Received: 29 October 2014

Analysis of impact of non-entangling FADs on incidental catches in the Indian Ocean tuna fishery

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Running heading: impact of non-entangling FADs

Abstract

This document presents the results of the analysis of catch data from three purse-seiner vessels operating at the Indian Ocean using entangling (mesh surface and hanging open) and non-entangling FADs (mesh surface and hanging attached) to fish tuna. Skipjack (*Katsuwonus pelamis*) was the main species in the reported captures, but also yellowfin (*Thunnus albacares*) and the bigeye tuna (*T. obesus*) were target species. Twelve other species, considered as by-catch, were also caught during the fishing operations.

Results showed that fishing on non-entangling FADs was more sustainable than that carried on entangling devices, particularly in relation to the number of sharks and turtles entangled. However, the efficiency of fishing operations done on non-entangling FADs was not different to that reported on traditional ones.

Key words: FADs, Indian Ocean, tuna fishery, shark entangling, by-catch

Introduction

The purse-seine fishing method is one of the most frequently used to catch middle-sized pelagic fish and tuna species. Purse-seiners set on a variety of school types or 'associations,' ranging from schools aggregated around to floating objects, such as logs and other naturally occurring debris, man-made Fish Aggregation Devices (FADs) (Fonteneau et al., 2000; Moreno et al., 2007), and dead corpses of whales, to schools swimming with live animals such as whales and whale sharks (Castro et al., 2002; Romanov, 2002). The importance of this associative behavior of tuna species is used to increase their vulnerability (Itano and Holland, 2000; Davies et al., 2014). Sets are also made on tuna schools not associated with floating objects or other animals (the so called free schools). These may be unassociated or free swimming schools that are usually feeding on baitfish or schools associated with geographic features such as seamounts and islands, or with oceanographic ones such as frontal areas or upwelling (González-Ramos, 1992; Ganzedo et al., 2006; Morato et al., 2010). Such sets are collectively termed school sets. Hampton and Bailey (1993) and Davies et al. (2014) provide a detailed description of the principal school associations targeted of the western Pacific and Indian Oceans purse seine fishery, which can be considered also for other areas.

Logs and other floating debris are found throughout the oceans, often concentrating along productive interfaces between currents and water masses. Schools of tuna aggregate around them for a variety of possible reasons (e.g. feeding, shelter, orientation, etc.) (Hall, 1992; Fréon and Dagorn, 2000; Castro et al., 2002). In the western tropical Pacific and in the Indian Ocean a viable purse-seine fishery was initially based on seining tuna schools associated with drifting objects (Doulman 1987; Davies et al., 2014). The first commercial fish aggregating devices (FADs) were installed in the Philippines at the beginning of 1960-70 in order to attract yellowfin tuna (*Thunnus albacares*) (Greenblatt, 1979). Natural drifting objects are mainly algae, jellyfish, whale corpses, seabird feathers, and part of trees (Nelson, 1999), but also almost any floating debris can work as a FAD (Hall and Roman, 2013).

Floating devices aggregate a considerable number of fish species, other than tuna, ranging from typically reef associated species such as the sergeant major, rainbow runner and barracuda, to the truly pelagic species such as the ocean triggerfish, oceanic whitetip shark, silky shark, dolphin fish and blue marlin (Hall, 1992; Castro et al., 2002; Romanov, 2002; Filmalter et al., 2013; Hall and Roman, 2013). Some of these species, particularly the small pelagic schooling fish such as the rainbow runner, mackerel scad, frigate tuna and kawakawa, can aggregate in big quantities (Romanov, 2002). To purse-seine fishermen, these species are collectively known as 'baitfish' (Hunter and Mitchell, 1967).

Nowadays, many purse-seine sets are targeting tuna schools associated with floating objects, including the floating man-made Fish Aggregating Devices (FADs) in all oceans (Fonteneau et al., 2000). The implementation of FAD to catch tuna species is observed worldwide since 1990 in all equatorial areas and they are still growing, nearly 2 million tons annually (about 60% of purse-seine catches), especially of skipjack (*Katsuwonus pelamis*) (70% of the catches are taken on FADs) (Fonteneau, 2011; Davies et al., 2014). Otherwise, most of bigeye tuna (*Thunnus obesus)* and yellowfin (*Thunnus albacares*) stocks are supposed overfished (Langley et al., 2009), and the specimens of these species that concentrated under FADs are mainly juveniles (i.e. 3 to 5 kg) (Robert et al., 2012), below the average weight considered adequate for a good stock management. In this way, the recent massive use of FADs in all the oceans by purse-seiners has introduced major uncertainties in most stock assessments, because analyses are hampered by changes in fishing effort in a FAD fishery (affecting the catchability and the use of CPUE as an index of abundance) (Fontenaeu et al., 2000; Davies et al., 2014).

According to Fonteneau et al (2000) and Filmalter et al. (2013), the massive use of FADs worldwide is perhaps an unsafe fishing mode, with could produce serious overfishing of many stock, not only of tuna species but also in the by-catch ones (e.g. sharks). However, Dagorn et al. (2013) point out that FADs, under an appropriate management regimen, could be an ecological fishing method, because it has less by-catch that other fishing gears. Thus, the problem of recruitment overfishing cause on tuna stocks (a high proportion of young-of-the-year tuna is caught), especially bigeye, could be minimized for optimal stock management of these fisheries (Floyd and Pauly, 1984). Mitigation measures for reducing the incidental catch of small yellowfin and bigeye tuna are currently being discussed by several international tuna commissions (Fonteneau et al., 2000). It is estimated that 7.3 million tons of non-target species (by-catch), including undersized tuna, are discarded annually by the world's fisheries (Kelleher, 2005). And this has considerable economic, ecological and developmental impacts (Garcia et al., 2003).

Although discards produced in a tuna purse seine fishery is in average almost 6 times less than a tuna longline fishery, and almost 13 time less than generated by a shrimp trawl fishery (Kelleher, 2005), when this purse seine is carry out with FADs the by-catch levels increase significantly (Hall, 1998). Globally, FAD fishing has been conservatively estimated as being responsible for over 100.000 tons of by-catch annually (Bromhead et al*.*, 2003). By-catch in FAD sets amount to one to ten percent of the total catch (compared to 1-2% in free-swimming schools), and comprises both undersized tuna (between 25 and 76%) and a wide variety of other pelagic species (Fonteneau et al., 2000; Hall and Roman, 2013). Small individual of the tuna species targeted amount to over 90-95 percent of those bycatches (Hall and Roman, 2013). These non-target species include dolphinfish, swordfish, billfish, wahoo, triggerfish, barracuda, rainbow runners, sharks and sea turtles (Fonteneau et al., 2000; Bromhead et al., *2003*; Norris, 2002; Filmalter et al., 2013; Davies et al., 2014).

In the Indian Ocean, the estimated annual by-catch generated by the European purse-seine fleet is over 11,590 tons, the 4.7% of the total tuna landed during the period 2003–2009 (Amandè et al., 2012). However, the use of FAD is becoming more widely distributed in tropical and subtropical waters (Fonteneau et al., 2000; Bromhead et al., 2003). Indeed, more than half of the worldwide tuna catch (estimated at around 3.5 million tons a year) comes from schools associated with floating objects (FADIO, 2004). This figure is increasing with the progressive use of FADs, being particularly prevalent in the Indian Ocean (Fonteneau and Hallier, 2003; FADIO, 2004; Davies et al., 2014).

On the other hand, the avoidance of incidental and undesirable captures of undersized tuna and other by-catch species is becoming an objective for the sustainability of the fishery (Hall and Roman, 2013). So, some fishing companies are promoting the use of non-entangling FADs (ne-FADs) in order to reduce, or eliminate if possible, the risk of entanglement of sharks and other not target species. The present report is the result of a preliminary study planned by Pesqueras Echebastar to assess the impact of a new design of ne-FADs, in order to implement a better practice of fishing.

Material and methods

Fishing records from three Echebastar's purse-seiners that operate in the Indian Ocean, from January to April 2013, were obtained and analyzed (Fig. 1). Data collection was done by trained observers on board the tuna-fishing vessels during one cruise (approximately 30 days), that recorded the number of haul, type of fishing operation (i. e. on free swimming school or on fish aggregated to drifting FADs), type of FAD (natural or artificial devices, and if these last were ne-FADs), date, hour, latitude and longitude, tuna school biomass estimation, by-catch species, capture of by-catch species (in number of individuals or wet weight), number of individuals entangled into the FADs nets, number of fish that were released alive into the sea, total catch, and catch of targeted species (i.e. tuna ones).

To determine the impact of ne-FADs (Fig. 2A) on the by-catch species, particularly sharks, the number of entangled specimens in each type of devices fished was compared for hauls with available data.

Statistical analysis of data was conducted to find differences among the type of hauls (sets) in relation to the catch of the tuna species and, particularly, between the by-catch species caught in entangling (e-FADs; Fig. 2B) and ne-FADs. The analysis of the data was carried out with Statistica v12 software (StatSoft Inc., 2011).

Results

A total of 168 hauls were carried out, ten of which were skunk sets (sets with zero capture), and in 22 sets the recorded information was not completed. Of the total 136 positive sets carried out, 7 were done on free swimming schools, 39 were made on natural/artificial drifting debris, 15 were on e-FADs, and 75 sets were done on ne-FADs.

1- Catch species composition

The target species were tuna fish species, being in order of importance the skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye tuna (*T. obesus*). Moreover, a group of 12 by-catch species were usually caught during fishing operations (Table 1). Three specimens of loggerhead turtle *Caretta caretta* were caught in three different hauls, but in two of them the FAD type was not recorded, and in the third one the fishing operation was on a natural drifting object. No marine mammals and sea birds were caught along the studied period.

Canthidermis maculatus, Aluterus monoceros, Carcharhinus falciformis and *Coryphaena hippurus* were the most common species in the by-catch. It was not possible to fit the contribution of these species to the total catch, because data were sometimes recorded in number of fish and sometime in wet weight, without references to the total length of individuals. This lack of information was because the samplers were not allowed to interfered during the fishing operations, and they only recorded the information they were able to obtain at any time.

The highest number of sharks specimens caught in a single haul was 75, and the highest number of specimens entangled in a single FAD was 2. Two silky sharks were caught entangled in the non-entangling FADs, because they were entangled by their pectoral fins in the float border, due to deficiencies at the joints of the net that cover the FAD's bamboo nucleus.

2- Entangling *vs.* non-entangling FADs

The number of entangled specimens caught in e-FADs oscillated between 0 and 2, being the 37.5% of haul positives. However, this number oscillated between 0 and 1 when the haul was done on ne-FADs, and the frequency of positive entangling was reduced to 2.6%. In this way, there were significant differences between sets carried out on free swimming school, natural devices or ne-FADs, with those carried out on e-FADs (Kruskal-Wallis ANOVA; H=27.8; $P<0.0001$; N=136), being the last those that generated a higher entanglement of specimens. There was significant difference between e-FADs and ne-FADs (Mann-Whitney U test; Z=4.4; $P<0.001$; N1=15; N2=75).

3- Efficiency of the non-entangling FADs

No significant differences in the total catch of target species were found between sets made on the different drifting debris or FADs types (Table 2). There were no differences in the capture levels of each of the three tuna target species caught around e-FADs or ne-FADs. Otherwise, captures of *Thunnus albacares* were higher when fished on free schools than on floating devices (Kruskal-Wallis ANOVA, H=11.3; $P=0.009$). This difference were observed in *T. obesus* and *Katsuwonus pelamis*.

4. Analysis of the by-catch

Significant differences were not observed in the contribution of by-catch species with independence of the types of sets made. When the analysis was done considering only sets on e-FADs or ne-FADs, significant differences were not observed in capture levels (by number of fish or weight) of the by-catch species.

Discussion

Many fishing, science, governmental and non-governmental organizations agree that reducing non-target catches should be one of the first steps in addressing the global problem of overfishing (Hall and Roman, 2013). However, strategies for by-catch reduction are rarely implemented instantaneously or completely. As Hall et al., (2000) explained, '*Not all by-catch problems yet have a satisfactory solution, and it is necessary to think of fisheries as dynamic systems, where evolution is taking place, and changes should be expected*'. Anyway, all possible strategies should be implemented in order to reach a sustainable use of marine resources (EJF, 2005). And, the massive use of FADs worldwide to fish tuna is an unsafe fishing mode that could produce serious overfishing of many fish stock, not only of the target species but also in the by-catch ones (e.g. endanger species like sharks, turtles, etc.) (Floyd and Pauly, 1984; Fonteneau et al., 2000; Filmalter et al., 2013; Hall and Roman, 2013).

Due to the behavioral pattern of many species to aggregate under floating devices (Hall, 1992; Parin and Fedoryakov, 1999; Freon and Dagorn, 2000; Castro et al., 2002; FADIO, 2004), tuna purse-seine fishing operation on FADs has resulted in increasing of captures of juvenile of several species, mainly bigeye tuna (*Thunnus obesus*) (Fonteneau et al., 2000). So, it is essential to develop an effective method to mitigate their impact to reach a sustainable use of tuna resources, and a more healthy population dynamic of the fished stocks. In this way, the Fishery Agency of Japan carried out experimental fishing operation by using two separate FADs with underwater light

(Kawamoto et al., 2012), which create solid and flashing light stimulus. However, they didn't get any conclusive results despite that they observed a decreasing in bigeye tuna by-catch. With the same objective, Pesquera Echebastar has developed a new design of FAD that lack of a tail of nets underneath in order to reduce the entanglement of sharks, turtles, and other endanger fish species frequently caught as by-catch is this fishery (Anonymous, 1993; Martínez-Rincón et al., 2009), but with similar efficiency for catching the target species. Despite that the amount of fish entangled in these new FADs (non-entangling) was much lower in absolute figures than reported for the classical ones, the average catch of tuna that the Echebastar's fleet obtained (mean=31.3 t per set, SD=29.0) was lightly higher than obtained with classical devices (mean = 23 t per set, SD=12.8). This also coincides with the results reported by the French tuna purse-seiner fleet that operate at the Indian Ocean. In this way, Goujon et al (2012) reported that catches obtained from sets made on ne- FADs was larger in average than those from other sets. And it was also higher than the mean catch per set of the French fleet along the recent history of this fishery. Also, Chassot et al. (2011) reported that the yield of ne-FADs was very similar to that of classical ones (around 25 t/set). In this way, the lack of nets pieces hanging from the float of the FAD, in ne-FADs, does not appear to affect its capacity to aggregate fish under it, and it seems to work in a similar way than drifting natural floats (Hall, 1992; Fréon and Dagorn, 2000; Castro et al., 2002).

The small number of fish (i.e., sharks) incidentally entangled in this first generation of ne-FADs indicates that the innovative work done can be improved and research on this objective must be continued. And future innovations should be addressed to remove those points where animal can be entangled yet, like the net fragment in the edges of FAD's float nucleus, where the fish look for refuge during the fishing maneuvers. Our results also indicate that the effort made by the fishing industry to reach the goal of zero entanglement of sharks and other animals in risk (e.g. turtles) isn't less profitable than to continue using the e-FADs.

On the other hand, it is known that high levels of by-catch can cause significant reductions in biomass, and may alter the ecological structure and diversity of the oceans (Hall et al., 2000).

Populations of many marine animals (e.g. mammals, sea turtles, sharks, seabirds and commercial fish species) have been impacted by poorly selective fishing gears (Hall et al., 2000). In this way, traditional drifting FADs are an important source of mortality in some already endangered species (Gilman and Freifeld, 2003; Filmalter et al., 2013; Lewison et al., 2004), and can work as an ecological trap (Marsac et al., 2000) with unknown consequences also for the target species (Hallier and Gaertner, 2008; Davies et al., 2014). Moreover, the negative bio-ecological effects of high by-catch levels will have economic negative impacts in the middle term (Garcia et al., 2003; Hall and Roma, 2013). Thus, cost of discarding by-catch are considerable, time and energy consuming, being low profitable. And if, the by-catch is of commercially valuable species (particularly at juvenile stages) can lead to reduced profits and declining yields, and be the cause of a premature collapse of the fisheries (Hall et al., 2000). Therefore, fishing companies should be the first ones interested in keeping healthy the exploited stocks. But, how can by-catch be minimized? We could reduce the by-catch by decreasing overall fishing effort and/or by reducing by-catch per unit of effort (Hall et al., 2000; Davies et al., 2014).

We haven't found any differences in the amount of non-tuna by-catch species caught under FADs or other drifting objects (algae, logs or debris). Neither significant differences were determined when the analysis was done considering only sets on e-FADs or ne-FADs. These results should be expected as the attraction of fish species by floating devices is the objective of such ones. The fact of fish being concentrated around FADs is the logical behavioral response of different animals (Hall, 1992; Castro et al., 2002). In other words, it should be keep into mind that FADs, entangling or non-entangling ones, are used to aggregate fish under or around the floating object, as an answer of natural fish behavior (Holland et al., 1990; Cayré, 1991; Hall, 1992; Freon and Dagorn, 2000; Castro et al., 2002), and for this reason it is not possible to reduce the by-catch in this fishery in a significant way. So, it is not possible to introduce any specific characteristic which attract the attention of the tuna species toward the FAD, but that will not produce an attracting reaction on other species or juveniles of the target ones.

Acknowledgements

The authors want to thank the collaboration of the crews of the F/V Campo Libre Alai, Demicu, Alakrana and Elai Alai, all belonging to the Echebastar Fishing Fleet. We also thanks to Mr. Santiago Jiménez and José Carlos Mendoza for their assistance during sampling and data collection.

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Captions of Figures and Tables

Figure 1. Geographical distribution of the fishing hauls in the West Indian Ocean considered in this work (black = fishing hauls with no data about the FAD type; green = free swimming school; red = natural/artificial floating debris -branches of trees, plastic box, wood pallets, etc.; blue = old entangling FADs; white = non-entangling FADs).

Figure 2. Non-entangling FAD used during this study (Top, A) and Entangling FAD (mesh surface and hanging open) with a tail of nets underneath that is used traditionally in the purse seine tuna fishery in the Indian Ocean (Down, B).

Table 1. Species caught in the West Indian Ocean, from January to April 2013, by three purse-seiners of the Echebastar fishing fleet.

Table 2. Descriptive Statistics of the total catch and the catch of each tuna species on free schools or on the different fish aggregating devices (natural or artificial).

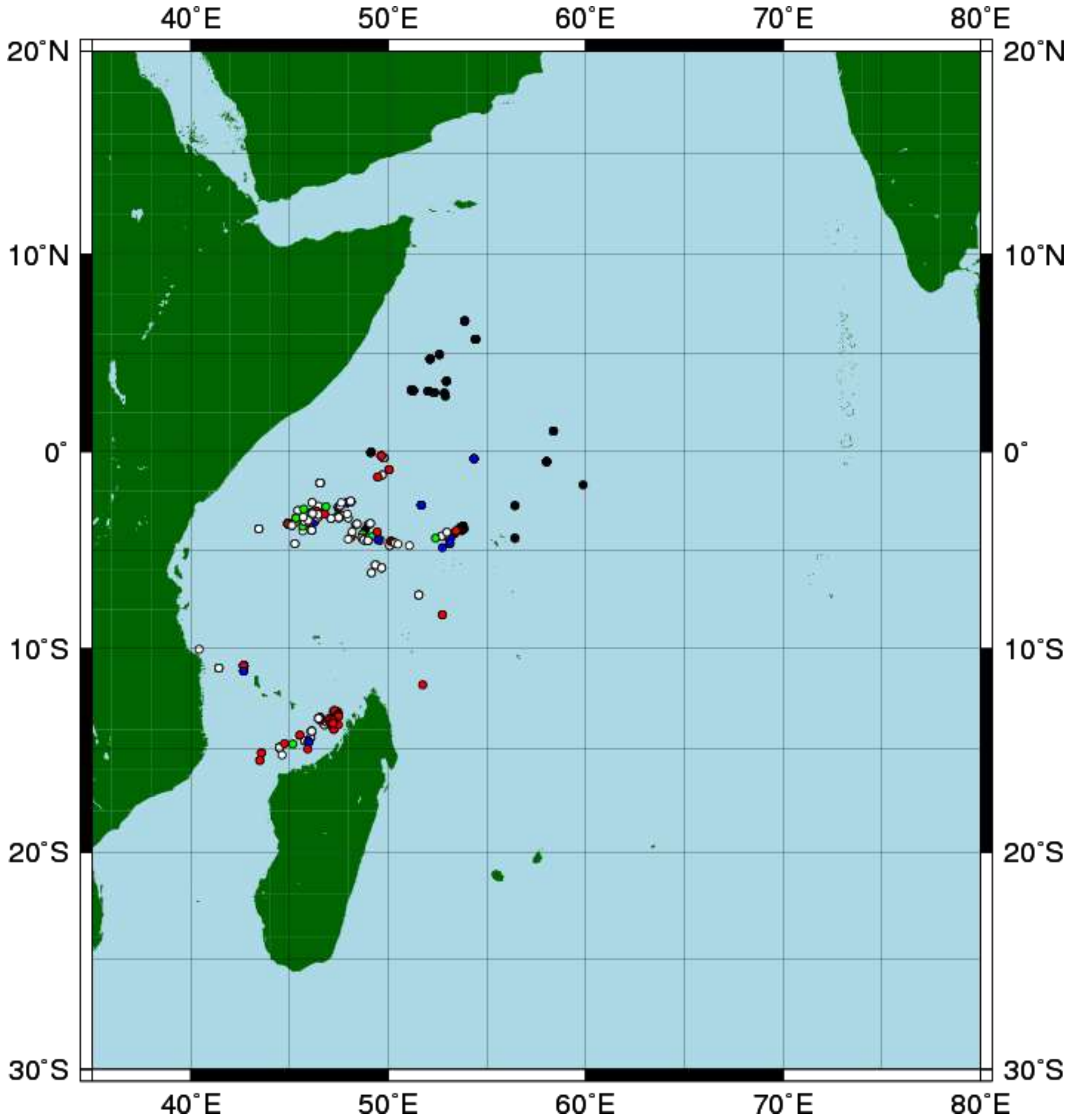

Figure 1. Geographical distribution of the fishing hauls in the West Indian Ocean considered in this work (black = fishing hauls with no data about the FAD type; green = free swimming school; red = natural/artificial floating debris -branches of trees, plastic box, wood pallets, etc.; blue = old entangling FADs; white = non-entangling FADs).

Figure 2. Non-entangling FAD used during this study (Top, A) and Entangling FAD (mesh surface and hanging open) with a tail of nets underneath that is used traditionally in the purse seine tuna fishery in the Indian Ocean (Down, B).

Table 1. Species caught in the West Indian Ocean, from January to April 2013, by three purse-seiners of the Echebastar fishing fleet.

Scientific name	FAO English name	Abbreviation
TARGET SPECIES		
Katsuwonus pelamis (Linnaeus 1758)	skipjack tuna	SKJ
Thunnus albacares (Castelnau 1872)	Yellowfin tuna	YFT
Thunnus obesus (Lowe 1839)	Bigeye tuna	BET
BY-CATCH SPECIES		
Elagatis bipinnulata (Quoy & Gaimard 1825)	Rainbow runner	
Acanthocybium solandri (Cuvier 1832)	Wahoo	
Sphyraena barracuda (Walbaum 1792)	Great barracuda	
Canthidermis maculatus (Bloch 1786)	Ocean triggerfish	
Aluterus monoceros (Linnaeus 1758)	Unicorn leatherjacket filefish	
Coryphaena hippurus Linnaeus 1758	Common dolphinfish	
Kyphosus sp.	-	
Xiphias gladius Linnaeus 1758	Swordfish	
Tetrapturus sp.	Marlin	
Carcharhinus falciformis (Müller & Henle 1839)	Silky shark	
Mobula spp.?	-	
Caretta caretta (Linnaeus 1758)	Loggerhead turtle	

Table 2. Descriptive Statistics of the total catch and the catch of each tuna species on free schools or on the different fish aggregating devices (natural or artificial).

	Valid N	Mean	Minimum	Maximum	Std.Dev.
All data pulled					
TOTAL CATCH (t)	125	28,18	0,00	105,00	26,47
YFT catch (t)	136	11,29	0,10	85,00	12,06
SKJ catch (t)	217	12,13	0,00	80,00	12,95
BET catch (t)	57	7,00	1,00	25,00	5,69
Free swimming schools					
TOTAL CATCH (t)	7	23,57	0,00	50,00	15,73
YFT catch (t)	5	26,60	15,00	50,00	14,33
SKJ catch (t)	2	12,50	10,00	15,00	3,53
BET catch (t)	2	3,500	2,00	5,00	2,12
Drifting debris					
TOTAL CATCH (t)	35	23,92	0,00	105,00	24,73
YFT catch (t)	36	9,00	0,10	25,00	5,83
SKJ catch (t)	49	9,80	0,00	55,00	10,69
BET catch (t)	6	10,50	3,00	20,00	7,714
Entangling FADs					
TOTAL CATCH (t)	9	23,00	12,00	55,00	12,79
YFT catch (t)	12	7,67	1,00	20,00	6,85
SKJ catch (t)	23	9,48	1,00	35,00	8,68
BET catch (t)	6	5,33	1,00	20,00	7,31
Non-entangling FADs					
TOTAL CATCH (t)	74	31,26	0,00	105,00	29,05
YFT catch (t)	55	10,74	1,00	85,00	12,69
SKJ catch (t)	130	13,54	0,00	80,00	14,74
BET catch (t)	37	6,54	1,00	25,00	5,06