
Nyali	LS	LS	2.5 ± 1.1	2.0 ± 0.8	5.5 ± 2.2	6.8 ± 2.1	5.6 ± 1.5	7.2 ± 1.4	4 ± 1.2	3.6 ± 1.1	13.7 ± 3.3	17.1 ± 3.5
Northern re-serve			2.7 ± 3.1	2.6 ± 3.1	5.7 ± 1.3	7.8 ± 5.0	5.0 ± 0.7	5.6 ± 2.1	3.0 ± 4.2	3.5 ± 5.4	15.2 ± 8.2	18.6 ± 12.3
Tradewinds			LS	LS	20.0 ± 8.0	22.8 ± 8.4	7.0 ± 1.5	4.8 ± 1.2	LS	LS	25.4 ± 6.5	27.9 ± 8.5
Mwaepe			4.5 ± 2.0	2.4 ± 1.4	3.3 ± 1.0	2.8 ± 2.5	**5.1 ± 0.5**	**3.2 ± 0.8**	LS	LS	**11.1 ± 1.9**	**7.5 ± 2.2**
Mvuleni			**4.9 ± 0.9**	**3.1 ± 1.1**	LS	LS	**12.7 ± 2.1**	**9.1 ± 1.7**	5.8 ± 1.4	5.1 ± 1.8	**21.8 ± 3.0**	**16.0 ± 3.1**
Mwanyaza			7.8 ± 1.8	5.3 ± 1.3	10.5 ± 3.5	6.8 ± 1.6	12.9 ± 2.6	10.9 ± 2.3	7.4 ± 1.6	12.8 ± 4.4	21.9 ± 2.9	19.3 ± 2.8
Chale			LS	LS	5.5 ± 1.7	5.4 ± 2.2	**21.2 ± 5.7**	**7.3 ± 2.2**	4.3 ± 1.0	4.2 ± 1.0	**29.4 ± 6.3**	**14.6 ± 3.6**
Southern gear restricted			4.8 ± 2.5	3.5 ± 2.3	8.4 ± 8.9	7.9 ± 10.6	11.8 ± 7.8	7.1 ± 3.9	5.2 ± 3.3	6.9 ± 5.3	21.9 ± 8.5	17.1 ± 9.2

d) Income, Ksh/fisher/day

Kanamai			LS	LS	896.9 ± 302.3	1103.7 ± 585.3	439.5 ± 48.3	497.1 ± 71.8			688.5 ± 172	827.9 ± 358.6
Mtwapa			2662.5 ± 3172	1301.6 ± 275.2	522.4 ± 338.6	1200.2 ± 1054.9	LS	LS	964.3 ± 321.9	921.5 ± 273.3	1179.6 ± 815.3	1215.8 ± 522.6
Kenyatta			**1095.2 ± 211.3**	**1516.6 ± 255.2**	**1210.8 ± 232.4**	**1652.4 ± 317.0**	**1274.1 ± 542.4**	**1739.1 ± 310.2**	**1292.2 ± 244.3**	**2021.2 ± 297.8**	**1172.2 ± 153.8**	**1695.9 ± 184.2**
Reef	**837.4 ± 474.6**	**1335.0 ± 389.6**	LS	LS	LS	LS	**1123.5 ± 172.9**	**1795.5 ± 358.6**	LS	LS	**854.2 ± 211.5**	**1333.9 ± 278.7**

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Site											
Nyali	LS	LS	1283.0 ± 581.4	1493.4 ± 964.1	1249.9 ± 539.0	1776.5 ± 1428.4	**1022.0 ± 204.9**	**1505.0 ± 279.4**	2191.7 ± 637.1	2476.6 ± 665.7	1272.7 ± 265.5	1379.8 ± 213.0
Northern marine reserve			1251.4 ± 1051.3	1142.7 ± 511.5	1117.9 ± 548.0	1357 ± 414.0	1091.4 ± 527.1	1477.3 ± 699.8	1259.8 ± 1088.6	1597.7 ± 1232.9	1033.4 ± 309.8	1290.7 ± 389.5
Tradewinds	LS	LS	1058.5 ± 360.0	1106.8 ± 369.1	908.1 ± 111.2	776.5 ± 162.3	LS	LS			1037.8 ± 210.3	1082.4 ± 255.7
Mwaepe	1020.4 ± 371.8	686.2 ± 302.9	**1810.6 ± 530.9**	**856.4 ± 517.4**	**883.0 ± 92.1**	**663.9 ± 103.2**	LS	LS			**1015.3 ± 164.0**	**793.0 ± 142.6**
Mvuleni	**868.5 ± 245.8**	**458.9 ± 126.3**	LS	LS	**1060.1 ± 190.1**	**767.0 ± 124**	1301.8 ± 298.0	1911.3 ± 765.7			**1068.5 ± 178.8**	**718.6 ± 136.2**
Mwanyaza	1102.8 ± 165.0	1079.7 ± 186.9	**1149.8 ± 347.4**	**675.1 ± 152.8**	**1133.9 ± 128.8**	**957.1 ± 253.3**	1697.5 ± 352.9	2496.0 ± 834.6			1259.0 ± 136.9	1253.5 ± 272.7
Chale	LS	LS	789.5 ± 256.7	599.7 ± 209.1	816.1 ± 230.7	549.2 ± 102.1	680.6 ± 192.9	714.2 ± 180.9			766.2 ± 126.0	594.6 ± 107.3
Sothern gear restricted			1040.8 ± 420.6	745.5 ± 586.4	1029.2 ± 669.2	699.5 ± 390.0	960.2 ± 163.8	742.7 ± 187.7	1162.7 ± 490.1	1684.9 ± 827.4	1029.3 ± 218.5	888.4 ± 337.3

Supplementary table 3. Catch as CPUE (mean ± 95CI) per fish catch categories (scavengers, rabbitfish, parrotfish, others) in studied landing sites for before and after covid19 curfews in marine and gear management fisheries. Kruskal Wallis tests were conducted, **bolded** values show significant differences ($P < 0.1$) in the period before and after covid. P-values were adjusted following methods by Benjamini and Hochberg (1995) to control for false discovery rates. Others is a diverse catch of mixed coral reef fish that include low value species not pooled into groups for higher price and include wrasses, squirrelfish, goatfish, angelfish and many other fish families.

Site	Rabbitfish		Scavengers		Parrotfish		Mixed or Others		Octopus	
	Before	After	Before	After	Before	After	Before	After	Before	After
Kanamai	0.50 ± 0.25	0.52 ± 0.48	0.82 ± 0.54	0.54 ± 0.52	0.10 ± 0.07	0.06 ± 0.09	1.70 ± 0.22	1.71 ± 0.34	0.55 ± 0.13	0.42 ± 0.11
Mtwapa	0.41 ± 0.49	0.51 ± 0.42	2.55 ± 3.23	3.12 ± 2.02	0.07 ± 0.10	0.41 ± 0.67	0.97 ± 0.65	0.28 ± 0.27	0.97 ± 1.04	0.2 ± 0.42
Kenyatta	1.63 ± 0.44	1.96 ± 0.37	**1.39 ± 0.32**	**2.44 ± 0.34**	0.08 ± 0.11	0.09 ± 0.11	0.33 ± 0.18	0.29 ± 0.14	0.58 ± 0.24	0.93 ± 0.29

Reef	0.31 ± 0.17	0.22 ± 0.11	0.17 ± 0.20	0.49 ± 0.55	1.74 ± 1.00	2.90 ± 0.88	0.75 ± 0.34	1.16 ± 0.71	1.02 ± 0.41	0.99 ± 0.29
Nyali	2.25 ± 1.00	1.56 ± 0.42	**0.51 ± 0.34**	**0.98 ± 0.34**	**0.47 ± 0.26**	**1.17 ± 0.43**	0.55 ± 0.35	0.39 ± 0.35	1.22 ± 0.44	1.13 ± 0.39
Northern reserve	1.02 ± 1.08	0.96 ± 0.94	1.09 ± 1.16	1.51 ± 1.48	0.49 ± 0.89	0.93 ± 1.48	0.86 ± 0.66	0.76 ± 0.80	0.87 ± 0.36	0.73 ± 0.50
Tradewinds	0.33 ± 0.21	0.59 ± 0.68	0.24 ± 0.29	0.22 ± 0.30	0.40 ± 0.12	0.29 ± 0.11	2.36 ± 0.94	2.65 ± 0.95	0.73 ± 0.24	0.48 ± 0.12
Mwaepe	0.14 ± 0.08	0.44 ± 0.31	0.80 ± 0.27	0.54 ± 0.43	**0.98 ± 0.18**	**0.59 ± 0.24**	0.88 ± 0.48	0.92 ± 0.50	0.98 ± 0.23	0.63 ± 0.19
Mvuleni	0.60 ± 0.22	0.29 ± 0.22	0.36 ± 0.13	0.54 ± 0.25	1.00 ± 0.38	0.72 ± 0.18	0.92 ± 0.21	0.78 ± 0.38	1.27 ± 0.41	0.80 ± 0.26
Mwanyaza	1.03 ± 0.45	1.81 ± 0.92	0.97 ± 0.35	0.71 ± 0.32	0.57 ± 0.20	0.34 ± 0.14	1.45 ± 0.26	1.28 ± 0.39	0.65 ± 0.21	0.45 ± 0.18
Chale	0.69 ± 0.28	0.88 ± 0.35	0.04 ± 0.02	0.13 ± 0.18	0.56 ± 0.18	0.38 ± 0.10	0.50 ± 0.22	0.37 ± 0.17	**1.36 ± 0.33**	**0.78 ± 0.24**
Southern gear restricted	0.56 ± 0.43	0.80 ± 0.75	0.48 ± 0.49	0.42 ± 0.30	0.70 ± 0.34	0.46 ± 0.23	1.22 ± 0.90	1.20 ± 1.08	1.00 ± 0.39	0.63 ± 0.20