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RESEARCH ARTICLE

Experimental evaluation of influence of FADs on community structure and fisheries in coastal Kenya

Emmanuel K. Mbaru[1,*], Dorcas Sigana[2], Renison K. Ruwa[1], Elizabeth M. Mueni[3], Collins K. Ndoro[3], Edward N. Kimani[1] and Boaz Kaunda-Arara[4]

[1] Kenya Marine and Fisheries Research Institute, P.O. Box 81651, 80100 Mombasa, Kenya
[2] College of Biological and Physical Sciences, University of Nairobi, P.O. Box 30197, 00100 Nairobi, Kenya
[3] Fisheries Department, Ministry of Agriculture, Livestock and Fisheries, P.O. Box 90423, 80100 Mombasa, Kenya
[4] Department of Fisheries and Aquatic Sciences, University of Eldoret, P.O. Box1125, 30100 Eldoret, Kenya

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Abstract – Fish aggregating devices (FADs) have been widely used by commercial fisheries to increase the catchability of pelagic stocks in the open sea. FADs have the potential to enhance nearshore small-scale fisheries where stocks are often overfished. This study examined changes in catch composition, abundance, catch and effort, and aspects of diversity in Kenya's nearshore coastal fisheries after deployment of anchored fish aggregating devices (AFADs). The study combined both fishery independent and dependent methods in assessing changes in fish assemblages post-deployment. Results showed orders of magnitude increase in length, weight, commercial value, and catch per unit effort (CPUE) of landed catch after deployment of FADs suggesting that FADs had a positive effect on the local fishery. Species richness at FAD sites increased post-deployment ($n = 281$) compared to pre-deployment values ($n = 223$). Simultaneous use of several complementary structural indices may be required in order to accurately describe and monitor fish assemblages around the FADs. The findings suggest that AFADs are capable of creating both short and long-term impacts on livelihoods, with the potential to deflect pressure on the overfished nearshore fish stocks. However, more research will be needed on redistribution of fish around FADs, design and placement configuration, and site selection amongst others.

Keywords: Fish aggregating devices / pelagic fishes / species diversity / Kenyan coast

1 Introduction

High densities of fish have been observed to aggregate around man-made and natural objects such as rafts (Gooding and Magnuson, 1967), driftwood (Hunter and Mitchell, 1967), jellyfish (Janssen and Harbison, 1981), and drifting algae (Kingsford and Choat, 1985). This aggregating behaviour is a consequence of many factors acting on the individuals and several mechanisms have been suggested to explain this phenomenon. Some of the more accepted mechanisms are: meeting point hypothesis (Castro et al., 2002; Soria et al., 2009), indicator log hypothesis (Hall et al., 1992a; Dagorn and Fréon, 1999), refuge from predators (Hunter and Mitchell, 1967), spatial orientation (Hall et al., 1992b), food supply (Kojima, 1956; Buckley and Miller, 1994), schooling companions (Hunter and Mitchell, 1967), substrate for species undergoing a change from a pelagic to other modes of existence (Hunter and Mitchell, 1967; Vassilopoulou et al., 2005), or that they duplicate natural aggregators such as sargassum seaweed (Rountree, 1989). Whatever the case, humans have exploited this strong association throughout history in order to locate and facilitate the capture of pelagic fish (Yabe and Mori, 1950; Massutí and Morales-Nin, 1997; Massutí et al., 1999). Initially, most of these fisheries took advantage of the existence of natural floating logs, but soon fishers started constructing artificial floating objects as fish aggregating devices (FADs) (Deudero et al., 1999). Following some success in the Pacific islands, FADs have rapidly expanded to other small-scale fisheries including island developing countries such as Maldives, Comoros and Mauritius in the Indian Ocean (Kingsford and Choat, 1985; Cayre et al., 1991; Houbert, 2009; Govinden et al., 2013). Currently, more than 121,000 drifting FADs (DFADs) have been deployed in the oceans (Ushioda, 2015) and the majority of the fish catches by industrial purse-seine vessels worldwide are made in

*Corresponding author: ekam.mbaru@yahoo.com

aggregations under DFADs (Dagorn et al., 2013; Fonteneau et al., 2013). As FAD fisheries continue to expand globally, research on FADs is equally gaining momentum. So far, more than 333 species of fish have been described as associating with floating objects (Castro et al., 2002). However, unlike the expanding FAD fisheries, research around FADs has not been well documented. The vast majority of the rapidly growing empirical research on FADs has focused mainly on DFADs (Dempster and Taquet, 2004). In contrast, there is a paucity of experimental investigations on associations of fishes with anchored fish aggregating devices (AFADs) particularly in tropical waters, and more so in the Western Indian Ocean (WIO) region. Although some studies have been conducted in the WIO such as Seychelles (Taquet et al., 2007; Ramos et al., 2010; Robert et al., 2012), Maldives (Govinden et al., 2013), Comoros (Cayré, 1991; Cayre et al., 1991; Rey-Valette et al., 2000), Reunion island (Taquet et al., 2007) and Mauritius (Houbert, 2009; Beverly et al., 2012), research on coastal waters of the African continent are scarce. Additionally, much of the focus in the tropical and temperate waters has been on the open water DFADs and concentrated on fish species composition (Dempster and Taquet, 2004), movements and residence times (Dagorn et al., 2007), aspects of bycatch (Dagorn et al., 2013; Davies et al., 2014), and fishing techniques (Dempster and Taquet, 2004). In contrast to DFADs, no study has specifically analyzed how AFADs function especially in the nearshore coastal fisheries. To address this gap, this study examines changes in fish catch composition, catch per unit effort (CPUE), and diversity of species after deployment of AFADs in nearshore coastal fisheries in Kenya. We combine both fishery independent and fishery dependent methods in assessing nearshore fish assemblage structure.

2 Materials and methods

2.1 Study area

All experiments with AFADs (hereafter called FADs) were carried out in coastal Kenya during April 2014 and February 2015. The marine fishery in Kenya is predominantly small-scale and artisanal with about 12,000 fishers intensely fishing nearshore coastal reefs using minimally selective fishing gears (Mbaru, 2012). A large majority (88%) of fishers use traditional fishing gears such as basket traps, beach seines, hook and lines, gillnets, spearguns, fence traps amongst others (Mbaru, 2012; Kawaka et al., 2017). Handmade canoes propelled by paddles or sail power are predominantly used to access inshore fishing grounds, while only a few fishers use motorized boats to access offshore waters. Although fishers along the coast know and express the potential of offshore fishing, most of them are unable to access the largely untapped offshore pelagic resources (Mbaru, 2012).

Fish composition and diversity data were collected from two sampling zones: Zone A (depth range: 100–135 m with 2 FADs) and Zone B (depth range: 140–165 m. with 3 FADs). Supplementary information with complete description of FAD design and deployment is provided All FADs were deployed at a distance of ~3 nautical miles from the nearest shoreline (Fig. 1). These locations are adjacent to fringing reefs where light level of fishing effort (several small boats a day) occurs in the inner reef. At each zone, the FADs were separated by ~600 m considered adequate to avoid interference (Dempster and Taquet, 2004). Daily sampling of landed artisanal catch data from the two zones is maintained by the local non-governmental organizations and the State Department of Fisheries (SDF) since 1995.

2.2 Fish aggregations at FADs

Three experienced divers equipped with SCUBA conducted underwater visual transects (UVCs) around the FADs in the two zones to assess fish composition and abundance. Prior to FADs deployment, 5 pre-deployment dives (one dive per identified FAD location) were conducted. After deployment, 28 standardized UVCs were conducted over the survey period extending from April 2014 to February 2015. Two of the 3 divers noted all the species encountered near the FADs recording their abundances and estimated sizes. The third diver was in charge of the safety of the group. Dive duration time was set at 20 min, however, the time was sometimes adjusted to 25–30 min depending on the amount of fish present and the environmental conditions (Graham et al., 2006). During each sampling time, divers descended to a depth of 10 m below the FADs and surveyed the waters below to a maximum of 20 m. Direct abundance estimates of species were conducted when fish schools consisted of less than 10 individuals, abundance of species in schools with >10 individuals were estimated by assigning to abundance classes. Maturity status was determined from sizes in Fishbase (Froese and Pauly, 2003).

2.3 Catch sampling

Catches of artisanal fishers in the FAD zones were recorded by onsite observers at the landing beaches adjacent to the zones. The observers operated during each FAD sampling day and recorded, the date, total number of boats, area fished, number of crew, gear used, time in, time out, total landing and the catch composition (weight, kg, and total length, cm, of each individual of species. Among the fishing gears recorded during catch surveys include; gillnets, hook and lines, basket traps, spearguns and others (see supplementary information for details of fishing effort for each gear used; Tab. S4). At least 8 days of data collection was achieved every month for a period of 13 months in 2014 and 2015, translating into 92 sampling days over the survey period. In addition to catch data from fishers, scientific observers also conducted 112 experimental fishing surveys (EFSs) at FADs over the survey period, consisting of 28 sampling days involving one recreational fishing boat and three motorized outrigger canoes, all equipped with trolling lines. Three nylon monofilament main lines attached to a baited hook were actively towed through surface waters from the stern of the recreational vessel, while four lines were used in one of the outrigger canoe. Occasionally, down riggers were used to troll the main line at certain depths. The other two outrigger canoes employed hand line fishing where three fishers in each boat launched a single monofilament nylon line with one to three baited hooks from a drifting outrigger canoe. In all instances, the bait used was fresh fish, squid or octopus either whole or cut. The preferred hook size was 3/0. Data from EFSs was used to complement UVCs and provided more insight into species description at FADs. Dates on which the sampling trips were conducted were selected randomly to avoid any form of auto-correlations. However, each FAD was visited on a quarterly interval in order to capture any seasonal variability of fish composition. Catch recorded by

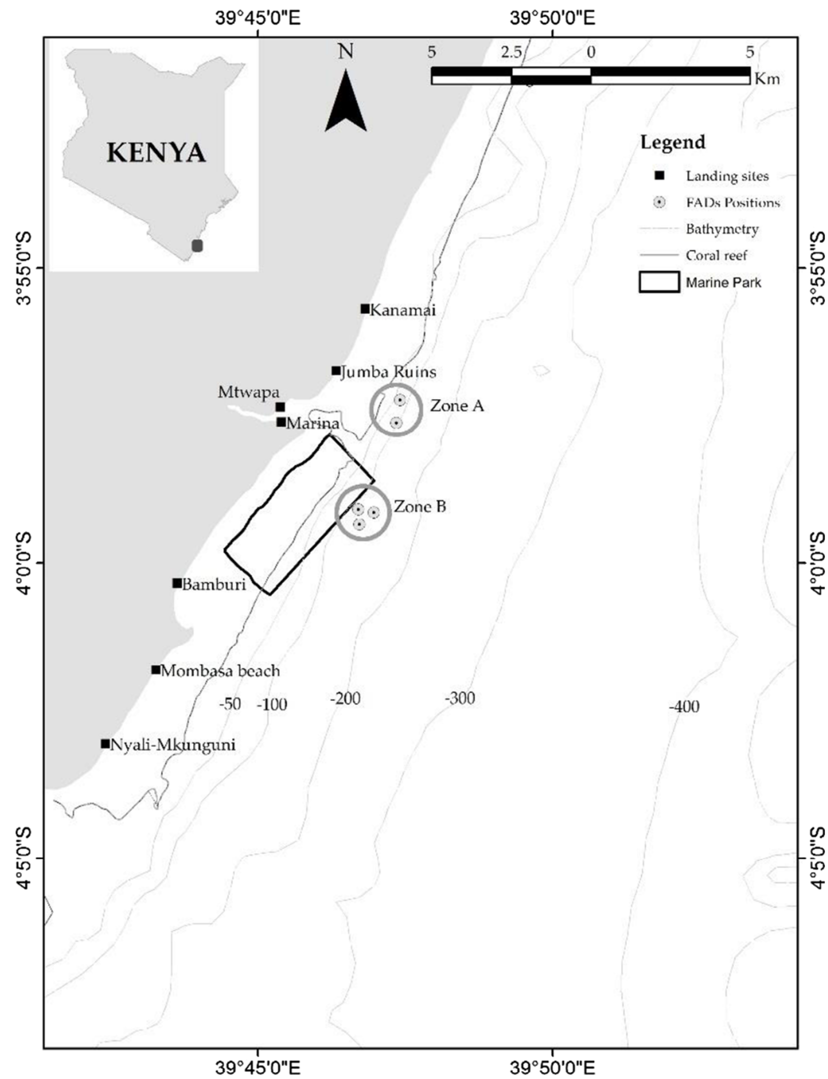

Fig. 1. Map showing the two sampling zones (A and B) fished by anchored fish aggregating devices (AFADs) in coastal Kenya.

scientific observers used the same criteria as that of the onsite observers. Observers identified landed and trolled catch to species level following Lieske and Myers (1994).

2.4 Data and statistical analysis

2.4.1 Species characterization and biomass estimation

Data analysis from the fisheries dependent and independent surveys followed a 3-phase approach for each sampling zone: (1) species composition and biomass of catch from fishers before and after FADs deployment by local fishers; (2) species composition and biomass of catch caught at FADs through EFSs; and (3) species composition and biomass of fish observed at FADs through UVCs. Ecological and trophic categorization of the species sampled at FADs followed Taquet and Diringer (2007). Fish species associated with FADs were classified into 3 groups according to their distance from the FADs: "intranatants" which remain within 2 m of the FAD, "extranatants" (10 m) and "circumnatants" (50 m) (Fréon and Dagorn, 2000). Average fish lengths of each species observed by divers were used to produce a biomass index (B_i, kg) of all species (Deudero et al., 1999): $B_i = 10^5 L_i^3 N_i$ L_i (cm) is the mean length of the species *i* and N_i the number of fish counted for the species *i*. We used this generic equation due to lack of precise Length/Weight relationships for several species observed.

2.4.2 Catch, effort and CPUE

Catches from the two sampling zones were considered separately for the following calculations: numbers (abundance), mean length, mean mass, mean value and CPUE. Variation of these parameters (with sampling zone) was tested using One-way ANOVAs, treating sampling periods as fixed effects in the case of catch data from fishers. However, FAD zone was treated as a fixed effect in the case of catch data from EFSs at FADs. The same approach was used to compare abundance of demersals and pelagics between the two zones by treating sampling period as a fixed effect. FADs were envisaged to increase landings of pelagic fishes but it was hypothesized that FADs would reduce fishing pressure on demersal fishes particularly those associated with coral reefs and, therefore, abundance and incomes from the two ecological groups was evaluated over the study period. This distinction was also important because pelagic fishes tend to

Table 1. The studied species diversity components and their descriptors. Indices based on presence-absence data are marked by [pa] .(1) Margalef (1958); (2) Heip (1974); (3) Berger and Parker (1970); (4) Shannon and Weaver (1949); (5) Simpson (1949); (6) Warwick and Clarke (1995); (7)
Q1 Clarke and Warwick (2001).

Component	Descriptor	Formula	Expected properties
Species richness	Species diversity[pa]	S=number of species	Standardize species richness by unit area
	Margalef	$Dmg = \frac{S-1}{\ln(N)}$	Adjusted species richness by N (1)
Evenness	Heip	$EHeip = \frac{\exp(H\prime)-1}{S-1}$	Sensitive to rare species (2)
	Berger parker	$1/d = N/N\max$	Sensitive to dominant species (3)
Number of species + evenness	Shannon-Wiener	$H\prime = -\sum_{i-1}^{s} pilogpi$	Sensitive to rare species (4)
	Simpson diversity	$1 - D = 1 - (\sum_{i-1}^{s} pi^2)$	Sensitive to dominant species (5)
Species taxonomy	Taxonomic diversity	$\Delta = 2\frac{\sum\sum_{i<j}\omega_{ij}X_iX_j}{N(N-1)}$	Extension of D including taxonomic relatedness (6)
	Taxonomic distinctness	$\Delta* = 2\frac{\sum\sum_{i<j}\omega_{ij}X_iX_j}{\sum\sum X_iX_j}$	Form of limiting the influence of species dominance, reflecting pure taxonomic relatedness (6)
	Average taxonomic distinctness[pa]	$\Delta^+ = 2\frac{\sum\sum_{i<j}\omega_{ij}}{S(S-1)}$	Equivalent of △ and △* in presence-absence data (7)
	Variation in taxonomic distinctness[pa] Λ^+ where $\omega = \Delta^+$	$\Lambda^+ = 2\frac{\sum\sum_{i<j}(\omega_{ij}-\varpi)^2}{S(S-1)}$	Evenness of the taxonomic level distribution in the (7) distinctness taxonomic tree

fetch higher prices than demersals in the domestic market. For significant ANOVA models and variables, Tukey–Kramer pairwise comparisons was used to identify differences in catch between sampling periods and FAD zones. Pre-deployment values were considered as controls and used to compare sizes, weights, CPUE and species composition of fish from experimental fishing over the FADs and landings by fishers over the FADs and other areas in the two sampling zones Total fishing effort (E_{td}) for each day was calculated by taking the mean effort of all interviewed fishers (n) and multiplying it by the total number of fishers (N) for the ith day, and expressed as follows:

$$E_{td} = \frac{\sum_{i-1}^{n} E_i}{n} \times N. \quad (1)$$

Individual fisher effort (E_i) was calculated as the absolute duration (i.e. the difference between a fisher's departure and arrival time from the landing site) of each outing (in hours). The catch per unit effort (CPUE, kg fisher $^{-1}$ day^{-1}) per fisher was calculated using:

$$CPUE = \frac{\sum_{i-1}^{n} \frac{C_i}{E_i}}{n}, \quad (2)$$

where $C_i$is the observed catch as number or mass (in kg) of fish caught by the ith group of fishers interviewed, E_i is the observed fishing effort for the ith group of fishers interviewed, and n is the number of fisher outings recorded throughout the survey period.

2.4.3 Species diversity indices

Diversity patterns were analyzed taking into account species richness, abundance, evenness and taxonomic composition of fish assemblages captured by fishers before and after deployment of FADs as well as those captured through EFSs at FADs. Diversity indices were computed separately for each fishing zone in order to account for spatial variations between FADs. The number of species sampled per day was taken as a measure of species density (S) (Rosenzweig, 1995). Because species richness is highly sensitive to sampling effort (Gaston and Spicer, 2013), we used a Chi-square Test of Independence, to test the effect of variations in the number of sampling days on the species richness. We further computed Margalef's species richness index (D_{mg}) (Margalef, 1958), which adjusts the number of species according to the total number of individuals sampled in each day. A similar approach was followed for UVC data except that the unit of variation was the number of UVCs rather than sampling days. Secondly, two indices of evenness; the Heip's evenness index (E_{Heip}) (Heip, 1974) and the Shannon-Wiener index (H') were analyzed for comparison. Complementary to the Heip index, the Berger Parker index (d) (Berger and Parker, 1970) was computed because it is only sensitive to variations in the most dominant species. Here, $1/d$, which increases when abundances are evenly distributed (maximum diversity) among the species and decreases with dominance, was computed. Also computed was the Simpson diversity concentration index (D) (Simpson, 1949), which combine both the number of species and evenness components in a single value. H' is assumed to be sensitive to the changes in abundance of rare species, while D

Table 2. Seasonal occurrence of the species beneath FADs observed through underwater visual census in coastal Kenya. Pre-deployment April 2014, Period_1 – April 2014; Period_2 – June 2014; Period _3 – November 2014; Period_4 – February 2015. Mean abundance is number of individuals per FAD ± SD. Intra – intranatant, Extra – extranatant, Circum – circumnatant species

Species name	Pre-deployment	Period_1	Period_2	Period_3	Period_4	Mean abundance	Fish type
Acanthocybium solandri				1	9	2 ± 1.14	Extra
Acanthurus dussumieri				3	10	2.6 ± 0.99	Intra
Acanthurus triostegus	3	19	12	4	7	8.4 ± 1.32	Intra
Amblygaster leiogaster				12	45	11.4 ± 4.67	Extra
Aphareus rutilans					8	1.6 ± 0	Extra
Caesio caerulaurea			2	9	20	6.2 ± 1.82	Extra
Carangoides armatus					27	5.4 ± 0	Extra
Carangoides coeruleopinnatus				3	9	2.4 ± 0.85	Extra
Cephalopholis argus				7	11	3.6 ± 0.57	Intra
Chaetodon auriga	2	13	35	2		10 ± 3.12	Intra
Cociella crocodilus				7	1	1.6 ± 0.85	Extra
Coryphaena hippurus		1	3	2	11	3.4 ± 0.92	Extra
Decapterus macarellus					31	6.2 ± 0	Extra
Diodon hystrix					1	0.2 ± 0	Intra
Epinephelus chabaudi					13	2.6 ± 0	Extra
Etelis carbunculus					10	2 ± 0	Extra
Gerres oyena		9	14	1	8	6.4 ± 1.08	Extra
Leptoscarus vaigiensis	2		8	14	23	9 ± 1.8	Extra
Lethrinus harak					1	0.2 ± 0	Extra
Lethrinus lentjan				16	20	7.2 ± 0.57	Extra
Lethrinus mahsena					1	0.2 ± 0	Extra
Lutjanus argentimaculatus					18	3.6 ± 0	Extra
Lutjanus fulviflamma				3	8	2.2 ± 0.71	Extra
Makaira indica				1		0.2 ± 0	Circum
Naso brachycentron		6	17	4	4	6.2 ± 1.25	Extra
Parupeneus macronemus			12	7	20	7.8 ± 1.32	Extra
Plectorhinchus flavomaculatus				2	3	1 ± 0.15	Extra
Rachycentron canadum			1		2	0.6 ± 0.15	Extra
Rastrelliger kanagurta				22	38	12 ± 2.27	Extra
Sarda orientalis		7		8	8	4.6 ± 0.12	Extra
Sardinella longiceps					1	0.2 ± 0	Extra
Seriola lalandi	2			16	9	5 ± 1.4	Extra
Scarus ghobban			4	2	3	1.8 ± 0.2	Extra
Scomberomorus plurilineatus				6	14	4 ± 1.14	Extra
Siganus sutor	4	12	25	22	23	16.4 ± 1.79	Extra
Sphyraena barracuda				1	5	1.2 ± 0.57	Extra
Euthynnus affinis		2	7	9	14	6.4 ± 1	Extra
Thunnus albacares				2	11	2.6 ± 1.28	Circum

is heavily influenced by the dominant species and is less sensitive to species richness than H' (Boyle et al., 1990). Simpson diversity (1–D), rather than D, which increases in value with diversity (Gaertner et al., 2008), was used. Four taxonomic indices proposed by Warwick and Clarke (1995), i.e. taxonomic diversity (Δ), taxonomic distinctness (Δ^*), average taxonomic distinctness ($\bigwedge+$), and variation in taxonomic distinctness ($\Delta+$) were further computed. These indices quantify the taxonomic diversity of a faunal assemblage in terms of average distance of all pairs of individuals (or species) in a sample by tracing these distances through a Linnaean taxonomic tree (Warwick and Clarke, 1995; Mérigot et al., 2007; Gaertner et al., 2008). Two sample t-tests for unequal variances (i.e. Welch's test) were carried out to investigate the effects of the sampling zones on the variation of each of the selected descriptors of diversity. Finally, a 2-stage procedure was carried out to identify both redundant and complementary descriptors of diversity. Firstly, the multicomponent structure of fish diversity was analyzed using principal component analyses (PCA). Secondly, pairwise correlations between all the indices studied were carried out using Spearman's rank correlation test. To determine the effect of FADs on the local fishery, mean values of each species diversity index before FADs deployment provided a baseline state, and comparisons were made with indices computed on catch and UVC data after deployment in order to monitor changes in species diversity in the two sampling zones. Table 1 provides the formulae for deriving the structural indices. Taxonomic indices were computed using the PRIMER v6 software (Clarke and Warwick, 2001), while all the other indices and statistical analyses were performed using R software (version 3.3.0, R Development Core Team 2016).

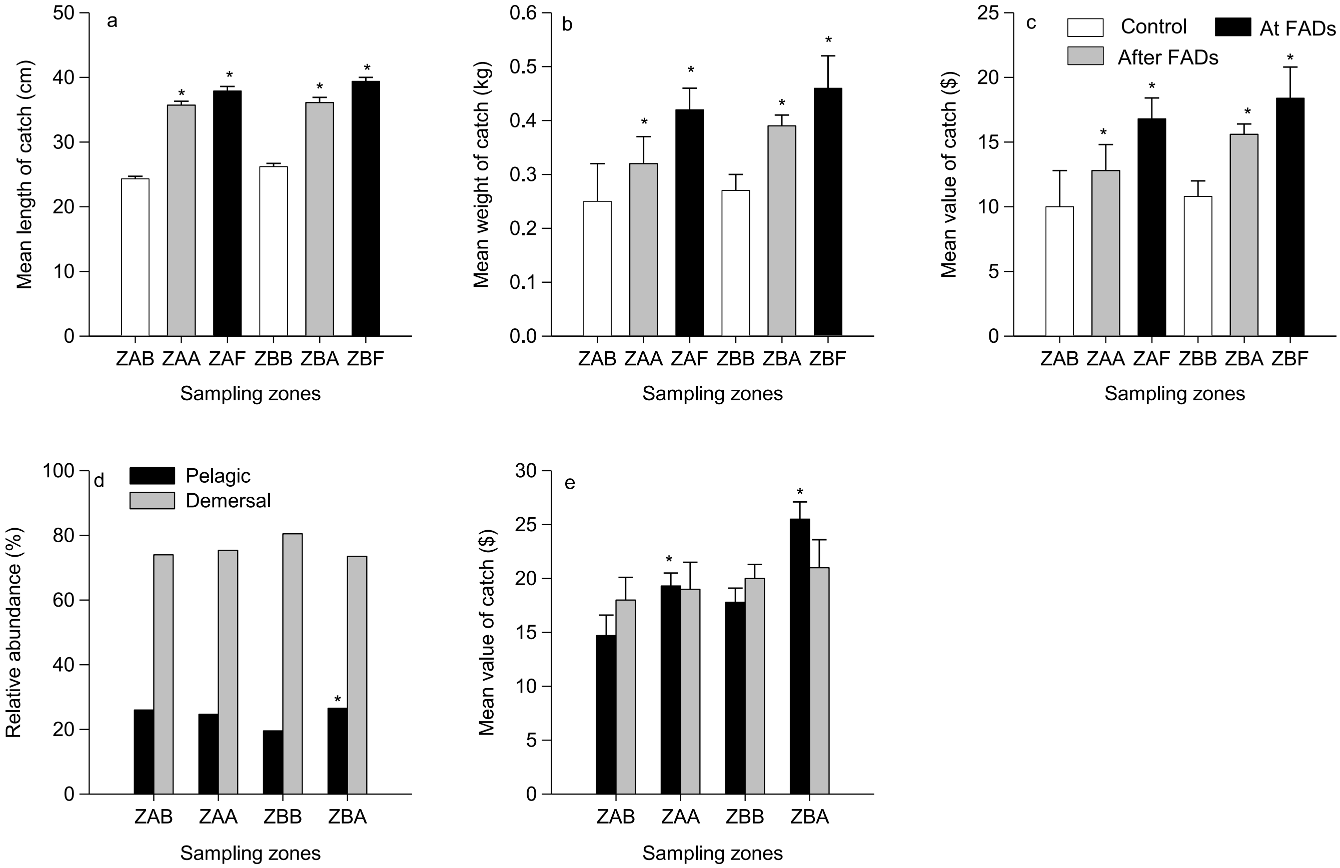

Fig. 2. The mean (SE) values of variables compared before and after deployment of AFADs in coastal Kenya. (a) length, (b) mass, (c) market value of catch per fisher, (d) Relative abundance of pelagics and demersals, (e) market value of catch per fisher for pelagics and demersals, Significant differences from controls are indicated; $*p < 0.05$. (ZAB – Zone A Before FADs; ZAA – Zone A After FADs; ZAF – Zone A At FADs; ZBB – Zone B Before FADs; ZBA – Zone B After FADs; ZBF – Zone A At FADs).

3 Results

3.1 Temporal changes in aggregations at FADs

A total of 38 species (5 intranatant, 30 extranatant, 3 circumnatant species) belonging to 20 families were recorded from all the 834 individual fish observed at 5 FADs (Tab. 2). The most dominant family was Scombridae (6 species), followed by the Carangidae and Lutjanidae (4 species), Scaridae, Lethrinidae, and Acanthuridae with 3 species each. Average densities of fishes were higher (>10 individuals per FAD) for *Rastrelliger kanagurta, Siganus sutor, Chaetodon auriga*, although these were highly associated with the shallow FADs in Zone A (Tab. S1). Biomass estimations at FADs varied substantially with biomass index ranging from $B_i = 0.01$ (10 species) to $B_i = 7.98$ (*S. sutor*) (Tab. S2). The most common pelagic species encountered at FADs were; *Acanthocybium solandri, Coryphaena hippurus, Makaira indica, Gerres oyena*, and *Decapterus macarellus* (Tab. 2). Most of the observed specimens were adults with the exception of a few juveniles of *S. sutor, L. vaigiensis, Lethrinus lentjan, Parupeneus macronemus and Scarus ghobban* (Tab. S1). Eight species; *Naso brachycentron, Lutjanus fulviflamma, P. macronemus G. oyena, Acanthurus triostegus, Acanthurus dussumieri, D. macarellus, L. lentjan* were observed around all FADs, with *Amblygaster leiogaster, G. oyena, A. triostegus, A. dussumieri* and *L. lentjan* appearing both as juveniles and adults (Tab. S1). Some species exhibited a strong affinity with shallow (100–135 m) FADs, while others showed no pattern of association. For example, higher densities of *S. sutor, P. macronemus and C. auriga* were observed around shallow FADs, while the majority of pelagic piscivores such as *A. solandri, Caesio caerulaurea, M. indica, C. armatus R. kanagurta, Scomberomorus plurilineatus, Sphyraena barracuda, Euthynnus affinis* and *Thunnus albacares* were observed around relatively deeper (140–165 m) FADs (Table S1). However, some pelagic piscivores such as *A. leiogaster, D. macarellus* were also seen in association with shallow FADs. Most small bodied fish (<20 cm) were observed few months after FAD deployment, while a relatively high percentage of pelagic piscivores were observed in the last two sampling visits (Tab. 2). The total number of species and individuals increased with each subsequent sampling, having its peak in the fourth sampling period (Tab. 2). For example, before FADs deployment, only 5 species (*A. triostegus, C. auriga, Leptoscarus vaigiensis, S. plurilineatus*, and *Seriola lalandi*) were observed from all FAD locations surveyed (Tab. 2). However, after FADs deployment, 8 species were observed during the first visit, 12 species during the second, 27 species during the third and 36 species during the final visit (species

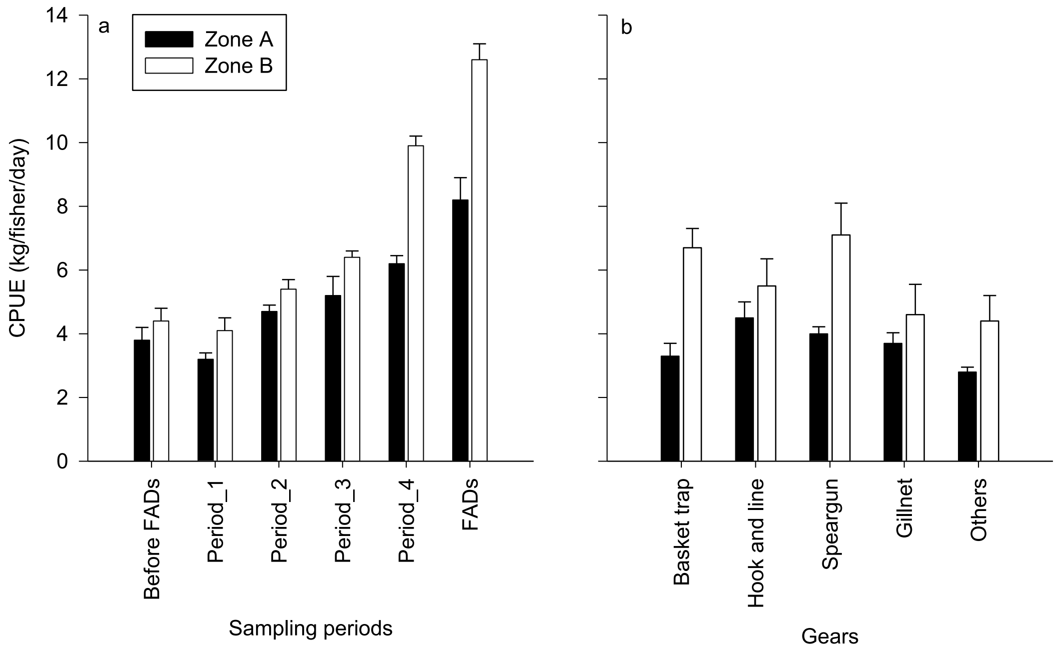

Fig. 3. CPUE (kg fisher $^{-1}$ day^{-1}) from the two sampling zones before and after deployment of FADs based on (a) sampling periods and (b) Sampling effort for gear used in Zone A and Zone B. Period_1 – April 2014; Period_2 – June 2014; Period _3 –November 2014; Period_4 – February 2015.

reported here exclude unidentified fishes). No relationship was found between depth of FADs and number of fish associated with them ($r^2 = 0.2$, $n = 5$, $p > 0.5$).

3.2 Effect of FADs on the local fishery

A total of 1281 individuals representing 108 species from 42 families were caught at FADs through EFSs (Tab. S2). Significant differences were found when means of specific fish metrics were analyzed in terms of length (cm), weight (kg), value (US$) and CPUE (kg fisher^{-1} day-$^{-1}$) before and after deployment of FADs in both zones (Fig. 2; Tab. S3). In Zone A, fishers experimentally fishing at the FADs captured 56% larger fish (37.9 ± 0.7 cm), while the landed fish were 46.9% larger (35.7 ± 0.6 cm); the sizes are compared to pre-deployment (control) mean size of fishes from the zone of 24.3 ± 0.4 cm (Fig. 2a; Tab. S3). In Zone B, fishers captured 50.4% larger fish (39.4 ± 0.6 cm) during experimental fishing at FADs, while the landed fish were 37.8% larger (36.1 ± 0.8 cm); the size increases are derived from a comparison with pre-deployment mean size (26.2 ± 0.5 cm) of fishes from the zone (Fig. 2a). In terms of weights; fishers captured 0.42 ± 0.04 kg or 68% more through experimental fishing at FADs, while total weight of landed fish was 0.32 ± 0.05 kg or 28% more after FADs deployment when compared to a mean catch of 0.25 ± 0.07 kg before deployment of FADs (controls) at the zone ($F_{2,641} = 81.7$, $p < 0.05$, Fig. 2b; Tab. S3). In Zone B, an average of 0.46 ± 0.06 kg or 70.4% more fish were captured by fishers through experimental fishing over the FADs compared with a pre-deployment average catch of 0.27 ± 0.03 kg, while fisher landings were 0.39 ± 0.02 kg or 44.5% more than the pre-deployment values from the zone ($F_{2,1225} = 125.2$, $p < 0.05$).

In Zone A, there was a 56.6% and 18.5% increase in economic value of the total fish caught through experimental fishing over the FADs, and those landed by fishers after FADs deployment, respectively, when compared with control (pre-deployment) mean value of $10.8 ± 2.8 (Fig. 2c; Tab. S3). However, in Zone B, there was slight increases of 64.3% and 39.3% in economic value of the total fish caught over the FADs and those landed by fishers after FADs deployment, respectively, when compared with control mean value of $11.2 ± 1.2.

Results demonstrated a substantial increase in CPUE at 115.8% and 26.3% for experimental fishers over the FADs, and for fishers landing after FADs deployment, respectively, when compared to a control mean CPUE of 3.8 ± 0.4 in Zone A (Fig. 3a; Tab. S3). In Zone B, an increase in CPUE of 186.4% by experimental fishers over the FADs and 47.7% by fishers landing at the shore after FADs deployment, was recorded compared to pre-deployment mean CPUE (control) of 4.4 ± 0.4. (Fig. 3a; Tab. S3). Significantly higher post-deployment CPUE values suggest that FADs had a positive economic effect on the local fishers. There was no significant difference in economic value of demersal fishes when compared between post- and pre-deployment of FADs in each of the two zones ($F_{1,101} = 1.1$, $p = 0.12$, Fig. 2d, Tab. S3). However, results revealed a 35.7% increase in number of pelagic fish caught in Zone B after FADs deployment ($F_{1,39} = 25.2$, $p < 0.05$, Tab. S3). In terms of commercial value, results showed a 31.3% increase in value of the total biomass of pelagic fishes caught after FADs deployment from a control mean of $14.7 ± 1.9 in Zone A (Fig. 2e, Tab. S3). For Zone B, there was a 43.3% increase in economic value of the pelagic fish caught after FADs deployment from a control mean of $17.8 ± 1.3 (Fig. 2e; Tab. S3). Variations in sampling effort and CPUE per gear type is presented in Table S4 and

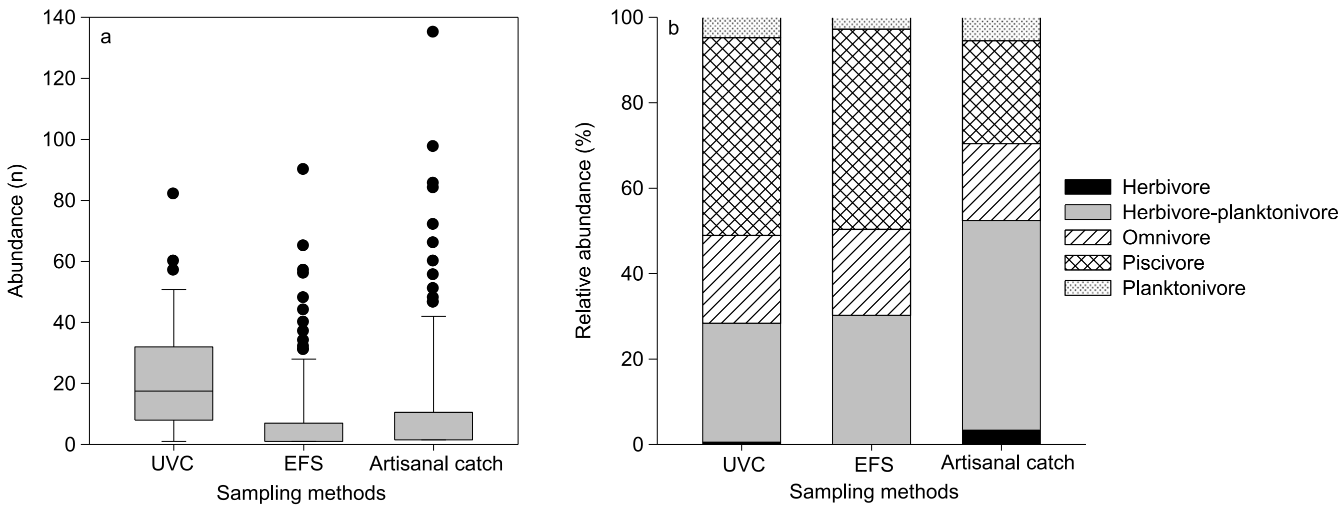

Fig. 4. (a) Number of fishes per sampling unit in each of the sampling methods used, (b) Trophic classification of fishes associated with FADs shown as % of fish abundance. The box-plot represent the quartiles around the median (line inside the box), the dots outside the box represent the outliers.

Table 3. Mean value and coefficient of variation (CV) of the diversity indices. Welch's *t*-test values shown for species diversity indices between the two sampling zones A and B in coastal Kenya. Indices descriptors are shown in Table 1. Significant values ($p < 0.05$) are marked by an asterisk.

Diversity indices	Indices codes	All zones		Zone A		Zone B		FADs	
		Mean	CV	*t*	*p*	*t*	*p*	*t*	*p*
Species diversity	S	106.67	1.97	0.17	0.87	0.21	0.84	0.04	0.84
Margalef	D_{mg}	–0.15	1.99	3.44	0.01*	3.13	0.01*	0.76	0.26
Heip	E_{heip}	0.42	1.97	0.01	0.03*	1.07	0.29	3.06	0.01*
Berger parker	$1/d$	10.59	1.97	57.47	0**	0.78	0.44	63.19	0.01**
Shannon-Weiner	H'	3.75	1.97	3.89	0.01*	7.04	0.01*	2.25	0.02
Simpson diversity	$1\text{-}D$	0.05	1.99	3.12	0.01*	0.41	0.69	6.11	0.01*
Taxonomic diversity	Δ	0.26	1.99	1.17	0.25	9.94	0.01*	50.71	0.01*
Taxonomic distinctness	Δ^*	0.43	1.99	2.32	0.03*	16.51	0.01*	52.54	0.01*
Average taxonomic distinctness	Δ^+	0.82	1.97	0.11	0.92	0.52	0.61	1.16	0.12
Variation in taxonomic distinctness	Λ^+	0.41	1.97	1.52	0.14	0.27	0.8	3.12	0.01*

* ($p < 0.05$);
** ($p < 0.01$)

Figure 3b, respectively, with Basket traps and spearguns having higher performance compared to the other gear types. Number of fishes per sampling unit in each of the sampling methods used post-deployment is shown in Figure 4a. Trophic classification of fishes associated with FADs shown as percentage of fish abundance is presented in Figure 4b.

3.3 Species diversity

The baseline data comprised of 11,697 individuals representing 223 species belonging to 57 families in the two zones before FADs deployment. Mean values of each diversity index (Tab. 3) were computed to provide a baseline state in order to monitor future changes in species diversity at the study zones. After FADs deployment, a total of 21,274 individuals representing 281 species from 68 families were sampled in both zones. The mean number of species found before and after FADs deployment ranged between 65 and 147, with a mean value (SD) of 106.67 (33.7) (Tab. 3). Welch's test carried out separately on each diversity descriptor showed significant effects before and after FADs deployment (Tab. 3, $p < 0.05$) for species richness (D_{mg}), evenness (E_{Heip}, $1/d$, $1–D$) and species taxonomy (Δ, Δ^*) for zone A. For zone B, significant sampling effect was detected for species richness (D_{mg}), evenness (H') and species taxonomy (Δ^*) after FADs deployment (Tab. 3, $p < 0.05$). Differences in species evenness (E_{Heip}, H', $1–D$) and species taxonomic diversities (Δ, Δ^*, Λ^+) were detected between the two FAD zones. A Principal Component Analysis of the diversity indices of the fish assemblages around the FADs (Fig. 5) revealed 2 principal components accounting for 91% of the total inertia (Tab. S6).

Table 4. Spearman's rank correlation matrix between the 10 selected diversity indices. All significant correlations are marked by an asterisk (*$p < 0.05$, **$p < 0.01$). Indices codes as in Table 1.

S	S									
D_{mg}	0.71	D_{mg}								
E_{heip}	–0.71	–0.71	E_{heip}							
$1/d$	0.31	0.31	0.2	$1/d$						
H'	0.83*	0.49	–0.49	0.37	H'					
$1–D$	–0.03	0.14	–0.49	–0.83*	–0.37	$1–D$				
Δ	–0.6	–0.49	0.94**	0.43	–0.31	–0.66	Δ			
Δ^*	–0.71	–0.71	1.0**	0.2	–0.49	–0.49	0.94**	Δ^*		
Δ^+	–0.49	–0.54	0.89*	0.54	–0.14	–0.83*	0.94**	0.89*	Δ^+	
Λ^+	–0.03	0.14	–0.49	–0.83*	–0.37	1.0**	–0.66	0.49	–0.83*	Λ^+

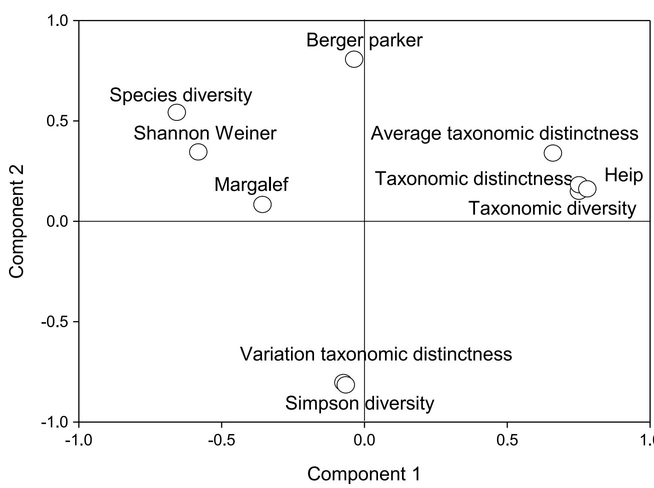

Fig. 5. PCA of the diversity indices of fish assemblages caught around the FADs in coastal Kenya. Indices descriptors as in Table 1.

The first principal component (55.2%) was highly correlated with three of the taxonomic diversity indices (Δ, Δ^*, Δ^+), species richness (S), species evenness (E_{Heip}) and the Shannon-Weiner diversity index (H') (Fig. 5). The second principal component (35.8%) was mainly explained by three indices; D_{mg} focusing on the number of species, species evenness ($1/d$) and taxonomic diversity (Λ^+).

The Spearman's correlations matrix indicated that D_{mg} and H' are not significantly correlated with any of the other diversity indices (Tab. 4). Spearman's correlations showed that E_{Heip} was highly correlated with three of the taxonomy indices (Δ, Δ^*, Δ^+) (Tab. 4). Similarly, the two species diversity indices S and D_{mg} were highly correlated with H'. Though D_{mg} and H' were not significantly correlated with any of the other diversity indices, PCA projections showed that they strongly contributed to component 1 and 2, respectively (Fig. 5). A summary of statistical indices for the fish species sampled before and after deployment of FADs is presented in Table S5. Factor loadings for the 10 diversity indices based on the PCA is presented in Table S6 and PCA results showing the two components and total variance explained are found in Table S7.

4 Discussion

4.1 Temporal changes in aggregations at FADs

Although sequential change in species composition at FADs begun immediately after deployment, our results show a slow recruitment process through time. Fish community exhibited peak abundance and diversity at the end of the sampling period and shoals were present several months after FAD placement. Only a few juveniles of rabbitfishes and parrotfishes appear to be rapidly attracted to the FADs. Previous experiments have also observed rapid recruitment processes for juveniles fishes at DFADs (Wickham and Russell, 1974; Druce and Kingsford, 1995). We observed only 38 species around FADs through UVCs and108 species were caught at the FADs through EFSs. This is in contrast to the 333 species reported around FADs by Castro et al. (2002). A number of factors could contribute to this disparity including limitations of UVC sampling (Bijoux et al., 2013), types of FADs deployed, overfishing of reefs in coastal Kenya (McClanahan et al., 2008; Mbaru, 2012), differences in assemblage structure between regions amongst others.

Similar to previous results by Deudero et al. (1999) and Taquet et al. (2007), the results show a high abundance of pelagic piscivores such as *A. solandri, M. indica, R. kanagurta, S. plurilineatus, S. barracuda, E. affinis* and *T. albacares* associated with relatively deeper FADs (see Tab. S1). These results are similar to distribution of those species reported elsewhere (Deudero et al., 1999; Taquet et al., 2007). However, contrary to other studies, species such as *A. leiogaster, C. caerulaurea, C. armatus, D. macarellus* and other pelagics that are largely observed in open water (Deudero et al., 1999, Taquet et al., 2007, Dagorn et al., 2013), were occasionally seen in association with shallow water FADs. Although we did not find any relationship between number of fish and depth of FADs, probably due to low numbers of fish observed at each FAD, we showed that some species were more or less confined to specific FADs (see Tab. S1) suggesting that associations between fish and FADs could be largely driven by other factors such as for food supply, shelter from predators or schooling companionship (Marsac et al., 2000; Hallier and Gaertner, 2008; Dagorn et al., 2010), rather than the structural component of the FAD itself (Helfman, 1981; Kingsford, 1993).

4.2 Catch, effort and CPUE

Increase in abundance, length, weight, value and CPUE of fish captured after FADs deployment showed that FADs had a positive effect on the local fishery. Abundance and value of pelagic fishes increased just ten months after FADs deployment. This rapid increase in fish abundance and value contrasts with other regions that have reported longer time periods of biomass build-up around FADs and consequent delayed influence on fisheries (Beverly et al., 2012). Additionally, our results showed larger schools at the deeper sites with closely spaced FADs compared to the widely spaced FADs at the shallow sites. Similar findings reported by Deudero et al. (1999) support the notion that FAD numbers per unit area and area of location could affect performance of FADs. Furthermore, closer spacing of FADs may support fish shoals in numbers large enough to attract transient predators such as the common dolphinfish (*C. hippurus*), the mackerel scad (*D. macarellus*) or Kawakawa (*E. affinis*) as observed in this study and others (McGill et al., 2007; Beverly et al., 2012). Taken together, these findings therefore suggest that AFADs can be employed to facilitate management of fisheries by offering alternative fishing option to artisanal fishers that often target the demersal coral reef fishes or by diverting effort from the more sensitive habitats or species (Ruttenberg, 2001; Beverly et al., 2012). Sequential increase of pelagic species after deployment somewhat suggests that FADs are viable mechanisms to increase the availability of pelagics even at a small spatial-scale.

Results showed a gradual increase in CPUE after FADs deployment in both zones. Similar increases in post-deployment CPUE has been reported in Mauritius (Houbert, 2009) and in Niue (Beverly et al., 2012). In our study, we also show higher CPUE values for other gears that are not associated with FADs such as basket traps and spearguns in both sampling zones signifying likely influence of FADs on catches in general.

4.3 Species diversity

The higher number of species ($n=281$) sampled after FADs deployment compared to pre-deployment numbers ($n=223$) suggested that FADs have the potential to affect local assemblage structure of fish populations. The weak correlations observed between the diversity indices as confirmed by the PCA and Spearman's tests suggested that there is less redundancy amongst the metrics and that simultaneous use of several complementary indices may be required in order to accurately describe and monitor fish assemblages around the FADs. However, when a diversity component is described by several indices, selecting the most intuitively simple index that is easy to understand and calculate is desirable (Purvis and Hector, 2000). The structural indices should be used alongside other attributes such as age structure and movement patterns in order to manage fish populations around FADs (Davies et al., 2014). In conclusion, while the study provides pioneering information on the temporal dynamics of fish associating with AFADs from coastal East Africa, the findings are subject to some limitations. For example, the absence of hydrographic maps prevented appropriate site selection for FAD deployment and may have affected FAD performance through influence of oceanographic features and dynamics (Chapman et al., 2005). Nonetheless, results are instructive and showed that fishers operating in AFAD areas had higher chances of catching larger high value fish, and spent less time fishing with attendant reduction in fuel and labour costs. These findings suggest that AFADs are capable of creating both short and long-term impacts on livelihoods, with the potential to deflect pressure on the overfished nearshore fish stocks. In order to maximize on the positive impacts of FADs, more research will be needed on redistribution of fish around FADs, design and placement configuration, and site selection, amongst others.

Supplementary Material

FAD design and deployment and Species taxonomy indices for each site individually are available as Online Resource 1.

The Supplementary Material is available at http://www.alr-journal.org/10.1051/alr/2017045/olm.

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