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Purse seine by-catch mitigation techniques

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Index

1. INTRODUCTION

Tropical tuna are known to associate with objects floating at the surface of the ocean. These objects can be natural, such as branches, debris, dead animals, or artificial, coming from human pollution, or constructed and released by fishers to increase their chances of finding tuna (Dagorn et al. 2000a). These man-made floating objects are named Fish Aggregating Devices (FADs). Although tuna purse seining generates relatively low levels of by-catch and discards, the fishing mode greatly affects the composition and volume of by-catch (Romanov 2002). In free school fishing (ie. schools not associated with floating objects), estimates of tuna discards and by-catch are more than three times less than in FAD fishing (Delgado *et al.* 2000), where a high diversity of species is captured. FAD-fishing is thus the major source of by-catch associated with the tuna purse seine fishery and is estimated to generate significant amounts of by-catch of vulnerable species such as sharks and sea turtles as well as juvenile fish of target and non-target species (Ariz *et al.* 1999, Hallier et al. 1999, Fonteneau *et al*. 2000, Anon. 2006). Nevertheless, other fishing modalities targeting pelagic fishes have a significant effect on by-catch (Anon. 2001). The term by-catch will be used throughout this document; this term has been used in scientific and popular literature for more than half a century and has been subject to a variety of definitions (FAO, 1997). For the purpose of this document we consider by-catch to be the part of the capture made up of non-targetted sizes and species.

More than 40 different species have been caught by the FAD associated fishery (Romanov 2002). This is a subject of great concern for Regional Fisheries Management Organisations (RFMOs) which are responsible for tuna research, conservation and management (eg. CCSBT, IATTC, ICCAT, IOTC and WCPFC). Over the past twenty years, tuna purse seiners have taken advantage of the associated concentrations of fish by using FADs. In the last ten years the catch using FADs has increased considerably and now more than 70% of the total catch in the Indian Ocean is obtained using FADs (Fonteneau *et al*. 2000).

In general, there is a lack of studies dealing with by-catch and purse seining (there are 10 times more longlining studies). The majority of specific research into by-catch on FADs has been published only recently (Dempster and Taquet 2004). The great majority of research has been conducted on anchored FADs (AFADs), principally due to difficulties in studying large mobile fish around drifting FADs (DFADs) in the open ocean, which are transitory in both space and time. Pelagic fish may treat anchored and drifting FADs differently (Holland et al. 1990, Fréon and Dagorn 2000) and the conclusions obtained on AFADs cannot reliably be extrapolated to DFADs.

Most of the recent work on DFADs is covered by two European projects: FADIO (Fish Aggregating Devices as Instrumented Observatories of pelagic ecosystems; www.fadio.ird) and MADE (Mitigating ADverse Ecological impacts of open ocean fisheries; www.made-project.eu). In both projects there has been an emphasis on collaboration and information sharing between scientists and fishermen (Calheiros et al. 2000, Moreno et al. 2007) which have been successful in addressing other issues like the one dealing with the dolphin by-catch issue.

In the present document by-catch issues relating to DFADs will be analyzed for three groups of species: 1) bigeye and small/juvenile tuna, 2) sharks and 3) marine turtles. Other species will not be explicitly considered due to the absence of robust scientific by-catch data although many of the principles discussed for these three groups will apply to other species as well. The dolphin by-catch issue will also not be discussed as dolphin mortality levels have been reduced to less than 0.1% since the early 90s (Hall, 1998). The success of the AIDCP, the multilateral agreement that entered into force in February 1999 and which advocates the use of special techniques to reduce the by-catch of dolphins (namely the Medina panel and "back down" operation, which ensure that encircled dolphins are released alive) has been widely recognised in this regard.


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2. BY-CATCH OF PURSE SEINE FISHERY

2.1 BY-CATCH OF JUVENILE BIGEYE AND SMALL TUNA

The use of DFADs has increased the vulnerability of small tunas and induced changes in fishing patterns by purse seine vessels (Menard *et al.* 2000). In addition, catches of juvenile tunas that are discarded or sold on local fish markets are generally absent from official statistics and, therefore, not included in the available statistics used as inputs of stock assessment models (Amandé *et al.* 2009). By-catch of tuna represents a significant proportion of the total by-catch of the purse seine fleets.

In the Atlantic Ocean during the period 2003-2007 annual by-catch was estimated to be approximately 6000 tons from 600 observed fishing sets (Amande et al. 2009), corresponding to an annual value of 76.3 t /1000 t of landed tunas (7.1 % of the total catch). Tuna discards represent 84 % of the total, i.e. 63.5t/1000 t with skipjack comprising the bulk of discarded tuna. Bigeye and little tunny represent only 2.2% of the total by-catch. In the Indian Ocean, by-catch has been estimated to be considerably less than in the Atlantic: Pianet et. al. (2008) estimated that by-catch amounted to approximately 35.5t /1000t of tuna landed (3.5% of the total catch). Of this, tuna accounts for 54% of the by-catch. Very few DFAD sets in the Indian Ocean have a high proportion of juvenile bigeye (Fonteneau et al. 2007).

In the Eastern Pacific Ocean (EPO), a preliminary estimate of by-catch by large purse seiners for species excluding dolphins and sea turtles was around 17662 t in 2007 (IATTC 2008). Between 1993 and 2007, the discarded catches were much less than the retained catches and total landings of the discarded catches varied more year-to-year than those of the retained catches, and did not decline over time. For floating-object sets the discards of large bigeye decreased from 1996 to 1998 but increased again from 1998 – 2000 (IATTC 2008).

In the Western and Central Pacific Ocean, total catch of tuna in 2008 represented 56% of the overall tuna catch. During 2008, the purse-seine fishery in that area accounted for an estimated 1 783 669 mt (74% of the total catch in the Area, and a record for this fishery). The WCPFC has been increasingly concerned about the vulnerability and exploitation rate of juvenile bigeye and in recent years yellowfin tuna, by purse seine effort on floating objects that may have pushed stocks toward an overfished state (Itano 2009).

2.2 SHARKS CATCH AND BY-CATCH

High seas fisheries produce amongst the largest by-catches of sharks globally and the most significant by-catches are in longline fisheries for tunas and billfish. In recent years there has been increased concern about shark mortality associated with tuna purse seine fishing on DFADS. As a result, tuna RFMOs have increasingly investigated shark mortality as a result of tuna fishing activity.

Sharks are highly susceptible to exploitation as a result of their slow growth, late maturation, and limited fecundity (Musick 1999). The results of a productivity-susceptibility analysis (PSA) from Kirby and Molony (2006) for several groups of large vertebrates in the WCPO indicated that sharks are a group of species at a high risk to tuna fishing. Ten species of shark are reported in the by-catch of purse seiners in WCPO waters. Of these, four are declared by the IUCN (IUCN 2001) as vulnerable (VU), 5 as near threatened (NT) and the other species is not evaluated (NE). In a similar ERA study performed in the Atlantic Ocean (Arrizabalaga et al. 2009) it was found that coastal sharks were the most vulnerable species group to purse seine fishing gear. Unfortunately, the impact of fishing on shark species is difficult to quantify, as in many cases, there is insufficient data or stock assessments to do so (IATTC 2006).

In the Atlantic (Amande *et al.* 2008a), the main species encountered in the by-catch are *Carcharhinus falciformis* (silky shark) which represents 79% in weight and 86% in numbers of all sharks landed. It is followed by two Sphyraenids, *Sphyraena zygaena* and *S. lewini*, representing 8.2 % of the individuals caught and 15.7 % of total weight. Some other species such as *Carcharhinus longimanus* and *Isurus oxyrinchus* are occasionally taken as by-catch. More than 91 % of shark catch, either in number or in weight, occurs during DFAD associated sets.

In the Indian Ocean, the average amount of pelagic sharks taken as by-catch (analysis of 108 DFAD-associated school sets carried out by the Russian/Liberian fleet; Romanov 2000) was 0.246 t per set. Analysis of 1162 DFAD-associated school sets carried out by the Spanish and French fleets (Amande *et al.* 2008b) gave figures of 0.802 t of sharks per set. In this Ocean, two species of Charcharinids, silky sharks and oceanic whitetip sharks, dominate the shark by-catch (94% of the individuals caught and 90% of total weight; Amande *et al.* 2008b). The silky shark is probably the most important species of oceanic shark in terms of catch weight taken in fisheries in the Arabian Sea and tropical Indian Ocean (Amandè 2007; Delgado de Molina *et al.* 2005; Gonzalez *et al.* 2007).

In the Eastern Pacific Ocean, between 2003 and 2005, 40% of the sets on floating objects resulted in shark by-catch (Scott 2007). Silky sharks account for 64% and Oceanic whitetip sharks for 21% of the total shark by-catch in the tuna purse-seine fishery of the eastern Pacific Ocean (Román-Verdesoto *et al.* 2005; Camhi *et al.* 2009). In the western central Pacific region, results from risk assessments presented by Kirby and Molony (2006) as well as subsequent multi-species analyses of both longline and purse seine fisheries for individual Pacific Island countries, silky sharks (*Carcharhinus falciformis*) and oceanic whitetip sharks (*Carcharhinus longimanus*) were identified as the two main shark species warranting greater attention (Manning *et al.* 2009).

It is clear from the information available from all the tuna RFMOs that both silky and oceanic whitetip sharks are the species most at risk from purse seine fishing gear. It is also generally agreed that declining populations of sharks may well result in unintentional changes in ecological structure in both coastal and offshore waters (Worm *et al.* 2005, Myers *et al.* 2007). In response to the decline of shark populations worldwide, a growing number of shark species have come under CITES controls in recent years, for example: the basking and whale sharks were included in Appendix II in 2002, the great white shark in 2004, and sawfishes in 2007. At the last conference hold in Qatar (March 2010) the US, jointly with Palau, introduced an amended proposal to include the oceanic whitetip shark (*Carcharhinus longimanus*) in Appendix II but the proposal was rejected.

2.3 SEA TURTLES

The impact of fishing on Sea turtles is not as great an issue for purse seining as it is for other fishing gears. Of the 42 papers presented in the Twenty-Seventh Annual Symposium on Sea Turtle Biology and Conservation and related with fisheries (Rees *et al.* 2008), not one dealt with purse seining. Turtle mortality as a result of purse seine fishing can occur in two ways; individuals directly trapped in seine nets and individuals who rest on DFADs and become entangled in the DFAD gear. The latter is often not as comprehensively quantified.

In the Atlantic Ocean, recordings of turtle by-catch are few (Amande *et al.* 2009) and made almost equally on DFAD (54%) and free school sets (46%). A total of 40 individuals were caught over 2003-2007. Turtles species composition is dominated by the green turtle (*Chelonia mydas*) followed by the kemp's Ridley turtle (*Lepidochelys kempii*), the leatherback turtle, (*Dermochelys coriacea*), the loggerhead turtle (*Caretta caretta*) and the olive Ridley turtle (*Lepidochelys olivacea*).

The same low level of turtle by-catch is also true for the Indian Ocean (Amande *et al.* 2008) although they are observed almost exclusively on DFAD sets (95%). Between 2003 and 2007 a total of 74 individuals were caught for an estimated weight of 1.8 t. These observations were mainly reported during the second part of the year when the fishery was actively fishing on DFADs. Turtles species composition was dominated by 3 species: the olive Ridley turtle, the green turtle and the hawksbill turtle (*Eretmochelys imbricata*). According to the observations, the olive Ridley turtle seems the most adversely impacted by the fishery and most of the by-catch occurs in the north of the western Indian Ocean (up to the equator). Almost 90 % of the turtles caught were discarded alive. In the Pacific Ocean turtle by-catch data has been collected by MMA observers since 1993 and again incidences are low for purse seining (Heberer 1994, Bailey *et al.* 1996). Of the 116 DFADs investigated by the RTTP in 1991, individual turtles were associated with only six DFADs (5.2%).

There is not always, however, agreement on the risk associated with turtle catches. For instance, in a PSA study conducted in the Indian Ocean (Murua *et al.* 2009) four species of sea turtles (*Caretta caretta, Dermochelys coriacea, Chelonia midas* and *Eretmochelys imbricate*) do not appear to be at risk. On the other hand, the IUCN lists two of those sea turtles species as endangered and the other two as critically endangered. This can largely be attributed to the level of catch. Although turtles may be globally at risk, they are generally not susceptible to being caught by purse seine gear.

3. REVIEW OF BY-CATCH MITIGATION TECHNIQUES

Effective bycatch mitigation measures to reduce or eliminate the bycatch caught by purse seining in DFAD fishing could be employed:

- before setting the purse seine net (Avoidance strategy)
- after setting the net but before hauling it (Releasing from net strategy)
- after loading the catch (Releasing from deck strategy)

In the present document these three scenarios will be addressed for three groups of species: 1) bigeye and small tuna, 2) sharks and 3) marine turtles.

3.1 MITIGATION TECHNIQUES FOR BIGEYE AND SMALL TUNA

3.1.1 BEFORE SETTING THE NET

In DFAD fishing all the efforts to develop any kind of measure to reduce by-catch should be concentrated on the DFAD, since it is normally assumed that if the fishing vessel has already sailed many nautical miles to an existing DFAD, the skipper eventually will make the set. Critical items that are essential for the mitigation of by-catch of tuna juveniles are the following:

- the development of acoustic instruments for fish discrimination
- the knowledge of the behaviour of the fish around the DFAD
- the physical configuration of the DFAD
- the cost of the equipment deployed on the DFAD.

Fish Discrimination

Fish finder devices have been improving over the years but there is still a lack of efficient fish discrimination equipment in the market. Tuna purse seiners are equipped with sophisticated detection technology such as long-range sonar and scientific-grade echosounders. At present, all the research is focused on fish species discrimination using echo sounders and scanning sonars. Accurate target-strength (TS) measurements are needed to convert integrated echo measurements into abundance estimates (MacLennan, 1990).

Improvement of remote discrimination of tuna species and/or sizes by means of equipment (HF and satellite buoys) installed on the DFAD is needed to prevent the fishing vessel going to a DFAD to make a set that should not been done.

The differences between HF buoys and satellite buoys are that HF buoys have a limited detection range (around 1000 nm depending on sea conditions) while satellite buoys have no range limitations. Satellite buoys have more autonomy (life time of satellite buoys is do- uble that of HF radio buoys) and are less detectable to other vessels. Some of the satellite buoys are equipped with sounders, however, skippers still think that sounder information is not trustworthy.

Apart from the acoustic signatures of the different fish species that are essential for fish discrimination, specific noises coming from the different species could help in fish discrimination. Fish can directly or indirectly produce different kinds of sounds:

- Hydrodynamic noise: Externally generated by tailbeats when swimming
- Feeding noise: Externally generated by clicks and snaps of jaws when feeding
- Vocalization: Internally generated by contraction of muscles around the swimbladder

While the first two kinds of sounds are passive and undoubtedly produced by tuna fish, the third sound is an active production of sound and has been only suggested for adult bluefin and yellowfin tuna (Allen and Demer 2003).

Passive acoustic devices such as an array of calibrated hydrophones on the DFAD could give information about the DFAD aggregation structure.

Fish behaviour around DFAD

Given the fact that most mitigating techniques are species specific, it is essential to know the behaviour of the fish around the DFAD in order to develop measures to reduce by-catch.

Fish tracking studies (Holland *et al.* 1990, Marsac and Cayré 1998, Dagorn *et al.* 1999, 2000b, 2007, Matsumoto *et al.* 2005, 2007) indicate that tunas are usually not located immediately beneath DFADs but rather swimming around DFADs at varying distances (Fig 1). Sometimes fish schools show differences in daytime and night time vertical movement patterns, usually related to foraging. There are also differences among species (skipjack, yellowfin and bigeye) in relation to their swimming depth and behaviour (Girard *et al*. 2004, Matsumoto 2007), but overlap is found in the depth between the three species. That overlapping makes difficult to implement some kind of by-catch mitigation measure for these specific factors.

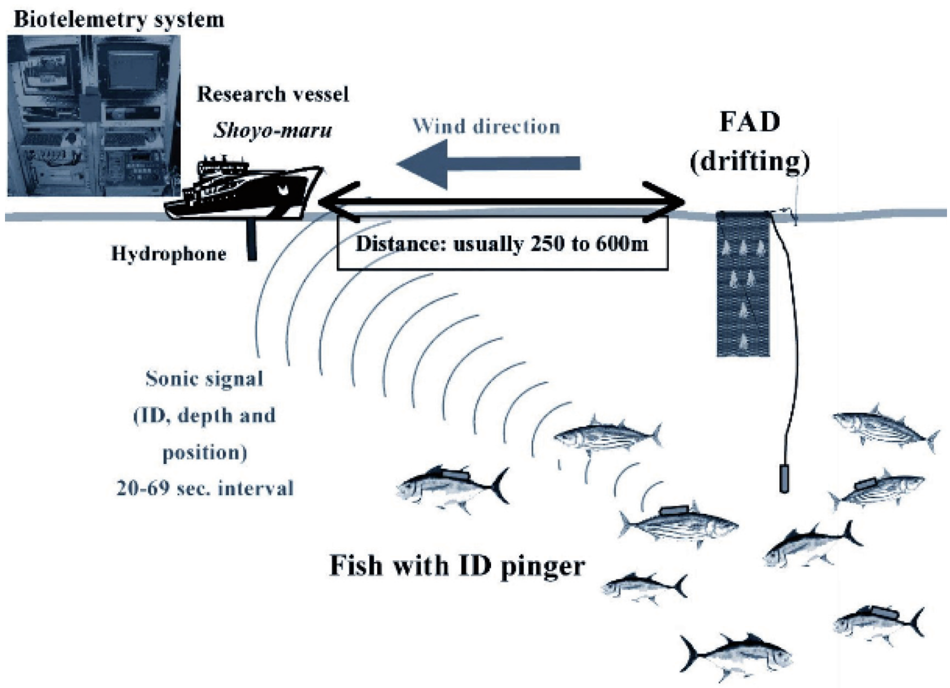

Figure 1. Behavioural studies using acoustic tracking equipment. From Matsumoto (2004)

Knowledge of fish behaviour has been dramatically improved using underwater observations. This could be useful to visually check DFAD aggregations and verify sounder and sonar images to refine acoustic estimates of sizes and species.

DFAD structure configuration

Mitigation measures related to the by-catch of tuna juveniles (mainly bigeye) are based mainly on the characteristics of the DFAD, along with the working depth of the purse seine net and the use of grids.

Lennert-Cody *et al.* (2007) examined gear influence on bigeye catch by EPO purse seine vessels and found that increased depth of the DFAD aggregator was positively correlated with bigeye catch, but geographic location within the EPO had the highest influence on bigeye catch. It was noted that a relatively small number of vessels caught a disproportionately high percentage of the EPO surface bigeye catch suggesting that other gear or operational factors may influence higher bigeye catch rates (Harley *et al.* 2007). Satoh *et al.* (2007) on the other hand, did not find a relationship between the presence/absence of bigeye tuna catch and the depth of DFADs. Similar results were obtained in the Papua New Guinea maritime region (Anon. 2007), where the depth of DFAD had no significant effect on the ratio of juvenile bigeye tuna catch per set.

Nelson (2004) suggested to test multi-DFAD or double-DFAD structures in order to mitigate bigeye by-catch (Fig. 2). The surface portion could be towed out from the set to liberate the small bigeye in the school and the deeper part (with the large bigeye) would be separated using a buoy. Further research is, however, needed to determine the behaviour of bigeye and the critical depth to separate the two parts of the aggregating structure of the DFAD.

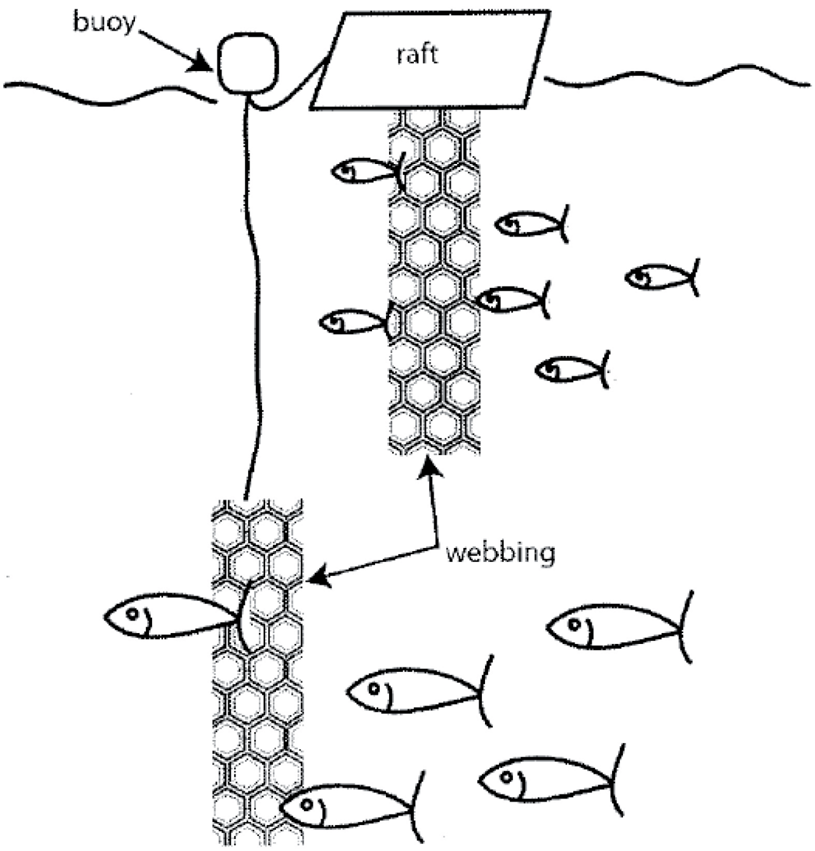

Figure 2. Double DFAD configuration showing surface and bottom portions. From Nelson (2004)

3.1.2 AFTER SETTING THE NET

Working depth of the purse seine net, mesh size and other characteristics of the netting, as well as the use of sorting grids seem to be the most promising alternatives for mitigation measures related to the by-catch of tuna juveniles.

Net characteristics

Limiting purse seine net depth does not seems to be a practical means to limit juvenile bigeye catch in the WCPO (Opnai 2002) while in EPO waters greater underwater depths with deeper purse-seines seem to have an effect (Lennert-Cody *et al.* 2008).

It is believed, on the other hand, that the use of large mesh size in part of the net body has potentially positive effects on reducing fishing mortality of juvenile bigeye tuna. Preliminary work (Anon. 2007) has shown that the juvenile bigeye by-catch rate was 0.10% of the total catch carried out by fishing vessels using purse seine nets with large sized mesh, while the rate was 0.28% of the total catch when using small sized mesh. This effect of larger mesh size in reducing juvenile catch by purse-seine is a necessary measure (Oshima 2008b) that must be combined with other measures, and it is more effective when the net is moving or is affected by currents.

Sorting grids and escape windows

Very few escapement devices have been tested in purse seining when compared with other fishing gears. Preliminary work on the use of rigid sorting grids mounted on the bag of the purse seine was carried out in Norwegian purse seining (Misund and Beltestad 1994, Beltestad and Misund 1995, Misund and Beltestad 2000). A By-catch Reducing Device (BRD), composed of a mesh panel in a section of the frontal wing of the purse seine has been evaluated by Gonçalvez et al. (2004), who noticed that most of the escapees were juveniles apparently in good condition.

The use of a rigid sorting grid in tuna purse seining has been rejected from the very beginning, because it is essential that a flexible sorting grid or escape window must pass through the power block (or in some few cases the roller hauler).

In 1999, the IATTC recommended giving priority to studies on sorting grids (IATTC 1999). Prior experiments with tuna fish kept in tanks (Nelson 2006) have shown that further testing of sorting grids at sea in real purse seines is worthwhile. Moreover, grids made out of very strong plastic or even metal, fitted permanently in the purse seine and able to go through the power block have been proposed for commercial tuna purse seining (Nelson 2007, ICCAT 2008).

Following fishing regulations from the Ecuadorian government it is compulsory for Ecuadorian and associated fishing vessels fishing in EPO waters to use a detailed flexible sorting grid (Fig. 3) designed by the SPR.

Figure 3. Sorting grid used in Ecuadorian and associated fishing vessels (Arrue's System)

Although purse seine is also an active fishing gear, the behaviour of the fish inside the net is very different when compared to other fishing gears, and it is accepted among the scientific community and fishers that the fish need an extra stimuli to go through the sorting grid.

Fish Behaviour related to the fishing gear

The use of large mesh and sorting grids face the same problem: unlike other fishing gears that use nets (trawls or gillnets), the contact of fish and net is limited in purse-seine and it might be necessary to force fish to go through the large mesh or the sorting grid by using other stimuli. There are several different stimuli (or a combination of some of them) to choose between them:

A. Mechanical stimuli: Air-bubble curtains formed by a conduit on the bottom releasing pressurized air bubbles that rise to the surface have been used as a fish deterrent (Brett and MacKinnon 1953, Taft 1986). This mechanical stimulus has been used mainly in fish ponds and hydroelectric facilities, but it could also be tested in a purse seine net.

B. Visual stimuli: Fish species show different peak wavelengths of spectral sensitivity. The light sensitivity of Pacific bluefin tuna is comparable to that of chub mackerel but lower than that of striped jack (Matsumoto *et al.* 2006). Moreover, some fish are more affected by an intermittent light than by a continuous light during trials at night (Nicol 1963). In some experiments involving migrating salmon, a beam of flashing light was more effective in deflecting the course of the fish than a continuous light and a curtain of air bubbles (Brett and MacKinnon 1953). In field experiments, tunas tended to move away from the intermittent light and came closer to the continuous light (Oshima, pers. com.) Panels of transparent netting may potentially improve the selectivity of purse seine nets as is the case with seine nets (Gray *et al.* 2000).

C. Sound stimuli: Fish species with swim bladders (e.g.: bigeye and yellowfin, Fig. 4) are known to be sensitive to sound in comparison to species without it (e.g. skipjack). The most effective acoustic stimulus to the yellowfin tuna was defined as the maximum one-third-octave level between 200 and 800 Hz, using sounds produced by dolphins: jaw pops, breaches, and tail slaps (Finneran *et al.* 2000).

Figure 4. Position of the swimbladder in tuna fish (AZTI)

3.1.3 AFTER HAULING THE NET

Release of bigeye and small tuna from the deck is not considered practical as it is presumed that the fish are already dead or in such poor condition that survival is unlikely.

3.2 MITIGATION TECHNIQUES FOR SHARKS

3.2.1 BEFORE SETTING THE NET

Attraction or repulsion of sharks could be used to repel the sharks from the DFADs. In both cases sharks could be attracted or repelled away from the DFAD using different kinds of stimuli:

A. electrical and electromagnetic stimuli
B. chemical stimuli
C. sound stimuli

Some of these stimuli may be effective: the use of chemical attractants and the use of sound, however, additional research should be implemented.

A. electrical and electromagnetic stimuli.

Sharks can use their electrosensory system to detect electric fields in their environment and are able to use their electrosense to detect preys and respond to electrical and electromagnetic fields using the ampullae of Lorenzini (Tricas 2001). Although most of the evidence is circumstantial, it is widely accepted that elasmobranches can detect the earth's geomagnetic field (Meyer *et al.* 2005). Stationary permanent magnetic fields generated by strong rare-earth magnets or cerium mischmetals alter elasmobranch swimming behavior as they enter the magnetic field and thus could be used as deterrents. Nevertheless, costs (20US$/kg) and environmental safety considerations prevent their utilization in purse seining and even in longlining.

B. Chemical stimuli.

EEG and behavioral experiments on lemon shark (Negaprion brevirostris) and nurse sharks (*Ginglymostoma cirratum*) demonstrate a marked sensitivity of these species to protein breakdown products, especially amino acids and amines (Mathewson and Hodgson 1972). In the early 1970s, interest in chemical shark repellents was renewed by the discovery of pardaxin, a natural shark repellent secreted by the Red Sea Moses sole, *Pardachirus marmoratus*. Previous work on surfactant[1] chemical shark repellents showed some promise and one study confirmed that dodecyl sulfate (an alkyl sulphate surfactant) is the most effective surfactant shark repellent (Sisneros and Nelson 2001).

Anyway, it does not meet the Navy's potency requirement for a nondirectional surrounding-cloud type repellent of 100 parts per billion (0.1 gml-1) and would only be practical as a directional repellent.

C. Sound stimuli.

Acoustic attraction of sharks has been studied in order to find the value of pulse intermittency attractive to sharks (Myrberg *et al.* 1969, Nelson and Johnson 1972).,These and other experiments were conducted under conditions of low ambient sound. Nevertheless, tuna purse seiners are fishing vessels with an enormous quantity of underwater noise that could mask all the stimulant sounds.

Observations on board purse seine vessels indicate that once sharks have been encircled during the set, they suffer a high probability of mortality due mainly to hypoxia.

[1] Surfactants: wetting agents that lower the surface tension of a liquid

Thus, attracting the sharks away from the DFAD before setting the net would appear to be the most convenient measure to reduce the incidental capture and mortality of sharks. To this end, proposals have been made to use “bait stations” (Kondel and Rusin 2007, Scott 2007) to move the sharks away from the DFADs. Testing alternatives for attracting sharks, but not tunas are proposed, starting with an initial test using a chum bucket, sound and fish-oil attractants. If also tunas are attracted to the initial test using all those three components, then an alternative test using sound and fish-oil attractants could be attempted to attract only sharks, and eventually only sound.

Nevertheless, according to every skipper interviewed, the tuna fish will follow the sharks if bait is used. If that whould be the case and only sound is used, then underwater noise coming from the vessels may mask the stimulant sounds.

3.2.2 AFTER SETTING THE NET

When the purse seine set is completed and the pursing starts, sharks have been seen swimming with the tuna. As a consequence and according to skippers opinion, procedures[2] such as the backdown procedure for dolphins are not feasible.

Attracting the sharks away from the net seems more difficult than attracting the sharks away from the DFAD, but some of the items discussed in the former section could be applied in this scenario.

3.2.3 AFTER HAULING THE NET

There is a general consensus among the scientific community that there is an urgent need to determine the survival rates of released sharks. The 70th meeting of the IATTC held in Antigua (Guatemala) in 2003 required fishermen on purse-seine vessels to promptly release unharmed, to the extent practicable, all sharks and other non-target species. Also in the 4th Meeting of the Working Group on By-catch, held in Kobe (Japan) in January 2004 the handling of shark by-catch in the purse seine fishery was also considered.

Some studies (Moyes 2006) suggest that sharks landed in apparently healthy condition are likely to survive long term if released (95% survival based on biochemical analyses; 100% based on PSATs). Skippers and tuna fleet managers have agreed that this is the only phase during purse seining where something can be done. Nevertheless, fishermen are reluctant to waste time releasing sharks when the tuna fish are dying in the bunt of the purse seine net, as it is known (Collette 2004) that the rapid chilling of fish immediately after death to an internal temperature below 10°C prevents the formation of histamine.

[2] Procedure for releasing captured dolphins. Backdown is a process whereby by running the seiner in reverse the flotline of the purse seine can be submerged and pulled from under the dolphin (Ben-Yami, 1994).

From the present knowledge on shark by-catch, it would appear that at present effort should be concentrated on dealing with the sharks when they are released, after hauling the net. The most advisable step would be to draft a preliminary "Careful Release Protocols for Sharks" detailing the possible scenarios encountered and the equipment and techniques to be used; taking advantage of similar protocols done for turtles caught in pelagic longline operations by Eperly et al. (2004). Also investigating the survival of sharks by means of tagging experiments using PSATs is important. Developments in pop-up satellite archival tags (PSATs) have greatly improved scientific understanding of the postrelease survival, behavior, and movements of marine vertebrates-animals from which it is not always practical to physically recover tags to obtain data. PSATs take measurements of physical conditions (e.g., temperature, pressure, light level) while attached to study animals, then independently detach at predetermined times, float to the surface, and transmit data to orbiting satellites of the Argos system. Argos is a satellite-based system which collects, processes and disseminates environmental data from fixed and mobile platforms worldwide. What makes Argos unique is the ability to geographically locate the source of the data anywhere on Earth utilizing the Doppler effect. Historically, these deployments have been limited to large pelagic marine vertebrates such as billfishes, tunas, sharks, and sea turtles. Recent miniaturization of tag components has led to the development of a new generation of PSATs that are 33% smaller, thus enabling the collection of high-resolution time-series data for smaller species.

3.3 MITIGATION TECHNIQUES FOR TURTLES

3.3.1 BEFORE SETTING THE NET

In this scenario, intensive effort should be concentrated on the structure and/or configuration of the DFAD. In FAD fishing, efforts by the scientific community and from some fishing companies have been made to mitigate the capture of incidental catch of sharks and sea turtles without reducing the FADs capability of aggregating fish. The importance of the hanging panel of netting in the productivity of the DFAD has been pointed out by skippers and scientific staff (Armstrong and Oliver 1995). The length of the hanging panel of netting is quite variable (between oceans and between skippers). From recorded data collected directly from the skippers, it varies from 45 to 55 meters in the Atlantic and from 6 to 25 meters in the Indian Ocean. In the Pacific Ocean the length is also highly variable: from 9 to 12 meters for Spanish and 20 to 30m for for Japanese fleet (Itano *et al*. 2004); up to 50 meters in the eastern Pacific (Bromhead 2003). Although the effectiveness of larger nets to attract tuna has not been evaluated (Fonteneau *et al.* 2000), the length of the nets hung underneath the DFAD have shown an increasing trend over time. According to interviews, Korean DFADs have the reputation of being the longest DFADs. As far as it is known, DFAD prototypes have been tested by some companies. In one case the DFAD prototype used a polyethylene pipe at both ends of a 3 to 6 meters cylinder made by sailcloth (Delgado de Molina *et al.* 2005b, Delgado de Molina *et al.* 2007). In the other case, a drifting alternative DFAD, a polyethylene pipe, full of holes, was suspended 20 cm below the surface to prevent being spotted by other vessels and using agricultural netting material as hanging netting (fishers, pers. com.)

For reducing the capture of sensitive species, an ecological DFAD that avoids the entanglement of marine turtles should be designed and implemented.

The design of an alternative DFAD that could prevent the incidental catch of sharks and sea turtles ("Ecological FAD") without loosing its capability of aggregating fish is one of the main objectives of the European project MADE. The design of the ecological FAD should take into account the following important criteria (Franco *et al.* 2009):

- The ecological DFAD should eliminate or at least reduce the incidental catch of sensitive species.
- The ecological DFAD cannot be made of materials that the fishermen do not accept (because of the price, accessibility of materials, work on board, etc.).
- The ecological DFAD should be as biodegradable as possible (to insure that the elements of the DFAD do not eventually end up in natural habitats (coral reefs, beaches...).
- The ecological DFAD should be made in such a way that it does not pose any risk to the crew in the deployment or the recovery of the DFAD.

3.3.2 AFTER SETTING THE NET

In this scenario, current practices established in all oceans seem sufficient to avoid turtle mortality, which is the use of speedboats to release the turtles unharmed from the net before passing through the power block.

3.3.3 AFTER HAULING THE NET

This situation will rarely be encountered as the number of sea turtles caught per set is small as mentioned above and by means of current practices turtle are rarely brought on deck.

Nevertheless, marine turtle survival studies should be carried out to determine the survival rates of released turtles after the set using the designed Careful Release Protocols for Marine Turtles. Techniques for studying survival probability after release include capture-mark-recapture (CMR) studies or satellite telemetry. Due to the relatively small number of turtles caught by purse seining, only the second method is viable using the Argos satellite system, currently the only system capable of full global coverage. Migrations and oceanic dive profiles have been followed and monitored by satellite telemetry of loggerhead sea turtles (Bentivegna 2002, Godley *et al.* 2003) and for leatherback turtles (Hughes *et al*. 1998; Hays *et al*. 2004).

In the following sections the present techniques that are being used for by-catch mitigation are presented which could be tested in a research program along with those that show promise but need additional work.

4. TECHNIQUES IN USE (CURRENT BEST PRACTICES)

To obtain information about the current best practices used in DFAD fisheries, interviews with the skippers and other staff of tuna companies have been carried out as well as with the observers on board the tuna purse seiners.
Current best practices carried out by the fishers usually follow RMO recommendations, and are generally successful if certain conditions are fulfilled:

- There is no risk for the crew.
- The fishing operation is not disturbed very much.
- There is some collateral advantage (e.g.: the grease of a crushed organism on the power block will make the net slip).

By-catch of juvenile bigeye and small tuna

The main best practice techniques observed are the following:

- Flexible sorting grids, as has been mentioned before, are being used by Ecuadorian and associated fishing vessels fishing in EPO waters. Although at the beginning skippers were reluctant to use them, because of their weakness, improvements in the latest models of sorting grids have made their use easier.
- The DFAD is usually towed out of the area encircled by the purse seine (especially by Spanish tuna purse seiners in the Indian Ocean), through the gap between the net and the prow of the vessel. Non-target species and juvenile tuna associated with the DFAD follow the DFAD. This operation has completely replaced the towing of the DFAD over the cork-line of the net.

Sharks

RMOs have since the 1990s drafted several recommendations regarding sharks, for example:

“In fisheries for tunas and tuna-like species that are not directed at sharks, CCMs shall take measures to encourage the release of live sharks that are caught incidentally and are not used for food or other purposes” (WCPFC in its Conservation and Management Measure 2009-04).

Main best practices are the following:

- Sharks brought on board are released as soon as possible to increase their chances of survival (Fig. 5).

Fig. 5. Taking a shark out from the brailer (AZTI)

- Some vessels (especially French tuna purse seiners in the Indian Ocean) have made some modifications on the main deck to accelerate the release of sharks and other species (Fig. 6).

Fig. 6. Double conveyor belt to release non-target species (AZTI)

- When encirclement of large animals occurs, fishers eventually free the animal without damage. The case of whale sharks is the most significant: when the head of the whale shark is facing the prow of the ship, using a speedboat, the purse seine net is cut and the whale shark is released. This is the standard operation in all oceans.

Turtles

Following FAO Guidelines to reduce sea turtle mortality in fishing operations RMOs have made the following recommendations for purse seiners to all the CPCs:

“i) Avoid encirclement of sea turtles to the extent practical.
ii) Develop and implement appropriate gear specifications to minimize by-catch of sea turtles.
iii) If encircled or entangled, take all possible measures to safely release sea turtles.
iv) For fish aggregating devices (FADs) that may entangle sea turtles, take necessary measures to monitor FADs and release entangled sea turtles, and recover these FADs when not in use.”

Current best practices related to turtles include the following:

- Turtles entangled in the purse seine net are released unharmed from the net before passing through the power block. The hauling fishing operation is stopped for this purpose. A speedboat is usually close to the power block position at the waterline.
- After checking the DFAD, turtles entangled in the webbing under DFADs are released unharmed.
- Some companies are themselves trying new designs of DFADs to prevent entanglement of turtles, mainly by modifications to the rack of the DFAD.

5. TECHNIQUES TO BE TESTED AT SEA

Table I summarizes the specific activities selected to be tested at sea. Criteria for final selection were:

- By-catch problem scope: degree of damage to the endangered species.
- Research plan duration and the probability of successfully finding specific solutions for by-catch.
- Degree of progress on specific research activities.
- Impact of the specific activities in solving by-catch reduction.
- Degree of application by the PS vessels of the specific by-catch measures (economic impact, investment needed for the new technique or solution, operating simplicity...).
- Degree of application of the specific by-catch mitigation measure for the different oceans (i.e. measures valid for different oceans are preferable.
- Social perception of specific by-catch problems (although not a scientific criteria, it has also been considered).

The following Table 1 shows selected specific activies to be tested at sea along with the perceived need for a dedicated vessel to conduct each activity, as well as if it requires preliminary work before going to sea and, finally, if each activity is vessel-type specific and if the specific research would be common for the different oceans.

Table 1. Specific research activities that need a dedicated purse seiner vessel.

	Remote discrimination (instrumented buoys)	*In situ* discrimination (acoustics, ROVs, cameras)	Test of ecological DFAD	Attraction to various stimuli	Selective devices (gear modification)	Change PS net characteristics[1] (gear modification)	Changes in fishing operation[2] (incl. Gear modification)	Estimate post-release survival	Understanding fish behaviour[3]
Sharks	✓	✓	✓	✓	✓	✓	✓	✓	✓
Turtles	✓	✓	✓			✓	✓	✓	✓
Bigeye	✓	✓			✓	✓	✓	✓	✓
Other species	✓	✓			✓	✓	✓	✓	✓
Need of a dedicated PS	no	yes	no	yes	yes	yes	yes	yes	yes
Vessel type specific	no	no	no	no	yes	yes	yes	yes	no
Ocean specific	no	no	yes	no	no	?	no	no	?

[1] Related to depth, and mesh size
[2] Related to brailing, belts, manipulation...etc
[3] Understanding fish behaviour : (i) before a vessel arrives (natural behavior) (ii) when vessel is present at the FAD

Table 1 shows the main mitigation issues as well as mitigation techniques that could be applied to the different by-catch species such as fish discrimination, understanding fish behaviour, survival of by-catch and selectivity after setting.

Brief description of specific activities selected

Fish Discrimination

This action would apply for all by-catch species. It would imply aiding the decision-making of fishers on the specific composition and sizes of the aggregations prior to setting. Discrimination could be done using ROVs or underwater cameras, and/or using acoustics in two ways: using equipment onboard purse seiners and/or using remote instruments, i.e. sounder buoys currently used by fishers. The latter shows a more promising impact in avoiding by-catch as having remote estimates of by-catch would prevent fishers from making long trips. The result of these activities would be a protocol to identify species under DFADs.

Understanding fish behaviour

The understanding of fish behaviour is essential for producing effective mitigation measures. This specific activity implies understanding fish behaviour around DFADs, fish behaviour related to gear, the effects of DFADs on fish behaviour and especially the potential effect on their habitat. Although habitat modification is not directly related to mitigating by-catch, it is related to the extensive use of DFADs and the possible effects on habitat modification. All regional fishery management organizations (RFMOs) have called attention to the need for a better understanding of the effects of thousands of DFADs on the spatial dynamics and behavior of tuna. This action implies collecting data to understand the effects of DFADs on fish behaviour. There is a hypothesis stating that DFADs are ecological traps that change tuna's natural migrations.

This action would imply on one hand, working with tuna biomass related to environmental factors (temperature, chlorophyll, FAD densities), along the trajectory of the DFADs so that "good conditions" or "bad conditions" can be related to tuna biomass under DFADs and hence work on the factors causing tuna to leave a FAD if the conditions are not good. On the other hand, it would imply measuring time residency of tunas around DFADs to see if the same individuals are following a DFAD along a trajectory or if an exchange of individuals occurs, so that the scale of the ecological trap could be tested. The former activity would imply collecting biomass from fishers´ echo-sounder buoys or from their catches throughout a DFAD´s lifetime and the second activity would imply acoustic tagging of tuna around DFADs.

Alternative DFAD designs

This action is devoted to mitigating shark and turtle ghost fishing. Diverse designs of Ecological DFADs are available to be tested at sea. Ecological DFADs should be as biodegradable as possible. Proper experimental design should take into account those areas in which turtle sightings are high. It would be desirable to monitor a significant number of Ecological DFADs together with traditional DFADs in the same area, in this way it would allow comparisons of turtle incidence within the same area between the two types of DFADs (alternative DFAD Vs. traditional ones). The experiments conducted within ISSF research should use ecological DFADs.

Mitigate Shark by-catch

Research activities on shark by-catch would imply: (i) Monitoring of handling and release practices onboard: recompilation of best current practices used on board. (ii) Research on shark attraction to various stimuli to exclude them from the net: this action needs both, experiments in captivity and in real conditions. Consultation with experts on acoustics resulted in a suggestion to conduct some experiments in real conditions at sea, even without having conducted preliminary studies in captivity. Stated reasons were the importance of knowing whether the vessel noise masks the sound of the attractor, as well as the possibility to observe the behaviour under real conditions. The final outcome of this activity would be the release of sharks from the net, without landing them.

(iii) Research on shark survival after release: this action could be done by tagging sharks or having them in captivity onboard or analysing their condition (blood, muscles...etc). Each technique has its pros and cons. Final outcomes of this activity would be Careful Release Protocols for Sharks.

Mitigate Turtles by-catch

Turtles are passively caught by the netting hanging under DFADs as well as by the netting providing shadow on the top of the DFAD floating structure. Changing the characteristics of the netting would avoid turtle entanglement (*see alternative DFAD designs*) above. Studying the survival of entangled turtles would imply, tagging turtles or having them in captivity onboard or analysing their condition (stressors, blood, muscles...etc). A protocol for turtle release from the net as well as handling onboard would be the final output of this research issue.

Selective devices

This mitigation issue implies (i) studying different sizes and species´ behaviour within the net (ii) researching the use of different stimuli to control fish behaviour within the net: the aim would be to allow fishes to be released through the selective device and to keep target species inside the net. (iii) testing different types of selective devices and their characteristics (sizes and positions in the net) from the results in previous activities.

Mitigate catch of bigeye tuna of undesirable size

This mitigation issue would imply, understanding bigeye behaviour related to fishing gear, related to DFAD design and working with selective devices (see understanding fish behaviour and the paragraph above).

Changes in fishing operation

This research activity implies two different actions, monitoring conditions during the fishing manoeuvre (oxygen, temperature), so that these operations can be improved to preserve the health of the different species while brailing (those inside the sac and inside the brailing gear) and, for instance, while moving with the belt. An added advantage of this action would be improving the health and hence quality of the target species for the market.

The other action would be to develop and adopt techniques to facilitate the release of the different by-catch species onboard, such as specific belts for by-catch.

6. MAIN CURRENT RESEARCH ON MITIGATION RELATED TO DFADs

This section aims to assist with decision-making as regards techniques to be tested at sea. Table 2 summarizes the main research on DFADs fishing that is currently underway in various parts of the world regarding gear modification for by-catch mitigation. The idea is to identify the main gaps in the current knowledge, to identify the research project progress for those activities as well as the oceans in which specific activities take place (the list is by no means exhaustive).

Table 2. Current research on by-catch mitigation related to DFADs

Mitigation issue/ technique	Specific activities	Degree of progress	Centres involved / project in progress	Ocean of research
Species and sizes discrimination prior to setting	The use of ROVs and underwater cameras to asses species composition	low	University of Hawaii (USA)	Pacific
	Acoustic library from equipments onboard	low	IEO (Spain) IATTC	Indian Pacific
	Acoustic library from buoys	low	AZTI (Spain) MADE EU project	Atlantic Indian
	Protocol to discriminate species	-	-	-
Ecological DFADs	Design	high	AZTI (Spain) MADE EU project JAMARK (Japan) IEO (Spain) IATTC IRD	Indian Pacific
	Test in real conditions	intermediate	JAMARK (Japan) IEO (Spain) NRIFSF – Japan AZTI (Spain) IATTC IRD	Pacific Atlantic Indian
Sharks	Survival after releasing	-	-	-
	Attraction to various stimulus in captivity	low	UCDAVIS	-
	Protocol to handle sharks onboard	intermediate	MADE EU project	Atlantic
Turtles	Survival after releasing	-	-	-
	Protocol to handle turtles onboard	-	-	-
Selective devices	Fish behaviour in the net	-	-	-
	Controlling movement in the net	low	JAMARK (Japan) NRIFSF - Japan	Indian Pacific
	Survival	low	IATTC programme	Pacific
Net designs	Gear behaviour/ sp.comp. caught	low	Pukyong national University (Korea) NRIFSF - Japan	Pacific
By-catch handling	Monitor conditions during fishing manoeuvre (oxygen, temp.,brailing, belt)	low	-	-
	Develop & adopt techniques to facilitate the release onboard	low	IATTC	Pacific
Habitat modification (Ecological trap hyp.)	Biomass Vs. environment/ Time residence Vs. environment	low	AZTI (Spain) MADE EU project IRD	Indian

7. PROMISING TECHNIQUES FOR THE NEAR FUTURE

Apart from the techniques to be tested in the research plan that are mentioned in Table I, there are a few promising techniques that have been previously commented on the review of mitigation techniques:

Passive acoustics

During the by-catch workshop held in Sukarrieta (November, 2009), passive acoustics appeared to be a promising technique to discriminate species and sizes prior to setting. The idea would be to record sounds emitted by the fish under DFADs in order to eventually identify the species present at the DFADs. This would require firstly, recording sounds around FADs and then to analyse the sounds to identify different species. Additional options which could be identified for the use on purse seiners would include:

(i) developing an instrumented buoy with a hydrophone (or an array of them) to remotely identify species as well as a receiver to be used onboard that gives information on the species present.

(ii) using a hydrophone *in situ* from the vessel (or speed-boat), prior to setting and having a receiver that provides fish species composition.

These options show promise for the future but have been rejected from the research plan due to the low development of progress on these activities and which would require longer research development.

For other discrimination tools, such as active acoustics, using both the equipment onboard and instrumented buoys with echo-sounders, research has already been conducted and equipment (receivers, software and hardware for detection) is ready to be used.

Developments of discrimination instruments

From the results of the specific activities within the Species and Sizes Discrimination invesigations, new radio buoys could be developed in collaboration with commercial companies. These developments are beyond the scope of the present Research Plan but according to the skippers they could be the most promising tools to mitigate by-catch

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8. ACRONYMS USED

AFAD	Anchored Fish Aggregation Device
AIDCP	Agreement on the International Dolphin Conservation Program
ALB	Albacore (*Thunnus alalunga*)
BET	Bigeye tuna (*Thunnus obesus*)
BRD	By-catch Reducing Device
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CCM	Commission Members, Cooperating non-Members, and participating Territories (WCPFC)
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMM	Conservation and Management Measure
CMR	Capture-Mark-Recapture studies
CPC	Contracting Parties and Cooperating non-Contracting Parties
DFAD	Drifting Fish Aggregation Device
EPO	Eastern Pacific Ocean
ERA	Ecological Risk Assessment
FAD	Fish Aggregation Device
FAO	Food and Agriculture Organization
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
IOTC	Indian Ocean Tuna Commission
ISSF	International Seafood Sustainability Foundation
MMA	Micronesian Maritime Authority
PAT	Pop-off Archival Tag
PSA	Productivity - Susceptibility Analysis
PSAT	Pop-up Satellite Archival Tag
RMO	Regional Fisheries Management Organizations
ROV	Remote Operated Vehicle
RTTP	SPC Regional Tuna Tagging Project
SKJ	Skipjack tuna (*Katsuwonus pelamis*)
SPC	South Pacific Commission
SPOT	Smart Position Or temperature transmitting Tag
SRP	Subsecretaría de Recursos Pesqueros (Ecuador)
WCPFC	Western and Central Pacific Fisheries Commission
WiMAX	Worldwide Interoperability for Microwave Access
YFT	Yellowfin tuna (*Thunnus albacares*)