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Trawling effort distribution and influence of vessel monitoring system (VMS) in Malindi-Ungwana Bay: Implications for resource management and marine spatial planning in Kenya

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ABSTRACT

Bottom trawling is a common fishing method for harvesting demersal marine resources such as prawns and ground fish species. However, bottom trawling is known to have negative impacts on marine ecosystems and several measures have been suggested to sustainably manage the fishing method including, mapping trawling pressure and restricting its use away from fragile marine ecosystems. In this study, we map spatio-temporal distribution of trawling effort using 8900 trawls obtained from logbook statistical data and consequently evaluate the effectiveness of a Vessel Monitoring System (VMS) and a Prawn Fisheries Management Plan (PFMP) in the Malindi-Ungwana Bay, Kenya. The PFMP and VMS aimed at restricting prawn trawling to areas beyond 3 nm from shoreline since 2010 in order to reduce conflict with artisanal fishers. Results show spatio-temporal adjustments in the distribution of fishing effort and catch rates of prawns following regulatory changes in the bay. Encroachment in no-trawl areas occurred gradually between 2011 and 2017 with some years (2013, 2016) depicting over 50% of fishing effort in the no-trawl areas. Trawling within the restricted zone produced higher catch per unit effort (CPUE) of prawns compared to fishing outside the zone. Introduction of VMS in 2017 led to a significant reduction of fishing effort in no-trawl area of about 80% by 2018. The change in fleet behaviour in the bay after introduction of the VMS, provides important insights on how marine spatial planning and technology could be applied to enhance compliance with fishing area regulations, reduce resource use conflicts and promote sustainable fisheries.

1. Introduction

There has been an increasing concern of the impact of bottom trawling on marine ecosystems [1,2]. The possible effects of bottom trawling include impacts on benthic organisms, alteration of habitats and community structure, and conflict with artisanal fishers [2–4]. Although bottom trawling is known to have negative impacts, the method is still preferred for exploitation of highly valuable bottom dwelling fishery species such as penaeid prawns due to its efficiency. Penaeid prawns form an economically important species for bottom trawls [5,6] and their diversity has been shown to be highest in the Indo-West Pacific region [7].

One of the suggested ways of sustainable management of shrimp trawling is the control of spatial and temporal distribution of fishing effort [8]. Restricting trawling effort away from the nearshore areas is seen as a way to protect some of the sensitive marine habitats from impacts of trawling and also reducing conflict among users as most of the artisanal fishing effort is concentrated in the shallow areas [4,9].

Benthic species such as the penaeid prawns are known to aggregate in response to the prevailing environmental factors and the aggregations are often structured according to species, size and age-class, and will often vary according to seasons, habitat type and depth [10–14]. Nearshore shallow zones are often deemed to be aggregation areas for prawns and the most productive fishing grounds for most marine organisms [15]. Reditribution of prawn trawling effort from shallow areas is therefore likely to affect fishing vessel dynamics as vessel movements

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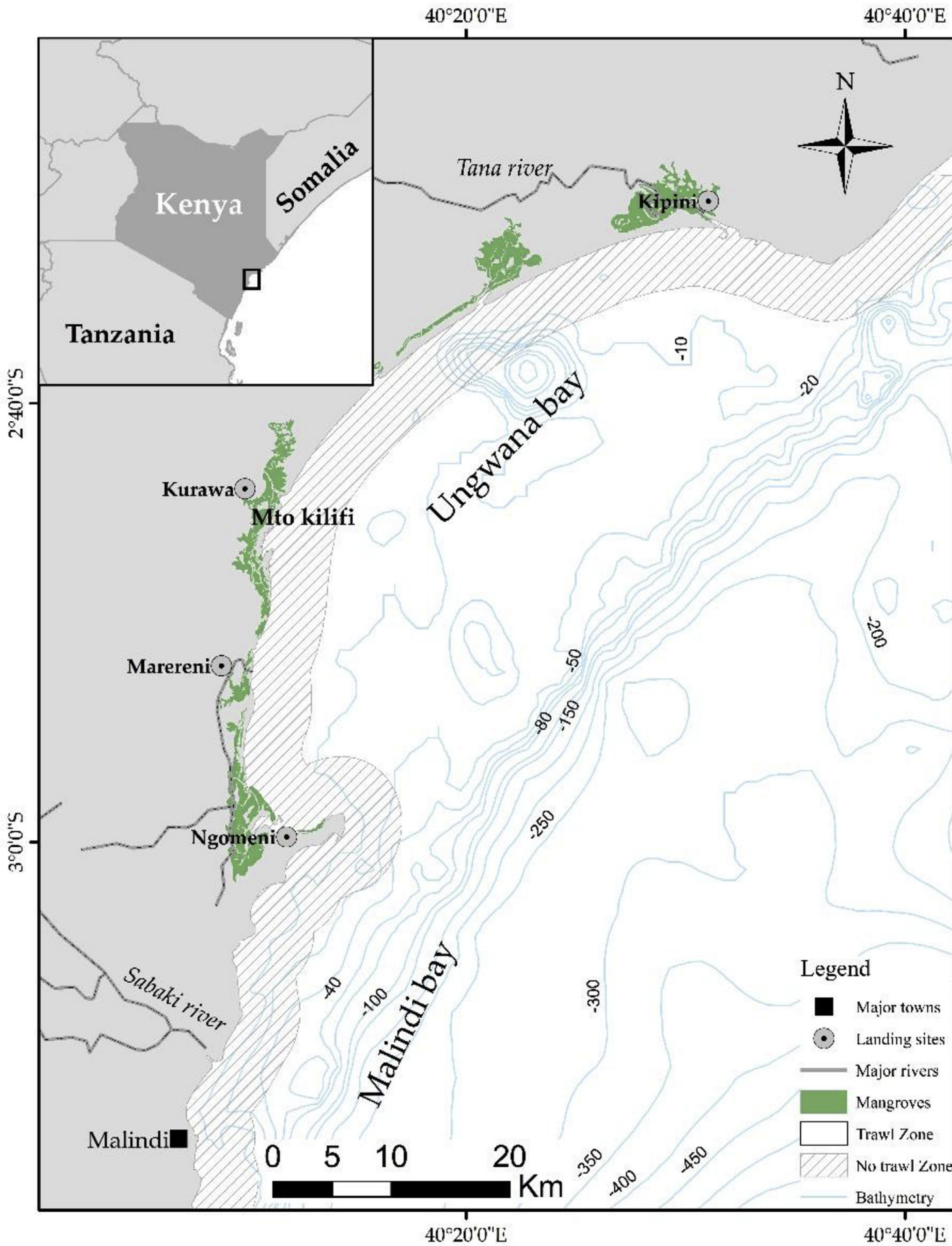

Fig. 1. A map of Kenyan North Coast showing the location of Malindi-Ungwana Bay, with the 3 nm designated no-trawl zone.

are determined by profit motives [16]. Vessel dynamics is also likely to affect ecosystem integrity through spatial variation in fishing pressure. Marine spatial planning for sustainable exploitation of resources need to consider ecosystem heterogeneity and resource-use patterns in addition to mapping of resource hotspots and potential areas for resource-use conflicts [17,18].

In Kenya, commercial prawn trawling occurs exclusively within the productive Malindi-Ungwana Bay. The Malindi-Ungwana Bay fisheries experienced resource use conflicts between the trawlers and artisanal fishers resulting into a trawling ban in 2006 [12,19] with subsequent lifting of the ban in 2010. The resource use conflict in the bay resulted from gear interference and declining artisanal catches. As a result of the conflict, a Prawn Fisheries Management Plan (PFMP-2010) was developed to help guide management of the fishery. The PFMP segregated the spatial extent of trawling and artisanal fishing areas and regulated fishing seasons for the trawlers. However, the extent to which these regulations are successful in regulating trawling in the bay is unclear due to lack of regular monitoring and surveillance, inadequate governance structures and lack of data to enforce marine spatial planning.

The present study therefore aimed to provide data and information useful in enforcing the PFMP of the bay through effective spatial planning. Data were collected to delineate the spatio-temporal patterns in the distribution of fishing effort (hours fished by each vessel), in addition to describing trends in catch-per-unit-effort (CPUE) of both target (prawns) and non-target (finfish) species. Effort and catch distribution are compared between no-trawling area (0–3 nm from the shore) and the permitted trawling zone (> 3 nm from the shore) in relation to the introduction of a Vessel Monitoring System (VMS) in the bay during 2017. The results have potential application in the implementation of the PFMP for reduction of resource use conflicts and

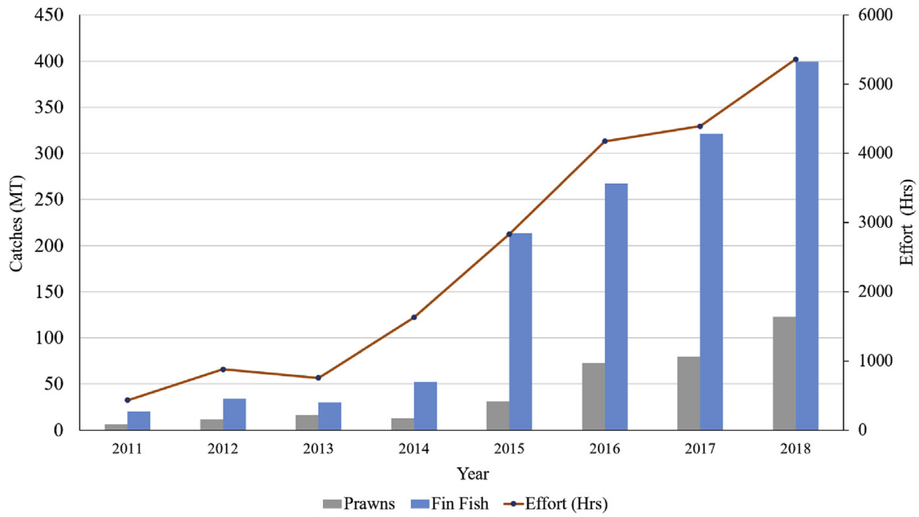

Fig. 2. Trends in total annual landings and trawling effort in the Malindi-Ungwana Bay fishery north coast Kenya.

sustainable fisheries management.

2. Materials and methods

2.1. Study site

This study focused on spatial distribution of trawling effort in the Malindi-Ungwana Bay on the north coast of Kenya (30.881° E, 2.407° S and 40.699° E, −3.28^0 S, Fig. 1). The bay is characterized by relatively shallow water ranging between 12 and 18 m deep in areas between 1.5 and 6.0 nm from shore and up to 100 m beyond 7 nm [20]. The bay is considered as one of the most productive and extensive shrimping area in the Western Indian Ocean (WIO) region with similar potential to Rufiji Delta in Tanzania, Maputo Bay in Mozambique, and the Madagascan shelf [21].

The artisanal fishers in the bay use mostly non-motorized fishing vessels limiting their fishing activities to the inshore fishing grounds of less than 3 nm from the shore. The increasing number of fishers coupled with increased bottom trawling effort has threatened the sustainability of fisheries resources in the bay [12,19].

The discharge of two rivers, Tana and Sabaki (Fig. 1) into the bay contributes to its higher biological productivity [22], which varies between the northeast (NEM) and southeast (SEM) monsoon seasons that prevail on the Kenyan coast. Briefly, the NEM season (November–March) is characterized by lower precipitation rates, higher SSTs, higher salinities and reduced river discharge while, the SEM season (April–October) has reversed sea conditions [22,23]. Prawn trawling is allowed in the bay during the SEM season whereas artisanal fishers are allowed year round. About 8 licensed fishing vessels (25–36 m length) trawl the bay for prawns using double rigged otter trawls with trawling hauls lasting between 1 and 2 h.

2.2. Data sources and analysis

2.2.1. Fishing effort and catch data

Data on trawling activities within the bay were obtained from the Kenya State Department for Fisheries and the Blue Economy (SDF& BE) covering 8 year period (2011 and 2018). This data included GPS positions (latitude and longitude) for the start and end of each haul, start and end time, total catches, and trawling dates obtained from the logbooks. During a fishing trip, catch is usually sorted into two portions; prawns (all penaeid prawn species) and finfish (all finfish species), the total catch (kg) per haul for the two groups is then recorded in the logbook. Fishing effort was calculated as the number of hours fished per haul.

2.2.2. Gridding and mapping of catch and effort data

Several methodologies have been suggested for effective mapping of fishing effort [17,24]. The three commonly used methods include: counting the frequency of fishing positions within cells of a spatial grid [25]; joining beginning and end of the fishing positions with straight lines and determining the parts of the lines lying within each crossed cell of the grid as fished areas, assuming constant speed [26]; or interpolating the potential swept area as an ellipse surrounding any two successive fishing positions [24].

In this study, we mapped fishing effort in the bay by combining the three methods. First by undertaking linear interpolation of the vessel position between the start and end of each fishing haul and joined this with a line. These lines were then merged with a hexagonal grid of 1 km minimum width and the parts lying within each crossed cell of the grid determined [26]. Each crossed grid was considered as a fished area [24]. With the assumption of constant speed during trawling, the fishing effort and catch for each grid cell were obtained by dividing hours spent in each haul by the number of grids fished and the amount of catch for each haul divided by the number of grids fished as suggested by [27,28]. Combining the three methods was necessary as the datasets were based on reported fishing positions which is different from the conventional VMS datasets where vessel positions are automatically transmitted by vessels to ground stations. Although a new data set for determining vessels positions using the new VMS system was available for 2018, we used the old method based on fishing positions reported using logbook entries so as to make the datasets comparable. Our analysis approach also demonstrates how reported fishing positions could be transformed and analyzed similar to data obtained from Vessel Monitoring Systems. The analysis was performed in R and ArcGIS 10.5.

The Kenya Prawn Fishery Management Plan (PFMP) designates the area from shore to 3 nm as no-trawl area, prawn trawling is only allowed in areas beyond 3 nm from the 1st of April to 30th October every year. Although the management plan prescribed no trawling activities below the 3 nm, no real time monitoring and surveillance measures were put in place to monitor trawler compliance prior to 2017. In 2017, a real time VMS was put in place by the State Department of Fisheries (SDF). Fishing vessel positions could therefore be monitored from the SDF offices in Mombasa. We compare fishing effort and catches in areas below and beyond the 3 nm mark before and after the installation of the real time VMS. Because of the likely non-conformity of the CPUE dataset, to conditions of parametric statistical analysis, the non-

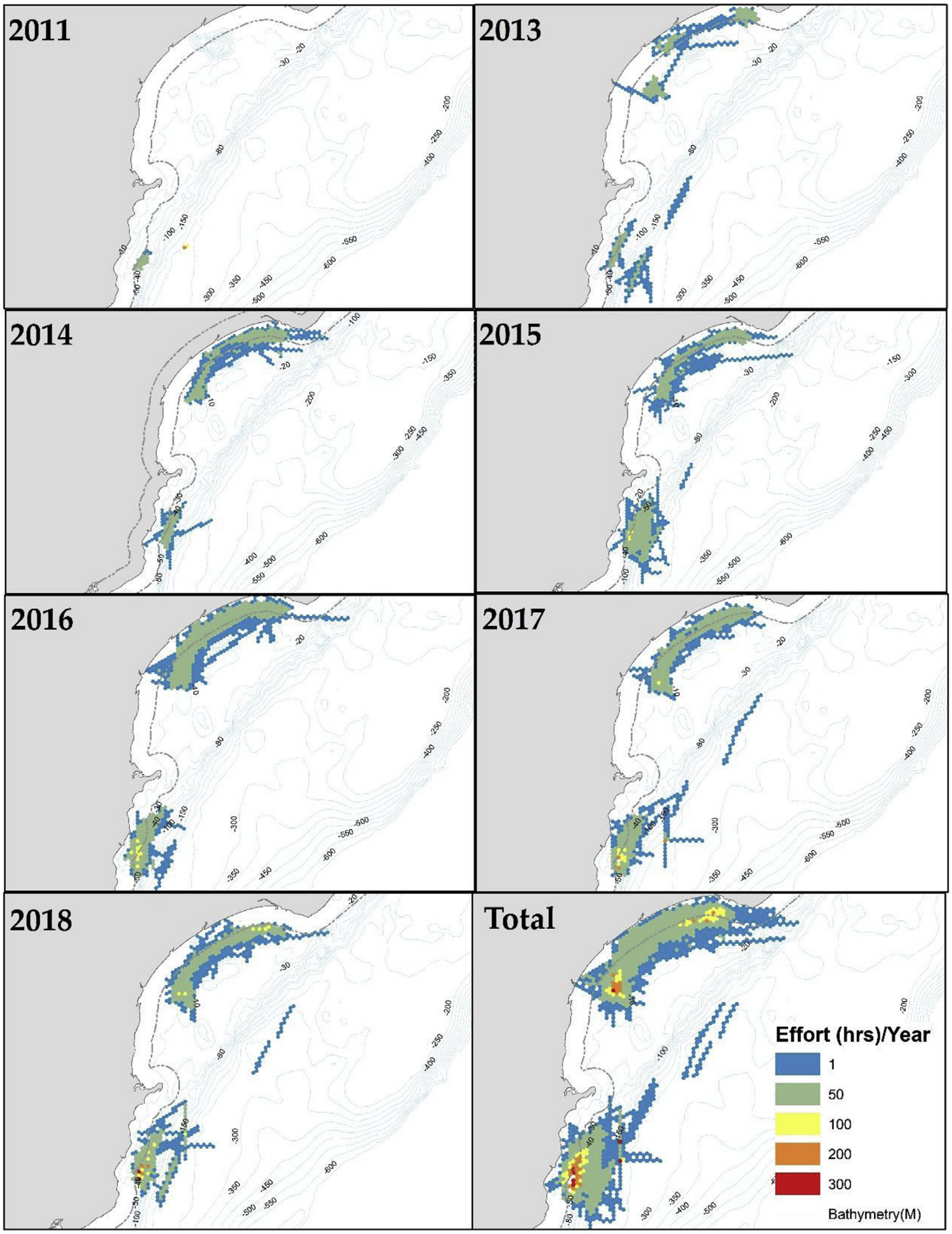

Fig. 3. Grid-based maps of 1000 min width hexagon showing the distribution of trawling effort (hr) in the Malindi-Ungwana Bay fishery between 2011 and 2018.

parametric Mann-Whitney *U* test was used to compare catch rates in and out of the 3 nm no-trawl zone. For the spatial analysis, data for 2012 was omitted as it contained a lot of errors on the GPS positions.

3. Results

3.1. Temporal trends in trawling effort and catches

Between 2011 and 2018, a gradual increase in the total landings and fishing effort for the vessels operating in the bay was observed (Fig. 2). The fishing effort increased 12-fold from 432 h in 2011–5360 h in 2018. The total annual catches of prawns and finfish increased from 6.4 MT and 19.8 MT in 2011 to 122.7 MT and 399.5 MT in 2018, respectively. Although the vessels are licensed to target prawns, a higher percentage of the catches are for the non-target finfish species, with an average of 22% of the total annual catches being prawns (Fig. 2).

3.2. Spatio-temporal distribution of trawling effort

The distribution of fishing effort in the bay from 2011 to 2018 are presented as gridded hexagons in Fig. 3. Two major areas of trawling concentration can be identified, the Ungwana Bay area (near Kipini, at the mouth of Tana River) with a mean annual trawling effort of 1389 h and the Malindi Bay area (near Malindi Town to the south) with mean annual trawling effort of 1281 h (see Fig. 1 for locations). A trawling effort concentration on the 3 nm margin in both Malindi and Ungwana

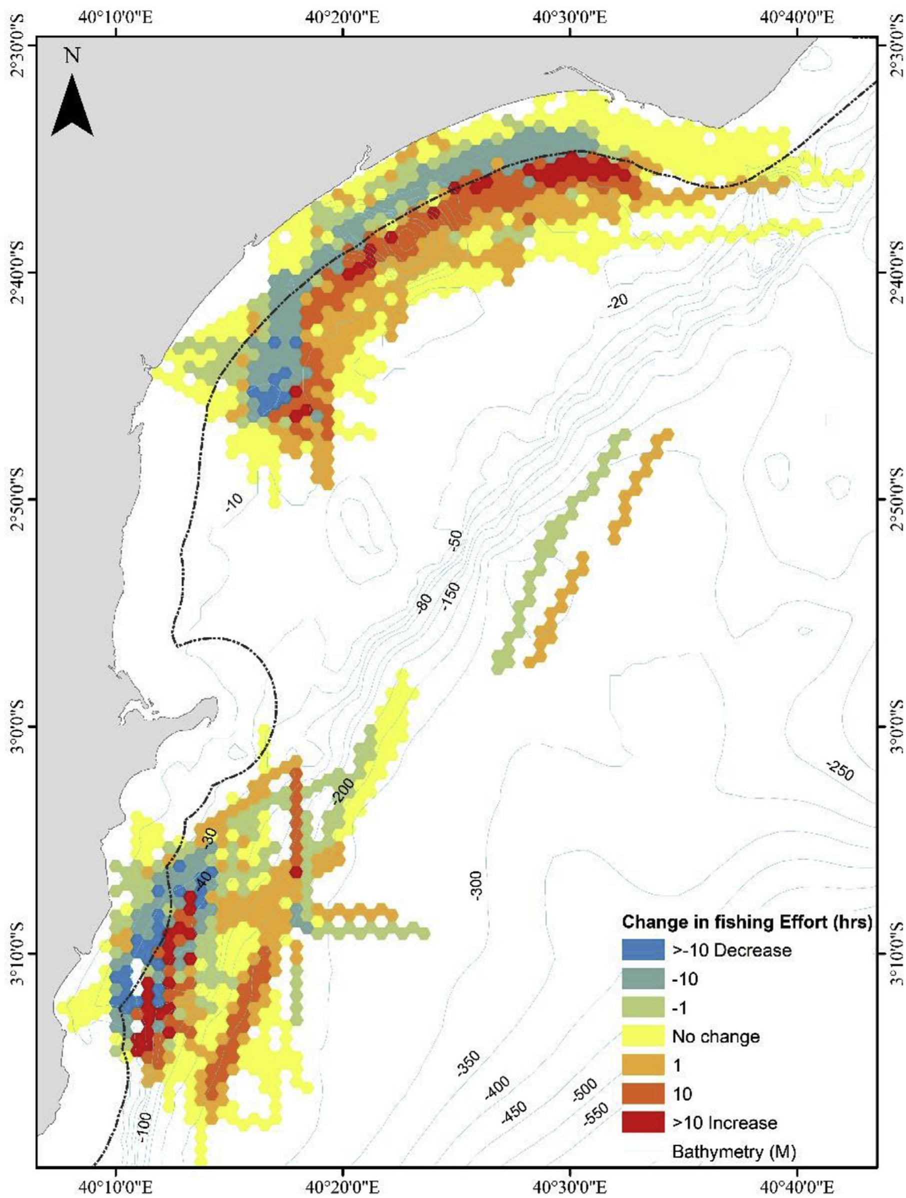

Fig. 4. Change in fishing effort distribution between 2017 and 2018 following VMS introduction in Malindi-Ungwana Bay fishery, negative value indicate a reduction and positive value indicate an increase in fishing pressure.

Bay areas is evident (Fig. 3), with the highest concentration in Malindi (2776 h) and Ungwana Bay (2082 h) area in 2018. The total area fished increased steadily with 20 and 650 grids fished in 2011 and 2018, respectively (Fig. 3). Trawling effort in the area below 3 nm (no-trawling zone) showed a rapid increase from 402 h in 2013 to 2039 h in 2016 with a big drop in effort below 3 nm observed from 2017 (884 h) to 2018 (236 h) (Fig. 3) following the activation of VMS operations in 2017. Although there was a decrease in fishing effort in the areas below the 3 nm from 884hrs to 236 h between 2017 and 2018, the fishing effort subsequently increased from 3268 h to 4760 h (~46% increase) in areas beyond the 3 nm boundary during the same period (Figs. 3 and 4).

3.3. Spatio-temporal distribution of CPUE

Figs. 5 and 6 show the variation of prawns and finfish CPUE, respectively, in the bay from 2011 to 2018 presented as 1 km gridded hexagons. The trawlers had higher catch rates of finfish than prawns especially in the Malindi Bay area (Figs. 5 and 6 and Table 1). Temporally, there has been a gradual increase in the CPUE for prawns ranging from 15 kg/hr in 2011 to 23 kg/hr in 2018 shown as color change from green towards red in Fig. 5. The non-parametric Mann-Whitney *U* test results showed that for prawns, there was significantly higher mean CPUE in areas below the 3 nm mark during 2013, 2014, 2016 and 2017, with higher CPUE in areas beyond the 3 nm mark only in 2015 (Table 1). For finfish catches, the areas beyond the 3 nm mark showed significantly higher catches in most of the years (viz. 2015, 2016, 2017) (Table 1).

4. Discussion

Fishing effort in the bay has increased steadily since 2011 with a significant proportion of the fishing activities (38%) taking place within the designated no-trawl area through encroachment. There was significant difference in fishers CPUE for prawns between the area below and beyond the 3 nm mark for most of the years, with fishers getting higher prawn catches below the 3 nm mark, this likely provided motivation for the illegal trawling activities within the no-trawling area. The

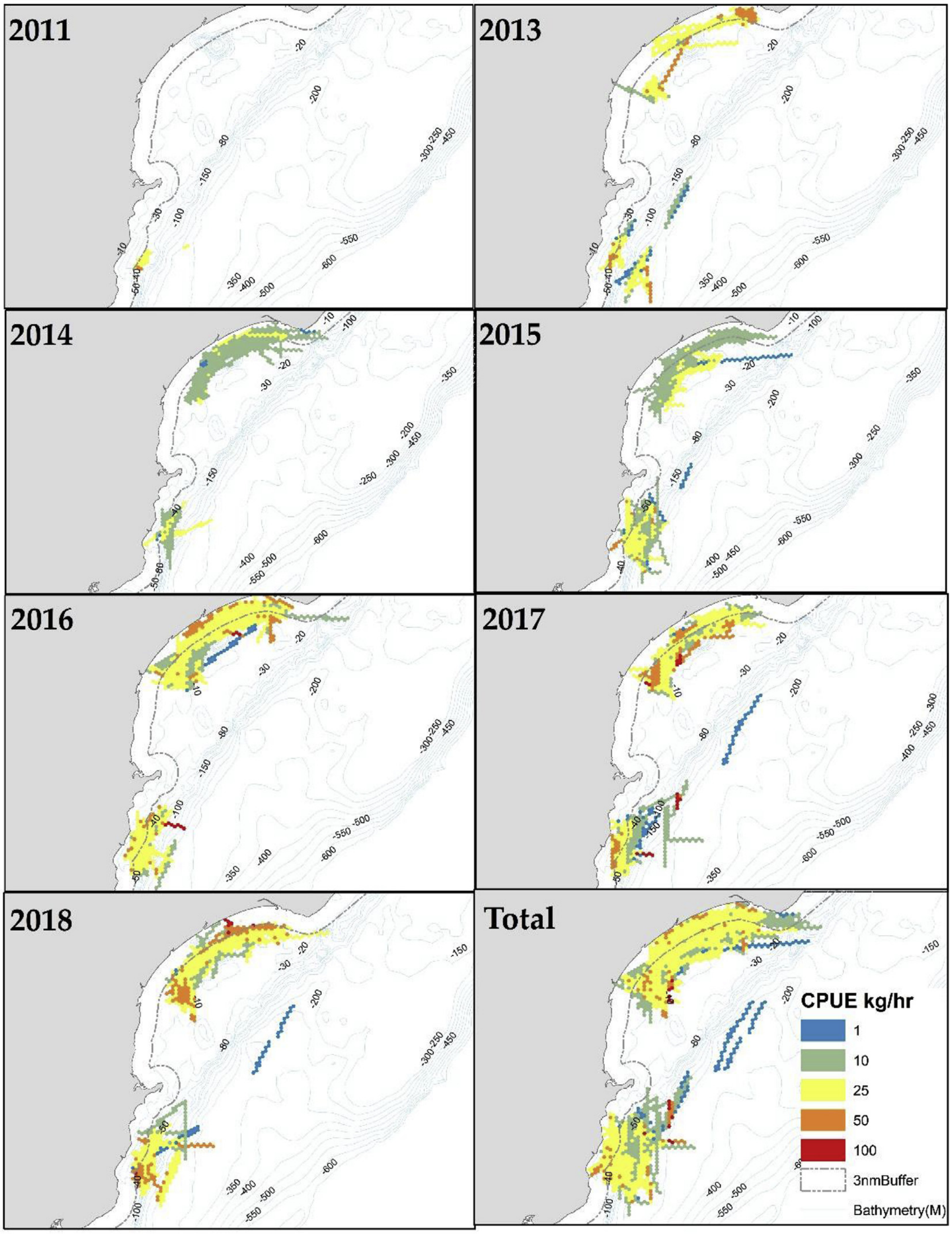

Fig. 5. Grid-based maps of 1000 minimum width hexagon showing the variations in Prawns CPUE (kg/hr) in the Malindi-Ungwana Bay fishery between the year 2011 and 2018.

results showed improved compliance with the no-trawling zone regulation after the installation of VMS system during 2017, with a non-compliance trawling reduction rate of 80%. The high percentage of fishing activities within the no-trawl area observed before the introduction of the VMS reflects limitation in the monitoring strategies of the fishing activities in the bay previously employed by the Kenya State Department of Fisheries and how governance limitations may contribute to overexploitation of resources. Such effective monitoring of fisher behaviour following VMS installation and enhanced compliance with management regulations has also been reported elsewhere [29,30].

The fisheries implication of pushing fishing effort to the deeper areas through area delineation and post VMS installation has led to an increase in the catch of non-target finfish species. The extent to which effort displacement may lead to overexploitation of the non-target species by the prawn trawlers is not clear but may be significant (Table 1.), and will require further evaluation. The re-distribution and increased fishing effort post VMS reported here is consistent with previous findings in other tropical prawn trawl fisheries [31,32]. The relatively lower CPUE in shallow areas observed before VMS installation in 2017 may be due to depletion of the stocks in the shallow areas due to higher fishing effort or impacts on habitats due to repeated trawling disturbances as reported elsewhere [33,34,34,35]. Vessels reported higher CPUE post VMS installation but fishing time also increased by

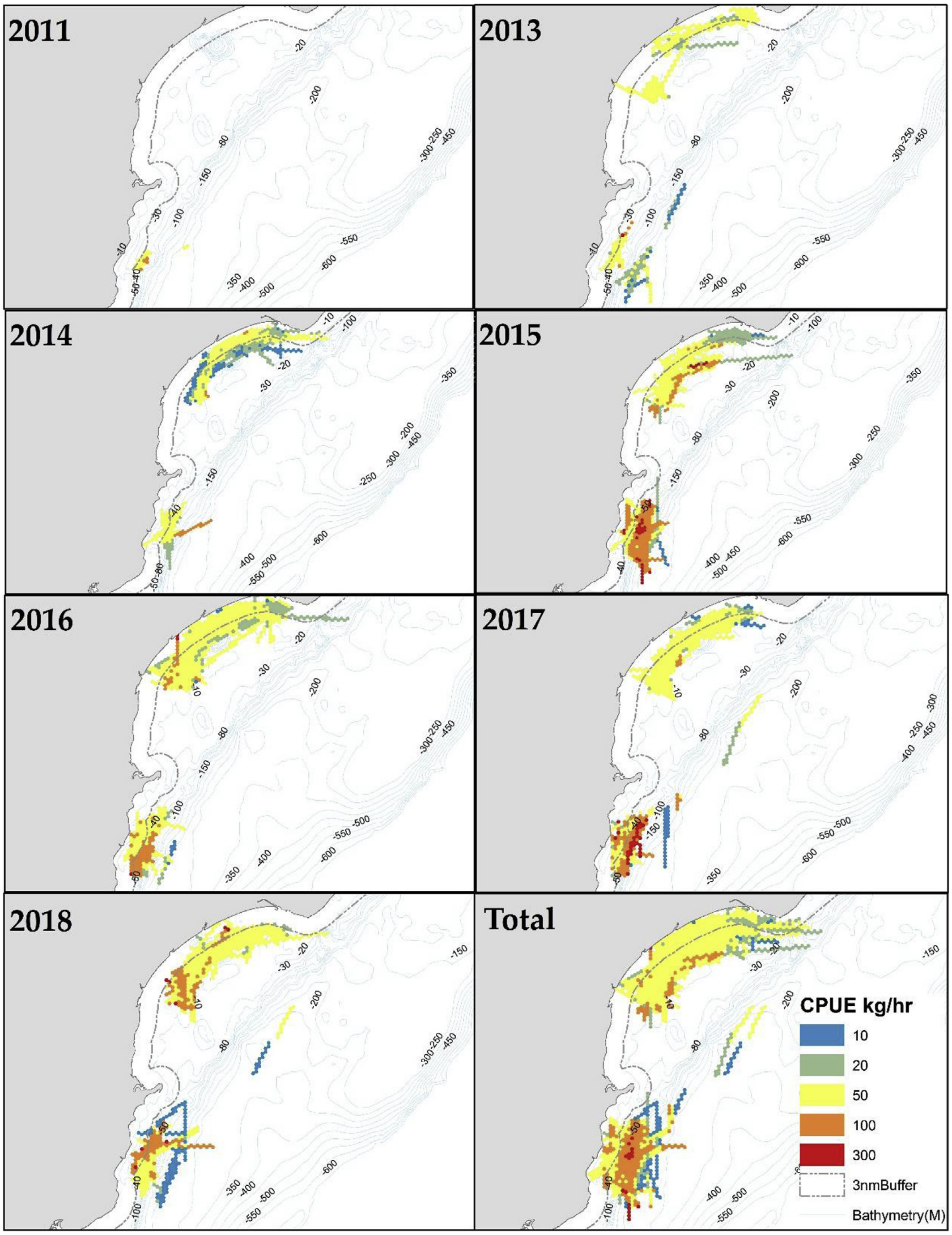

Fig. 6. Grid-based maps of 1000 minimum width hexagon showing the variations of finfish CPUE (kg/hr) in the Malindi-Ungwana Bay fishery between the year 2011 and 2018.

about 21% perhaps constraining the net profit margin.

The results show concentration of fishing activities in two major areas, the Ungwana Bay and Malindi Bay areas adjacent to the Tana and Sabaki River mouths. The occurrence of fishing hotspots near the river mouths may reflect the patchiness of effective trawlable grounds, with the distinct gap occurring in between the two fishing patches likely indicating untrawlable areas. The spatial patterns in catches shows a higher CPUE of prawns in the Ugwana Bay area compared to Malindi Bay. Spatial planning regimes like the PFMP of Malindi-Ungwana Bay should consider patchiness of fishing grounds [36] in fishing effort allocation in order to reduce resource use conflicts. The spatial patchiness of fishing pressure suggests that marine spatial planning that includes fishing boundaries should take into account the distribution of fishing activities rather than a blanket standard distance line from the coastline as currently proposed under the Malindi-Ungwana Bay PFMP.

There is a good motivation for fishing in the 3 nm restricted zone, this area has the highest CPUE especially for prawns. Some of the factors influencing compliance is the amount of gains to be obtained as anticipated by the fishers [37]. Compliance is always difficult with sedentary species like prawns as their biomass is higher in the shallow areas [15] thereby motivating poaching in these areas. Although it may be more profitable for the trawlers to fish in the no-trawl zone (shorter time to grounds, high biomass nursery ground), the risk of the prawn trawlers fishing in the no-trawl is predictable and deterrent. The bay is dominated by artisanal fishers whose interaction with the prawn trawlers can trigger conflicts which have been experienced previously

Table 1
Summary table showing descriptive statistics and results of Mann- Whitney *U* test on comparison of (a) Prawn and (b) fin fish catch rates inside and outside the prawn trawling zone of 3 nm from shoreline. nd - not determined.

Year	Area	Mean Kg/hr	sd	W	p value
a) Prawns					
2011	> 3 nm	17.22	11.86		nd
2012	> 3 nm	10.92	9.00		nd
2013	< 3 nm	25.35	14.03	13054	0.0000
	> 3 nm	18.90	23.41		
2014	< 3 nm	9.97	7.51	51378	0.0000
	> 3 nm	6.82	5.63		
2015	< 3 nm	9.23	6.29	109050	0.0472
	> 3 nm	12.12	11.22		
2016	< 3 nm	19.31	13.69	375850	0.0004
	> 3 nm	17.75	15.54		
2017	< 3 nm	23.05	17.72	319730	0.0000
	> 3 nm	18.92	16.37		
2018	< 3 nm	23.60	15.44	90418	0.61
	> 3 nm	24.27	17.11		
b) Finfish					
2011	> 3 nm	54.30	61.72		nd
2012	> 3 nm	34.18	15.19		nd
2013	< 3 nm	46.12	29.51	12659	0.0000
	> 3 nm	33.89	41.48		
2014	< 3 nm	34.26	34.44	42776	0.318
	> 3 nm	31.21	31.76		
2015	< 3 nm	36.80	47.81	61067	0.0000
	> 3 nm	102.12	119.99		
2016	< 3 nm	60.19	66.51	290830	0.0000
	> 3 nm	79.15	84.35		
2017	< 3 nm	67.83	69.55	262510	0.1104
	> 3 nm	82.72	90.08		
2018	< 3 nm	114.08	81.22	124160	0.0000
	> 3 nm	76.35	76.29		

[19,38]. However, in order for the trawlers to be compliant, they have to understand the benefits of not fishing in a restricted area [37,39].

5. Conclusion

There have been reported cases of conflicts between artisanal and commercial fishers in the bay especially due to the of loss of artisanal fishing gears (e.g. set nets). These cases have mostly been contested by the prawn trawlers. Our study reflects a high non-compliance fishing within the 3 nm zone especially before VMS installation in 2017. The current installation of the VMS in trawlers has shown a change in fleet behavior. Consequently, a review of the current PFMP of the bay should address real-time monitoring and surveillance data and also establish socio-economic factors that may results from the restriction of trawlers from the shallow areas so that prawn trawling may remain economically feasible. We recommend further research work to help better address the question of whether fishing patterns are influenced by other factors in the bay such as habitat distribution or environmental conditions. Establishing no-trawl zones based on spatial-temporal distribution of resources and fishing effort may be necessary so as to make the fisheries sustainable.

Conflicts of interest

We wish to confirm that there are no known conflicts of interest associated with this publication. Further, all of the sources of funding and support for the work described in this publication have been acknowledged.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpol.2019.103677.

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