Doctorate Dissertation

Studies on the evaluation of fish attraction performance around anchored Fish Aggregating Devices (aFADs)

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Chapter 6 provides discussions on the key findings in this study and future technical issues to be considered for implementation of aFADs

Chapter 1

Insights of artisanal fishing condition in Kenya and the potential of aFADs to re-distribute the fishing effort to the offshore

1.1 Fisheries in Kenya

Fisheries in Kenya contribute less than 1% to the country's GDP. However, fisheries are recognised for the strategic values such as important source of livelihood to fishing communities. In addition, it contributes to food security and provide raw materials for production of animal feeds as well as fish oil and bioactive molecules for pharmaceutical industry. Fisheries also support auxiliary industries such as net making, packaging material industries, boat building and repair, transport, sports and recreation. Total fishery and aquaculture production in Kenya amounted to 186,700 tonnes in 2013, with 83% comes from inland capture fisheries (of which Lake Victoria contributed about 90%). The marine sector is outshone by the freshwater sector (Smart Fish 2011; Gomes 2012; FAO 2016). Fish consumption has been declining from a modest 6.0 kg/caput in 2000 to 4.5 kg/caput in 2011. The value of fish exports was about USD 62.9 million in 2012, about 5 times greater than the USD 12.3 million in fish imports. The fisheries sector generates direct and indirect employment for about 2.3 million Kenyans. In 2013, around 129,300 people derived their livelihood directly from fishing and fish farming activities (including 48,300 in inland waters, 13,100 in coastal waters fishing and around 67,900 in fish farming) (FAO 2016). Marine capture fisheries produce less than 9,000 tonnes per year, of which compared to neighbouring countries is low (FAO 2016). In Kenya, fishing in coral reef lagoons is one of the main sources of expendable income and animal protein for coastal people (Fig.1-1) (Glaesel 1997; Melleret-King 2000).

1.2 Status of the marine fishery in Kenya

Kenya has a coastline of about 640 km stretching from 1º 30'S at the Somali border to 5º 25'S at the Tanzanian border (Maina 2012). Although the Kenyan EEZ was extended from 200 to 350 nm in 2009 (Fig.1-2) (FAO 2009), the coastal artisanal fishery largely operates within a narrow continental shelf confined to a small strip of 2.5 to 3.0 nm (McClanahan and Mangi 2004; Samoilys et al. 2011). This region is largely dominated by fringing coral reefs, which occur within 12 nm of the coast (Fondo 2004). Some of the rich inshore grounds within this strip include the Funzi-Shirazi bay, the Diani-Chale area, Malindi-Ungwana Bay, the North Kenya Bank and the Lamu Archipelago (Maina 2012). Most fishing activities take place between September and April (North-east monsoons) when the sea is calm (Mbaru et al. 2010, 2011). However, between May and August (South-east monsoons) the fishing ability is mostly limited due to rough sea (McManus 1996; McCLanahan and Mangi 2004; Morison 2004).

In the marine fisheries, different types of gear and vessels are deployed. The vessels include dugout canoes, motorized boats, sailboats (*dhow*), outrigger canoe (*ngalawa*), and open fishing boat (*mashuwa*) built to withstand rough seas and open fishing voyages. Major gears used by the artisanal fishers include: gillnets, beach seine nets, cast-nets, long-lines, hand-lines, spears, basket traps (*lema*), barricades (*uzio*) and weir traps (*tata*) (FAO 2016).

Fishing effort of artisanal fisheries tends to concentrate within the narrow continental shelf because of limitations in terms of the vessels and equipment used. For example, lobsters, crabs and octopus are increasingly targeted because of their high market prices (FAO 2016). Prawns are harvested by around 900 small-scale fishers along the entire Kenyan coastline in the inshore areas and by semi-industrial (KCDP 2015; KMFRI 2015; FAO 2016). In addition, the small and medium pelagic fishery in Kenya which is multi-species, multi-gear and multi-fleet target mostly the families Scombridae (trevallies), Sphyraenidae (barracudas), Scaridae (parrotfishes), Siganidae (rabbitfishes) and Hemiramphidae (halfbeaks). In addition, tuna fishery is carried out by artisanal fleet of around 800 small-scale vessels, all of which are typically confined to within 3-5 nm of the coast (Poseidon et al. 2014).

According to DoF (2010) the marine sub-sector's annual potential of between 150,000 – 300,000 metric tons and contributes to around 0.5% of the country Gross Domestic Product (GDP) yearly. These apparent low yields have been associated with the use of rudimentary fishing technology within the heavily fished near shore areas (Muthiga and McClanahan 1987). Such as the use of beach seines, spear guns, trawlers and dynamite fishing that are of great concern due to their destructive and unselective nature by the ever increasing population (Shumway 1999; Mueni and Mwangi 2001; Okemwa et al. 2004). In particular, the negative impacts of beach seines on nursery and breeding grounds as well as high capture of juveniles is documented (Rubens 1996; McClanahan et al. 1997). However, illegal fishing using beach seines persists in most areas along the coast, despite being banned in 2001 (McClanahan et al. 2005). The incapacity of the local fishers venturing into the offshore waters has subsequently resulted into under exploitation of deep-sea fishing areas which are believed to be richer in pelagic stocks (FAO 2009).

Consequently, the marine fisheries in Kenya have historically received much less research and management attention (Muthiga and McClanahan 1987; Obura 2001; DoF 2004; Fondo 2004). Nevertheless, the importance of this sub-sector cannot be underestimated as it supports about 80,000 fishers directly (UNEP 2006), and about 800,000 individuals (processors, traders and other service providers) indirectly (DoF 2010).

In this thesis, I first discussed the status of the beach seine fishery in Lamu from the data collected under the Kenya Coastal Project (KCDP) as a case study to have a better understanding of the marine fisheries in Kenya.

1.3 Investigating catch composition of beach seine fishery in Lamu, Kenya

Fishing with beach seine nets in reef lagoons contributes substantially to food security and economic activity in coastal villages in Kenya (FAO 2011). Beach seining is particularly common in Lamu area in the north coast, where it has been assimilated into the fishing culture after being introduced by migrant fishers over 30 years ago (FiD 2015). However, beach seining is considered to be a destructive fishing activity, and its use has been banned in Kenya since 2001 (Kenya Gazette Notice No. 7565 Vol. CIII. No. 69, 2001). Nevertheless, many artisanal fishers do not comply with the ban (McClanahan et al. 2005), and the number of beach seine nets in the marine artisanal fishery has remained relatively constant, with frame surveys reporting 139 nets (2008), 211 nets (2012) and 193 nets (2014) over the past decade (FiD 2015). Cinner et al. (2009) suggested that fishers do not comply with the ban because of lack of alternative employment opportunities. Noncompliance with regulations undermines the effectiveness of fisheries management (Madrigal-Ballestero et al. 2013; Turner et al. 2014; Pomeroy et al. 2015).

The physical effects of beach seining on reefs and associated habitats have been well documented (McClanahan and Mangi 2001). Areas affected by beach seining often have significantly smaller corals and a lower density of coral colonies (Mangi and Roberts 2006). Dragging a net across the seafloor leads to resuspension of bottom sediment, increasing turbidity and smothering benthic organisms (Jones 1992). It also removes or crushes epibenthic organisms such as corals, seagrasses and sponges (Sainsbury et al. 1997). Beach seine nets are long and mobile, and can therefore affect large areas of seafloor habitats where they are frequently used (McManus 1997; Auster 1998; Watling and Norse 1998). Beach seining captures a range of fish species and sizes that occur in the intertidal and shallow subtidal zones (Gough et al. 2009), and the codend mesh size used will determine the selectivity of the gear (FAO 2011). Using a small mesh size is likely to capture a larger proportion of juvenile fishes (Nunoo and Azuma 2015), and the lead line of the net may also destroy fish spawning grounds while being dragged over the seafloor. Fisheries regulations that specify a minimum mesh size can be used to manipulate the selectivity properties of gear, to reduce the proportion of juvenile fishes smaller than a given size in catches. Mesh size can also be adjusted to reduce catches of non-target species, through size selectivity (MacLennan 1992; 1995). Knowledge of fishing gear selectivity is therefore important within the context of fisheries management. Therefore, the effects of codend mesh sizes on the species composition and size of fish caught by beach seine nets in Lamu was assessed in this chapter.

1.4 Materials and methods

1.4.1 Study sites

Catch assessment surveys were carried out on 1st–7th May 2014, 6th–12th March 2015, and 9th–14th May 2016 at the main beach seine fishing grounds in Lamu (Kiunga, Faza, Kizingitini) (Fig. 1-3). The area is highly productive with rich fishing grounds influenced by northeast and southeast monsoon winds. The sampled beach seines comprised of a seine body with different nominal codend mesh sizes of 25 mm, 38 mm and 44 mm, with anterior and posterior wings attached, which is hauled by up to 30 fishers at a time. The upper part of the net is maintained on the surface by a float line (150 – 400 m long) and the footrope on the seafloor comprises a lead line with sinkers to prevent fish from escaping the enclosure. The wings are attached to hauling ropes (FAO 2011).

1.4.2 Data collection

A representative catch sample was collected with a bucket from 33 hauls (Table 1-1), after removing marine litter. The sub-sample of the catch was identified to species level using field guides (Smith and Heemstra 1986; Lieske and Myers 1994). Fish total length (TL) was measured to the nearest 1 mm using a fixed ruler on a fish measuring board, and individual weights were recorded to the nearest 0.01 g using a weighing balance. Fish were grouped into length class categories to enable a comparative analysis between codend mesh sizes.

1.4.3 Data analysis

Simpson's Diversity Index was used as a measure of diversity for individual mesh sizes, because it takes into account the number of species present, as well as the relative abundance of each species. The index was calculated using the equation,

$$D = \sum (n\,(n-1)) / ((N\,(N-1)),$$

Where *n* is the number of individuals of each species, and *N* is the total number of individuals of all species. A non-parametric Kruskal–Wallis test was used to compare the fish that was retained by the three mesh sizes, based on the mean ranks of groups. Mesh selectivity was also determined from size frequencies of the dominant species caught by the different codend mesh sizes, based on the assumption that the community is the same. The length at maturity (L_{mat}) of dominant species was obtained from Hicks and McClanahan (2012) and the proportion of fish smaller than L_{mat} retained by the different mesh sizes was calculated.

1.5 Results

Species composition included bony fishes, crustaceans, molluscs, cephalopods and echinoderms. About 98 species belonging to 41 families were collected and the catch was dominated by three major families; namely Scaridae, Siganidae, and Lethrinidae. The main families that were caught and retained by the 25 mm mesh, but escaped from 38 mm and 44 mm mesh, were small-bodied fish species including Apogonidae (fragile cardinal fish *Apogon fragilis*, reef-flat cardinalfish *Ostorhinchus taeniophorus*, orangelined cardinalfish *Taeniamia fucata*), Monocanthidae (spectacled filefish *Cantherhines fronticinctus*), Clupeidae (spotted sardinella *Amblygaster sirm*) and Labridae (three-ribbon wrasse *Stethojulis strigiventer*).

In terms of numbers of fish, 25 mm and 38 mm meshes caught mostly marbled parrotfish *Leptoscarus vaigiensis*, followed by whitespotted rabbitfish *Siganus sutor* and pink ear emperor *Lethrinus lentjan*, whereas similar numbers of *L. vaigiensis* and *S. sutor* were caught by the 44 mm mesh (Table 1-2). In terms of weight, *S. sutor* dominated the catch made with the 44 mm mesh, followed by *L. vaigiensis* and *L. lentjan*. Catches made by the 38 mm mesh were dominated by *L. vaigiensis*, followed by *S. sutor* and *L. lentjan* (Table 1-3). The Simpson index indicated that the samples caught with the 25 mm mesh had the highest diversity (D = 10.67), followed by the 38 mm mesh (D = 6.69) and the 44 mm mesh (D = 3.04).

Mesh selectivity for the three dominant species differed significantly (Kruskal-Wallis test, $p<0.05$; *L. vaigiensis* H = 87.09, *S. sutor* H = 34.61, and *L. lenjan* H = 179.82). Some 48.0% of *L. vaigiensis* retained by the 25 mm mesh were smaller than the 15.1 cm L_{mat}. Similarly, 90.2% of *S. sutor* caught with the 25 mm mesh were smaller than the L_{mat} of 20.2 cm, and 88.7% of *L. lentjan* were also smaller than the L_{mat} of 20.3 cm (Fig.1- 4). Some 53.1% of *L. vaigiensis* landed by the 38 mm mesh, 50% of *S. sutor*, and 60% of *L. lentjan* were smaller than the respective L_{mat} estimates (Fig.1-5). Only 14.1% of *L. vaigiensis* retained with the 44 mm mesh were smaller than L_{mat}. However, the 44 mm mesh also retained substantial proportions of immature (< L_{mat}) *S. sutor* (76.9%) and *L. lentjan* (60%) (Fig.1-6). The sample size of *L. lentjan* was small, and may have affected the results. Overall, the results confirmed that the 25 mm mesh size retained proportionally more individuals smaller than the L_{mat} than the 38 mm and 44 mm meshes (Fig.1-7).

1.6 Discussion

Comprehensive studies on the species composition and size structure of beach seine catches and the effects of gear selectivity on target species are limited in Kenya, where the use of beach seines are prohibited, although not strictly enforced. Attempts to replace beach seine nets with other gear types have been ineffective, and the use of beach seines persists. As an alternative to prohibiting beach seines, implementing a larger mesh size might reduce the impacts on exploited fish populations. Therefore, we analyzed fish caught with different codend mesh sizes, to assess species and size selectivity.

Beach seines with fine mesh codends are active fishing gears known for efficiently capturing a wide range of fish sizes including small, immature individuals (Mangi and Roberts 2006). Beach seines are also known to catch a high diversity of fish species, but with only a few species dominating by weight or numbers (Gell and Whittington 2002). The results from the present study support the findings by Cinner et al. (2009) and Unworth and Cullen (2010) that beach seine catches are dominated by seagrass fish assemblages and coral reef affiliated species that utilize sea grass meadows for feeding.

Catches made with 25 mm mesh were most diverse, because the finer mesh retained small-bodied species, such as *A. fragilis*, *O. taeniophorus*, and *T. fucata* which may escape through the 38 mm and 44 mm meshes. Similar results were observed in various studies in South Africa (Lasiak 1984), Ghana (Nunoo et al. 2007) and the western Aegean Sea (Stergiou et al. 1997). Lasiak (1984) confirmed that the species diversity reflects differences in sampling techniques, length and mesh size of gears used, and the differences in the shore-zone fish assemblage. The 25 mm mesh caught both mature and immature *L. vaigiensis*, *S. sutor* and *L. lentjan*. These are the most abundant and commercially important species for the Kenyan artisanal fisheries (Hicks and McClanahan 2012). Using the 38 mm and 44 mm meshes generally increased the size at first capture of these species, but also reduced the quantity of fish caught by the gear. This poses a conundrum, because the Lamu fishing communities depend on fish for food security and economic activity, and reducing catch rates by increasing mesh size may affect their income. At the same time, the natural resource-base may be under stress from over-harvesting of juvenile fish by small mesh sizes. The concerns surrounding the capture of juvenile fish are that potential yields may be reduced by growth overfishing, or that too few individuals survive to maturity, resulting in recruitment overfishing (Hutchings and Lamberth 2002).

It is suggested that an appropriate mesh size is introduced (not a biological optimum, but larger than 25 mm mesh) through stakeholder agreements or voluntary action by fishers. This is already practiced by some fishers in Lamu, who use nets with 38 mm and 44 mm codend mesh sizes. An experimental procedure to collect sufficient data to support robust selectivity analysis is suggested. Reliable measurements of mesh size should be considered during stock assessments, when estimating fishing mortality rates. Moreover, enforcement officers and net makers should ensure fishers use recommended codend mesh sizes. By regulating mesh sizes, and without outright banning of beach seine nets, fisheries managers should be able to control fishing mortality of smaller species and immature individuals of dominant larger species. As a mitigation measure, this study recommends deployment of anchored Fish Aggregating Devices (hereafter referred as aFADs) offshore which will reduce fishing pressure along the coastline and this will have a positive impact on the ecosystem. In addition, it will also improve on the catch composition of the small scale fishers and improve on their living standards.

1.7 Purpose/rationale of the present study

From the case study of beach seine fishery in Lamu, I described the present status of artisanal fisheries in general that mainly consisted of small catch amount and catch of immature fish species. While artisanal fisheries are often considered to be 'eco-friendly' by their nature, it is well-documented that intensive artisanal fishing can contribute to the degradation of marine resources by affecting the ecological balance and losses of local biodiversity (McClanahan et al. 1990, 2001). This seems also to be the case in Kenya. One of the major changes in the state of the coral reefs in Kenya is the dramatic decline in the number and individual size of finfish. Fishing activities have reduced fish populations in studied reefs causing a severe decline in the species richness of the fished areas (Mangi et al. 2007).

Unrestricted access into the marine fishery in the Kenya's coastline and the increased use of improper fishing technology (such as beach seine fishing net) are considered to be the major cause of this decline (Ochiewo 2004; Oluoch et al. 2009). Increased poverty is driving people into fisheries, thereby increasing fishing pressure. Compliance levels to most of the fisheries regulations have been low, which has been linked to poor enforcement. In some cases, the rules are unknown and unclear to fishers (Mangi et al. 2007). In a different study on Kenyan coastal fisheries carried out by Hoorweg et al. (2009), nearly all fishers interviewed were concerned with the degradation of marine resources and mentioned declining catches. Reasons for reduction in marine resources given included the growing number of fishers, official establishment of no-take areas, rough weather (notably the heavy El-Niño rains of 1997/98) and competing fisheries such as commercial trawling (Hoorweg et al. 2006). A report by Poseidon et al. (2014) also concluded that while the domestic prawn/shrimp and demersal fisheries are exploited by small-scale vessels and industrial activity is lacking, stocks are probably overfished and subject to overfishing due to poor fisheries management.

In order to arrive at a more sustainable fisheries and increase food security despite the challenges facing the marine fishery in Kenya. It is prerogative that the number of fishers, and hence the fishing effort exerted in the coastal zone, is strictly managed. The reduction of fishing effort in the inshore fisheries is the most promising option. This is achievable through the displacement of effort to the near offshore area. Since full potential of small and medium pelagic fisheries along the Kenyan coast is not yet known (KCDP 2015) and the potential maximum sustainable yield biomass is estimated to be at least 15 times higher than current documented marine catches (FAO 2016). With this regard, introduction of aFADs has a potential to achieve sustainability of marine fisheries as well as to ensure healthy and productive fisheries by enhancing nearshore small-scale fisheries where stocks are often overfished. The aFADs are meant to relocate fishers from the heavily exploited lagoon areas to the open sea, with a view to increasing their catch rate and concurrently reducing fishing pressure in the lagoon and to increase the supply of fish on the local market. The aFADs also represent a win-win opportunity for fishers and coral reef conservation. In addition, the aFADs have the potential to improve fishers' incomes both in the short and long term, through increased catch prices of valuable fish species associated with aFADs. From the above objectives, my thesis presents a review of aFADs in chapter 2 to present the current status and issues in countries where aFADs are commonly used. I focussed on the key information of the aFADs in the region.

Figures and Tables (Chapter 1)

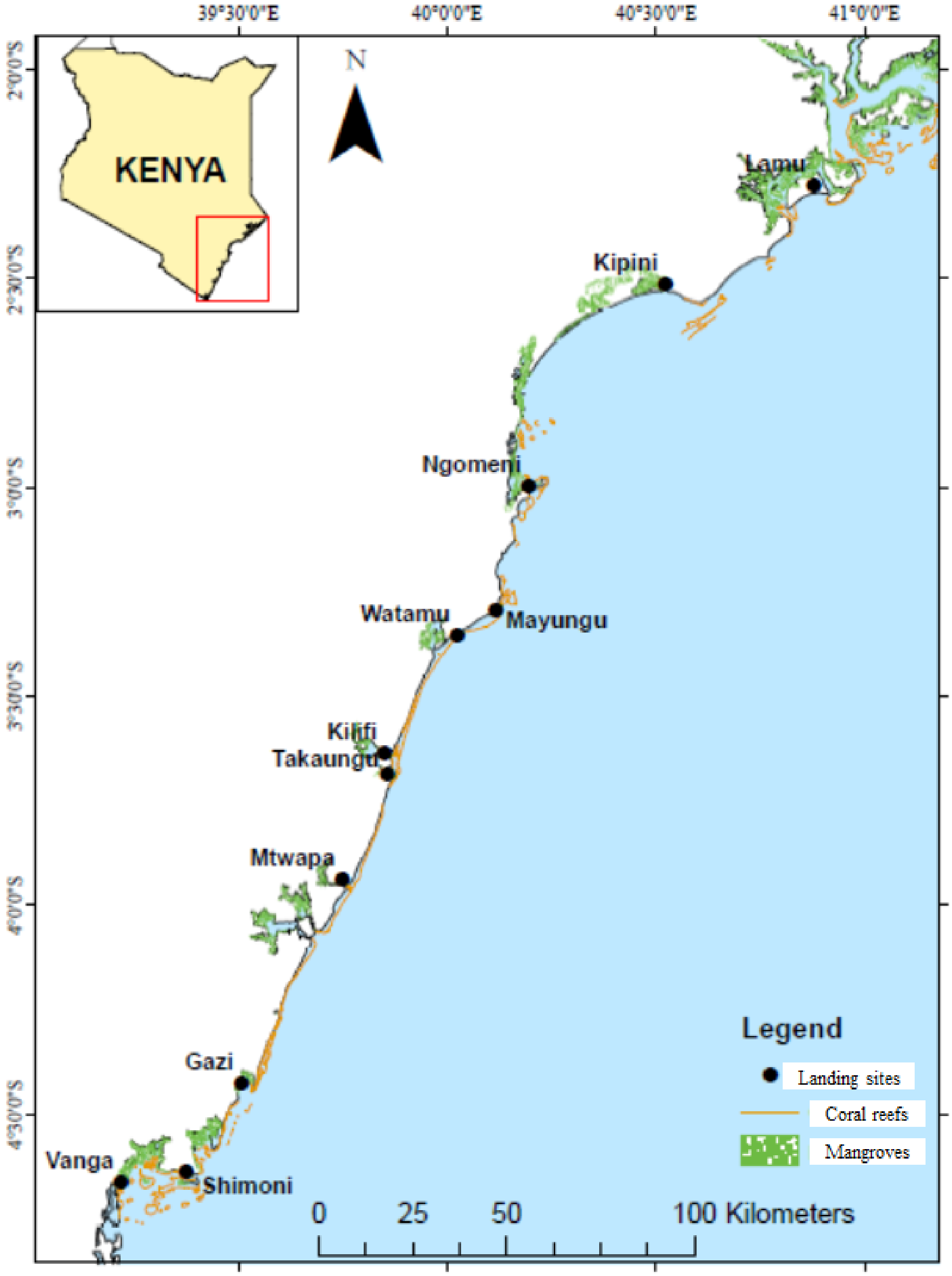


Figure 1-1. A map showing marine waters of Kenya and the main fish landing sites (Source: small and medium pelagic management plan 2013)

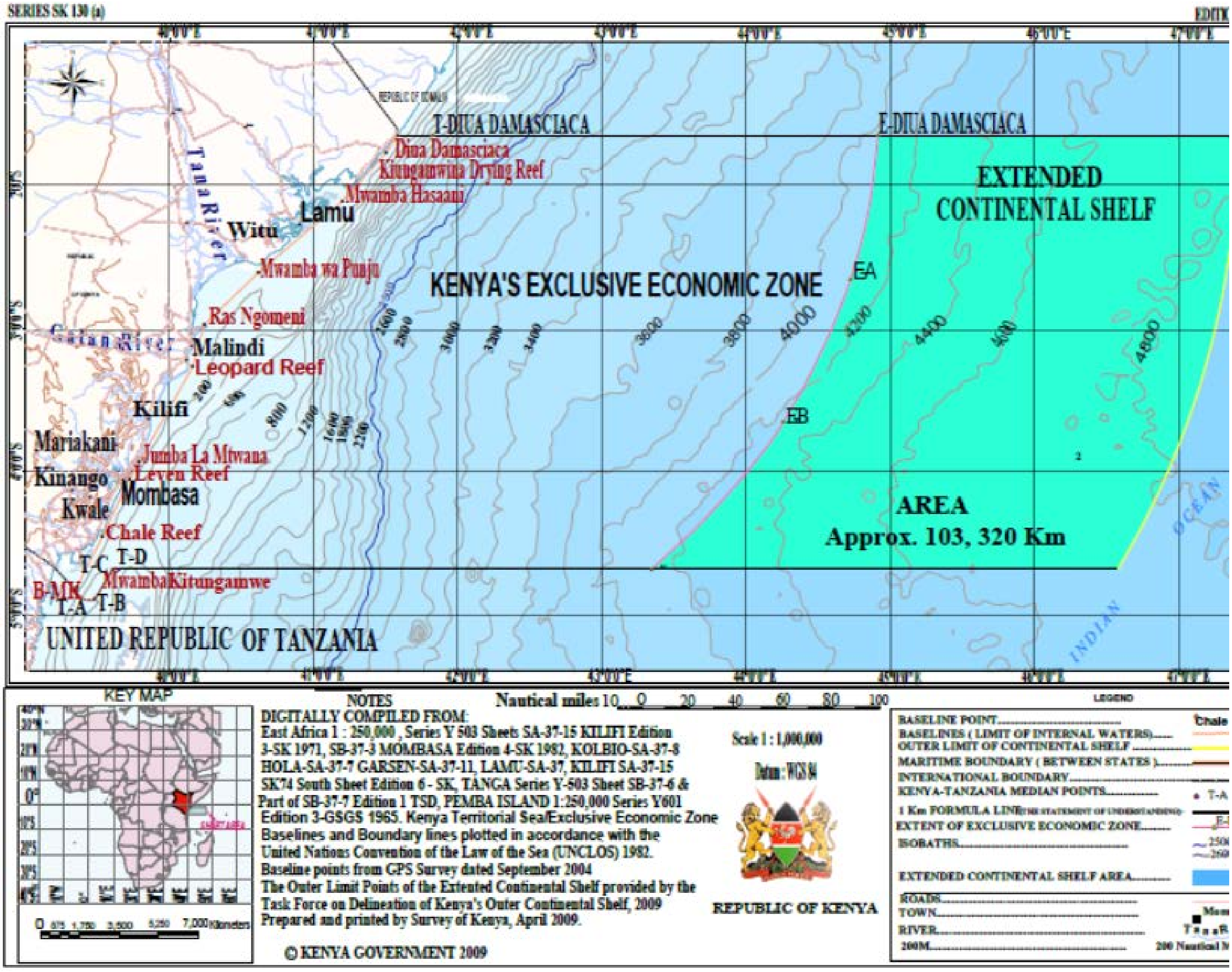


Figure 1-2. Kenyan Territorial Sea and Exclusive Economic Zone (EEZ) (Source: FAO 2009)

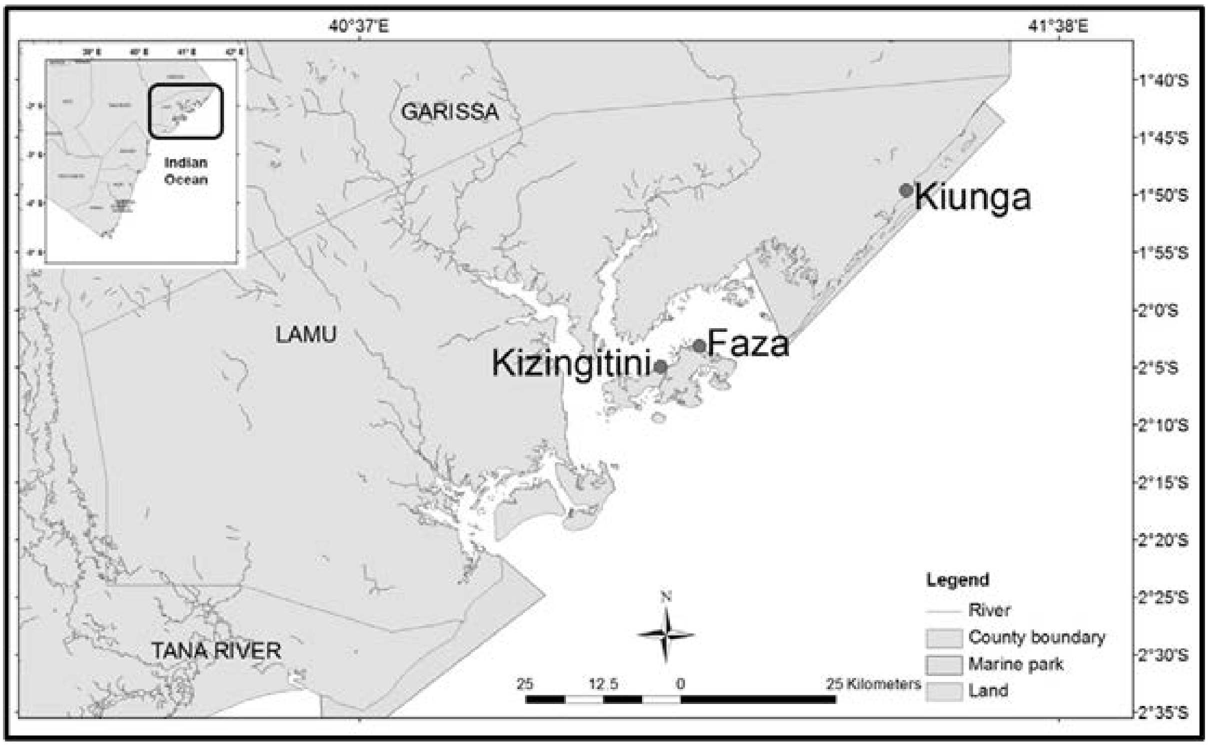


Figure 1-3. A map of the north coast Kenya, with dark filled circles showing the sampling sites in Lamu

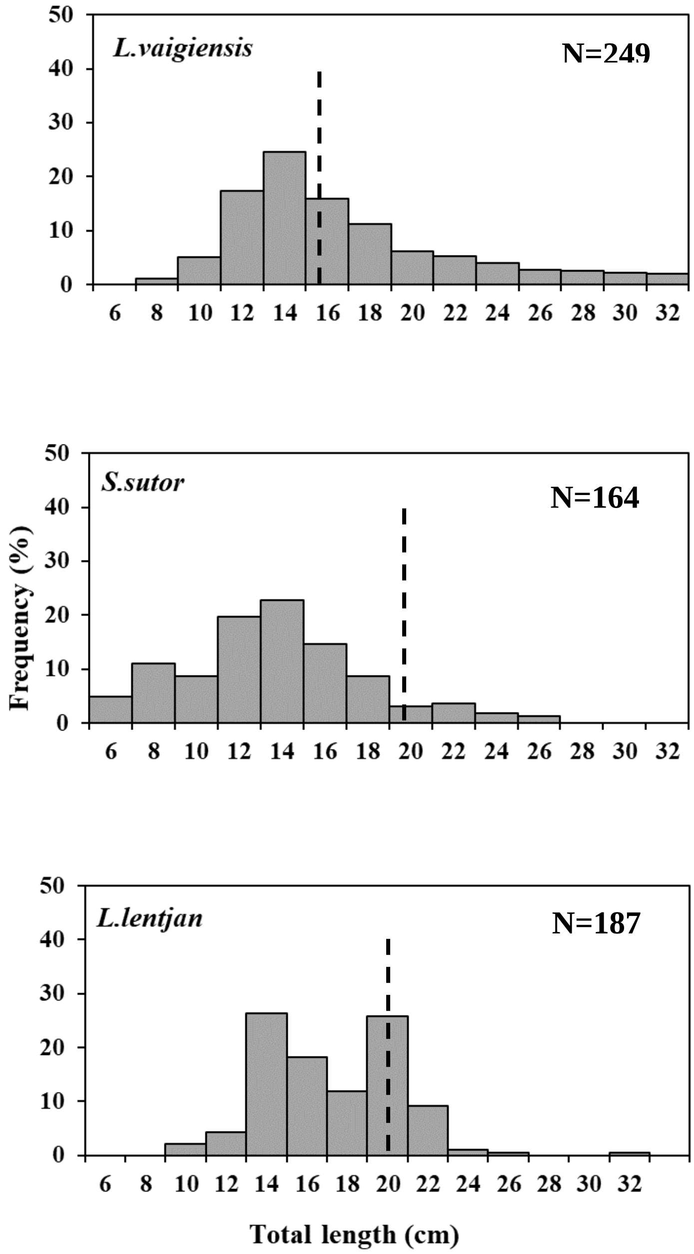


Figure 1-4. Comparative size frequency graphs for 25 mm codend mesh size of the three dominant species. Dotted lines designated the size of L_{mat}.

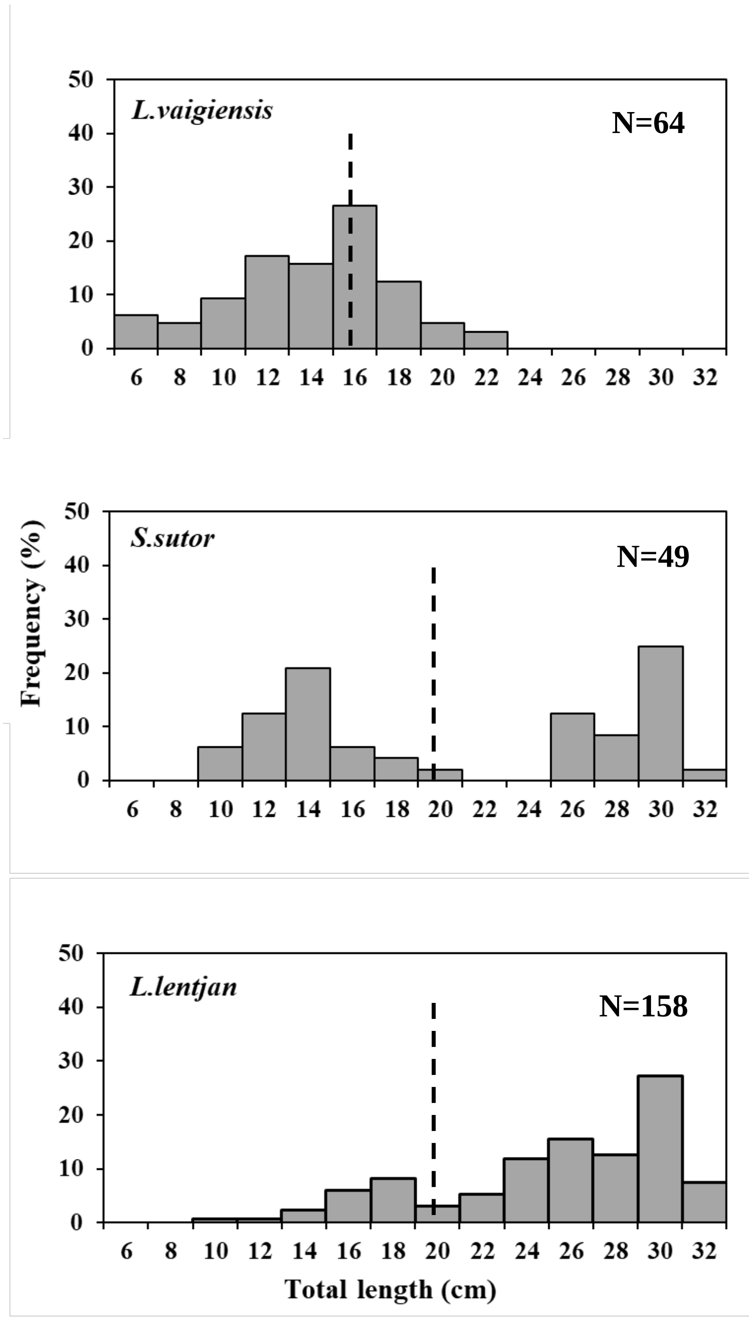


Figure 1-5. Comparative size frequency graphs for 38 mm codend mesh size of the three dominant species. Dotted lines designated the size of L_{mat}.

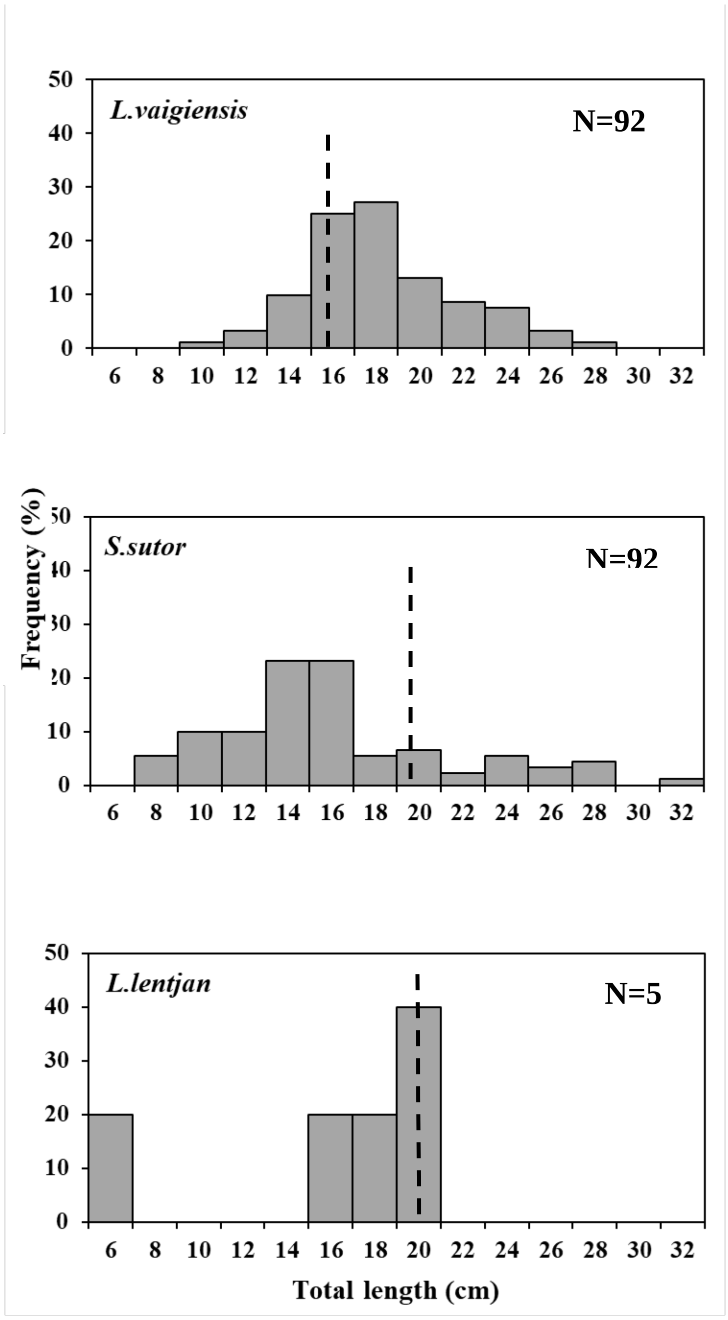


Figure 1-6. Comparative size frequency graphs for 44 mm codend mesh size of the three dominant species. Dotted lines designated the size of L_{mat}.

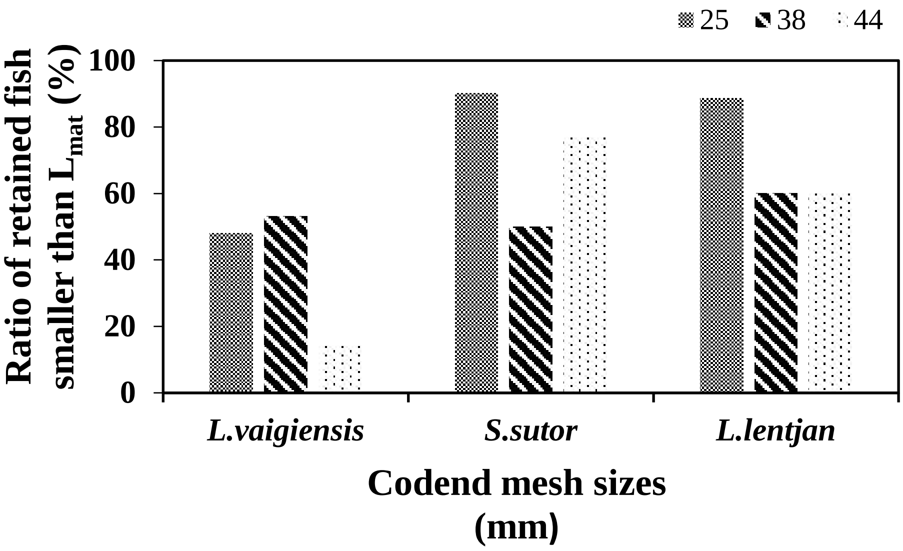


Figure 1-7. Ratios (%) of the three dominant species <L_{mat} retained by different codend mesh sizes.

Table 1-1. Summary of the field surveys

Year	Season	Haul No.	Sampled amount (A, kgs)	Catch amount (B, kgs)	Sampling ratio (A/B)	Nominal codend mesh sizes (mm)
2014	SEM	1	9,0	20,0	0,45	25
2014	SEM	2	20,74	250,0	0,08	38
2014	SEM	2	19,26	150,0	0,13	44
2015	NEM	1	6,2	100,0	0,06	25
2015	NEM	4	17,42	93,0	0,19	25
2015	NEM	2	4,94	120,0	0,04	38
2015	NEM	3	27,76	65,0	0,43	38
2015	NEM	2	10,7	50,0	0,21	38
2015	NEM	1	4,2	15,0	0,28	44
2016	SEM	9	25,5	250,0	0,10	25
2016	SEM	3	13,3	227,0	0,06	38
2016	SEM	3	21,0	1530,0	0,01	38

Table 1-2. Species composition by count (%) by codend mesh sizes.

Family	Species	25 mm	38 mm	44 mm
	Numbers	**1367**	**789**	**229**
	D	**10.67**	**6.69**	**3.04**
Scaridae	*Leptoscarus vaigiensis*	18.6	26.1	40.2
Lethrinidae	*Lethrinus lentjan*	13.8	6.3	1.7
Siganidae	*Siganus sutor*	13.2	25.9	40.2
Lethrinidae	*Lethrinus mahsena*	10.8	5.1	7.9
Terapontidae	*Pelates quadrilineatus*	5.2	0.8	0.0
Gerreidae	*Gerres oyena*	4.9	1.3	0.0
Scaridae	*Scarus psittacus*	3.8	1.0	0.0
Siganidae	*Siganus canaliculatus*	3.7	5.3	0.0
Scaridae	*Scarus ghobban*	3.2	1.3	0.4
Lethrinidae	*Lethrinus nebulosus*	2.6	1.6	2.6
Sphyraenidae	*Sphyraena flavicauda*	2.3	5.4	1.7
Mullidae	*Parupeneus rubescens*	2.1	0.3	0.0
Lutjanidae	*Lutjanus fulviflamma*	1.7	0.6	0.4
Scombridae	*Sarda sarda*	1.7	0.1	0.0
Labridae	*Stethojulis strigiventer*	1.4	0.0	0.0
Haemulidae	*Plectorhinchus gaterinus*	1.0	0.9	0.0
Hemiramphidae	*Hemiramphus far*	0.7	1.9	0.0
Labridae	*Cheilio inermis*	0.4	1.6	2.6
Plotosidae	*Plotosus lineatus*	0.4	0.1	0.0
Gobiidae	*Priolepis cincta*	0.4	0.0	0.0
Scaridae	*Scarus sordidus*	0.4	0.0	0.0
Sphyraenidae	*Sphyraena jello*	0.4	0.0	0.0
Haemulidae	*Plectorhinchus flavomaculatı*	0.4	1.9	2.2
Clupeidae	*Amblygaster sirm*	0.3	0.0	0.0
Leiognathidae	*Karalla daura*	0.3	0.1	0.0
Siganidae	*Siganus stellatus*	0.3	0.1	0.0
Sepiidae	*Squid*	0.3	0.0	0.0
Scaridae	*Calotomus spinidens*	0.3	3.2	0.0
Apogonidae	*Apogon fragilis*	0.2	0.0	0.0
Lethrinidae	*Lethrinus microdon*	0.2	0.0	0.0
Apogonidae	*Ostorhinchus taeniophorus*	0.2	0.0	0.0
Haemulidae	*Scolopsis ghanam*	0.2	0.1	0.0
Apogonidae	*Taeniamia fucata*	0.2	0.0	0.0
Monacanthidae	*Cantherhines fronticinctus*	0.2	0.0	0.0
Carangidae	*Caranx ignobilis*	0.2	0.1	0.0
Apogonidae	*Cheilodipterus quinquelineat*	0.2	0.3	0.0
Carangidae	*Gnathodan speciousus*	0.1	0.3	0.0
Tetraodontidae	*Arothron hispidus*	0.1	0.3	0.0
Chanidae	*Chanos chanos*	0.1	0.3	0.0
Fistulariidae	*Fistularia petimba*	0.1	0.3	0.0
Lutjanidae	*Lutjanus gibbus*	0.1	0.4	0.0
Monacanthidae	*Paramonocanthus frenatus*	0.1	0.3	0.0
Clupeidae	*Sardinella gibbosa*	0.1	0.3	0.0
Scombridae	*Rastrelliger kanagurta*	0.0	0.3	0.0
Ephippidae	*Platax teira*	0.0	0.5	0.0
Labridae	*Halichoeres scapularis*	0.0	0.3	0.0
Lethrinidae	*Lethrinus harak*	0.0	0.4	0.0
Serranidae	*Dermatolepsis striolata*	0.0	0.5	0.0
Serranidae	*Epinephelus coioides*	0.0	0.5	0.0
Serranidae	*Epinephelus malabaricus*	0.0	0.3	0.0
Pomacentridae	*Abudefduf sexfasciatus*	0.0	0.5	0.0

Table 1-3. Species composition by weight (%) by codend mesh sizes.

Family	Species	25 mm	38 mm	44 mm
Carangidae	*Caranx ignobilis*	24.5	0.0	0.0
Siganidae	*Siganus sutor*	15.3	18.9	38.0
Scaridae	*Leptoscarus vaigiensis*	15.1	26.2	33.3
Lethrinidae	*Lethrinus lentjan*	11.9	5.9	1.2
Lethrinidae	*Lethrinus mahsena*	4.1	1.6	2.8
Siganidae	*Siganus canaliculatus*	3.2	5.6	0.0
Gerreidae	*Gerres oyena*	2.6	0.6	0.0
Sphyraenidae	*Sphyraena jello*	1.9	0.0	0.0
Hemiramphidae	*Hemiramphus far*	1.8	3.0	0.0
Terapontidae	*Pelates quadrilineatus*	1.8	0.3	0.0
Scombridae	*Sarda sarda*	1.7	0.1	0.0
Sphyraenidae	*Sphyraena flavicauda*	1.5	9.5	4.8
Scaridae	*Scarus psittacus*	1.3	0.2	0.0
Scaridae	*Scarus ghobban*	1.3	1.1	0.1
Lutjanidae	*Lutjanus fulviflamma*	1.3	0.7	0.1
Sphyraenidae	*Sphyraena putnamae*	1.0	0.0	0.0
Mullidae	*Parupeneus rubescens*	1.0	0.1	0.0
Chanidae	*Chanos chanos*	1.0	0.5	0.0
Haemulidae	*Plectorhinchus flavomaculatus*	0.8	6.7	6.3
Lethrinidae	*Lethrinus nebulosus*	0.6	2.2	7.0
Tetraodontidae	*Arothron hispidus*	0.4	0.5	0.0
Carangidae	*Gnathodan speciousus*	0.4	0.0	0.0
Labridae	*Cheilio inermis*	0.3	1.8	4.8
Siganidae	*Siganus stellatus*	0.3	0.0	0.0
Scombridae	*Scomberoides tol*	0.3	0.0	0.0
Sepiidae	*Squid*	0.3	0.0	0.0
Scaridae	*Calotomus spinidens*	0.1	0.9	0.0
Haemulidae	*Plectorhinchus schotaf*	0.1	0.8	0.0
Chirocentridae	*Chirocentus dorab*	0.1	0.2	0.0
Gobiidae	*Amblygobius albimaculatus*	0.1	0.1	0.0
Monacanthidae	*Cantherhines fronticinctus*	0.1	0.0	0.0
Scaridae	*Scarus sordidus*	0.1	0.0	0.0
Lethrinidae	*Lethrinus elongatus*	0.1	0.0	0.0
Plotosidae	*Plotosus lineatus*	0.1	0.7	0.0
Fistulariidae	*Fistularia petimba*	0.0	0.2	0.0
Lutjanidae	*Lutjanus gibbus*	0.0	0.3	0.0
Albulidae	*Albula glossodonta*	0.0	2.8	0.0
Serranidae	*Epinephelus coioides*	0.0	2.1	0.0
Ephippidae	*Platax teira*	0.0	1.0	0.0
Scaridae	*Calotomus carolinus*	0.0	0.8	0.0
Lethrinidae	*Lethrinus borbonicus*	0.0	0.8	0.0
Lethrinidae	*Lethrinus harak*	0.0	0.7	0.0
Haemulidae	*Diagramma pictum*	0.0	0.6	0.0
Acanthuridae	*Acanthurus dussumieri*	0.0	0.6	0.0
Toxopneustidae	*Tripneustes gratila*	0.0	0.0	1.6

Chapter 2

A review on aFADs as a tool to promote and manage artisanal fisheries

In this chapter, I discussed about countries in the Eastern Asia and Indian Ocean regions where aFADs were traditionary used or successfully implemented. The main focus was on the implementation of aFADs, their designs, fisheries, target species and others in the above mentioned regions. The aim was to give information since aFADs are an important tool for promoting and managing artisanal and small-scale commercial fisheries all over the world including Kenya. The aFADs are known to increase localized catches at reduced costs and thereby improving food security and livelihoods for coastal communities.

2.1 Outline of Fish Aggregating Devices (FADs)

Fish Aggregating Devices, or FADs are simply man-made, floating devices, which make use of the natural habit by aggregating pelagic fishes for subsistence, recreational and commercial fishing. The use of FADs has increased, this has reduced the uncertainty of finding fish and has generated new opportunities with greater reliability in all oceanic areas. The success of FADs in aggregating fish has made these devices important to the commercial, local and sports fisheries of many tropical, sub-tropical seas and oceans in the world (Buckley and Miller 1994; Higashi 1994; Kitamado and Kataoka 1996; Dagorn et al. 2010). However, there have been several concerns that FADs may modify both fish movement and the condition for pelagic fish such as tuna species, which has been hypothesized as a significant ecosystem impact (Marsac et al. 2000; Dempster and Taquet 2004; Hallier and Gaertner 2008).

There are two main types of FADs. The first type used is drifting FADs (dFADs) that drift freely with the currents and are deployed for exclusive use of the boat or fleet that set them afloat (Beverly et al.2012). They are deployed in both EEZ and high seas areas with the aim of increasing the efficiency of the high volume purse seine fishing. This phenomenon has been exploited by fishers to augment their catch, and over the past few decades, dFADs have grown to be the key component of tropical pelagic fisheries including tuna industrial fishing fleets (Bromhead et al. 2003; Dagorn et al. 2013; Davies et al. 2014). The dFAD related purse seining is nowadays a technologically advanced fishery that yields over half of the worldwide recorded tuna landings (Fonteneau et al. 2000a, 2000b; Moreno et al. 2007). However, dFADs has raised concerns regarding adverse effects on migratory patterns (Hallier and Gaertner 2008; Menard et al. 2000), school composition status (Fonteneau et al. 2000b), growth (Jaquemet 2011), predation rates (Essington et al. 2002) and juvenile catches (Fonteneau et al. 2013). Because of these concerns and economic importance, dFADs are frequently studied and reviewed lately (Dagorn et al. 2013; Fonteneau et al. 2013; Davies et al.2014).

The second type of FADs is known as anchored FADs (aFADs, also referred to as moored FADs). The role of aFADs in fisheries and in the regions is different from dFADs. Unlike dFADs for commercial purse seine fisheries, the introduction of aFADs has mainly been promoted throughout the world to assist small-scale fisheries (Itano et al. 2004). The aFADs were first used in the Philippines before World War II to support small-scale fisheries (de Jesus 1982). Its use was documented in the Mediterranean and was first introduced into the Pacific from the Philippines, via Hawaii, in the late 1970s with a high rate of success: in 1984 more than 600 aFADs were deployed in the western and central Pacific Ocean region (Desurmont and Chapman 2000). The aFADs are used extensively by many countries (Fréon and Dagorn 2000), in the Pacific (Holland et al.2000; Kakuma 2000; Dagorn et al.2013), Indian (Tessier et al. 2000) and Atlantic oceans (Morales-nin 2000; Reynal et al. 2000).

In general, aFADs are mainly placed in coastal and offshore zones, at depths from less than 100 m (Yusfiandayani 2013) up to 5000 m (Aprieto 1991) in order to attract pelagic species including tunas. Construction and sizes vary from small scale traditional types made from natural materials to large scale modern types made from steels and/or plastics. They are frequently used to provide enhanced opportunity for artisanal and semi-industrial fishers and are usually fished using several techniques, such as trolling, pole and line, traps, vertical long-line, handline, ringnet and sometimes purse-seine.

In the industrial sector, private investors fund the deployment and monitoring of their own aFADs. These industrial aFADs are used extensively in countries like Indonesia, Papua New Guinea, the Philippines, Thailand, Federated States of Micronesia and the Solomon Islands (Desurmont and Chapman 2000). In small-scale fisheries, aFADs are almost exclusively maintained and deployed by the public sector and overseas funding agencies (de San and Pages 1998). Many aFAD settlement programs are designed as a small-scale fishery management approach to relieve the frequently heavy fishing pressure being experienced by coastal species by transferring effort toward pelagic species, including tunas. These programs are thought to provide many positive benefits for local fisheries (Beverly et al. 2012). Since aFADs are gaining popularity and are important for small scale fisheries, I investigated beach seine being one of the most important fishery that contributes substantially to food security and economic activity in coastal villages in Kenya part of the Western Indian Ocean and how viable aFADs can be adopted in the country.

2.2 Examples of major countries implementing aFADs

Use of FADs is confirmed in 37 countries and regions in Atlantic Ocean, 33 in Pacific Ocean, 18 in Indian Ocean and 8 in the Mediterranean Sea according to (Taquet 2013). These numbers are many and probably cover most countries that deploy aFADs, but geographical coverage would be inevitably biased depending on author's base. In case of the review by Taquet (2013), aFADs in Atlantic Ocean was reported in detail, but in Pacific, eastern Asian countries such as South Korea or Taiwan, which are strong users of both aFADs and dFADs were not covered. Accordingly, we present aFADs information for the following 5 countries based on the available information.

2.2.1 The Philippines

There is a wide variety of types and designs of aFADs used in the Philippines made of natural and modern materials including brush pile, twigs, bamboo, scrap tires, concrete and steel. The most popular type that emerged as the most economical and effective in terms of resource management and income enhancement for fishers i.e. the bamboo raft aFADs called "*payao*". The use of *payaos* is widespread where thousands are anchored throughout to support subsistence, artisanal and commercial fisheries (Barut 1999). There is no statistics on the total number of *payaos* all over Philippines, but it was estimated that there were about 3000 *payaos* in Moro Gulf in the southern Philippines. Some *payao* fishing grounds are also found in the other parts of the archipelagic waters whereby established viable tuna and small pelagic fisheries exist (Barut 1999). Generally, *payaos* are crowded in the nearshore fishing grounds about 30 *payaos* anchored for each boat. They used simple bundles of bamboo provided on the underside with a hanging line of coconut leaves, later evolved into well-constructed double layer bamboo rafts with empty oil drums filled with concrete used to anchor the payao. This type of *payaos* are still commonly used in the coastal Philippine waters, but steel longer lasting raft type *payaos* are favored for use in exposed, offshore areas subject to rough sea conditions (Fig. 2-1).

Payaos support several small-scale fisheries such as handline fishery for tunas, purse seine and ringnet in the Philippines. *Payaos* are either owned by fishing companies or leased by concessionaires to the fishing companies for 20% of the price of the haul (Aprieto 1991). *Payaos* attract variety of species; the catches consist largely of juvenile tunas and small pelagic fish. In addition, 99% of the tuna production in the Philippines' waters are payao-associated. Thus *payaos* may increase the total catch of tunas, but since majority of tunas in Philippine waters are apparently juvenile, the use of payaos increased the catch of small tunas without size selectivity (White 1982).

2.2.2 Indonesia

Traditional aFADs are called "*rakit*" and "*rumpon*" in Indonesia. *Rakit* is a kind of small aFADs made of traditional materials and deployed in shallow waters (50 - 200 m) while *rumpon* is relatively large scale aFADs set at waters ranging (400 - 4000 m deep) (Mathews et al.1995). They are used particularly in the eastern Indonesia waters since time immemorial (Gooding and Magnuson 1967; Yusfiandayani 2013). *Rumpon* is categorized by its deployment depth, while *rakit* sometimes referred to as shallow water *rumpon* in some reports (Monintja and Mathews 2000; Yusfiandayani 2013). Some fishers construct their *rakit* or *rumpon* in traditional manner by coconut leaves and bamboo stems to catch small pelagic fishes that looks similar to payaos in the Philippines. Due to long history of payaos in the Philippines and being the first country to use the aFADs to support small scale fisheries, Indonesia adopted the same technology to their country. While some fishers construct them using modern materials (Fig. 2-2). The *rumpon* usually lasts for a period of two months or less (Yusfiandayani et al. 2015).

The aFADs have been widely employed by artisanal fishers in the northern Java Sea and southern Celebes Sea. Fishers used aFADs to aggregate pelagic species inclusive of yellowfin tuna, skipjack tuna, mackerel, scads, carangids and sardines. The main fishing gear used around aFADs are handlining, trolling (Monintja 1993; Mathew et al. 1996), pole and line fishing (Monintja and Mathews 2000). In 2014, the approximate number of deep *rumpon* anchored by fishers were 250 units. There is a concern that pelagic species that aggregate around aFADs can be over exploited so easily that fishers are encouraged to collect catch and effort data to monitor the health status of the fish stocks (Yusfiandayani 2013). In that regards, the use of aFADs in Indonesia waters must be licensed by the Directorate of Capture Fisheries, Ministry of Marine Affairs and Fisheries Republic of Indonesia (Yusfiandayani 2013).

2.2.3 Japan

Japan also has a long history on aFADs usage such as 1500s in Tottori Prefecture, western part of Japan, they used FADs known as "*tsukegi*" or artificial drifting object made of brushwood to attract dolphinfish (Tottori Prefectural Government Web-page). Fishers in the southwestern parts of Japan used FAD (drifted and anchored) for their fishing. The traditional aFADs had a short lifetime (Otake 2013) about 1-2 years in Okinawa (Kai 2013). This led to development of aFADs that have a longer lifetime which was initiated by the local government in 1959 (Kumamoto 2013). In 1982 fishers who worked in South Pacific Ocean and the local government in Okinawa successfully developed high endurance aFADs called "*Payao*" adopting Philippine's name, and practiced modern fishing (Kai 2013; Wakabayashi 2013). This success story had an impact on the fisheries in the neighboring regions and aFADs spread to Miyazaki or Kochi Prefectures. From this, the MarinoForum 21, incorporated body of marine industries including fisheries, shipbuilding and environment assessment published a criterion for the design and construction of aFADs in 1992 (MarinoForum21 1992). Additionally, Fisheries Agency of Japan has published a book that presents the necessary requirements of aFADs. In order to construct and deploy aFADs it is necessary to pass through several administrations (Fisheries Agency 2015) levels including Fisheries Adjustment Commission. They also have to be approved by the coastguard and the local and/or national authorities. For example, available numbers of aFADs in Okinawa waters is limited less than 200 in numbers from the fisheries management point of view.

According to Kumamoto (Kumamoto 2013), aFADs in Japan are categorized by their designs i.e. “Surface type”, “Surface and mid-water (Subsurface) type” and “Mid-water type” (Fig. 2-3). The aFADs are also classified according to its function such as “Modern type”, “Simplified type” and “Traditional type” (Wakabayashi 2013). For example, “Modern type” aFADs are used by recreational fishing normally installed with oceanographic sensors for environmental monitoring. The aFADs depth ranges from 14 m to 3000 m in Japan. The Prefectures that use aFADs for commercial fisheries include Kuroshio current area whereby “Surface type” and “Modern type” aFADs are popular; Okinawa (Kai 2013); Kagoshima (Sakaki 2013); Miyazaki (Nakanishi and Tokeshi 2013); Oita (Nishiyama 2010); Kochi (Inaba 2013); Wakayama (Wakayama Prefectural Government Web-page); Mie (Mie Prefectural Government Web-page); Kanagawa (Anon 2013) and Tokyo (Bureau of industrial and labour affairs 2017). Which are large in size (e.g. aFAD off Kochi is L7.5xW3.9xH3.5 m) and equipped with sensors to measure water temperature, wind speed, current and direction of water to provide environmental information to the public. In waters where the sea traffic is heavy, “Mid-water type” aFADs are used.

The main target species for commercial fishing around Japan’s aFADs are pelagic fish including marlin, sailfish, billfish, swordfish, tunas, skipjacks, yellowtail, amberjack, dolphinfish and jack mackerels. They are mainly captured by hook and lines such as angling, trolling, longlines, but also by various purse seines. In the case of south islands of Kagoshima, landing of tuna and skipjack are all from aFADs fishing grounds. Available fishing methods around aFADs fishing grounds are mostly determined by regulations of various levels such as voluntary agreement among users to regulations. For example, fishers only employ either trolling, skipjack pole and line, bait angling or dolphinfish surrounding net for “Surface type” aFADs in Miyazaki Prefecture (Nakanishi and Tokeshi 2013)

2.2.4 Mauritius

Mauritius is one of the first countries in the South West Indian Ocean to start aFAD fishery (Venkatasami and Momode 1996). The aFAD fishery was introduced in Mauritius through an UNDP/FAO project to stop the declining fish landings from artisanal fishing sector and to control the increasing fishing pressure on the lagoon stocks. The artisanal aFAD fishery was to divert fishing effort away from the lagoon or from traditional fishing grounds to the outer/off-lagoon areas (Cayré 1991). There was no local development stage in this country and the modern aFAD designs was introduced as shown in (Fig. 2-4). The aFADs are anchored at depths varying from 800 to 3000 m. The average lifetime of an aFAD has been estimated to be around 500 days (Chooramun and Senedhun 2013). Those aFADs were also introduced to Madagascar and Comoro Islands after Mauritius (Cayré et al. 1991).

As of 2013, 28 aFADs were deployed around Mauritius for artisanal fishers and other stakeholders. The fishing techniques generally practiced around aFADs are trolling with artificial bait, slow trolling with live bait, handlining, longlining and drift lining etc. Detailed information on fishing gear used around aFADs in Mauritius is presented by de San and Pages (1998). The main species caught are albacore tuna, yellowfin tuna and skipjack tuna (Chooramun and Senedhun 2013). The production of artisanal aFADs fishery on the west coast, where most aFADs have been set (21 out of 28 from 2010 to 2012), was between 243 and 331 t per year (Chooramun and Senedhun 2013) equivalent to 5-6% of the total national catch (Beverly et al. 2012).

2.2.5 Maldives

Maldives has one of the highest numbers aFADs in the Indian Ocean. Deep-water aFADs about (1000 − 2000 m deep) were first introduced in the early 1980s by FAO project (Naeem and Latheefa 1995). By 1990, there were 10 aFADs deployed around the Maldives with the national tuna catch increasing from 30 000 t in 1980 to 70 000 t in 1990. Due to its success, Maldives maintained an array of about 45 aFADs, making it the largest aFADs array (Shainee and Leira 2011). Typical arrangement of aFADs are shown in (Fig.2-5). Different from traditional design found in Philippines or Indonesia, modern materials such as fiber- reinforced plastic (FRP) are used for floating part and netting is used as mid-water attractor instead of coconut leaves, that was typically used in aFADs in Southeast Asian countries. The average lifespan of aFADs installed from 1993 to 2008 was approximately 2 years and 1 month. About 82% of aFADs installed each year in the Maldives are lost (Shainee and Leira 2011).

Tuna catches in the Maldives peaked in 2006 with a catch of 166 000 t (138 000 t of skipjack tuna and 23 000 t of yellowfin tuna), majority of the catch was from aFADs. However, in 2010 the tuna catches plummeted to 77 000 t. Species composition of Skipjack tuna form nearly 60% of the catch in the Maldivian pole and line fishery. Followed by yellowfin tuna (30-35%) (Naeem and Latheefa 1995; Shainee and Leira 2011).

2.3 Issues related to aFADs

2.3.1 Impacts to the ecosystem

Not only aFADs, but also any artificial habitats may alter local marine ecosystem. Several studies indicated that if aFADs are anchored at greater distances from the coast, might also attract tunas swimming offshore (Marsac et al.1996). This kind of impact is also reported for birds. It was reported that marine renewable energy installations that is similarly constructed in the ocean like aFADs give a risk of collision, disturbance, displacement, and so on to marine bird (Grecian et al. 2010). Apart from, migration/movement of animals, aFADs may change biomass of certain species in the ecosystem. Impacts of aFADs to the ecosystems depend on cases as: 1. aFADs only redistribute the exploitable biomass without increasing stock size, 2. aFADs increase exploitable biomass without increasing stock size, and 3. aFADs increase both exploitable biomass and stock size according to (Polovina 2013). It is difficult to identify the case, but these cases except the impact is dependable on the local marine ecosystem available biomass (e.g. catch) and stock changes in the system.

Since aFADs are deployed to create new habitats for commercial species, diet of the associated fish sometimes become different from fish in common habitats. Fonteneau (1997) suggested that free-school tunas mostly occur in rich-food area, while aFAD locations are mainly not chosen by such criteria. As a result, differences in empty stomach rate, diet diversity and consequently growth of skipjack and yellowfin tuna was reported in the western Indian Ocean (Jaquemet et al. 2011).

2.3.2 Over-exploitation

While aFADs can displace fishing effort from existing fishing grounds to others, there are concerns that pelagic species that aggregate around FADs (both dFADs and aFADs) can easily be over exploited. In general, FADs merely concentrate fish in one localized area, making them easier to catch (Beverly et al. 2012). In addition, aFADs increase catch and its consistency thus enhance food security, and reduce search time and operating costs for fishers that the fishing effort will concentrate to aFADs. Massive capture of fecund individuals or spawning stock, that are major target species around aFADs are considered to results in recruitment overfishing (Fonteneau et al. 2000b) and this has been reported in Philippines for example (Floyd and Pauly 1984). Therefore, aFADs accelerate fisheries collapse when the fishery is already overfished (Cabral et al. 2014). Although fishing capacities for dFADs and aFADs users are different (e.g. industrial purse seine and artisanal fishers), aFADs deployment in most cases is aimed to reallocate fishing effort in the region, in the process over-exploited cases could be possible (Grossman et al. 1997). Arrangement of aFADs array is proposed in some areas (Beverly et al. 2012; Dagorn et al. 2007) for efficient use of the array of aFADs and to allocate fishing efforts, but the diversity of target species and gear types would make it difficult to determine the optimal number and density of aFADs for any given area (Taquet 2011). Besides, this will not solve the over-exploitation issue because it would only redistribute fish stocks in the area. Fishing capacity control (FAO, 2009) is necessary for sustainable use of aFADs. To achieve this, collection of high-quality data at certain level and monitoring protocols are required (Beverly et al. 2012). Recently a new idea has been introduced on the use of aFADs as Fish Enhancing Devices (FEDs) for small-scale and artisanal fisheries that are deployed in the banned water or fisheries under strong regulations (Cabral et al. 2014).

2. 3.3 Bycatch

Issue on bycatch of juveniles and other endangered species associated with aFADs is being observed in different countries. In the Philippines, fishing operations take place all year-round, there has been claims that *payaos* tend to selectively attract juveniles and are therefore detrimental to the fishery (Floyd and Pauly 1984). This kind of bycatch of immature fish of dolphinfish and kingfish was also reported in Australia (Dempster 2004). It is well-known that juveniles of commercially important fish such as yellowtail aggregates under aFAD (Sakakura and Tsukamoto 1998). Therefore, the juvenile fish are most likely to be captured by the use of less selective fishing gear and method. Although the issue on bycatch of endangered animals seems more serious with dFADs (entanglements to dFADs), few cases have been reported about sharks and turtles caught by fisheries operated around aFADs (Beverly et al. 2012). This issue may be mitigated by using fishing methods that have efficient size and species selective properties, probably using proper angling gear, and also by training aFAD users to handle and release bycatch species if or when they are caught.

2. 3.4 Aggregation of undesired fish

Brown chub *Kyphosus bigibbus* is an herbivorous fish associated with decrease in seaweed beds or "*isoyake*", and is a serious issue to the coastal ecosystem in Japan. This fish has been frequently observed around aFADs in southern Japan (Gejima 2009; Ito et al. 2009; Karama and Matsushita unpublished data). It will be a problem if aFADs provide suitable habitat to brown chub for their growth and increase in numbers. However, this fact may be a flipside that aFADs can be used as a gathering device for undesired animals such as brown chub for termination activity.

2. 3.5 Ghost gear

Ghost aFADs that break from their moorings and particularly those with plastic components form marine debris that can pollute beaches, reefs and the open seas. The aFADs have also been identified as one source of abandoned, lost or otherwise discarded fishing gear, even though the issue is more serious with dFADs (FAO 2009). The negative impacts of this type of marine debris can create a hazard to navigation, creation of beach litter, introduction of synthetic materials into the marine food web, transporting alien species, and additional clean-up costs (Macfadyen et al. 2009). These issues relate to management framework, practices, and technical aspects. There have been several initiatives conducted to promote cheaper and longer lasting aFADs (Ben-Yami et al. 1989; Higashi 1994; de San and Pages 1998; Holland et al. 2000; Chapman et al. 2005; Kai 2013). The average lifespan of aFADs in the Western Indian Ocean had increased to two years by the 1990s. From 2001 to 2008, aFADs were lasting four to eight years in Niue, but longevity is still a recurring problem for aFADs (de San and Pages 1998; Sharp 2011). The lifespan of an aFAD can be increased significantly by using proven designs made with recommended materials, carrying out regular monitoring and maintenance. One recommendation from the Tahiti conference on FADs in 2011 was that reducing the number of components (shackles and swivels) in the anchored system was likely to increase aFAD longevity (Taquet 2011).

2. 4 Management of aFADs

Operation around aFADs has increased and more consistent catches, reduce time, reduce cost and increase in safety for small-boat operation (Boy and Smith 1984; Sharp 2011) but comes with responsibilities for management towards long-term societal and ecological profit.

According to the FAO Code of Conduct for Responsible Fisheries, it is stated that “States should, within the framework of coastal area management plans, establish management systems for fish aggregation devices (FAO 1995). The FAO Technical Guidelines on the Implementation of the Code of Conduct Fishing Operations FAO (1996) also states clearly that for aFADs to be sustained for a long term budget allocation for deployment, maintenance and replacement of aFADs should be included. Spacing requirements for aFADs are designated in countries like Indonesia and the Philippines, but have been poorly policed due to a lack of resources and political will (Bailey et al. 2012). Weak state regulation and implementation of aFADs also means that the distribution access of aFADs is mainly determined by informal agreements between fishing companies and communities (Bailey et al. 2013).

The aFADs have been instrumental in the fishing cooperatives and have provided fisheries managers with a way to safe-guarding the very important marine resources by providing fishers with some alternative ways such as bottom fishing and lobster fishing in the Galapagos Islands, for example (Diaz et al.2005; Chalen et al. 2007).

The aFADs can also be used to separate waters, MPAs in the Komodo National Park in Indonesia and in the Western Indian Ocean have been employed to facilitate management (Anon 2000). The aFADs are also used to demarcate the boundaries between areas such as closed areas and fishing zones. For example, aFADs have been used for demarcating marine zones in the Philippines, doubling as marker buoys and aFADs (Anon 2003). Thus, aFADs can be a tool to reduce conflicts between neighboring groups/countries by reducing incentives for fishers to follow the movement of target species into adjacent waters. However, since fishers compete for the same resources in a typical fishing community set up, consultation/adjustment/agreement with stakeholders on where to install aFADs, and seeking their participation in the construction, fabrication and maintenance of aFADs. This active participation of stakeholders can avoid conflicts.

2. 5 Discussion

From the review it is clear that aFADs has been practiced for a very long time and it has evolved to more advance structure with the help of the technology. It is also clear that aFADs are an important tool for promoting and managing artisanal and small-scale commercial fisheries all over the world, increasing localized catches at reduced costs and thereby improving food security and livelihoods for coastal communities. In order to maximize on the positive impacts of aFADs and minimize on the issues that are associated with aFADs, it is important to back up the importance of aFADs with scientific evidence. In this regard, I examined several techniques that have been used to evaluate the ability of fish attraction by the aFADs in chapters 3 and 4. The results can also be used to relate and applied in Kenya although further research studies are recommended to confirm the appropriate aFADs design, placement configuration, and site selection around the aFADs due to different environmental conditions among others.

There are various studies on aFADs that have been developed using various techniques to understand the fish attraction: optical techniques (Taquet et al. 2000; Dempster 2004), acoustic telemetry (Girard et al., 2004; Ohta and Kakuma 2005; Schaefer and Fuller 2005), use of echosounder (Routree 1990; Deudero et al.1999; Dempster 2005; Stanton et al. 2010) and biotelemetry (Musyl et al. 2003). These studies have provided valuable information on individual fish behaviour (biotelemetry), near-surface pelagic fish communities around aFADs (optical techniques), sub-stocks (fishing and tag and release data) or studies of distribution including continous sampling of large volumes of water and high resolution measurements of vertical and horizontal distribution and aggregation of fish schools (echo sounding). For this thesis, I combined these techniques to understand the association of fish and its habitat around the aFADs. Therefore, in chapter 3, I presented seasonal fish fauna observed by optical observation techniques to investigate the effects of aFADs in a short range. Considering the importance of knowing the spatial distribution of pelagic fish aggregations associated with aFADs in a wide range around aFADs which has remained mostly unknown. I discussed this in details in chapter 4, since quantitative characterisation of pelagic fish communities associated with floating objects at the scale of aggregations is a prerequisite for implementing sustainable management of aFAD fisheries.

Figures and Tables (Chapter 2)

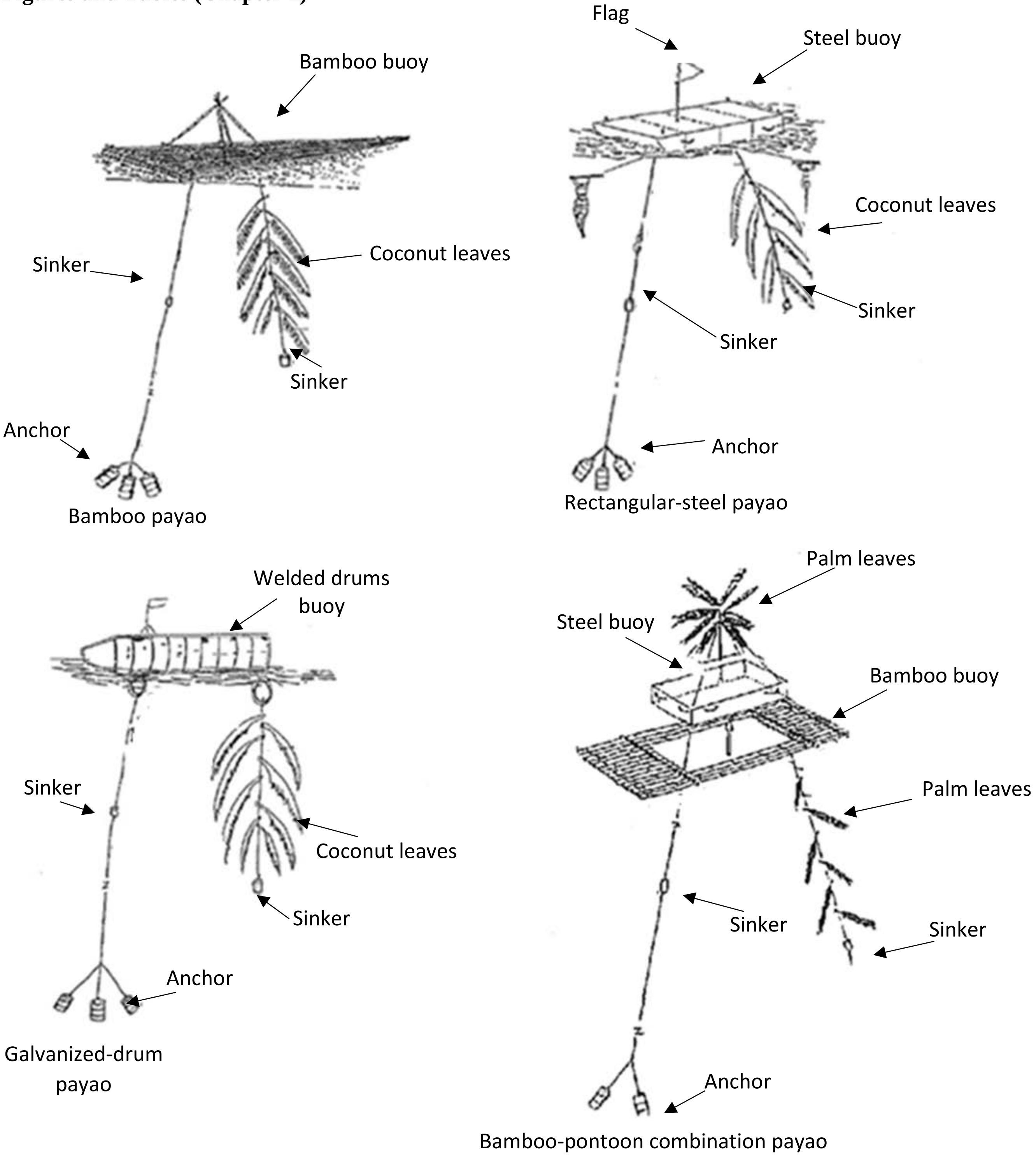


Figure 2-1. Types of aFADs (*payaos*) used in the Philippines (Adapted from Dickson and Natividad 2000)

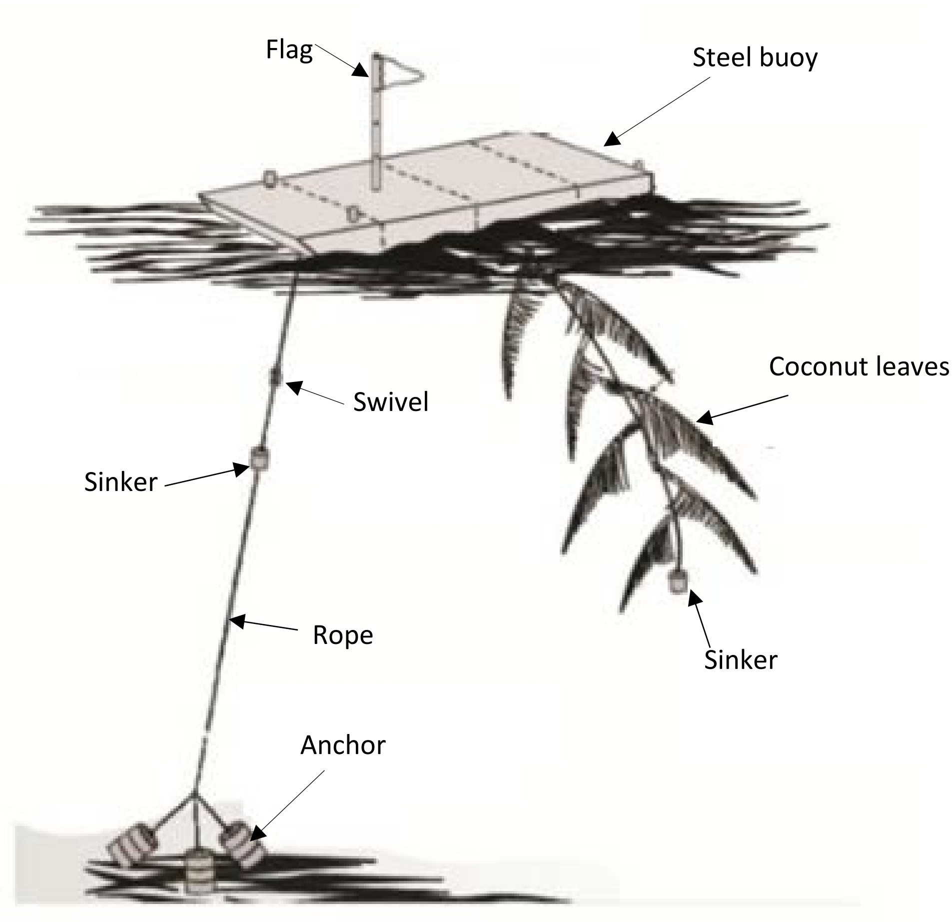


Figure 2-2. A type of aFAD (*rumpon*) used in Indonesia (Courtesy of Dr. Mohammad Riyanto)

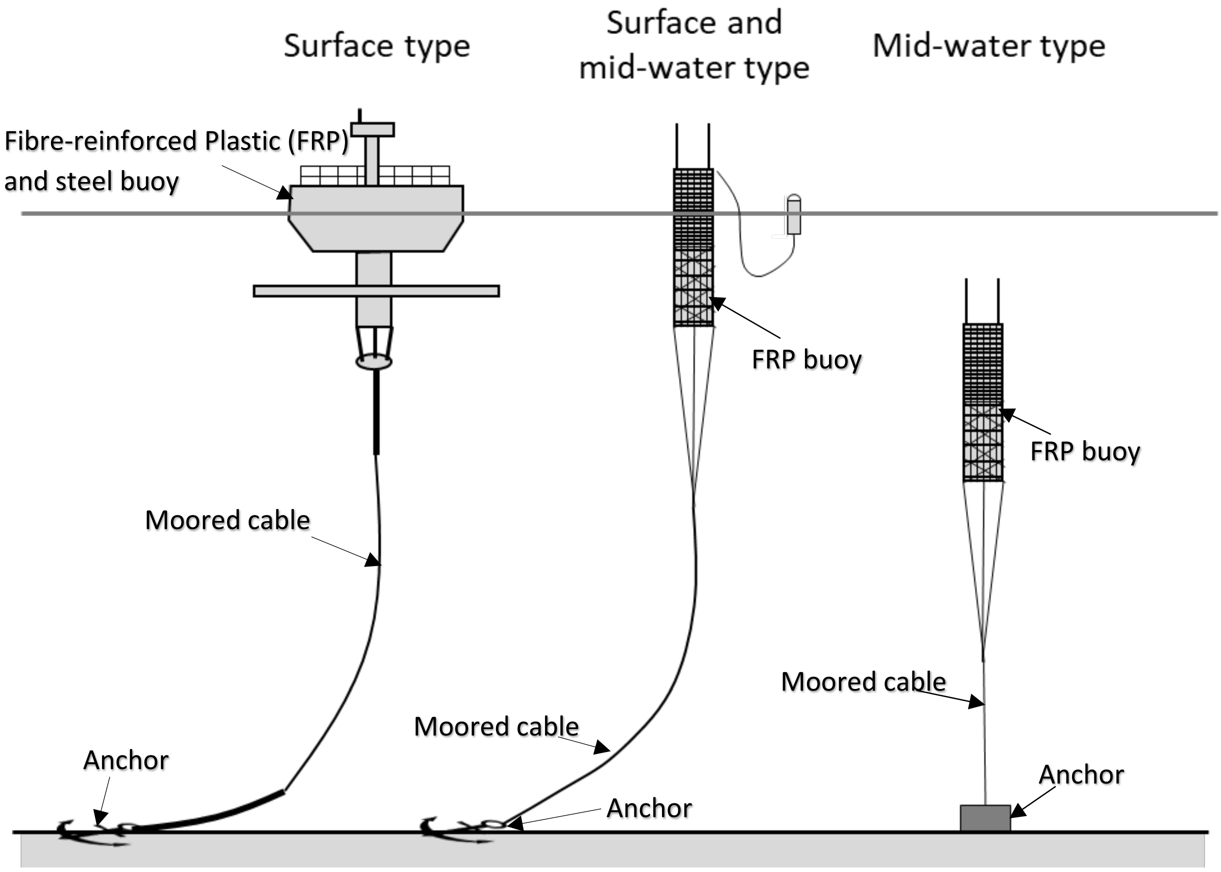


Figure 2- 3. Types of aFADs used in Japan. (Adapted from Kumamoto 2013)

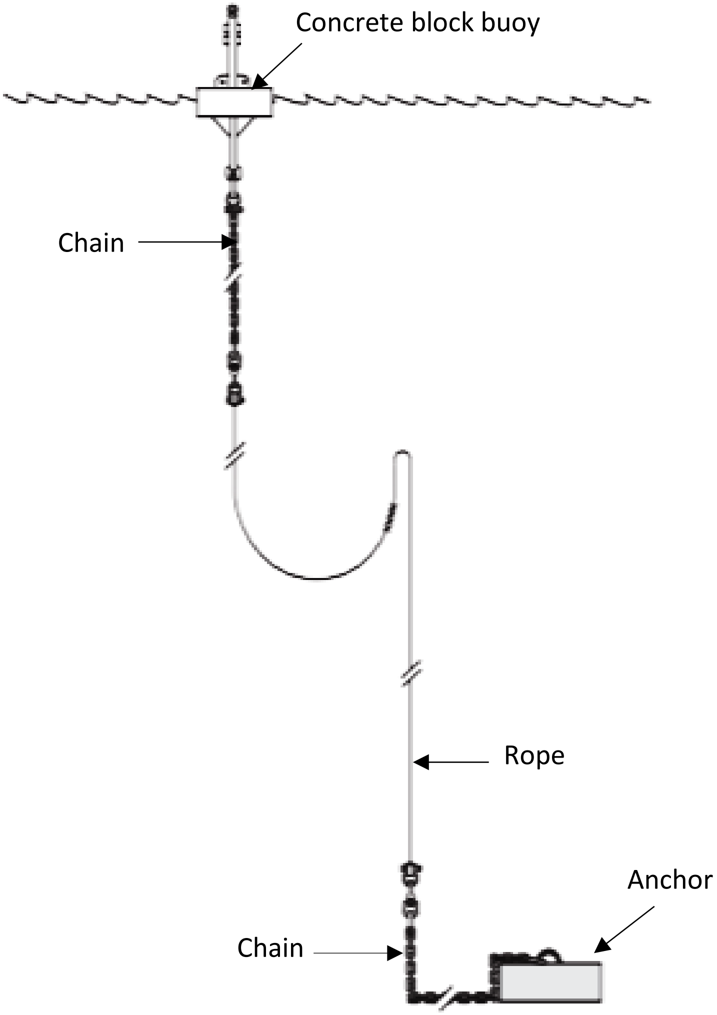


Figure 2-4. A type of aFAD used in Mauritius.(Adapted from Chapman et al. 2005)

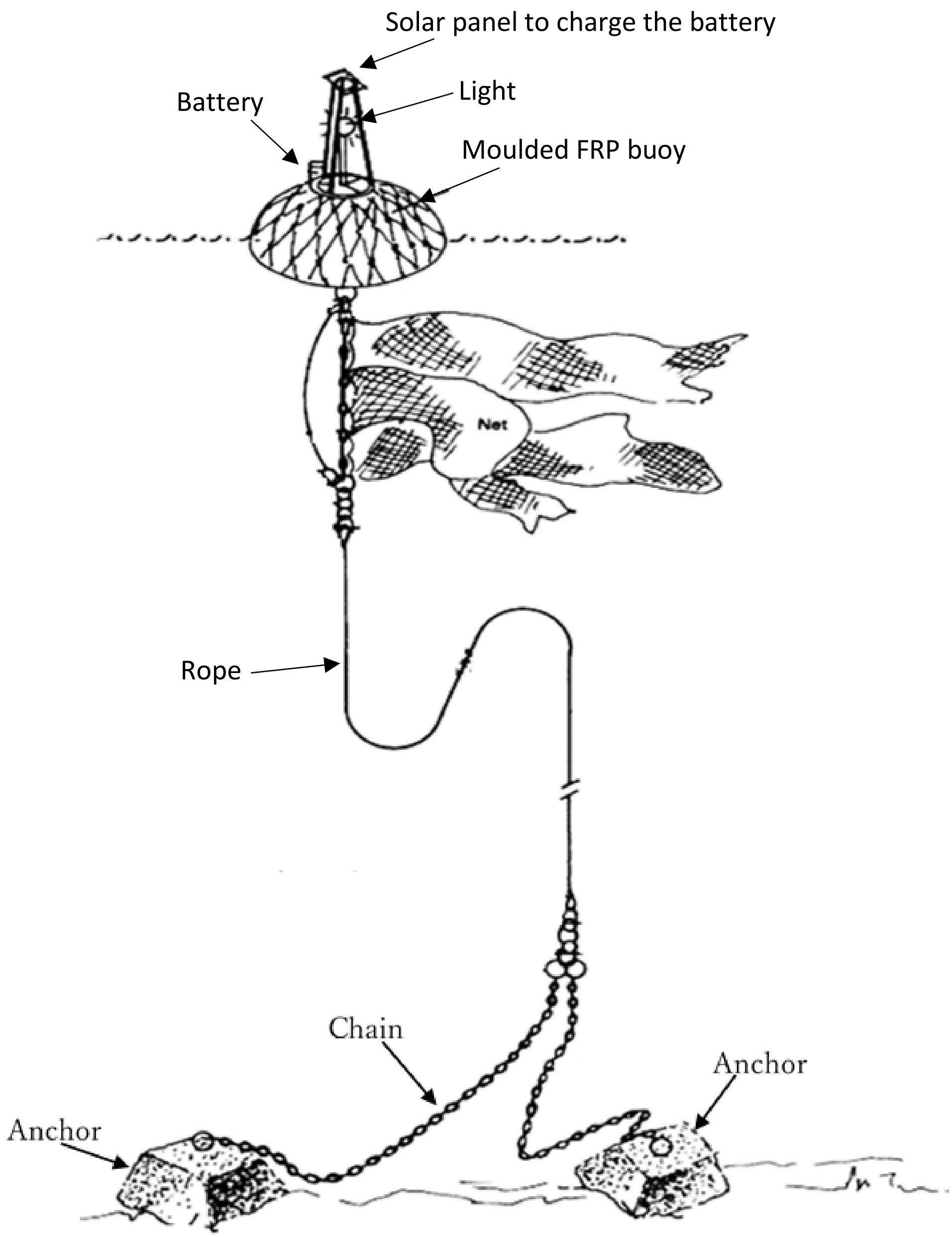


Figure 2-5. A type of aFAD used in the Maldives (Adapted from Shainee and Leira 2011)

Chapter 3

Evaluation of fish attraction around aFADs by optical techniques.

In order to evaluate fish communities around the aFADs in Goto Islands, I identified the fish species and the numbers on a regular basis by using two different optical observation techniques including Remotely Operated Vehicle (hereafter to be referred to ROV) and underwater fixed point time lapse camera (hereafter to be referred to underwater camera). These methods were meant to understand the occurrence of other large fish species and its temporal and spatial variation around the aFADs.

3.1 Materials and Methods

3.1.1 Study sites (North and South aFADs)

Floating aFADs have been installed 70 m deep in the northern part and 100 m deep in the southern part of Kabashima Island in Goto Islands situated in the East China Sea, off the western coast of Kyushu, Nagasaki Prefecture (Fig.3-1). These aFADs are cylindrical in shape made of fiber-reinforced plastic (FRP) with 1.4 m diameter and 7 m length moored on the sea floor by an anchor made of two layers' concrete. The two layers' concrete block whose upper layer measurement (L 50 cm x W 340 cm x H 340 cm) stacked on the lower layer of (L 178 cm x W 840 cm x D 840 cm) for the north aFAD (Fig.3-2). While the south aFAD is moored with a 10-ton type danforth anchor as shown in (Fig.3-3).

3.1.2 ROV and underwater camera

Data on species aggregating around the aFADs was collected by observation method using ROV (DELTA 100 R) from Q.I Co., Ltd (https://www.qi-inc.com/) at a maximum depth of 150 m. The ROV moved freely around all directions including (up, down, left and right) with 3 compact high-power thrusters. The depth and the direction was always controlled and confirmed from the screen in the boat. The recorded data was limited to a depth between 0 to 10 m, and a radius of 10 m range from the aFADs, so it was difficult to evaluate spatial distribution and abundance around the entire aFADs.

Brinno's time lapse camera (TLC 200) at a field of view angle 59^{o} and a focal length of 36 mm was housed in underwater case (SONY MPK-DVF 5 M that could withstand pressure of up to 75 m). In addition, a 4 GB SD card was used, still images were recorded at a resolution of (1,280 × 720 pixels) over 43 days at every 3 minutes' intervals shooting and 50 days for every 5 minutes' intervals. A charge-coupled device (CCD) was used with the camera at a field of view angle 46^{o}. Data on night time observation was never collected in this survey since artificial lighting was never used.

3.1.3 Data collected by ROV

Data was collected using ROV from seven monthly surveys done on 20th April, 17th May, 14th June, 19th July, 21st August, 15th September and 20th October in 2018 for about 30 minutes at each aFAD by training vessel Kakuyo maru (LOA 42.79 m, 155 GT, 1050 kWx2) that belongs to Nagasaki University. During the surveys, a small boat loaded with a set of ROV equipment, a DVD recorder and a small generator was always anchored to the aFADs with a rope about 1 m in length from the boat, then the ROV was submerged at a depth of 7 m from the water surface in order to record the fish around the aFADs (Fig. 3-4). The images of the CCD camera were recorded by the DVD recorder. The recorded videos were then copied to the DVD and was played in the laboratory. From the scene where the fish was seen, it was paused, the fish was examined, the species identified and the number of fish was recorded.

3.1.4 Data collected by underwater camera

In order to observe the state of the fish communities around the aFADs other than the monthly surveys done by Kakuyo maru. The underwater camera was only deployed twice at the north aFAD; firstly, from 14th June to 19th July and secondly, from 19th July to 20th August in 2018. It was suspended from the north aFAD with a rope and deployed at a depth of 3 m to 4 m (Fig. 3-4). The underwater camera was set to shoot after every 3 minutes' for the first time, while the second time it was set to shoot after every 5 minutes' intervals. Both fish species and numbers were recorded sufficiently with high quality image (1,280 × 720 pixels) at the set intervals despite the shooting intervals being different. The underwater camera was retrieved at the time of monthly surveys by Kakuyo maru and taken back to the laboratory where the images were downloaded. For this study, I only examined the fish images by identifying the species, took count on the numbers observed and recorded. I categorized the fish species that were hard to identify as "unknown species".

I further examined the change in the total number of fish species observed at the north aFADs over time. However, since the shooting interval was different, the number of shots taken within a fixed time was different. To avoid overestimating the number of individuals due to different effort. During comparison on the number of observations per hour, effort amount was unified by the number of individuals of each fish species observed for the second time multiplied by 5/3 (1st shooting interval: 2nd shooting interval = 3: 5).

3.1.5 Analysis

To determine the species occurrence and their numbers around the aFADs, I calculated the species diversity using Shannon diversity index (*H'*) (Shannon and Weaver 1963) which is a measure of an ecosystem's species richness and species evenness. If an ecosystem has poor species diversity, it may not function properly or efficiently. A diverse species assemblage also contributes to ecosystem diversity.

Shannon diversity index (*H*') is commonly used to characterize species' diversity in a community. It accounts for the abundance of the species present. *H*' does increase with increasing numbers of species. Shannon diversity index (*H*') is expressed by the equation below.

$$H' = -\sum p_{ij} log_2 p_{ij}$$

Whereby p_{ij} is the probability of the occurrence of a certain species *j* among all the populations observed in the *i*th month. Shannon diversity index (*H*') for each month for both aFADs was determined from the fish species and the number of individuals observed by ROV and by underwater camera. The probability p_{ij} of fish species *j* appearing in month *i* from April to October was obtained from the number n_{ij} of fish species *j* observed at month *i* and the total number *N* of fish species observed at month *i*.

$$p_{ij} = n_{ij}/N_i$$

By substituting p_{ij} into the first equation, *H*' of *i* month was obtained.

Similarity index by Bray-Curtis (Bray and Curtis 1957) was calculated in order to determine whether the fish species observed at the north aFAD and the south aFAD was the same from the ROV data. I also determined whether the fish species observed by the two methods (ROV and underwater camera) were the same at the north aFAD. Bray-Curtis similarity index (*B*) is a measure of how similar the two samples were in terms of species composition. Since the duration of data collected by the two methods at the north aFAD was different, I pooled two data sets from the ROV (e.g. for 14th June and 19th July and for 19th July and 21st August) and compared with two sets of data from the time lapse camera (14th June to 19th July and 19th July to 20th August). The equation of the Bray-Curtis similarity index (B) is shown below.

$$B = \sum_{a=1}^{n} |X_{aj} - X_{ak}| / \sum_{a=1}^{n} (X_{aj} + X_{ak})$$

Whereby, X_{aj} is the number of individual species observed by ROV, X_{ak} is the number of individual species observed by underwater camera. *a* is the number of the particular species observed. *Xaj* can be substituted by the number of individual species observed at the north aFAD by ROV and *Xak* is the number of individual species observed at the south aFAD by ROV. When *B*=0, it means that the communities are 100 % similar and when *B*=1, it means that the communities are not similar at all.

I then determined the water temperature up to 3 m depth obtained by CTD (SBE-911plus, Sea-bird Scientific, USA) around the aFADs to relate to species diversity.

3.2 Result

3.2.1 Observation of fish species around the aFADs

From the monthly ROV data (from April to October), seven families and 11 species were observed around the north aFAD (Table 3-1). Around the south aFAD, thirteen families and 15 species were observed (Table 3-2). For the underwater camera data deployed at the north aFAD (from June to August), nine families and 11 species were observed (Table 3-3, 4 and 5). From the data collected by both the techniques, I identified 12 species to be of commercial important such as greater amberjack *Seriola dumerili*, amberjack *Seriola lalandi Valenciennes,* rainbow runner *Elagatis bipinnulata,* barred knifejaw *Oplegnathus fasciatus*, yellowfin tuna *Thunnus albacares*, spotted knifejaw *Oplegnathus punctatus,* threadsail filefish *Stephanolepis cirrhifer,* leatherjacket *Aluterus monoceros,* common dolphin fish *Coryphaena hippurus Linnaeus,* filefish *Thamnaconus modestus,* bream *Hyperoglyphe japonica* and largescale blackfish *Girella punctata Gray*.

3.2.2 Observation of fish species by ROV

From the ROV data, more fish species were observed around the south aFAD (15 fish species) as compared to the north aFAD (11 fish species). However, ten of the fish species were observed around both the aFADs. These included, stripey *Microcanthus strigatus*, Indo-pacific sergeant *Abudefduf vaigiensis*, black-banded blenny *Petroscirtes breviceps*, *G. punctata, S. cirrhifer*, *A. monoceros, E. bipinnulata*, *S. dumerili*, *O. fasciatus* and *O. punctatus*.

The total number of fish species increased gradually from June to August. The maximum number of fish was observed in September and decreased in October. Around the north aFAD, *G. punctata*, *P. breviceps* and *M. strigatus* were mostly observed throughout the study period (Fig.3-5). While around the south aFADs, the total number of fish increased gradually from May and peaked in August then started to decrease in September. One month earlier than the north aFAD. *G. punctata*, *P. breviceps* and *S. dumerili* were also observed during the study period around the south aFAD. Half-lined cardinal *Apogon semilineatus Temminck and Schlegel* was only observed around the south aFAD and specifically in April with the highest number of fish (Fig.3-6). Overall, the Shannon diversity index *H*' around the north aFAD and the south aFAD was 2.28 and 2.97 respectively. In addition, 95% confidence interval estimated by a bootstrap method (n = 1000) was 1.97 - 2.39 for the north aFAD and 2.75 - 3.02 for the south aFAD. The Shannon diversity index *H*' between the north aFAD and the south aFAD were different. The Bray-Curtis similarity index for overall was 0.68, this suggested that fish fauna at the two aFADs observed by ROV were different.

Monthly Shannon diversity index *H*' was also determined, around the north aFAD the index increased gradually from April and peaked in August (2.40) then decreased. Likewise, around the south aFAD the diversity index *H'* increased gradually from April and peaked in July (2.60) then decreased after summer season (Fig.3-7). The monthly Bray-Curtis similarity index decreased with time from April to October. The Bray-Curtis similarity index became smaller (0.57) indicated the fish fauna were slightly different. The fish species observed in April were totally different between the two aFADs but with time the two aFADs become slightly different thus recorded low similarity index in October (Fig.3-8).

3.2.3 Observation of fish species by underwater camera around the north aFAD

From underwater camera that was deployed at the north aFAD only, highest number of fish was recorded in July that mainly consisted of *S. lalandi* and *G. punctata*. June and August recorded five different species (Fig.3-9). The overall Shannon diversity index *H*' for the fish observed was 1.37, 95% confidence interval was 1.24 - 1.75 determined by the bootstrap method.

Shannon diversity index *H'* for the three months when the underwater camera was deployed was also determined. The index recorded high diversity (1.91) in June, decreased in July (1.48) and lowest in August (1.27). 95% confidence interval estimated by the bootstrap method was 1.82 - 2.02, 1.41 – 1.55 and 1.15 – 1.35 respectively (Fig.3-10).

In addition, fish were observed from sunrise (at 05:00 hrs) to sunset (19:00 hrs). During the day the number of fish observed increased with time and was highest at 10:00 hrs and 11:00 hrs (600 individuals / hour). And after the noon the numbers drastically decreased (100 individuals/ hour or less). *S. lalandi* and *G. punctata* were mostly recorded during the period. The number of *G. punctata* was high between 10:00 hrs and 11:00 hrs. In addition, *O. fasciatus* and *C. hippurus* were more in numbers only around 10: 00 and 11:00 hrs (Fig.3-11).

3.2.4 The difference in the observation result by ROV and underwater camera around the north aFAD

The Shannon diversity indices *H*' for the north aFAD obtained by the ROV and the underwater camera for the same duration were 3.05 and 1.37 respectively. The diversity index obtained from ROV showed a larger value as compared to the underwater camera. The 95% confidence intervals obtained by the bootstrap method was 2.96 - 3.26 for ROV and 1.24 - 1.75 for the underwater camera. All Bray-Curtis similarity indices for overall and by periods were more than 0.9, this suggested that fish fauna at the aFAD observed by the two observation techniques were markedly different (Fig.3-12).

3.2.5 The difference between water temperatures around the aFADs

At the north aFAD, the water temperature increased gradually from April (17^{o}C) to August where it peaked (26^{o}C) then started to decrease in September to (25^{o}C) and October (23^{o}C). On the other hand, around the south aFAD, the water temperature increased gradually from April (17ºC) to August (26ºC), the same temperature was maintained in September then decreased in October (23ºC) (Fig.3-13).

3.3 Discussion

Both aFADs in Goto Islands attracted fishes in considerable numbers. However, the south aFAD recorded most number of fish species and highest diversity which could be attributed to geographical and environment conditions of the aFADs positions. About twelve commercial important fish species were observed around both aFADs in Goto Islands such as *S. lalandi*, *C. hippurus* etc that have recorded strong evidence of association with floating structures exists from previous studies (Rountree 1990; Deudero et al. 1999; Dempster 2005). As found in several previous studies (Hunter and Mitchell 1968; Castro et al. 1999; Deudero et al. 1999), Carangidae was the most frequently observed family. For Monocanthidae, there is no previous evidence for association with aFADs (Kingsford, 1993), and were seen utmost thrice around both aFADs unlikely they regularly associate with aFADs. The four most numerically abundant taxa, Trachurus sp., *C. hippurus*, *S. lalandi* and *S. dumerili*, are widely observed around aFADs throughout the world (Hunter and Mitchell 1968; Druce and Kingsford 1995; Castro et al. 1999; Deudero et al. 1999). Various Porifera and Nereidae species were also found at both aFADs which formed food for the juveniles of *O. fasciatus* and *S. dumerili*.

Availability of fishes, particularly juveniles, appeared to be the most important factor contributing to seasonality in assemblages of fishes around both aFADs in Goto Islands, as observed previously in other locations (Rountree 1990; Castro et al. 1999; Deudero et al. 1999; Dempster 2005). These seasonal patterns are due to combination of biological and physical processes, including spawning periods, which regulate the availability of juveniles that only associate with aFADs for a certain part of their life history or seasonal shifts in water temperature. For example, around the north aFAD the number of *S. dumerili* and *E. bipinnulata* decreased in August and September when the water temperature increased to 26ºC and numbers increased in October when the water temperature decreased to 23ºC. In addition, *C. hippurus*, *A. semilineatus* and longfin batfish *Platax teira* were never observed since August. While around the south aFAD there was no clear relationship between the water temperature and diversity index from August, as the water temperature increased most fish moved out of the south aFAD. In addition, commercial important fish species such as *S. lalandi*, *T. albacares* and *C. hippurus* were observed around the aFADs during different times of the year and tended to decrease when the temperature peaked. Species like *C. hippurus* were observed to frequent around the aFADs in Goto Islands and stayed for utmost 3 days (Takahashi et al. unpublished data) and from this study yellowfin was observed in June (Table 3-3). The above mentioned fish species are targets for various fisheries including angling, handline and troll fisheries in Goto Islands. Thus, the aFADs are good grounds for fishers targetting such species. This observation concurred with several studies that found out large fish such as *C. hippurus* occured seasonally around aFADs in some areas, due to polewards habitat extensions of juveniles into sub-tropical regions when water temperatures were suitable (Norton 1999, Bennett 2001) or migrationary pathways linked to reproductive behavior in tropical waters (Oxenford 1999).

For the 26 hours observation by underwater camera at the north aFAD, showed that *G. punctata* had a high frequency at 10:00 hrs and 11:00 hrs only and not at sunset. *G. punctata* is a daytime fish and rests at night (Ryõnosuke 1956). It uses daytime to swim around the north aFADs and provided shelter in the night. *S. lalandi* was also observed throughout and recorded highest (above 30) at 05:00 hrs, 06:00 hrs, 10:00 hrs, 11:00 hrs, 17:00 hrs and 18:00 hrs. *S. lalandi* was observed to chase after small fish from the underwater camera recordings. In order to understand such observations, a further study is necessary on stomach contents analysis of the predatory fish such as *S. lalandi*. This is because predation activities have also been observed under anchored floating objects. For instance, marlin *Makaira nigricans* have been observed hunting small schools of blackfin tuna *Thunnus atlanticus* under aFADs in Martinique, Carribean (M. Taquet, Ifremer, Pointe Fort, 97231 Le Robert, Martinique, France, pers. comm.). I anticipated such phenomena in this study that the presence of *S. lalandi* and *C. hipparus* could have been due to feeding on juveniles fish that aggregated around the aFADs. In addition, Kojima (1961) observed migratory fish species such as *S. lalandi* and *C. hippurus* to prey on sardines, *A. semilineatus*, *O. fasciatus* and *O. punctatus*. However, Klima and Wikham (1971) did observe large pelagic predators (e.g. amberjack, *Seriola spp* and *E. bipinnulata* with mixed schools of small pelagic fish e.g. round scad *Decapterus punctatus*, spanish sardine *Sardinella anchovia*, and scaled sardine *Harengula pensacolae*) but the large fish were not feeding on the small ones. The presence of the migratory fish such as *S. lalandi* and *C. hippurus* signified that the aFADs around Goto Islands are good fishing grounds for coastal fishers. This observation indicated that both predators such Thunnus sp., and prey species such as Trachurus sp., were encountered around the aFADs (Fig.3-14). Therefore, I found it necessary to confirm the possibility of predation around the aFADs in Goto Islands in chapter 4. From this study, it is evident that aFADs can function as nursery grounds for juveniles and feeding grounds for the larger fish.

Moreover, these observations could have also been attributed by the different observation techniques used. The underwater camera recorded more families and species of fish than the ROV although diversity was low in the underwater camera observation according to the Shannon diversity indices *H*'. Okamoto (1989) compared 2 different visual observation techniques (SCUBA diving and ROV) around artificial reefs and concluded that their performances were not different when observation was done around flat and open water. However, the diver could observe more species and number of fish when the observation was in a complex seafloor, there was low visibility and smaller size fish existed. This was mainly due to the differences in visual sensitivity between human eyes and cameras. For this study, the other reasons that could have contributed to the findings were 1) Difference in mobility of the two techniques used, 2) Influences of the spatial and temporal fish distribution;

1) Difference in mobility of the two techniques used: I observed fish fauna from top to bottom of the aFAD. The ROV could focus all sides of the aFADs whereby fish and the aFAD were captured on the same screen. Therefore, the ROV could observe fish dwelling on the surface and even the fish that were staying at the aFADs.

Fish species that were frequently observed by the ROV such as *G. punctate, P. breviceps, M. strigatus* and *A. vaigiensis* are categorized as type II or III species by Ogawa's fish behavior categories in the artificial reefs (Table 3-6) (Ogawa 1984) that their bodies come into contact with the objects or swim/stay close to the objects. On the contrary, the underwater camera was fixed on the cylindrical body of the aFAD and I was only able to observe the water column from the aFAD to the outside. For this technique, type II species that come into contact with the body of the aFAD was seldom observed while type III fish including *G. punctate* was frequently observed (Table 3-7).

2) Influences of spatial and temporal fish distribution: Shimizu et al. (2000) studied fish distribution around aFADs in Ishigaki Island, Okinawa by diving observation and reported that large predator fish such as *C. hippurus* and *T. albacares* had maintained horizontal distance of 20-100 m. Also *T. albacares* was reported to stay at a deeper layer around 20 m while *C. hippurus* was near the surface. In case this was the same situation in Goto Islands, then it was difficult for me to observe those species because the ROV was only positioned around the aFADs. The time lapse camera could not be able to focus such long range and was only able to observe the fixed layer of the aFAD. Therefore, I found the fish fauna to be quite different between the two observation techniques during the same season. It is therefore important to understand the distribution of fish schools around the aFADs to gain knowledge about the local marine ecosystem created around the aFADs for sustainable use and better fisheries management. It is also important to understand the characteristics and performance of underwater observation techniques/methods and it is also good to combine plural methods that can compliment each other as shown in a study by Doray et al. (2007). Such findings will help in providing noble ideas for aFADs research activities. In this regard, I investigated the fish distribution in terms of fish assemblages (prey schools) in chapter 4 that are known to aggregate close to far distance from the aFADs, I prefered echo sounding being a good technique for such observations.

Figures and Tables (Chapter 3)

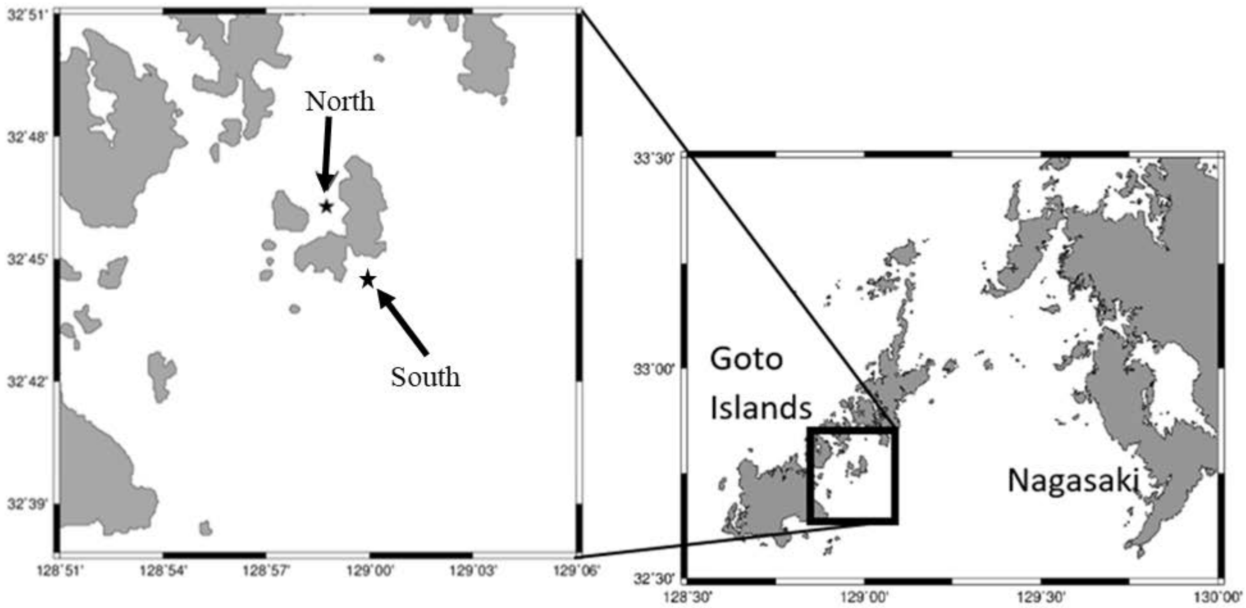


Figure. 3-1 A map of the study sites, the stars indicate positions of the aFADs in Goto Islands

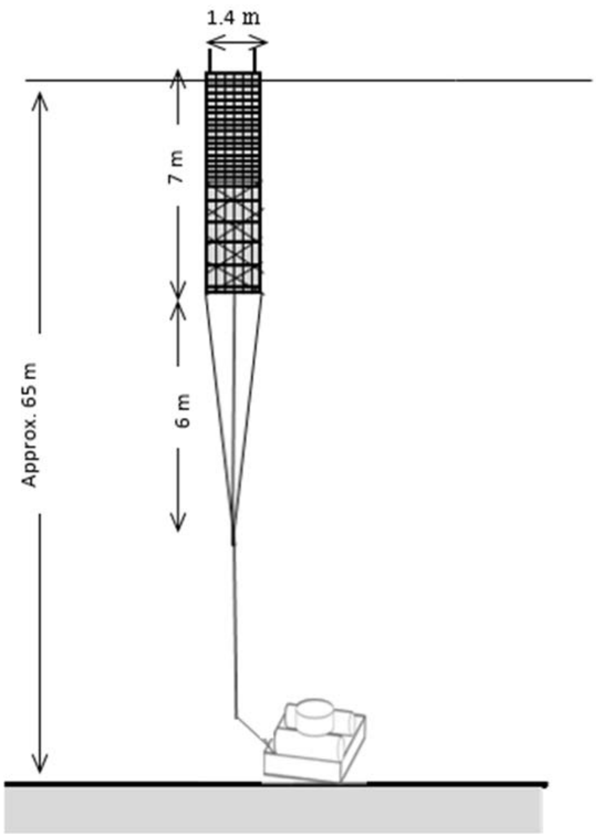


Figure. 3-2. A drawing of the aFADs deployed in the northern part of Kabashima in Goto Islands.

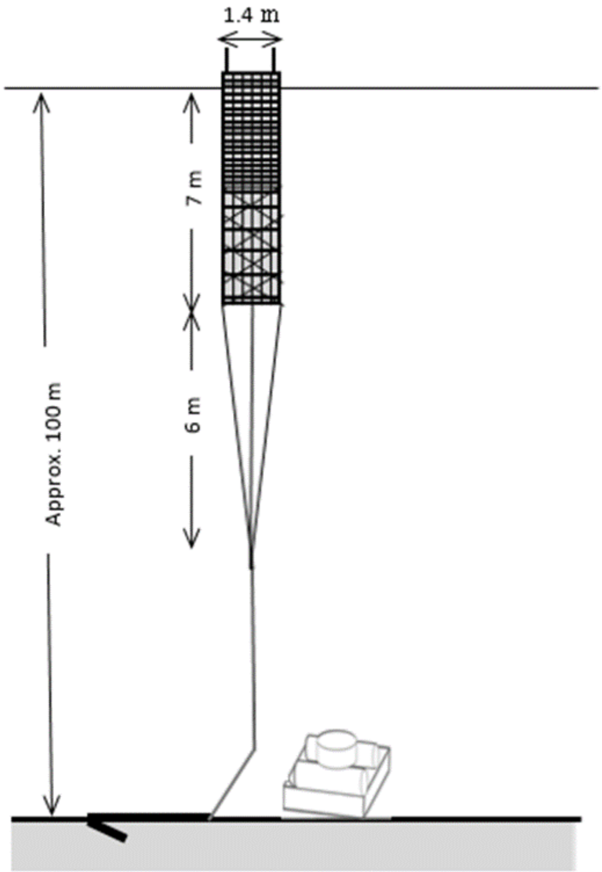


Figure. 3-3. A drawing of the aFADs deployed in the southern part of Kabashima in Goto Islands.

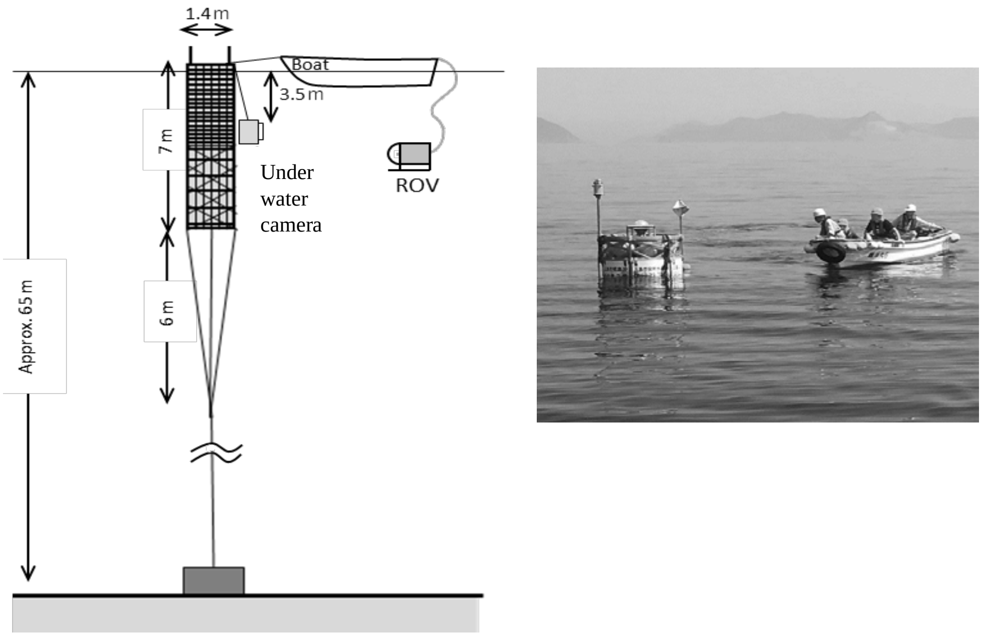


Figure. 3-4. A sketch of aFAD installed in Kabashima Island and the outline of the observation methods (the ROV and the underwater camera).

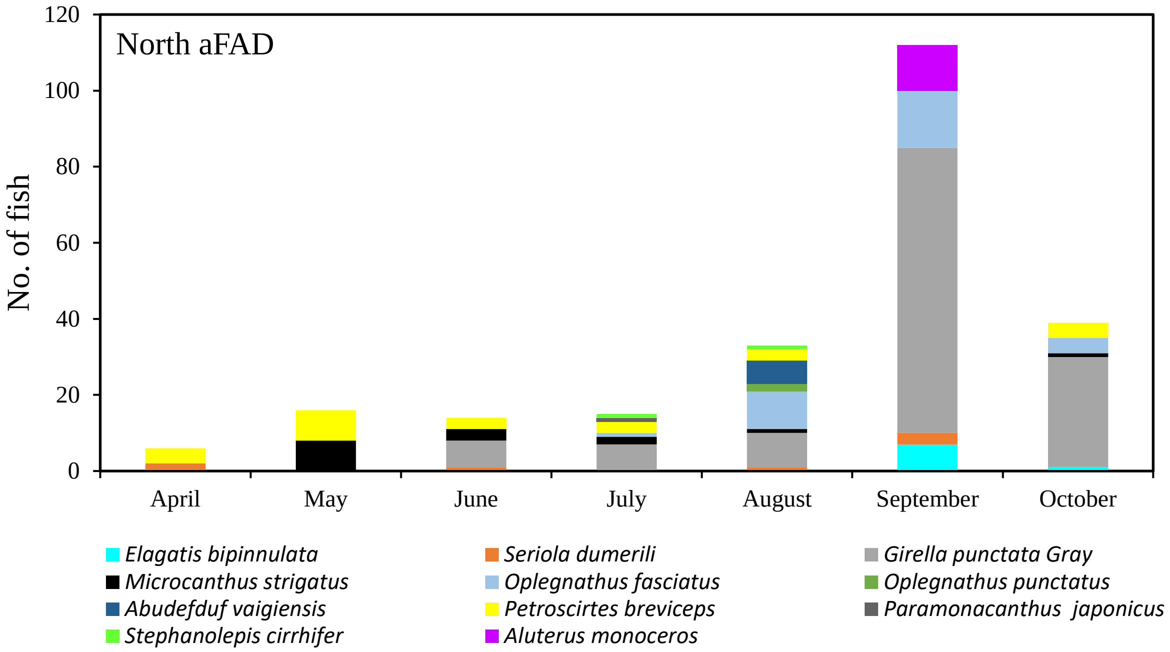


Figure. 3-5. Fish species and number of individuals observed monthly by ROV at the north aFAD

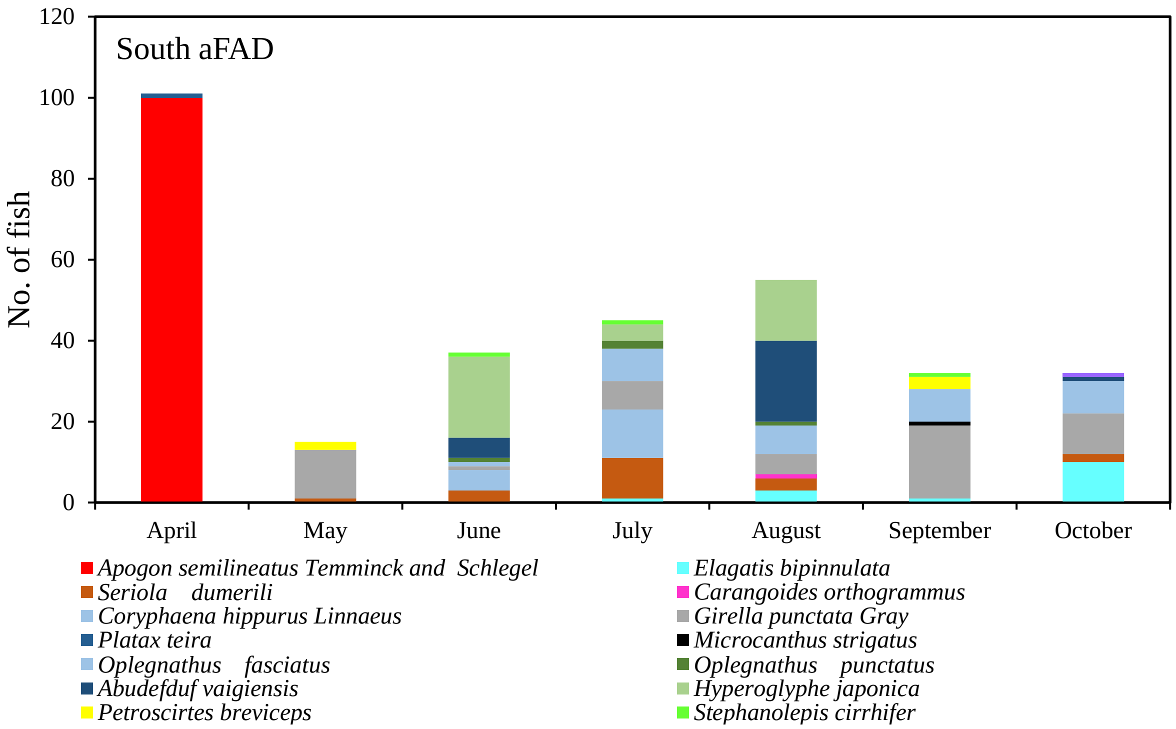


Figure. 3-6. Fish species and number of individuals observed monthly by ROV at the South aFADs

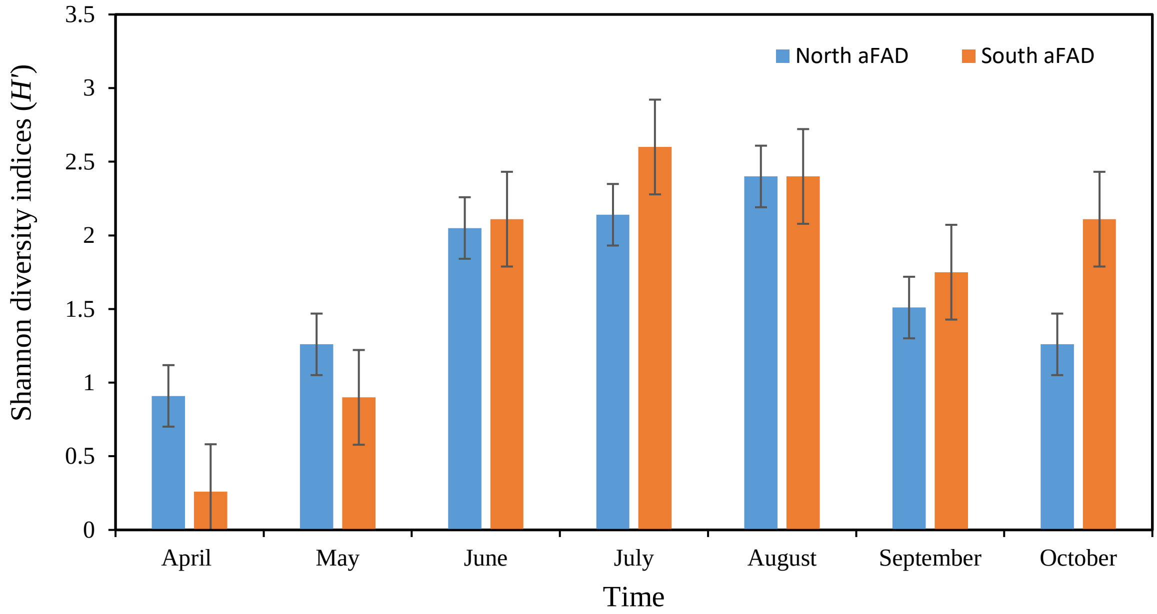


Figure. 3-7. Shannon diversity indices *(H')* of the north and south aFADs observed by ROVs with 95% bootstrap confidence intervals (CIs)

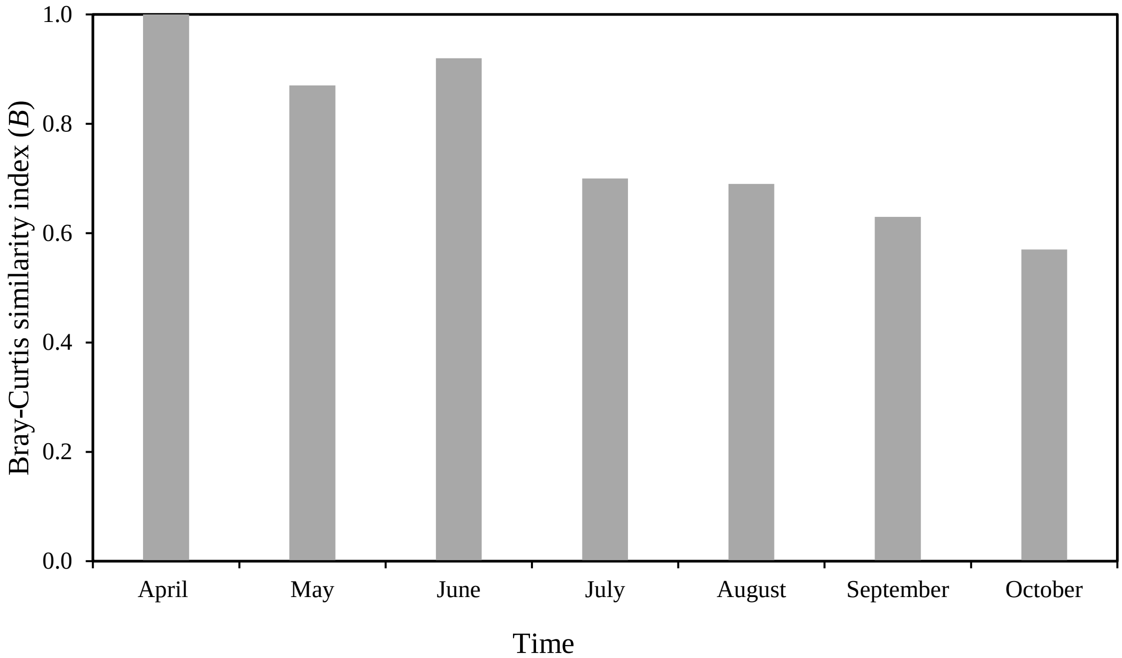


Figure. 3-8. Bray-Curtis similarity index *(B)* of the north and the south aFADs

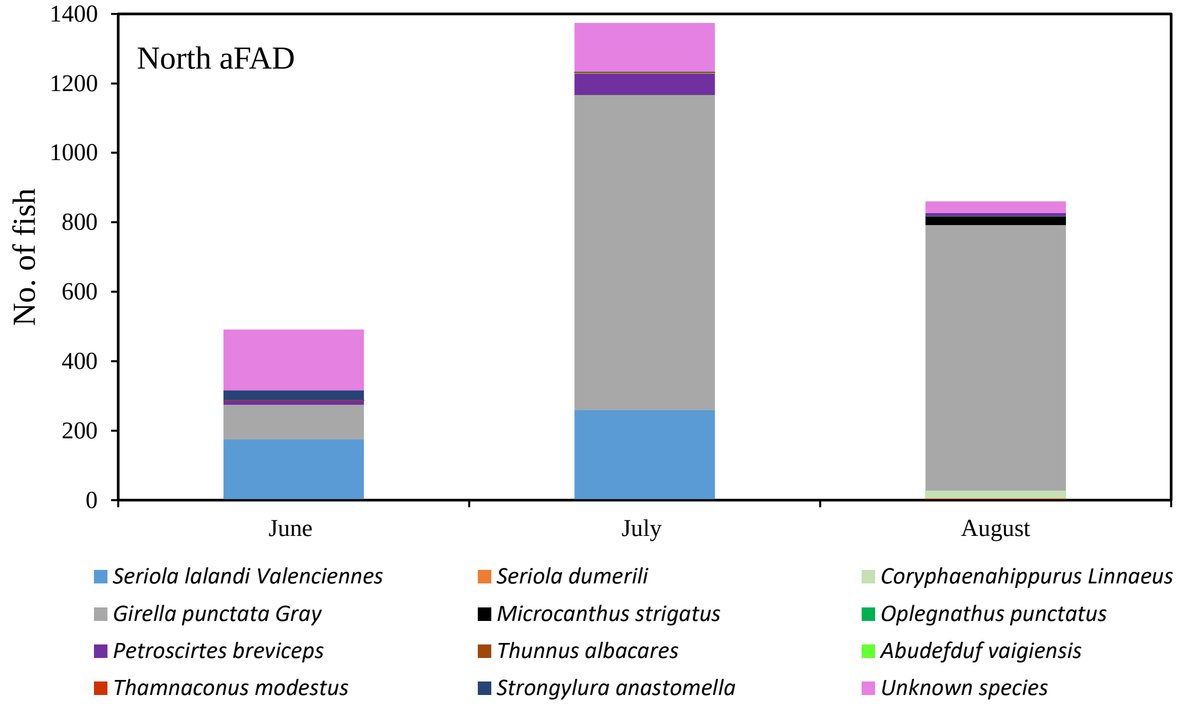


Figure. 3-9. Fish species and number of individuals observed by underwater camera at the north aFAD

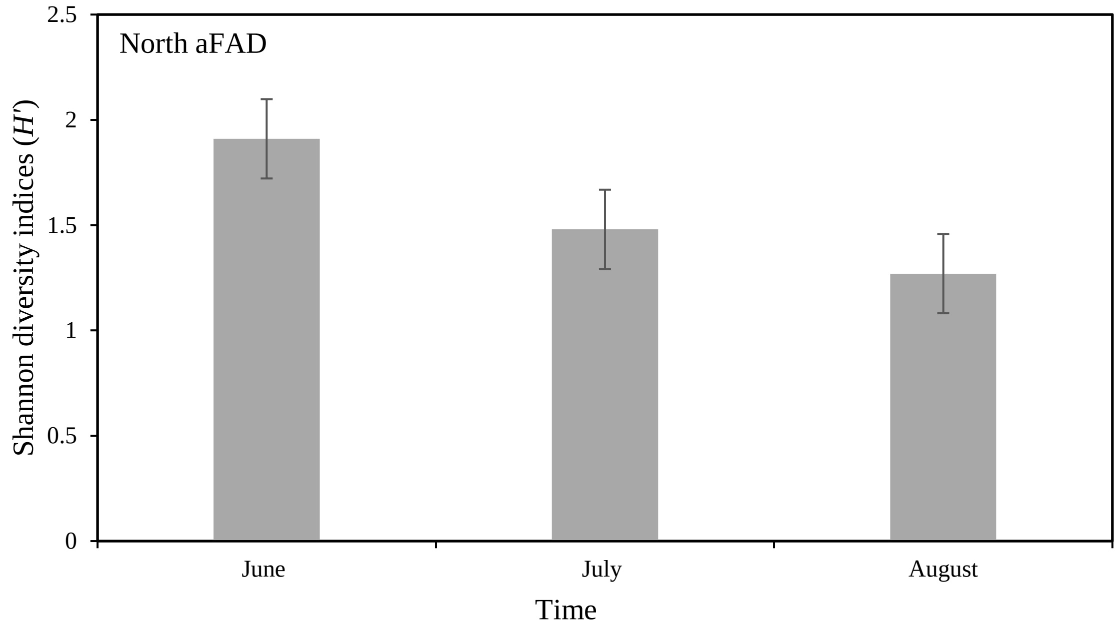


Figure. 3-10. Shannon diversity indices *(H')* of the north aFAD observed by underwater camera with 95% bootstrap confidence intervals (CIs).

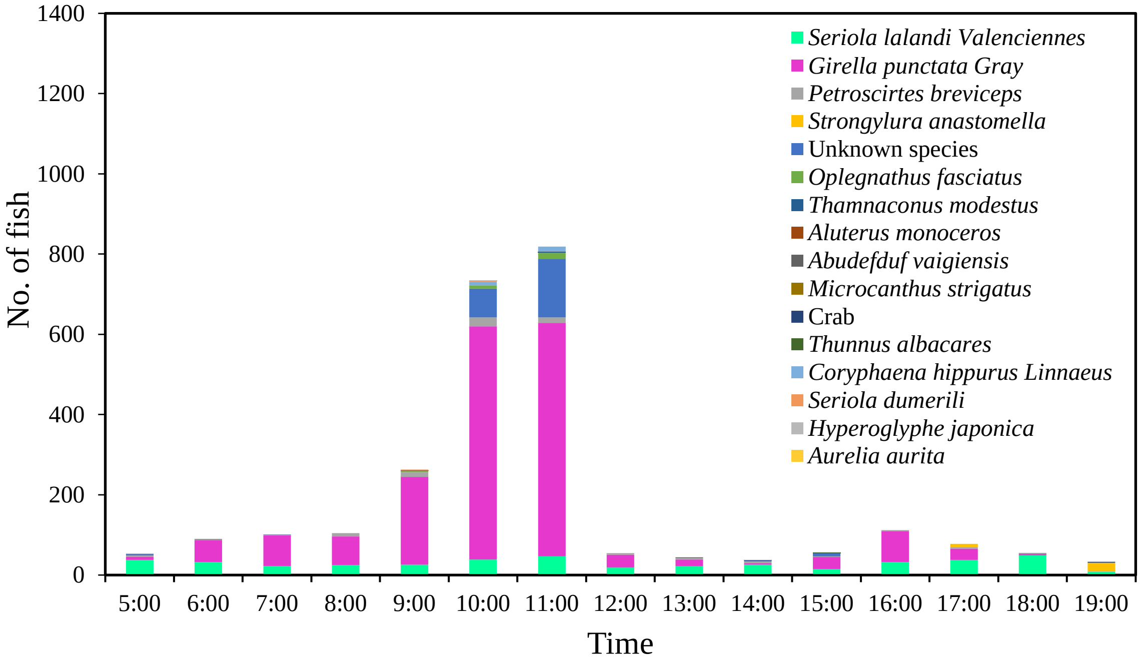


Figure. 3-11. Fish species and number of individuals observed by underwater camera at the north aFAD within a day.

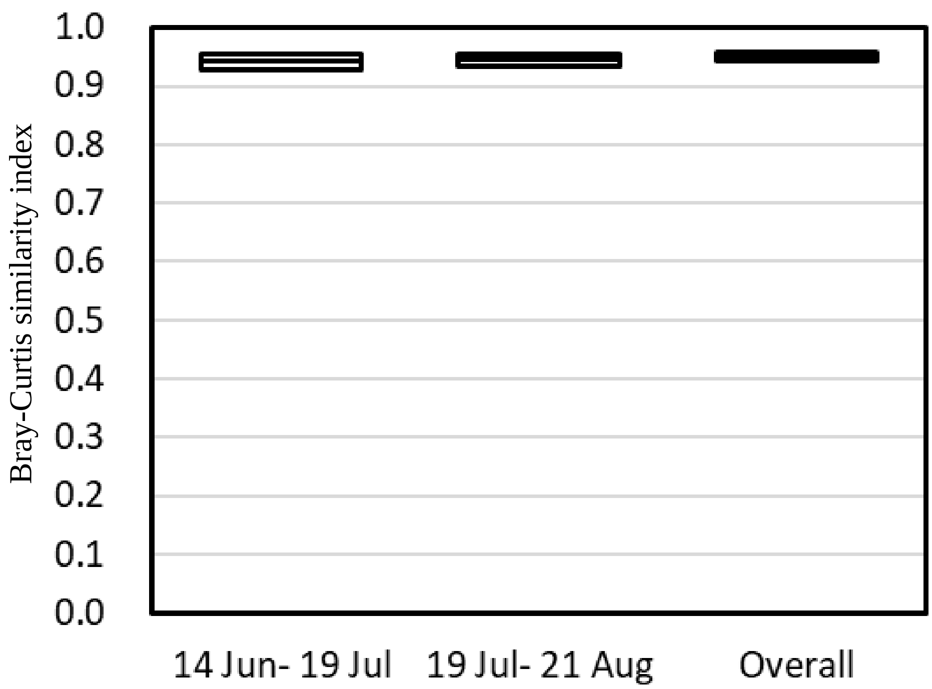


Figure. 3-12. Bray-Curtis similarity index (*B*) between fish fauna by the ROV and the underwater camera with 95% confidence intervals. Horizontal lines in boxes designate Shannon diversity indices and vertical distances of boxes show 95% confidence intervals estimated by bootstrapping (n=1000).

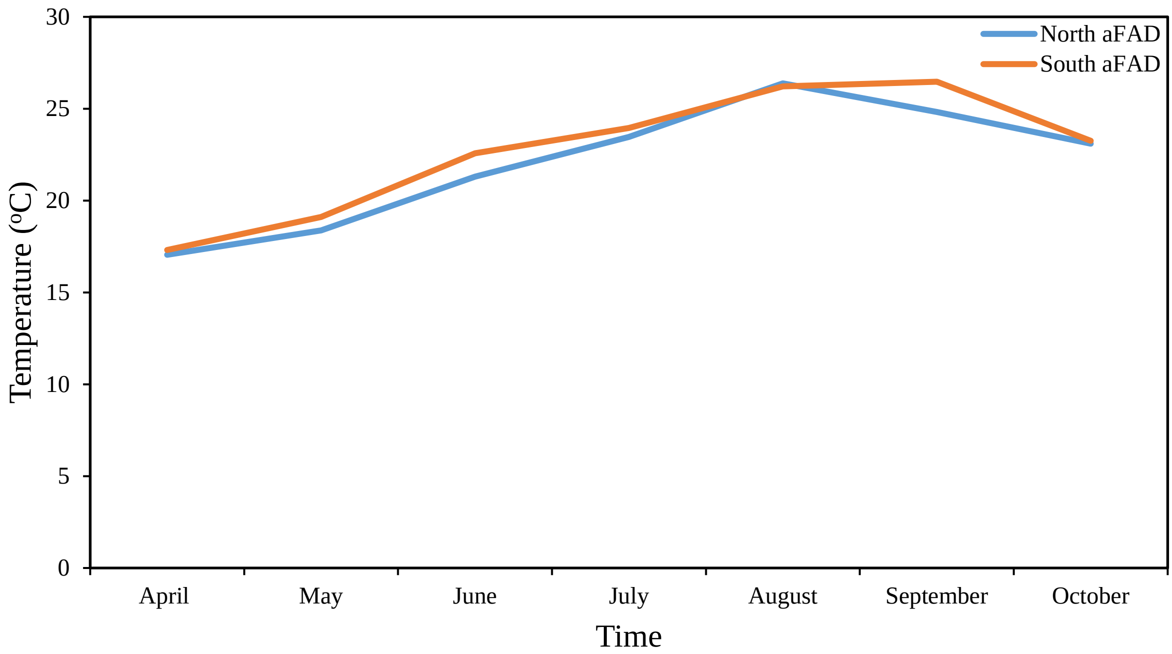


Figure. 3-13. Monthly changes of surface water temperature (3 m) around the north aFAD and the south aFAD obtained from CTD

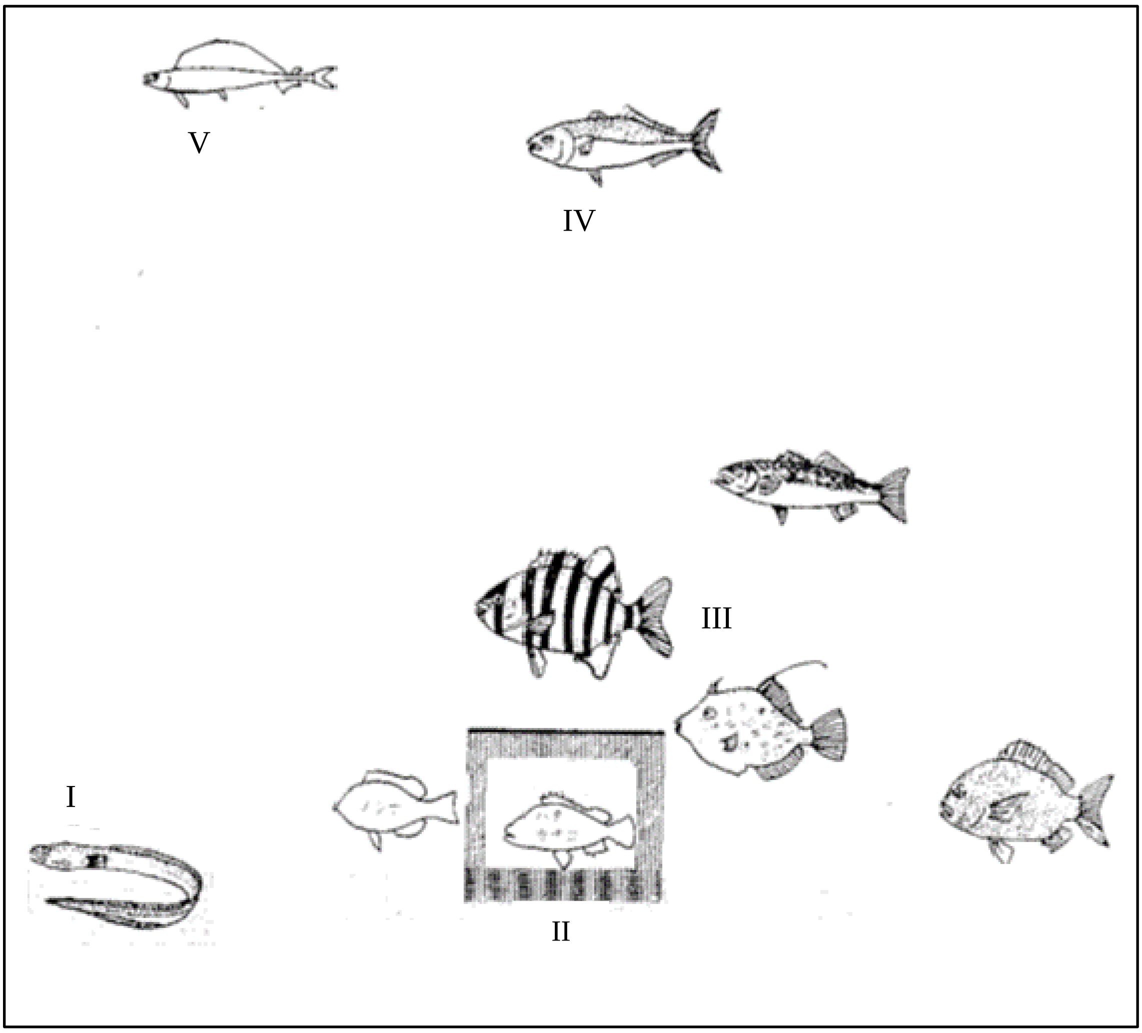


Figure. 3-14. Relative position of fish around the reefs including aFADs (Ogawa 1984). I-V represents type of the environment. The species included I (Japanese eel *Anguilla japonica*), II (rock trout *Hexagrammos otakii*), III (Barred knifejaw *Opleganathus fasciatus*), IV (Trachurus *sp.*,) and V (Thunnus *sp.*,).

Table. 3-1 Fish species and number of individuals observed by ROV around the north aFAD

Order , Family, Species	Common names	April	May	June	July	August	September	October
Beloniformes								
Belonidae								
Strongylura anastomella	Pacific needlefish	0	0	0	0	0	0	0
Perciformes								
Apogonidae								
Apogon semilineatus Temminck and Schlegel	Half-lined cardinal	0	0	0	0	0	0	0
Perciformes								
Carangidae								
Elagatis bipinnulata	Rainbow runner	0	0	0	0	0	7	1
Perciformes								
Carangidae								
Seriola lalandi Valenciennes	Amberjack	0	0	0	0	0	0	0
Perciformes								
Carangidae								
Seriola dumerili	Greater amberjack	2	0	1	0	1	3	0
Perciformes								
Carangidae								
Carangoides orthogrammus	Island trevally	0	0	0	0	0	0	0
Perciformes								
Coryphaenidae								
Coryphaena hippurus Linnaeus	Common dolphinfish	0	0	0	0	0	0	0
Perciformes								
Girellidae								
Girella punctata Gray	Largescale blackfish	0	0	7	7	9	75	29
Perciformes								
Ephippidae								
Platax teira	Longfin batfish	0	0	0	0	0	0	0
Perciformes								
Scorpididae								
Microcanthus strigatus	Stripey	0	8	3	2	1	0	1
Perciformes								
Oplegnathidae								
Oplegnathus fasciatus	Barred knifejaw	0	0	0	1	10	15	4
Perciformes								
Pomacentridae								
Oplegnathus punctatus	Spotted knifejaw	0	0	0	0	2	0	0
Perciformes								
Pomacentridae								
Abudefduf vaigiensis	Indo-Pacific sergeant	0	0	0	0	6	0	0
Perciformes								
Scombridae								
Thunnus albacares	Yellowfin tuna	0	0	0	0	0	0	0
Perciformes								
Centrolophidae								
Hyperoglyphe japonica	bream	0	0	0	0	0	0	0
Perciformes								
Blenniidae								
Petroscirtes breviceps	Black-banded blenny	4	8	3	3	3	0	4
Tetraodontiformes								
Monacanthidae								
Paramonacanthus japonicus	Hair-finned leatherjack	0	0	0	1	0	0	0
Tetraodontiformes								
Monacanthidae								
Stephanolepis cirrhifer	Threadsail filefish	0	0	0	1	1	0	0
Tetraodontiformes								
Monacanthidae								
Thamnaconus modestus	Filefish	0	0	0	0	0	0	0
Tetraodontiformes								
Monacanthidae								
Aluterus monoceros	Leatherjacket	0	0	0	0	0	0	0

Table.3-2 Fish species and number of individuals observed by ROV around the south aFAD

Order , Family, Species	Common names	April	May	June	July	August	September	October
Beloniformes Belonidae *Strongylura anastomella*	Pacific needlefish	0	0	0	0	0	0	0
Perciformes Apogonidae *Apogon semilineatus Temminck and Schlegel*	Half-lined cardinal	100	0	0	0	0	0	0
Perciformes Carangidae *Elagatis bipinnulata*	Rainbow runner	0	0	0	1	3	1	10
Perciformes Carangidae *Seriola lalandi Valenciennes*	Amberjack	0	0	0	0	0	0	0
Perciformes Carangidae *Seriola dumerili*	Greater amberjack	0	1	3	10	3	0	2
Perciformes Carangidae *Carangoides orthogrammus*	Island trevally	0	0	0	0	1	0	0
Perciformes Coryphaenidae *Coryphaena hippurus Linnaeus*	Common dolphinfish	0	0	5	12	0	0	0
Perciformes Girellidae *Girella punctata Gray*	Largescale blackfish	0	12	1	7	5	18	10
Perciformes Ephippidae *Platax teira*	Longfin batfish	1	0	0	0	0	0	0
Perciformes Scorpididae *Microcanthus strigatus*	Stripey	0	0	0	0	0	1	0
Perciformes Oplegnathidae *Oplegnathus fasciatus*	Barred knifejaw	0	0	1	8	7	8	8
Perciformes Pomacentridae *Oplegnathus punctatus*	Spotted knifejaw	0	0	1	2	1	0	0
Perciformes Pomacentridae *Abudefduf vaigiensis*	Indo-Pacific sergeant	0	0	5	0	20	0	1
Perciformes Scombridae *Thunnus albacares*	Yellowfin tuna	0	0	0	0	0	0	0
Perciformes Centrolophidae *Hyperoglyphe japonica*	bream	0	2	0	0	0	3	0
Perciformes Blenniidae *Petroscirtes breviceps*	Black-banded blenny	0	2	0	0	0	3	0
Tetraodontiformes Monacanthidae *Paramonacanthus japonicus*	Hair-finned leatherjacket	0	0	0	0	0	0	0
Tetraodontiformes Monacanthidae *Stephanolepis cirrhifer*	Threadsail filefish	0	0	1	1	0	1	0
Tetraodontiformes Monacanthidae *Thamnaconus modestus*	Filefish	0	0	0	0	0	0	0
Tetraodontiformes Monacanthidae *Aluterus monoceros*	Leatherjacket	0	0	0	0	0	0	1

Table.3-3 Fish species and number of individuals observed by underwater camera around the north aFAD in June

Order , Family, Species	Common names	14th	15th	16th	17th	18th	19th	20th	21st	22nd	23rd	24th	25th	26th	27th	28th	29th	30th
Beloniformes																		
Belonidae																		
Strongylura anastomella	Pacific needlefish	8	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Apogonidae																		
Apogon semilineatus Temminck and Schlegel	Half-lined cardinal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Carangidae																		
Elagatis bipinnulata	Rainbow runner	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Carangidae																		
Seriola lalandi Valenciennes	Amberjack	0	1	0	0	0	0	2	11	25	27	23	18	22	11	8	5	22
Perciformes																		
Carangidae																		
Seriola dumerili	Greater amberjack	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Carangidae																		
Carangoides orthogrammus	Island trevally	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Coryphaenidae																		
Coryphaena hippurus Linnaeus	Common dolphinfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Girellidae																		
Girella punctata Gray	Largescale blackfish	0	0	5	3	4	3	2	2	1	9	0	17	5	12	23	4	10
Perciformes																		
Ephippidae																		
Platax teira	Longfin batfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Scorpididae																		
Microcanthus strigatus	Stripey	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Oplegnathidae																		
Oplegnathus fasciatus	Barred knifejaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Pomacentridae																		
Oplegnathus punctatus	Spotted knifejaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Pomacentridae																		
Abudefduf vaigiensis	Indo-Pacific sergeant	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Scombridae																		
Thunnus albacares	Yellowfin tuna	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Centrolophidae																		
Hyperoglyphe japonica	bream	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																		
Blenniidae																		
Petroscirtes breviceps	Black-banded blenny	0	0	0	2	1	2	1	0	0	3	1	0	0	0	0	1	1
Tetraodontiformes																		
Monacanthidae																		
Paramonacanthus japonicus	Hair-finned leatherjacket	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraodontiformes																		
Monacanthidae																		
Stephanolepis cirrhifer	Threadsail filefish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraodontiformes																		
Monacanthidae																		
Thamnaconus modestus	Filefish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraodontiformes																		
Monacanthidae																		
Aluterus monoceros	Leatherjacket	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unknown species		0	8	14	0	0	0	0	0	0	0	0	0	0	28	0	125	0

Table. 3-4 Fish species and number of individuals observed by underwater camera around the north aFAD in July

Order , Family, Species	Common names	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th	21st	22nd	23rd	24th	25th	26th	27th	28th	29th	30th	31st
Beloniformes																																
Belonidae																																
Strongylura anastomella	Pacific needlefish	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Apogonidae																																
Apogon semilineatus Temminck and Schlegel	Half-lined cardinal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Carangidae																																
Elagatis bipinnulata	Rainbow runner	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Carangidae																																
Seriola lalandi Valenciennes	Amberjack	29	46	14	9	0	1	2	2	11	9	23	27	19	4	15	24	14	6	2	0	0	1	1	0	1	0	0	0	0	0	0
Perciformes																																
Carangidae																																
Seriola dumerili	Greater amberjack	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Carangidae																																
Carangoides orthogrammus	Island trevally	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Coryphaenidae																																
Coryphaena hippurus Linnaeus	Common dolphinfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Girellidae																																
Girella punctata Gray	Largescale blackfish	6	19	17	104	11	1	6	20	21	19	10	11	1	32	56	88	88	21	3	0	5	50	117	18	52	78	2	8	4	23	15
Perciformes																																
Ephippidae																																
Platax teira	Longfin batfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Scorpididae																																
Microcanthus strigatus	Stripey	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Oplegnathidae																																
Oplegnathus fasciatus	Barred knifejaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Pomacentridae																																
Oplegnathus punctatus	Spotted knifejaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Pomacentridae																																
Abudefduf vaigiensis	Indo-Pacific sergeant	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Scombridae																																
Thunnus albacares	Yellowfin tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Centrolophidae																																
Hyperoglyphe japonica	bream	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																																
Blenniidae																																
Petroscirtes breviceps	Black-banded blenny	1	1	1	7	12	3	3	4	0	0	0	0	0	0	0	1	1	3	1	0	2	3	5	7	0	1	2	0	1	0	2
Tetraodontiformes																																
Monacanthidae																																
Paramonacanthus japonicus	Hair-finned leatherjacket	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraodontiformes																																
Monacanthidae																																
Stephanolepis cirrhifer	Threadsail filefish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraodontiformes																																
Monacanthidae																																
Thamnaconus modestus	Filefish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Tetraodontiformes																																
Monacanthidae																																
Aluterus monoceros	Leatherjacket	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unkown species		0	0	12	0	0	21	0	7	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table. 3-5 Fish species and number of individuals observed by underwater camera around the north aFAD in August

Order , Family, Species	Common names	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
Beloniformes																					
Belonidae																					
Strongylura anastomella	Pacific needlefish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																					
Apogonidae																					
Apogon semilineatus Temminck and Schlegel	Half-lined cardinal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																					
Carangidae																					
Elagatis bipinnulata	Rainbow runner	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																					
Carangidae																					
Seriola lalandi Valenciennes	Amberjack	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																					
Carangidae																					
Seriola dumerili	Greater amberjack	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0
Perciformes																					
Carangidae																					
Carangoides orthogrammus	Island trevally	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																					
Coryphaenidae																					
Coryphaena hippurus Linnaeus	Common dolphinfish	0	0	0	0	0	0	0	4	12	0	1	0	0	0	0	0	5	0	0	0
Perciformes																					
Girellidae																					
Girella punctata Gray	Largescale blackfish	48	0	44	9	3	20	0	2	1	1	3	1	0	390	191	1	8	10	28	5
Perciformes																					
Ephippidae																					
Platax teira	Longfin batfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																					
Scorpididae																					
Microcanthus strigatus	Stripey	0	0	2	0	0	3	0	1	0	0	0	0	0	5	8	3	1	1	0	1
Perciformes																					
Oplegnathidae																					
Oplegnathus fasciatus	Barred knifejaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																					
Pomacentridae																					
Oplegnathus punctatus	Spotted knifejaw	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Perciformes																					
Pomacentridae																					
Abudefduf vaigiensis	Indo-Pacific sergeant	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																					
Scombridae																					
Thunnus albacares	Yellowfin tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																					
Centrolophidae																					
Hyperoglyphe japonica	bream	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perciformes																					
Blenniidae																					
Petroscirtes breviceps	Black-banded blenny	2	1	1	2	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Tetraodontiformes																					
Monacanthidae																					
Paramonacanthus japonicus	Hair-finned leatherjack	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraodontiformes																					
Monacanthidae																					
Stephanolepis cirrhifer	Threadsail filefish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraodontiformes																					
Monacanthidae																					
Thamnaconus modestus	Filefish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraodontiformes																					
Monacanthidae																					
Aluterus monoceros	Leatherjacket	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unknown species		0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3-6. The association of fish species around the aFADs observed by ROV, modified from (Ogawa 1984)

Type of the environment	Fish species
Type II	*Petroscirtes breviceps, Apogon semilineatus Temminck and Schlegel , Platax teira , Hyperoglyphe japonica*
Type III	*Microcanthus strigatus, Girella punctata Gray, paramonacanthus japonicas, Oplegnathus fasciatus, Oplegnathus punctatus, Stephanolepis cirrhifer, Aluterus monoceros, Elagatis bipinnulata, Abudefduf vaigiensis*
Type IV	Juveniles of *Seriola lalandi Valenciennes ,Carangoides orthogrammus*
Type V	*Coryphaena hippurus Linnaeus*

Table 3-7. The association of fish species around the aFADs observed by underwater camera, modified from (Ogawa 1984)

Type of the environment	Fish species
Type II	*Petroscirtes breviceps, Hyperoglyphe japonica*
Type III	*Microcanthus strigatus, Girella punctata Gray,* juveniles of *Oplegnathus fasciatus, Thamnaconus modestus Aluterus monoceros, Abudefduf vaigiensis*
Type IV	Juveniles of *Seriola dumerili*
Type V	*Seriola lalandi Valenciennes, Coryphaena hippurus Linnaeus, Thunnus albacares*

Chapter 4

Evaluation of fish attraction around aFADs by use of acoustic technique; echosounder

This chapter further investigated the distribution of fish schools around the aFADs using echo sounder. I also confirmed the possibility of predation process around the aFADs having observed presence of predatory fish in my previous chapter. It is often suggested that large predators, such as *T. albacares* and *C. hippurus* are attracted to aFADs by the aggregations of juvenile fishes (Wickham et al. 1973; Barut 1988), although other studies have cast doubt on whether predatory species feed extensively upon the juvenile fishes around aFADs (Brock 1985; Buckley and Miller 1994). It is known that biological interactions among the various species around aFADs may influence assemblage composition. Species-specific patterns of use and residence times may contribute significantly to short-term variability of fish assemblages at aFADs. This chapter explored on such possibilities around the aFADs by use of echosounder.

Echosounders have proven to be a powerful tool in studying the spatial and temporal distributions of fish schools in broad areas (Stanton et al. 2010). It has long been recognized that acoustic backscatter strength gives the total pixels that represents the fish schools and can be used to make inferences about the species composition and size distribution of acoustic scatterers (Holliday and Pieper 1995; Jech and Michaels 2006). Therfore, I adopted this technique in my study to determine the distribution of fish schools around the aFADs to confirm with the observation made in chapter 3.

4.1 Materials and methods

4.1.1 Study site

The study site was around aFADs presented in chapter 3; refer map (Fig.3-1) and sketches of aFADs drawings (Figs.3-2, 3-3).

4.1.2 Echosounder specifications

Echo sounder, FSS-1BB (Furuno, Japan) multi-frequency echo sounder that distinguish between fish species was equipped on Kakuyo maru. FSS-1BB equipped with CHIRP (Compressed High-intensity Radar Pulse) technology which modifies the pulse so that a range of frequencies are between 28 to 60 kHz and 130 to 210 kHz. The transmission of a modulated pulse across these ranges, targets pulses that are closer together than a particular pulse length, reflect the pulse at a different frequency for those further apart than the pulse length, and each shows up separately on the monitor at a range or pulse sweep known as the bandwidth. The echo signal that return from a target, is the same as the frequency with which the target was struck, so two targets even close together in shallow water will return a slightly different frequency signal that gives quite simply, stunningly improved separation and detail results. The Delta SV Echogram, a frequency distribution of difference in echo intergral (SVs) between two CHIRP frequencies, in FSS-1BB provides information, in % probability, of the three species displayed, it also provided information on the lower depth, upper depth, latitude and longitude of where the fish was observed (Fig 4-2). The echo integration technique assessed the fish abundance by depth layers and by location but does not acoustically measure fish biomass by species.

Based on the database of FSS-1BB of Kakuyo maru, echoes were distinguished into three distinguished species i.e. either as jack mackerel *Trachurus japonicus*, Japanese anchovy *Engraulis japonicus* or silver-stripe round herring *Spratelloides gracilis* (hereafter to be referred to as jack mackerel, anchovy and herring respectively). These species had been set in the database of FSS-1BB while echo data and angling results were made to coinside with each other by Kakuyo maru. The operator with a quick glance at the screen can easily get an overview and can further choose to mark an area with the mouse for further analysis. The screenshot showed fish schools of the three main categories including jack macherel, anchovy and herring with percentage distribution and the depth. The particular fish school where the arrow is pointing at is shown on the lower part of the right side at low resolution. Which is also shown on the left screen at high resolution and the parameters extracted from this school are given in the table on the lower image to describe the fish school (Fig. 4-2).

4.1.3 Data collection

The study was carried out around the north and south aFADs periodically for 17 times monthly cruises, a total of 27 days on-board Kakuyo maru from April 2017 to October 2018 except for January 2018 (due to unfavorable weather condition) and in March 2018 (when the training ship was serviced) (Table 4-1). I used an 8-direction line-transect surveys to ensure Kakuyo maru frequently passed near the head of the aFADs during the surveys similar to Josse et al. (1999). The surveys were done around each aFADs at a radius of 0.4 nm (approximately 740 m) from each aFAD. This method sampled an area well centered around the aFADs and suited this study (Fig 4-1).

Flow condition data around aFADs was collected by Acoustic Doppler Current Profiler (ADCP, Ocean Surveyor, Teledyne RD Instruments, USA) simultaneously with the line-transects. Also, immediately after the line-transects, conductivity, temperature and depth data was also collected by CTD (SBE-911 plus, Sea-bird Scientific, USA).

4.1.4 Data analysis

The acoustic data obtained from the training ship's PC installed with echosounder software was downloaded and ran in the laboratory using FURUNO FSS-IBB echogram replay software installed in the laboratory's PC. Screen shots of the fish schools' images were taken and saved. Thereafter, post processing of the images was performed using image analysis software (ImageJ ver. 1.51g, USA). The purpose of image processing is acoustic shoal detection as defined by Weill et al. (1993) comprising a set of samples (pixels) which form an echogram. Echo images were binarized (black/white) by using RGB values. Then analysed to measure the aggregate of the selected echoes individually as strength values. Strength value is a logarithmic measure of the proportion of the incident energy backscattered by the target (MacLennan and Simmonds 1992). Summation of the strength values represented the total pixels (size of fish school observed in one transect). In addition, the date of survey, exact positions of the fish schools (longitudes and latitudes), actual time that the fish schools were observed, depth discrimination from the top part and the bottom part of the image (lower depth and upper depth), the Sea Surface Temperature (SST), the actual temperature where the fish school was observed (obtained from the CTD), water current velocity at the exact depth where the fish schools were observed and the probability of percentage composition for the three main fish schools were also integrated for analysis.

I determined the temporal and spatial distributions of fish schools recorded in 2017 and 2018 both in the north and south aFADs. The horizontal distance between observed school and aFAD was calculated as:

$$d = \sqrt{(l_A \Delta\Theta_{\mathrm{AB}})^2 + (l_a \Delta ø_{\mathrm{AB}})^2}$$

Where d is the horizontal distance between the fish school and the aFADs, l_{A} is the distance per every longitude where the fish school was observed, Θ_{AB} is the coordinate of the longitude where the fish school was observed. l_{a} is the distance per every latitude where the fish school was observed. $ø_{\mathrm{AB}}$ is the coordinate of the longitude where the fish school was observed.

Species identification for the observed fish schools was also done by using the Delta SV Echogram of FSS-1BB. From the percentage probability obtained from the three main schools, if a particular school either jack mackerel, anchovy and herring composition probability was >80%. I chose that to be the particular species for that transect.

4.2 Results

4.2.1 Distribution of fish schools around the north and south aFADs

Generally, more number of fish schools were observed at the north aFAD as compared to the south aFAD. At the north aFAD in 2017, the highest number of fish schools were recorded in July (61) followed by August (54) and lowest was recorded in May (7) while in 2018 the number of fish schools peaked in May (47) earlier than the previous year and recorded lowest number of fish schools in October (3). At the south aFAD, highest number of fish schools were observed in July (26) and December (26) and the lowest number was recorded in September (1) in 2017. In 2018, highest number of fish schools were recorded in April (26) and lowest in August (2) (Fig.4-3).

In terms of numbers of fish schools for the individual three main species was as followed; at the north aFAD in 2017, jack mackerel recorded the highest number of fish schools in July (26), followed by August (18) and recorded the lowest number of fish schools in November (1). Anchovy recorded the highest number of fish schools in August (47) followed by July (37) and lowest in May (2). Herring recorded highest number of fish schools in August (32), July (15) and lowest in May (1). In 2018, jack mackerel recorded highest number of fish schools in May (10), followed by August (9) and lowest in February (1). In addition, anchovy recorded highest number of fish schools in May (34) followed by June (30), July (27) and recorded lowest number of fish schools in February (2). While herring recorded highest number of fish schools in June (25), followed by May (24) and recorded lowest in February (1) (Fig.4-4).

Moreover, at the south aFAD, the number of fish schools recorded was lowest compared to the north aFAD. In 2017, jack mackerel recorded highest number of fish schools in June (12), followed by December (12) and recorded lowest number of fish school in October (1). Anchovy recorded highest number in July (13), followed by June (11) and lowest in October (5). Herring recorded same number of fish schools in May (9) and June (9) which was the highest recorded. The lowest number of fish school was recorded in October (2) and November (2). In 2018, jack mackerel recorded highest number of fish schools in April (7) and lowest in August (1), anchovy recorded highest number of fish schools in June (10), then April (7) and May (7) and lowest in July (1) and August (1). Herring recorded highest number of fish schools in June (10) and lowest in September (1) (Fig.4-5).

In terms of the school size, medium school size recorded the highest number in both the aFADs in all the months and largest school size recorded the least. In 2017, at the north aFAD, medium school size recorded the highest in July (47) and August (27). In 2018, May (28) recorded the highest number of medium school size. At the south aFAD, the highest number of medium school size was recorded in June (15) followed by July (10) in 2017 while in 2018 April (21) recorded highest number followed by May (10) (Fig. 4-6). At the north aFAD, mostly small, medium, large and largest school sizes were observed to aggregate closer and on the upper side of the aFAD while at the south aFAD the different school sizes were mostly aggregated on the downward side of the aFAD, very few small and large school sizes were distributed away from the aFAD (Fig.4-7).

Generally, at the north aFAD jack mackerel and anchovy recorded highest number of medium school size about 63% and 48% respectively. Herring recorded highest number of large school size 43%.

At the south aFAD, all the three species recorded highest number of medium school size for jack mackerel was (44%), anchovy (50%) and herring (50%) while the largest school size recorded 1% for jack mackerel and anchovy (Fig.4-8).

4.2.2 Distances of fish schools from the aFADs

Around both aFADs, all the categories of school size tended to concentrate more at 100 m from both the aFADs and the numbers decreased with increase distance from the aFADs. Medium school size recorded highest number in all the distance from the aFADs. Followed by large school size. Largest school size recorded the least in terms of numbers and the distance from the aFADs (Fig.4-9).

In terms of individual species distribution, all the three species around both aFADs recorded more number of fish schools at 100 m from the aFADs than further from the aFADs (600 m). The number of fish schools decreased with increased distance from the aFADs. At the north aFAD, jack mackerel recorded the least number of fish schools with increased distance from the aFAD. At 100 m recorded (27) and at 600 m recorded (2). Anchovy recorded higher number of fish schools in all the distance from the aFAD as compared to the other two species. At 100 m recorded (66) and at 600 m was (5) while herring at 100 m was (51) and at 600 m recorded (4). At the south aFAD, at 100 m, jack mackerel and anchovy recorded same number of fish schools (23) and herring recorded (19). Jack mackerel recorded a fish school (1) at 700 m (Fig. 4-10). Thus, all the 3 species tended to stay closer to the aFADs.

4.2.3 Number of fish schools in terms of depth distribution around the aFADs

Around the north aFAD, medium school size recorded most number of fish schools in all the depths along the water column and recorded highest number (97) at 70 m depth. Followed by 60 m depth that recorded (43) number of fish schools. The lowest number of medium size fish schools was recorded at 80 m depth (3). Small school size recorded the highest number of fish schools at 70 m depth (20). Large school size was only recorded at 30 m depth (1) and 60 m depth (3). The largest school size was recorded at 30 m - 50 m depth and 70 m – 80 m depth. While around the south aFAD, small, medium and large school sizes were recorded in all depths. All the three school sizes recorded highest number of fish schools at 100 m depth such as small, medium and large school size recorded (7), (36) and (12) respectively. The largest school size was only recorded at 60 m depth (2) and 90 m depth (1) (Fig.4-11).

The three species were observed to be distributed throughout the water column at both aFADs. Around the north aFAD, at 70 m depth jack mackerel and herring recorded the same number of fish schools (27%) while anchovy recorded the highest (46%). The lowest number of fish schools was recorded at 10 m depth and the distribution was jack mackerel (7%), anchovy (14%) and herring (7%). At the south aFAD, highest number of fish schools were distributed between 90 m and 110 m depth. At

100 m, jack mackerel recorded (37%), anchovy (39%) and herring (25%). While the lowest was recorded at 50 m depth by jack mackerel and herring of (1%) (Fig.4-12).

Fish schools were distributed along the water column in summer from June to August in both years. In 2017, there was hardly fish schools recorded in April but in May jack mackerel and anchovy were distributed between 60 m and 70 m. In 2018, fish schools were distributed between 10 m to 40 m depth and between 80 m to 100 m depth in April and May. In winter, schools of jack mackerel and herring were observed between 50 m to 60 m and between 70 m and 80 m in both years (Fig.4-13).

At the south aFAD in 2017, fish schools were distributed throughout the water column and dominated by anchovy and mackerel in June and July, herring was only observed in some depths such as 20 m, 50 m, 80 m and 95 m. In 2018, the fish schools were mainly composed of anchovy and herring between 15 m - 35 m and 80 - 90 m, jack mackerel was only observed at 40 m depth. In winter, the fish schools were between 85 m to 100 m deep in both years (Fig. 4-14).

4.2.4 Temperature and fish schools around the aFADs

At the north aFAD, fish schools increased with increased temperature and peaked in July (22^{o}C) in 2017 and May (18^{o}C) in 2018. Increased in temperature in August (23^{o}C) resulted to a decrease in fish schools in the first year. Similar pattern was observed in June the following year where temperature increased to 21^{o}C and the fish schools decreased. The fish schools continued to decrease due to temperature decrease and recorded the lowest in February 2018 with temperature of 14^{o}C. The fish schools started to increase again with increase in temperature and peaked in August (25^{o}C) but started to decrease in October when temperature was 21^{o}C. At the south aFAD, the temperature pattern was not so clear between the observed temperature and fish schools due to unfavourable weather conditions since the aFAD is located in the open sea. I observed, fish schools increased with increased temperature in the first 4 sampling months until July (20^{o}C) there after increase in temperature led to decrease in fish schools. High number of fish schools were recorded between 17^{o}C and 19^{o}C (Fig.4-15).

For each species, at the north aFAD, there was no clear pattern between the number of fish species and the temperature. I observed jack mackerel was (16) highest in terms of numbers of fish schools when temperature was 17^{o}C, the number of anchovy was high with increased temperature, at 17^{o}C the number of fish schools was 26, at 20^{o}C the number of fish schools was 40 and at 23^{o}C the number of fish schools was 41. For herring, the number of fish schools was high 34 when temperature was 23^{o}C and the number decreased (27) with decreased in temperature 20^{o}C. While at the south aFAD, number of fish schools for mackerel (24), anchovy (20) peaked when the temperature was 17^{o}C, and herring peaked (11) at 18^{o}C (Fig.4-16).

4.2.5 Current conditions in terms of velocity and direction in relation to fish schools around the aFADs

Number of fish schools increased with decrease in current velocity around the north aFAD. High number of fish schools was recorded in July and August 2017 when the current velocity was lowest 131 mm/s and 240 mm/s respectively. However, it was different in May 2018, that recorded high velocity 2,685 mm/s and high number of fish schools. Further increased in velocity resulted to decrease in number of fish schools. The dominant direction at the north aFAD observed was East South East (ESE) and South South East (SSE) where the fish schools were peaked. At the south aFAD, the number of fish schools increased with decrease in velocity. The dominant direction was East (E) and East South East (ESE) where the fish schools recorded highest in numbers. The number of fish schools were high in July and December 2017 where the velocity was amongst the lowest 143 mm/s and 291 mm/s respectively. However, in September 2017 and April 2018 the current velocity was zero (Fig. 4-17).

In terms of species distribution, lowest velocity recorded highest number of jack mackerel (51), anchovy (109) and mackerel (69). The number of fish schools for all the species decreased with increase in velocity except around 3000 mm/s where the fish schools increased in number; jack mackerel (29), anchovy (94) and herring (74 m). While at the south aFADs similar observation was recorded whereby low velocity, high number of fish schools was recorded of jack mackerel (52), anchovy (60) and herring (38) (Fig.4-18).

4.3 Discussion

The aFADs are convenient oceanic observatories for studying aggregative behavior of pelagic fish around floating objects (e.g. Freon and Dagorn 2000). Intergrating different techniques such as optical, acoustics and biotelmetry techniques can be used to understand the species, size composition and spatio-temporal distribution of pelagic fish aggregations in the sea. It opens up new prospects for estimating fish schools aggregation associated with aFADs. Such estimates are of prime importance for fishery management purposes and for quantitative studies of the aggregation of pelagic fish around aFADs. From this study, I observed jack mackerel, anchovy and herring to be distributed between 100 m and 600 m from the aFADs, and high number of medium school sizes were recorded at 100 m (Fig.4-10). I also confirmed the distribution of the three species throughout the water column between 10 m depth to 80 m for the north aFAD and 10 m to 110 m depth for the south aFAD (Fig. 4-11). These observations gained from the acoustic surveys around the aFADs in Goto Islands provided a partial image of the aggregations of fish schools in its vertical and horizontal extensions. This observation confirmed various studies (Cayre and Chabanne 1986; Holland et al. 1990, Marsac et al. 1996) that horizontal and vertical distribution of fish schools near aFADs existed. According Marsac and Cayre (1997) the fish swim at a variable distance from the aFADs up to 5 nm in the daytime and 7 nm at night. Some authors (Holland et al. 1990; Cayre and Marsac 1993) have shown influence of aFADs on pelagic vertical movement. However, the results differ regarding fauna composition determined from the observation of aFAD related catches. According to Depoutot (1987), using acoustic survey techniques sampling the top 100 m of the ocean, demonstrated that aggregations showed spatial and temporal variability. In chapter 3, I observed diversity of fish species that were associated with the aFADs. Thus the two techniques confirmed the fish distribution of fish species around the aFADs which is a promising venture to the artisanal fishery due to increase in catch.

In this study, I also observed highest number of fish schools around the north aFAD as compared to the south aFAD (Fig.4-3). While in chapter 3, highest diversity of the other fish species was recorded at the south aFAD compared to the north aFAD by ROV (Figs. 3-5 and 3-6). In addition, north aFAD recorded highest number of medium school size at a 70 m depth (97) while at the south aFAD medium school size recorded highest number of fish schools at 100 m depth (36) (Fig.4-11). This was attributed to the position of the aFADs. The north aFAD is located in an enclosed lagoon while south aFAD is located in the open sea which could have been influenced by strong currents that pushed the fish schools close to the aFAD. The position of the aFADs influenced the distribution of both the fish schools and other large fish species observed in chapter 3. In relation to the position of the aFAD, the distribution of the jack mackerel, anchovy and herring with depth around both the north and south aFADs could have been attributed to changes in temperature and current velocity and the fish positioning themselves in relation to the current as observed in Fig. 4-7. A variety of oceanographic and atmospheric variables are known to influence the spatio-temporal distribution of pelagic and migratory marine organisms. In addition, the relative importance of these variables to a particular organism will depend on the spatial scale at which these processes operate and the functional importance of this scale to the organism. Seasonal effect and environmental parameters such as temperature are other factors that attributed to my observations. Temperature is known to predict biologically important changes in fish abundance (Fiedler and Bernard 1987; Iwasaki 1970). From this study, increased in number of fish schools was due to increased temperature and I observed the fish schools of jack mackerel and anchovy peaked when temperature was 17ºC and herring peaked when the temperature was 18ºC (Figs.4-14 and 4-15). This study concurred with several studies that presented observational evidence that suggested current velocity and direction influences where certain pelagic species are located around aFADs with respect to the direction of the current (e.g. Klima and Wickham 1971; Rountree 1990). Short-term changes in oceanographic conditions, causing daily variability in sea-surface temperatures, may explain part of the variability in numbers of pelagic fishes around aFADs.

Around the aFADs in Goto Islands, I observed high number of fish schools when the current velocity was low and the fish schools decreased with increase in current velocity. In addition, variations in current speeds may affect the ability of certain taxa to remain associated with aFADs, particularly small juvenile fishes with limited swimming abilities when currents become stronger. While little direct evidence indicates current speed affects fish assemblages at aFADs, Kakuma (2000) found that catches of *T. albacares* were higher when currents were weak around aFADs off Okinawa Island, Japan, suggesting either greater association or better fishing efficiency during weak currents.

Several studies have indicated that fish assemblages around aFADs may be highly seasonal (Rountree 1990; Castro et al. 1999), although few have been of sufficient duration to establish seasonal patterns of association (Deudero et al. 1999). Seasonal patterns may be due to the appearance of juvenile fishes that only associate with aFADs for a certain life-history stage (Kingsford 1993; Deudero et al. 1999) or migrations driven by changes in water temperature (Norton 1999; Bennett 2001). Migrations that cause distribution of fish schools are simply directed movements in response to ontogenetic changes in behavioral requirements such as feeding and reproduction (Nakamura 1969). This concurred with my study whereby I observed highest number of fish schools in May and June and decreased in July to October at both aFADs. Furthermore, I observed highest number of jack mackerel, anchovy and herring in May and June in 2018 could be spawning period for these fish (Fig. 4-4).

The seasonal variability of fish assemblages around aFADs may be relatively easily explained, shifts in the composition and abundance of fishes around aFADs over time scales ranging from days to weeks though more difficult. This study also concurred with Macusi et al. (2017) that aggregations of fish under aFADs are segregated based on species, sizes, and water depth. He further found out that small fish schools including anchovies, herrings and mackerels which settle around the aFADs are followed by predatory fish such skipjack tuna *Katsuwonus pelamis*, frigate tuna *Auxis thazard*, bullet tuna *Auxis rochei rochei*, and juvenile *T. albacares* for weeks or months after they have settled in the aFAD (Castro et al. 2002). Which then other fish such as tunas are known to prey on a wide range of species including the mackerels and anchovies (Barut 1988; Jaquemet et al. 2011). This concurred with my observation based on 2018 data that I compared with the short range analysis from chapter 3, the number of fish schools were highest between April and June and decreased in July to September at both the aFADs (Fig.4-3). From the short range study in chapter 3, the number of different fish and the diversity was highest in July and August including *S. dumerili* and *C. hippurus* that were observed during this time (Fig.3-6, 3-7 and 3-9). This was probably due to several reasons such as predation by large fish that visited around the aFADs after the small fish species have settled in. The opportunistic feeding behavior of tunas and its predisposition to social interaction (Robert et al. 2013) may have implications on its movement from one aFAD to another to feed on the prey (Ménard et al. 2006). However, this aspect need to be explored further to understand the reasons contributing to these observations to be able to confirm the small number of fish schools recorded on the upper depth of the water column by echo sounder were preyed by the predatory fish recorded by the ROV and underwater camera in chapter 3.

In chapters 3 and 4, I presented fish fauna and their spatio-temporal distributions around aFADs in short and long distance ranges. Their behaviors in a short range was observed by ROV observation only for a limited duration (30 mins. in this study) but fish residency for a longer duration which is also an important aspect in management of aFADs as a part of wider fishing area, remains unknown. I therefore targeted this in the next chapter. Ultrasonic telemetry studies have described patterns of use for larger aFAD associated species such as *T. albacares* over short (Holland et al. 1990; Dagorn et al. 2000a) and long (Klimley and Holloway 1999) time scales, indicating repeated arrival at and departure from the vicinity of FADs. Smaller aFAD associated species may associate with structure more closely and for longer periods. Hunter and Mitchell (1968) identified large differences in minimum residence times of several taxa by conventional tagging and visual recapture, with several species capable of residing for periods >2 weeks. With this regard, I further investigated the residency of two commercial important fish species in Goto Islands to be be able to confirm the observations made in chapters 3 and 4.

Figures and Tables (Chapter 4)

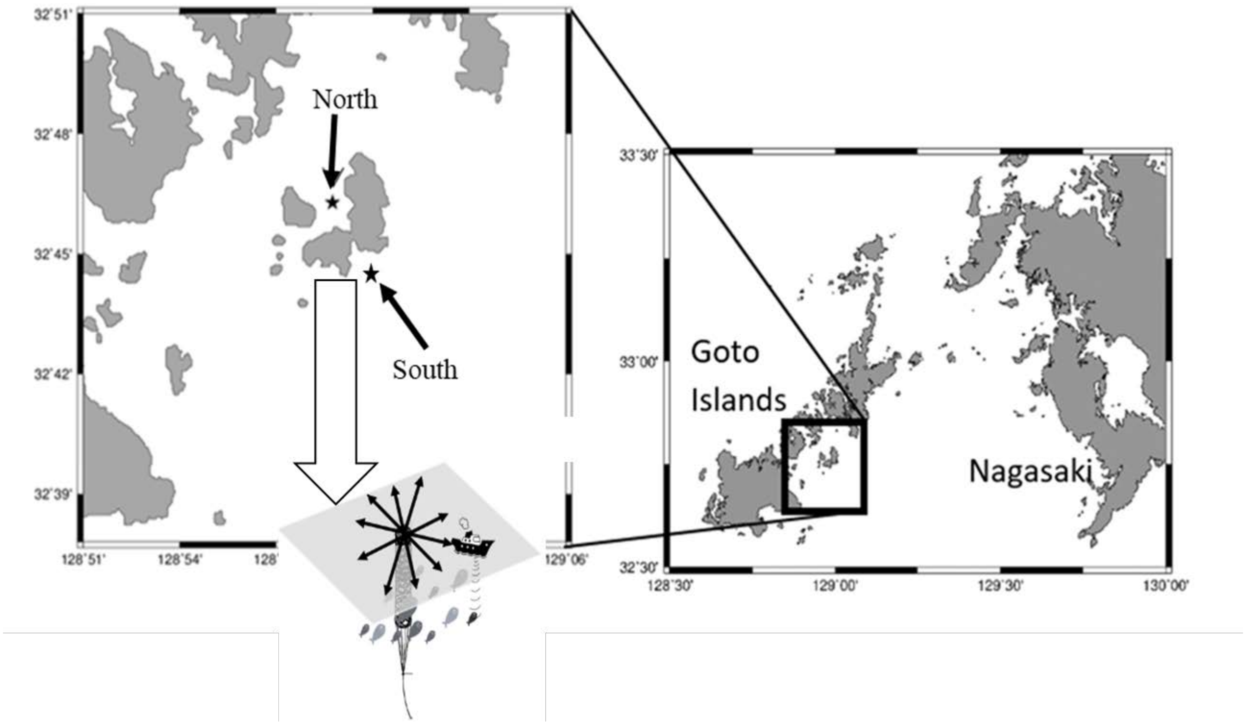
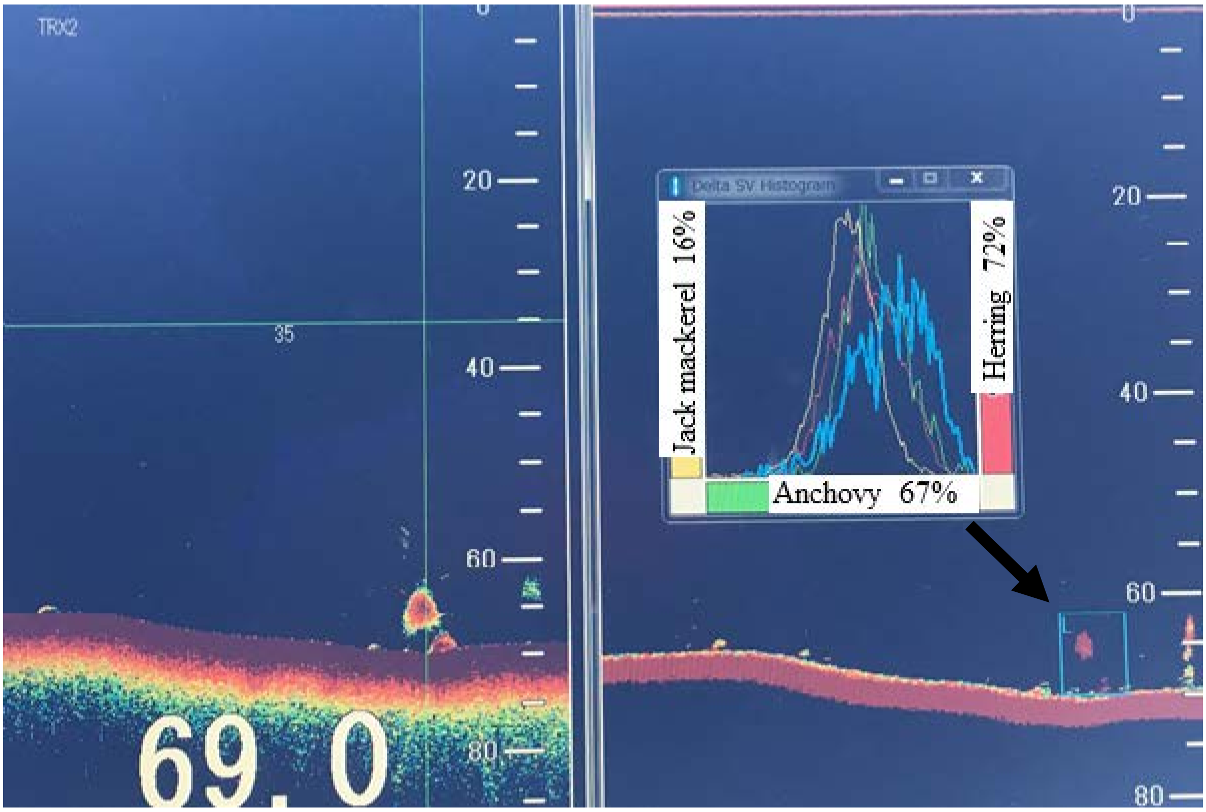


Figure.4-1. A map of the study sites showing 8-line transects made during the surveys around each aFAD denoted with stars.



School parameters

Species: % composition:	Jack mackerel (16%), Anchovy (67%), Herring(72%)
Date:	21-08-2018
Actual observed time:	08:54:09
Longitude:	128.98
Latitude:	32.77
Avg depth:	66 m
Pixels (Strength value)	Red (609),Yellow(375), Blue(16)
Total pixels	1000

Figure. 4-2 An example of school recorded by echo sounder and identified by image processing system. The table at the bottom was meant to describe the specific school that was recorded by the echo sounder.

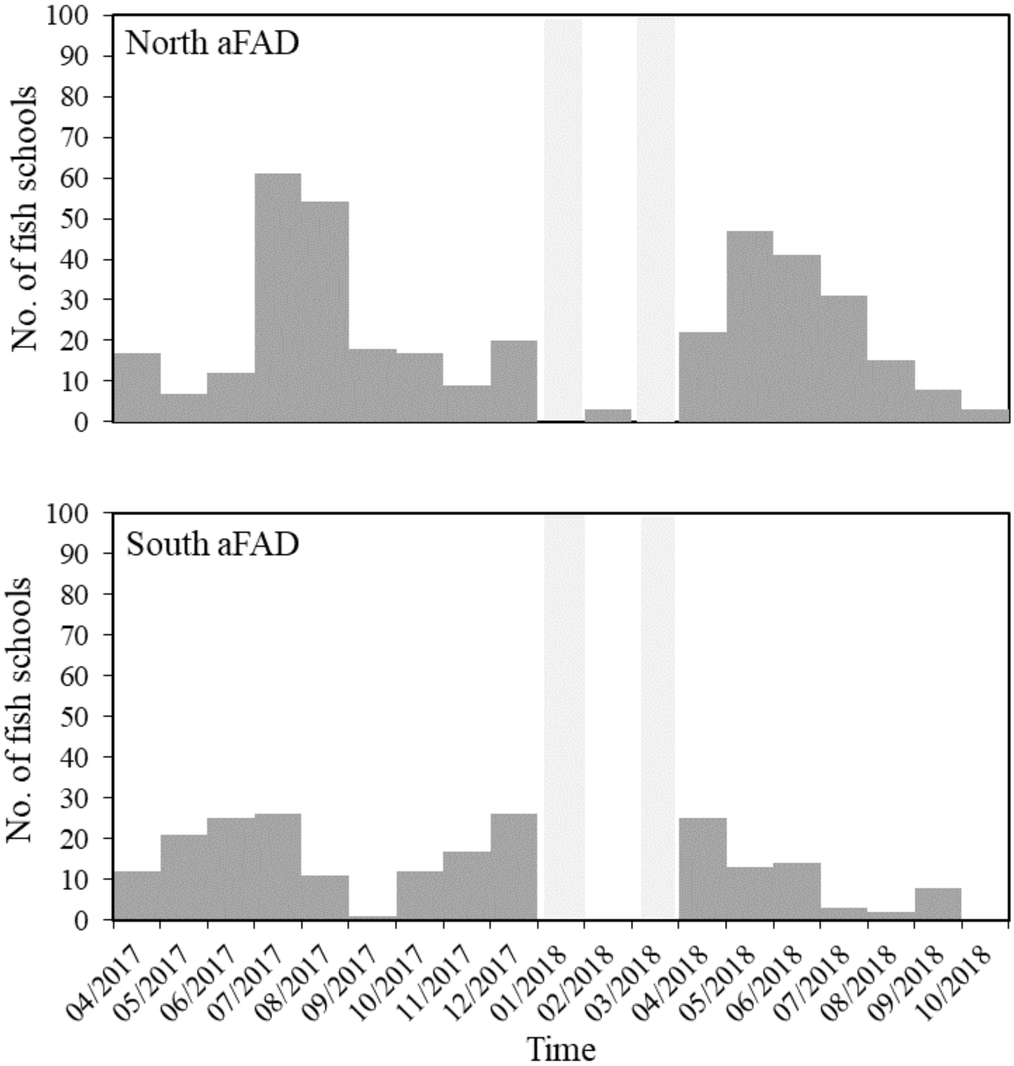


Figure.4-3. Temporal changes of observed number of fish schools around the aFADs. The light shaded areas indicate the months that were not sampled

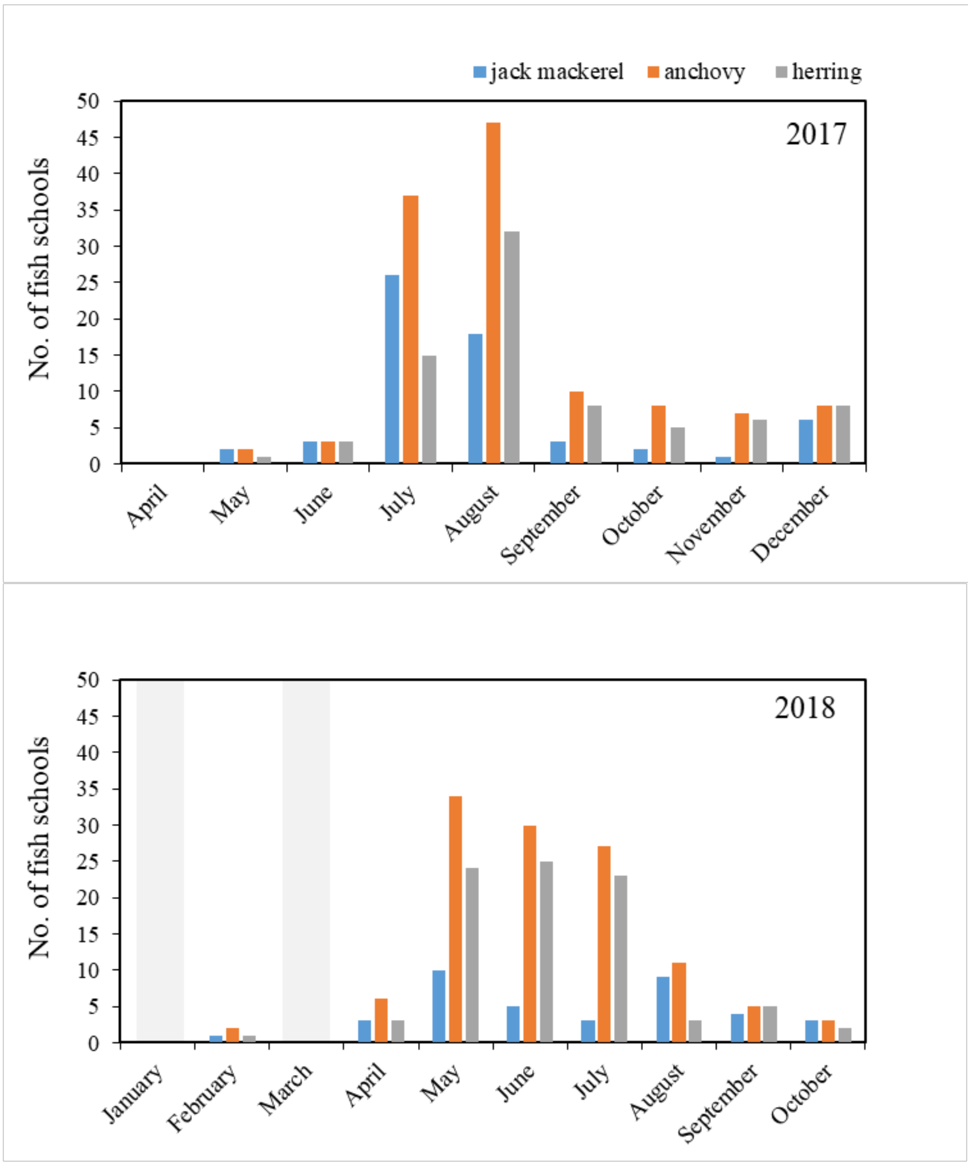


Figure.4-4. Monthly occurrence of the number of fish schools in terms of the three species around the north aFAD. The light shaded areas indicate months that were not sampled

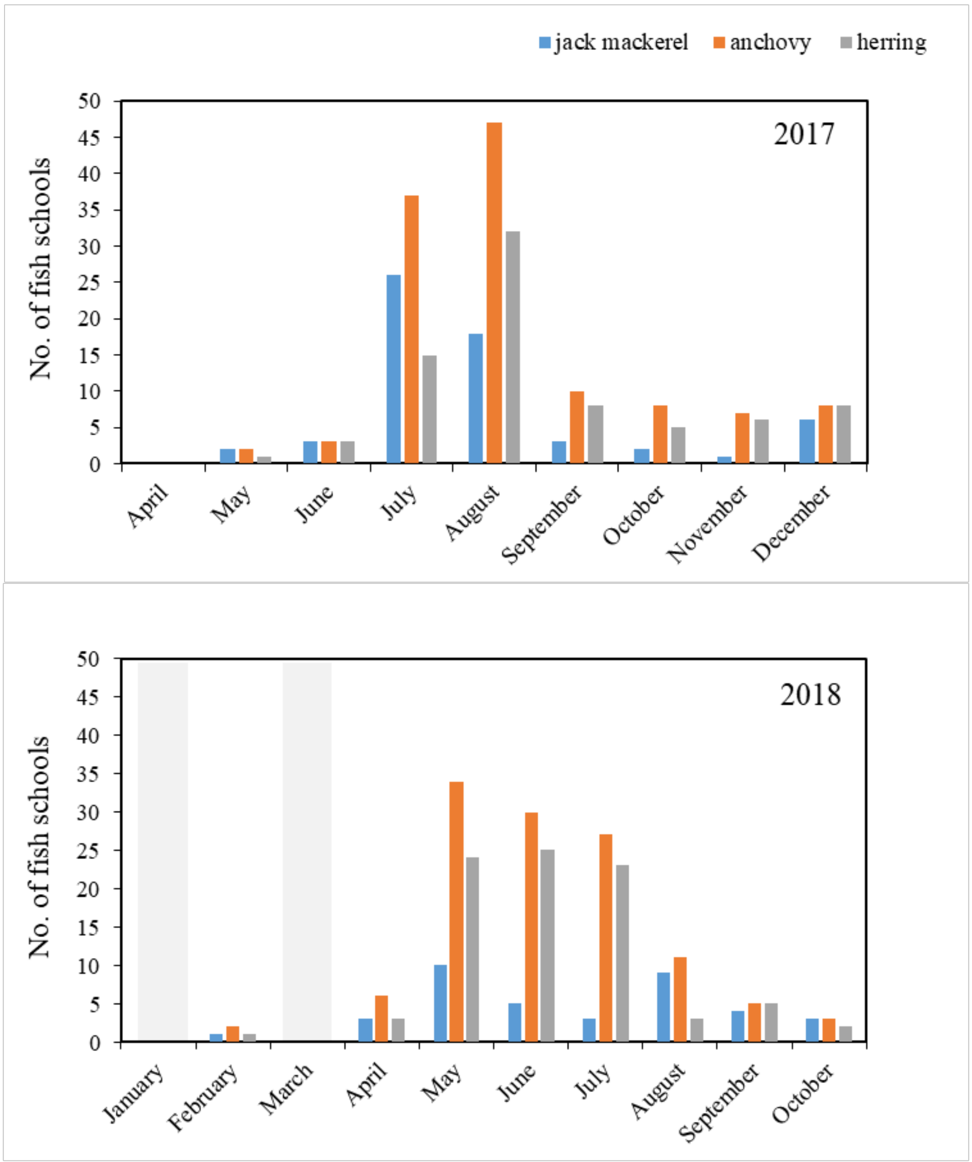


Figure.4-5. Monthly occurrence of the number of fish schools in terms of the three species around the south aFAD. The light shaded areas indicate months that were not sampled

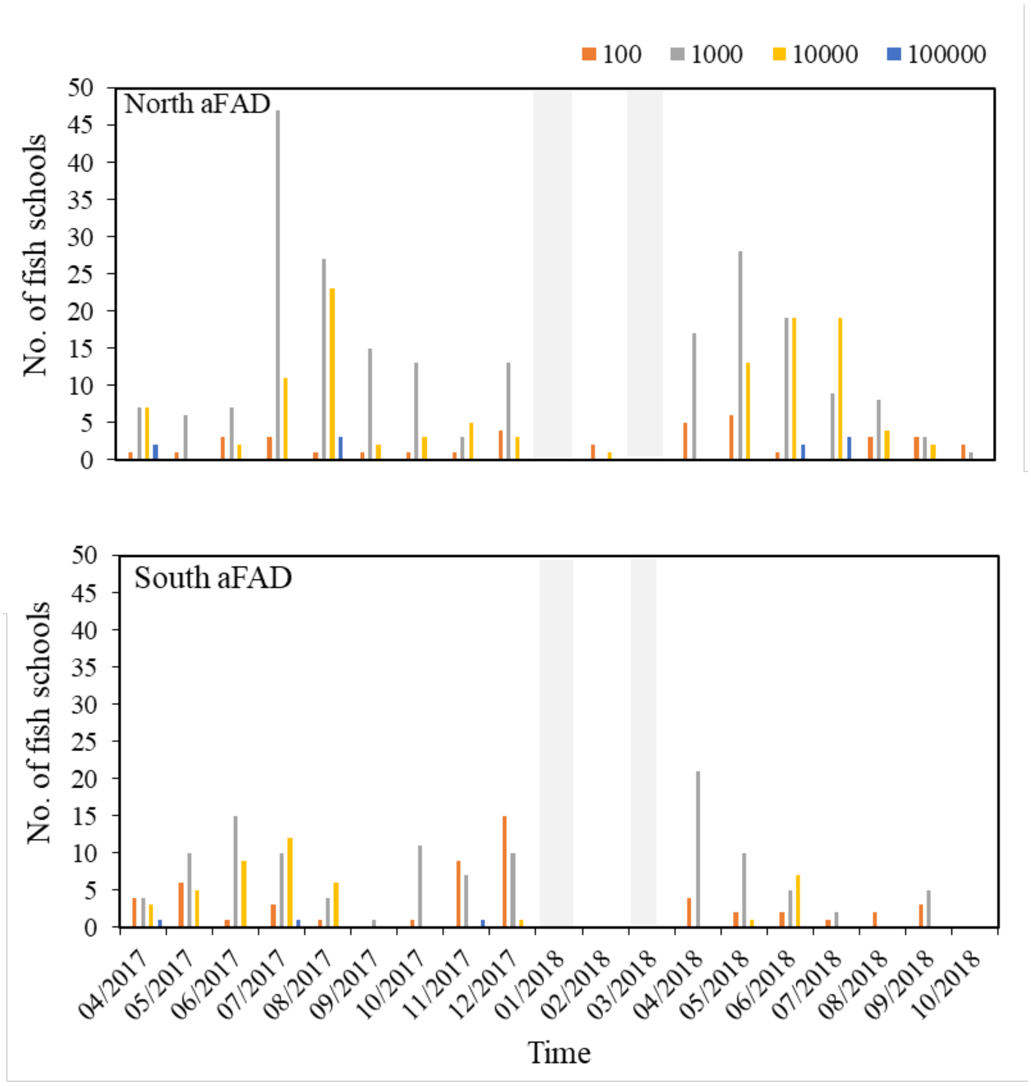


Figure.4-6 School size frequencies around the aFADs. The light shaded areas indicate months that were not sampled. Size range from 100 to 100000. 100 indicates small school size, 1000 medium school size, 10000 large school size and 100000 indicates the largest school size.

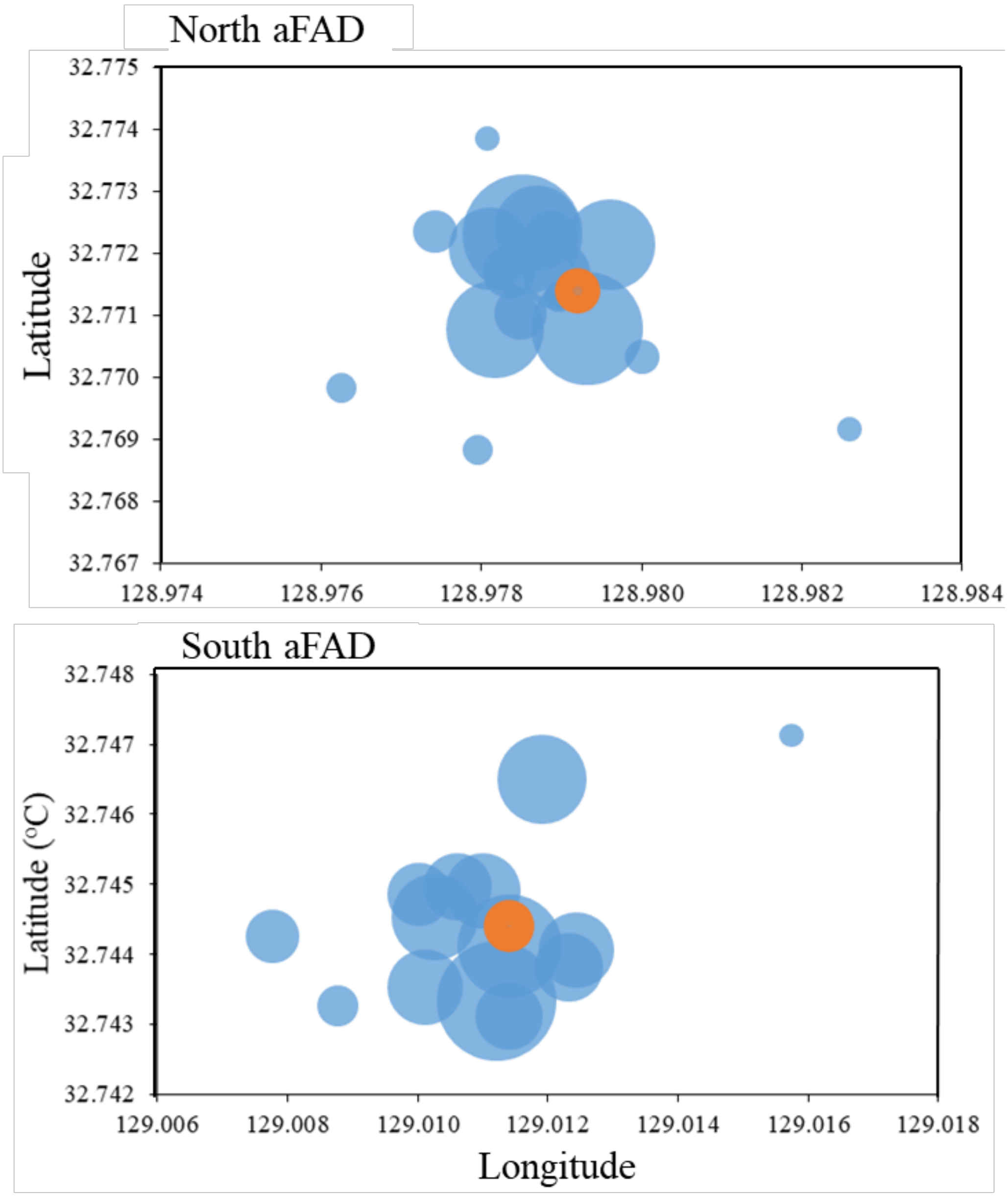


Figure.4-7 Fish schools' distribution from the aFADs by longitude and latitude

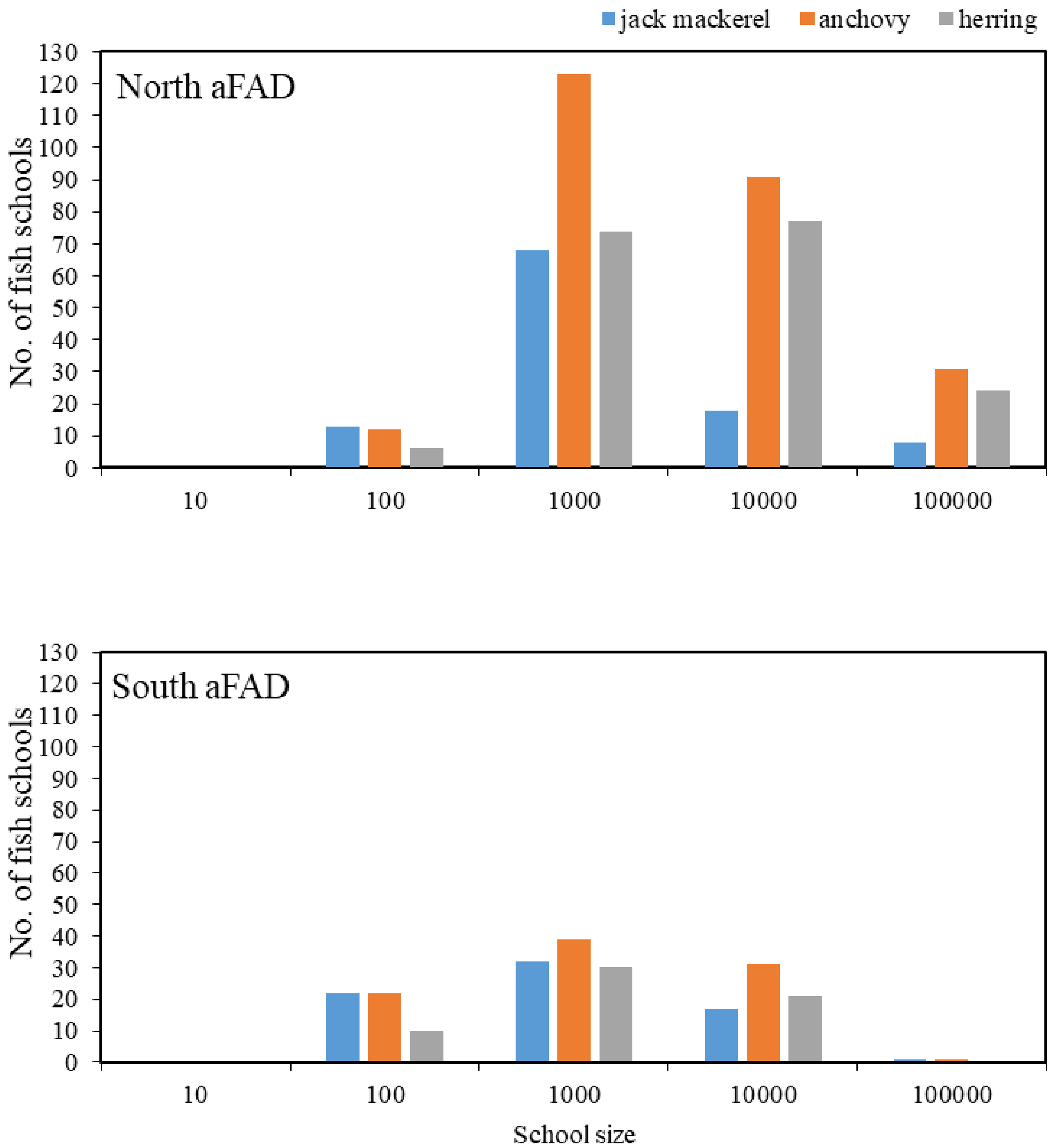


Figure.4-8 Number of fish schools in terms of school size for each species at the aFADs. Size range from 100 to 100000. 100 indicates small school size, 1000 medium school size, 10000 large school size and 100000 indicates the largest school size.

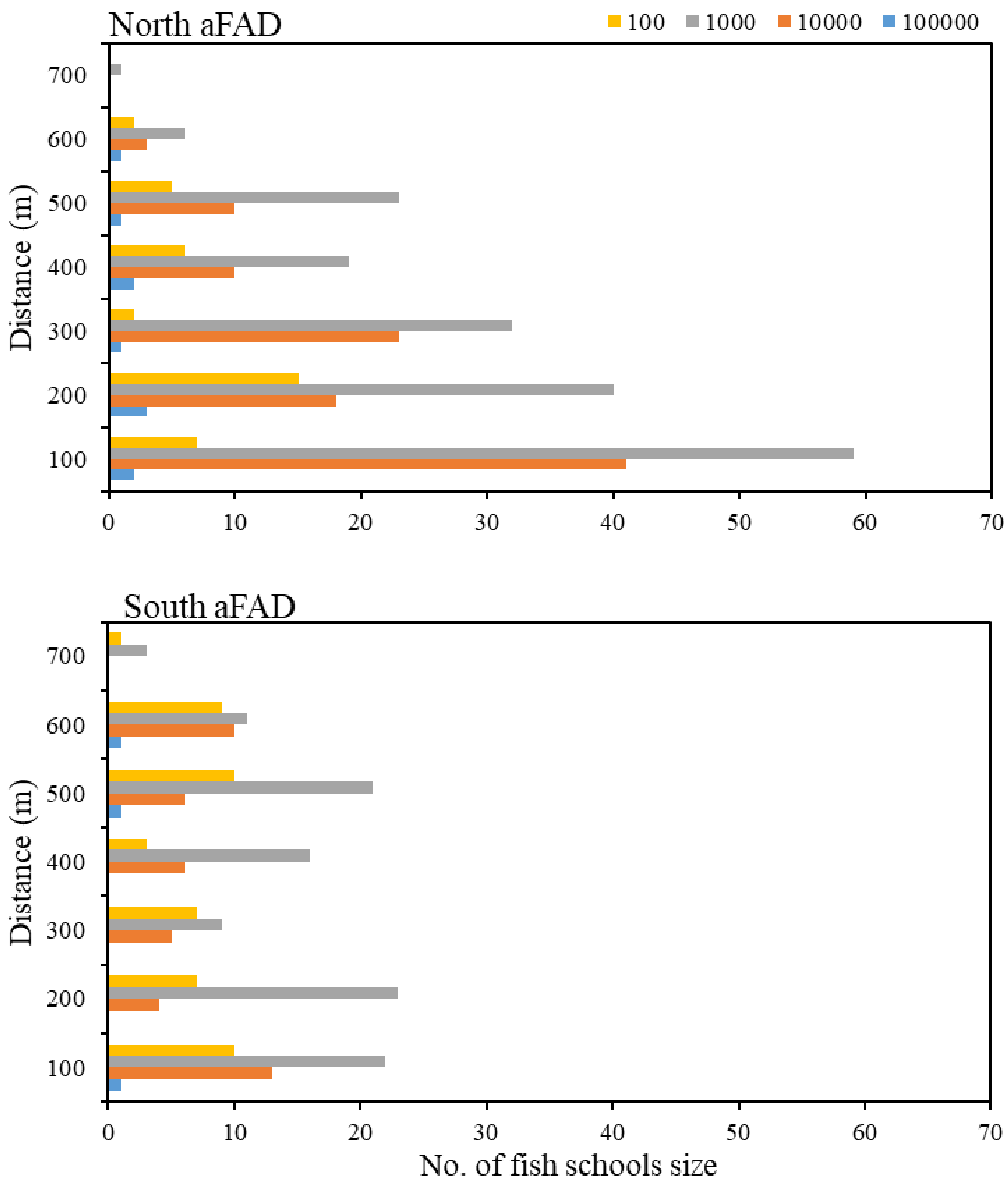


Figure. 4-9. Distance from the aFADs (between 100 m and 700 m) and the distribution of numbers of fish schools size. Size range from 100 to 100000. 100 indicates small school size, 1000 medium school size, 10000 large school size and 100000 indicates the largest school size.

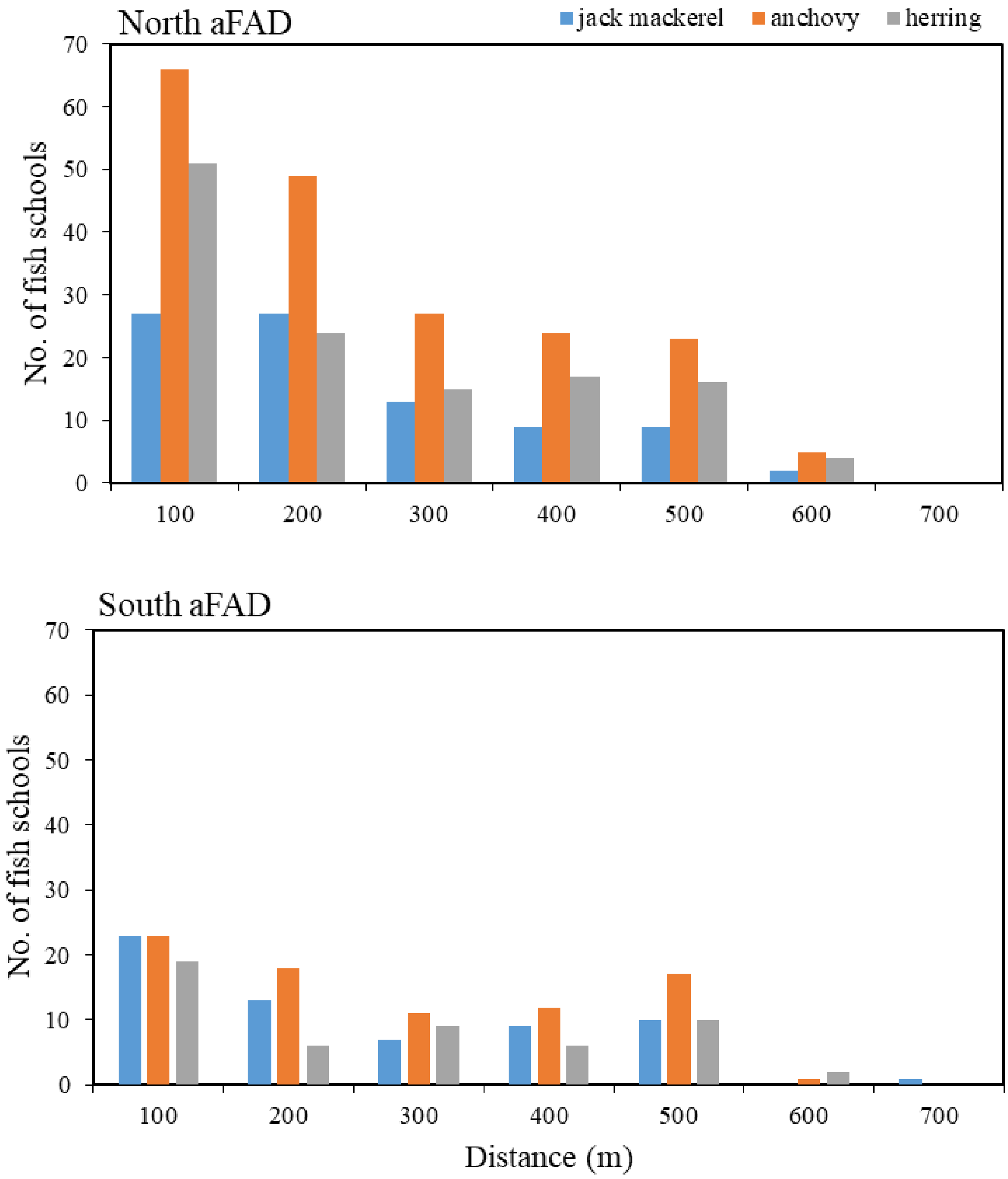


Figure. 4-10. Distance from the aFADs and fish schools distribution of the three species

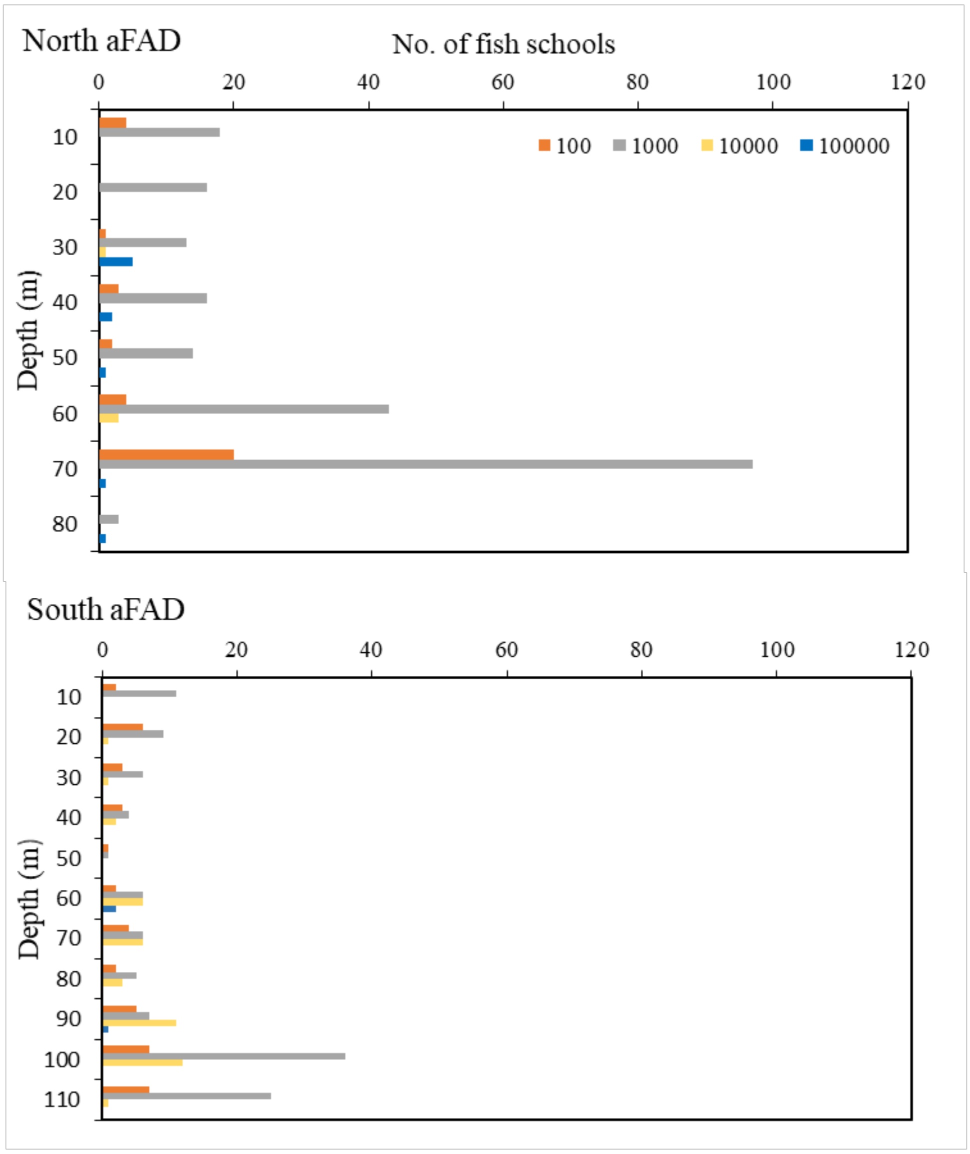


Figure. 4-11. Number of fish schools in terms of depth distribution around the aFADs

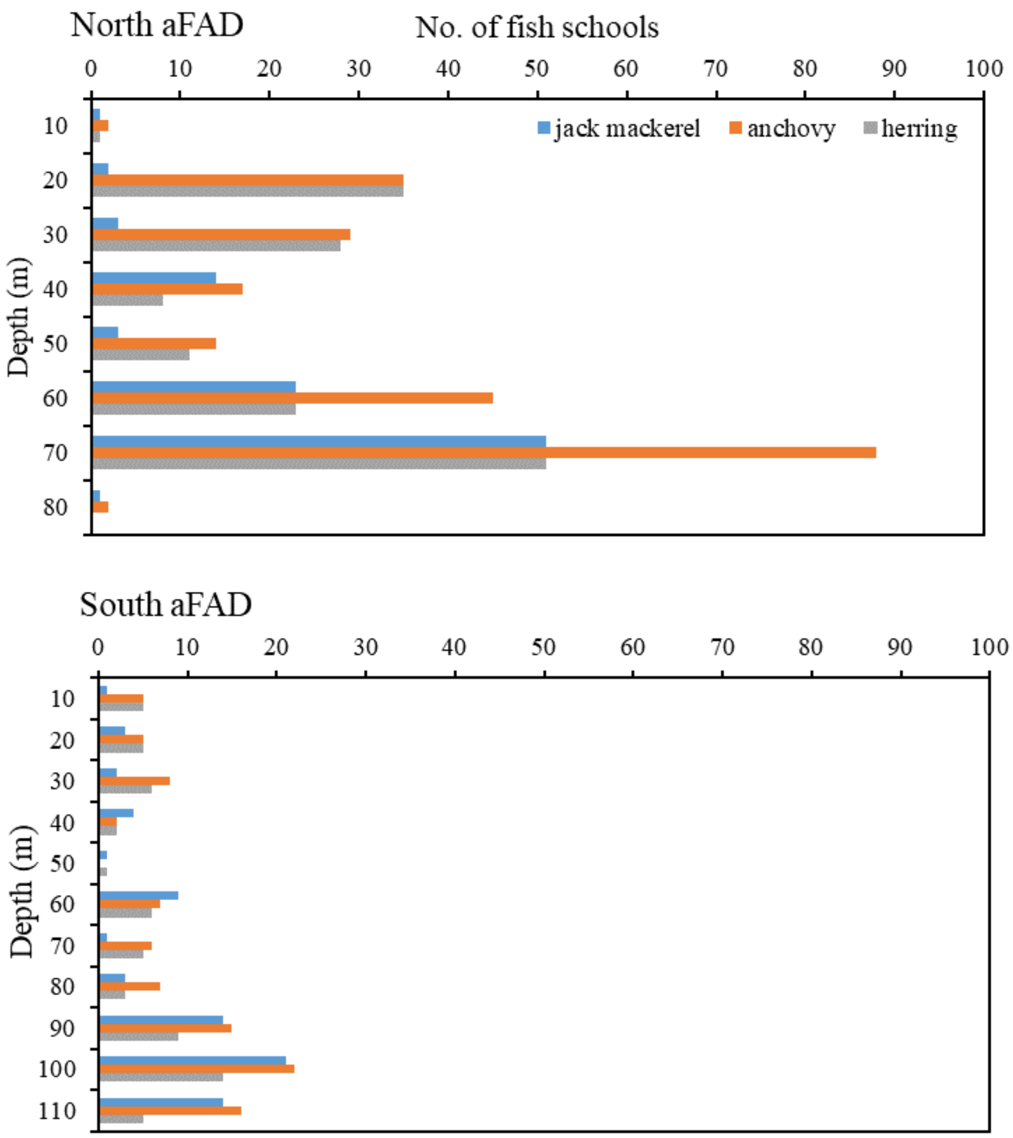


Figure. 4-12. Number of fish schools in terms of depth distribution by each species around the aFADs

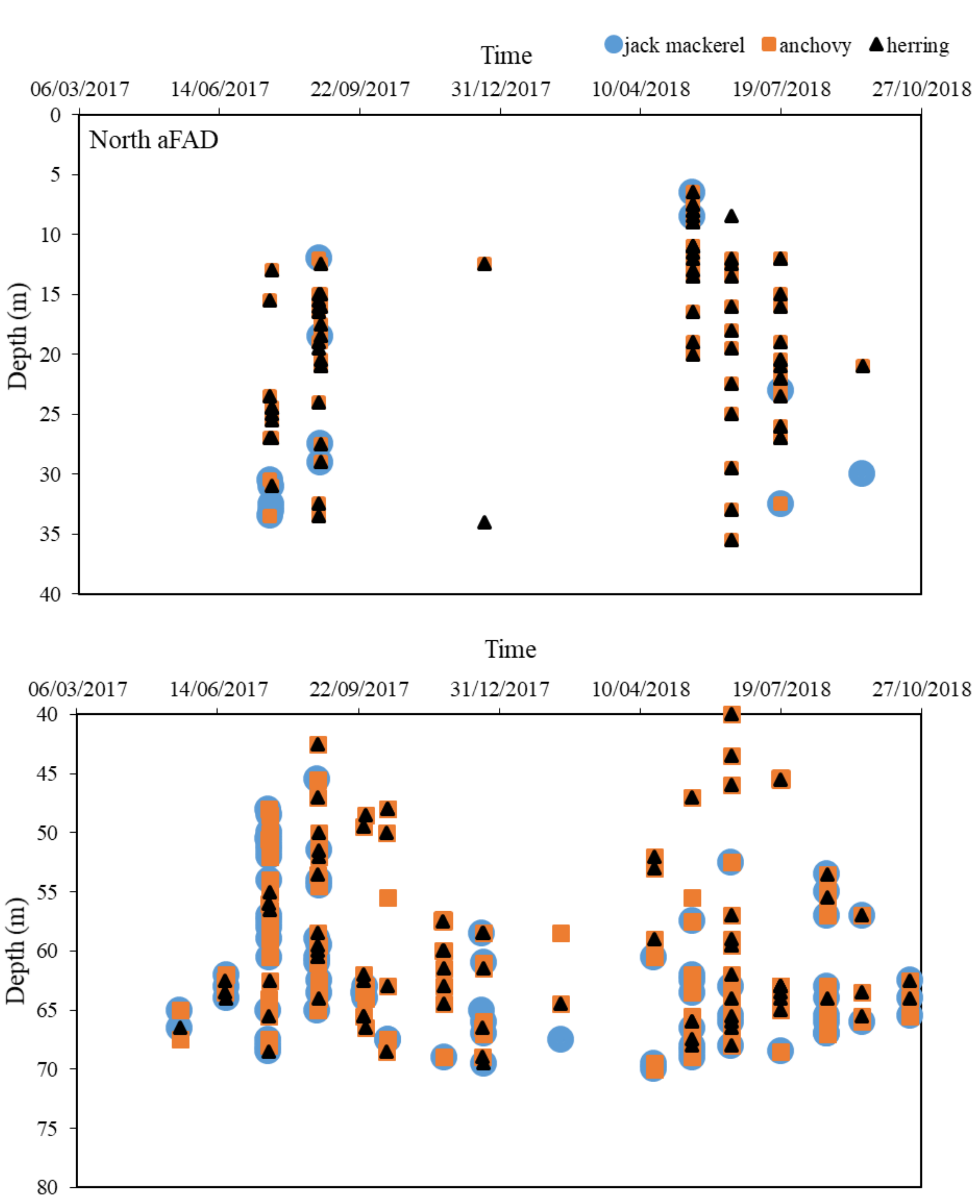


Figure. 4-13. Monthly distribution of number of fish schools with depth around the north aFAD

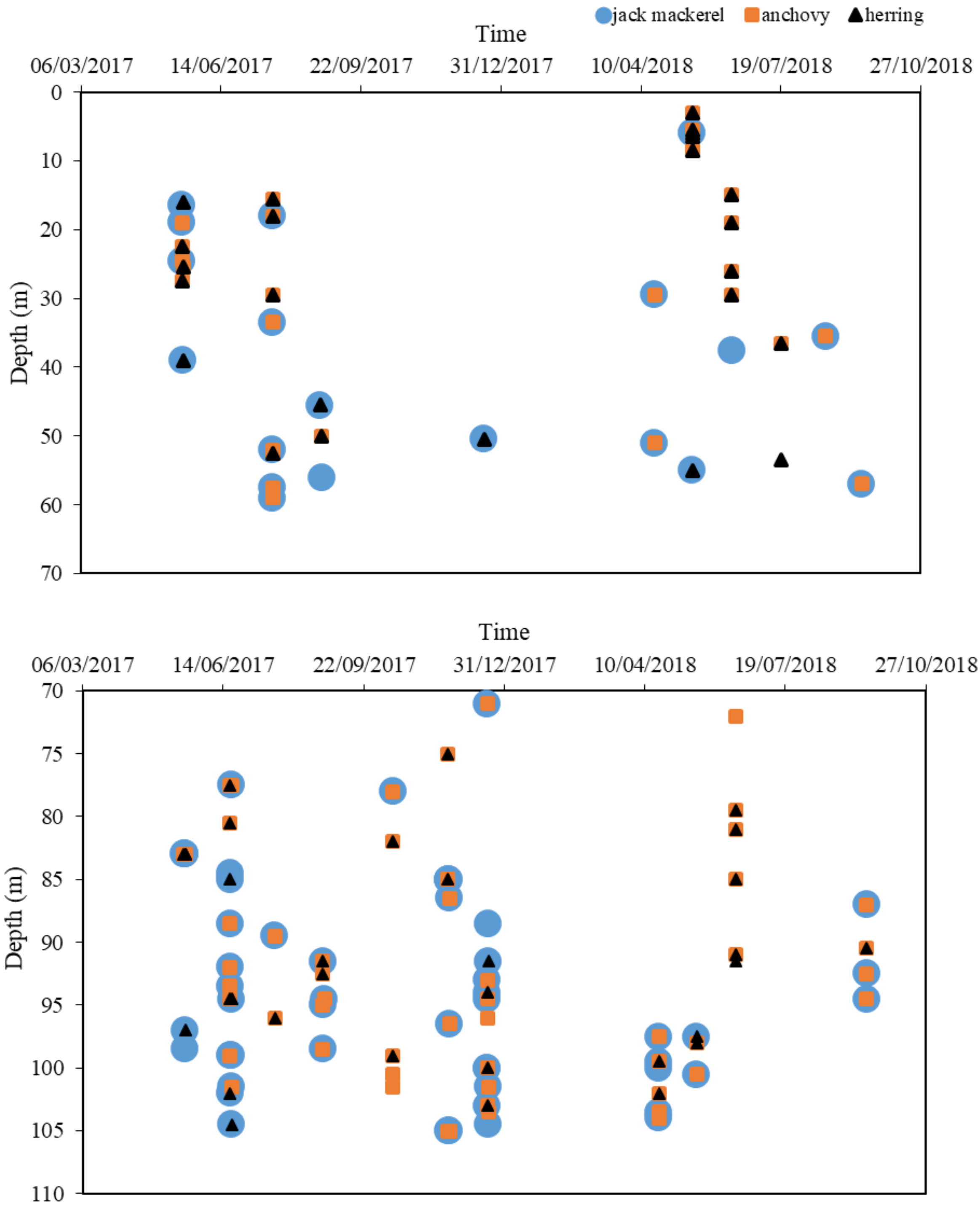


Figure. 4-14. Monthly distribution of number of fish schools with depth around the south aFAD

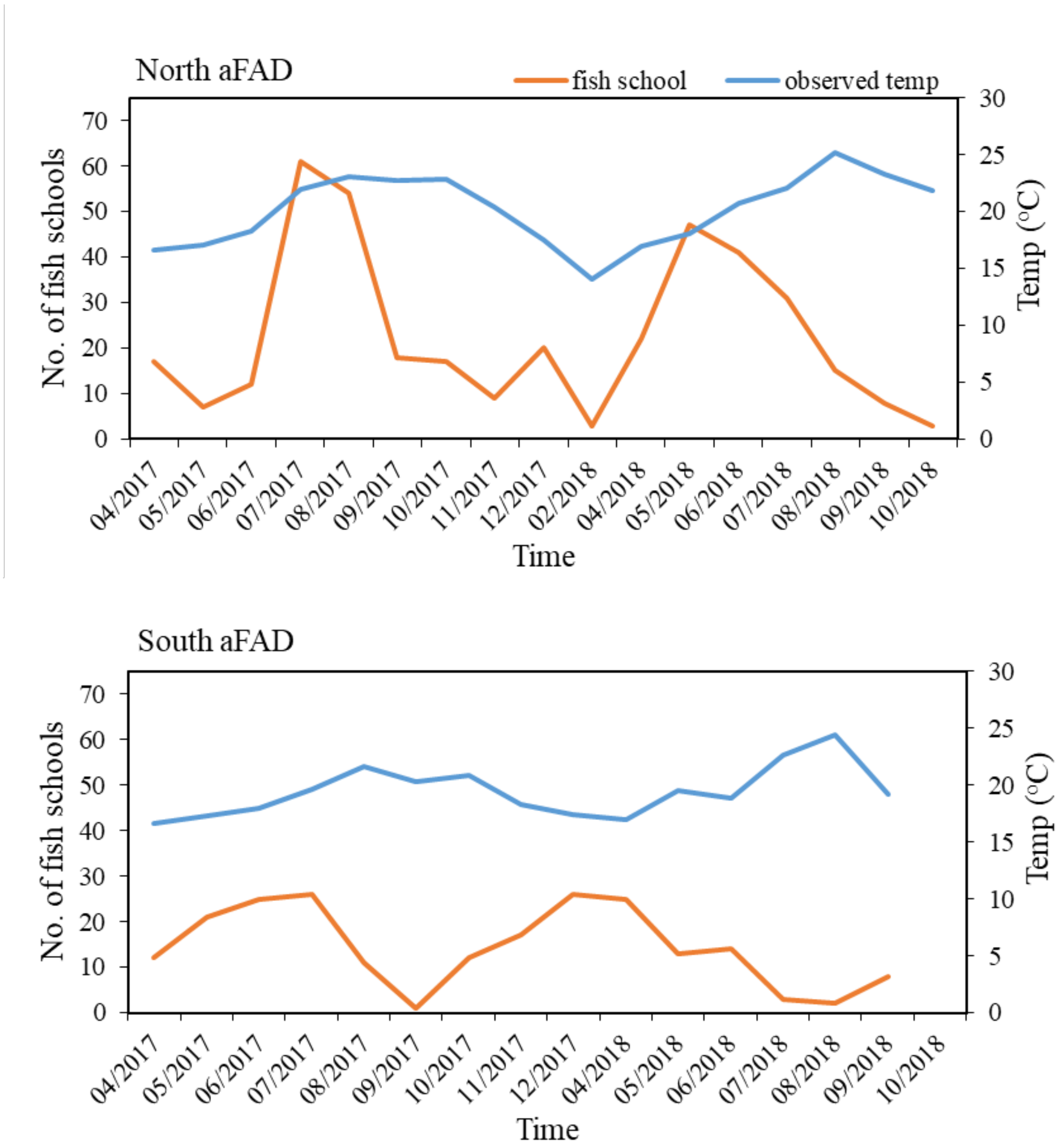


Figure. 4-15. Monthly trend in temperature with number of fish schools around the aFADs

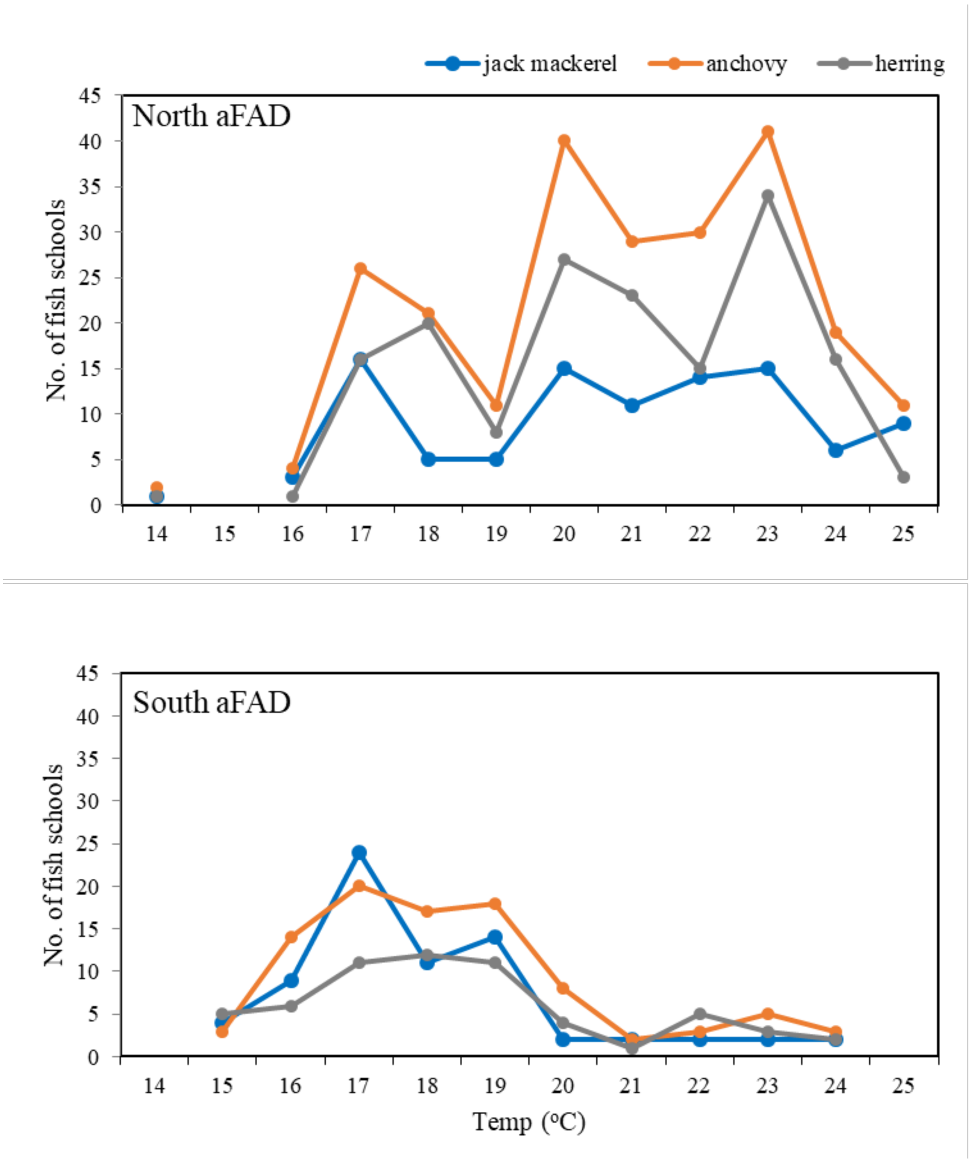


Figure. 4-16. Changes in number of fish schools of the three species with temperature

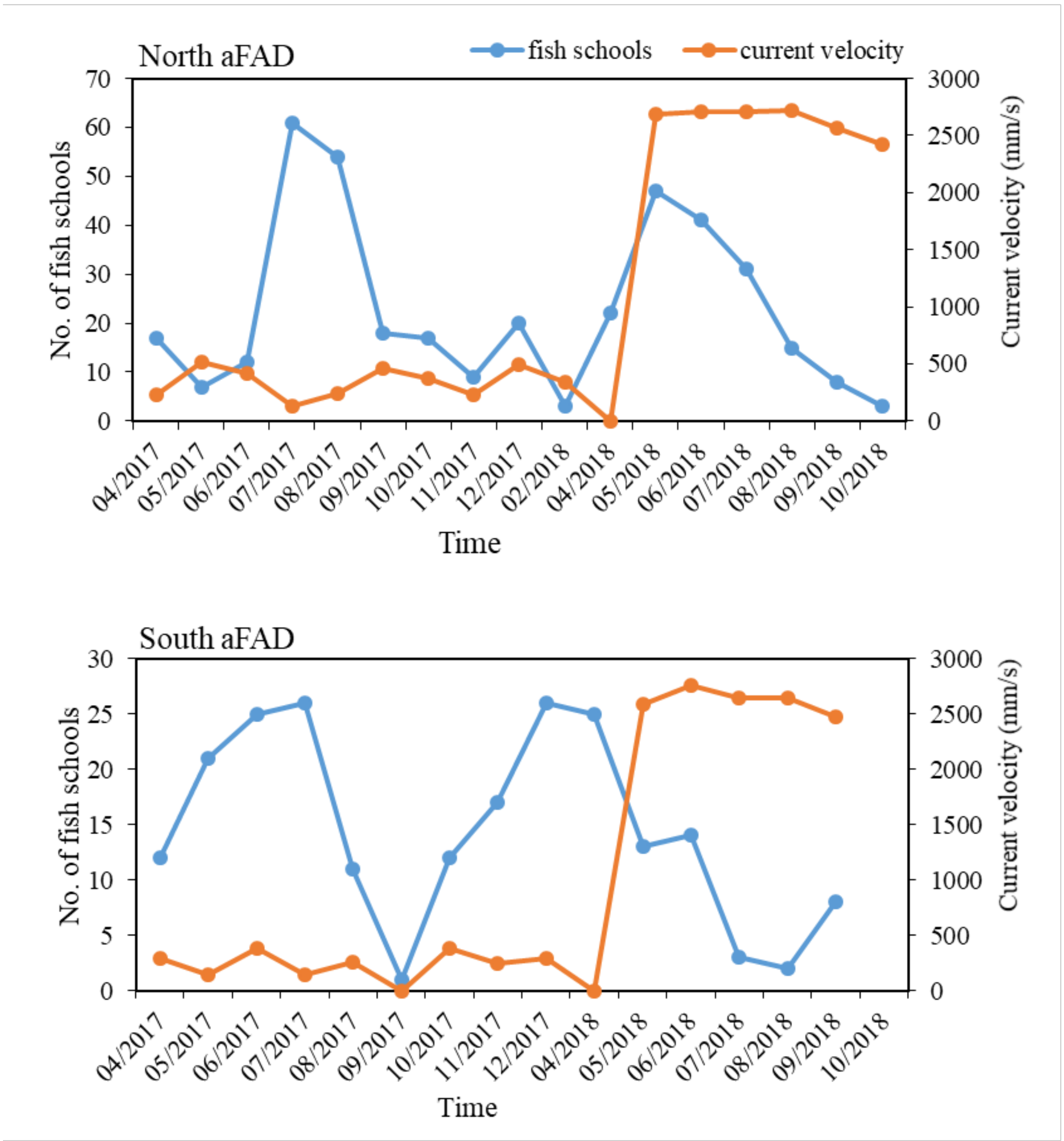


Figure.4-17. Monthly current velocity and fish distribution around the aFADs

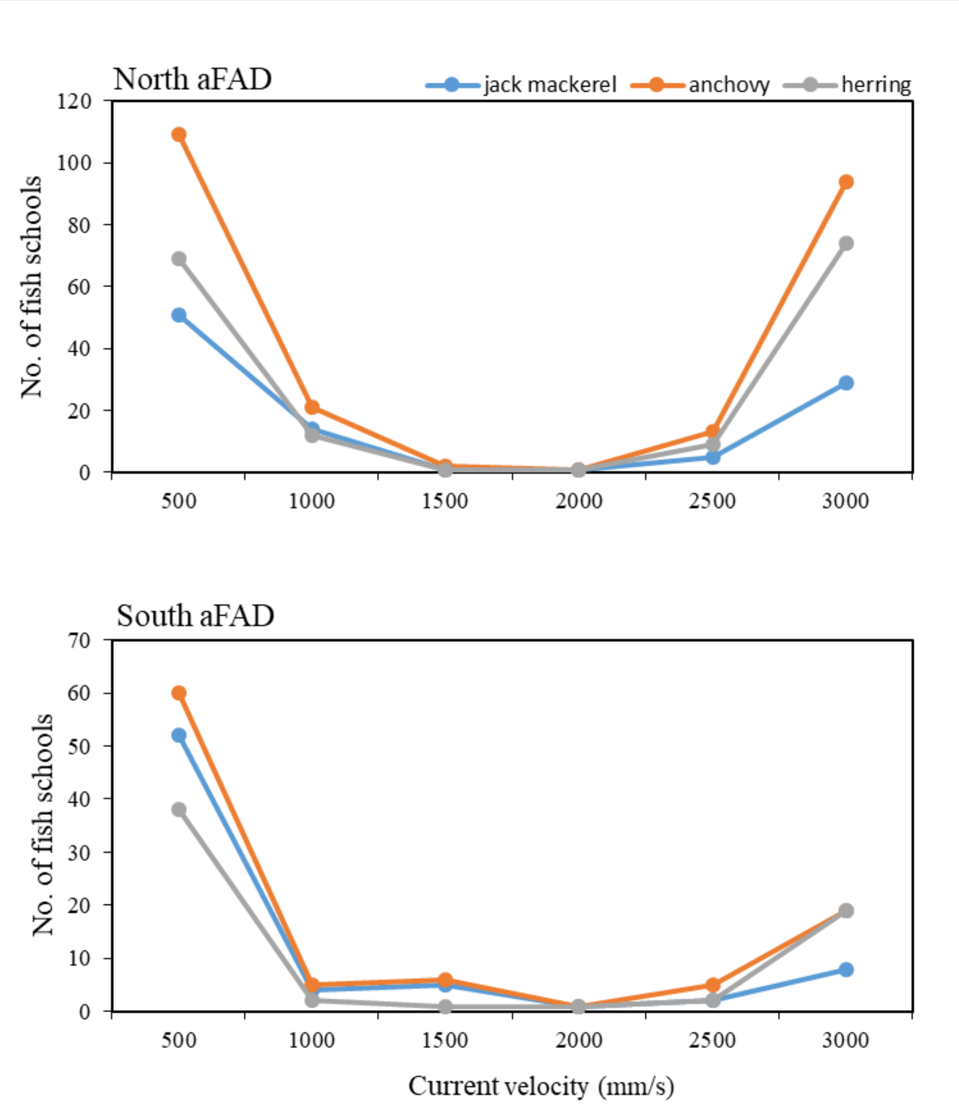


Figure.4-18. Current velocity and fish distribution by species around the aFADs

Table 4-1. Summary of sampling days during the study period

Year 2017			Year 2018		
Start date	**End date**	**Number of days sampled**	**Start date**	**End date**	**Number of days sampled**
24/04/2017	25/04/2017	2	13/02/2018	13/02/2018	1
17/05/2017	18/05/2017	2	20/04/2018	20/04/2018	1
19/06/2017	20/06/2017	2	17/05/2018	17/05/2018	1
20/07/2017	21/07/2017	2	14/06/2018	14/06/2018	1
24/08/2017	25/08/2017	2	19/07/2018	19/07/2018	1
26/09/2017	27/09/2017	2	20/08/2018	21/08/2018	2
12/10/2017	13/10/2017	2	15/09/2018	15/09/2018	1
21/11/2017	22/11/2017	2	19/10/2018	19/10/2018	1
19/12/2017	20/12/2017	2			
Total number of days sampled		18			9

Chapter 5

Evaluation of fish residency by biotelemetry technique around the aFADs

Biotelemetry is currently a burgeoning field, presenting the opportunity to track the movement of individuals over periods of months (Egli and Babcock 2004; March et al. 2010) or years (Afonso et al. 2008; Meyer et al. 2010), and giving researchers the opportunity to test hypotheses relating to long-term habitat usage and/or site fidelity. The methodology is being utilized particularly to answer important questions relating to the habitat usage and movement of important fish species (e.g., Meyer et al. 2000; O'Toole et al. 2011). Having confirmed the distribution of fish species and fish schools around the aFADs at short and long ranges from monthly observations in chapter 3 and chapter 4, it was important to understand the movement pattern and residency of the fish around the aFADs and the neighboring habitats that that was covered in this chapter. I discussed the movement pattern and residency of two commercially important fish species around Offshore Wind Turbine (hereafter to be reffered to as OWT) that was assumed to function as aFADs.

5.1 Movement pattern of red seabream *Pagrus major* and yellowtail *Seriola quinqueradiata* around OWT in Goto Islands, Japan using acoustic telemetry

The Japan's first full-scale 2 megawatts floating OWT was installed and became operational in October 2013, initially located 1 km off the Coast of Kabashima Island, then moved to the present position (5 km off Fukue Island) in 2016 (Fig.5-1). The artificial hard substrates placed on the seabed (part of the offshore energy units) to support the OWT act as artificial reefs create new habitats in areas dominated by soft bottoms and can cause significant changes due to new trophic opportunities and changes in local food web (Langhamer et al. 2009). Since OWT in this study floats on sea surface, it may function as aFAD. In this regard, the artificial reefs may host communities different to those on natural reefs and could also alter or modify the diversity of species in nearby areas (Connell and Glasby 1999; Connell 2000). The concerns related to OWT have been that fish might be repelled from OWT as confirmed by a study of Atlantic cod *Gadus morhua* being a benthic predatory fish and their seasonal changes of fish distribution near OWT (Reubens et al. 2013). However, this study investigated whether the OWT in Goto Islands forms a suitable habitat for fish since hard substrates e.g. artificial reefs, have been reported to attract and concentrate fishes to enhance local fish stocks (Leitão et al. 2008, 2009). According to various studies, several mechanisms stimulate such behavior of the habitats such as (1) shelter against currents and predators (Jessee et al. 1985; Bohnsack 1989), (2) additional food provision (Fabi et al. 2006; Leitão et al. 2007) and provision of nursery and recruitment sites (Bull and Kendall 1994).

Currently, no information is available on the residency of species and their movement patterns around the OWT and the neighboring habitats that include artificial reefs, natural reefs and aFADs (studied in Chapters 3 and 4) in Goto Islands. Therefore, this study documents results of acoustic telemetry to investigate the behaivour of two commercial and indigenous fish species i.e. red seabream *Pagrus major* and yellowtail *Seriola quinqueradiata* around OWT and the neighboring habitats in Goto Islands. The main objective was to gain a better understanding on the effect of OWT and the neighboring habitats. The specific objectives were to identify individual (1) movements around the OWT and the neighboring habitats (2) fish residency and (3) Seasonality in occurrence of the fish within the OWT and the neighboring habitats (winter and summer seasons).

5.2 Materials and methods

5.2.1 Study sites

The study was conducted between Feb and Oct 2017 in the waters between Fukue and Kabashima Islands in Goto Islands. The OWT is situated approximately 100 m deep, 5 km off Fukue Island, south end of Goto Islands. Its total spar length is 172 m (total length submerged is 76 m and rotor diameter is 80 m). The other neighboring habitats included artificial reefs that are installed at the northern part about 98 m deep approximately 1.6 km from the OWT and at southern part about 75 m deep approximately 3.0 km from the OWT (to be referred to as AN and AS respectively). Forty 4 m-cube reefs were placed at AN in 1993 while 120 hemispherical reefs were set at AS in 2015. There is also a natural reef of depth range 56 - 59 m approximately 1.9 km at the southern part of the OWT (also referred to as NR) and a large-scale trapnet set approximately 4.2 km western side of the OWT about 47 m deep (also referred to as TN) (Fig.5-1). Two aFADs, northern aFAD (F1) and southern aFAD (F2), are anchored around Kabashima Island approximately 11 km north from the OWT which were studied in Chapters 3 and 4 in detail. Their distances from OWT are approximately 10.7 km north for F1 and approximately 11.8 km north for F2.

5.2.2 Fish tagging

This study focussed on two important commercial species in Japan, especially in the studied region, i.e. *P. major*, according to previous studies the species is known to be attracted to marine facilities (e.g. Wang et al. 2014). It consisted of 1% annual catch amount of Nagasaki Prefecture in 2014 (Nagasaki Prefectural Government Web: http://www.pref.nagasaki.jp/shared/uploads/2017/05 /1493698087.pdf "Accessed 07 Jan 2019"). The second species was *S. quinqueradiata* commonly known to aggregate on topographic features such as seamounts, natural reefs (Takagi et al. 2001; Ito et al. 2013) and accounted for 5% of annual catch amount of Nagasaki Prefecture in 2014 (Nagasaki

Prefectural Government Web: http://www.pref.nagasaki.jp/shared/uploads/2017/05/1493698087.pdf "Accessed 07 Jan 2019").

The first tagging was conducted on 1st Feb 2017 (winter) whereby 27 *P. major* were tagged and the second tagging was carried out on 13th July 2017 for 8 *P. major* and 14th July for 20 *S. quinqueradiata* (summer). I considered winter season from 1st Feb to 16th Mar and summer season from 13th July to 13th Oct 2017. The fish were collected using hook and line in winter and trapnet fishing in summer within the study sites by local fishers in Goto Islands. After capture, the individual fish were kept for one or two days in an aerated water tank for *P. major* caught by hook and line fishing or a net cage for *P. major* and *S. quinqueradiata* caught by trapnet before surgical implantation of the acoustic transmitter (i.e. tagging). The fish were lightly anaesthetized in seawater containing dissolved phenoxyethanol at a concentration of 0.3−0.4 mg/L. Then the total lengths were measured to the nearest 1 cm. The size ranged from 35 to 46 cm for *P. major* (in winter and summer) and *S. quinqueradiata* was from 75 to 92 cm. The fish were then transferred onto a "V" shaped tagging table where seawater was supplied to the fish mouths to oxygenate the gills. The fish eyes were covered using artificial chamois material. The transmitters were surgically implanted into the fish following standard tag implantation techniques (Meyer et al. 2000; Fujioka et al. 2010). An incision of 1-2 cm was made in the abdominal musculature by a sharp scalpel, approximately 2-3 cm proximal to the anus where the transmitter was inserted into the peritoneal cavity and the incision was closed with two independent sutures. The entire implantation procedure generally took less than two minutes. To facilitate identification of the fish in the case of recaptures, all fish were tagged with external plastic dart tags or T-bar anchor tags inserted through the pterygiophores of the second dorsal fin for external recognition if recaptured. After full recovery up to two hours' observation for survival, the fish were then released around the OWT.

5.2.3 Acoustic monitoring

Seven acoustic monitoring receivers (Vemco VR2W, Halifax, Canada, diameter of 60 mm, 340 mm length, a weight under water 300 g and a battery life of about 450 days) were used to monitor the presence of pulse coded acoustic transmitters within their detection range. The transmitters used that emitted fish IDs were V9 (Vemco, Halifax, Canada, 9 mm in diameter, 21 mm in length, power output 145 dB re 1 µPa @ 1 m, 180-300 s repeat rate). And V13(Vemco, 13 mm in diameter, 36 mm in length, power output 153 dB re 1 µPa @ 1 m, 35-65 s repeat rate). It is known that the detection range of the receiver is influenced by differences in geography, deployed depth, seasons, and weather, even in a day (day/night) (Medwin and Clay 1997; Singh et al. 2009; Kessel et al. 2014). The probability of signal reception by a receiver that decreases as the distance between a receiver and a transmitter increases is referred to as detection probability (Claisse et al. 2011; Topping and Szedlmayer 2011). This study assumed the detection ranges of 450 m (V9) and 700 m (V13) respectively based on web-based software

"Seawater Range Calculator" (Vemco Web: https://vemco.com/range-calculator/ "Accessed 09 Jan 2019").

At the OWT, one receiver was attached on the surface approximately 10 m under the sea surface, three receivers were deployed at AN, AS and NR moored with anchors attached to a rope approximately 10 m above the seabed, which was connected to a subsurface buoy. Two receivers were deployed on F1 and F2, and one other receiver was deployed at TN suspended 5 m from the sea surface. All receivers were coated by waterproof tape to prevent signal occlusion due to biofouling (Heupel et al. 2008).

The acoustic receivers were deployed at OWT, AS, TN, F1 and F2 in winter and two more receivers were deployed at AN and NR in summer. Detailed summary of monitoring durations including the deployment date, recovered date, days deployed, the exact positions of the receivers and the scale of various habitats is shown in Table 5-1. I used data sets from 1st Feb to 16th Mar (44 days) for the fish tagged in winter and 13th July to 13th Oct 2017 (110 days) for the fish tagged in summer.

5.2.4 Analysis

Number of detections in a specific period is usually used to describe the occurrence of tagged fish within the range of a receiver (Reubens et al. 2013). However, for this study I used detection rate (number of detections/number of days detected) to standardize the index of habitat preference of fish since the deployment durations of receivers were different by winter and summer. In this context, a fish was considered as being present in the study sites on a given day if it was detected at least twice on that day (Meyer et al. 2007; Reubens et al. 2013). I further quantify the residency of each tagged fish at the different habitats using residency index. This index was calculated by dividing the number of days a specimen was detected by the days at liberty (Abecasis and Erzini 2008). Days at liberty is defined as the number of days between the date of release and the date of last detection. The residency index ranges between 0 (completely absent in the study area) and 1 (permanently present in the study area).

As shown in Fig. 5-1, the monitoring sites were located within 5 km distance from OWT except for two sites i.e. F1 and F2. I considered those sites (OWT, AN, AS, NR and TN) as one habitat. From this, I calculated the residence time with event analysis to determine the duration of habitat usage; emigration (event) times were analyzed by the product limit method of Kaplan and Meier (1958). This was achieved by estimation of the cumulative residual rate for the two species in the different seasons tagged. In this study, the "event" represents termination of residence from habitats. This method allows for right censoring of fish still present by the time of analysis or removed by means not related to the events under analysis (i.e. moved to other waters or removed due to fishing and natural mortalities). The package "OISurv" (2.42) was used in R (ver 3.5.0) to estimate the Kaplan-Meier (K-M) survival function (Ohta and Kakuma 2005; Fujioka et al. 2010). This analysis estimated residence to the site at *t* days assuming fish *j* were released on the same day and examined the entire distribution of emigration and right-censor times. Median residence time is the number of days when only 50% of respective two fish species resided at the all sites (habitats) in this study.

The K-M product estimator $\hat{S}_{\mathrm{j}(t)}$ for j^{th} species was calculated using the formula below:

$$\hat{S}_{\mathrm{j}(t)} = \prod_{t_k < t} \left(1 - \frac{d_{jk}}{r_{jk}}\right)$$

where *t* is the days over which residence was estimated from the product of the conditional probabilities of residence at each emigration *k*, d_{jk} represents the number of individuals that emigrated and r_{jk} represents the number of individuals at risk of an emigration at time t_k for j^{th} species (Kaplan and Meier 1958). Residence time was defined as the time from tagging to the time of loss, independent of how the loss occurred.

5.3 Results

5.3.1 Movement pattern of the tagged fish

From the fixed study periods, 20 (74%) *P. major* were detected for 1 day up to 20 days in the winter (Table 5- 2). In summer, 7 (70%) *P. major* were detected within 1 day (Table 5-3) and 15 (75%) *S. quinqueradiata* were detected for 1 day up to 8 days in the summer (Table 5-4).

Twelve *P. major* were present at OWT on the released day. Out of which, 7 fish (IDs 1, 5, 10, 12, 15, 16 and 18) then moved to TN and stayed for several days (longest duration recorded was 7 days by ID 10). One fish ID 5 then moved to F2 on 17$^{\mathrm{th}}$ Feb for a day then completely disappeared. Out of the 5 fish that were only detected at OWT on the released day, 1 fish (ID 13) returned around OWT after a month and stay for 1 day then disappeared. Six *P. major* (IDs 2, 9, 21, 22, 23 25) moved directly to TN without any detection at OWT. Thus, 13 fish moved to TN between 1$^{\mathrm{st}}$ Feb and 16$^{\mathrm{th}}$ Mar 2017. In addition, one fish (ID 2) then moved to OWT after one or so months on 13$^{\mathrm{th}}$ Mar. Other *P. major* such as ID 26 was only detected at F1 for a day on 16$^{\mathrm{th}}$ Feb, which was about 16 days after released. One other fish (ID 27) stayed at AS for about 20 days from 5$^{\mathrm{th}}$ Feb to 13$^{\mathrm{th}}$ Mar (Fig. 5-2).

Seven *P. major* were detected at OWT within the released day. Out of which one fish (ID 29) moved to TN on the same day then disappeared completely (Fig.5-3). Despite additional monitoring receivers deployed in two more sites around OWT, the *P. major* was only detected within a day in summer.

Most *S. quinqueradiata* were detected in all habitats a few days after the released day as shown in Figs. 5-4a and 5-4b. Whereby ten *S. quinqueradiata* were detected at the OWT within 2 days after released (IDs 36, 37, 38, 39, 41, 42, 47, 49, 50 and 51) but 4 fish disappeared completely after the first day (IDs 36, 38, 41 and, 49). While two fish (IDs 39 and 51) were detected on the second day and disappeared within the same day. Moreover, three fish (ID 37, 42, 50) were detected at the OWT for 1-3 days. IDs 37 and 42 then moved and used multiple sites (AS, NR, F1, F2 for ID 37 and NR, AS, F1 for ID42) before they disappeared. ID 37 recoded the longest detection at NR for 6 days while ID 42 recorded the longest detection at AS for 5 days (Fig. 5-4b). ID 40 was detected at AN after released then moved to NR after 10 days where it was detected for a day and disappeared. ID 43 was only detected at AS for 8 days after released. IDs 44 and 46 were only detected at the TN after released. However, ID 46 then moved to F1 on 26th Aug (more than a month after released) and used the site for a day. Moreover, ID 45 was detected on the second day after released at NR and stayed at the site for 5 days. Then moved and stayed at AS for 2 days and was lastly detected at F1 on 7th Oct (85 days after released) for a day then disappeared.

5.3.2 Habitat usage of the tagged fish

The detection rate and number of fish found at each site are shown in Fig. 5-5. In winter, the detection rate for *P. major* was highest at TN (244/day) used by 13 fish, followed by the OWT (78/day) used by 13 fish, AS (19/day) by one fish, F2 (15/day) by one fish and the least used site was F1 (1/day) by 1 fish. At TN, the residency index was low between 0.02 and 0.25. However, three fish recorded high residency indices of 0.50, 0.86 and 0.88. At OWT, the residency index was low between 0.02 and 0.1 except one fish recorded high residency index of 0.5. At AS, the residency index was 0.49. While both F1 and F2 recorded low residency indices of 0.06 (Table 5- 2).

The detection rate of *P. major* in summer was highest at OWT (54/day) used by 7 fish followed by TN (3/day) by 1 fish. However, no residency was recorded at both sites since all the fish disappeared within the same day when they were released (Table5-3). Thus, habitat use by *P. major* was different between winter and summer. This species tended to stay for shorter duration around the OWT where they were released, then moved to coastal area (TN) and stayed for some time during winter, while most of them moved somewhere out of detection ranges in summer.

The detection rate for *S. quinqueradiata* in summer was highest at the OWT (248/day) used by 10 fish, followed by AS (159/day) used by 4 fish, NR (96/day) by 5 fish. In addition, TN (14/day) by 3 fish, AN (12/day) by 1 fish, F2 (11/day) by 1 fish and the least used habitat was F1 (3/day) by 4 fish (Fig. 5-5). However, at OWT recorded a low residency index between 0.01 and 0.4. At AS, residency index was low between 0.02 and 0.33 except one fish recorded high residency index of 0.80. At NR, low residency index was recorded between 0.06 and 0.09 except one fish that recorded a high residency index of 0.60. At TN low residency index was recorded between 0.02 and 0.1. In addition, at F1 low residency index was recorded between 0.01 and 0.2 and at F2 was 0.04 (Table 4). *S. quinqueradiata* tended to use the OWT longer than *P. major*. This species also frequently used AS and NR located at the southern part of the OWT.

Residence time estimated derived from K-M product limit method varied by seasons and species (Fig.5-6). In winter, *P. major* median residence time (when 50% of fish still present) was 10 days then declined gradually up to 35 days before complete disappearance after 41st day. In summer, it was a day and the *P. major* completely disappeared on the same day. While *S. quinqueradiata* median residence time was 3 days and complete disappearance was on the 25th day.

5.4 Discussion

P. major and *S. quinqueradiata*, as many other fish species, is liable to natural spatial and temporal patterns in movements and habitat use (Neat et al. 2006; Righton et al. 2007). Environmental factors play an important role in these patterns, leading to differences in its behavior (Righton et al. 2001). Spatial movement differs from sedentary groups with strong site fidelity to dispersers roaming around in large geographical areas (Robichaud and Rose 2004). Temporal movements may differ substantially between stocks and could be related to prey availability, predation pressure and abiotic factors (e.g. light regime, prevailing currents) (Righton et al. 2001; Reubens et al. 2013). The present study provides important preliminary evidence concerning the movement pattern of *P. major* and *S. quinqueradiata* around the OWT and the neighboring habitats off Fukue Island in Goto Islands.

Studies on fish distributions around the OWT showed that several species, such as pouting *Trisopterus luscus* and Atlantic cod *Gadus morhua* can reside in high densities at distances of meters to tens of meters from the turbines (Reubens et al. 2011, 2013; Bergström et al. 2014). However, this was different from this study. I observed low affinity of *P. major* and *S. quinqueradiata* to OWT in relation to the neighboring habitats. The fish stayed around the OWT not more than three days irrespective of the seasons but preferred other habitats surrounding the OWT (Figs. 5-2-4a and 5-4b). OWT being a floating type turbine could have attributed to these observations in Goto Island. Probably the structure of the OWT could not attract sufficient benthic invertabrates such as echinorderm, worms, molluscs and crustaceans that *P. major* feeds on being demersal oceanodromous as well as small fish that *S. quinqueradiata* feeds on.

P. major tagged in winter was observed at the released site (OWT, 100 m deep) within a day and recorded low residency index, then detected at TN (47 m deep) from 2nd February to 16th Mar 2017. One fish (ID27) used AS (75 m deep) for 20 days and one other fish (ID26) directly moved to the northern part and used (F1, 70 m deep) briefly, this meant that majority of fish moved to the coastal shallower area. It is well known that *P. major* migrate to shallower waters in late spring and early summer to spawn depending on the geographical latitude, in southern warmer waters spawning usually commences early (Watanabe and Kiron 1995; Hakuta and Tabeta 2013; Russell et al. 2014). For this study the *P. majors'* total length was between 35cm and 36 cm which indicated that all the fish were within the L_{mat} (33 cm) could have migrated to shallower coastal area for spawning. In addition, this observation was due to the increasing temperature that augmented the fish swimming activity and was within the temperature range of *P. major* (15^{o} ~ 26^{o} C) (Takeuchi et al. 2016). According to communication from the fishermen operating TN, they stated that they never found any tagged *P. major* in their catches during the monitoring period. With this regard, TN can be said to be an artificial complex reef structures with large volume built in the shallower waters, according to Kakimoto (1998) epibenthic species such as *P. major* preferred bottom habitats including artificial or natural reefs.

On the other hand, *P. major* tagged during summer was only observed at the OWT just after released and one fish then moved to TN within the same day (Fig. 5-3). Thus, *P. major* were never detected at habitats around the OWT, and probably moved to other waters. This could have been caused by high temperatures during the summer whereby the SST temperature was more than 28^{o}C in August 2017 (Nagasaki Prefectural Institute of Fisheries Web: http://www.marinelabo.nagasaki.jp/gyokaikyo/2017/170803-2.htm "Accessed 02 Nov 2018") that was out of their suitable water temperatures (15^{o} ~ 26^{o} C). They might have descended to deeper habitat off island where the water temperature was low (Nakabo 2002).

Fifteen *S. quinqueradiata* tagged in summer were detected in all the sites for some days. Out of which, 10 fish were only detected at the OWT then disappeared within three days. In addition, 6 fish were observed at plural sites for different number of days. This movement pattern seems to be different from *P. major* in winter and summer because *S. quinqueradiata* frequently moved in all the habitats including floating objects (OWT, F1, F2) and benthic habitats (NR, AN, AS, TN). They were especially observed at the OWT, AS and NR (Fig. 5-4a and 5-4b). This indicated that *S. quinqueradiata* makes extensive migrations in terms of distance and in terms of depths between habitats around the OWT. These results concurred with several studies that pelagic predators such as tunas aggregate around localized seamounts and lumps (Klimley et al. 2003; Fujioka et al. 2010). Kasai et al. (2000) also confirmed that yellowtails including *S. quinqueradiata* would stay in some restricted areas during the night, move via the frontal area to another coastal area to feed then return. This observation suggested a possibility that *S. quinqueradiata* to have utilized the OWT and the neighboring habitats as feeding grounds and shelters.

From this chapter, I can conclude that *P. major* preferred the coastal area including TN in winter while most of them moved out of detection ranges in summer probably the sites were not favorable habitats due to their life history behavior. While some *S. quinqueradiata* stayed around the OWT for longer durations (about 3 days) as compared to *P. major* then moved to the neighboring habitats and were detected in all the sites. This confirmed with the chapter 3, whereby I observed many Seriola spp around the aFADs (F1 and F2) and in chapter 4, I observed the prey for the predatory fish. As a result, residence time of the habitat around the OWT for *P. major* tagged was 10 days in winter and a day in summer. Residence time for *S. quinqueradiata* in summer was 3 days. This suggested that these species could have used the neighboring habitas more as compared to the OWT probably for feeding purpose. The observed durations were shorter than expected suggesting that these species moved around the OWT for a limited time. Further investigation on the relationship between fish movement and environmental factors is necessary since changes in the environmental conditions have an influence on habitat usage and fish residency as I have seen in my previous chapter increase in temperature influenced the distribution of fish schools around the aFADs. This will assist in explaining the reasons for these findings in terms of the movement pattern by the two commercial important species around the OWT and neighboring habitats. Such findings can be used to enhance future designs of the artificial structures and their integration with the natural environments to increase their positive effect.

Figures and Tables (Chapter 5)

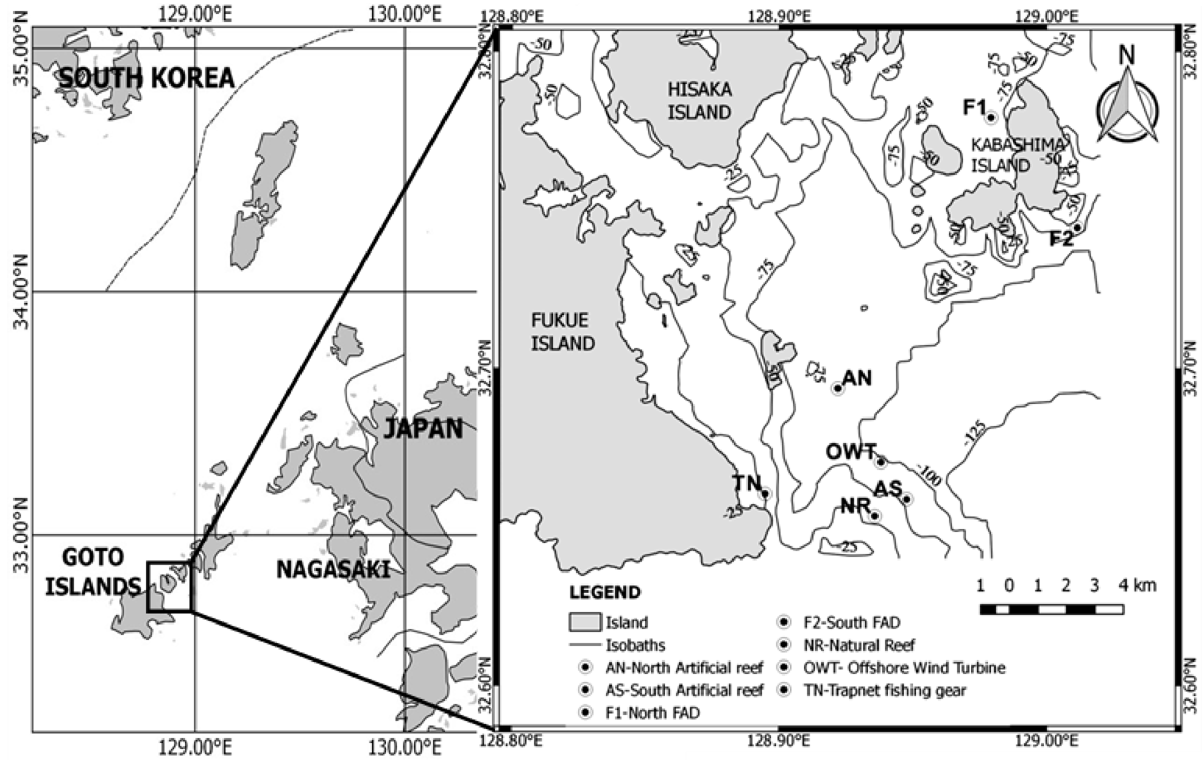


Figure. 5-1. A Map of the study sites in Goto Islands, the locations of the deployed monitoring receivers. Including Offshore Wind Turbine (OWT), north artificial reef (AN), south artificial reef (AS), natural reef (NR), trapnet (TN), north FAD (F1) and south FAD (F2).

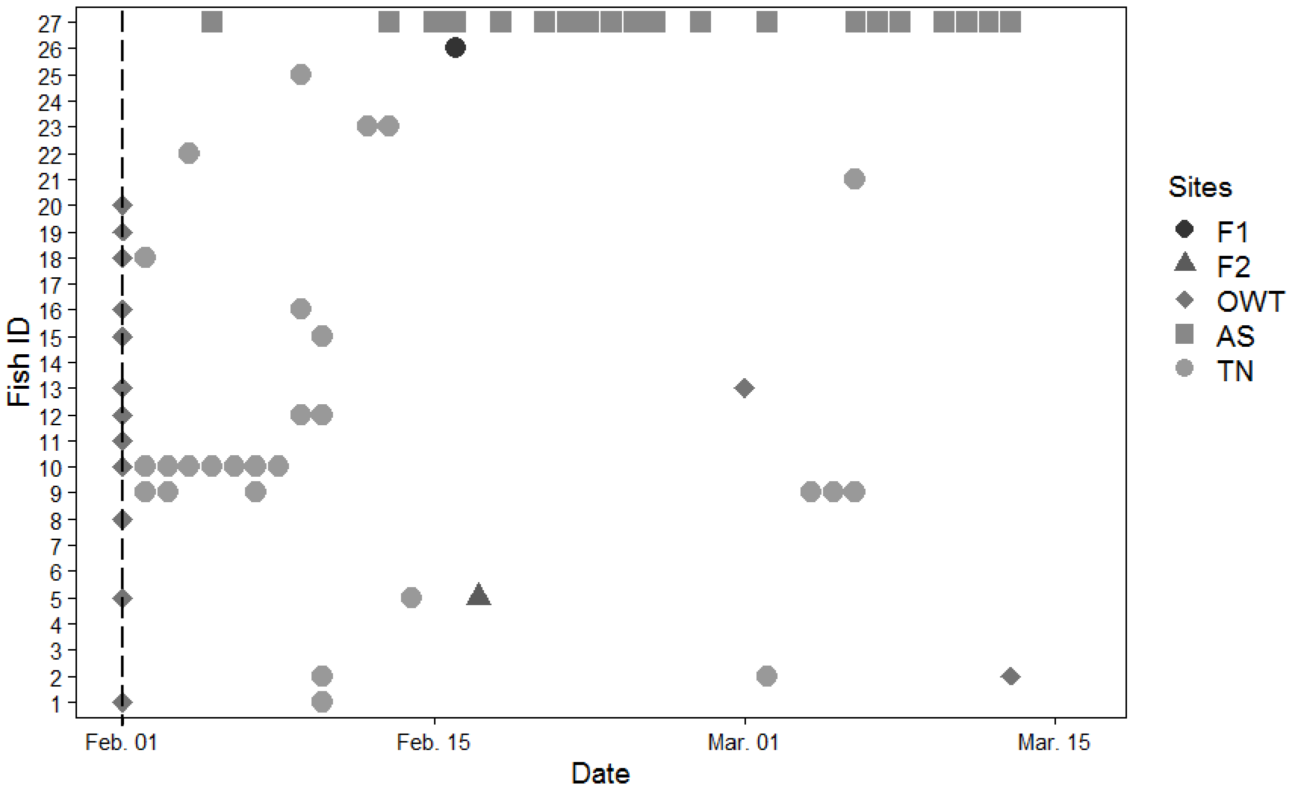


Figure. 5-2. Detection history of *P. major* tagged in winter. Dotted line indicated the released date on (Feb. 01).

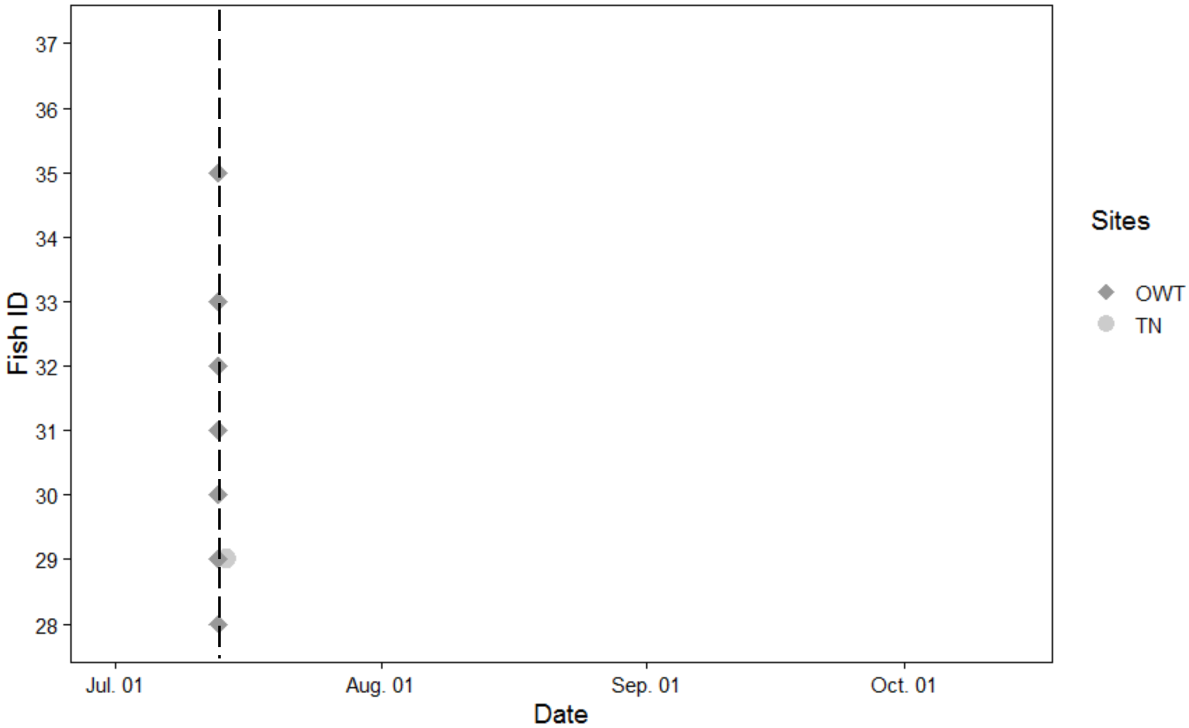


Fig.5-3. Detection history of *P. major* tagged in summer. Dotted line indicated the released date on (Jul. 13).

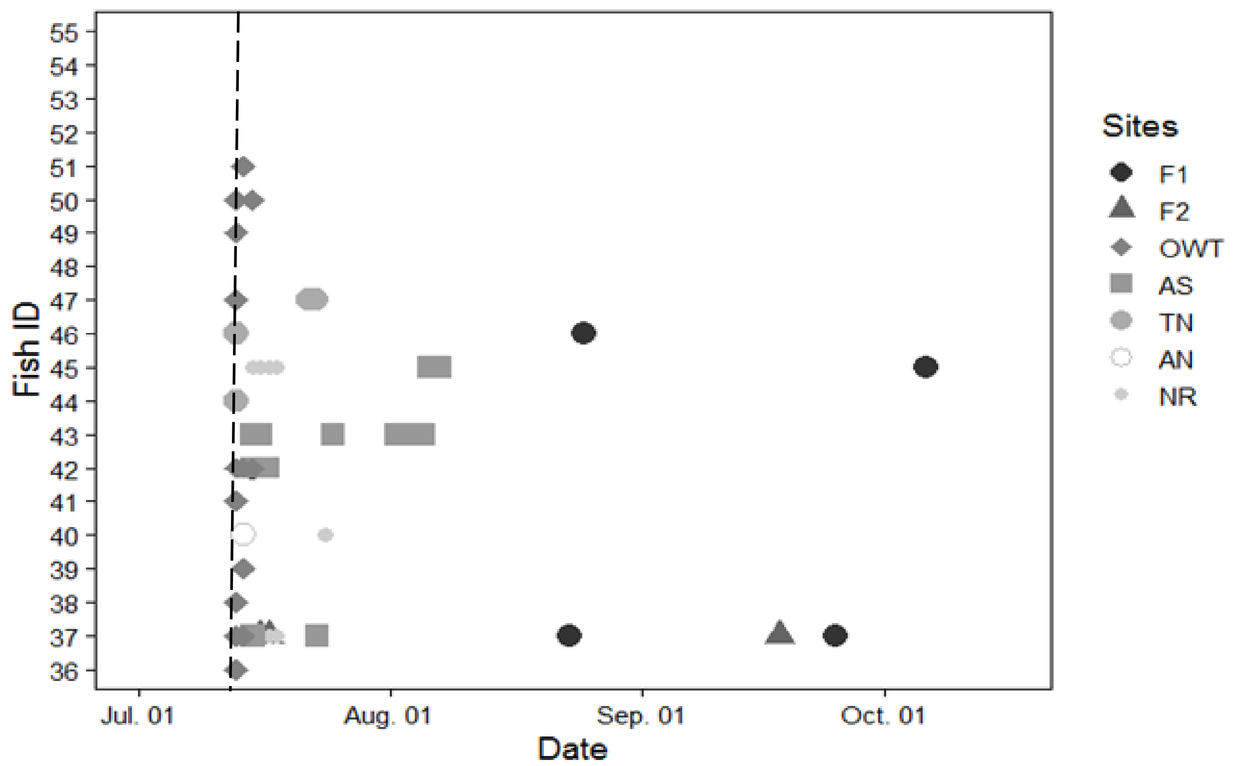


Figure.5-4a. Detection history of *S. quinqueradiata* tagged in summer. Dotted line indicated the released date on (Jul. 14).

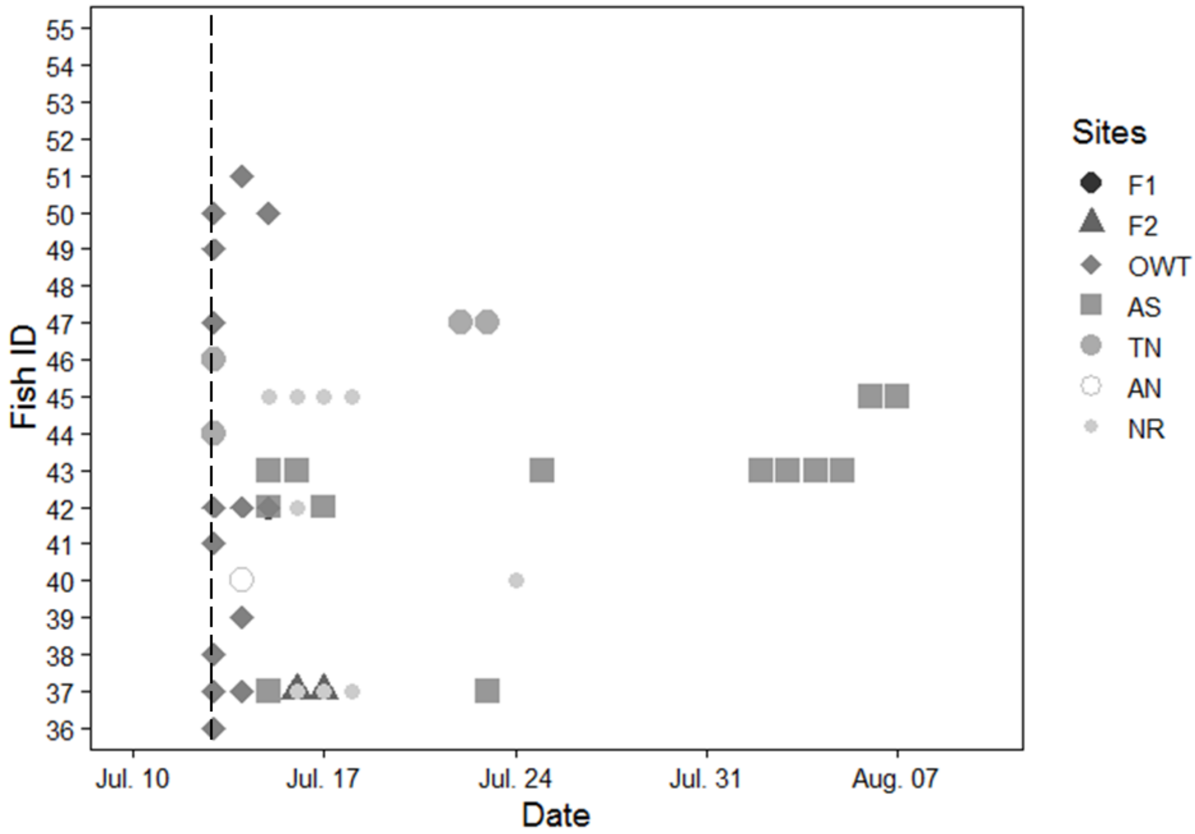


Figure.5-4b. Detection history of *S. quinqueradiata* from 10th July to 10th Aug 2017. Dotted line indicated the released date on (Jul. 14).

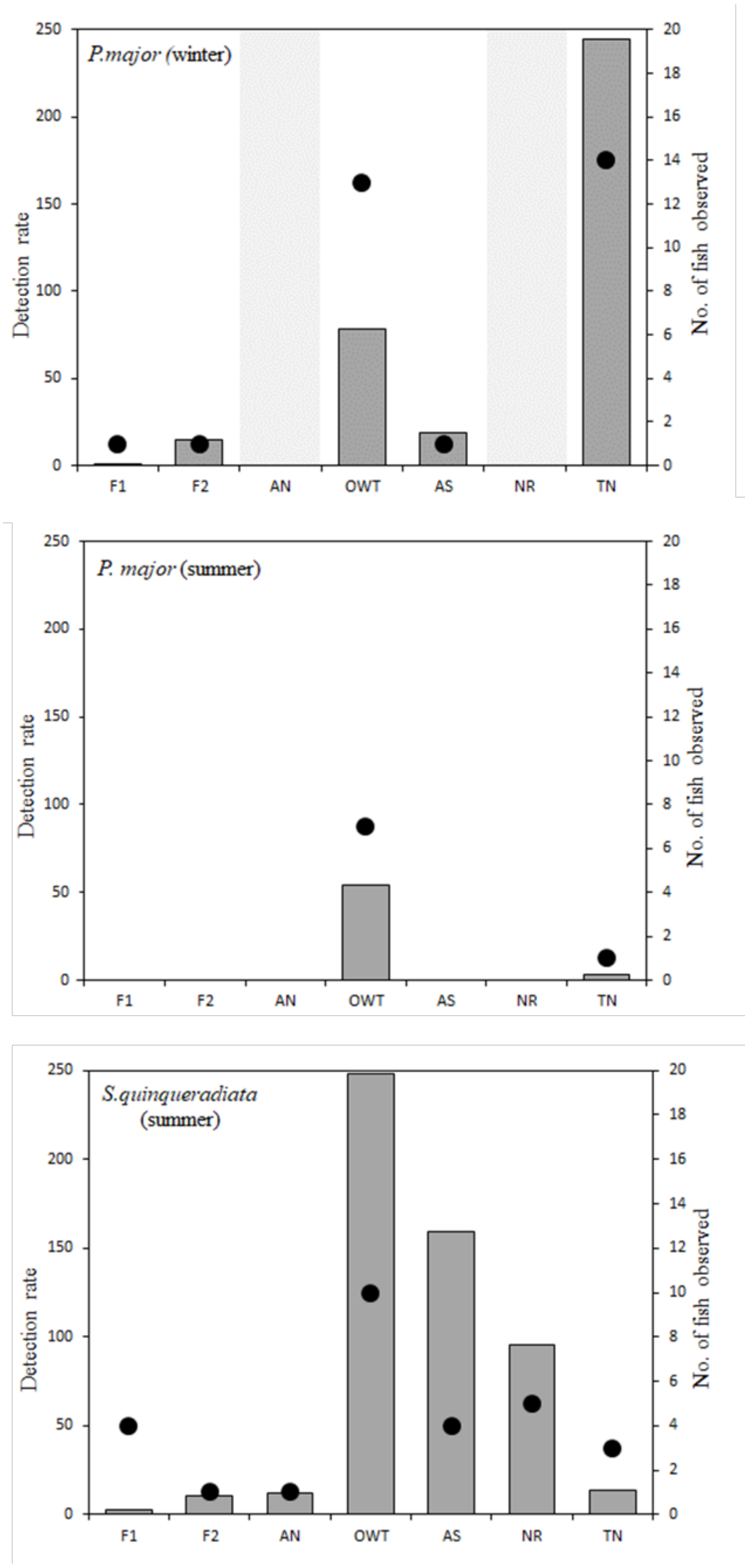


Figure. 5-5. Detection rate by *P. major* tagged in winter, *P. major* and *S. quinqueradiata* tagged in summer. Vertical bars indicate the detection rate and the dots indicate the number of fish observed. Vertical bars filled with gray shades in the top graph for *P. major* (winter) showed the sites where the receivers were not deployed.

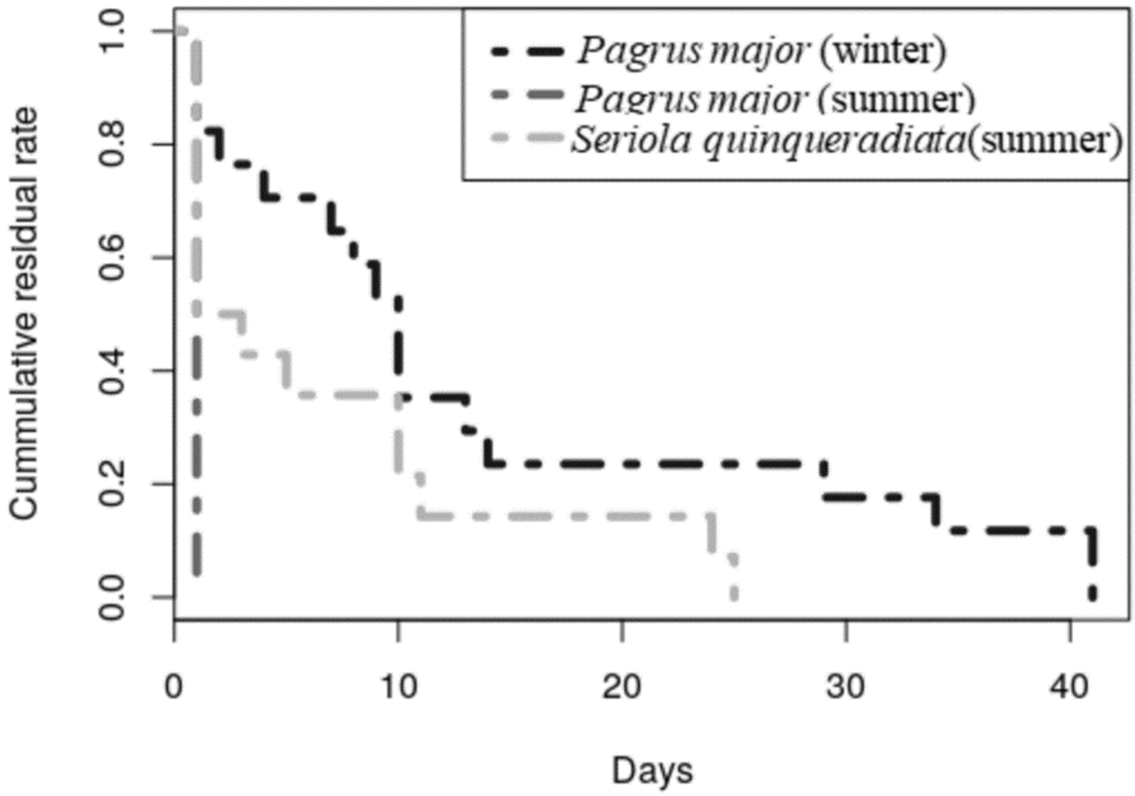


Figure.5-6. Residence time estimates of *P. major* and *S. quinqueradiata* from KM analysis during the study from 1st Feb to 16th Mar (winter) and 13th July to 13th Oct (summer)

Table 5-1. Deployment information

Habitat name	Deployment Location	Deployment date (Start)	Recovered date(End)	Days deployed	Bottom depth (m)	Characteristics
Offshore Wind Turbine	32°40’13.98” N, 128°56’17.04” E	1st Feb	16th Mar	44	~ 100	Installed off Fukue Island in Goto Islnds
(OWT)		22nd June	11th Oct	112		
North FAD (F1)	32°46’16.98” N, 128°58’45.00” E	1st Feb	12th Oct	254	~ 70	Installed at the Northern part of Kabashima Island in Goto Islands. ~ 10.7 km northwest of the OWT
South FAD (F2)	32°44’40.02” N, 129°00’40.98” E	1st Feb	12th Oct	254	~ 100	Installed at the Southern part ~11.8 km of Kabashima Island
North Artificial reef (AN)	32°39’31.80” N, 128°56’51.42” E	13th July	13th Oct	93	~ 98	Installed at the Northern part of OWT ~ 1.6 km.
South Artificial reef (AS)	32°41’37.62” N, 128°55’19.02” E	1st Feb	17th Mar	45	~ 75	Installed at southern part of OWT ~ 3 km.
		27th June	13th Oct	109		
Natural reef (NR)	32°39’12.66” N, 128°56’08.76” E	13th July	13 th Oct	93	~ 56 - 59	Located at the southern part of the OWT ~ 1.9 km
Trapnet fishing gear (TN)	32°39’37.44” N, 128°53’41.16” E	1st Feb	14th Nov	287	~ 47	Installed at the western part of the OWT ~ 4.2 km

Table 5-2. Summary of acoustic monitoring data for 27 *P. major* tagged in winter

0 indicates the days at liberty and days detected was within the released date and disappeared completely thus residency index was 0

/ indicates the fish ID was only detected once hence omitted in the analysis

Winter							
***Pagrus major* (N=27)**							
Fish ID	**Total length (cm)**	**Tag type**	**Date released**	**Sites detected**	**Days at liberty**	**Days detected**	**Residency index**
1	37	V9	01/02/2017	OWT	0	0	0.00
1				TN	0	0	0.00
2	39	V9	01/02/2017	OWT	41	1	0.02
2				TN	41	1	0.02
3	39	V9	01/02/2017	Not detected	/	/	/
4	36	V9	01/02/2017	Not detected	/	/	/
5	37	V9	01/02/2017	OWT	18	1	0.06
5				TN	18	1	0.06
5				F2	18	1	0.06
6	36	V9	01/02/2017	Not detected	/	/	/
7	37	V9	01/02/2017	Not detected	/	/	/
8	35	V9	01/02/2017	OWT	41	1	0.02
9	36	V9	01/02/2017	TN	7	6	0.86
10	36	V9	01/02/2017	OWT	8	1	0.13
10				TN	8	7	0.88
11	35	V9	01/02/2017	OWT	0	0	0.00
12	36	V9	01/02/2017	OWT	10	1	0.10
12				TN	10	2	0.20
13	38	V9	01/02/2017	OWT	29	2	0.07
14	38	V9	01/02/2017	Not detected	/	/	/
15	42	V9	01/02/2017	OWT	10	1	0.10
15				TN	10	1	0.10
16	40	V9	01/02/2017	OWT	9	1	0.11
16				TN	9	1	0.11
17	43	V9	01/02/2017	Not detected	/	/	/
18	41	V13	01/02/2017	OWT	2	1	0.50
18				TN	2	1	0.50
19	42	V13	01/02/2017	OWT	0	0	0.00
20	37	V13	01/02/2017	OWT	0	0	0.00
21	46	V13	01/02/2017	TN	34	1	0.03
22	45	V13	01/02/2017	TN	4	1	0.25
23	38	V13	01/02/2017	TN	13	2	0.15
24	41	V13	01/02/2017	Not detected	/	/	/
25	40	V9	01/02/2017	TN	41	1	0.02
26	38	V9	01/02/2017	F1	17	1	0.06
27	41	V9	02/02/2017	AS	41	20	0.49

Table 5-3 Summary of acoustic monitoring data for 27 *P. major* tagged in summer.

0 indicates the days at liberty and days detected was within the released date and disappeared completely thus residency index was 0

/ indicates the fish ID was only detected once hence omitted in the analysis

Fish ID	Total length (cm)	Tag type	Date released	Sites detected	Days at liberty	Days detected	Residency index
Summer							
***Pagrus major* (N=8)**							
28	42	V9	13/07/2017	OWT	0	0	0.00
29	39	V9	13/07/2017	OWT	0	0	0.00
29				TN	0	0	0.00
30	44	V9	13/07/2017	OWT	0	0	0.00
31	43	V9	13/07/2017	OWT	0	0	0.00
32	38	V9	13/07/2017	OWT	0	0	0.00
33	45	V9	13/07/2017	OWT	0	0	0.00
34	46	V9	13/07/2017	Not detected	/	/	/
35	41	V9	13/07/2017	OWT	0	0	0.00

Table 5-4 Summary of acoustic monitoring data for 20 *S. quinqueradiata* tagged in summer

0 indicates the days at liberty and days detected was within the released date and disappeared completely thus residency index was 0

/ indicates the fish ID was only detected once hence omitted in the analysis

Summer							
***S. quinqueradiata* (N=20)**							
Fish ID	**Total length (cm)**	**Tag type**	**Date released**	**Sites detected**	**Days at liberty**	**Days detected**	**Residency index**
36	87	V13	14/07/2017	OWT	0	0	0.00
37	88	V13	14/07/2017	OWT	75	1	0.01
37				NR	75	6	0.08
37				AS	75	3	0.04
37				F1	75	2	0.03
37				F2	75	3	0.04
38	89	V13	14/07/2017	OWT	0	0	0.00
39	92	V13	14/07/2017	OWT	0	0	0.00
40	81	V13	14/07/2017	AN	11	1	0.09
40				NR	11	1	0.09
41	91	V13	14/07/2017	OWT	0	0	0.00
42	80	V13	14/07/2017	OWT	5	2	0.40
42				NR	5	3	0.60
42				AS	5	4	0.80
42				F1	5	1	0.20
43	82	V13	14/07/2017	AS	24	8	0.33
44	84	V13	14/07/2017	TN	0	0	0.00
45	85	V13	14/07/2017	NR	89	5	0.06
45				AS	89	2	0.02
45				F1	89	1	0.01
46	79	V13	14/07/2017	TN	44	1	0.02
46				F1	44	1	0.02
47	83	V13	14/07/2017	OWT	10	1	0.10
47				TN	10	1	0.10
48	89	V13	14/07/2017	Not detected	/	/	/
49	77	V13	14/07/2017	OWT	0	0	0.00
50	75	V13	14/07/2017	OWT	0	0	0.00
51	77	V9	14/07/2017	OWT	0	0	0.00
52	92	V13	14/07/2017	/	/	/	/
53	74	V13	14/07/2017	/	/	/	/
54	85	V13	14/07/2017	/	/	/	/
55	91	V13	14/07/2017	/	/	/	/

Chapter 6

General discussion

The Kenyan coastal fishery being a multi-species, multi-gear and multi-vessel operation has inconsistent and irregular effort throughout the year (McClanahan 1998; Gomes 2012). The fishery has expanded with an increasing number of participants in the industry (Ochiewo 2004). In addition, due to artisanal fishers' financial disempowerment and lack of resources, environmental degradation of fishing grounds has tremendous effect on the fishery resources. As a result of the increased number of fishers, most of whom use inappropriate nets and gears therefore inshore fishing areas are being destroyed, which in turn decreases productivity and the economic livelihood of local communities (Cinner et al. 2008). In addition, local fishers cite a significant decrease in catch. This has perpetuated the decline of the inshore environmental and economic resources. Contributing to the perplexity of the situation, offshore marine resources are abundant and vastly underutilized by the local fishers (Ruwa 2011). Therefore, in order to reduce stresses that have been exerted on the inshore fisheries in Kenya. I propose use of aFADs to be adopted in Kenya as an alternative measure since this technology has not been utilized yet and has a potential to redistribute the effort offshore where rich resources including pelagics are present. In addition, the fishers have been hesitant to comply with measures such as the use of a proposed minimum mesh size set or destructive gears that caused degradation of the inshore resources. Therefore, aFADs will reduce pressure at the inshore, allow recovery of the fisheries resources and also will enable the fishers to use fishery resources that have not been overexploited. In addition, it will improve the catch composition of the marine fishery from small size immature individuals to a better marketable fish size. This in turn will improve on the income of the fishers and improve on the food security.

As observed in chapter 1, beach seine fishery commonly practiced in reef lagoons in Kenya, with potentially destructive impacts on reefs and other habitats (Jones 1992; McClanahan and Mangi 2001; Mangi and Roberts 2006). The species composition and size frequency of catches made by nets with codend mesh sizes of 25 mm, 38 mm and 44 mm were evaluated for samples collected during three sampling trips in the Lamu area between 2014 and 2016. A total of 98 fish species belonging to 41 families were recorded. Most species with highest diversity (D = 10.67) were caught by the 25 mm codend mesh, followed by the 38 mm (D = 6.69) and 44 mm meshes (D = 3.04), respectively. Size frequencies of dominant species *L. vaigiensis*, *S. sutor* and *L. lentjan* depended on the codend mesh size sampled, with the 25 mm mesh retaining more immature individuals than the other two meshes. It is concluded that codend mesh size influences catch properties of beach seine nets used in Lamu. However, as a long term solution my study recommended the allocation of fishing efforts from current fisheries resources to the untapped resources. The deployment of aFADs was considered as a promising tool for this purpose. Since the ban in 2001 and the recommendation of using larger mesh size has not been well implemented. A better alternative is to allow the fishers to use the same gear with the proposed mesh size after the coastline where the resources have not yet been utilized. In addition, regulation of the aFAD fishery should be put in place after continuous monitoring of the catch for a certain period of time for better fish catch and effort allocation for sustainable fishery.

In chapter 2, I reviewed several benefits that were associated with deployment of aFADs such as operation around aFADs has increased and ensured more consistent catches at reduce time, reduce cost and increase in safety for small-boat operation. The aFADs have been instrumental in the fishing cooperatives and have provided fisheries managers with a way to safe-guarding the very important marine resources by providing fishers with some alternative ways. The aFADs are also used to demarcate boundaries between areas such as closed areas and fishing zones. For example, aFADs have been used for demarcating marine zones in the Philippines (Anon 2003). On the other hand, some issues associated with aFADs were being a foreign body in the ocean may alter local marine ecosystem such as changing migration routes of certain species (Marsac et al.1996). There are also concerns that pelagic species that aggregate around aFADs can easily be over exploited since they concentrate fish in one localized area, making them easier to catch (Beverly et al. 2012). The aFADs are also associated with issue on bycatch of juveniles and other endangered species (Floyd and Pauly 1984). In order to maximise on the benefits and minimize and be able to control on the issues related to aFADs, studies on the evaluation of fish attraction performance around the aFADs are vital and that triggered my studies.

In Chapter 3, Fish faunas and their succession around aFADs were observed by optical techniques including ROV and underwater camera. These two techniques were very useful in capturing fish species around the aFADs at a short range. These techniques complimented my data and enable me evaluate commercially important species and diversity around the aFADs, although I also found the fish fauna to be different by both techniques because of some technical and biological reasons. From both techniques, I was able to observe about 12 commercially important species such as such as *S. dumerili, S. lalandi, E. bipinnulata, O. fasciatus, T. albacares, O. punctatus* and *G. punctata*. Some of which were predatory fish including *S. dumerili, E. bipinnulata and C. hippurus* that were observed to aggregate around the aFADs in some months during the data collection period.

In chapter 4, surveys by using the echo sounder having species identification ability was conducted to understand the temporal and spatial distribution of fish schools around aFADs at long range. The number of fish schools increased with time in the two study sites but peaked in terms of in different months during the study period. This was attributed by a number of factors including the position of the aFADs whereby the north aFAD is located in an enclosed lagoon while the south aFAD is located in the open sea. The other factors that attributed to increased in number of fish schools was due to increased in temperature and the current velocity whereby the highest number of fish schools was recorded when the current velocity was low and the fish schools decreased with increase in current velocity. All the above mentioned factors also influenced the distribution of the fish schools of jack mackerel, anchovy and herring both horizontally and vertically at the aFADs. Mostly the fish schools were highest in numbers within 100 – 200 m from the aFADs and tended to distribute deeper in the water columns.

In chapter 5, I investigated movement pattern of two commercial important fish around OWT that was assumed to function as aFADs and neighboring habitats in Goto Islands. *P. major* in winter used coastal area while avoided sites that were hot in summer and *S. quinqueradiata* in summer used OWT and all neighboring habitats but residence time was short. Residence time for the studied habitats from the Kaplan-Meier curve was 10 days for *P. major* in winter, a day in summer and 3 days for *S. quinqueradiata*. The two species utilized the other habitats more for various purposes such as *P. major* preferred bottom habitats including artificial or natural reefs for feeding purpose and *S. quinqueradiata* made extensive migrations around the OWT and the neighboring habitats probably for feeding and habitat. These observations concurred with studies by Kakimoto (1998) and Kasai et al. (2000).

From my studies, I found out that intergrating several techniques is a good way to collect data around the aFADs, since it provided an understanding of fish attraction around the aFADs in terms of fish fauna at short range (chapter 3), spatio- temporal distributions of fish schools at long range (chapter 4) and habitat usage and residency of two commercially important species in Goto Islands (chapter 5) (Fig.6-1). It is well-known that fish attraction to aFADs can be caused by 1. Feeding 2. Spawning 3. Nursery and recruitment 4. Predation by large fish fauna (Jessee et al. 1985; Bull and Kendall 1994; Fabi et al. 2006; Leitão et al. 2007). Integrated techniques in this study provided facts that helps understanding the mechanisms of fish attraction to the aFADs that were different by species and seasons in Goto Islands. For example, I observed presence of predatory fish such *S. dumerili, E. bipinnulata* and *C. hipparus* at the south aFAD from May to October by ROV. While from the echo sounder surveys, I observed the distribution of fish schools aggregating at the south aFAD during the same period from May to October (Fig. 6-2). The assumption with this observation between the different techniques was that the distribution was similar despite the data collection period. I also observed the presence of the fish schools and the predatory fish to aggregate around the aFADs at the same time in a short distance (chapter 3). This concurred with the previous studies that presence of predatory fish could have been attributed to the presence of other fish species that aggregate around the aFADs. Therefore, findings in chapters 3 and 4 complimented each other and I was able to consider predatory-prey relationship. However, a further study such as stomach content analysis to determine weather the predatory fish observed fed on the fish schools that aggregated around the aFADs in Goto Island. In addition, biotelemetry survey enabled me to understand the connectivity of the habitats in terms of residency of two commercially important species in Goto islands. I observed the *S. quinqueradiata* moved and used the north and south aFADs from July to October during the study period whereby similar species *S. dumerili* was observed by ROV to aggregate around the aFADs during the same months. In addition the number of fish schools were also observed highest in numbers during the same months by the echosounder. This indicated that the *S. quinqueradiata* used the aFADs for various purposes such as feeding and habitat. This technique complimented and confirmed the results of the previous chapters that used optical and acoustic techniques. Thus the three techniques intergrated was able to give information of the relationships in terms of fish fauna and fish schools at the two aFADs in Goto Islands (Fig. 6-2).

By intergrating the various techniques in my study, I established several relationships such as predatory-prey relationship, feeding relationships and movement and residency around the aFADs in Goto Islands. I anticipated such phenomena in this study that the presence of *S. lalandi* and *C. hipparus* could have been due to feeding on juveniles fish that aggregated around the aFADs. Since I observed in chapter 3 the presence of predatory fish occurred in the same months where the number of mackerels, anchovies and herrings fish schools were present. I anticipated the occurrence of the predatory fish could have been influenced by the presence of the fish schools that they could be preying on. This observation indicated that both predators such Thunnus sp., and prey species such as Trachurus sp., were encountered around the aFADs in Goto Islands. From this study, it is evident that aFADs can function as nursery grounds for juveniles and feeding grounds for the larger fish. In chapter 5, I also observed *P. major* being epibenthic species preferred bottom habitats including artificial or natural reefs. In addition, many Seriola spp were observd around the aFADs and in chapter 4, I observed presence of the fish schools (prey) for the predatory fish. This suggested that these species could have used the neighboring habitas probably for different purposes including feeding on the fish schools and as habitat (Fig.6-2).

From this study, aFADs can be an alternative for the stresses of fisheries resources being an important tool in a number of artisanal fisheries including small-scale fishery based on traditional methods, sport, and commercial fisheries, especially in tropical waters. My findings concurred with various studies such as (Galea 1961; Klima and Wickham 1971; Beets 1989; Hilborn and Medley 1989; Friedlander et al. 1994; Higashi 1994; Hall et al. 1999). This alternative measure will assist in recovery of inshore fishery and will help in improving the fishers' catch by redistributing the effort from inshore to offshore in regions where fishing efforts are too much biased in coastal waters. However, there are several factors that need to be put into perspective such as the location which is very important. I observed in my study the difference in trends in terms of fish fauna and fish schools despite the two sites being 2 km apart. Also the purpose of the aFADs is important to consider such as to deploy aFADs for certain life stages of the fishes (juveniles), demarcating marine zones or for a certain target fishery. The other aspects that also fall in place are the type of aFADs and the costs.

6.1 Future technical issues that need to be considered for implementation of aFADs

I confirmed from my studies that aFADs in Goto Island attracted fish fauna and fish schools. I also found out that some commercial important fish fauna utilized the sites for various purposes including feeding. However, socio-economic studies including a cost- benefit analysis around the aFADs is necessary as a tool to facilitate management. A comparison of increase in fishing effort around the aFADs should be compared against open water fishing. The results will assist in quantifying the net increase in total value of catch production as a result of fishing around the aFADs and determination of return on investment of the aFADs over time. Also determination of savings in fuel consumed when fishing around the aFADs against open water fishing. Fuel cost savings added to the increase value of production to determine the net economic benefits of the aFADs. These researches are very important to fisheries because fishers may not adopt new fishing methods like aFADs if they do not understand the connectivity of this particular new fishing technique to their economic wellbeing (Stewart et al. 2006). Likewise, compliancy and sustainability may be a toll order if implementation strategies are designed in ways that are insensitive to the needs of those dependent on the resource (Wilen 2004). When introducing new fishing techniques, as successful fisheries projects may need to direct outcomes at local values (Brandt 2007). Additionally, in developing countries including Kenya, the low opportunity cost experienced by fishers in the context of an excess labour force and the limited costs of entering an introduced fishery is assumed to lead to a bio economic equilibrium in which the fishery is heavily overexploited (McManus 1997).

It is also important to monitor catch and effort data, and ideally to involve fishers in the process, so as to determine the levels of exploitation around the aFADs and the impact on the overall fishery. When there is any doubt over the health of the resources a precautionary approach should be taken and the aFAD re-analyzed to determine its impact on fishing mortality. Fishing at aFADs should therefore be subject to input or output controls. Moreover, the results of aFADs should be documented and reported to regional fishery organizations and the information and knowledge shared between countries, so that there will be better understanding on the use and development of sustainable aFADs in the future. This was also supported by (Beverly et al. 2012).

Figures and Tables (Chapter 6)

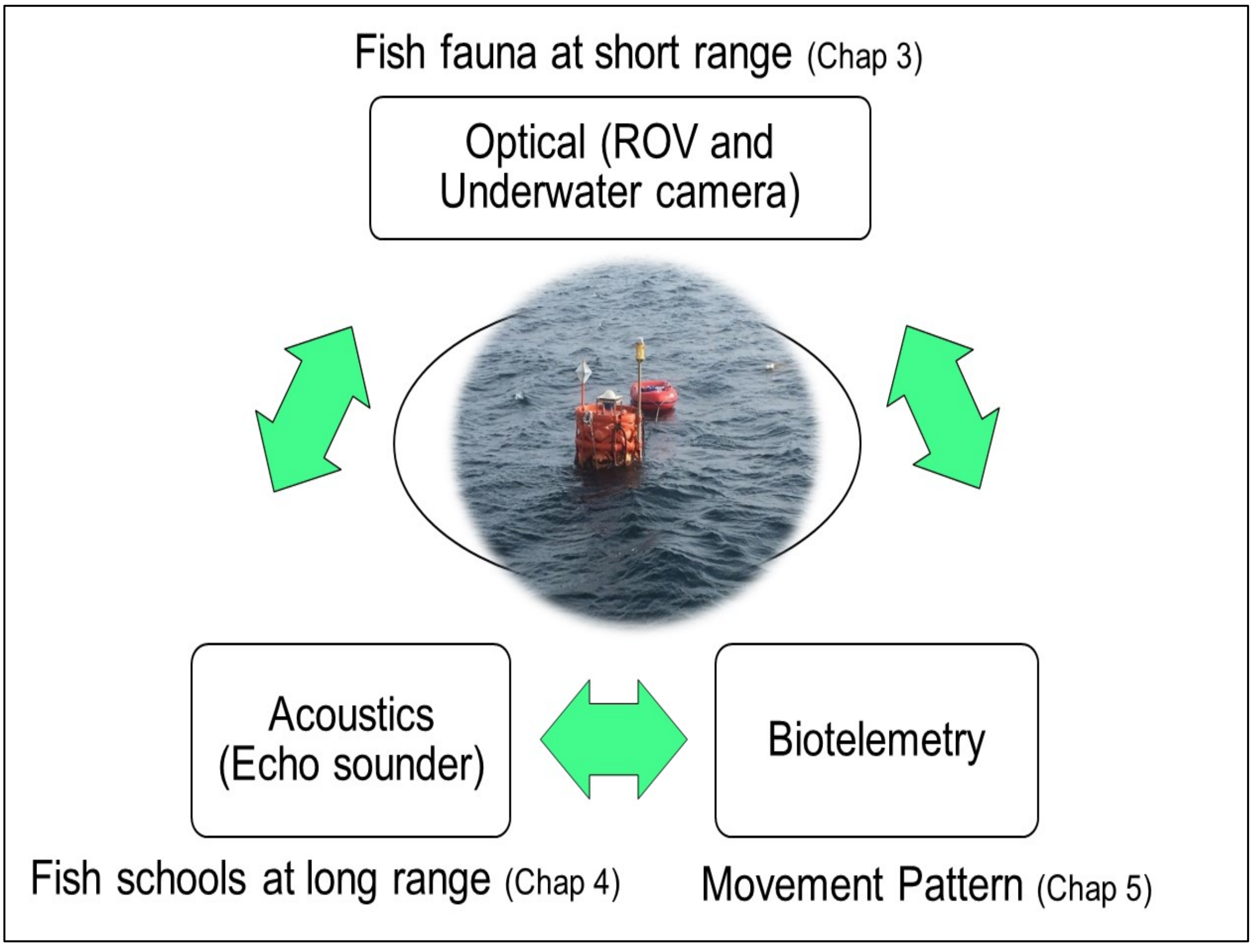


Fig.6-1. Intergrating various techniques during the study period and information established

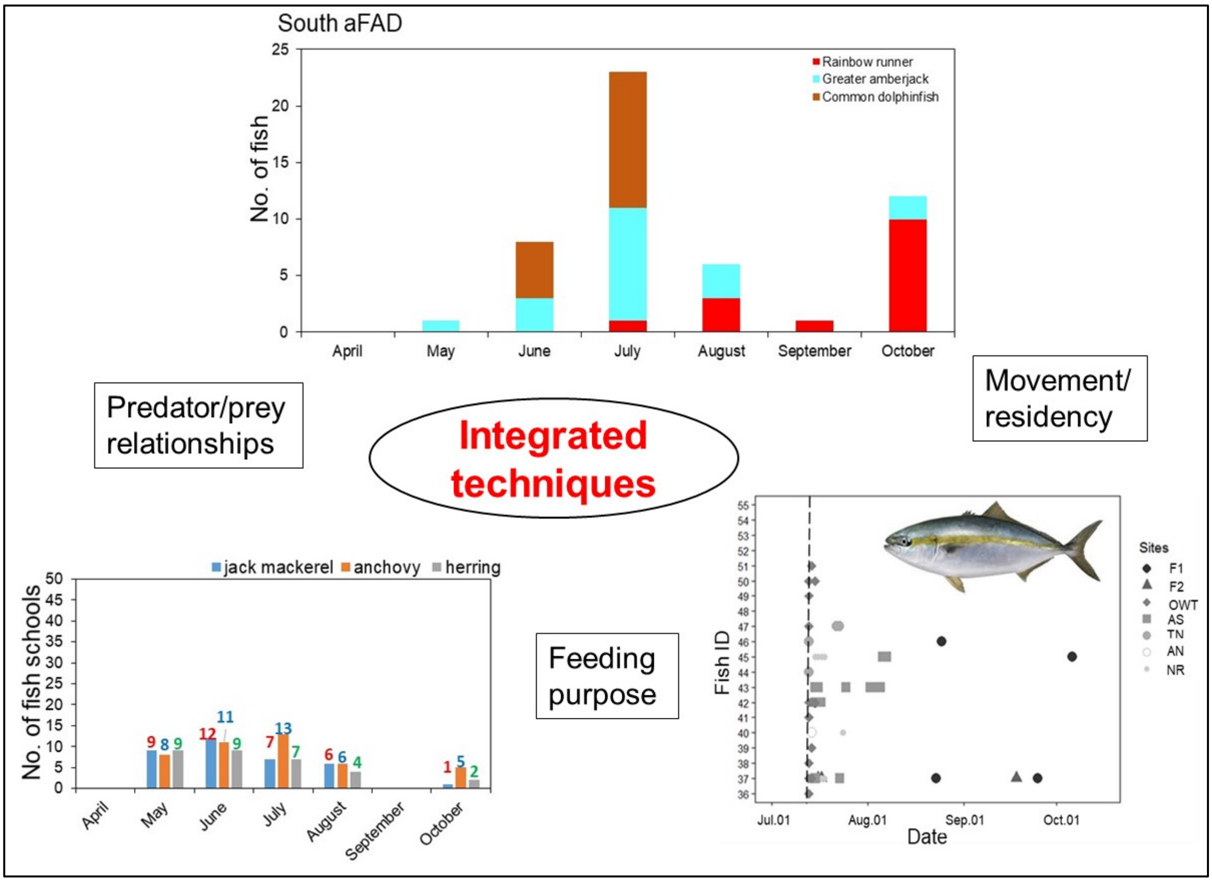


Fig.6-2. Intergrating various techniques and the type of relationships established at the aFADs in Goto Islands during the study period

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Abbreviation list

ADCP: Acoustic Doppler current profiler

aFADs: anchored Fish Aggregating Devices

CCD: Charge- couple device

CHIRP: Compressed High-intensity Radar Pulse

CTD: Conductivity Temperature Depth

dFADs: drift Fish Aggregating Devices

DoF: Department of Fisheries

EEZ: Exclusive Economic Zone

FADs: Fish Aggregating Devices

FAO: Food and Agriculture Organization

FiD: Fisheries Department

FRP: Fiber-reinforced plastic

g: gram

GDP: Gross domestic product

KCDP: Kenya Coastal Development Project

KMFRI: Kenya Marine and Fisheries Research Institute

m: metre

mm: Millimetre

nm: nautical miles

OWT: Offshore Wind Turbine

ROV: Remotely Operated Vehicle

SST: Sea Surface Temperature

TL: Total length

UNEP: United Nations Environmental Programme