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Bottom shrimp trawling impacts on species distribution and fishery dynamics; Ungwana Bay fishery Kenya before and after the 2006 trawl ban

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Abstract The Malindi–Ungwana Bay fishery Kenya is one of the most important marine fisheries of the Western Indian Ocean. There are two fishing grounds: Formosa and Malindi, with a designated 5-nM no-trawl zone offshore. However, the fishery was faced with numerous resource use conflicts and a decline in catches, culminating in a trawl ban in 2006. This study analyses catches and fishery dynamics before and after the 2006 trawl ban. Results show that artisanal landings declined before the ban, but rapidly recovered within 2 years after the ban was imposed. However, shrimp landings in the artisanal fishery remain low. Commercial shrimp landings gradually declined before the ban: ~550 t in 2001 to 250 t in 2006, and the shrimp: fish bycatch ratio was 1:1.5 compared to early reports of 1:7 in 1999. SIMPER analyses shows that 6 and 16 families (groups) accounted for 91.0 and 90.2% of the similarity in catch within the Formosa and Malindi fishing grounds, respectively. Formosa was important for Claridae, Cichlidae and Protopteridae, while Malindi recorded Carangidae, Siganidae, Carcharhinidae and Lethrinidae as the main families. Future studies should therefore embark on analyses of the factors driving the spatio-temporal distributions of the species and assess the impacts of bottom trawling on fishery dynamics before the trawl ban can be lifted.

Keywords Malindi–Ungwana Bay Kenya · Bottom trawl · Artisanal fishery · Catch per unit effort · SIMPER analysis

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Introduction

The Malindi–Ungwana Bay complex, Kenya, comprises the larger Ungwana Bay extending from Ras-Shaka in the north of Kipini to Ras Ngomeni in the south, and the smaller Malindi Bay, which straddles the mouth of the Athi River at Sabaki off the Eastern coast of Africa (Fig. 1). The complex, commonly referred to as the Ungwana Bay, is part of the wider Western Indian Ocean (WIO) Ecoregion. The continental shelf is narrow, extending up to only 60 km offshore, and the fishing grounds are shallow, averaging 12–18 m deep at 1.5 and 6.0 nM offshore [1]. However, the waters provide rich fishing grounds both inshore and offshore, and are home to a commercial bottom trawl fishery as well as resident and migrant artisanal fishery sectors. Two main rivers, the Athi and the Tana, drain into the Malindi and Ungwana bays, respectively, and thus enrich the waters of this complex and the associated fisheries.

The Malindi–Ungwana Bay commercial bottom trawl fishery is restricted to the 5–200 nM waters, while the

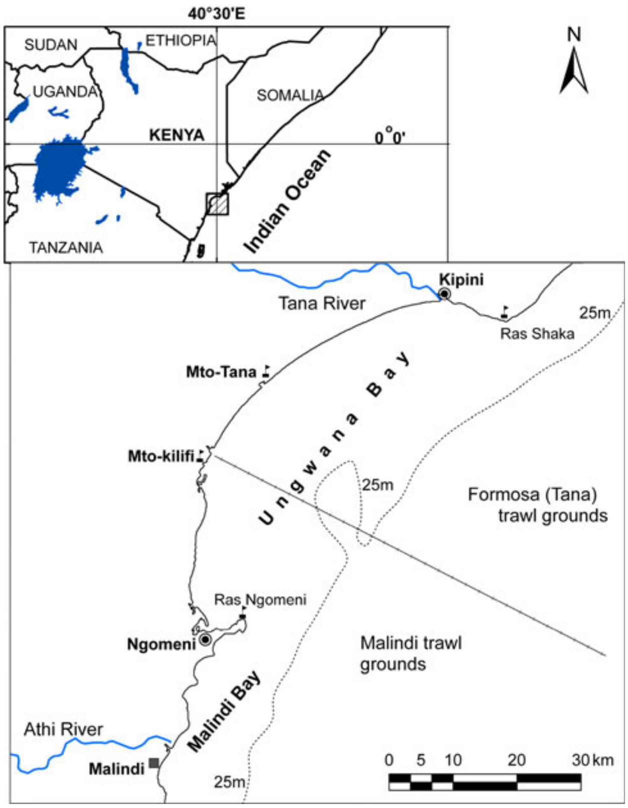

Fig. 1 Map of the Eastern Coast of Africa showing the location of the study site: the entire Malindi–Ungwana Bay Kenya and demarcation of the Formosa and Malindi fishing grounds of the commercial bottom trawlers

resident-migrant artisanal fishery exploits the 0–5 nM. Therefore, the 0–5 nM waters are designated as a trawl exclusion zone (TEZ) [2], setting an arbitrary area-based resource-use guide for the various fisheries of this important bay. The fishing grounds are some of the most productive and extensive shrimping areas on the East African coast [3, 4]. Consequently, fisheries remain an important source of livelihood for the coastal fisher communities of East Africa [1, 5].

The commercial bottom trawl fishery dates back to the early 1970s and is Kenya's only marine commercial shrimp fishery [6–9]. The fishery targets five main penaeid species: *Fenneropenaeus indicus* H. Milne Edwards, *P. monodon* Fabricius, *Metapenaeus monoceros* Fabricius, *P. semisulcatus* De Haan and *Marsupenaeus japonicus* Bate. The fishing fleet is mainly comprised of industrial trawlers that range in size from 25 to 40 m long and 115–1,500 horsepower engines equipped with blast freezers and freezing holds with 30–350 t storage capacity [3]. The trawlers employ double-rigged, stern or outrigger trawling as the predominant method of fishing, with funnel-shaped otter trawl gear mostly towed behind the vessels [1]. The nets are made of polypropylene with 50–55 and <40 mm diamond mesh sizes at the body and cod end, respectively.

On the other hand, the resident-migrant artisanal fishery has been in existence for several hundreds of years and is closely associated with trade dhows dating back to the sixteenth century Arab invasion of the East Africa Coast [5, 10]. The vessels used in the artisanal fishery are mainly traditional crafts including *mtumbwi*, *hori*, *ngalawa* and *dau*, which account for more than 40% of the vessels in the fishery. The *mtumbwi* are dug-out canoes measuring about 4 m long with curved bottoms. On the other hand, the *hori* and *ngalawa* are canoes made of plankwood, but differ in that the *ngalawa* are fitted with outriggers [1]. The *dau* is a flat bottom, plankwood vessel propelled by small sails. Other fishing crafts such as *mashua* and *jahazi* employ dual modes of propulsion, including inbuilt engines and lateen sails, and account for <20% of the fishing vessels [5]. The *mashua* are mainly used for out-of-reef fishing and employ sails as the main mode of propulsion, while the *jahazi* are the preferred fishing crafts for open-sea fishing and transportation of cargo [1]. The artisanal fishery is mainly based on traditional fishing gear comprising homemade basket (*malema*) traps, intertidal fixed weir (*uzio*) traps made of sticks, spear guns (*bunduki*) made from wood and some rubber bands, and wooden spears (*ngovya*) for octopus and crab fishing [1]. Modern gear in the fishery is limited to gillnets, drift nets, beach seines, handlines and longlines. Sardine nets (*kimia*) with <5 cm mesh sizes are used to target the small-sized sardine species [1, 11].

Worldwide, resource use conflicts between artisanal and commercial fisheries date back several centuries. As early as the late fourteenth century, Jones [12] identified historical complaints about bottom trawling by artisanal fishermen, including indiscriminate harvesting of undersized and non-target species in a deteriorating artisanal fishery in New Zealand. In the Malindi–Ungwana Bay fishery, conflicts over resource use and partitioning between the artisanal and the commercial bottom trawl fisheries escalated before the trawl ban in 2006, augmented by undefined harvest strategies and an increase in the use of deleterious fishing practices over the years [1, 5, 13]. These problems threaten the very livelihoods of the coastal fisher communities depending on these fisheries. Moreover, the impacts of bottom trawling on target and non-target species, and the damage to habitats and the associated benthic biota among others cannot be ignored [12, 14–18]. To date, this long-established technique of bottom trawling continues to attract increasing criticism for both the perceived damage to the environment and to the fisher livelihoods it may cause, especially with conflicts over the partitioning of fishing grounds. Many governments have devised harvest strategies incorporating seasonal bans and restricted fishing grounds, while others have banned bottom trawling altogether. Such management strategies have helped the recovery of the affected fisheries and associated marine resources. For example, while assessing the effects of a 1978 sustained ban on trawling in an Indonesian shrimp fishery, Chong et al. [19] reported that the over-fished stocks showed recovery within a 7-year period. With this background, the Kenyan government suspended bottom trawling in the Malindi–Ungwana Bay in 2006 when resource use conflicts with artisanal fishers over perceived declining catches, habitat impacts and destruction of artisanal fishing gear by the trawlers escalated because of the continuous encroachment on the artisanal fishing grounds by the commercial vessels. This encroachment is partly attributed to the higher abundance of the target shrimp species in the 3–5 nM waters [1]. However, information on the status of the stocks and the biology of the species, including growth, reproductive cycles and feeding ecology, was still lacking, leading to an indefinite trawl ban in 2006. Consequently, conducting extensive research was necessary in order to provide the much needed data and information on the species for definition of sustainable resource exploitation strategies. Therefore, a number of scientific trawl surveys were conducted, including the 2002 study by the Kenya Marine and Fisheries Research Institute (KMFRI-2002); the 2003 study by the Department of Fisheries and Aquatic Sciences, MOI University (DFAS-MOI, 2003); the 2009 trawl surveys under the Kenya Coastal Development Project (KCDP-2009); and the ongoing South West Indian Ocean Fisheries (SWIOF, 2010–2011) project. These studies have gone a long way in ensuring protection, management and development of the marine and coastal ecosystems of the Eastern Africa Region as outlined in the UNEP Nairobi Convention, 2010.

This study investigated the situation in the Malindi–Ungwana Bay fishery, looking at the trends in both the artisanal and commercial bottom trawl fisheries before and after the trawl ban in 2006. The study examined shrimp landings and retained fish bycatch in the commercial bottom trawl fishery during 2001–2006, and trends in landings from the artisanal fishery during the 2001–2006 pre-trawl ban period and the 2006–2008 no-trawl years. Specifically, the study compared landings in both the commercial and the artisanal fisheries to investigate the temporal and seasonal and, bathymetric and spatial variations in the commercial bottom trawl fishery shrimp CPUE, and to model the spatial and temporal differences in composition of the artisanal landings. The results of the study provide a baseline for future scientific assessments of the impacts of bottom trawling in the Malindi–Ungwana Bay fishery.

Materials and methods

Study area

The Malindi–Ungwana Bay complex extends along a 210-km coastal stretch running from Malindi town in the south to Ras-Shaka in the north of Kipini (Fig. 1). The bay straddles 2° 30′ S and 3° 30′ S, and longitudes 40° 00′ E and 41° 00′ E. The fishery is resource-partitioned into a 0–5 nM TEZ artisanal fishery and a commercial bottom trawl fishery exploiting the 5–200 nM exclusive economic zone (EEZ) (Government of Kenya, 2008). The commercial trawling grounds are amorphously divided into three main areas: (a) Malindi shallow, lying off the Malindi Bay, (b) Ngomeni, running from Ras-Ngomeni to the waters off Mto-Tana, and (c) Kipini, covering the shrimping grounds off Mto-Tana to the waters off Ras-Shaka [1, 4]. The fishing grounds cover an estimated 35,300 km^2, but the coastline is characterized by fringing reefs with occasional outcrops, thus limiting the effective trawlable grounds to about 20,000 km^2 [1, 4]. Most of the trawling is conducted in waters shallower than 70 m [3, 7]. The Tana and Athi Rivers drain into the bay, adding terrigenous sediments [20, 21].

Like the rest of the East African coast, the bay experiences a tropical humid climate with two distinct seasons: the dry Northeast monsoon (NEM) season (October–March) and the wet Southeast monsoon (SEM) season (April–September) [5, 22]. These seasons greatly influence the productivity of the marine and coastal fisheries as well as the fishing patterns along the coast [1, 22].

Data collection

In the commercial bottom trawl fishery, sampling surveys were conducted during 2001 through 2006. During this period, increased resource use conflicts led the government to impose stiffer legislations on the commercial bottom trawl fishery, including the need to utilize discarded bycatch and reduction of fishing effort by imposition of a ban on night trawling. Further, the vessels were installed with mandatory turtle excluder devices (TEDs) and vessel monitoring systems (VMS) equipment. A monitoring program was also initiated to assess the fishing activities of commercial bottom trawlers using onboard data collectors from the Fisheries Department (FD-Kenya) and KMFRI. Data collected included coordinates of the fished areas, water depths, catch of target shrimp species and retained bycatch, tow and haul durations, and the number of hours fished each day. Further, the quantity of discarded bycatch including debris was estimated by sampling each haul and extrapolating to the overall haul size. Due the nature of the fishing activities of the commercial trawlers augmented by limited storage onboard the vessels, only a few discarded-bycatch hauls could be selected for analysis of species composition. This analysis would provide a quick assessment of its potential impacts and a baseline for future assessment of bycatch discards in the commercial bottom trawl fishery.

In the artisanal fishery, data were collected using FD-Kenya data collectors at designated fish landing sites and villages (Government of Kenya, unpublished data, 1991) in 2001-2008. Moreover, the precision of data reporting in these designated sites has been enhanced by the recently initiated beach management units (BMUs) at the landing sites and villages under a community-based fisheries management program of the FD-Kenya. Data collected included daily catch by species and fishing grounds, sizes and types of gear and vessels, number of fishers per vessel, and age and experience (duration of years fished) of the fishers. However, wide variations in the fishing vessel design and size, gear types and numbers per vessel and demographic factors, including age and experience of the fishers, were evident in this fishery. Consequently, precise data needed for standardization of the fishing effort in the artisanal fishery would require extensive manpower. Available data showed very wide disparities for similar vessels, and the number of fishers per vessel varied daily even for the same vessels in addition to variations in vessel age, materials, and mode of construction and propulsion. A similar observation was noted on the number and types of fishing gear onboard the vessels, and the age of the fishers in each vessel and hours fished each day. These variations present numerous challenges for standardization of the fishing effort in the artisanal fishery, and therefore standardization of the fishing effort and analysis of CPUE in the artisanal fishery was considered of secondary importance in the present study.

Data analysis

Data analysis was conducted using MS Excel and Community Analysis Package 4.0 (CAP4-Pisces Conservation) software. In the commercial bottom trawl fishery, analysis was conducted assuming a variant species system targeting shrimps only, and fish were considered only as bycatch. The fishing effort in this fishery was expressed as the average hours fished within a 24-h day and the catch per unit effort (CPUE) expressed as kg/h. Further, the ratio of catch of the target species against bycatch was calculated using the total retained catch for each haul. In the fishery, discarding low value fish is common. However, in the present study, the discarded bycatch quantities were not included in the analysis because of the quality of the estimations of this portion of the catch onboard the commercial vessels. Prior to analysis, all data were tested for homogeneity (Levene test), and where necessary, they were normalized using the fourth-root transformation. Spatio-temporal variations in CPUE were analysed using two-way ANOVA to test for significance differences between years and seasons, and between fishing areas. Variations in spatial distribution of the target shrimp and bycatch species by fishing area and depth were analyzed by zoning the Formosa and Malindi fishing grounds into "shallow" (<25 m) and "deep" (>25 m). Further, the spatial-bathymetric distribution of the shrimp stocks in the bay were assessed by analysis of the shrimp CPUE of the commercial bottom trawl fishery for the Formosa and Malindi fishing grounds, and by bathymetric zones comparing the shallow and the deeper fishing grounds. All tests were considered significant at a probability level of $p < 0.05$ (95% confidence).

To assess the impacts of the bottom trawling, the artisanal fishery 2001–2008 catch data were analysed for differences in spatial and temporal composition in taxa or fishery groups and abundance using the non-metric multidimensional scaling (MDS) technique in CAP4 software. Further, two-way analysis of similarity (ANOSIM) [23] was used to test for differences across years and fishing areas, while two-way similarity percentage (SIMPER) analysis [23] was used to identify the dominant taxa or taxon group contributing to similarity and dissimilarity within and between the fishing grounds during 2001–2008. Both the ANOSIM and SIMPER use the Bray–Curtis [24] measure of similarity. The SIMPER analysis breaks down the contribution of each taxon to the observed similarity (or dissimilarity) between samples and allows identification of taxa that are most important in creating the observed pattern of similarity.

Results

Trends in fisheries landings

In the artisanal fishery, the annual landings of both fish and shrimp generally oscillated, with no discernible trends during the study period. In this fishery, the annual landing of shrimps ranged from 71.5–187.1 t during 2001–2008, with the highest landings recorded during 2004 (Fig. 2). The annual fish landings averaged at 885.4–1540 t and showed an increase from 2006, reaching a peak in 2008. The combined fish and shrimp landings in the artisanal fishery averaged 1,013.7–1,653.2 t during 2001–2008.

Unlike the artisanal fishery, the commercial bottom trawl fishery showed a clear downward trend, and shrimp catches declined by more than 50% during 2001–2006: from 553.7 t in 2001 to 257.3 t in 2006. During the same period, the retained bycatch was 432.0 t in 2001, increasing to 602.3 t in 2004, but declined to 315.6 t in 2006 before the trawl ban. The combined fish and shrimp landings during 2001–2006 averaged at 572.9–985.6 t, which is far lower than the artisanal fishery landings. The mean ratio of the target shrimp catch to the retained bycatch was 1:1.5. The mean shrimp CPUE ranged between 42.95 ± 4.6 kg/h

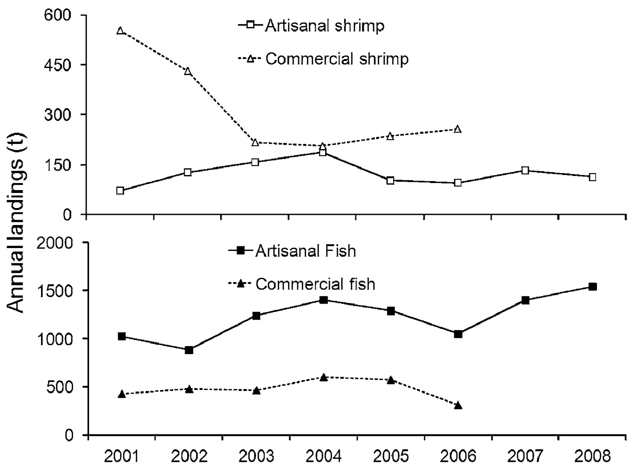

Fig. 2 Annual landings of shrimp and fish in the artisanal and commercial bottom trawl fisheries of the Malindi–Ungwana Bay Kenya

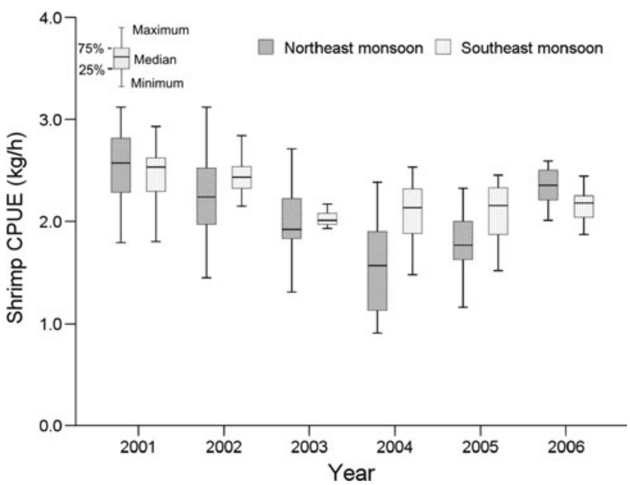

Fig. 3 Annual and seasonal trends (fourth-root transformed) in shrimp CPUE (kg/h) in the commercial bottom trawl fishery Malindi–Ungwana Bay from 2001 to 2006 when the ban on bottom trawling was effected in the fishery

recorded in 2001 and 15.76 ± 5.1 kg/h recorded in 2004. Two-way ANOVA tests for differences in the shrimp CPUE of the commercial bottom trawl fishery during 2001–2006 showed a highly significant difference between the years ($p < 0.05$). Tukey's HSD post hoc test showed significant differences between all years ($p < 0.05$) except 2001 versus 2002, 2002 versus 2006, 2003 versus 2004 and 2005, and between 2004 versus 2005.

Seasonal variations in CPUE between the NEM and SEM seasons within years were not significantly different. However, highly significant differences were evident between seasons across the years ($p < 0.05$). The mean CPUEs by season ranged between 47.6 ± 5.6 kg/h recorded in the 2001 to 10.7 ± 5.8 kg/h in the 2004 NEM seasons compared to 38.3 ± 3.4 kg/h in the 2001 and 17.3 ± 1.6 kg/h in the 2003 SEM seasons. However, Tukey's HSD post hoc tests only revealed significant differences in CPUEs between 2001 versus 2003, 2004 and 2005 NEM and SEMs, and 2001 NEM versus 2006 SEM; NEM and SEM in 2002 versus 2004 and 2005 NEM; 2002 SEM versus 2003 NEM; 2004 NEM versus both NEM and SEM in 2006; and the NEM seasons of 2005 versus 2006 (Fig. 3).

Spatial-bathymetric distribution of shrimp in the bay

The overall mean CPUEs varied by fishing area. The Formosa "shallow" and "deep" recorded 31.2 ± 0.4 and 24.3 ± 1.8 kg/h compared to 21.8 ± 0.9 and 23.5 ± 0.7 kg/h in Malindi "shallow" and "deep", respectively. Results of two-way ANOVA for the spatial-bathymetric distribution of the shrimp stocks showed significant differences by fishing area, and the Formosa grounds recorded higher CPUEs than the Malindi fishing grounds ($p < 0.05$) (Fig. 4). There were no significant differences in mean CPUE between the shallow and deep bathymetric zones ($p = 0.17$), although the Malindi fishing grounds recorded generally higher shrimp CPUE in the deeper bathymetric zones compared to the shallow zones. On the contrary, the shallow bathymetric zones in the Formosa fishing grounds recorded higher CPUEs than the deep zones (Fig. 4).

Variations in species composition in the artisanal fishery

In 2001–2008, a total of 29 fish families and two ecological groups—"mixed pelagic" and "mixed demersal" comprising small-sized pelagic and demersal species or species of low commercial/food value, respectively were identified and used for ordination analysis of the artisanal fishery.

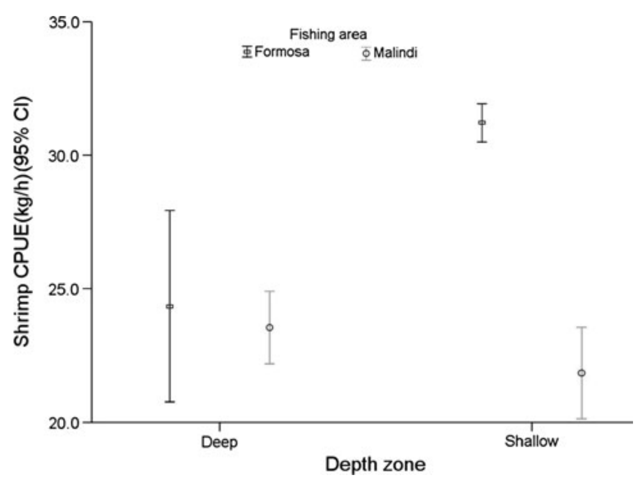

Fig. 4 Spatial and bathymetric variation in shrimp CPUE (95% confidence interval) in the Malindi–Ungwana Bay commercial bottom trawl fishery. The *error bars* show the mean (*circle*/*square*) ± standard deviation (SD)

The mixed pelagic and mixed demersal groups are often landed by the artisanal fishers for food fish. Results of the non-metric MDS on the composition of annual landings in the fishing grounds of the bay showed distinct differences across years and fishing areas (Fig. 5). The non-metric MDS showed similarity in the species composition between the 2001–2008 years, with the Malindi fishing grounds showing higher similarity over the years compared to the Formosa fishing grounds (Fig. 5).

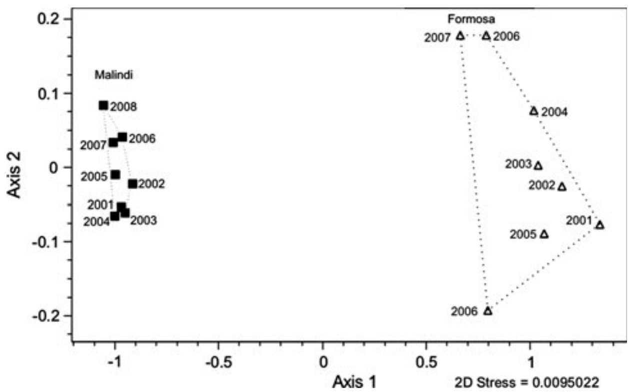

Fig. 5 Non-metric multidimensional scaling (NMDS) catch composition data (by family) [$\mathrm{Log}_{10}(X + 1)$ transformed data] in catches of the artisanal fishery in the Formosa and Malindi fishing areas during 2001–2008 data (stress level 0.0095)

Two-way ANOSIM analysis for differences across years and fishing areas showed significant differences across 2001–2008 in the Formosa and Malindi fishing areas ($p < 0.05$). Further, two-way SIMPER analysis showed 78.6 and 77.5% average similarity where 91 and 90.2% within-area similarity was attributed to 6 and 16 species in the Formosa and Malindi fishing grounds, respectively. The variations in taxonomic composition of the artisanal landings were attributed to a higher abundance of brackish water families, including Claridae, Cichlidae and Protopteridae, in the Formosa fishing areas, while the Malindi grounds were dominated by the two ecological groups, mixed demersal and mixed pelagic species, and the families Carangidae, Siganidae, Carcharhinidae and Lethrinidae (Table 1a, b). The six taxonomic/ecological groups also accounted for higher contribution to the artisanal landings in the whole fishery. Penaeid shrimps accounted for <1.5% of the combined artisanal fishery landings. Furthermore,

Table 1 SIMPER analysis of the artisanal fish landings across 2001–2008 showing the fish groups/families contributing to about 91.2% similarity within the (a) Formosa and (b) Malindi fishing grounds of Ungwana Bay, Kenya

Group	Aver. abundance	Aver. similarity	% Contribution
(a) Formosa area			
Claridae	167.9	32.8	41.7
Cichlidae	95.9	17.7	22.5
Protopteridae	64.2	13.1	16.7
Penaeidae	19.9	3.1	4.0
Carcharhinidae	13.9	2.5	3.2
Mixed demersals	15.7	2.4	3.0
			91.0
(b) Malindi area			
Mixed demersals	151.2	13.5	17.5
Mixed pelagics	123.9	10.7	13.8
Carangidae	91.8	7.1	9.2
Siganidae	53.1	4.8	6.1
Carcharhinidae	61.8	4.4	5.7
Lethrinidae	51.4	4.4	5.7
Penaeidae	36.2	3.3	4.3
Istiophoridae	36.6	3.2	4.1
Lutjanidae	37.3	3.1	4.1
Mugilidae	36.4	3.1	4.0
Scombridae	37.0	2.5	3.2
Acanthuridae	29.1	2.0	2.6
Serranidae	20.6	1.7	2.2
Octopodiformes	19.7	1.6	2.1
Scaridae	19.2	1.6	2.0
Clupeidae	17.6	1.5	1.9
Palinuridae	16.3	1.4	1.8
			90.2

The average similarity across 2001–2008 was 78.6 and 77.5% for the Formosa and Malindi fishing grounds, respectively

Table 2 SIMPER analysis of the artisanal fish landings during 2001–2008 showing the fish groups/families contributing to about 90.8% dissimilarity between the Formosa and Malindi fishing grounds of Ungwana Bay, Kenya

Family/group	Formosa Average	Malindi Abundance	Average dissimilarity	% contribution
Claridae	167.9	0.0	12.2	14.4
Mixed demersals	15.7	151.2	9.7	11.4
Mixed pelagics	0.8	123.9	8.8	10.4
Cichlidae	95.9	0.0	7.0	8.2
Carangidae	2.9	91.8	6.5	7.7
Protopteridae	64.2	0.0	4.7	5.5
Siganidae	2.5	53.1	3.6	4.3
Lethrinidae	2.2	51.4	3.5	4.1
Carcharhinidae	13.9	61.8	3.5	4.1
Istiophoridae	1.3	36.6	2.5	3.0
Mugilidae	3.8	36.4	2.4	2.8
Scombridae	7.7	37.0	2.3	2.7
Lutjanidae	5.7	37.3	2.3	2.7
Acanthuridae	0.4	29.1	2.0	2.4
Chanidae	0.8	20.6	1.4	1.6
Serranidae	1.9	20.6	1.3	1.6
Sphyraenidae	1.5	20.0	1.3	1.5
Scaridae	1.5	19.2	1.3	1.5
Clupeidae	0.0	17.6	1.3	1.5
				91.3

The average dissimilarity between the composition of the artisanal catch landings of the Formosa and Malindi fishing grounds during 2001–2008 was 84.8%

SIMPER analysis for species composition in the Formosa and Malindi fishing grounds revealed that 19 species accounted for 91.3% dissimilarity between the two fishing grounds, and the target penaeid shrimp species were absent from this group, contributing only <1.5% to the dissimilarity between fishing grounds. The overall average dissimilarity between the Formosa and Malindi fishing grounds was estimated at 84.8% (Table 2).

Discussion

Results of this study show that the combined fish and shrimp landings were higher in the artisanal fishery than in the commercial bottom trawl fishery. However, it should be noted that the commercial bottom trawl fishery was also characterized by undisclosed amounts of discards of low value fish, juveniles and other discards. Notwithstanding, the higher landings in the artisanal fishery clearly confirm the importance of the Malindi–Ungwana Bay to the fisher communities along this coast. Moreover, the artisanal fisheries within the Malindi–Ungwana Bay account for about 61% of the total marine fish and shrimp landings from the bay. Further, despite the small-scale nature of the artisanal fishery, the sector is a primary source of livelihood for thousands of households along the entire coast. Current estimates show that the artisanal fishery of the Malindi–Ungwana Bay directly employs over 2,000 fishermen [25] who use environmentally sound fishing gear ranging from traditional traps, hand lines, long lines, cast nets and gill and seine nets.

In 2001–2006, wide fluctuations in landings were observed in the artisanal fishery, whereas the commercial bottom trawl fishery recorded a downward trend throughout the period before its ban in 2006. The fluctuations in artisanal landings may be attributed to variations in trawling activities related to the number of operational vessels during this period and fluctuations in fishing effort within the artisanal fishery. The impacts of the extreme weather conditions associated with the 1997–1998 El Niño may also partly explain the fluctuations due to long-term effects of these conditions especially on the ecosystem. The El Niño phenomenon may lead to tropicalization of the ecosystem, disruption of the normal food web, and induced changes in species composition and migrations of a large number of fish and invertebrate species populations, as noted in the South American Pacific Coast fishery after the 1982–1983 El Niño [26]. Schwing et al. [27] noted that the factors of concern are those affecting the general biological productivity and availability of food, aggregation for schooling and reproduction, larval dispersal, barriers to migration, physiological effects of extreme conditions, and changes in species composition and interactions. Furthermore, the El Niño weather is often preceded and followed by La Niña-type weather, and hence the impacts of the El Niño are often long term [28, 29]. In the Malindi–Ungwana Bay fishery, the main factors include the effects of freshwater flooding into the bay and input of terrigenous sediments/nutrients from the rivers draining into the bay. Moreover, the adverse 1997–1998 El Niño weather also orchestrated a reduction in fishing intensity in the bay, thus giving the fishery time to recover, especially for overfished species. Consequently, the period after the El Niño provided a great opportunity for recovery of the Malindi–Ungwana Bay fishery stocks. Further, the period after these adverse weather conditions and the expected effects of change in exploitation patterns presented an opportunity for re-assessment of the fishery and species composition within the fishing grounds, although few or no studies were conducted to assess the El Niño impacts. The recorded steady increase in artisanal fishery landings during 2002–2004 coincides well with the decrease in fishing efforts in the commercial bottom shrimp fishery. An increase in the trawling activities during 2004–2006 before the trawl ban and the continued encroachment into the artisanal TEZ grounds may also explain the decline in the artisanal fishery landings during this period. Moreover, increased conflicts and damage to fishing gear of the artisanal fishery by the trawlers due to TEZ encroachment by commercial vessels also disrupted the fishing activities within the artisanal fishery and may partly account for the decline in catches. This is evidenced by the increase in artisanal landings during 2006–2008 after the ban on trawling activities in the bay. Additional factors include the recovery of the benthic habitats and fish stocks, reduced pressure on the TEZ from the commercial bottom trawl fishery fleet and a likely increase in fishing activities in the artisanal fishery in the absence of El Niño phenomenon within the WIO region after 1998.

In the commercial bottom trawl fishery, a steady decline in catches during 2001–2003 was recorded and was attributable to the decrease in fishing effort due to an imposed 4-month closed-season regulation in 2001, running from November–February each year [30]. This seasonal closure was meant to safeguard the breeding populations and allow for the recovery of the stocks based on earlier studies indicating that the November–February period was the main breeding season for the target penaeid stocks and other fish species [4, 9]. However, despite the ban on commercial bottom trawling, the artisanal fishery continued to record low landings of the target shrimp species. This may be attributed to the fact that the penaeid shrimps are not target species for artisanal fishery. Moreover, this subsector may be poorly equipped to exploit the bottom shrimp stocks since the main gear used are inexpensive passive gillnets, spears and driftnets, which target only fish. This may suggest that there were no conflicts between the artisanal and the commercial bottom trawl fisheries in terms of the target species. However, conflicts in partitioning of the fishing grounds and the impacts of bottom trawls on the ecosystem cannot be ignored. The impacts of bottom trawling on the Malindi–Ungwana Bay fisheries resources have been documented in earlier studies [3].

In the Malindi–Ungwana Bay fishery, the trawling activities have been characterized by excessive discarding of low value bycatch at sea. In this study the overall ratio of shrimp to retained fish bycatch was 1:1.5 compared to a ratio of 1:7 recorded by Fulanda [1]. Moreover, the retained bycatch increased from 432.0 t in 2001 to 602.3 t in 2004 although a decline was recorded in 2006, indicating that the retained bycatch increased over the years before the trawl ban. Mwatha [4] estimated the rate of combined bycatch discard in the commercial bottom trawl fishery at 8 t/day (average of 340 kg/trawler/h), which is still substantial compared to fish and shrimp landing estimates of 4.2–6.9 t/day in the artisanal fishery. Similarly, Mwatha [4] also noted that over 25% of the discarded bycatch consisted of juveniles of commercial fish species such as *Otolithes ruber*, *Johnius* sp. (Sciaenidae) and *Pomadysis* sp. (Haemulidae), which are target species for the artisanal fishery. Moreover, even the low-value commercial species are edible food fish that present valuable bycatch for the artisanal fishers of this coast. Consequently, policies for utilization of the discarded fish bycatch must be designed to ensure lower discards, and high food and protein sufficiency for the coastal communities whose livelihoods depend on these resources. Furthermore, there was a continued TEZ encroachment by the trawlers especially during 2001–2003 before a ban on night trawling was imposed. Therefore, a substantial part of the catch was obtained from the 3–5 nM TEZ area, and the discarded bycatch thus ultimately impacted the artisanal fishery landings in this bay [3]. Consequently, the years preceding the 2006 trawl ban were characterised by severe conflicts between the artisanal and commercial bottom trawl fisheries sectors with regard to resource partitioning and the deleterious fishing methods of the commercial bottom trawl fishery. These conflicts may further explain the variations in annual landings especially in the commercial bottom trawl fishery. In the late 1990s the FD-Kenya recommended retention of all bycatch in the commercial bottom trawl fishery in an effort to secure fish food supply and at the same to engage in resolution of the conflicts associated with the commercial bottom trawl fishery [31]. During 2001–2004, a regional remedial action on shrimp trawl bycatch management in the WIO region was initiated in Kenya to, among others, promote bycatch reduction and undertake measures to increase utilisation of bycatch in the commercial bottom trawl fisheries of the WIO [32]. The reduction in bycatch discards is indicated by the higher amounts of retained bycatch and the increase in shrimp: retained bycatch ratio from 1:7 in 1999 [3] to 1:1.5 recorded in the present study is partly attributed to these initiatives by the FD-Kenya to ensure sustainable management of the Malindi–Ungwana Bay fishery. The current estimated ratio of shrimps to discarded bycatch recorded in the Malindi–Ungwana Bay fishery appears within the 1:3–1:15 ranges reported in other bottom trawl fisheries in the tropics [17]. The initiatives to reduce discarding in bycatch and promote the utilization of these edible species have greatly improved the conditions in the artisanal fishery, and the increase in annual landings during 2006–2008 may be suggestive of a recovering fishery and habitat. The 2006 trawl ban also appears to have safeguarded habitat degradation associated with bottom trawling and the encroachment on the shallower TEZ grounds by the commercial bottom trawl fishery vessels. The absence of a significant increase in artisanal landings may therefore be attributed to the continued use of technologically inferior vessels and gear. This contrasts earlier observations that landings in the artisanal fishery would be significantly higher due to increased fishing activities and access to wider fishing grounds after the trawl ban [11]. Consequently, the 2006 ban on commercial bottom trawling provides for proliferation of the Malindi–Ungwana Bay fishery stocks and an opportunity to re-design strategic long-term resource exploitation patterns for sustainable management.

In this study, the landings of the target shrimp species of the commercial bottom trawl fishery were not significantly different between the NEM and SEM seasons within years. This suggests that the fishing activities of the commercial bottom trawl fishery were not influenced by the seasons. Moreover, the trawlers exploited the absence of the artisanal fishers in the TEZ grounds during the adverse SEM season to encroach on and exploit the fishing grounds within 3–5 nM TEZ. However, juvenile penaeid shrimp abundance, catchability and size appeared to be slightly influenced by seasons and bathymetric factors. Macia [33] observed that water depth, salinity, temperature and turbidity are key factors influencing the spatial distribution of juvenile shrimp species. In a separate study in north Kuwait Bay, Bishop and Khan [34] found that some species of juvenile penaeid shrimps such as *Metapenaeus affinis* were more catchable at shallower waters, while the bigger sizes were more abundant at deeper fishing grounds. The Malindi–Ungwana Bay fishery is predominantly a shallow-water shrimp resource [1], but wide variations in depth are evident between the Formosa and Malindi fishing grounds. In the present study there was a significant difference in the spatial distribution of the target shrimp species between the shallow water fishing grounds of Formosa and Malindi based on commercial bottom trawl fishery CPUE. However, the deeper fishing grounds of both the Formosa and Malindi areas showed no significant differences in CPUE, confirming that resource-use patterns in the bay were predominantly targeted on shallow fishing grounds. These observations may be partly attributed to variability in fishing effort, trawlability of the fishing grounds and the spatio-temporal distribution of the species [3]. Similar observations have been recorded in other fisheries [1, 34]. The overall mean CPUEs of the target shrimp species in both the Formosa and Malindi fishing grounds are slightly lower than an estimate of 47 kg/h reported by Mwatha [4] for the entire fishery based on a single trawl survey. Consequently, there is a need to continuously monitor the Malindi–Ungwana Bay fishery in an effort to maintain a rich data and information base for the sustainable management of the fishery.

The SIMPER analysis for spatial–temporal distribution of the species with water depth reveals that the Formosa fishing grounds are more important for the artisanal fishery partly because of the high contribution of brackish water species. The Malindi fishing grounds are equally important and significantly contribute to the fisheries catch of mixed pelagic and demersal species, and Carangidae. Somers [35] noted that sediment type is an important factor in the distribution of prawn species, and the spatial distributions of individual shrimp species are often related to depth and/or sediment type. Thus, sediment and nutrient discharge from rivers feeding the bay is important for the fishery. In the Gulf of Carpentaria, Australia, Somers [36] observed that *Fenneropenaeus merguiensis* mainly occurred in waters shallower than 20 m, while *P. esculentus* was dominant at <35 m water depths where the sediments were mainly sand or muddy sands. In contrast, *P. semisulcatus* preferred mud or sandy mud sediments, while *Metapenaeus endeavouri* also preferred sand or muddy sand sediments. In the far northern Great Barrier Reef, Australia, the spatial distribution of commercially important penaeid shrimps has been coarsely differentiated by a combination of three factors: water depth, mud content of the sediment and seafloor rugosity [37]. Earlier studies in the Malindi–Ungwana Bay indicate that fish and shrimp larvae are more abundant from the shore up to 3 nautical miles off shore [38]. Therefore, the distribution of the shrimp species in Malindi–Ungwana Bay appears to be influenced by a combination of several factors, including water depth, salinity, temperature and turbidity, sediment type and seafloor rugosity. Furthermore, the shrimp species utilize the mangrove creeks and near-shore ecosystems as nursery grounds during their early life stages (Wakwabi EO, unpubl. data, 1988). The near-shore ecosystems are therefore critically important as nursery grounds for both fish and shrimps. Consequently, the restriction or total ban of trawling activities in the near shore ecosystems is crucial for the maintenance of the important ecological functions of these habitats. More research is needed for an extensive assessment of the Malindi–Ungwana Bay fishery habitats, and to test the ecological and economical implications of any changes applied in the management of this important fishery including considerations of lifting of the trawl ban.

In 2001–2006, the Malindi–Ungwana Bay fishery was placed under increased surveillance and monitoring to curb the fishing patterns of the commercial bottom trawl fishery and reduce resource-use conflicts with the artisanal fishery. Before the ban in 2006, annual landings in both the artisanal and commercial bottom trawl fisheries fluctuated widely, mainly because of variations in fishing efforts due to increasing conflicts between the two subsectors. Consequently, the increase in landings in the artisanal fishery after 2006 clearly indicates a spill-over effect from the ban on commercial bottom trawling since there was no observed change in fishing activities, vessels and/or gear used in this artisanal fishery. Furthermore, Fulanda et al.

[1] observed that based on the current gear and vessels, the resource exploitation level in the artisanal fishery constitutes an under-exploitation of the 0–5 nM TEZ fishing grounds. Fiorentino et al. [39] noted a significant increase in the spawning-stock biomass of the red mullet *Mullus barbatus* in the Gulf of Castellammare in the central Mediterranean after a 14-year trawl ban, and attributed these observations to various factors including lower fishing mortality and probable effects of increasing sea surface temperatures. Moreover, the study further observed an increase in the mean size of females at >50-m water depths in the post-ban period. Similarly, changes in recruitment patterns of the population were noted with higher recruit numbers and a broader recruitment period. Consequently, the trawl ban in the Malindi–Ungwana Bay is expected to replenish the fish stocks and boost the resource potential of this important fishery.

Noting the benefits accrued from the ban on trawling in the Malindi–Ungwana Bay fishery, a wide spectrum of research on the fishery stocks, fishing effort levels and the influence of oceanographic factors and other anthropogenic activities on the productivity of the fishery is needed before any options to lift the current trawl can be considered. This is because the artisanal fishery and the coastal communities they support must be given the protection of designated fishing zones from which commercial fishing vessels are excluded. Furthermore, the economic sustainability of the artisanal fishery must also be re-evaluated. In addition, the consequences of lifting the trawl ban and the level to which it would jeopardise the sustainability of the artisanal fishery must be assessed through analysis of the viability of commercial bottom trawl fishery under alternative assumptions, especially with target species versus bycatch ratios and catch rates. The artisanal fisher attitudes towards the trawlers and their predisposition either to fight back in the event of the trawl ban being lifted must also be considered. Additionally, a strict enforcement of the existing regulations measures, including closed seasons, and the use of suitable bycatch reduction devices (BRDs) must be implemented and monitored by the FD-Kenya and BMUs. Further detailed analysis of discarded and retained bycatch must be emphasised in future surveys for the sustainability of this fishery. It is concluded that both the artisanal and commercial bottom trawl fisheries are highly dynamic and exhibit resilience to adverse exploitation and weather changes. Therefore, continuous monitoring is recommended for sustainable management of the Malindi–Ungwana Bay fishery and to safeguard the coastal fisher communities whose livelihoods are totally dependent on this fishery.

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