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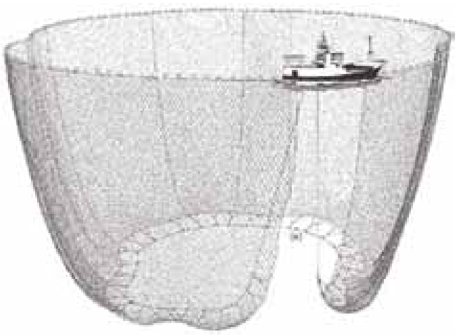
Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world



***Cover photographs*: Courtesy of M. Roman/IATTC.**
***Cover illustration*: Courtesy of FAO.**

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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Preparation of this document

This report has been prepared at the request of the responsible service for Highly Migratory Species of the Fisheries and Aquaculture Department of the Food and Agriculture Organization (FAO) of the United Nations to inform the public discussion on some of the ecological impacts of the tropical tuna purse seine fisheries of the world.

It provides a review of the information available in published papers, or documents presented at the tuna regional fishery management organizations (RFMOs) scientific and technical meetings, and workshops. As the bycatch process is a very dynamic one, changing by economic reasons, technological changes, and mitigation effort, it describes the conditions reported in the documents currently available, but the readers are encouraged to visit the websites of the tuna RFMOs for the most recent data.

Abstract

This report provides a review of our knowledge of the bycatches, defined as discarded dead, from the tropical tuna purse seine fisheries of the world. The major fishing grounds involved (eastern and western Pacific, eastern Atlantic, and western Indian Oceans) share the gear, the ways of fishing, and the structure of the pelagic communities. Because of that, the species taken in association with tuna schools tend to be the same in all regions.

After describing the gear and fishing operations, it discusses the reasons why bycatches happen, and explores the options to mitigate them.

The types of sets used to capture tunas and the detection methods used to locate the schools are a major factor to determine which are the catches and the bycatches. The main bycatches are tunas, sharks and rays, pelagic bony fishes, billfishes, and sea turtles. The total discards amount to one to five percent of the total tonnage captured, and tunas of the species targeted amount to over 90–95 percent of those bycatches. The silky shark is the most common shark species by far, followed by the oceanic whitetip sharks. Marlins and sailfishes are also taken but in reduced numbers. Olive ridley sea turtles are the most common turtle captured, but the majority of them are released alive and unharmed. Rainbow runners, mahi-mahis, wahoos and amberjack yellowtail are the major pelagic bony fishes taken with the tunas. They are being retained in increasing numbers for utilization.

Besides discussing problems of estimation, the report presents most of the ideas proposed or in different stages of testing, to mitigate those bycatches, including ways to avoid the captures, or to release the individuals from the net or from the deck.

Finally, the known or potential ecological impacts of the rapidly increasing fishery on fish aggregating devices (FADs) are reviewed, emphasizing some of the uncertainties that still prevail.

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Contents

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Finally, many thanks go to all the observers from all the programmes that have contributed, with their dedication, and the quality of their work to the production of all our databases.

Abbreviations and acronyms

AIDCP	Agreement on the International Dolphin Conservation Program
BPUE	bycatch per unit of effort
BR	bycatch rate
CPS	capture per set
CPUE	catch per unit of effort
CWP	Coordinating Working Party on Fishery Statistics
EPO	Eastern Pacific Ocean
FAD	fish aggregating device
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICES	International Council for the Exploration of the Sea
IOTC	Indian Ocean Tuna Commission
ISSCFG	International Standard Statistical Classification of Fishing Gear
MADE	Mitigating ADverse Ecological impacts of open ocean fisheries
MPA	marine protected area
NFMS	National Marine Fisheries Service (the United States of America)
NPS	numbers per set
RFMO	regional fisheries management organization
SPC	Secretariat of the Pacific Community
t-RFMO	tuna regional fisheries management organization
VMS	vessel monitoring system
WCPFC	Western and Central Pacific Fisheries Commission
WPO	Western Pacific Ocean
WPPS	weight per positive set
WPS	weight per set

1. Introduction

SCOPE OF THE REVIEW

Fishers have harvested tunas for millennia, with a variety of gear types that range from beach seines and “almadrabas” (a type of floating trap) to longlines, trawls, gillnets and purse seines. From coastal operations, the fleets began to move farther from their ports with the development of new vessels, and gear technology (Orbach, 1977). The search for tunas began to grow with the use of “baitboats”, vessels prepared to catch tuna with pole and line, using live bait. In the 1920s, fishers would catch live bait and start fishing when a school of tunas was detected by chumming the water, and when the tunas entered in a feeding frenzy, naked hooks were enough to catch them. The technique had been used by the natives of Maldives long before (Doumenge, 1998). The need to catch bait, and then to keep the bait alive were major limitations to the geographical extent of the pole and line fishery, and also to the time fishers could spend fishing before having to return to replenish bait (Gillet, 2011). This fishery was thus limited to the coastal region. During their explorations of fishing grounds, fishers noticed that, in some regions, schools of tunas could be seen feeding on the surface in large numbers, sometimes associated with floating objects, in other cases with dolphins or whales. However, their technology did not allow them to exploit these large aggregations in a more effective manner until further improvements happened, affecting vessels and gear. In the late 1960s, the purse seiner brought about a revolution, increasing the production and the range of the fisheries, and introducing a whole array of new technologies for detection and capture of the tunas. The cost of the increase in production was the loss of some of the selectivity of the hook and line fishery.

The objective of this review is to describe the bycatch and the non-tuna catch of the purse seine fisheries targeting tropical tunas in all oceans of the world. These fisheries produce annually 75–90 percent of the world production of these species (skipjack tuna [*Katsuwonus pelamis*], yellowfin tuna [*Thunnus albacares*], and bigeye tuna [*Thunnus obesus*]), which is more than 4 million tonnes. The proportion of the catch taken in purse seines ranges from 35 percent in the Indian Ocean to 82 percent in the Eastern Pacific Ocean (EPO) (ISSF, 2011). These species are very abundant in tropical waters, with skipjack and yellowfin living in shallower habitats and warmer waters than bigeye tunas. In the Western and Central Pacific, skipjack amounts to almost 70 percent of the total catch, while in other oceans it is only 35–41 percent of the total. The proportion of yellowfin in the catch is highest in the Indian Ocean (36 percent) and lowest in the Western and Central Pacific (20 percent). Bigeye tuna is less abundant in the Western and Central Pacific (5 percent) and it reaches about 20 percent in the Eastern Pacific and Atlantic Oceans.

As their vertical distributions are strongly influenced by the location of the thermocline, and the thermocline depth varies from 20 m to hundreds of metres, their vertical ranges are also very variable. Most of the catch in purse seine nets comes from the upper 100 m of the water column. The purse seine fisheries coexist in the tropics with industrial longline fisheries that target mainly bigeye tunas, with yellowfin being another species of interest. Practically all catches of skipjack come from purse seiners or pole and line operations, but not longlines.

The above three species share some characteristics: they grow fast, reproduce early (age at maturity ranges from 1.5 to 4 years), and are short-lived (maximum age for skipjack is 8 years, 9 years for yellowfin, and 16 years for bigeye tunas, but very few reach these ages). Skipjack is the smallest, with a maximum length of slightly more than 1 m, while yellowfin can grow almost to 2.4 m, and bigeye may reach 2.5 m of fork length (Schaefer, 2001; Collette, 2010). They are fast-swimming schooling species, with a diet composed of fish, pelagic crustaceans, and squids. Trophic levels are 3.5–4.5 (Froese and Pauly, 2010). They form multispecies schools, and, frequently, juveniles of bigeye and yellowfin may be found schooling with skipjack schools, as their sizes are similar.

The issue of bycatch in fisheries has been growing in significance from the point of view of management, and for those interested in the conservation of marine species. It is a complex problem that generates widely different reactions among all interested parties. For some it is a waste issue, for others it is a major conservation threat to many long-lived species. Many fishers are also aware of the need to conserve the structure of the ecosystems they live off, and are prepared to work to find solutions. In many cases, those in the fishing industry are being pressed to act because it is a subject that may affect their ability to continue fishing, or it may affect the marketing of their products.

In the tuna fisheries, the bycatch issue became very visible in the EPO because of the mortality of dolphins in the tuna fishery, and its controversies in the 1960s (Perrin, 1969; Hall, 1998; Gosliner, 1999). For many years, this subject dominated the agenda at the Inter-American Tropical Tuna Commission (IATTC), the tuna regional fisheries management organization (t-RFMO), where this interaction was taking place. As the mortality, abated in the early 1990s (Hall, Campa and Gómez, 2003), the interest switched to other conservation priorities.

The declines in some populations of leatherback (*Dermochelys coriacea*) and loggerhead (*Caretta caretta*) sea turtles and of albatrosses became a high priority for conservation organizations and fisheries managers. Very little data were available, but it was known that they were caught in longline fisheries in considerable numbers (Lewison, Freeman and Crowder, 2004). With very few or low-coverage observer programmes, there were no good estimates of the impacts of the different fisheries, but there were indices of the status of the populations based on counts during the nesting season in beaches or rookeries, and some of these showed sharp declines (Spotila *et al.*, 2000). Thus, for most t-RFMOs, the work on bycatch started with this emphasis. Longlines are selective for sizes, capturing mostly yellowfin and bigeye tunas of modal sizes 100–140 cm with low tuna discards, but they have bycatch of seabirds, sea turtles, and sharks that are much higher than for purse seiners. For example, OFP (2008a) and Clarke (2009) show that, for sharks, more than 90 percent of the bycatch is from longliners.

Only recently, with the rapid growth of the purse seine fisheries on fish aggregating devices (FADs), has the issue of other bycatch in the seine fisheries become visible to the public, because of the campaigns of environmental organizations (Greenpeace, 2010), and a challenge to fisheries managers. Because of this sequence of priorities, the agendas of the bycatch working groups in the t-RFMOs have been dominated by longline bycatch in recent years, and there is a considerable prevalence of papers on this subject. Consideration of the impacts of tuna fisheries on sharks is the most recent development, generated by the difficult situation of many shark populations (Fowler *et al.*, 2005; Camhi, Pikitch and Babcock, 2008; Dulvy *et al.*, 2008; Camhi, 2009; Camhi *et al.*, 2009a; Baum and Blanchard, 2010).

Another significant subject that came to prominence with the expansion of the FAD fisheries was the increasing capture of juvenile bigeye and yellowfin tunas in the sets on FADs. Some of these were retained, others discarded, but they added pressures on stocks that were targeted by other fisheries (e.g. bigeye tuna was the main target of important longline fisheries). There were also discards of skipjack tunas that were unmarketable because of size, or other reasons.

FAO has steered these developments through the different international plans of action for sea turtles, seabirds and sharks, workshop reports, and through Technical Consultations and world reports on bycatch issues, reduction of “Wastage”, etc. (e.g. Alverson *et al.*, 1994; Clucas, 1997; Pascoe, 1997; Brothers, Gales and Reid, 1999; FAO, 1999a, 1999b, 2006, 2009; Kelleher, 2005; Gilman, Moth-Poulsen and Bianchi, 2007).

2. Definitions and framework

PURSE SEINERS AND THEIR FISHING OPERATIONS

This review covers only purse seine fisheries (Figure 1) that produce tunas as the major component of their catch. The fish are pursued by vessels of a broad range of sizes and capacities, from those capable of carrying only a few tonnes to those capable of carrying more than 3 000 tonnes. The range in vessel lengths is 20–120 m. The net length may reach more than 2 200 m and its depths are usually from 150 m to 350 m; the mesh size varies from 7.5 cm to 25 cm but the vast majority is of 10.8 cm stretched mesh.

FIGURE 1
Diagram of a tuna purse seine vessel

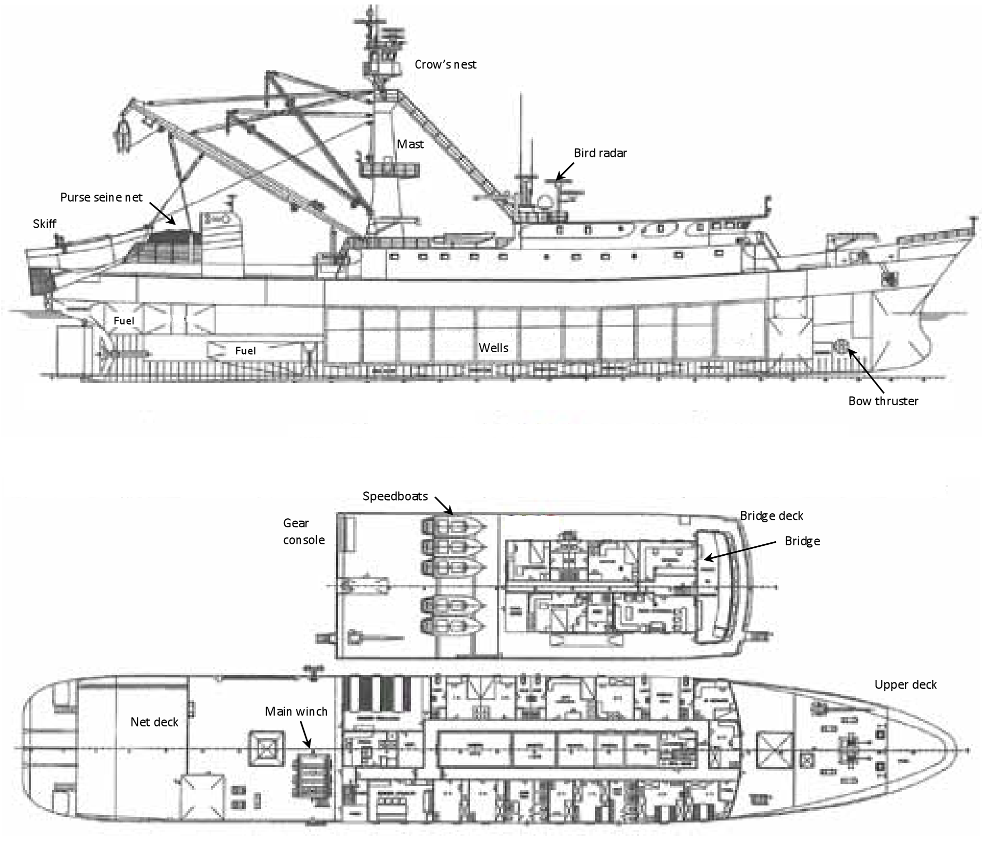
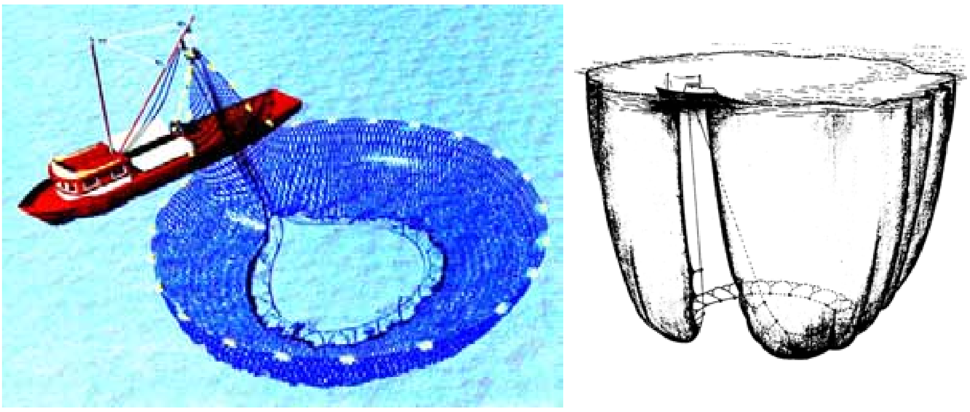


Figure 2 shows a diagram of the structure of most seines used in the tuna fisheries. Figure 3 shows the theoretical maximum area encircled by the net, based on parameters for the EPO (maximum theoretical net diameter about 600 m).

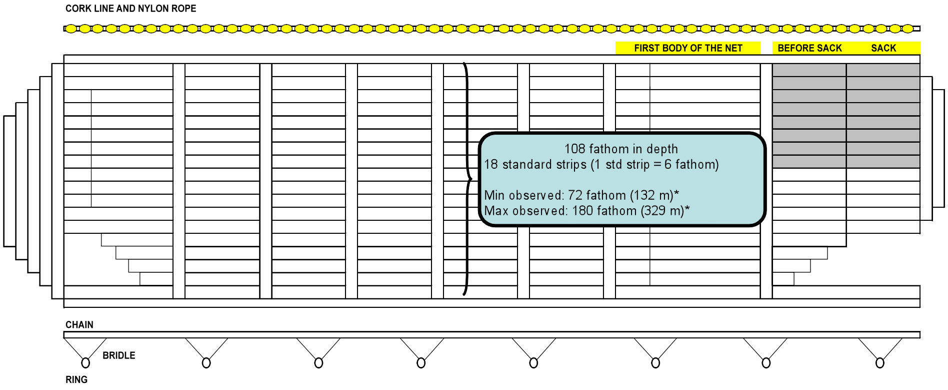
If the length of the towline is added, a 15 percent factor needs to be added to the length. The length and depth of the nets show considerable variability, with length

FIGURE 2
Diagrams of a purse seinel



Graphic by Jim Bean for NOAA/Communications Collective

Purse seine net design (typical EPO net)



* For vessels that made 50% or more
FO sets during 2004-2008 - EPO

modes at 1 280 m and 1 330 m (700–850 fathoms), and depths with a strong mode at 180 m, and a typical range of 180–240 m (100–130 fathoms) (Figures 4 and 5).

The combinations found in the EPO are included in Figure 6. The dimensions change and adapt to different ocean conditions. As an example, dimensions of nets from French seiners operating in the Atlantic increased in length from 700–800 m in the 1960s to about 1 500 m in the early 2000s, with depths going from 100 m to 225 m in the same period (Gaertner and Sacchi, 2000).

Figure 7 shows the trends in the EPO, trying to separate the types of sets where the changes have been more significant. Nets have been becoming deeper in the EPO, especially for the vessels fishing on FADs, and longer for the vessels setting on dolphin.

Bycatch figures for industrial tuna longline fisheries are very scarce, and observer coverage is not sufficient to draw many conclusions. Longlines are selective for sizes, capturing mostly yellowfin and bigeye tunas of modal sizes 100–140 cm with lower tuna discards, but they have a bycatch of seabirds, sea turtles, and sharks that is much higher than for purse seiners (Chapter 1).

FIGURE 3
Maximum dimension of encirclement

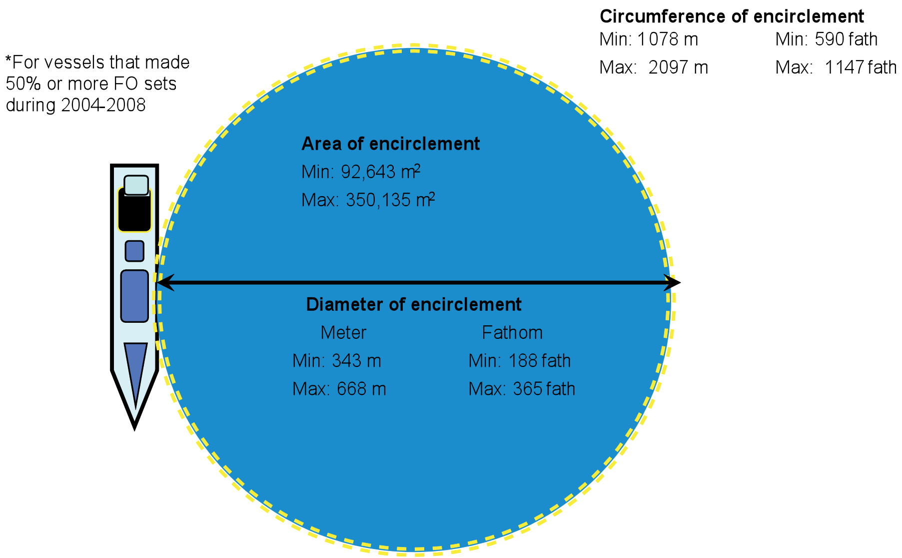
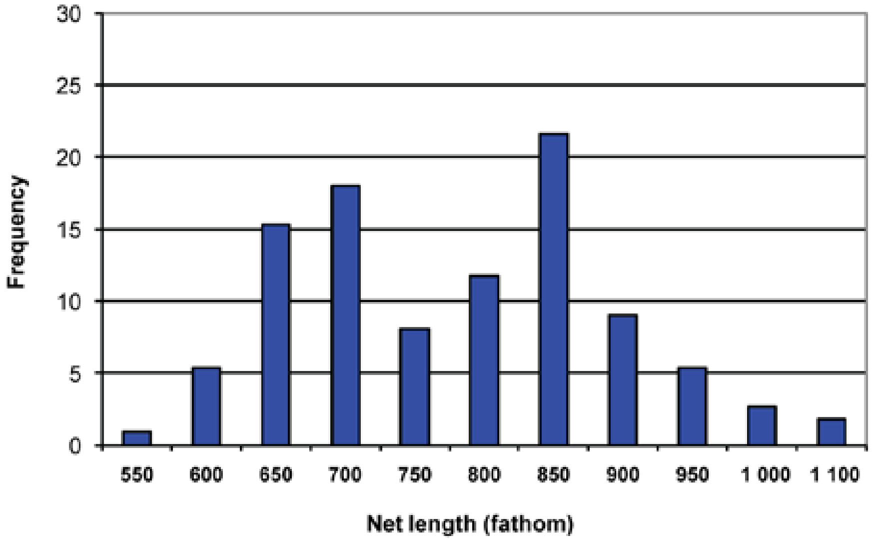


FIGURE 4
Frequency distribution of net lengths for vessels that made 50 percent or more floating object sets in 2004–2008.



However, the fishing depth is much less than the vertical dimension of the net and it depends on several factors that affect its dynamic behaviour (Misund, Dickson and Beltestad, 1992; Gaertner and Sacchi, 2000; Kim, 2000; Santana *et al.*, 2002; Kim *et al.*, 2007; Kim and Park, 2009). In general, fishing depth ranges between 45 percent and 75 percent of the net vertical dimension, with values of 55–66 percent being the most common (Delgado de Molina *et al.*, 2010). The fishing depth of the net determines the maximum depth at which the vessel can set without risking the loss or damage of the net, and this value should be taken conservatively, because of concerns with map or instruments inaccuracy, and the possibility of topographic features rising from the bottom. Therefore, probably, 90–160 m is the minimum depth for a set, depending

FIGURE 5
Frequency distribution of net depths for vessels that made 50 percent or more floating object sets during 2004–2008

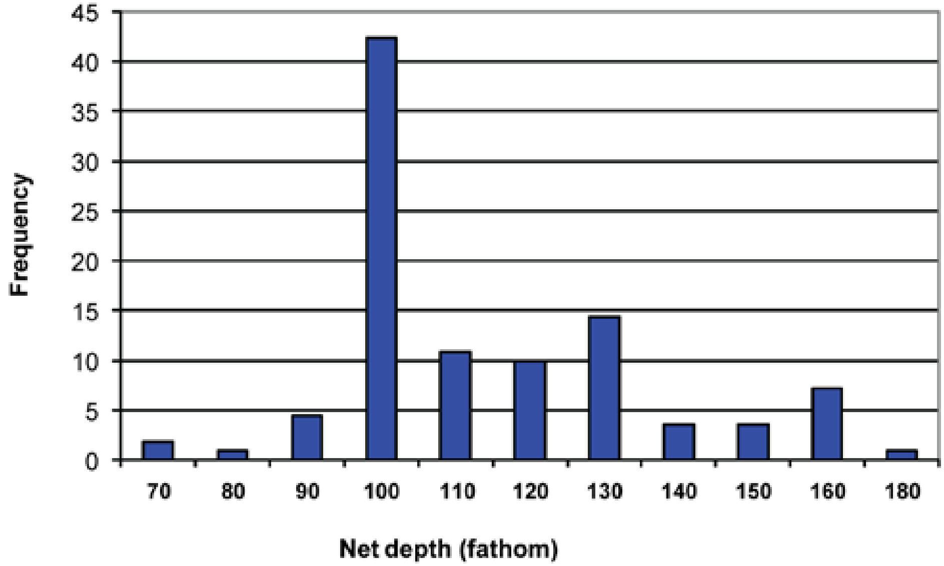
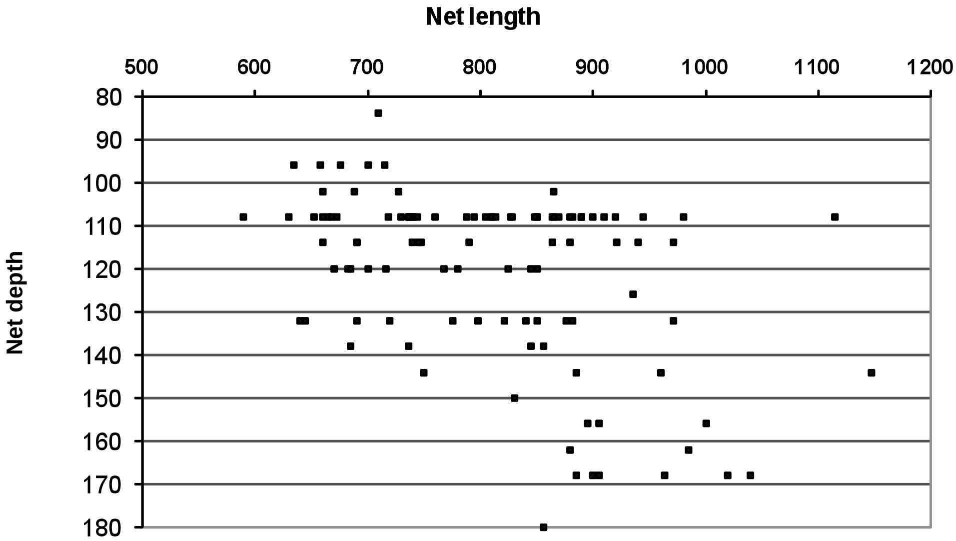
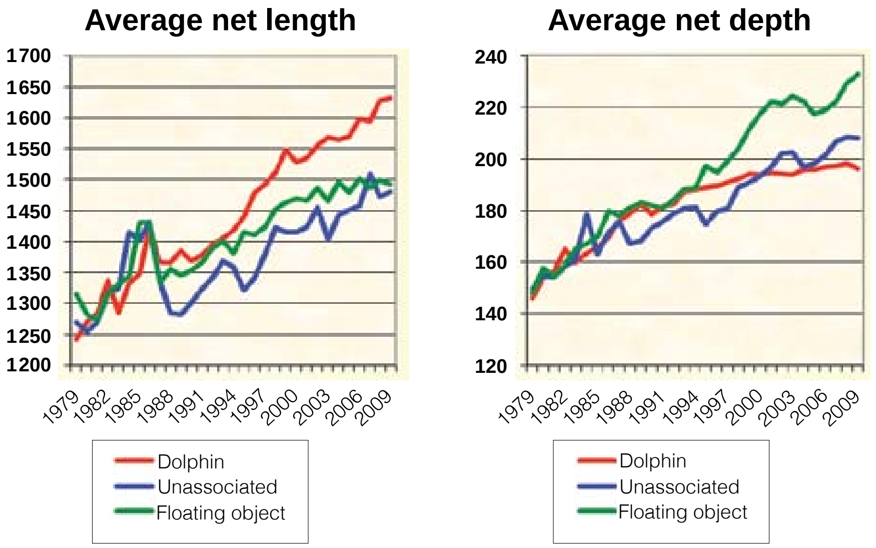


FIGURE 6
Combinations of length and depth in purse seine nets (in fathoms), for vessels that made 50 percent or more floating object sets during 2004–2008



on the net characteristics. The top of the net is hung on a floatline, and the bottom is attached to a leadline, which usually consists of a steel chain with steel rings, known as “purse rings”, and is attached below the chain. The purse line that runs through the purse rings is made of steel and allows the pursing of the net. Purse seiners are equipped with a power block to purse the lead line after fish are inside of the net. Descriptions of the gear and operations can be found in Ben-Yami (1994), and Sacchi (2008). Further information is also available at www.fao.org/fishery/geartype/249/en, and video materials in www.tunaseiners.com, and by Internet search for videos using terms such as “tuna seiners” or “tuna purse seine”.

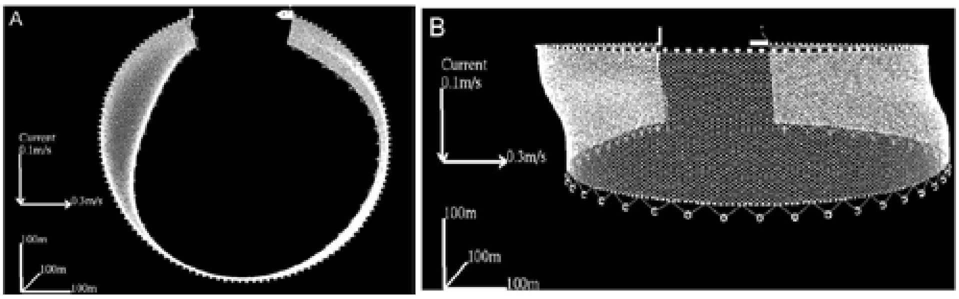
FIGURE 7
Equipment trends (EPO)



The construction of the nets must follow the characteristics of the oceanic areas where they will be used (e.g. thermocline depths), and the behaviour of the target species. While sinking, the net shape will be affected by currents, by its construction (materials, etc.), and by the manoeuvre of the vessel (Kim *et al.*, 2007). Sinking speed is a very important variable that may affect the captures in a set, but it is seldom available. Before encirclement is complete, there are two escape routes: dive under the net, or swim through the open section of the net (Figure 8).

For some species, the thermocline may act as a barrier to keep them from escaping vertically. For other species, their perception of the situation in unclear, given the dimensions of the net, and the escape options are not identified as such. For very large animals, such as whales, a third option is to simply charge the netting and break through. The pursing operation begins to close the bottom of the net. In a later stage, the escape routes are restricted, and when pursing is finished, and the purse cable has closed the bottom opening, there are no more escape routes. As the mesh is more than 10 cm stretched mesh, very small individuals can go through it, although not all species will be willing to squeeze through a tight opening. Some may become enmeshed in

FIGURE 8
Completing the encirclement



Source: Kim and Park (2009).

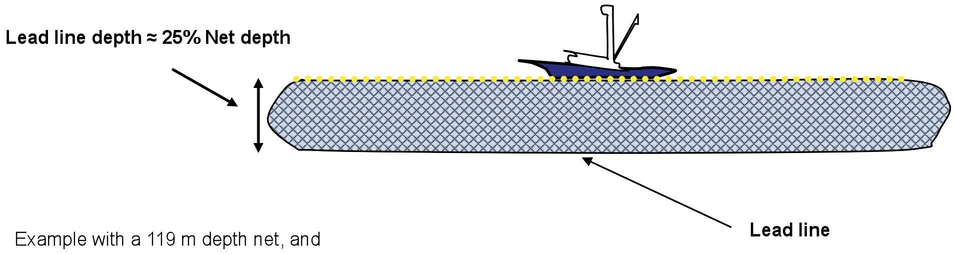
the webbing. It is important to understand the escape routes because target schools, and all others species/individuals associated with them, have opportunities to escape, and some may have behaviours (e.g. diving deep when scared) that may result in their escape (Delgado de Molina *et al.*, 2005a; Viera and Pianet, 2006).

An example of the temporal sequence of the set is illustrated in Figures 9–14, based on the studies by Kim *et al.* (2007) and Kim and Park (2009). Setting takes 7–8 minutes, and pursing 20–25 minutes (Kim and Park, 2009). The whole process lasts less than 30 minutes in general, but sets in adverse environmental conditions, or with malfunctions may take much longer. After the net is closed, the volume of the net is reduced to facilitate the loading of the catch. This phase of the set may last several hours, depending on the volume of the catch, the size of the brailer, etc. The duration of the set is important for judging the level of stress of the individuals captured and their chances of survival if released (discussed below). The geometry of the net during the set is also significant for understanding the vertical dimension of the operation, and the volume enclosed, which may determine which schools and individuals are captured (Delgado de Molina *et al.*, 2010a).

In this technical paper, the definition of a purse seine is as in the International Standard Statistical Classification of Fishing Gear (ISSCFG) standard (Coordinating Working Party on Fishery Statistics [CWP]–FAO, tenth session [Madrid, 22–29 July 1980]), and more recently stated by the International Council for the Exploration of the Sea (ICES)–FAO in 2007.

FIGURE 9

Lead line depth estimation during pursing at set start

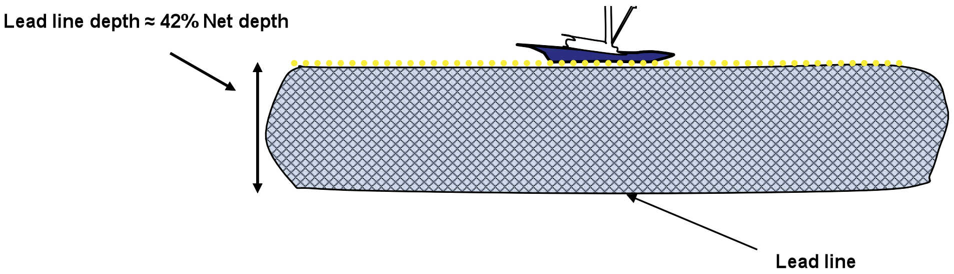


Example with a 119 m depth net, and 19 min. pursing. Depth taken at the centre of lead line

Source: Kim *et al.* (2007).

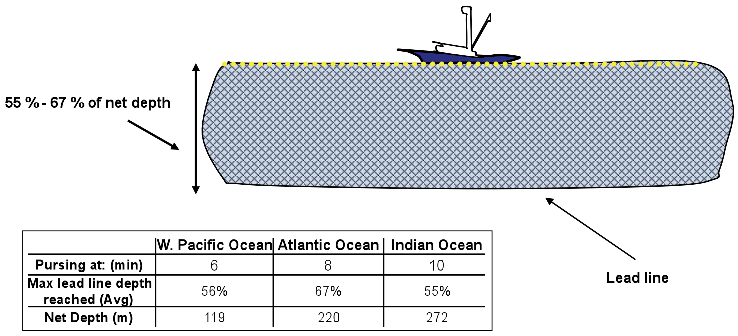
FIGURE 10

Lead line depth estimation during pursing at 3 minutes



Source: Kim *et al.* (2007).

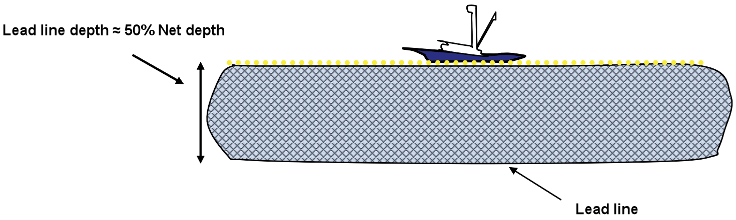
FIGURE 11
Lead line depth estimation during – maximum depth reached by the lead line



	W. Pacific Ocean	Atlantic Ocean	Indian Ocean
Pursing at: (min)	6	8	10
Max lead line depth reached (Avg)	56%	67%	55%
Net Depth (m)	119	220	272

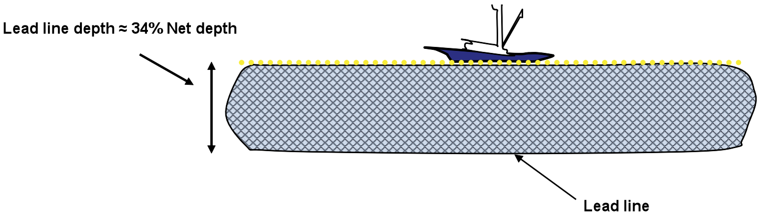
Sources: Kim *et al*. (2007); Santana *et al*. (2002).

FIGURE 12
Lead line depth estimation during pursing at 9 min



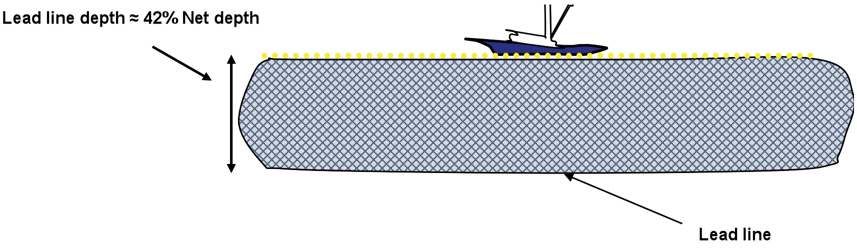
Source: Kim *et al*. (2007).

FIGURE 13
Lead line depth estimation during pursing at 12 min



Source: Kim *et al*. (2007).

FIGURE 14
Lead line depth estimation during pursing at 15 min



Source: Kim *et al.* (2007).

1. SURROUNDING NETS

A surrounding net catches the fish by surrounding them from both the sides and from underneath. It consists of netting framed by lines; a float line along the top at the surface and a weighted line along the bottom.

1.1. Purse seines

Purse seines are designed to catch schooling fish. A purse seine is made of a long wall of netting framed with a lead line and a float line. The purse seine is set from one or two boats to surround a detected school of fish. A purse line threaded through purse rings spaced along the bottom of the net is drawn tight (pursed) to stop the school of fish escaping downwards under the net.

1.1.1. One boat operated purse seines

This category comprises purse seines operated by a single boat, with or without an auxiliary skiff. The strongest part of the net, the "bunt", is where the catch is concentrated and is usually placed at one end of the purse seine. Handling of the gear may be mechanized, e.g. by a hydraulic power block or a net drum." (IICES Working Group on Fish Technology and Fish Behavior Report 2007, ftp://ftp.fao.org/FI/DOCUMENT/rebyc/ices/WGFTFB07.pdf; further information is also availble at www.fao.org/fishery/vesseltype/150/en).

The vast majority of the seiners that participate in the tuna fisheries fall into the category of one boat operated purse seines. The targets in tropical waters are yellowfin tuna, bigeye tuna, and skipjack tunas, and to a much lesser extent, and in some regions, some other tuna or small tuna-like fish such as black skipjack (*Euthynnus lineatus*), frigate tunas (*Auxis thazard*), bullet tunas (*Auxis rochei*), and bonito (*Sarda* spp.). These fish generally feed on baitfish near the surface, or associated with floating objects. In temperate waters, the purse seiners catch either small juvenile bluefin tuna (*Thunnus orientalis*, *T. maccoyi* or *T. thynnus*) when they are feeding on baitfish, or large bluefin tuna while they surface for spawning activities. Also in temperate waters, purse seine is occasionally used to harvest albacore (*T. alalunga*), generally during the night when fish come to the surface to feed. However, these operations producing bluefin or albacore tunas are not the subject of this review.

There are smaller purse seine nets used for less-industrialized fishing near coastal areas, mostly targeting small tuna-like fish, such as frigate tunas, and bonitos. These operations are not well documented, and they are believed to be of minor significance compared with the operations of the major tropical tuna fleets. However, the coastal distribution of their sets may result in encounters with high densities of some vulnerable species near nesting beaches, foraging grounds, etc.

Ben-Yami (1994) describes the process after encirclement is completed: "Once the encirclement is finished, the extremity of the net that stayed attached to the skiff is transferred aboard the purse seiner and the two extremities of the purse line cable are hauled with the winch as quickly as possible in order to close the net at its bottom (this is called 'pursing' because it is similar to pulling the draw string of an old-fashioned purse). It is worth observing that, until the purse seine is not closed, the tunas can still dive below the net or the purse seine vessel and escape. It the net extends all the way from the surface down to the thermocline, the chance of fish escaping through the bottom would be reduced. During pursing, and especially when there is a current, the skiff is attached to the starboard side of the vessel, where it can pull it away from the net in order to prevent the purse seiner from drifting over the net. The pursing operation may take, for large purse seines, about 15 to 20 minutes.

When most of the purse seine has been retrieved, the tunas have been grouped within a restricted area along the portside of the vessel. Then the fish are harvested from the purse seine using a large scoop net called the "brailer" (brailing operation);

several tons of fish are taken on board each time. The duration of this operation will obviously depend upon the quantity of fish in the net, the size of the brailer, and other operational factors. In some operations targeting the bluefin tuna in the Mediterranean Sea, off Australia or off Baja California, a limited fishery for live fish has developed to supply sea ranching operations. In these cases, the pursing is stopped at half way, when the fish are not so crowded. This is to keep the fish alive, as most of the live fish caught are transferred to transport cages for tuna farming.

A mixture of species and sizes is enclosed in the net, after the smaller ones have escaped, or have squeezed through the meshes. The numbers, species or sizes, and the fates of these escaped individuals are not known (Davis, 2002); they are not visible even when there are observers on board the vessel. The selectivity of the purse seine with regards to the smaller fishes has not been studied, although experiments in other fisheries, comparing small seines with very small mesh experimental nets show that many species and sizes are not retained at all (Massutí, Morales and Deudero, 1999).

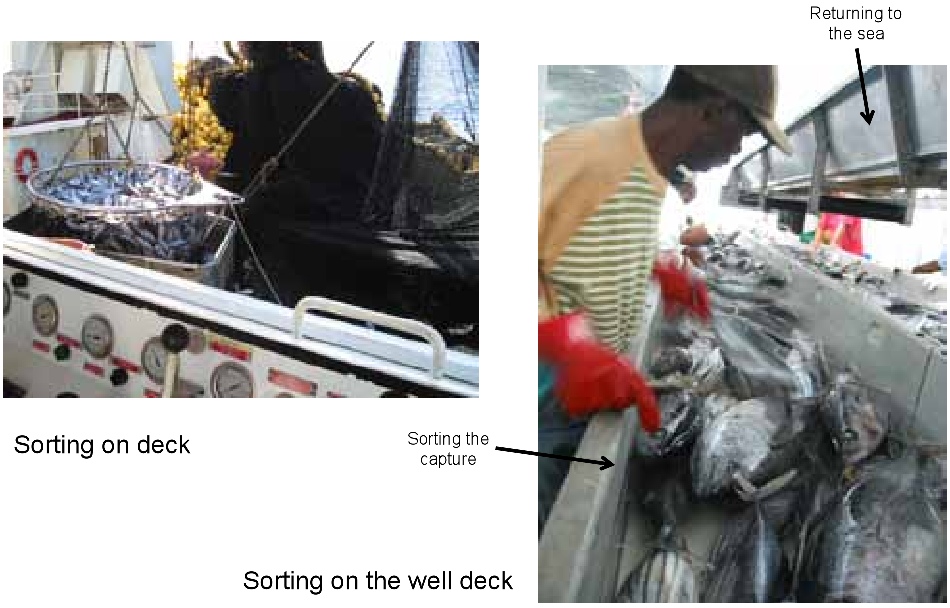
Some details need to be added to the above description because of their potential significance for bycatch issues. The individuals retained in the net are brought on board using a brailer (capacity usually 2–8 tonnes). The capacity of the brailer, and the amount of fish loaded may result in different conditions for the individuals brought on board that way, and, for those released, their survival may be affected.

The fish arriving on the deck of the seiner (i) go to a platform on the deck used for sorting (the hopper), and from there down to the wells; or (ii) are transferred directly through an opening on the main deck to the well deck at a lower level, for sorting in a conveyor belt that carries the fish to the wells. The second method is replacing the first one in most vessels. Fishes that are selected to be discarded are set aside and may remain on the main deck, or on the well deck, until the crew has finished handling and storing the catch. In some vessels, another conveyor belt is used to carry the individuals to be discarded to the side of the seiner for release (Plate 1). The tuna catch is kept, in the industrial purse seiners, in wells of 20–100 tonnes each (total well tonnage for the majority of the fleet: 800–3 000 tonnes) with brine freezing at –20 °C. As mentioned above, videos showing the operations of different sizes and styles of vessels in different oceans can be found on the Internet. Readers unfamiliar with the purse seining operation are encouraged to access these materials, which will greatly enhance their understanding of the operations.

Besides the sophisticated technology to handle the net, most seiners carry an array of instruments to facilitate navigation, and detection of tuna schools. They include:

- Bird radar: used to detect seabirds frequently associated with tuna schools. Examples of this would be the S-Band Furuno Model FR-1760 DS (60 kW) FR-2137/2167 (30 kW) or earlier X–Band models (12–25 kW).
- Echo sounder/fish finder/sonar: provides information on the location of targets, school volume/tonnage and the models with multibeam and split-beam transducers can provide some additional information on subjects such as fish size distributions. Examples would be the Simrad ES60 (frequency 120 kHz), and Furuno FCV620 or the Furuno FCV295 or FCV1150 (dual frequency from range 28–200 kHz). The more common sonars include the Furuno CSH5L55. The characteristics of these instruments may be significant from the point of view of identifying sets with excessive bycatch, or with species or size compositions that may help in decision-making.

PLATE 1
Conveyor belts for sorting the capture.



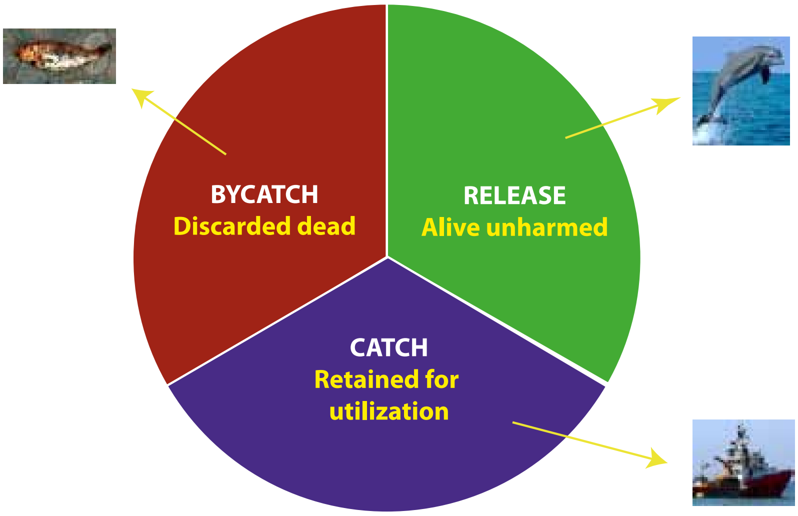
Sorting on deck

Sorting on the well deck

CAPTURE, CATCH AND BYCATCH

The definition of bycatch has been discussed in many documents, and whichever definition is selected, there will be objections by some. The concept has been applied to issues as diverse as the “trash” fish caught in some shrimp trawl fisheries (Stobutzki, Miller and Brewer, 2001; Stobutzki *et al.*, 2002), the discards of undersized individuals of the species of interest to the fishers, and the incidental mortality of component of the megafauna (marine mammals, sea turtles, seabirds). In an attempt to avoid a long elaboration of the subject, the definitions used in this review are the simplest, and most direct available, considering that one of the main purposes of the definition is to facilitate the communication with the fishers and other stakeholders (Figure 15).

FIGURE 15
Definition of bycatch: capture = catch + bycatch + release



Capture is defined as the total number or biomass of individuals caught (physically retained) in the net or other type of gear. There are three possible alternative fates for the capture:

- Catch is the part of the capture retained for utilization (consumption, sale, use as bait, etc.).
- Release is the part of the capture released alive, and assumed to survive the fishing operation.
- Bycatch is the part of the capture that is discarded dead, or assumed to die as a result of the fishing operation (Hall, 1996).

According to this definition, "bycatch" has a negative connotation, and that is the case with fishers, and with the conservation organizations that identify the concept as a target of campaigns. It is a resource wasted unnecessarily, and everyone can agree that it should be reduced if possible. Whatever is retained, is part of the catch, and as such should be the subject of fisheries management, even if not the main object of a fishery. For example, many marlins and some sharks caught in tuna purse seine fisheries are retained. As they have economic value, they have no negative connotation for the fishers, and the reduction of that component of the capture is not desirable to them. However, the important concept is that of accounting for all fishing mortality, and managing all species that are retained in significant numbers (Alverson *et al.*, 1994; Chopin, Arimoto and Inoue, 1996; Pascoe, 1997; Hall, Alverson and Metuzals, 2000). If the marlins and sharks of the example above are added to the harvest in directed fisheries, and to the bycatch in other fisheries, then the management of those species should decide on the actions to follow, with knowledge of the total impacts of all fisheries on those populations. The management measures could affect catch and bycatch of those species. A major advantage of this definition is that the concepts are dynamic; catch and bycatch are decisions of the fishers that may change over time.

Some authors differentiate between "discards" of the target species and "bycatch" of all other species, but the difficulty of establishing which the target species are, and the dynamics of the fisheries that turn today's bycatch into tomorrow's catch, make the approach used here simpler: bycatch are dead discards. At the same time, the approach selected separates unintended catch of a valuable species from the negative concept of bycatch as catching something that does not have "value" or cannot be retained for legal reasons. The concept is basically the same as the definition used by Hall and Mainprize (2005).

The three terms are: capture = catch + release + bycatch

Catch shows the economic component of the fishing operation, with utilization defined in a broad way, as any use that has economic value for the fishers.

The sum of catch and bycatch shows the ecological impact of the fishing operations, the total removals from the populations. Bycatch happens because:

- A species does not have a market.
- An individual of a marketable species is too small for the market.
- An individual of a marketable species is damaged or spoiled during the fishing operation, during brailing, etc.
- A species or individual cannot be legally retained.
- The decisions on retention are influenced by the limited storage in the vessels, the production of the current trip, and the expectations of future catches. For example, a set made a couple of days prior to the start of a closure may result in a higher level of retention if the vessel is not full. All these reasons may change with time or with economic conditions as:

- A market may develop for a species.
- If the value of a species increases (e.g. because of scarcity, or a very high demand for other reasons), it may be profitable to retain and/or process smaller individuals.
- The damaged individual may be kept for lower quality utilization (e.g. fishmeal instead of direct consumption market).
- The regulations may change.

The terms “target species”, “primary target species”, and “bycatch species” are avoided in this review because of the dynamic situations described above, and also because of the inability to know, in most cases, what fishers have in mind when they decide on a fishing ground or gear. The economic decisions that skippers and boat owners make probably include all the components present in those grounds.

One could argue that tuna purse seine fisheries have a clear target, because of the gear, the fishing methods, and even the characteristics of the storage system (a brine solution that is not adequate for preserving other species). However, the retention of non-tuna species (discussed below) has been growing in recent years and, as it is possible to adapt the wells to retain other species, with time they are becoming a larger proportion of the vessels’ production.

The term tropical tunas refers mostly to the skipjack tuna, yellowfin tuna, and bigeye tuna. Black skipjack tuna (*Euthynnus lineatus*), kawakawa (*E. affinis*), bonito (*Sarda* spp.), frigate tunas (*Auxis thazard*), and bullet tunas (*A. rochei*) are other tuna species present in the fishing grounds, but their retention is less significant because of their lower value, or their catches are rare. In some cases, they are retained and sold in large quantities in local markets such as Abidjan, Côte d’Ivoire (Romagny *et al.*, 2000; Goujon, 2004a).

3. Purse seining

A few technological developments, such as synthetic materials for the netting (nylon), and a hydraulic system to manipulate the seine (the power block), allowed the switch from a pole and line fishery to a purse seine fishery (McNeely, 1961; Orbach, 1977; Francis *et al.*, 1992). These innovations were introduced in the Eastern Pacific, but spread rapidly to other ocean areas.

When purse seining was adopted, in the mid-1950s, it was natural to use the information on these associations to locate and catch tunas with the new gear, and the purse seine fishing operations, called sets, were frequently made encircling the tuna schools, floating objects, whales, or groups of dolphins.

TYPES OF PURSE SEINE SETS

Although the purse seining operation is always basically the same, there are different ways in which tunas are detected and encircled, and this gives rise to a classification of purse seine sets in several types. The detection may happen because of some behaviour of a tuna school that makes them visible, or because of an association of a tuna school with objects or with other species (seabirds, dolphins, whales, whale sharks, etc.). The main types are described below.

School sets

In these sets, the tuna school is detected because of its activity at or near the surface of the water. Typically, a disturbance on the ocean surface is detected from the vessel. A tuna school in a feeding frenzy or other type of very active behaviour close to the surface has caused the disturbance. Fishers recognize and identify, with different names, a variety of school sets. Breezers, jumpers, boilers and foamers are some of the descriptive names they apply to these signals of the presence of fish. Although there are situations where many schools are encountered in an area, in a given season, this type of set is the least predictable of all because fish behaviour may change abruptly in response to environmental or biological factors, and the schools may go deep, flee from predators, etc. The other difficulty with school sets is that the target tuna school is moving freely, and it is not “fixed” in space, as happens in other types of sets. Thus, the encirclement with the net is much more difficult, and the evasion of the school, or a misjudgement on the direction of movement of the school, may result in a “skunk” set, an appropriately named failed operation with no or little capture.

Many types of school sets are found in the IATTC databases, according to the records obtained copying from fishers’ logbooks for the period 1955-current. The main types and their relative frequencies are shown in Table 1. Classes with less than 1000 records, and sets that were “estimated” (e.g. assigned) were arbitrarily excluded, to simplify the issue.

Are all these sets the same type of set from the point of view of the catch and bycatch they produce? Some names may be synonyms arising from regional differences in jargon, but many reflect different perceptions by the fishers, and their knowledge is very valuable. Perhaps research on the local ecological knowledge on this subject could advance the discussion (Moreno *et al.*, 2007a). There are reasons to believe that the school set group is heterogeneous. For example, fireballs are night sets, while breezers tend to be day sets, because the observation of a breeze on the surface is more difficult at night, except perhaps with a full moon.

TABLE 1
School set categories (in percentage terms), 1960–2009

Description	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09
Breezers	58.7	67.9	67.0	74.0	71.8	76.7	75.7	86.8	89.9	95.1
Jumpers	21.0	12.9	18.9	16.3	15.8	13.6	19.6	11.0	8.8	4.7
Foamers	5.0	6.2	2.2	1.8	4.8	6.5	2.4	0.9	0.6	0.0
Black spot	3.5	6.0	3.9	2.7	2.0	1.0	0.8	0.4	0.3	0.0
Boilers	4.3	2.7	4.0	2.5	3.6	1.0	1.0	0.5	0.3	0.1
Finners	2.0	1.6	1.9	1.1	0.6	0.3	0.0	0.0	0.0	0.0
Fireballs	3.3	1.3	1.4	0.7	0.7	0.6	0.1	0.2	0.0	0.0
Shiners	1.2	1.1	0.7	0.8	0.8	0.2	0.3	0.1	0.0	0.0

Source: From IATTC logbook database.

The behaviour of tunas, and the accompanying species, by day and by night may result in different species or sizes being vulnerable in different periods. However, the numerical dominance of the breezers is so clear, that the statistical "noise" created by combining these classes into one may diminish the significance of the heterogeneity. However, if jumpers, foamers, and boilers have different characteristics in species, or sizes of all species involved, it would be preferable to limit any analysis of trends in average capture per set, etc., to a more homogeneous group such as breezers, or do a comparative study, when the data allow that, to decide on the validity of the pooling operation.

Understanding the differences in the tuna behaviours reflected by the fishers' nomenclature may also help improve bycatch estimates, and also other fisheries estimates (e.g. catch per unit of effort [CPUE] figures because of the possibility of different search systems being used according to the type of detection made). It is also possible that the extensive use of bird radars to locate tuna schools, which started in the early 1980s and has expanded continuously, may have resulted in an effective search system that tends to detect breezing tunas rather than the other behaviours. There could be cases where the classification of a set is difficult. Is a school of tuna found close to a live whale or whale shark associated with the animal, or is it simply a spatial coincidence caused by their attraction to a common stimulus, or environment, e.g. they are both feeding on the same prey aggregation, or in a highly productive patch?

SCHOOL SETS OR UNASSOCIATED SETS?

Two names, school sets and unassociated sets, have been used for the same type of set. In recent years, part of the literature has replaced school sets with unassociated sets. School set seems to imply that this is the only type of set where a school is captured. Unassociated set is a definition by a negative, and the tuna schools are frequently associated with other schools of different species, and also with seabirds, that facilitate the detection. Both terms can be used, but school set is preferred because the fishers use and understand this one to describe these sets. This is one case where researchers try to impose a definition that is meaningful to them, replacing one that is meaningful to the fishers. As one of the objectives of tuna researchers should be to communicate with fishers, it makes sense that they follow the language of those that spend their time fishing, and understand their logic. When a vessel makes a set, it is made on a log, on a FAD, on dolphins, or on a school of tunas. The description is correct and accurate, and the logic is obvious.

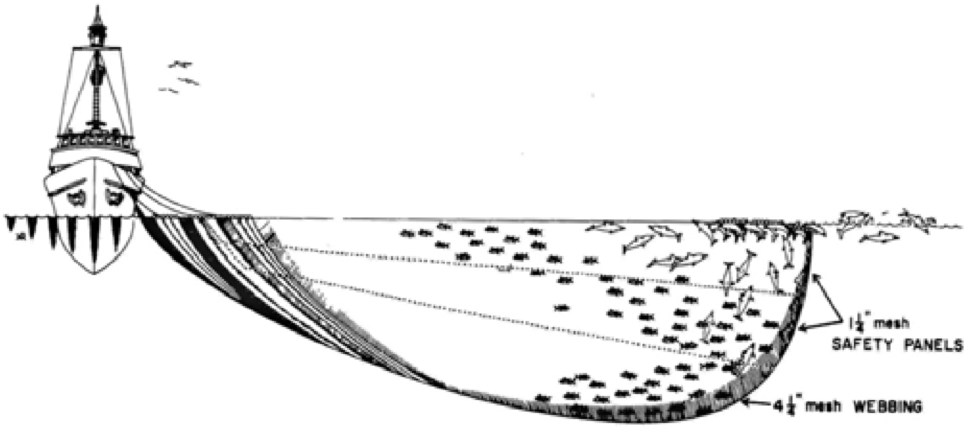
However, the numbers of these sets are low, and their influence on the statistics is probably negligible.

Dolphin sets

Yellowfin tunas can also be found in the Eastern Pacific in association with dolphins of the genera *Stenella* (*S. attenuata,* and *S. longirostris*) and *Delphinus* (*D. delphis*). This association is quite common in some regions of the Eastern Pacific but very rare or absent in other ocean areas (Donahue and Edwards, 1996). The other major tuna species are very rare in these sets. The fishers detect a group of dolphins; give chase with several speedboats until the group is "turned" and stops. Then they encircle the group of dolphins, and the yellowfin associated to them that stayed with them during the chase. A manoeuvre, called the "backdown" follows. It consists of putting the vessel in reverse, and pulling the net. The net first elongates, and then it sinks several metres below the surface in the farthest section from the boat. This allows the dolphins to exit the net, while at the same time the vessel is pulling the net under the dolphin group (Figure 16). After the dolphins are out of the net, and using several techniques to liberate any left in the net, the set continues in the usual way (Francis *et al.*, 1992). This fishery is practically monospecific for yellowfin tuna, and the sizes of tunas caught are quite large, with the vast majority being more than 80 cm in length, with average weights in the different regions of 14–31 kg (IATTC data).

FIGURE 16

Diagram of a dolphin set: net cross-section during backdown using fine mesh, double-depth safety panels



Source: Peters (1979).

Sets on seamounts

In many regions, tuna schools are found associated with seamounts (Yasui, 1986; Fonteneau, 1991; Holland, Kleiber and Kajiura, 1999; Holland and Grubbs, 2007; Pitcher *et al.*, 2007; Morato *et al.*, 2008), and the category is used to classify sets. A recent review of the impact of seamounts on longline catch (Morato *et al.*, 2010) shows some significant impacts on catch rates for all tuna species, and some of these may also affect purse seine catches. However, there are very few detailed studies with large sample sizes, and it is difficult to make comparisons of catch or bycatch rates because even the definition of what constitutes a seamount is not obvious (is it taller than x metres from the bottom, or the tip reaching less than y metres from the surface?;

are oceanic ridges just a sum of seamounts or is there a ridge effect also?), and the distance at which it may affect catch rates is not easy to determine (is it the same in all directions? are there up-current/down-current differences? are effects influenced by current speed? by the slope of the seamount?). It is quite likely that "seamount" is a heterogeneous category, including very different shapes and sizes.

Amandè *et al.* (2008a) show figures for the Indian Ocean, but the database contains only 34 seamount sets, and they estimate that seamount sets are close to 1 percent of all sets. Their definition of seamount is "within 5 miles from known seamount location". Most of the species found in seamount sets are also found in the other types of sets in the region, but the list described for seamounts is shorter than the lists generated from other set types, perhaps reflecting the small sample size. The expectation is that seamounts will have a higher biodiversity (Pitcher *et al.*, 2007).

As there are probable ecological differences near seamounts, as compared with the open ocean, it is possible that the bycatch in these sets is different, but the analyses will have to be performed with a much higher data density.

Floating object sets

Many species are found growing on or under floating objects, and the association with the objects, ranging from physical attachment to looser associations, affects their biology, ecology and biogeography. A discipline of ecology named "rafting ecology" addresses the subject, and a major review has been published recently (Thiel and Gutow, 2005a, 2005b; Thiel and Haye, 2006). A list of more than 300 fish species associated with floating objects has been compiled (Castro, Santiago and Santana-Ortega, 2002). Several tuna species of commercial and recreational value are included among them. Fishers discovered the association of tuna schools with floating objects early on, and took advantage of the opportunity offered by a behaviour that made the detection and the capture easier than for unassociated schools, because of the strength of the association that kept the school relatively fixed in space, drifting with the object. The fishery on floating objects started as an opportunistic operation, whenever an object was encountered. References describing the early fishery on floating objects in different oceans can be found in Stretta *et al.* (1997), Scott *et al.* (1999), and Le Gall, Cayré and Taquet (2000a).

Especially productive were the coastal waters in regions where there were significant inputs from the continent, such as those with abundant forests, and tropical rivers that could carry a lot of material during the floods that mark the beginning of the rainy season. This is expected close to the areas where the Inter-Tropical Convergence Zone intersects the continents. In these regions, tree trunks and branches, aquatic plants, and other materials coming from the land were carried out to sea, and the tunas present in those areas associated with them (Caddy and Majkowski, 1996). The purse seine sets made on these objects were called log sets by the fishers because tree trunks and branches were the most common type of object. In some regions without coastal forests, or major rivers (e.g. Central, Southern and Baja California), bundles of seaweeds called kelp "patties" played the role of the logs, but their abundance was frequently limited. These "patties" originated in kelp beds (*Macrocystis pyrifera*), when plants were uprooted by storms or other causes. As these seaweeds are quite large and have floats, they form structures that persist in the ocean (Graham, Vasquez and Buschmann, 2007).

The list in Table 2 shows the main types of objects sighted and set on in the period 1987–1990 (from IATTC observer database [Hall *et al.*, 1999a]). The largest category is a broad set of plant materials (tree trunks, branches, etc.), mostly unidentified trees, but also bamboo and other canes, palm trees, and mangrove trees. Kelp patties were the predominant type of object in the northern section, on the California Current system, but few of them produced sets. This group was followed by two categories of objects of anthropomorphic origin (crates, pallets, lost fishing gear, etc.). There is another grouping composed of dead animals (whale sharks, sharks, very few whales, and other animals including pinnipeds as the main component). A small proportion of the sightings consisted of FADs, but they led to many sets. Stretta *et al.* (1997) describe the types of objects from the Atlantic and Indian Ocean fisheries. In the Atlantic Ocean, plastic objects prevailed, while in the Indian Ocean tree trunks and branches were the most common by far.

TABLE 2

Types of floating objects observed in the Eastern Pacific Ocean, 1987–1990

Type of object	Sightings % (n= 2723)	Sets % (n= 2492)
Plant material	48.2	47.2
Kelp	5.5	0.8
Dead animals	4.8	3.2
Wooden artefact	16.9	17.8
Bycatched equipment	13.7	11.8
Non-wooden artefact	5.9	5.8
FADs	3.1	12.6
Others and unidentified	1.7	0.7

Note: A sighting is an observation that did not lead to a set.
Source: From Hall *et al.* (1999a, 1999b).

Sets on tuna schools associated with live whales are considered a separate type because of the behaviour of the animals that creates different conditions for the association. They are quite rare, and the main whale species involved is the sei whale (*Balaenoptera borealis*), in the Indian Ocean (Stretta *et al.*, 1997; Romanov, 2002), and in the Western Pacific (Hampton and Bailey, 1999). Stretta *et al.* (1997) found that in the Atlantic the Bryde's whale (*B. edeni*) is the most common, followed by the fin whale (*B. physalus*). Other cetaceans such as the minke whale (*B. acutorostrata*), pilot whales (*Globicephala macrorhynchus*), and the rough-toothed dolphin (*Steno bredanensis*) have been reported with much lower frequency. The rough-toothed dolphin is occasionally captured in floating object sets, and it may associate with them. The samples available are not large enough to make comparisons. In almost all cases, these animals escape under or through the net, which they can break. Table 3 shows all captures in the Eastern Pacific over a decade. No mortality was observed in the period, and only three individuals were released by the crew. These captures may not be the result of an association, but of a simple common attraction to prey schools, or environmental conditions (Fréon and Dagorn, 2000). These sets may be defined as whale sets, or as school sets. They are so infrequent that it is difficult to make them a category of their own, and in almost all cases they are not associated with floating objects.

Sets on tunas associated with whale sharks (*Rhincodon typus*), are also infrequent (< 0.5 percent of all sets), or about 80 sets/year in the Eastern Pacific; less than 0.1 percent of the sets in the Western Pacific (Harley, Williams and Hampton, 2009), but in some regions are quite significant (32 percent of sets in the Western Atlantic–Caribbean [Gaertner and Medina-Gaertner, 1999]). When they are captured, they have to be released by the crew, and some mortality may result from the capture, handling and release process. In the Eastern Pacific, there have been no observed mortalities. Not all mortality would be observable in this case if there are post-release impacts.

Cooperative fishing between a seiner and a bait boat, that becomes an attractor, is practised in different regions (e.g. off Ghana), but it is not common, and sample size limitations make difficult to produce the comparisons needed.

TABLE 3

Sets involving whales in the Eastern Pacific Ocean, 1999–2009

Common name	Sets	Evaded encirclement	Escaped by ripping net before capture	Captured in the net	Escaped by ripping net after capture	Released by crew	Killed
Unidentified Baleen whale	134	153	113	5	5	0	0
Unidentified large whale	35	76	26	2	2	0	0
Fin whale	15	84	14	3	2	1	0
Bryde’s whale	9	9	1	2	1	1	0
Unidentified whale	7	5	6	0	0	0	0
Sei whale	5	3	3	0	0	0	0
Blue whale	4	5	1	0	0	0	0
Humpback whale	3	6	0	1	0	1	0
Sperm whale	1	1	0	0	0	0	0

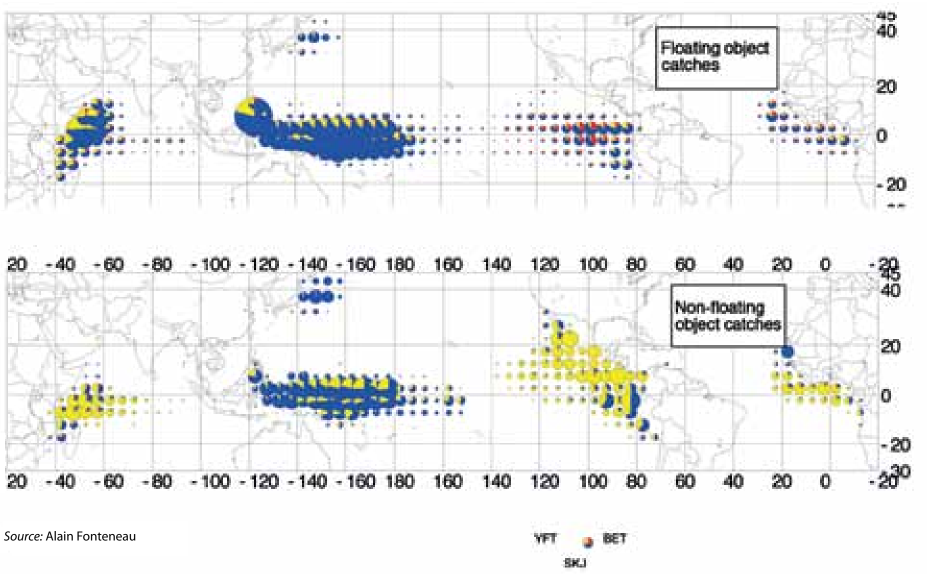
Source: IATTC observer database.

The locations and seasonality of the log fishing areas were well defined in most oceans (see Stequert and Marsac, 1989; Ariz *et al.*, 1999, for the Atlantic; Hall *et al.*, 1999a, for the Eastern Pacific; Hallier and Parajua, 1999, for the Indian Ocean; and Hampton and Bailey, 1999, for the Western Pacific). A review of the fisheries on floating objects in all oceans was the object of two workshops in 1992 (La Jolla, the United States of America) and in 1999 (Martinique) (Scott *et al.*, 1999; Le Gall *et al.*, 2000a), and a map of their initial distribution can be found in Fréon and Dagorn (2000). For the Caribbean, Gomes *et al.* (1998), and Gaertner and Medina-Gaertner (1999), describe the use of floating objects in fisheries for different pelagic species. The global map of these areas is in Figure 17, comparing areas with different set types, on floating objects and others. Others include mostly school sets in all oceans, but in the Eastern Pacific dolphin sets are also included.

Figures 18–21 show the detailed distributions of catches on floating objects and non-floating objects in the major fishing areas (Eastern Pacific, Western and Central Pacific, Eastern Atlantic, and Western Indian Ocean, courtesy of A. Fonteneau).

FIGURE 17

Floating object and non-floating object catches, 1997–2006



Source: Alain Fonteneau

FIGURE 18

Floating object and non-floating object catches in the Eastern Pacific Ocean, 1997–2006

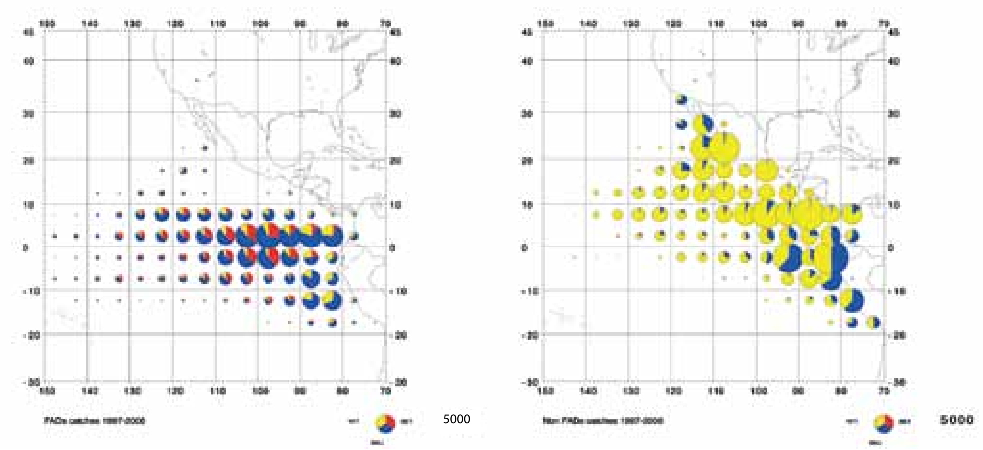


FIGURE 19

Floating object and non-floating object catches in the Western and Central Pacific Ocean, 1997–2006

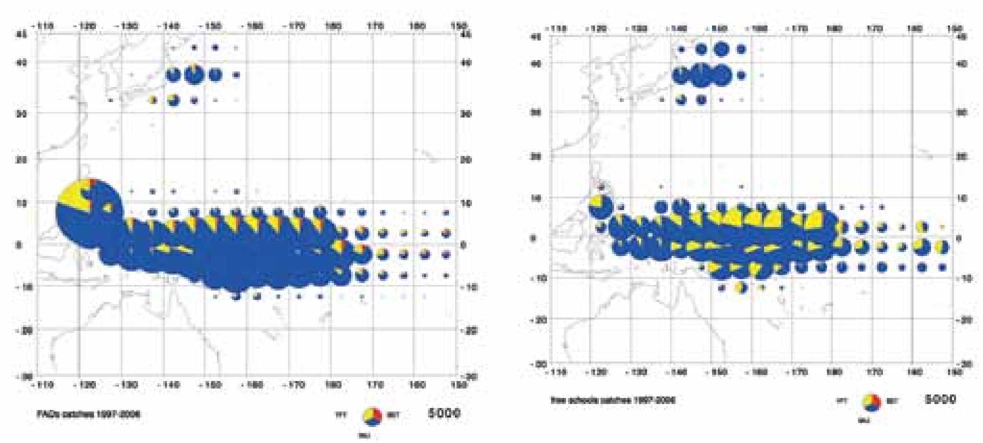


FIGURE 20

Floating object and non-floating object catches in the Eastern Atlantic Ocean, 1997–2006

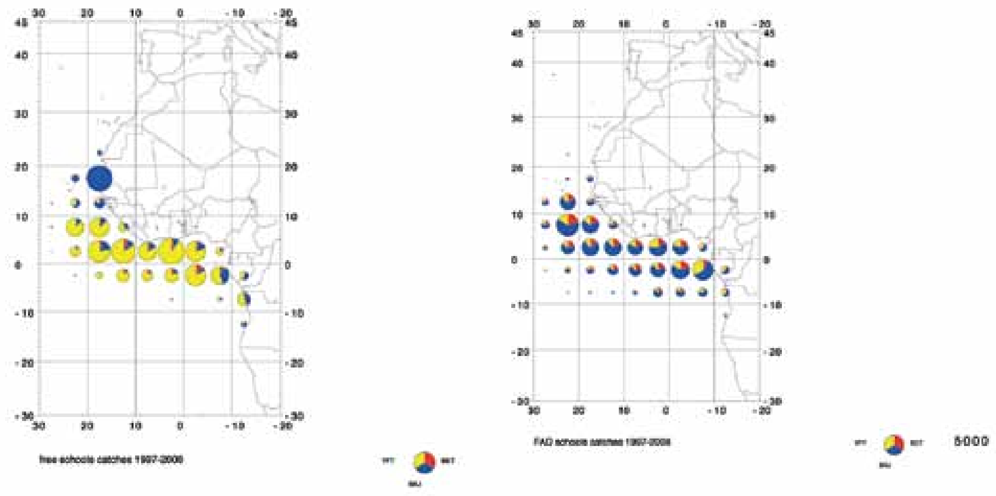
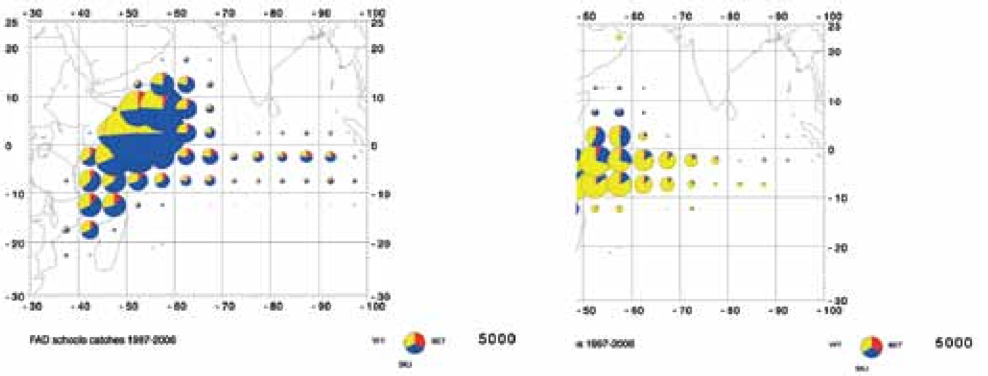


FIGURE 21
Floating object and non-floating object catches in the Western Indian Ocean, 1997–2006



With the increases in human populations in coastal areas, in marine shipping, fishing, and other marine and coastal activities, the introduction of anthropogenic objects increased, and tunas also associated with them. In contrast, natural objects such as trees may be decreasing in some areas because of deforestation (Caddy and Majkowski, 1996). The name log set was applied by extension to sets that were not exactly on logs, but on human-made objects found adrift. The objects that attracted tunas were of a wide range of shapes, sizes, colours, and other characteristics. Among the commonest types of floating objects were wooden objects of human manufacture (boxes, crates, planks, etc.), discarded fishing gear, dead animals (e.g. dead whales or sea lions), and kelp "patties". There seemed to be no clear connection between the characteristics of the objects, within the range of the natural objects observed, and the amount of tuna present under them (Hall *et al.*, 1999b). The common characteristic of all log sets, is that they are made on "encountered" floating objects.

4. From log fishing to fishing on fish aggregating devices

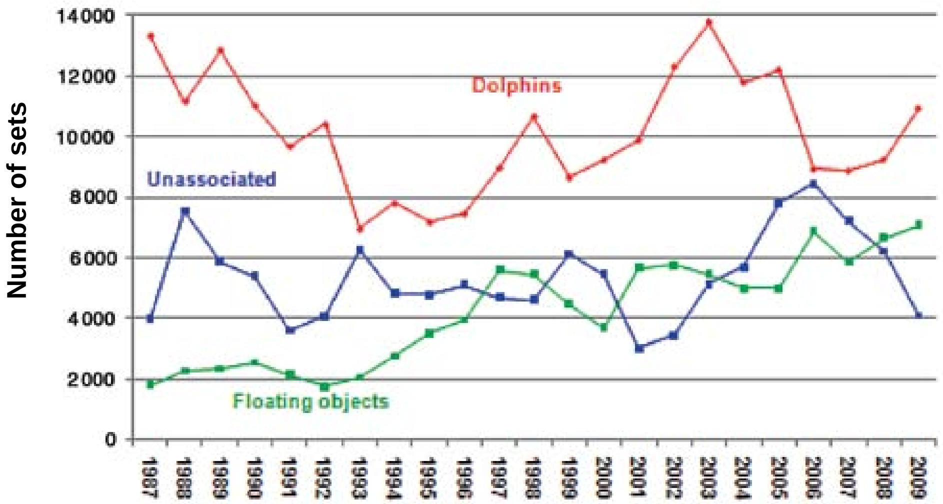
The fishers began to modify encountered objects, tying two or three together, adding buckets with fish entrails, and adding devices to facilitate re-encounters (radar reflectors, flags, radio buoys). When an encountered object is modified in some way to enhance its attraction, and especially to improve the chances of locating it again, it is called a FAD (short for fish aggregating device) to indicate the human intervention in its characteristics. This definition of FAD was adopted early on, in the different observer programmes, and it was quite consistent across oceans.

During this period, there was still a reliance on encountered objects, but it became more common for fishers to transport the modified objects to other areas, if the vessel was changing its search area. Finally, fishers began to build and deploy their own floating objects, setting them adrift outfitted with different devices that allowed the tracking of their positions. The term FADs was used for these; the random encounters were replaced with a systematic planting of objects. These fishing operations are called FAD sets. The catches in these sets in all ocean areas are a mixture of skipjack, yellowfin and bigeye, with a clear predominance of skipjack. A characteristic of these sets is that the yellowfin and bigeye tend to be juveniles.

In the early 1990s, these fisheries for tropical tunas on floating objects deployed by the fishers expanded rapidly in all oceans (Fonteneau, 1993; Ariz *et al.*, 1999; Fonteneau *et al.*, 2000; Marsac, Fonteneau and Ménard, 2000; Gillett, McCoy and Itano, 2002). Fonteneau (2010) shows the geographical changes happening during the expansion of the fishery in the Eastern Atlantic. Figure 22 shows the recent growth in numbers of sets on floating objects in the Eastern Pacific, from 2 000 sets in the early 1990s, to more than 6 000 in the period 2006–09.

FIGURE 22

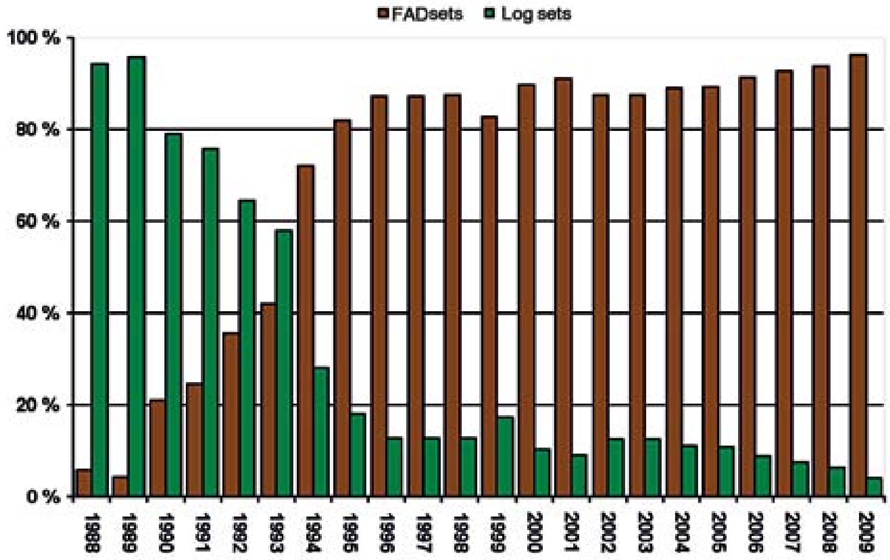
Number of purse seine sets by set type in the Eastern Pacific Ocean, 1987–2009



Note: Vessels > 364 tonnes capacity.

FIGURE 23

FAD sets versus logs, changes in percentage of sets in the Eastern Pacific Ocean



Source: IATTC Observer database.

In the late 1970s and early 1980s, there was a brief peak. Figure 23 shows the steady replacement of sets on logs by sets on FADs.

Figures 24 and 25 show the geographical expansion of the fishery on floating objects in the EPO.

However, FADs are not successful everywhere; areas with fast currents (Figure 26) tend to be the most productive for this way of fishing, and large sections of the ocean do not have the conditions for a FAD fishery.

FIGURE 24

Sets on floating objects: distribution prior to expansion of FAD fishery

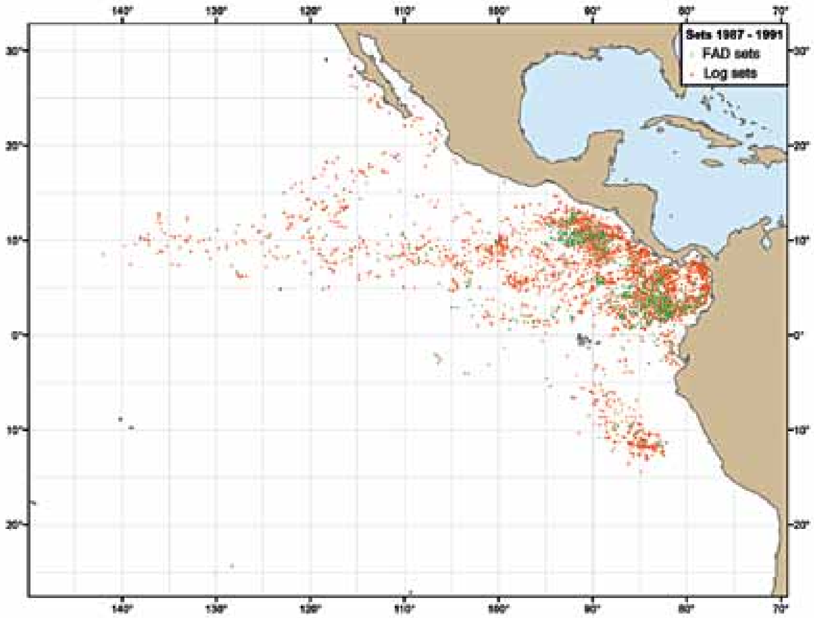


FIGURE 25
Sets on floating objects: Recent distribution

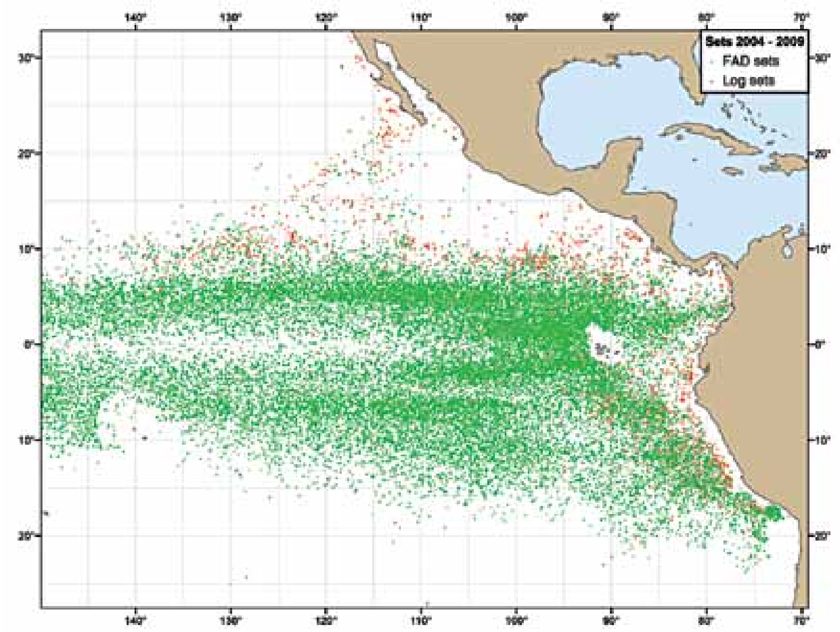
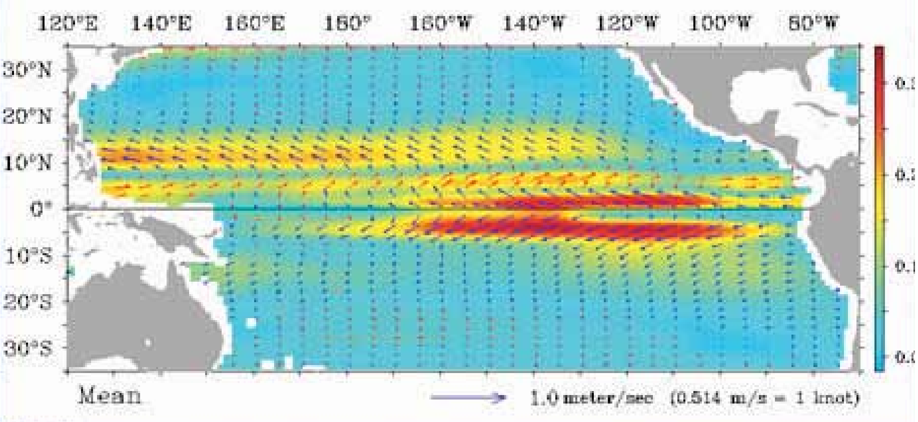


FIGURE 26
Ten-year mean Pacific Ocean surface current speeds, 1993–2002

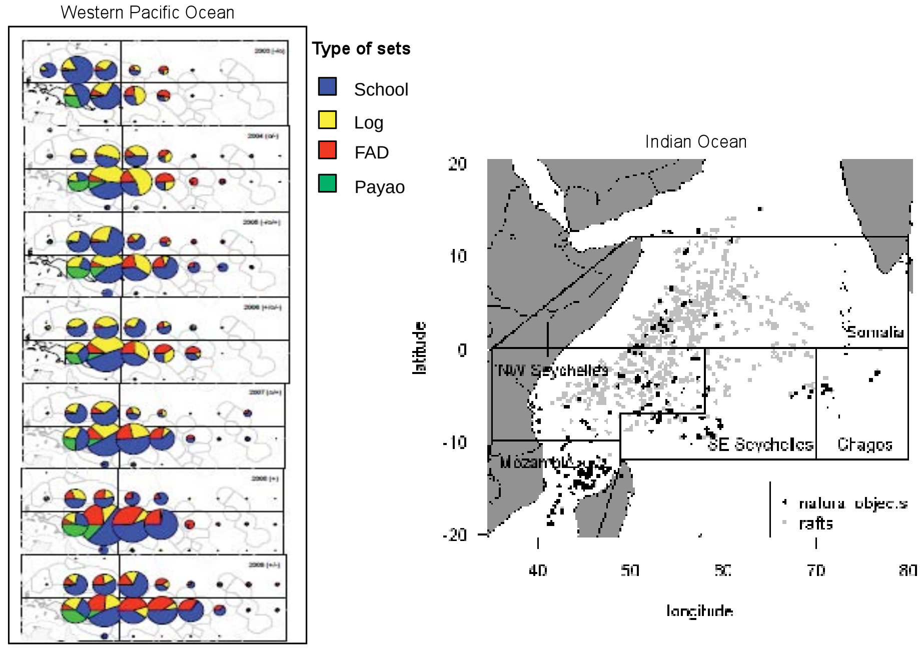


Source: Bonjean and Lagerloef (2002).

Figure 27 shows the expansion of the fishery in the Western Pacific Ocean (WPO) (Williams and Terawasi, 2009) and in the Indian Ocean (Fauvel *et al.*, 2009). The relationship between current speed and FAD productivity could be a result of faster speeds meaning more distance covered, and more chances for detection of the FAD, or it could simply be that with fast currents the schools are closer to the FAD (Dempster and Kingsford, 2003), so their location and capture is easier. Are there large regions in the oceans where FAD fishing does not succeed, that hold large biomasses of tunas not vulnerable to the purse seine fishery? In general, the addition of FADs could simply increase the density of objects in an area, or it may create new fishing areas, but this expansion is limited by oceanographic conditions. The Western Indian Ocean may be an example of the former (Fauvel *et al.*, 2009), while the EPO could be an example of the latter.

FIGURE 27

Recent expansion of the floating objects fishery in the Western Pacific and Indian Oceans, 2003–09



Source: Williams and Terawasi (2009).

Over the years, the technology to locate the objects has evolved rapidly, and the radio buoys were replaced with self-call buoys, and later with satellite devices. Although the traditional objects have been surface floating objects, they can also be deployed below the surface.

The success of the FAD fisheries is based on:

a. As the schools are “fixed” under the object, the capture process is effective in a very high percentage of the attempts (Figure 28). In the EPO, sets without capture (skunk sets) are 5–8 percent of the sets on FADs, but almost 30 percent of the sets on unassociated schools (Table 4). Skunk sets are less than 5 percent on FADs versus more than 25 percent in school sets for the Spanish fleet in recent years in the Atlantic (Delgado de Molina *et al.*, 2010b). For the Indian Ocean (Pianet *et al.*, 2009), a record of the proportion of skunk sets for 1981–2008 is available. The most recent years (2006–08) show that 8.5 percent of floating object sets are skunk sets, compared with 46 percent of school sets. Therefore, roughly, the odds of failing to capture the school are five times higher when it is not associated with a floating object. An *et al.*, (2009) report 40 percent of school sets as skunk sets for the fleet of the Republic of Korea in the Western Pacific.

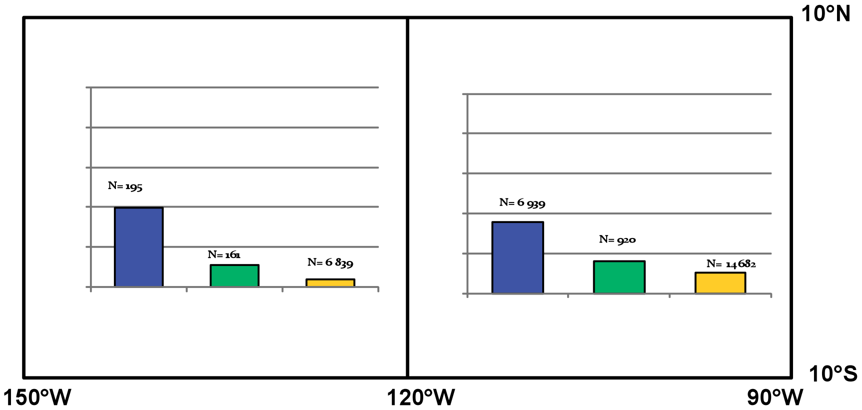
b. the average capture per set is much higher under FADs than in school sets (in the EPO: 35–38 tonnes per set versus 20–25 tonnes for unassociated sets, with the comparison based in all sets, including null sets; Figure 29). This difference may result from different school sizes adopting different behaviours, or more probably, by more than one school being captured on FAD sets, from different or from the same species. This difference remains even if the skunk sets from both groups are eliminated, but it is reduced (48 tonnes in FAD sets versus 36 tonnes in school sets). In the Eastern Atlantic, the catch per set is used with only positive sets (i.e. sets with capture > 0), and even with this definition sets on floating objects have higher catches. In the WPO, the CPUE in tonnes/day for skipjack is higher in FAD or log sets than in school sets (Figure 27). In the Indian Ocean, for the French fleet, the CPUE when fishing on floating objects is more than 60 percent higher than when fishing school sets. In the Indian Ocean, there are data for the whole period 1981–2008, and for the main fleets (Pianet *et al.*, 2009): in 2006–08, CPUE in tonnes per searching day on floating objects was about twice the tonnage on school sets. These CPUE figures are not so comparable because the allocation of search effort between set types is far from simple. Catch per positive FAD set is 11 percent higher than in positive school sets. Although the dominant species is usually the skipjack tuna, the proportions of bigeye tuna are quite variable between ocean areas, with a higher abundance of bigeye tuna in FAD sets in the EPO than in the WPO.

c. The use of energy and other costs are greatly reduced as the search process is minimized in time and distance, although some of the FAD sets happen very far offshore from the ports of origin. The use of helicopters is less frequent in vessels fishing on FADs, and this is a major energy expenditure. The use of auxiliary vessels, in support of the FAD fishing operations, also changes the energy use, and it affects the efficiency of the operations (Ariz *et al.*, 1999; Pallarés *et al.*, 2001; Pallarés *et al.*, 2002; Goujon, 2004a; Itano, 2007). These vessels are banned in the EPO because their effectiveness enhanced the overcapacity problem. IATTC Resolution C99-07 reads, "2. Prohibit the use of tender vessels operating in support of vessels fishing on FADs in the EPO, without prejudice to similar activities in other parts of the world…." These vessels are not banned in other ocean areas. The auxiliary vessels could play a role in assessing the bycatch present under FADs, and contributing to better decisions by the fishers. However, perhaps the information provided by acoustics on the FADs may have similar benefits, with lower costs.

d. As the results of a) and b) contribute jointly to increasing the production of FAD sets, this fishery is much more productive than a fishery based solely on school sets. The combination of a much higher proportion of successful sets, where the school did not evade capture and a larger school when the capture is made results in substantial gains. The drawback is that average sizes of tunas caught on floating objects are smaller than in school or dolphin sets, so the bycatch of tunas is higher, and the value of the catch may be lower on a per-tonne basis (Pianet *et al.*, 2009; IATTC, 2010). Moreover, the yield per recruit of yellowfin and bigeye tuna are lowered because of the catches of sizes below the optimal.

FIGURE 28

Proportion of unsuccessful "skunk" sets in two areas in the Eastern Pacific Ocean, 2005–09



Note: Capture = 0 tonnes.

FIGURE 29

Capture per set (tonnes), in two areas in the Eastern Pacific Ocean, 2005–09

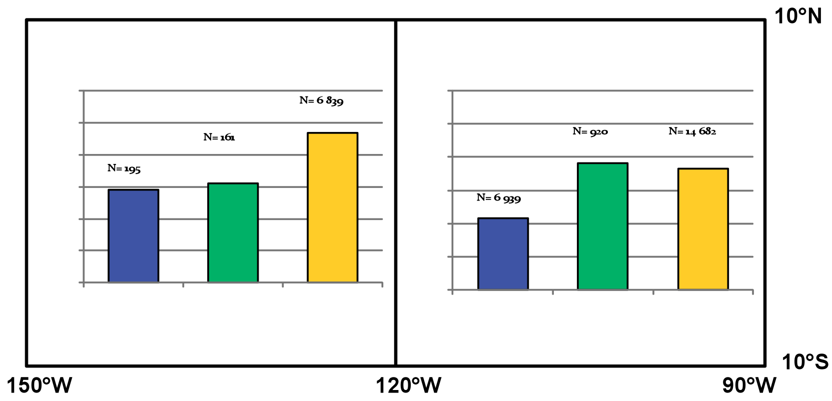


FIGURE 30

CPUE skipjack tonnes/day in the Western Pacific Ocean

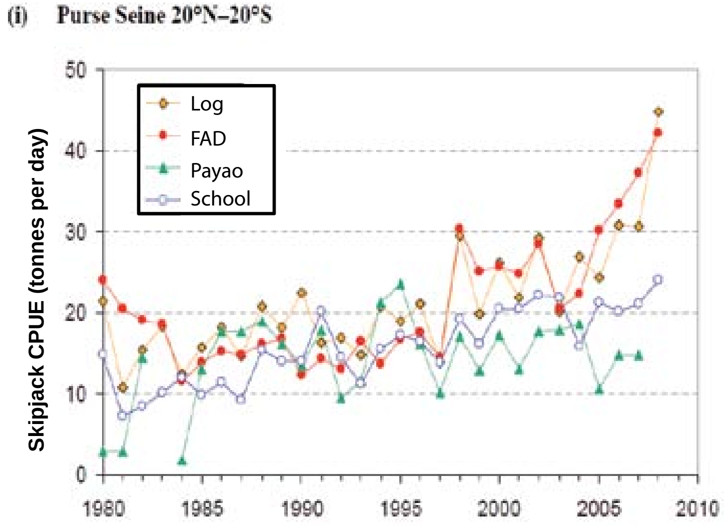


TABLE 4

Percentage of "skunk sets" (sets with zero capture) in the Eastern Pacific Ocean in two periods: 1999–2004 versus 2005–2009 by set type

		Number of sets by type						
Period	Capture/set	Dolphin	FAD	Log	Whale shark	Anch. Buoy	School	Whale
1994-2004	Cps= 0	7 024	2 164	743	5	44	12 554	81
1994-2004	Cps= 0	74 068	37 133	5 280	94	202	26 655	174
% "skunk" sets		**8.7**	5.5	12.3	5.1	17.9	32.0	31.8
Period								
2005-2009	Cps= 0	4 654	2 052	344	35	21	8 213	27
2005-2009	Cps= 0	36 048	25 707	2 111	463	135	20 134	88
% "skunk" sets		**11.4**	**7.4**	**14.0**	**7.0**	**13.5**	**29.0**	**23.5**

Source: IATTC observer database.

FISHING ON FLOATING OBJECTS

FAD characteristics, and operations on FADs

When the fishery on FADs started, there were many different designs of FADs in use, and with time they began to converge in a few models, but the construction and equipment of the FADs is very dynamic, and changes happen in a very short period. The dimensions of FADs are the result of a balance between attraction, which could be related to size (Rountree, 1989), and practical limitation on the seiner to carry them or the materials needed. The number of FADs deployed must also balance the ability of the vessel to track them, the costs of the instruments, current patterns, etc. There is a wide range of strategies in use. In the EPO, the observers were requested to provide more detailed information on the FADs, and since 2004, there has been a significant database on FADs. Some of the findings of the first few years are summarized in Tables 5–10. As most of the characteristics of the FADs, and of the way they are utilized are common to all oceans, the database from IATTC is used to provide the detailed descriptions.

FAD components and evolution

In recent years, the IATTC has started a programme to try to produce a full description of the FADs, as a way to track the changes taking place and their implications for the data collection efforts. In a way, changes in FAD characteristics or equipment may affect the fishing power of a vessel, and they should be tracked. Figure 31 and Plate - 29 shows a diagram of a common FAD from the EPO. Itano *et al.* (2004) provides descriptions off materials and construction of a variety of anchored and drifting FADs from the Western and Central Pacific.

FIGURE 31
FAD components

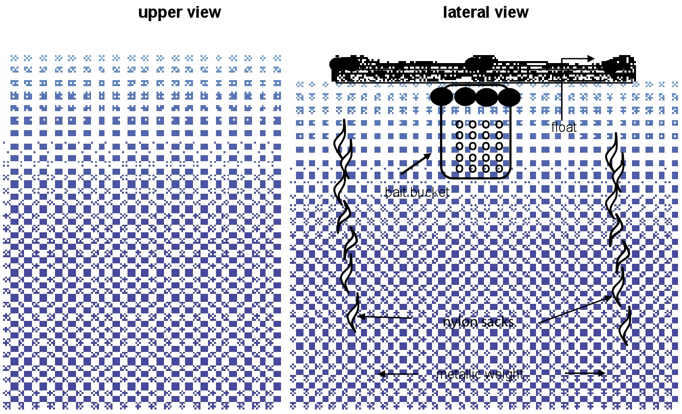


Table 5 shows the origin of the objects being set on. In the period 2005–09, two-thirds of the objects had been planted by the same vessel that was setting on them in the previous trip. Adding those planted by the vessel in a previous trip, and those transferred from another vessel, it results in almost 90 percent of the sets being made in “controlled” FADs, with 2 percent of the sets being made on encountered objects, and almost 10 percent “taken” from another vessel.

Table 6 shows the proportion of sets with the different components and attractive elements. Most FADs contain a common set of basic components: floatation elements (usually bamboo), ropes, netting material, and some weight.

PLATE 2
FADs stac ked on the upper deck

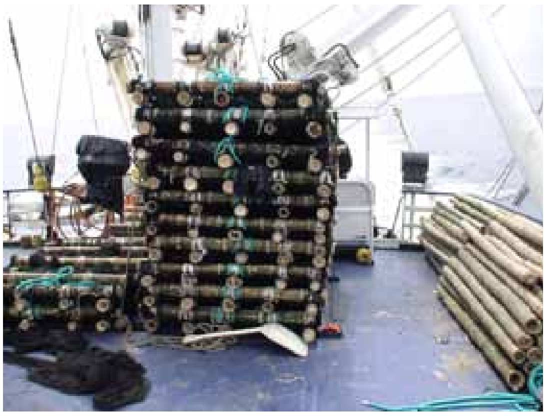


TABLE 5
Percentage of FAD sets by its origin in the Eastern Pacific Ocean (first FAD encounter only)

Floating object origin	2005	2006	2007	2008	2009
Drifting object found	2.3	2.3	2.2	2.1	1.8
Other vessel-no owner consent	10.4	10.9	9.6	10.7	9.6
Other vessel owner consent	18.5	14.9	14.8	16.6	16.6
Your vessel-planted previous trip	59.1	64.8	67.4	65.8	63.4
Your vessel-planted current trip	9.8	7.0	6.0	4.9	8.5

However, the table highlights some constant changes; for example, the use of PVC pipes, in addition to the bamboo frame, more than doubled in the four years of the study, probably reflecting an intention to increase long-term floatability, to prolong the use of the FAD, and to improve the chances of recovering the instruments deployed. FADs are being prepared to last longer, and this may have impacts on catch and bycatch. Plastic sheets, sacks and bags are used to enhance the visibility of the FAD, normally tied to the netting materials, and are included among the basic elements of the FAD in more FADs every year, with a five-fold increase in five years. Lights do not play a major role in attraction in this case. However, there are also opportunistic additions, such as dead animals, trees, etc., which are found and turned into FADs or added to FADs to increase attraction.

Weight is added to the FADs using chain, cables or metal rings in almost 75 percent of the FADs. About 24 percent of the FADs include a bait container hung under the FAD.

Table 7 shows the methods used by the fishers to locate the FADs based on the proportions of FAD sets. Visual markers on the FADs or radar reflectors are no longer important to locate the FADs. The detection of the FADs is now based on satellite systems that are replacing the radio systems used before. More than 90 percent of the sets made on FADs were on FADs that had a satellite system in 2009.

To complete the description, Table 8 shows the information that the instruments attached to the FADs provide to the seiner, which is also changing fast. Directional instruments are decreasing (down from 46 percent to 27 percent in the period of study), while GPS positioning has jumped from 70 percent to 98 percent. Information on tuna quantity and water temperature data doubled in frequency in the period, provided by acoustic and other instruments. Currently, 30 percent of FADs can report the tuna quantity present underneath, a figure double the percentage available four years earlier, saving the fishers from fruitless trips, and increasing the fishing power of the vessels.

Table 9 shows the rapid replacement of radio transmitters by satellite equipment, and the fast spread of instruments providing water temperature.

Finally, Table 10 and Figure 32 show the depth of the netting that the fishers hang under the FAD. This variable may be important to determine the attractiveness of the FAD for deeper species (Minami *et al.*, 2007; Satoh *et al.*, 2007; Lennert-Cody, Roberts and Stephenson, 2008). The vast majority of the FADs carry 10–30 m of netting underneath.

The effects of these differences are unknown, but several of them have the potential to affect the attraction characteristics, drifting speed, and duration afloat of the FAD, and in this way they may affect catch and bycatch on them. An example of this is the depth of the netting, and the inference that it may enhance the attraction to deeper swimming bigeye tunas, which has been the subject of several research projects to be discussed later.

The most sophisticated FAD attachments include rapidly improving acoustic systems to send to the vessel data on fish abundance under the FAD, an example of the technological creep that may affect fishing effort estimates (Marchal *et al.*, 2007).

TABLE 6

Percentage of sets with each FAD component in the Eastern Pacific Ocean

Component	2005	2006	2007	2008	2009
Artificial light for actracting fish	0.8	0.9	1.6	0.4	0.3
Bait container / bait	25.0	28.2	23.8	23.9	25.5
Cane / bamboo	84.3	85.0	86.8	87.3	88.5
Chain / cable / rings	83.9	73.2	75.0	80.0	83.4
Cord / rope	92.9	94.4	94.7	96.0	97.3
Dead animal	5.2	5.1	5.5	4.7	4.9
Floats / corks	88.9	82.6	84.6	80.8	81.5
Metal drum / plastic drum	5.5	7.8	5.5	5.9	7.2
Net material	98.0	97.3	98.0	98.8	99.3
Planks / pallets / plywood	8.2	6.9	6.2	5.0	5.9
Plastic sheeting	3.6	7.8	10.0	20.2	31.7
PVC or other plastic tubes	12.8	17.6	16.4	26.9	34.0
Sacks / bags	14.4	19.6	19.6	19.1	21.9
Tree	1.0	1.4	1.3	0.9	0.4

TABLE 7

Location method leading to a FAD set (percentage of sets) in the Eastern Pacific Ocean

Location method	2005	2006	2007	2008	2009
Direction finder	27.9	15.8	6.0	3.2	0.6
Radar	1.1	2.3	1.6	1.9	0.8
Satellite	62.8	72.9	85.0	86.6	91.5
Visual-birds	1.4	1.6	1.3	1.6	1.2
Visual-the object itself	5.9	6.3	5.2	6.0	5.5

TABLE 8

Percentage of FAD set by each transmission capability in the Eastern Pacific Ocean

Transmission capability	2005	2006	2007	2008	2009
Direction to the object	47.4	39.5	35.1	31.5	27.1
GPS	73.5	81.4	93.0	95.3	98.0
Tuna quantity	12.9	14.2	18.5	24.1	29.6
Water temperature	31.8	42.7	56.8	57.1	60.9

TABLE 9

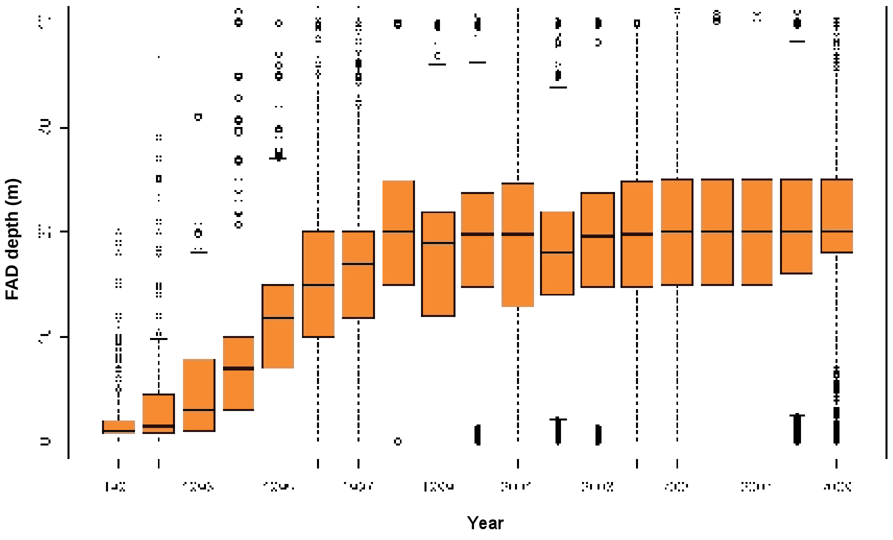
Percentage of FAD sets with each piece of equipment in the Eastern Pacific Ocean

Equipment	2005	2006	2007	2008	2009
Buoy, cork, etc.	7.3	6.7	4.9	3.5	2.6
Flag	4.6	5.8	5.3	4.1	1.5
Lights	7.1	5.7	9.3	5.7	3.5
Radar reflector	0.1	0.3	0.4	0.1	0.1
Radio transmitter / beeper	38.4	24.1	12.4	6.2	1.9
Satellite buoy	74.4	82.4	93.5	96.0	98.7

TABLE 10
Percentage of frequency of depth of net webbing under FADs set on in the Eastern Pacific Ocean

Maximum depth (meters)	2005	2006	2007	2008	2009
<10	7.7	10.5	7.2	7.0	5.5
10-20	36.7	34.4	38.9	37.2	33.7
20-30	46.5	43.0	43.2	43.7	49.0
30-40	8.4	11.5	10.0	10.8	10.3
40-50	0.6	0.6	0.7	1.3	1.2
>= 50	0.1	0.1	0.0	0.1	0.3

FIGURE 32
Depth of netting material hanging from FAD in the Eastern Pacific Ocean



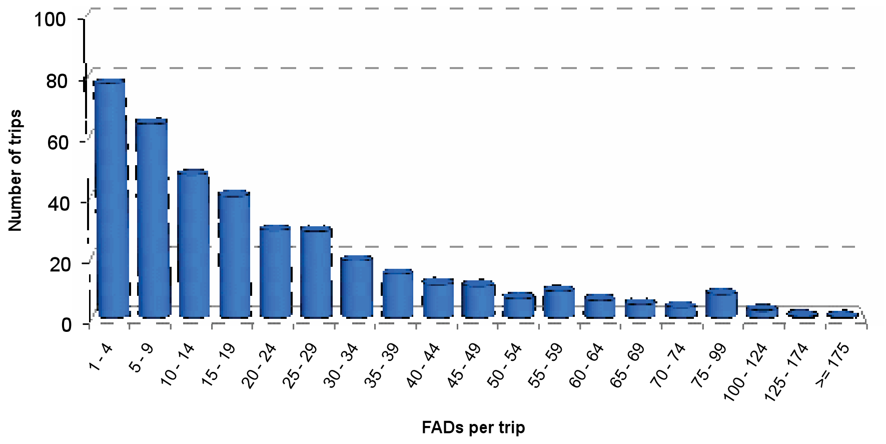
In most cases, the information available from logbooks or observers does not distinguish between sets on logs or FADs. As the IATTC has gathered an extensive database with 100 percent observer coverage from 1993 up to today, the data from this source are available to answer many detailed questions that cannot be answered for the other ocean areas. When the type of object is not specified, or a comparison cannot be made because there is no matching of data, floating object sets is used, as a generic combination of log, FAD, and payao sets.

FAD operations: deployment

Observers collect data on FAD deployment and utilization. The patterns obtained are quite consistent from year to year, with the probable exception of El Niño years. In the EPO, vessels sail to the equator, west of the Galapagos Islands (Ecuador) and deploy a series of FADs at the beginning of a trip. The number of FADs deployed is very variable, ranging from none to more than 170 in a trip. Figure 33 shows the distribution of FADs deployed per trip, for the period 2005–09. There is a long tail, with some vessels deploying more than 100 FADs in a trip, but for all trips the average is about 20 FADs, similar to the average of Mina *et al.* (2002) for operations in the Indian Ocean. Figure 32 illustrates the slowly increasing trend in the numbers deployed per trip.

The currents in the equatorial area take the FADs at a very good speed in a northwest or southwest direction, and the location of the sets suggests that, after some time, they all turn west. Figure 33 shows, as an example, data for 2006. With red symbols, it indicates the points of deployment, generally aligned along the route of the vessel, and with green symbols the locations of sets on those FADs. Based on these data, Figure 36 shows the vectors of movement, as if all the objects had been planted at the centre of the diagram, and a vector connecting the points of deployment and setting. The few deployments outside of this area were omitted. The length of each vector is proportional to the distance covered, and the vector with the scale (600 nautical miles) is shown in the map. There is a clear predominance of drifts towards the quadrant

FIGURE 33
Average of number of FADs deployed per trip in the Eastern Pacific Ocean, 2005–09



	2005	2006	2007	2008	2009
Fads deployed	4 455	8 003	8 390	9 594	100 771
Fads recovered	4 069	6 070	7 457	7 994	8 781

FIGURE 34
FADs seeded by trip in the Eastern Pacific Ocean

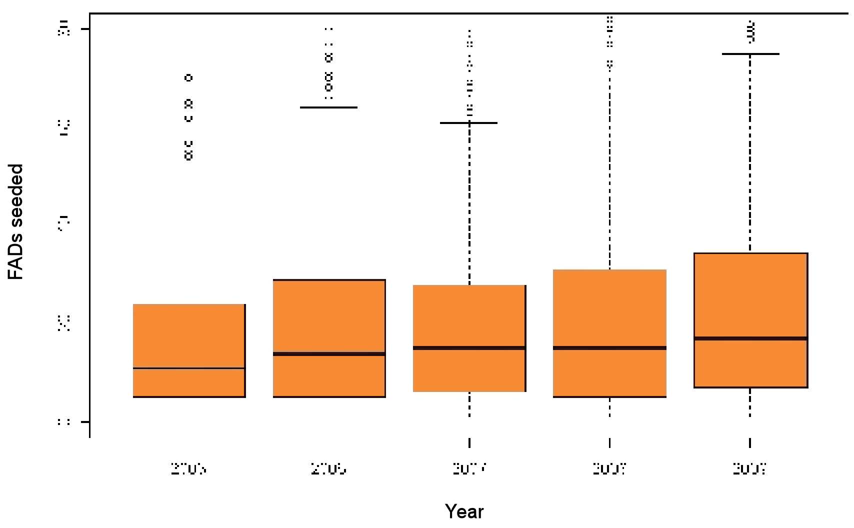


FIGURE 35
Location of deployment of FADs and the subsequent sets, 2006

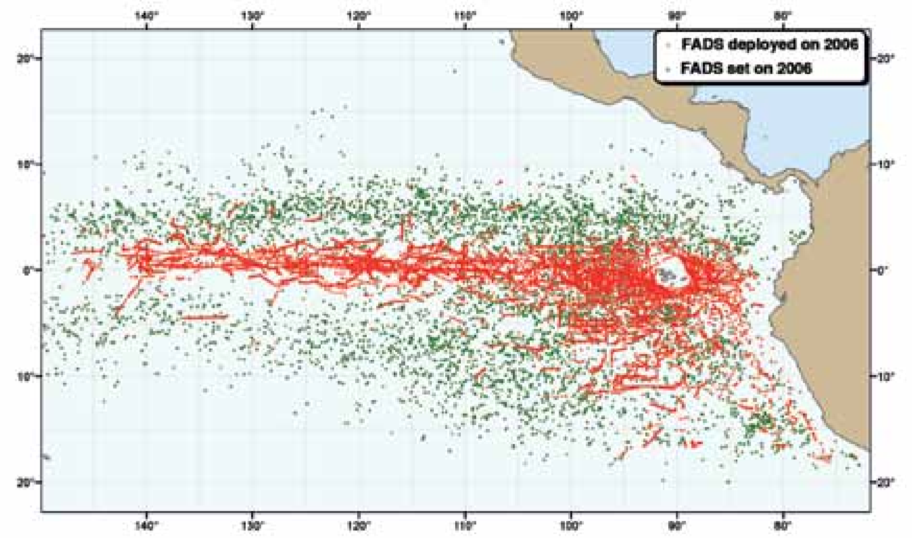
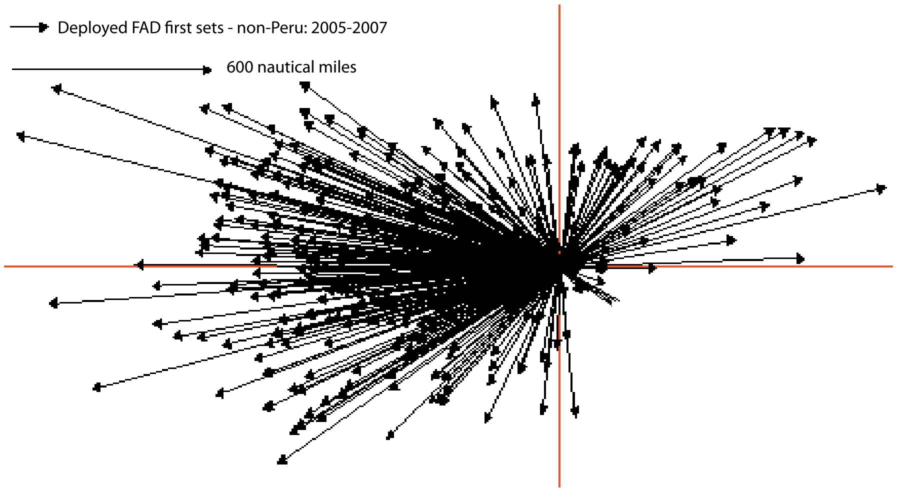


FIGURE 36
Vectors of FAD drift, from origin of deployment (centre) to first set – Eastern Pacific Ocean equatorial region, 2005–07

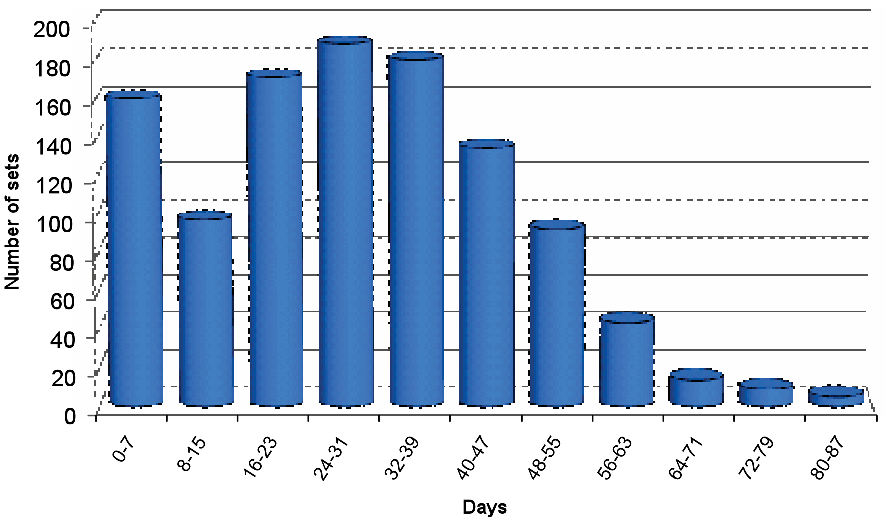


bracketed by the northwest and southwest direction angles (135–225°). The distances covered by the FAD are quite long, showing the speed and persistence of the current system (Figure 26).

FAD "soaking" time

Although some sets are made the day after deployment, most fishers prefer to leave the FADs drifting for some weeks before checking them. The mode is at about 30–40 days (Figure 37), and this choice may reflect practical considerations (such as length of trip, scattering of FADs), and an assessment of the time it takes to form a fully attractive

FIGURE 37
Time in days between FAD seeding and its first set (same trip) in the Eastern Pacific Ocean, 2005–09



community on a new object. There is also a concept that, after fishing a FAD, some time must elapse to renew its population (Cayre and Marsac, 1991).

Time of sets

The vast majority of the sets happen early in the morning, starting before the sun is up (Figure 38 and 39). Combining data from Fonteneau *et al.* (2010a), with data from the EPO, the modes appear either one hour before sunrise or just at sunrise for all fleets. Harley, Williams and Hampton (2009) show the same peak for drifting logs and FADs for the WPO, consistent across all fleets studied. Payaos have the same peak and an additional peak in late afternoon. Although there are suggestions that more sets in daylight hours are being made, the pattern as of today is clear. In the EPO, sets start a bit earlier than in the other regions. Only 5 percent or fewer sets are made 8 hours or more after sunrise. Only species associated with the FAD at this time of the day are going to be caught. In contrast, school sets, are distributed quite evenly during the day, with only a small decline towards the afternoon in the Atlantic and Indian Oceans (Fonteneau *et al.*, 2010a), or a small increase late in the day in the WPO (Harley, Williams and Hampton, 2009).

Duration of sets

The duration of sets is a key element to explore the possibility of releasing individuals from the net or deck. It is very variable, depending on vessel technology, gear characteristics, capture volume, etc. The duration of the sets, a crucial variable for the survival of species to be released, is shown in Figures 40–42 for the EPO. Three periods were used to look at trends. A large proportion of the sets take 2–3 hours to complete. The mode of the most recent period is shifted towards lower values, and the frequency of very long sets is decreasing with time, showing a shortening of the sets, which is clear on the cumulative distribution (Figure 41). The variability of the sets is best appreciated from Figure 42, which shows, for the period 2004–08, the complete distribution of the sets in a “gunshot” view. The vertical structures in the data arise from rounding-off of capture figures. Stretta *et al.* (1997) show very similar distributions for the Atlantic and Indian Oceans, with mode at 2 hours and 20 minutes, and a range of 2–3 h covering the bulk of the distribution. More recently, Delgado de Molina *et al.* (2005a) show for the

FIGURE 38
Percentage of FAD sets by time of day (hours before/after sunrise)

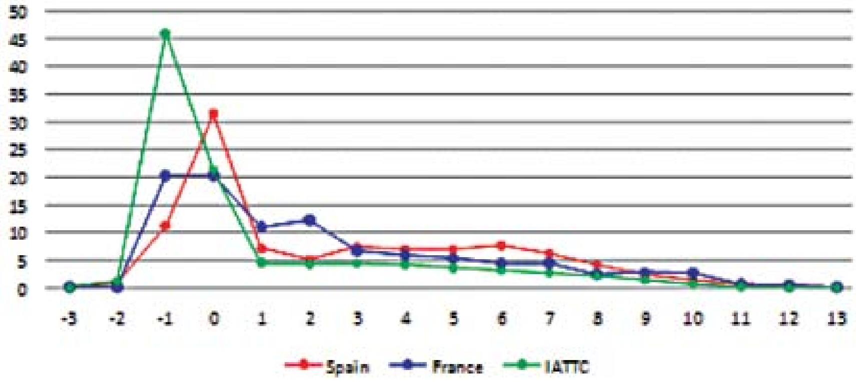
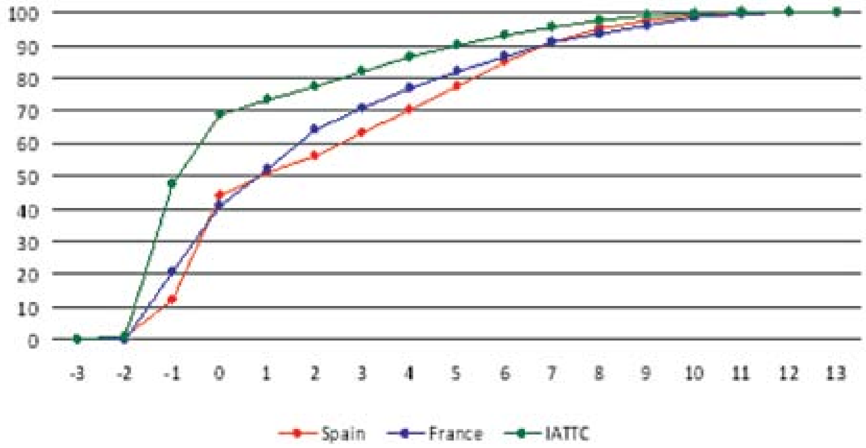


FIGURE 39
Cumulative percentage of FAD sets by time of day (hours before/after sunrise)



Sources: Fonteneau *et al.* (2010) and IATTC.

Spanish fleet in the Indian Ocean that most school sets are completed in 2–3 h (mode at 2–2:30 h), and that FAD sets last longer (2–4 h, with a broad mode from 2–3:30 h). Stretta *et al.* (1997) also offer a scattergram of time versus capture volume for both oceans, and Viera and Pianet (2006) fit regressions to duration of set as a function of capture, and obtain (a) an intercept of 1:30 h and a slope of close to one hour (0.9 h) added for every 100 tonnes in the capture in school sets, and (b) a similar intercept (1:35 h) and a slope of more than 20 minutes per hundred tonnes for FAD sets. In both regressions, the number of points is limited, and there are influential observations at high values that drive the fit, but the FAD regressions have a very low R^2, and their predictive value is poor.

Once a set is started, its duration can vary over a wide range depending on many factors, among them:

- net length and depth (affect speed of net recovery);
- winch power (affect net recovery);
- malfunctions (affect net recovery or brailing time);
- amount and sizes of tuna captured (affect brailing time);
- brailer capacity (affect brailing time);
- abundant bycatch or small tuna discarded delays the set as it is sorted;
- environmental conditions (rough seas).

FIGURE 40

Duration of FAD sets in the Eastern Pacific Ocean – frequency distribution, periods 1994–1998, 1999–2003, 2004–2008

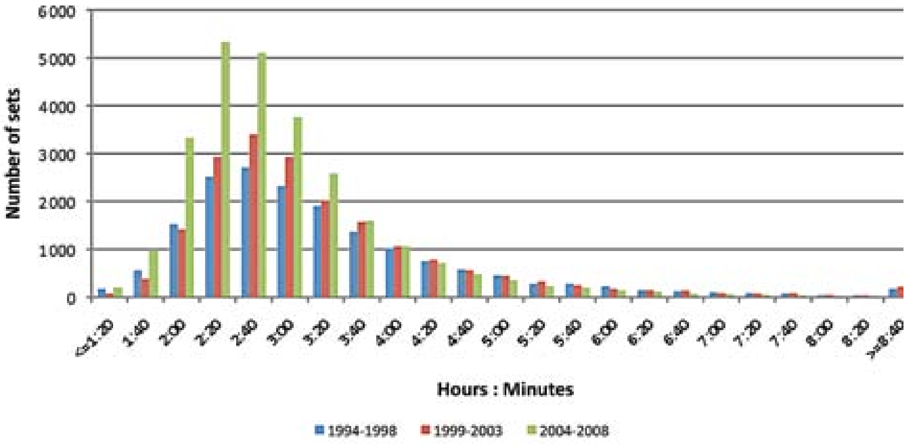


FIGURE 41

Duration of FAD sets in the Eastern Pacific Ocean – cumulative distribution periods: 1994–1998, 1999–2003, 2004–2008

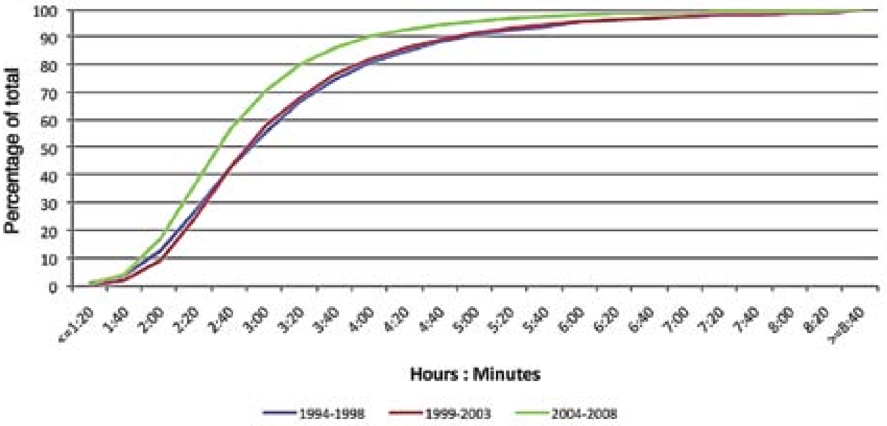
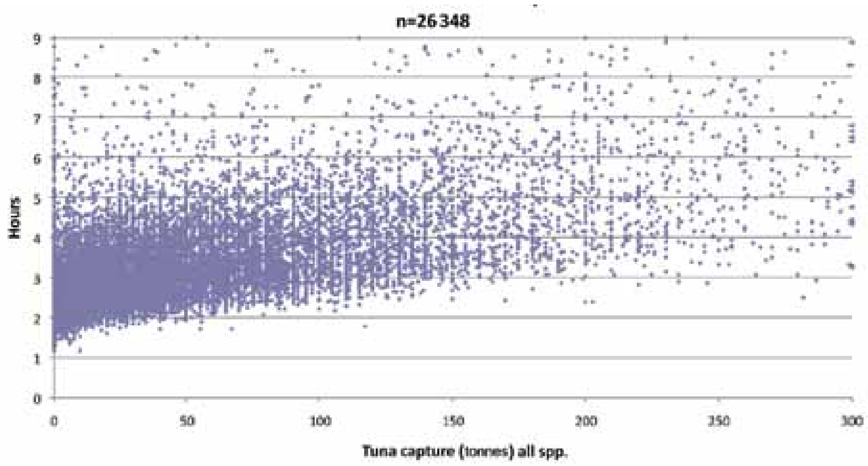


FIGURE 42

Duration of FAD sets as a function of tuna capture in the Eastern Pacific Ocean, 2004–2008

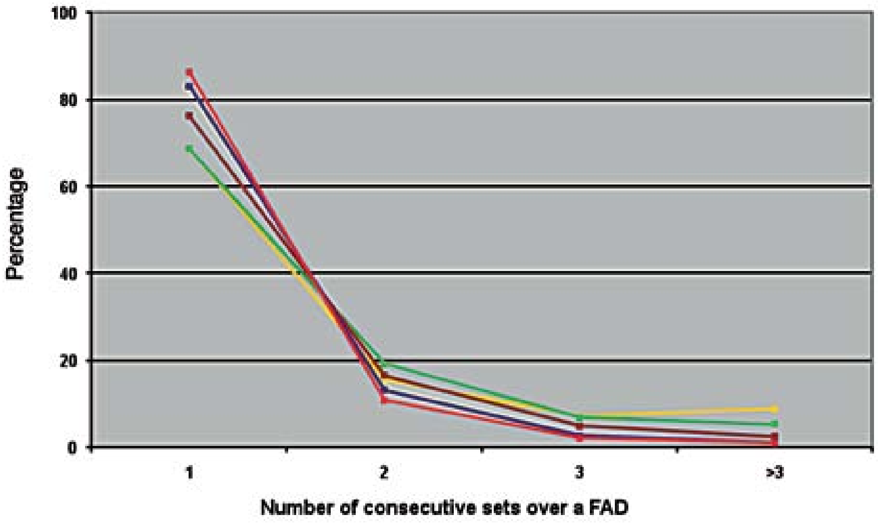


Number of sets made on an object

Many successful sets can be made on the same object. Figure 43 shows the number of repeated sets per FAD in the EPO, in different periods. The tendency is to decrease the number of repeated sets on the same FAD; the mode has always been one set, but the frequency of one-set FADs is growing. Catch and bycatch may change in successive sets, and a few studies have addressed the issue (Ariz *et al.*, 1991; Hall and García, 1992).

FIGURE 43

Proportion of number of consecutive sets on a FAD in different periods in the Eastern Pacific Ocean



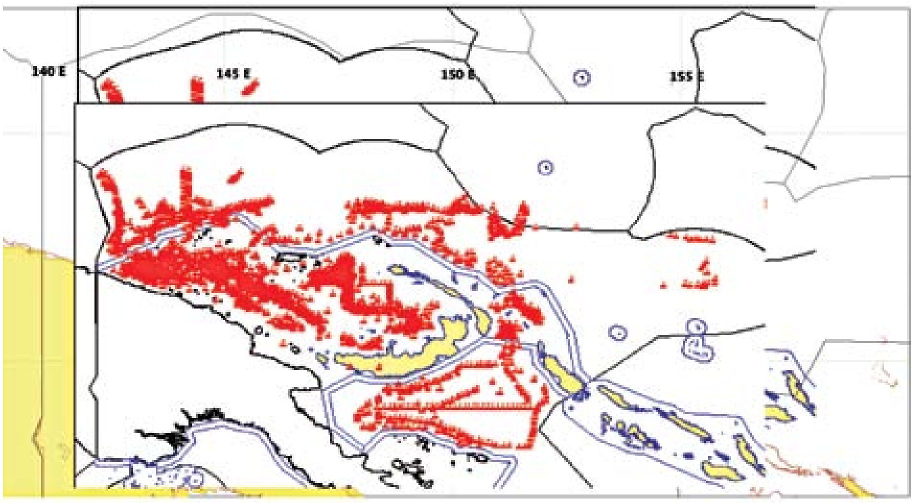
These types of data could be used to model survival of released species, when observer data are not available, and improve the mortality estimates. They also inform physiologists and others of the duration of the stressful conditions in the net, which may suggest which species may survive the capture process.

Fishing on payaos (anchored FADs)

Predating this use of drifting objects by several centuries, coastal fishers, many in island countries, had started deploying anchored objects to attract fishes (Désurmont and Chapman, 2001). In the Philippines, a type of anchored object using palm leaves to provide an attractive structure, called "payaos" has been used since the 1970s or even earlier (Greenblatt, 1979; Kihara, 1981; Matsumoto, Kazama and Aasted, 1981; De San, 1982; Brock, 1985a, 1985b). They are especially important in Papua New Guinea, where the deployment of FADs increased significantly in the mid-1990s (Figure 44–45; Leroy *et al.*, 2010) and in the Philippines, where they were blamed for reductions in tuna production in the early 1980s because of the higher vulnerability of very small tunas (Floyd and Pauly, 1984). There were about 2 000 payaos by 1981, some inshore, and some in deep water.

They are extensively used for tuna fishing in many locations in the WPO (Bromhead *et al.*, 2000; Itano, Fukofuka and Brogan, 2004; Kumoru and Koren, 2007; Sokimi, 2008, 2009), and also in the Caribbean, and to a much lesser extent in the Indian and Atlantic Oceans (Matsumoto, Kazama and Aasted, 1981; Preston, 1982; Boy and Smith, 1984;

FIGURE 44
Network of payaos around Papua New Guinea



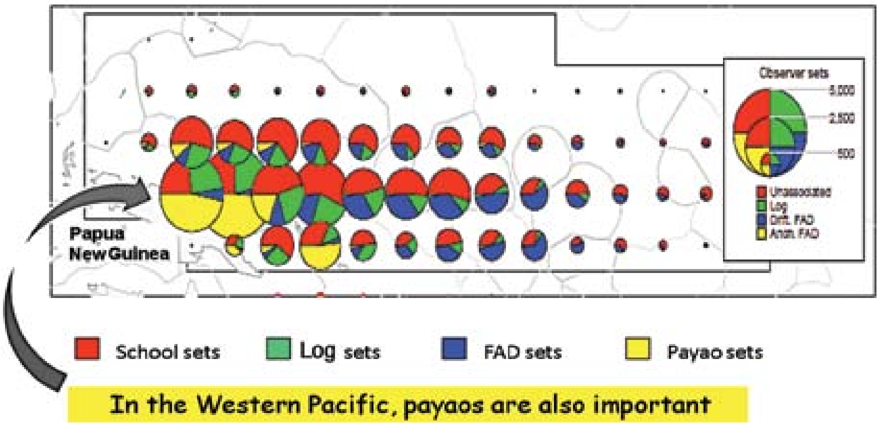
Note: 800 active ones.
Source: Kumoru (2002).

Frusher, 1986; references in Le Gall, Cayré and Taquet [2000b]; Taquet [2004]). They are not used in the EPO.

They were initially placed in coastal, shallow waters, and mainly utilized by small-scale artisanal vessels, but in some cases they have expanded into deeper, farther offshore locations, and they are been used by vessels of a wide range of sizes. The technology has evolved into more complex mooring systems (Désurmont and Chapman, 2001), with the support of the Secretariat of the Pacific Community through their technical assistance programmes (Anderson and Gates, 1996; Gates, Cusack and Watt, 1996; Gates, Preston and Chapman, 1998). The targets in these fisheries include tunas, but also a variety of other species. In general, the purse seine targets include mostly smaller sizes than the fisheries on unassociated schools, or drifting FADs (Babaran, 2006). Only in the WPO is a substantial part of the purse seine effort directed to payaos.

Besides these payaos, deployed with the goal of attracting fishes, there is another group of anchored structures deployed for scientific purposes. Oceanographic buoys

FIGURE 45
Distribution of floating objects in the Western Pacific Ocean



organized in arrays, or isolated, are also present in the fishing grounds of the tuna fleets. One example of these is the Tropical Atmosphere Ocean Project – Tropical Ocean Global Atmosphere Project with 70 buoys deployed in the Pacific Ocean (www.pmel.noaa.gov/tao/). Sets on these buoys are not enough for detailed analysis. A recent resolution (IATTC C-10-03) aims to discourage this practice, which may have negative impacts on research programmes that spend significant amounts of money to create these networks of data-collecting buoys. Similar networks are present in the Indian Ocean (www.pmel.noaa.gov/tao/doc/RAMA_BAMS.pdf) and in the Atlantic (www.pmel.noaa.gov/pirata/PIRATA_2008.pdf).

Payaos are deployed and maintained by fishers, or by local or national government agencies (e.g. the state of Hawaii, the United States of America www.hawaii.edu/HIMB/FADS/) for use by commercial and recreational fishers.

There are also other fisheries that utilize anchored FADs to attract other species but that may occasionally catch some tunas. An example is the fishery using "kannizzatti" or "cannizzi" in the Mediterranean (Sacchi, 2008), focused mainly on mahi-mahi (*Coryphaena hippurus*).

The name of payaos is used in this paper for anchored FADs of all types.

Within the group of anchored objects, there may also be differences in construction, materials, etc. Besides these, there are at least two variables that could affect the composition of catch and bycatch: (i) distance to the coast (island or continent); and (ii) depth where it is anchored. These two variables may affect potential sources of recruitment to the payao. Coastal, demersal or even benthic species may be attracted to the payao if the object is close enough to be detected by these species that may be absent in FADs drifting offshore, or in very deep waters. As the mooring technology advanced, they could be placed in deeper waters. Ideally, a 2 × 2 matrix, coastal vs offshore, shallow vs deep would allow for all comparisons if there were enough data.

When all these categories, logs, FADs, and payaos, are lumped together, or when there is no clear description of which type is been used, the name "floating object sets" is used in this paper, implying that data for FADs, logs and payaos have been pooled together, or that there is no specific identification to separate the data into categories. Hence:

- Floating object sets = log sets + fad sets + payao sets
- Occasionally, some authors may separate:
- drifting objects = logs + FADs (or dFADs for drifting FADs)
- anchored object = payaos (or aFADs for anchored FADs)

It is important to complete the research needed to conclude, on solid statistical grounds, whether this pooling is an adequate description of the heterogeneity of the data, and decide on the level of discrimination needed. Not enough stratification and too much stratification are both problems to be avoided. As the majority of the data available from all t-RFMOs are aggregated, most analyses will have to be based on aggregate data to allow for comparison, but some discussion on the possible sources of differentiation between logs, FADs and payaos will be useful in order to explore the reasons.

A classification of floating object sets

Anchored versus drifting objects

It is not known if the mechanisms of attraction and the behaviour of the different species around anchored objects is the same as in drifting ones, but environmental conditions around anchored and drifting objects may be quite different because:

- The resistance of the anchoring system to the currents may create oceanographic structures in the water column, absent or different in a drifting FAD.

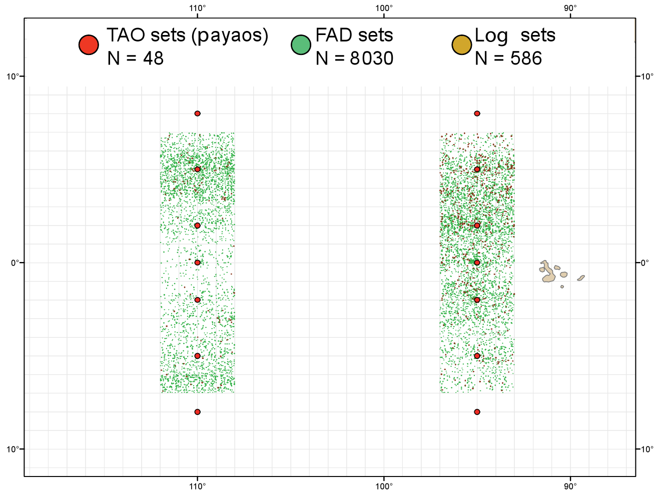
- The anchoring system may bring up tunas from deeper layers to the FAD (e.g. more bigeye tuna attracted to anchor FADs).
- The drift over a long track may allow more species and more schools to encounter a drifting object than an anchored one.
- The movement of the anchoring system caused by the passage of waves, and the currents may create sounds and vibrations that may affect the ability of tunas and other species to detect the structures or their attraction (e.g. Babaran et al., 2008).
- The colonization of the anchor system and of a FAD by marine species, including those growing on the structure, and those more closely associated with it, may be quite different, and that may affect the attraction of the objects.
- The structures hung by the fishers under drifting FADs (netting, bait buckets, etc.) may be different from those more commonly used under anchored FAD (e.g. palm fronds under payaos, or instruments in oceanographic buoys).
- The anchored objects may tend to have a more coastal, or shallow distribution, and the drifting objects may be set on much farther offshore.
- The demersal species or benthic species that may associate with anchored objects especially with shallow ones may not have any contact with drifting objects.
- These differences may affect the species, and size composition of the communities associated with the objects, their temporal persistence, or the diel patterns of their association (Dempster, 2004; Perkol-Finkel et al., 2008), and the diets of the species (Brock, 1985b).
- Logs versus FADs
- Are there structural differences between logs ("encountered objects") and drifting FADs ("deployed objects built for this purpose") that may affect their attractiveness for tunas, or their retention?
- FADs are built with underwater components to enhance their visibility, and perhaps also their attractiveness to tunas (netting, bait buckets, etc.). Some logs may have significant underwater profiles (e.g. trees with many branches, trees that may float vertically, dead whales) but in most cases the underwater profiles will be absent, or less deep, than in the case of FADs.
- FADs also have components to add floatability (buoys, floats, PVC tubes) that may result in longer periods floating.
- The transmitting devices that facilitate relocation are usually tethered to the FAD, so FADs have two components, and logs usually only one. As a result of the presence of the transmitting devices, FADs will be set more frequently than logs. If repeated sets on an object, especially when repeated over a short time span, have differences in species composition or abundance (e.g. lower abundances because of shorter time to renew the biomass removed), then FADs will show these differences.
- The prevalent FAD design (a bamboo raft) sits quite flat on the water, partially submerged; logs may also be flat (e.g. a tree trunk, a seaweed patty, a pallet), but there are some with significant aerial components (e.g. full trees, large boxes).
- The drift patterns and the drifting speed may be affected by both the underwater and the above-water components.

To make statistical comparisons between all these types of sets, logs, FADs and payaos, there are very few datasets with the sample sizes needed. The number of payaos is only sufficient in the WPO, and, even there, there is a whole array of depths, and distances to land masses that may make even the payao data heterogeneous. FADs and logs in some cases are set on in different areas or seasons, with a confounding effect on the figures.

A simplistic examination of two areas of the EPO (Figure 46) where there are a few anchored oceanographic buoys that receive some sets showed similarities and differences shown in Figures 47 and 48. With very close to 100 percent observer

FIGURE 46

Area for comparative study between floating object types in the Eastern Pacific Ocean



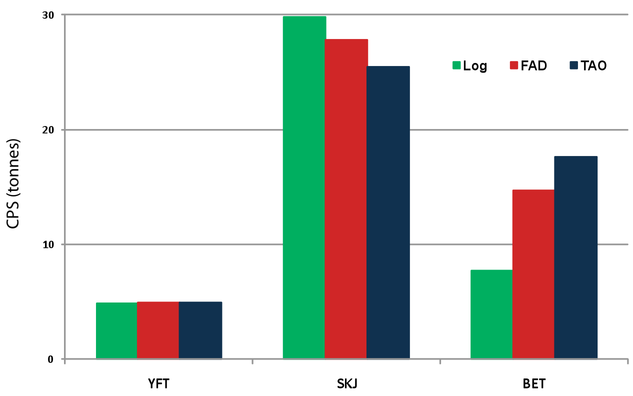
coverage, the observer estimates may have some errors because of misidentification of species, or inaccurate estimates of numbers or weights, but they are not expected to be significant, so the observed differences reflect the total number of sets in those areas. Comparisons of different years show similar patterns.

For the main tuna species, the results are quite different (Figure 47). Yellowfin tuna, the least abundant under objects, shows no differences in the captures in the three types of sets. Skipjack tuna increases from payao to FAD to log, with a maximum change of 15 percent (higher on logs than on payaos). Bigeye tuna capture per set is almost double in payaos than on logs (17.5 tonnes vs 7.7 tonnes per set), the most striking difference. FADs (14.7 tonnes/set) are closer to payaos. What payaos and FADs have in common is that the vertical dimension of the object is generally much longer than in logs. The vast majority of logs have are only from a few inches to a couple of metres in vertical profile, as opposed to 25–35 m in FADs, and much more on these payaos, anchored in depths of thousands of metres of water. As a result of this, it is possible that FADs and payaos may attract the deeper swimming bigeye tuna more effectively than the shallower logs. Another possible explanation for the difference is that the residence time of the bigeye tuna may be longer at anchored objects, so more schools are aggregated under payaos over time.

Figure 48 shows the weight per set (WPS) (capture per set [CPS] in tonnes) for a few other species that may be part of the catch or bycatch. For these, the differences are much higher. Payaos have very little associated fauna, compared with FADs, and logs are much higher than the other two. For these species, there are very large differences. Logs have many more silky sharks, mahi-mahi, and rainbow runners than FADs, and both are much higher in the density of all species than the anchored buoys. The question is whether these differences are real, or: (i) an artefact of the changes in the fishing operation required by the presence of the mooring, which may cause the loss of some fish from the payao set; or (ii) a result of the fact that many of these moored oceanographic buoys are in a less-productive water mass (warmer, and flowing to the east) than the FADs or logs that could be

FIGURE 47

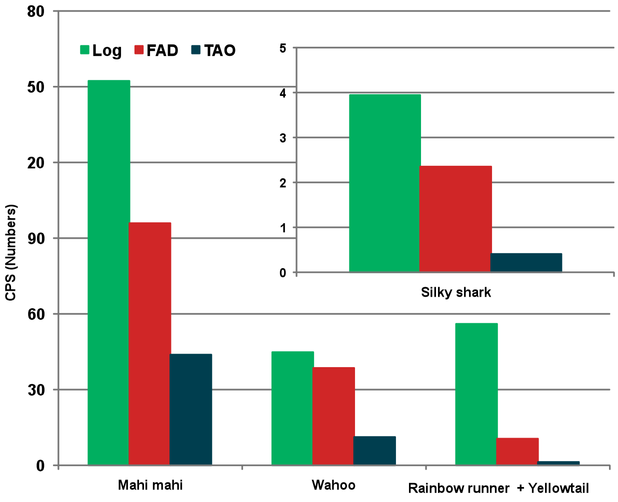
Capture per set of major tuna species by type of floating object in the Eastern Pacific Ocean



TAO are anchored buoys (payaos)

FIGURE 48

Capture per set of silky shark and pelagic fishes by floating object type in the Eastern Pacific Ocean



spatially near, but in a different oceanographic setting. A finer analysis is required. These differences may be the result of different modalities for fishing on anchored versus other objects (Itano *et al.*, 2004), but they are not valid reasons for the FAD–log disparities. Some possible reasons are that FADs are set more frequently because they are being tracked, and this reduces the associated fauna by depletion, or that logs may come from areas where the initial colonization is more important. The drift speed of FADs and logs may result in differences. In any case, the extrapolation of data from anchored to drifting and from logs to FADs or vice versa should be handled with great caution.

Kumoru (2007) found very few differences between the catch and bycatch comparing anchored with drifting objects, in a small sample off Papua New Guinea. The tuna species present, and most of the species associated, were in similar proportions, and of similar size compositions. An exception was the silky sharks, with large individuals prevailing in anchored objects and smaller ones under drifting objects. However, the location of the payaos or FADs makes a difference (e.g. Kumasi *et al.*, 2010).

Sets on slow-moving species (whale sharks and whales) are sometimes included as log sets, (EPO), sometimes as school sets (whale sets in the Atlantic and Indian Oceans). In this review, they are not considered in detail because: (i) they are uncommon in most oceans, and the databases are too limited to compare their characteristics with the others; and (ii) as they may vary in depth and speed depending on the species, and on their behaviour, it is not obvious that they should be pooled into a single group. Therefore, it is hard to decide whether they are just another "drifting" object, or whether they belong in a separate group, or in several groups. Dead animals are included in the log group.

Nomenclature of floating object sets

When the fishery started modifying objects and adding radios to them in the EPO, the IATTC adopted an operational definition to separate them from the natural floating objects, encountered by chance. Fish Aggregating Devices (FADs) were then defined as: "Objects constructed and deployed, or encountered and modified by the fishers, to attract fish, and to facilitate their aggregation and capture, outfitted, in most cases, with a system to aid in their relocation. They can be anchored or drifting."

The Conservation and Management Measures Nos. 2008-01, and 2009-02 from the Western and Central Pacific Fisheries Commission (WCPFC; e.g. in its Sixth Regular Session, Papeete, 2009), defined FADs as:

"The definition of a FAD in footnote 1 to CMM 2008-01 [For the purposes of these measures, the term Fish Aggregation Device (FAD) means any man-made device, or natural floating object, whether anchored or not, that is capable of aggregating fish.] shall be interpreted as including:

"any object or group of objects, of any size, that has or has not been deployed, that is living or non-living, including but not limited to buoys, floats, netting, webbing, plastics, bamboo, logs and whale sharks floating on or near the surface of the water that fish may associate with."

The main differences with the definition proposed here are that logs, FADs and payaos are all lumped together, and that living organisms are also defined as FADs. There is a linguistic issue in that a tangle of floating seaweed, a tree trunk carried to the ocean by a river, or a whale shark are not devices as such, i.e. a piece of equipment or a mechanism designed to serve a special purpose or perform a special function.

From the point of view of management, there are enough differences in the species composition and sizes that associate with the different types of attractors that a separation in these types will help pinpoint the targets for management actions.

This paper uses a simplified nomenclature, recognizing the historic origin of each type of floating object. All objects are classified as FADs, logs or payaos (Table 11).

TABLE 11
Simplified nomenclature of floating object sets

	Anchored	Drifting
Encountered	n.a.	log
Deployed	Payao (= anchored FAD)	FAD

Note: n.a. = not applicable.

The major categories are anchored versus drifting objects. Most scientists agree that the behaviour of many species around anchored objects is not the same as around drifting objects, and these differences were the basis for the separation. These were discussed at length at workshops in La Jolla (Scott *et al.*, 1999) and Martinique (Le Gall, Cayré and Taquet, 2000a). This stratification of anchored versus drifting is expected to have some impact in the Western and Central Pacific where sets on payaos are very important in a section of the fishery. In the other oceans, the proportion is much lower, to the point of being negligible.

Beyond this, the level of stratification needed to separate meaningful units has not been demonstrated. Do catch and bycatch under FADs and logs made in the same area, and roughly at the same time, differ? Not all FADs are equal, although the designs seem to be converging. Not all logs are equal. Are objects with netting hanging underneath, equivalent to objects without it (e.g. Lennert-Cody, Roberts and Stephenson, 2008)? Which characteristics of FADs and logs make a difference?

Although encountered drifting objects have been used for many years (Stretta and Slepoukha, 1983; Ariz *et al.*, 1999; Hall *et al.*, 1999b), the introduction of the drifting FAD fishery had a major impact on the production of the tuna fisheries in all oceans of the world within a relatively short period (Fonteneau *et al.*, 2000). Figure 23 shows, for the EPO, the switch in predominance from "encountered" objects, to deployed objects; by 1994, the deployed objects had become the prevailing way of fishing on floating objects.

As the fishery on deployed drifting objects (FADs) has substantially replaced the fishery on encountered objects, the more recent information is dominated by the former in most oceans of the world. Differentiating a set on a floating object from a set on a school of tunas that happened to be close to an object is not always obvious, because some objects may be submerged. For regulatory reasons, sets on objects have been defined as sets within 500–1 000 m from an object by some t-RFMOs that needed the definition in order to enforce some recommendation. However, in practice, as the vast majority of the sets on floating objects happen early in the morning, and the vessel has approached the object before setting, and without searching, it is not so problematic to determine the type of set in those cases (Harley, Williams and Hampton, 2009).

The fishers had to find the right areas for FAD deployment and drift, and when that was determined, the scale of the harvest grew consistently. There are also areas where drifting FADs have been deployed, and they have not produced profitable catches. Hence, only a portion of the range of the tropical tunas is being fished with FAD. The areas where FADs are effective do not always coincide with the areas where encountered object sets were important prior to the increase in the FAD fisheries; thus, a major geographical shift in fishing effort has happened in some ocean areas.

This review distinguishes, where possible, between anchored and drifting objects. Drifting objects (encountered or deployed) are today the most common technique to catch tropical tunas in all oceans of the world. In many cases, the information available does not distinguish between these types. As the IATTC has gathered an extensive database with 100 percent observer coverage from 1993 up to today, the data from this source are available to answer many detailed questions that cannot be answered for the other ocean areas.

Another issue that has some scientific interest is the classification of fishes into associated with or aggregated under a FAD (Castro, Santiago and Santana-Ortega, 2002). From the point of view of this review, the significant fact that separates groups is whether they are captured in the set or not, rather than the motivation to be close to the FAD.

HYPOTHESES ON THE ASSOCIATIONS OF DIFFERENT SPECIES WITH FLOATING OBJECTS

Some marine species are attracted to floating objects, and associate with them for varying amounts of time. Some spend a few hours; others are associated for prolonged periods. Some species are very close to the object, while others are more loosely associated. Parin and Fedoryako (1999) have described, and given names to, these communities associated with objects, based on their proximity to the object. There is a very high level of similarity in the composition of those communities in all oceans of the world. They call the components of the community living in very close contact with the object the “intranatant”, those present within 2 m of the object the “extranatant”, and those outside this radius and up to 10 m the “circumnatant”.

Various reasons have been proposed to explain the association of some fish species with floating objects, and it is probable that different species or sizes of fish associate for different reasons. There are several competing hypotheses on the subject, and some excellent reviews are available (Dagorn and Fréon, 1999; Fréon and Dagorn, 2000; Castro, Santiago and Santana-Ortega, 2002; Dempster and Taquet, 2004; Dempster, 2005). Many of the hypotheses suggested do not apply to tuna schools (e.g. spawning substrate, cleaning stations, protection from predators, and substitute of the sea bed). The stomach contents of payao-associated or FAD-associated tunas usually have less food than those of tunas caught in school sets (Brock, 1985b; Batalyants, 1993; Buckley and Miller, 1994; Ménard *et al.*, 2000a; R. Olson, personal communication, 2010). Thus, food does not appear to be part of the attraction mechanism for tuna schools. As the association appears to be mostly nocturnal for tunas around drifting FADs, visual stimulus or shade attractions do not seem likely. Some authors believe FADs operate as a nursery habitat for some species (Castro, Santiago and Santana-Ortega, 2002; Andaloro *et al.*, 2007). For small individuals, the floating objects can provide some protection from predators (Gooding and Magnuson, 1967; Hunter and Mitchell, 1967; Mitchell and Hunter, 1970; Rountree, 1989), although predators of small fishes are also associated with FADs.

This leaves a few hypotheses, the main ones being that the object is a meeting point to re-form schools (Soria and Dagorn, 1992; Freon and Misund, 1999; Soria *et al.*, 2009), or that the object is an indicator of a productive water mass (Hall, 1992).

According to the first one, tuna schools spend time foraging, and in the process the schools may become smaller than optimal, or individuals may become separated from the school; after a day or days of foraging, the schools seek floating objects, and re-aggregate into larger schools (Dagorn, 1994; Fréon and Dagorn, 2000). Simulation studies support this hypothesis, and show its evolutionary advantages (Dagorn and Fréon, 1999), and some experimental evidence agrees with the predictions (Soria *et al.*, 2009).

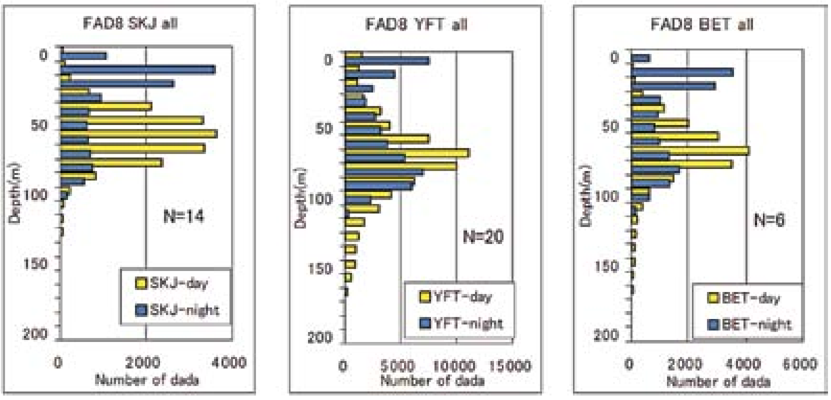
According to the second one, when tunas encounter floating objects in the oceans, their presence is an indicator of a productive water mass (e.g. because of terrestrial contributions, currents aggregating materials), and by associating with the object during the night, they make sure that they do not swim away from the productive area, as could happen if they swam randomly during the night. Natural floating objects originate in, are retained in, and in some cases may also drift to, areas of high productivity. The retention of floating objects in some coastal regions may not only keep small individuals in a productive area, but also may keep them away from predators.

As the association of tunas with objects began millennia before humans introduced debris in many areas, it is possible to see that the main areas of the natural floating objects fisheries coincide with areas of major continental inputs to the coastal zone. The characteristics of these areas include: abundant coastal vegetation, well-marked dry and rainy seasons, and significant freshwater flows to the oceans (large or many rivers) to transport materials (Hall *et al.*, 1999b; Scott *et al.*, 1999).

Most of the sets on FADs are made very early in the morning (Stretta *et al.*, 1997; Goujon, 2004a; Fonteneau *et al.*, 2009; Harley, Williams and Hampton, 2009), because the fishers believe that the largest numbers of tunas are aggregated under the objects at that time, and research supports this (Figure 49). This supports the idea that the association is mostly nocturnal, although observations and sets confirm that there are some schools under FADs during daylight hours (e.g. 17 percent of successful sets in the Indian Ocean [Hallier and Parajua, 1999]). For payaos in the WPO, there is also a sunrise peak and a much smaller secondary peak in the frequency of sets at sundown (Hampton and Bailey, 1999; Harley, Williams and Hampton, 2009). Other species present at the time will be taken, regardless of whether they are permanent residents on the FADs or transient. Some of the species may be associated with other species, and not directly with the object itself.

FIGURE 49

Vertical distribution of three tuna species around drifting FADs



Source: Matsumoto, Okamoto and Toyonaga (2006).

Tunas do not associate with objects to find food – their stomachs are generally empty when they are caught in sets on objects (Hallier and Gaertner, 2008). As is known from other areas where objects are not present, tunas do not need to associate with objects. Therefore, for the behaviour to develop, there must be some evolutionary advantage in doing so. However, the distribution of the FADs is not the same as that of the natural objects, and it is possible that the behaviour has turned maladaptive (ecological trap hypothesis), or at least lost the original adaptive value.

There are no controlled sets to compare the fauna that could be captured in sets in open waters but in the vicinity of drifting FADs. School sets made in the same region as where the FAD fisheries are operating are only made after detection of some activity of the tuna school, so it is not the result of a random process. Not all tuna species and sizes associate with floating objects. Large yellowfin and bigeye are not common under objects in the Pacific (Kumasi *et al.*, 2010; IATTC, 2010), but larger sizes of yellowfin and bigeye are found under FADs in the Atlantic and Indian Oceans (Fonteneau *et al.*, 2005). It is not known whether this lack of association reflects the fact that the objects are found in a habitat unsuitable for these individuals (because of temperature, oxygen, prey availability, etc.), or if the objects are not detected by the schools (e.g. fishes are in deeper water), or are not attractive to them, or if they are associated, but at a distance that prevents their capture in the sets.

BEHAVIOUR OF DIFFERENT SPECIES AROUND FLOATING OBJECTS

The behaviour and ecology of different species around anchored or drifting objects have been the focus of several research projects in recent years. The studies of rafting ecology were reviewed by (Thiel and Gutow, 2005a, 2005b), and cover most groups of marine organisms.

The behaviour of large pelagic fishes around floating objects has also generated much interest. Following the initial studies of Hunter and Mitchell (1968), and Gooding and Magnuson (1967) using visual means, ultrasonic telemetry has been used to describe the behaviour of the larger species (Holland, Brill and Chang, 1990; Cayre, 1991; Klimley and Holloway, 1999; Dagorn, Josse and Bach, 2000; Schaefer and Fuller, 2002; Girard, Benhamou and Dagorn, 2004), and there are a few studies of small individuals of the larger species, e.g. Babaran *et al.* (2009) tracking 22–26 cm yellowfin tunas that spent all their time in the upper 25 m of the water column.

However, most of these studies describe the behaviour around anchored objects, and it is not likely that those results can be extrapolated to drifting objects, although some authors believe much is to be gained from studies on anchored objects (Dagorn, Holland and Filmalter, 2010). Studies on drifting FADs are very limited (Schaefer and Fuller, 2002; Taquet *et al.*, 2007a; Taquet *et al.*, 2007b; Dagorn *et al.*, 2007; Marianne, Dagorn and Jean-Louis, 2010). The residence times of tunas on FADs appear to be a few days at a time, about 3–10 days. For example, Babaran *et al.* (2009) tracked small yellowfin that spent up to 60 hours under the same payao. However, the sample sizes in drifting object settings is still very low, given the spatial heterogeneities of the fishing areas (current speed, bathymetry, etc.). Interesting approaches are being tested, such as comparing condition indices of fishes captured on FADs and schools (Marianne, Dagorn and Jean-Louis, 2010). Ignorance of the behaviour of most species under logs and FADs is a major gap in knowledge, as most of the tuna purse seine fishing effort is directed towards floating objects.

Around payaos, the average residence time of yellowfin and bigeye tunas was estimated at 5–8 days, with a maximum of more than 2 months; there was also some site fidelity, with tunas tending to return to the original FAD where they were released (Dagorn, Holland and Itano, 2007). They are capable of finding their orientation from up to 10 km (Girard, Benhamou and Dagorn, 2004). The tuna schools are shallower at night than during the day in most studies carried out with anchored FADs (Holland, Brill and Chang, 1990; Cayre, 1991; Josse, Bach and Dagorn, 1998; Brill *et al.*, 1999; Babaran *et al.*, 2009). Moreover, there is a considerable vertical overlap among the different species during the night and early morning, which is the preferred time for setting (Leroy *et al.*, 2010). Yellowfin and skipjack spend most of their time in the mixed layer (Brill *et al.*, 2005; Dagorn *et al.*, 2006a), with bigeye staying deeper but foraging on the deep scattering layer when it rises (Leroy *et al.*, 2010). Bigeye tuna spends more time in shallow water during the new moon, while skipjack behaviour is the opposite (Langley, 2004).

The studies have also covered individual objects, or networks of objects (e.g. Marsac and Cayre, 1998). The empirical knowledge of the fishers is that the maximum catch can be obtained very close to sunrise, hence, sets start just before sunrise, as discussed above, and this has determined the daily rhythm of the fishery. It appears that most tunas move to shallower waters at night, and their peak abundance happens at or close to sunrise (Brill *et al.*, 1999).

Despite the scientific interest of these studies, and their value to improve stock assessments, they have not yet offered much information that is valuable to reduce bycatch. If during the day the tuna schools become less vulnerable or if average school size decreases, then it would be difficult to switch the fishing operations to those alternative conditions. If experiments of this type are continued, care must be taken to perform them in well-specified conditions; the communities associated to logs, FADs, and payaos are quite heterogeneous in both composition and biomass, so conclusions on behavioural patterns across them cannot be extrapolated.

Payaos can range from modest in size to very large (Ohta, Kakuma and Kanashiro, 2001; Ohta and Kakuma, 2005), and the impact of the fishing operations on them may reflect these differences. Locations with different current or productivity conditions may translate into different behaviours. It is believed that when there are FADs in an area, some species such as bigeye tuna become shallower (Leroy *et al.*, 2010). The behaviour of tunas on anchored objects is likely to differ from the behaviour around drifting objects; for example, yellowfin and bigeye tunas associate with anchored FADs in Hawaii during the day (Holland, Brill and Chang, 1990). Residence times around FADs have shown a very large variability in different experiments, but they have almost all been performed on anchored FADs (Holland, Brill and Chang, 1990; Cayré and Marsac, 1993; Brill *et al.*, 1999; Klimley and Holloway, 1999; Dagorn, Josse and Bach, 2000; Ohta, Kakuma and Kanashiro, 2001; Schaefer and Fuller, 2002, 2005; Girard, Benhamou and Dagorn, 2004; Ohta and Kakuma, 2005). The composition of the diet and stomach fullness is different for payaos and drifting FADs (Jaquemet, Potier and Menard, 2011).

The association of tunas with payaos in the Bismarck Sea is of very short duration, perhaps because of the high density of payaos (Leroy *et al.*, 2010), while other studies show much longer residence times (Ohta and Kakuma, 2005; Dagorn, Holland and Itano, 2007). Studies tracking individuals from different species from the same FAD show simultaneous departures in some cases, indicating the multispecies school structure (Leroy *et al.*, 2010).

There is a concept termed the "effective range of influence" of an object (Fréon and Dagorn, 2000). The concept can be applied to anchored or drifting objects, and it defines an area of influence, based on the detection and/or orientation abilities of the species. For tunas around anchored objects, it appears to be in the range of 5–7 nautical miles (Cayre and Chabanne, 1986; Holland, Brill and Chang, 1990; Cayre, 1991). Experiments are needed for drifting objects, and for other species to complete the picture.

Perhaps the most interesting studies for bycatch reduction would be those centring on the behaviour and physiological conditions of the different species inside the purse seine, and during the whole operation. If there is stratification inside the net by size or by species, then it could be used to devise escape procedures. If there is differential mortality, it will also provide an opportunity. If hypoxia or anoxia is a significant factor for mortality, then the conditions in the net can be modified. This is another significant gap in the understanding of the processes leading to mortality of individuals that are to be discarded.

FLOATING OBJECT OPERATIONS

The dominance of FADs, whose construction seems to be converging to a successful model in the EPO, is making the extrapolation simpler. It seems that the stratification between anchored and drifting FADs should be a default, on the basis of their differences, unless statistical evidence supports the pooling. This issue is only relevant in the Western and Central Pacific, where payaos receive a significant proportion of the sets. Oceanographic buoys, another type of anchored object (although anchored for another purpose than to serve as a FAD) do not receive significant effort to make a comparison.

To maintain the review within reasonable limits, the focus is on the association of tunas with drifting floating objects, with an emphasis on those deployed by the fishers because it is the prevailing way of fishing tunas in the world today. Although sets on logs and on FADs may happen at the same location, and time, the transition from a log-fishery to a FAD-fishery has resulted in clear changes. To begin with, the number of sets on floating objects, not depending on encounters, has expanded by a large factor (Figures 22 and 23; Fauvel *et al.*, 2009).

The geographical changes resulting from the development of the FAD fishery for the Eastern Atlantic and for the EPO are a westward shift of the fishery (Figures 24 and 25; Ariz *et al.*, 1999; Hallier and Gaertner, 2008). From a coastal fishery, the effort has switched to an offshore fishery. There have also been changes in seasonality, with the log fishery being prevalent in May–July, while FADs are available most of the year (Figure 50). This triple switch in geography, season, and type of object, makes it very difficult to compare the characteristics of log and FAD sets, and even school sets and floating object sets predominate in different areas (Figure 51); there is a basic confounding that limits the statistical analyses, even when the databases are very complete.

On the other hand, Fauvel *et al.* (2009), show much less dramatic changes in the spatial distribution of the fishery after the increase in the number of FAD sets for the Atlantic and Indian Oceans. In earlier years, Fonteneau *et al.* (2002) showed the northward expansion of the Indian Ocean fishery as a result of increased FAD utilization. The major impact of the FAD introduction appears to be an increase in the number of floating objects, and the change in geographical distribution is less marked.

FIGURE 50
Seasonal distribution of effort in the Eastern Pacific Ocean

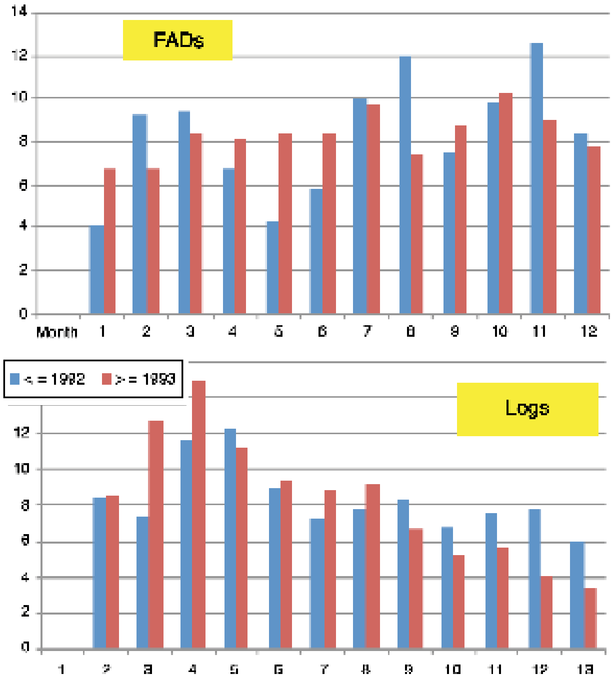
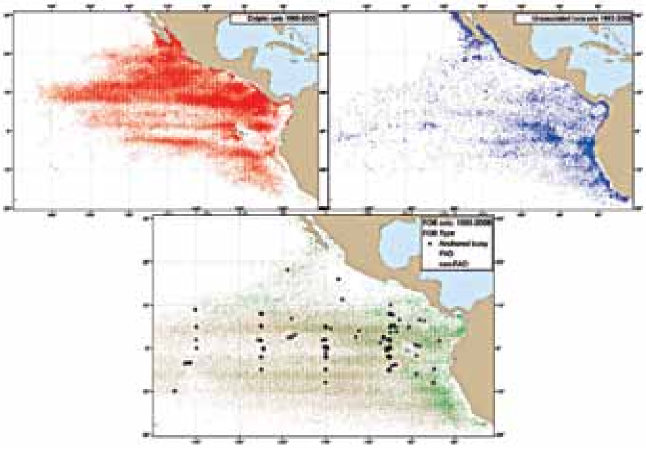


FIGURE 51
Distribution of sets by type in the Eastern Pacific Ocean



Fishing operations on logs, FADs and payaos

The fishery on drifting objects has several characteristics that need to be reviewed in order to understand what they have in common, and in what they differ from payaos, and the influence of the type of drifting object and payao on the catch and bycatch (Itano, 2007). A purse seiner leaving port on a fishing trip will select the area to search based on: information from other vessels; climatic (e.g. storms) and oceanographic (e.g. satellite information on water temperature, productivity, location of fronts) information; economic factors (fish prices, fuel costs, etc.); legal limitations (permits, spatial or temporal closures); and previous results and activities from the vessel and from other vessels from the same or associated companies. Some characteristics of the vessels will influence their operations (Arrizabalaga *et al.*, 2001; Gaertner and Pallares, 2002; Reales, 2002; Itano, 2002, 2004, 2007), and the collection of information at the level of detail needed is critical (Matsumoto *et al.*, 2000). Examples of forms describing the purse seine, the electronics and other equipment from the vessels, and which can be used to help in the standardization work, are available from the IATTC Web site (www.iattc.org Downloads/Gear descriptions). All the issues relevant to the standardization of fishing effort for CPUE studies apply directly to the bycatch estimation (Coan and Itano, 2003).Vessels planning a trip on logs will search in the well-defined areas and seasons where tunas are frequently associated with floating objects. Vessels planning a trip on FADs have several options. They know: the position of FADs deployed by them in previous trips; the position of FADs deployed by other vessels that share that information (e.g. from the same company); and the position for deployment, and expected drift of the FADs that the vessels carry and are going to plant. The drift of the FADs described before, results in two strips running east–west, where most of the fishing takes place. Both are only a few degrees wide, north and south of the Galapagos Islands. The drift of the FADs in most oceans is "predictable" with a reasonable error, and the satellite will bring the vessel to the precise location. Difficulties may arise if the FADs scatter to a point that the search becomes onerous.

Some FADs have acoustic systems to detect and transmit information on the biomass underneath, and the seiner may decide which FAD to visit based on that. In other cases, where that information is not available, the vessel approaches a FAD the previous day or a few hours before sunrise, and tries to assess (using the acoustic devices of the seiner) whether it is worthwhile making a set, or whether it is better to continue searching for another FAD. The purse seining operations usually start before the sun is up (Figure 38; Hall *et al.*, 1999a; Hallier and Parajua, 1999; Hampton and Bailey, 1999; Fonteneau *et al.*, 2010b).

In sets on payaos, manoeuvres have been developed to avoid encircling and entangling the mooring lines, but besides that, the operation is very similar to sets on drifting objects (Bromhead *et al.*, 2000). An excellent review of operations on and characteristics of payaos in the WPO is available (Itano, Fukofuka and Brogan, 2004). Fishing operations on payaos may happen throughout the day, but are prevalent during daylight periods (e.g. recreational fishing, trolling). Purse seiner sets have a major peak before sunrise, and a secondary peak at much lower level close to sunset (Harley, Williams and Hampton, 2009).

Duration of fishing trips

The duration of fishing trips depends on many variables, including the type of fishing, fishing success, location of fishing grounds, weather, vessel capacity, and vessel speed. As a generalization, it is possible to use a modal value of about 45–50 days, with a broad range of from less than a week to more than 5 months (Figures 52 and 53). For the Indian Ocean, Sarralde, Delgado de Molina and Ariz (2006) report trip lengths of 18–60 days, with modes of about 30–40 days.

The development of the FAD fisheries, shown here in the last two histograms, has resulted in a shortening of trips with respect to the initial distribution. Fewer sets are needed to fill the vessels, as the production in FAD sets is higher than in the other types of sets.

FIGURE 52

Duration of observed tuna purse seine trips in the Eastern Pacific Ocean, 1979–2010

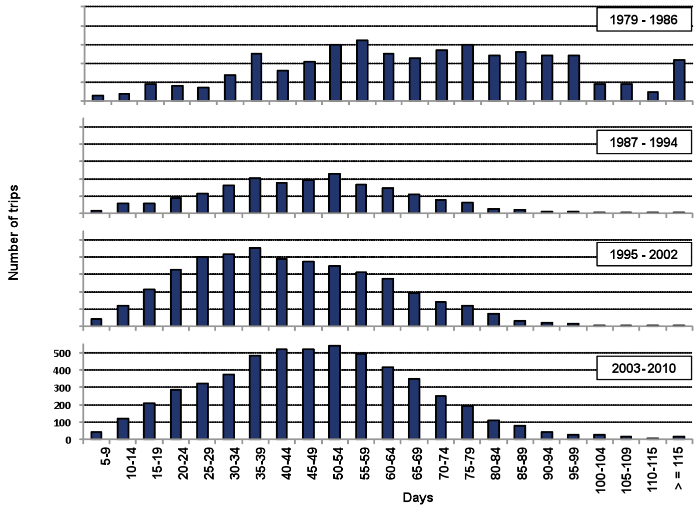
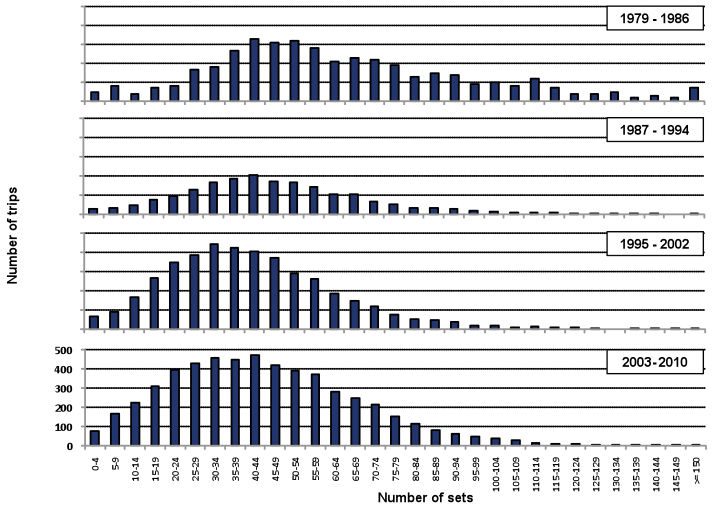


FIGURE 53

Number of sets made on observed tuna purse seine trips in the Eastern Pacific Ocean



5. Conditions during the capture process that may cause mortality

Given the large dimensions of the purse seines used in the fishery, most of the individuals or schools have enough space to move freely at the beginning of the set. The description of the sets begins with chaotic movements inside the net.

As the purse cable is closed, the shallowing of the net brings up schools that may have been in deeper water. In areas with deep thermoclines, this may be a stressor working on the deeper swimming species (e.g. bigeye tuna).

According to the observations from tuna skippers, they frequently see chaotic movement at the beginning of the set, and then things settle down. There are no observations of what happens inside the net with the different species and sizes. Are they stratified vertically? Do they interact with one another? This type of information may prove critical in attempts to release some individuals from the net, but it is a gap in the current knowledge.

As the net is retrieved, the volume inside shrinks, and different stressors may begin to have an impact. Temperature is likely to rise, given the restricted water circulation, and the shallowing of everything as the set progresses. In the tropical locations where this fishery takes place, the temperature may by itself cause some mortality, especially in prolonged sets.

Oxygen inside the net may be reduced during the set, given the large biomass consuming it. As the movement of the schools is restricted, their possibilities for ventilation decrease. Hypoxia, or even anoxia, may be an important stressor acting on the capture.

Physical contacts between individuals or with the net may result in injuries and abrasions that may prove lethal for some species (Misund and Beltestad, 2000; Suuronen and Erickson, 2010).

The next stage of the set is the brailing process. Large scoop nets (usually capable of lifting 2–4 tonnes of fish, but some can lift 8 tonnes) are used to bring the fish on board the seiner. The fish then go a large tray on the main deck (called a hopper) to be sorted out. In this case, the bycatch is tossed aside on the deck of the boat, and in general it is left there until the end of the set. Alternatively, the fish go to the well deck through an opening in the main deck. In this case, the fish fall onto a conveyor belt that distributes the catch to the wells (Plate 1). The species and individuals to be discarded are still mixed on the conveyor belt, and the crews sort them out from the belt. In some vessels, again, the individuals to be discarded are tossed aside until the set is over. In other vessels, there is another conveyor belt with the specific purpose of taking the bycatch out of the vessel.

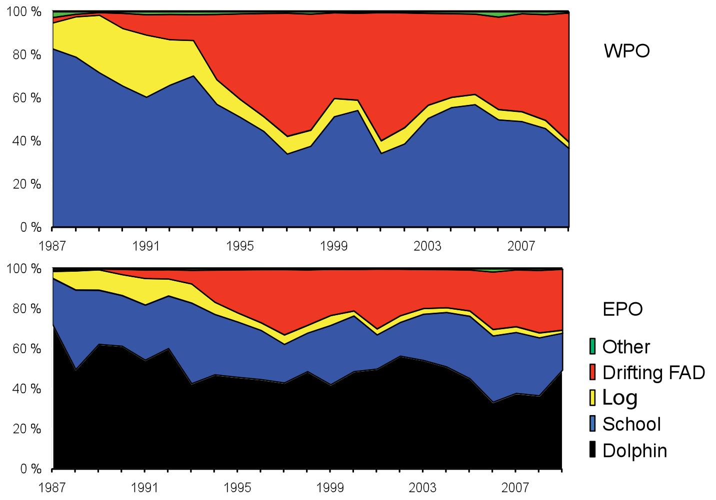
The amount of time spent out of the water by an individual that is to be discarded depends on the duration of the set, the type of brailing operation, the system the vessel uses to return the bycatch to the water, and the way the crew handles the return process. Moreover, as this time may affect the survival of the individual, it is necessary to understand the process, and perhaps modify some components to improve survival. Taking a precautionary approach, and lacking evidence that individuals or species can survive the encirclement, brailing, and handling on board, it is assumed that all the capture that undergoes the full process is dead or dying when returned to the sea. Some shark experts believe that this may not be the case for some shark species. When research evidence shows survival, and allows a rate to be estimated, then the data should incorporate this correction. Reviews of the survival of fish escaping from different gear types are found in Chopin and Arimoto (1995), Chopin, Arimoto and Inoue (1996), Davis (2002), Suuronen (2005), and He (2010).

In all cases, the best way to reduce bycatch is by avoiding the capture of the unwanted individuals.

6. Distribution of effort by set type

FIGURE 54

Proportion of set types in the Western Pacific Ocean (WPO) and Eastern Pacific Ocean (EPO), 1987–2009



Source: William and Terawasi (2010).

Different fleets in different oceans utilize strategies that are adapted to their local conditions, markets and technology. This results in very variable proportions of sets of the different types. Moreover, these fleets are very dynamic, and changes are frequent. Figure 54 compares the changes in the Eastern and Western Pacific in recent decades, and they both show FADs becoming the major component of the fisheries, in terms of number of sets. In the EPO, dolphin sets represent an important part of the effort, and a segment of the fleet uses dolphin sets as the major source of its catches. Figure 55 shows the trends in the Atlantic and Indian Oceans. Pianet *et al.* (2010) show that for several fleets operating in the Atlantic the fishery on objects went from about 30 percent of the sets in the early 1990s to slightly more than 50 percent now; but the French fleet made only about 20 percent of sets on floating objects, while the Spanish fleet has made more than 60 percent of sets on floating objects in recent years (Delgado de Molina *et al.*, 2010b). In the Indian Ocean, for 2004–07 (Amandè *et al.*, 2008a), the distribution was 54 percent of school sets, 45 percent of FAD sets, and 1 percent of seamount sets. The category of seamount is not used in other oceans

FIGURE 55

Proportion of set types in the Western Indian Ocean (WIO, 1987–2008) and Eastern Atlantic Ocean (EAO, 1991–2008)

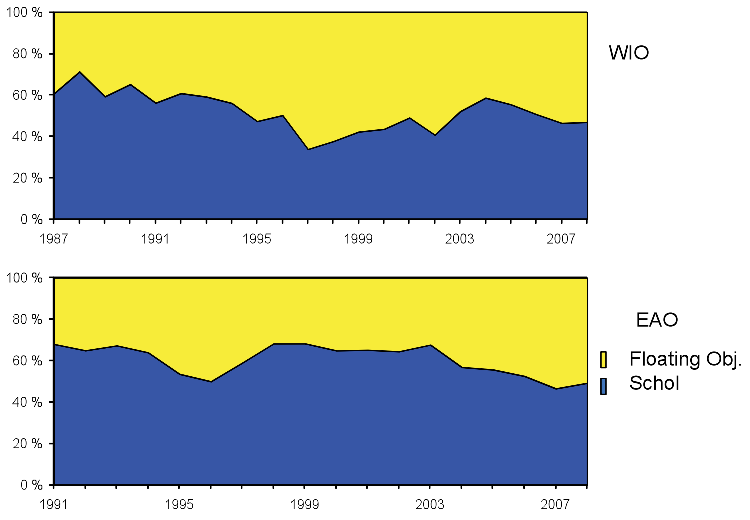
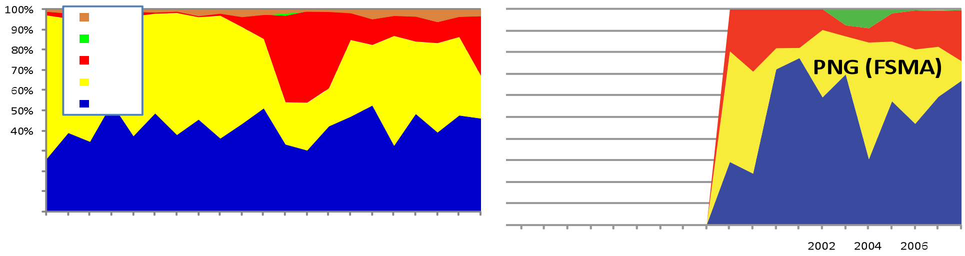


FIGURE 56

Percent catch by set type by fleet in the Western and Central Pacific



(Fonteneau, 1991), and these sets are included in the FAD set category because of their characteristics in the Atlantic and Indian Oceans. Figure 56 shows the variability by flag in the distribution of set types. Different fishing strategies are using by different fleets, and this causes problems if the sampling effort is not well distributed among the flags.

7. Sources of information on bycatch in the tuna purse seine fisheries

BIBLIOGRAPHIC INFORMATION

Information on research and management of bycatch, including all resolutions currently in place, is usually found on the Web sites of the t-RFMOs (provided above). The working groups on bycatch or on ecosystems are the places for the analyses and interpretation of the data. Two bibliographic projects are under way to bring all the information on bycatch issues together, and make it available in a systematic way. A database is being organized for the WCPFC (Williams, 2007; Fitzsimmons, 2010), and the International Commission for the Conservation of Atlantic Tunas (ICCAT) has another initiative to produce a meta-database (Cotter, 2010). These two will support the researchers and managers, at a time when the agendas have diversified so rapidly that it is hard to keep current with the activity on the subject. Perhaps, all t-RFMOs could contribute to a single bibliographic centre, providing service to all.

The best source of information for research and estimation of bycatch can be found in the t-RFMOs and related Web sites:

- IATTC – www.iattc.org
- ICCAT – www.iccat.int
- Indian Ocean Tuna Commission (IOTC) – www.iotc.org
- Secretariat of the Pacific Community (SPC) – www.spc.int
- WCPFC – www.wcpfc.int

BYCATCH DATA

Information on bycatch may come from three sources: logbooks (or other fisher's records), observer data, and electronic monitoring. In the EPO, the observer programmes were initiated to monitor dolphin mortality, and as the vast majority of the sets on dolphins were made by the larger vessels, they were limited to them (vessels of more than 363 tonnes capacity). In all oceans, the predominant sources of tuna catches are vessels of this size. These data may not be representative of the bycatch in smaller vessels that have smaller, shallower nets, and may be limited in their area of operations to more coastal regions. Therefore, extrapolations should be restricted to vessels operating with similar gear and in similar spatial and temporal strata.

Observer data are usually more complete and reliable because of the standardization of the collection process, and the dedication of the observer to that task. The quality of the observations made may depend on many conditions of the fishing operation, and on the requirements from the observer, whether they only collect scientific data, or if they have also enforcement functions (AIDCP MOP-21-09). Attempts are been made in all RFMOs to improve data quality, through observer training, identification guides, and setting of minimum standards (WCPFC-SC3/GN WP-6, 2007, at http://www.wcpfc.int/taxonomy/term/108/all?page=1; IOTC-2010-S14-CoC10-add1[E], at http://www.iotc.org/files/proceedings/2010/s/IOTC-2010-S14-CoC10-add1[E].pdf; IOTC-2010-ROS-R[E] on its Regional Observer Scheme and IOTC Resolution 10/04, at http://www.iotc.org/files/proceedings/2010/wros/IOTC-2010-WROS-R percent5BE percent5D.pdf; Domingo *et al.*, 2010).

However, there are cases where gathering quality information is not possible, even for a well-trained and motivated observer. For example, if the crew is forced to dump the catch, opening the sack by releasing the ortza (e.g. if a set is prolonged because of a malfunction, and the catch spoils in the water, or if the vessel completes its load and has no more storage space), then the observation will be of very poor quality with regard to species composition and quantity.

If the bycatch is thrown overboard from the deck, then the observation could be quite accurate for species taken in small numbers (e.g. billfishes, sharks), or accurate in composition but poor in the quantitative sense (e.g. large catches of small fishes such as triggerfishes) when only a weight can be seen.

Information on the catches of tuna purse seiners can be obtained from programmes sampling the landings of the vessels – the species composition of the catch, together with information on length frequency distributions, sex ratios, and in some cases reproductive and age data. However, this information does not provide a complete idea of the impacts of the fishery on the target species, and on other components of the ecosystems. Bycatch is occasionally reported by the fishers, but it is widely believed that only well-designed observer or electronic monitoring programmes can show the overall impacts with some accuracy.

Observer programmes are expensive and complex, and their level of coverage varies widely across the t-RFMOs (Table 12). In the EPO, the IATTC has been placing observers in 100 percent of the trips by seiners larger than 363 tonnes of capacity since 1993, following the requirements of an international agreement signed by many States

TABLE 12

Observer coverage

	EPO	WPO		Indian Ocean						Athlantic Ocean					
1979	29.3														
1980	29.6														
1981	28.2														
1982	25.2														
1983	n/a														
1984	13														
1985	21														
1986	29.8														
1987	47.9														
1988	42.3														
1989	51.5														
1990	52														
1991	53.2														
1992	96.2														
1993	100														
1994	100	2.0	1.5												
1995	100	2.0	3.6												
1996	100	3.0	5.7												
1997	100	3.0	4.9												
1998	100	3.0	5.6												
1999	100	2.0	3.1												
2000	100	4.0	3.5												
2001	98.2	5.0	4.8								9.6	13.4	7.5	10.0	8.4
2002	99.3	7.0	8.2								13.3	16.8	20.4	12.2	17.3
2003	99.3	6.0	8.2	2.3	4.0	1.4	2.4	2.4	2.7	1.5	23.2	21.9	20.9	32.7	24.6
2004	100	11	10.9	4.9	8.0	2.3	3.2	1.6	2.6	1.8	19.8	15.4	15.7	31.1	21.8
2005	100		7.7	3.7	6.7	3.6	3.0	2.9	4.5	3.7	11.6	8.5	18.1	20.1	19.1
2006	100		2.1			3.9	4.2	2.3	3.5	3.6					
2007	100					8.1				6.2					
2008	100														
2009	100														
UNIT	trips	sets	days fish	days	sets	sets	days	sets	sets	sets	days	trips	schools	obj. S	all sets
Ref	1	2	3	4	4	5	6	6	7	8	9	9	9	9	9

[1] Hammond and Tsai, 1983;
Hammond, 1984;
Hall and Boyer, 1986;
IATTC Annual reports 1985;
AIDCP Reports, 1993

[2] Molony, 2005

[3] OFP 2008

[4] Sarralde *et al.*, 2006 (Spanish fleet)

[5] Amande *et al.*, 2008

[6] Gonzalez *et al.*, 2007 (Spanish fleet)

[7] Sanchez *et al.*, 2007 (Spanish fleet)

[8] Amande *et al.*, 2010

[9] Sarralde *et al.*, 2007 (Spanish fleet)

to reduce dolphin mortality with a system of individual vessel mortality limits (the Agreement on the International Dolphin Conservation Program).

The only way to control the dolphin mortality of each vessel accurately was with full coverage of all trips of all flags. This leaves only the smaller seiners uncovered by the IATTC, but, in some cases, national programmes are providing some level of coverage (Dreyfus-León, Vaca-Rodríguez and Compeán-Jiménez, 2000). Prior to that, the EPO observer programme was initiated by the United States National Marine Fisheries Service during the 1960s when a few isolated trips were covered in United States-flagged vessels to monitor dolphin mortality. Beginning in 1972, the programme was expanded, and in 1979 the IATTC started sharing the observer coverage for the United States fleet. With the growth of fleets flagged in other countries, the IATTC share of the total sample increased (IATTC, 2008). In the WPO, coverage is going to be raised to 100 percent very soon. The Indian and Atlantic Oceans have observer coverage targets of 10 percent of their trips. In the Indian Ocean, coverage increased from 2 percent of fishing days in 2005 to 8 percent in 2007 (Amandè *et al.*, 2008b; Ariz *et al.*, 2010), and a Regional Observer Scheme has recently been adopted (IOTC-2010-ROS-R[E] and IOTC Resolution 10/04).

One of the problems of low sampling coverage is that, as the different fleets use different strategies, it is very easy to have a sample that is not well balanced, and does not have the right proportions of the different set types or modalities. Stratification can help solve these problems, if the numbers of samples in each stratum is adequate. An illustration of this is shown in Table 12 where the observer coverage of the regions is listed. Sarralde *et al.* (2007) present values for the Spanish fleet in the Atlantic that allows the calculation and comparison of coverage in units of trips, days fished, sets by type and all sets combined. Some of these values are reasonably similar, but the coverage of school sets is more than double the coverage of trips (31.15 percent vs 15.4 percent). This is because of operational preferences, and seasonal variability. Exploring the reasons for these discrepancies helps to understand the operational characteristics of the fleets. Another problem caused by low sampling coverage is the inability to record rare events with high mortality that may be significant in population terms, or the production of large overestimates if a rare event is sampled.

All observer programmes collect information on the vessel, gear, fishing operations, catch, bycatch, etc., and much of this is useful for estimation of bycatch or comparative studies of the effect of gear or practices on bycatch rates (Herrera and Evrat, 1998; Ariz *et al.*, 2010).

COMPARISON OF THE DATA COLLECTED BY THE DIFFERENT OBSERVER PROGRAMMES

The observer programmes from the different t-RFMOs have been mentioned above. Appendix 1 compares the data they collect on the different fleets. An obvious need for improved science and management would be to make sure that all programmes collect the same information, using similar definitions, etc. Consistency would enable comparisons across oceans.

The observer data from all t-RFMOs can be divided into several groups of data:

- vessel, gear, and trip data;
- set information;
- effort data (search);
- catch and bycatch;
- floating object characteristics – FADs.

The fields in red are only applicable to IATTC data and they are related to the tuna–dolphin issue, so they are specific to the EPO. For example, the nets of vessels that fish on dolphins, have a special section called a “dolphin safety panel” that is added to the net to reduce entanglements of dolphins. Information on other equipment and their utilization is also linked to this problem.

However, the rapid development and the changing nature of the FAD fishery have resulted in information gaps (Dempster and Taquet, 2004) that may make it more difficult to understand the causes of bycatch. These gaps are being addressed to some extent, but the transition in focus causes lags even in identifying which information is needed for the new objectives. The collection of information on FADs has been significantly improved in recent years (see the floating object observer form in Appendix 2).

What information is especially relevant to bycatch issues? Besides the typical requirements for fisheries studies, additional data may be of use for bycatch studies, and many of these variables are not being collected:

- Detection equipment: Acoustic systems may provide information on the composition and size distribution of the schools to be set on, prior to setting.
- All the characteristics of the net and of the vessel that affect the speed of net hauling are important (dimensions of net, power of winches, etc.).
- FAD characteristics in detail, including underwater components.
- Whether there is towing of the FADs out of the area encircled or not.
- Presence and use of sorting grids.
- Description of the brailers, and other equipment involved in the brailing process.
- The characteristics of the sorting process on board.
- The systems used to return the bycatch to the water.
- The training of the crews. There is no current training concerning handling bycatch, but it needs to be developed.

8. Estimating bycatch

To estimate the total bycatch of a fleet in a period there are several options: (a) estimate a ratio expressing the bycatch per unit of effort (BPUE) (set), or per tonnes of tuna captured or retained, and extrapolate it to the total amount of effort by the fleet in sets, or the total tonnage captured or retained (Hall, 1999; Borges *et al.*, 2004); (b)develop a model from observer data to predict the bycatch in unobserved sets; (c) estimate total mortality of a population, and subtract an estimate of natural mortality where available, with the traditional fisheries methods; and (d) use tagging methods. Costs or logistic difficulties have limited most of the research to methods (a) and (b). Extrapolation based on observer data is the most common method in use in the tuna fisheries. Useful discussions of design issues, and of options utilized to estimate different bycatches can be found in: Hall and Boyer (1986); Matsuoka (1999); Hall (1999); Lawson (2001, 2006a); Babcock, Pikitch and Hudson (2003); Borges, Olim and Erzini (2003); and Bravington, Burridge and Toscas (2003).

The total tonnage retained (total catch) can be obtained from landing information; the other totals should come from other sources. The ratios must be observed at sea. Therefore, in order to estimate bycatch, it is necessary to make observations at sea, during the fishing operations. An additional statistical consideration is that the sampling units in observer programmes are usually trips, and a low coverage of trips may leave many gaps in the spatial–temporal coverage, besides introducing covariation in the data.

The issues of sampling units to utilize (trips, sets, etc.) and of alternative sampling designs require significant consideration in order to optimize the use of resources (Stratoudakis *et al.*, 2001; Stratoudakis *et al.*, 1999; Lennert-Cody, 2001; Allen *et al.*, 2002; Borges *et al.*, 2004; Borges *et al.*, 2005; Lawson, 2010), although practical reasons make the trip the most common unit for observer programmes. Potential biases to consider in observer programmes include non-representative practices in the presence of the observer (an "observer effect"), and pressures on the observer to affect reports (Liggins, Bradley and Kennelly, 1997; Lawson and Williams, 2005; Lennert-Cody and Berk, 2005; Benoit and Allard, 2009). These issues must be added to the usual precision and reliability problems arising from observer coverages, which are frequently very limited, or not distributed in an effective way (Pianet, Pallarés and Petit, 2000; Lawson, 2004a, 2006a; Cotter and Pilling, 2007). Fonteneau *et al.* (2008, 2009), and Lawson (2008) provide a list of potential biases affecting the sampling of catches by observers or port samplers, and many of these may apply also to bycatch. The variability of bycatch of the tuna species that are the object of the fishery is influenced by even more factors (Rochet and Trenkel, 2005).

The sources of information are limited to human observers (fishers or on-board observers) or electronic means. To date, it has not been possible to develop electronic monitoring systems able to produce the data needed in this fishery, but the experimentation needed for their development has begun. In some cases, it may be possible to ask fishers to report on bycatch, but these happen at the moment of maximum activity in the vessel, and there is also a potential conflict of interest; hence, scientific observers have been the only source of data for the estimates.

To obtain bycatch estimates of a given precision for a species would require a level of coverage that would depend on its statistical distribution (Lawson, 2006a; Pianet, Pallarés and Petit, 2000; Lennert-Cody, 2001; Babcock, Pikitch and Hudson, 2003; Sánchez *et al.*, 2007), assuming that a series of assumptions are valid (Rochet and

Trenkel, 2005). Some species are present in many sets in small numbers; others show a large number of zeroes, and some very large figures in a few sets (Fletcher, Mackenzie and Villouta, 2005; Kawakita *et al.*, 2005; Minami *et al.*, 2007; Amandè *et al.*, 2008b; Shono, 2008). In other cases, it is not possible to differentiate missing record of zeroes when relying on logbooks (Andrade, 2007). To obtain good estimates for all species would require a level of observer coverage determined by the rare species, with the "worst" distributions, and this would be very costly.

Except for the IATTC programme that has 100 percent coverage for the larger seiners, all other observer programmes require statistical procedures to estimate the totals from samples that are in some cases very limited (Lawson, 2006b). In the case of the IATTC, some estimation is needed for trips missing in the database (e.g. data on bycatch not provided by national programmes in earlier years), and there is a fleet of smaller seiners that is not covered in total (Dreyfus-León, Vaca-Rodríguez and Compeán-Jiménez, 2000; Lennert-Cody, 2001; Sánchez *et al.*, 2007). As data provision by the national programmes is practically complete, the estimation error shrinks. Coverages of the order of 10–33 percent have been estimated as adequate to reduce some biases, and to provide a reasonable level of precision for some species (Lawson, 1997; Hall, 1999; Lennert-Cody, 2001; Babcock *et al.*, 2003; Lawson, 2006a; Sánchez *et al.*, 2007; Amandè *et al.*, 2010a) based on simulations, or on the characteristics of the statistical distributions.

The traditional approach has been the use of ratio estimates using the tonnage caught in a set, or simply the average capture per set, and extrapolated to fleet totals (Lo, Powers and Wahlen, 1982; Hammond, 1984; Stratoudakis *et al.*, 1999). Frequently, this is applied with a stratification scheme, or with a procedure of post-stratification. Ratio estimates are frequently biased at low sample coverage, and there are corrected formulas or procedures to deal with the biases (Rao, 1969; Cochran, 1977; Efron, 1982; Hall and Boyer, 1986; Efron and Tibshirani, 1993; Stratoudakis *et al.*, 1999). As mentioned above, other approaches are being developed to address the issues of the high number of zeroes in some distributions (Minami *et al.*, 2007; Shono, 2008; Yee, 2010; Li, Jiao and He, 2011).

Given the very heterogeneous nature of the fishing operations, the data need to be stratified (Hall and Boyer, 1986; Lennert-Cody, 2001; Amandè *et al.*, 2008b; Chassot *et al.*, 2009). In order to stratify, and to standardize results, critical information on the vessels, gear and operations are needed (e.g. Matsumoto *et al.*, 2000; Gaertner and Pallares, 2001; Lawson, Coan and Hinton, 2002; Itano, 2004).

Some of the classifications that could be used to stratify are presented in the following sections.

STRATIFICATION BY TYPES OF SETS

This is an obvious variable to use, but the level of partition within each type of set is not clear, and it has to be discussed. The distributions of set types, mentioned above, are important for understanding the differences among ocean basins.

Dolphin sets

These sets are only significant in numbers in the EPO. Yellowfin tuna associates with different dolphin species, and there is some geographical separation in the different associations. In the past, sets on common dolphins, and sets on pure groups of spotted dolphins, or mixed groups of spotted and eastern spinners have been kept as separate strata because the behaviour of the different groups resulted in different mortality rates for the dolphins. However, that stratification was only meaningful for dolphin mortality estimates. In any case, bycatch of other species in dolphin sets is so low, and limited to the EPO, that this issue is not a significant one for most of the species.

Floating object sets

The major categories are anchored versus drifting objects. This stratification of anchored versus drifting is expected to have some impact on the Western and Central Pacific, where sets on payaos are of significant magnitude (OFP, 2010a). In the other oceans, the proportion is much lower, to the point of probably being negligible.

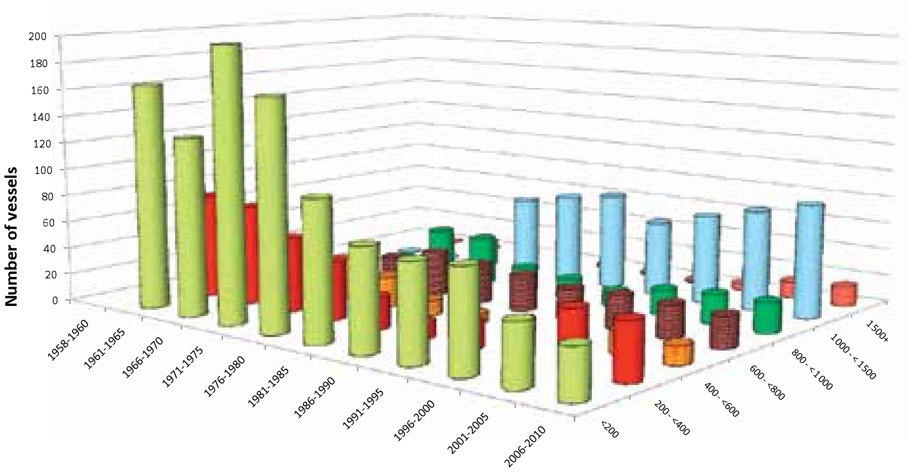
Beyond this, the level of stratification needed to separate meaningful units is not obvious. Are typical FADs the same as "encountered" logs with regard to catch and bycatch, even when all other sources of heterogeneity are accounted for? Are objects with netting hanging underneath (FADs), equivalent to objects without it (logs)? Which characteristics of FADs or logs make a difference? There are many different designs of FADs in use (Itano, Fukofuka and Brogan, 2004), but as the fishery is relatively new, there is still development, innovation and imitation.

The largest category of logs is a broad and ill-defined set including a very large number of objects of anthropomorphic origin (crates, pallets, lost fishing gear, etc.), or plant materials (tree trunks, branches, etc.). There is another group of dead animals (whale sharks, sharks, very few whales, and other animals including pinnipeds as the main group). Sets on live whales are only a handful, so it is not a sample large enough to make comparisons. Cooperative fishing between a seiner and a bait boat is not frequent. A more detailed list of the natural objects and artefacts that attracted tunas is shown in Hall *et al.* (1999a). Stratifications for this period would have been quite complex, not having adequate samples of some combinations to determine which types could be pooled together.

Frequently, the types of sets are not mixed at random in time or space. There are areas and seasons where one type of set is prevalent, and some other type may be completely absent (e.g. Figure 27), and this is a confounding effect that complicates the statistical comparisons.

FIGURE 57

Distribution of the tuna purse seine fleet by size class in the Eastern Pacific Ocean, 1961–2010



OTHER POSSIBLE STRATIFICATION VARIABLES

Different stratification schemes have been utilized for estimation in the different fisheries. Besides set type, the flag of the vessel has frequently been used where there is a variation in the operational mode by fleet.

- Season and areas: frequently, the fleets operate in different areas and/or ecoregions in different seasons, following oceanographic changes, migrations (Hall and

Boyer, 1986; Pianet, Pallarés and Petit, 2000; Sibert, 2005). These are the most obvious choices when detailed data on the location and date of the fleet operations are known. Vessels without observers may have their activities reported through a vessel monitoring system (VMS) that could provide information on the fishing grounds visited in a trip, and exact locations for sets.

- Flag of the vessel: frequently, it is associated with differences in equipment, fishing modalities, fishing areas, base ports, etc. (e.g. Figure 56).
- Vessel capacity: the smaller seiners tend to operate closer to the coast, the nets are smaller, etc., so their capture rates, and the species composition of the captures may be different. Vessel size and/or tonnage may affect both catch and bycatch rates, and they have changed over time (Figure 57).
- Gear characteristics: for example, net depth, acoustic equipment, presence of sorting grid.
- Vessel characteristics relevant to bycatch: brailer size, method to handle discards, etc.
- FAD characteristics: presence and depth of netting, etc.

Some of these characteristics are applied on a set-by-set basis (e.g. location), others are for a full trip (e.g. net depth). Thus, the level of detail needed in order to stratify will limit the application of some to observed trips, unless other sources such as VMS systems can fill in the data needs.

OBSERVER ISSUES AND ESTIMATION

Although observer data are by far the best for estimating bycatch, they are very far from perfect, and they offer a variety of problems that need to be considered when judging the quality of the data produced (e.g. Lawson, 2004b; Lawson and Williams, 2005). A full treatment of this subject would require a very long review, but some of the problems are covered briefly here.

Potential errors:

- Identification of species: The observers must identify a number of species in each set. Not all species are easy to identify, or the training of the observers may have been insufficient, but it is possible that individuals are assigned to the wrong species. A case in mind is the discrimination between juvenile yellowfin and bigeye tunas, which is problematic even for experts (Lawson and Williams, 2005; Fonteneau *et al.*, 2009). Good training and good identification aids are needed to address this issue.
- Misjudgement of quantities: Observers are asked to produce estimates of numbers or tonnages of the different species. Sometimes these values must be examined at some point during the loading operation, and it is not a trivial exercise.
- Misjudgements of sizes: Again, fish sizes must be examined in many cases, to allocate the quantity to size groups.
- Misjudgement of condition: In some cases, the observers are asked to state the condition of an individual to be released, without the proper training to judge the condition, or without the possibility of making a close examination.
- Impossibility to observe simultaneously all discards that may be originating from different locations of the vessel.
- All other errors, including positions, time of day, gear descriptions, etc.
- Potential biases:
- Representativeness: If the observer programme is voluntary, it is possible to avoid areas or conditions that lead to high bycatch when an observer is present. Comparison of the spatial distributions of effort in vessel with and without observers, or of other characteristics of the trips and their catches may show the presence of these biases.

- It is also possible that the mitigation equipment and actions are affected by the presence of the observer, with the crew becoming much more attentive to the release of bycatch, to the use of mitigation equipment, etc. This is an issue only in some fisheries, where there is an opportunity for the crew to affect survival of the individuals taken incidentally.
- Attempts to influence or alter the observer reports. Through bribes or intimidation, the skipper or crew may try to affect the observer reports. When there are many data for each observer, it is possible to compare the individual results with the rest of the observer population in order to detect anomalies (Lennert-Cody and Berk, 2007).

9. Species taken in association with tropical tunas

The group of species taken in floating object sets is remarkably similar in most oceans, reflecting the similarity of the pelagic communities in the open oceans throughout the world (Bailey, Williams and Itano, 1996; Stretta *et al.*, 1997; Arenas, Hall and García, 1999; Williams, 1999; Castro, Santiago and Santana-Ortega, 2002; Romanov, 2002; Taquet *et al.*, 2007b; Molony, 2008). At the same time, it is not easy to determine how different the communities associated with floating objects are, when comparing them with the communities not associated with them. School sets may help show the differences, but there is not really any kind of "random' sampling of the pelagic ecosystem, away from the objects, to study the differences. School sets have the bias that they occur under some special circumstances, and the schools are detected by the behaviour of the tunas. Comparison with catch by other gear types are not always adequate, as the operations can be different (e.g. longline catches are made on hooks, and frequently in much deeper waters). Some species have a strong association with floating objects (e.g. mahi-mahi [*Coryphaena hippurus*]), while others are seldom found in association with them (e.g. blue sharks [*Prionace glauca*], and leatherback sea turtles [*Dermochelys coriacea*]).

The group of species captured incidentally in school sets is considerably shorter. As these sets result from detection of schools of tuna engaged in feeding or other surface activities, not many species can maintain the cruising speed of the tuna schools. Similarly, the incidental captures in dolphin sets are very low, and limited to a few species. In this case, not only the other individuals have to keep up with the tuna school, but they must also stay with it during the chase of the dolphin–tuna group by the speedboats that precedes the set (median time about 15–20 minutes).

It should be noted that the data obtained by observers do not represent the totality of what was associated with the object (Massutí, Morales and Deudero, 1999). Small species or individuals may escape through the meshes, sometimes with injuries. Some species may avoid capture by diving before the net is closed at the bottom. The estimates of weights or numbers of triggerfishes and other small pelagic species may be absent, or only partial, with much guesswork.

Some authors have tried to classify the fishes associated with an object in groups based on their proximity (Parin and Fedoryako, 1999; Fréon and Dagorn, 2000). From the point of view of their capture, this classification does not make much difference, as they are all retained in the seine, given the dimensions of the net.

In the following sections, the bycatch of the different groups is reviewed. Using the databases available at the IATTC, four tables were prepared, summarizing the information on the numbers and tonnages captured (capture) and discarded dead or presumed dead (bycatch) for the period 1993–2009. To simplify the presentation, some minor or unidentified taxa were removed, but they do not constitute a major fraction of the total. As the observer programme functioned at levels very close to 100 percent for most of the period, the presentation is limited to the point estimates, with the understanding that the errors are negligible.

To present the data available for the EPO, a set of tables is included. Tables 13 and 14 show the tuna data in tonnes for: capture per set, bycatch per set, percentage bycatch, and total tonnage discarded for yellowfin, skipjack, bigeye tunas, and all three species combined, by type of set for 1993–2009. Tables 15–30 summarize the captures and bycatch of all other species:

- Tables 15–18: capture in numbers;
- Tables 19–22: bycatch in numbers;
- Tables 23–26: capture in tonnes;
- Tables 27–30: bycatch in tonnes.

TABLE 13

Capture and bycatch per set for each of the three major tuna species in the Eastern Pacific Ocean

YELLOWFIN TUNA																		
Year	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Avg. all Years**
Dolphin Sets																		
Capture/set	15.9	16.9	19.2	19.1	17.1	14.6	17.0	17.4	25.7	25.5	21.2	16.4	14.5	11.5	12.1	14.5	16.6	17.6
Bycatch/set	0.0	0.1	0.3	0.1	0.1	0.1	0.1	0.0	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1
% Bycatch	0.3	0.6	1.5	0.7	0.4	0.4	0.3	0.3	1.0	0.4	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.4
Total Bycatch	271	577	2 545	879	620	709	471	397	2 463	1 289	1 503	346	166	121	216	368	296	779
Floating Obj. Sets																		
Capture/set	8.4	7.8	5.5	6.3	5.0	4.6	9.9	13.0	11.1	6.2	6.0	5.6	5.0	5.0	4.9	4.8	4.7	6.4
Bycatch/set	1.5	1.3	0.7	1.1	0.7	0.5	1.2	1.4	0.6	0.3	0.7	0.4	0.4	0.2	0.1	0.1	0.1	0.5
% Bycatch	18.2	16.3	13.7	17.3	15.1	11.6	12.1	10.7	5.2	5.0	11.0	6.4	8.4	3.7	3.0	1.8	2.5	8.6
Total Bycatch	3 158	3 337	2 579	4 394	4 483	3 183	5 282	5 099	3 525	1 788	3 608	1 782	2 041	1 325	890	609	800	2 817
School Sets																		
Capture/set	12.2	9.5	8.3	8.5	9.8	13.1	9.6	8.6	17.7	12.7	10.9	9.8	7.2	3.3	5.2	3.0	3.8	8.3
Bycatch/set	0.3	0.2	0.0	0.2	0.1	0.2	0.1	0.1	0.3	0.2	0.1	0.2	0.1	0.0	0.2	0.0	0.1	0.1
% Bycatch	2.1	1.7	0.5	2.4	1.3	1.4	1.5	1.6	2.0	1.7	1.3	1.6	1.3	0.8	2.9	0.2	2.1	1.6
Total Bycatch	1 313	617	151	1 039	413	806	794	711	1 040	1 063	839	881	722	219	840	42	358	697
SKIPJACK TUNA																		
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all Years
Dolphin Sets																		
Capture/set	0.1	0.1	0.4	0.3	1.0	0.5	0.2	0.1	0.2	0.3	1.1	1.0	1.1	0.5	0.4	0.9	0.3	0.5
Bycatch/set	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Bycatch	12.7	2.6	8.6	7.3	1.2	0.8	6.5	3.6	13.9	2.2	11.8	1.6	1.4	0.6	0.4	0.8	0.7	3.9
Total Bycatch	84	27	319	204	127	34	125	18	232	69	1676	156	150	19	10	50	35	196
Floating Obj. Sets																		
Capture/set	20.4	20.4	24.8	21.6	22.6	21.7	42.5	35.2	22.7	22.2	32.5	25.4	28.1	27.4	18.3	21.8	21.6	25.2
Bycatch/set	4.0	3.6	4.4	6.0	5.4	3.8	5.0	5.1	2.1	2.0	3.4	3.2	3.0	1.5	1.0	0.9	0.8	3.0
% Bycatch	19.8	17.6	17.6	27.7	24.0	17.3	11.8	14.4	9.5	9.2	10.6	12.5	10.6	5.4	5.4	4.1	3.7	11.7
Total Bycatch	9 939	9 513	14 904	23 464	30 198	20 880	22 554	18 715	12 265	11 733	19 081	15 868	14 852	11 091	6 222	6 142	5 940	14 904
School Sets																		
Capture/set	2.6	2.9	5.4	4.7	3.9	3.8	11.4	13.1	2.7	5.9	9.3	8.9	11.7	10.0	9.5	17.9	11.6	8.8
Bycatch/set	0.1	0.2	0.3	0.2	0.3	0.4	0.7	1.2	0.1	0.2	0.3	0.2	0.3	0.1	0.1	0.5	0.2	0.3
% Bycatch	4.6	7.2	5.7	4.5	7.5	11.1	6.1	9.5	3.8	3.6	3.1	2.6	2.8	1.4	1.3	2.8	1.3	3.8
Total Bycatch	659	986	1 150	835	1 012	1 730	3 367	5 775	318	704	1 696	1 158	2 226	1 293	927	2 974	826	1 626
BIGEYE TUNA																		
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all Years
Dolphin Sets																		
Capture/set	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	0.0	0.0	0.0
Bycatch/set	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	0.0	0.0	0.0
% Bycatch	0.0	66.7	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	0.9
Total Bycatch	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
School Sets																		
Capture/set	0.6	0.2	0.6	0.7	0.4	0.3	0.2	0.3	0.1	0.2	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.3
Bycatch/set	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	0.0	0.0	0.0
% Bycatch	3.4	7.1	0.4	1.1	0.7	1.7	0.8	4.9	3.1	2.2	2.2	0.5	9.7	0.8	1.2	0.2	0.0	2.4
Total Bycatch	85	53	7	25	7	14	8	53	11	23	35	5	130	57	7	6	0	31
Floating Obj. Sets																		
Capture/set	3.6	10.5	10.8	14.2	10.5	7.6	12.1	23.9	9.7	7.8	9.3	11.4	10.7	9.6	9.2	10.1	8.8	10.5
Bycatch/set	0.3	0.9	1.0	1.5	1.0	0.5	1.0	1.5	0.2	0.2	0.4	0.3	0.4	0.2	0.2	0.3	0.2	0.5
% Bycatch	8.4	8.3	9.3	10.3	9.5	6.9	8.4	6.2	2.3	2.1	4.4	2.8	3.4	2.6	1.7	3.4	1.8	5.0
Total Bycatch	562	2 217	3 243	5 664	5 395	2 808	4 924	5 364	1 243	926	2 291	1 744	1 822	2 328	1 032	2 281	1 084	2 643

TABLE 14
Capture and bycatch per set for the three major tuna species in the Eastern Pacific Ocean

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg.all Years
Dolphin sets																		
Capture/set	15.9	17.0	19.6	19.4	18.2	15.1	17.2	17.5	25.9	25.8	22.3	17.4	15.6	11.9	12.5	15.4	16.9	18.2
Bycatch/set	0.1	0.1	0.3	0.2	0.1	0.1	0.1	0.1	0.3	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1
%Bycatch	0.4	0.6	1.7	0.8	0.5	0.4	0.4	0.3	1.1	0.4	1.0	0.2	0.2	0.1	0.1	0.2	0.1	0.5
Total Bycatch	355	604	2 864	1 082	748	743	579	415	2 695	1 358	3 179	502	316	140	226	418	331	975
Floating Obj. Sets																		
Capture/set	32.5	38.7	41.1	42.0	38.0	34.0	64.4	72.0	43.5	36.1	47.8	42.3	43.8	42.0	32.4	36.8	35.1	42.1
Bycatch/set	5.9	5.7	6.1	8.5	7.2	4.8	7.2	7.9	2.9	2.5	4.5	3.9	3.8	1.9	1.3	1.3	1.1	4.0
%Bycatch	18.1	14.8	14.9	20.3	18.8	14.2	11.2	11.0	6.8	6.9	9.4	9.1	8.6	4.5	0.4	3.6	3.1	9.6
Total Bycatch	13 659	15 067	20 726	33 522	40 077	26 870	32 760	29 178	17 033	14 447	24 979	19 394	18 715	14 744	8 144	9 032	7 824	20 363
School Sets																		
Capture/set	15.3	12.5	14.3	13.9	14.1	17.1	21.2	21.9	20.6	18.8	20.5	18.9	19.1	13.4	14.8	21.1	15.5	17.4
Bycatch/set	0.4	0.4	0.4	0.4	0.4	0.6	0.8	1.4	0.5	0.4	0.4	0.4	0.4	0.2	0.3	0.5	0.2	0.5
%Bycatch	2.6	3.1	2.5	3.0	3.0	3.6	3.9	6.4	2.2	2.3	2.1	2.0	2.3	1.3	1.9	2.4	1.5	2.7
Total Bycatch	2 057	1 657	1 309	1 898	1 432	2 550	4 169	6 540	1 369	1 789	2 570	2 044	3 078	1 569	1 774	3 022	1 184	2 354

TABLE 15
Capture in numbers, all species in the Eastern Pacific Ocean, 1993–2009 – dolphin sets

Dolphin sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Sailfish	693	360	387	442	320	1.070	720	816	540	758	1.088	644	960	825	971	1.052	748	729
Blue marlin	64	55	51	58	86	77	81	84	72	71	115	68	133	88	76	81	154	83
Black marlin	60	57	71	70	48	64	73	129	117	111	175	114	130	98	87	78	58	91
Stripped marlin	125	32	65	125	76	98	63	45	28	66	104	120	195	137	114	129	92	95
Unid. & Others	120	42	38	103	28	55	42	73	41	47	58	36	48	74	66	94	68	61
Total	1 061	546	611	797	558	1 365	979	1 148	799	1 052	1 538	982	1 466	1 222	1 314	1.434	1 120	1 058
Mahi mahi	222	111	801	402	64	225	210	715	938	323	295	692	785	164	341	727	429	438
Wahoo	53	478	254	23	1.179	1.789	35	96	56	43	75	92	183	310	99	178	54	294
Rainbow runner	2	1	7	1	1	18	3	44	2	4	0	0	24	23	0	120	5	15
Yellowtail	49	1.709	0	0	4.317	8	0	10	45	20	103	38	2	4	1	0	3	371
Total	327	2 299	1 063	426	5 561	2 040	249	865	1 041	389	472	821	994	501	441	1 024	491	1 118
Silky shark	2 191	1 468	6.694	1 872	1 967	5 693	2 548	1 036	3 882	1 465	1 899	2 311	1 459	835	1 251	1 171	1 103	2 285
Unid. & Others	632	513	997	4 344	280	336	349	4 767	223	264	413	328	232	290	440	231	842	911
Whitetip shark	298	170	724	350	212	183	72	42	21	36	19	14	5	7	2	9	37	129
Hammerhead shark	312	76	76	96	88	181	112	466	67	127	108	96	58	66	56	53	36	122
Total	3 433	2 227	8 491	6 662	2 547	6 393	3 080	6 311	4 192	1 892	2 438	1 749	1 754	1 198	1 749	1 464	2 018	3 447
Mantaray	509	375	555	385	396	338	480	1 349	570	1 119	1 350	535	657	1 011	597	387	792	671
Stingray	134	205	144	176	993	170	151	160	174	153	135	86	173	202	133	100	122	201
Total	643	579	699	561	1 399	598	631	1 509	744	1 272	1 485	621	831	1 213	730	488	914	872
Olive ridley	13	13	14	9	7	20	9	11	4	7	3	2	4	3	3	0	2	7
Unid. turtle	2	9	3	2	2	7	3	2	5	2	3	0	1	0	2	0	1	3
Green/bjack turtle	0	0	1	0	2	1	4	0	0	0	0	0	0	0	0	0	0	0
Loggerhead turtle	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Hawkbill turtle	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Leatherback turtle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	15	23	18	12	12	28	17	13	9	9	6	2	5	3	5	0	3	11

TABLE 16

Capture in numbers, all species in the Eastern Pacific Ocean, 1993–2009 – school sets

School sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Sailfish	1 121	1 011	489	275	428	785	582	746	1 387	322	1 710	401	226	301	708	135	78	630
Blue marlin	108	137	82	78	166	66	145	211	133	432	128	107	118	120	95	99	63	135
Black marlin	143	75	75	89	73	84	144	181	69	148	82	68	70	127	76	57	27	93
Stripped marlin	145	95	116	154	146	55	77	88	91	540	150	66	147	260	101	181	20	143
Unid. & others	106	18	48	39	30	23	45	44	62	16	108	26	27	53	92	86	24	50
Total	1 622	1 336	810	635	844	1 014	994	1 270	1 743	1 457	2 179	667	588	860	1 071	558	212	1 051
Mahi mahi	13 481	7 991	23 055	7 617	5 629	5 879	179	19 323	8 130	4 349	4 083	7 789	19 855	19 895	21 243	5 284	1 790	10 423
Wahoo	6 399	629	282	329	1 609	317	250	827	1 050	292	231	446	493	557	856	633	137	896
Rainbow runner	38	31	12	10 443	3 154	156	202	2 654	159	582	600	103	395	540	330	107	0	1 147
Yellowtail	35 067	4 258	19 484	153 652	3 837	2 924	46 435	17 975	60	2 774	197	3 490	2 132	52 161	27 081	34 796	1 518	23 937
Total	54 986	12 911	42 833	172 041	14 229	9 276	48 676	39 879	9 390	7 997	5 110	11 828	22 875	73 153	49 510	40 719	3 445	36 403
Silky shark	14 337	9 677	4 376	3 585	8 795	1 632	4 091	3 950	2 410	4 156	3 262	3 259	1 249	1 658	4 526	1 017	662	4 273
Unid. & others	1 063	3 353	1 403	1 165	490	351	262	2 378	429	999	637	768	400	1 081	965	425	354	972
Whitetip shark	655	316	1 199	194	328	222	205	424	16	161	47	4	0	1	0	0	2	222
Hammerhead shark	652	817	437	900	376	559	782	551	66	235	301	716	290	201	200	234	77	441
Total	16 708	14 263	7 414	5 844	9 989	2 764	5 339	7 303	2 920	5 550	4 247	4 746	1 939	2 941	5 692	1 676	1 095	5 908
Mantaray	9 674	1 408	2 330	1 485	709	9 953	1 563	3 407	489	5 540	2 097	2 218	2 265	2 303	1 503	1 032	202	2 834
stingray	1 857	1 507	151	165	106	259	403	221	64	60	8 347	39	52	91	54	24	18	789
Total	11 531	2 915	2 481	1 650	816	10 212	1 966	3 628	553	5 600	10 444	2 257	2 317	2 394	1 557	1 056	220	3 623
Olive ridley	41	17	11	9	33	22	18	29	11	3	4	3	6	4	1	0	0	12
Unid. Turtle	16	2	7	6	15	8	4	9	14	5	0	2	7	0	0	0	1	6
Green/bjack turtle	13	9	2	1	3	1	2	0	2	0	0	0	1	0	1	0	0	2
Loggerhead turtle	4	2	2	0	3	0	3	0	0	0	0	0	0	0	0	0	0	1
Hawkbill turtle	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Leatherback turtle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	74	32	22	16	53	31	27	38	27	8	4	5	15	4	4	0	1	21

TABLE 17

Capture in numbers, all species in the Eastern Pacific Ocean, 1993–2009 – floating object sets

Log sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Sailfish	105	10	56	51	109	13	90	74	89	51	51	41	225	295	57	76	51	85
Blue marlin	605	477	564	482	892	1 088	1 538	864	1 074	1 308	1 405	1 072	1 537	1 283	891	913	1 226	1 013
Black marlin	490	376	401	423	650	694	835	442	778	703	968	421	665	1 001	504	528	484	609
Stripped marlin	404	179	109	57	110	100	277	75	106	218	133	87	140	224	203	124	156	159
Unid. & Others	6 41	162	106	80	80	86	139	38	56	66	95	74	71	272	123	148	85	137
Total	2 140	1 194	1 180	1 042	1 733	1 968	2 790	1 419	2 015	2 294	2 601	1 654	2 413	2 780	1 721	1 712	1 951	1 918
Mahi mahi	302 810	607 350	491 714	565 381	455 654	334 638	585 578	551 690	857 835	652 671	325 159	334 790	269 780	348 718	368 914	327 178	473 286	46 1950
Wahoo	78 720	338 363	233 553	149 474	320 104	223 641	149 912	157 983	571 102	688 803	292 769	190 345	210 827	214 227	214 963	126 929	269 715	237 143
Rainbow runner	17 153	15 402	11 035	36 073	79 780	180 246	189 547	85 902	103 467	113 342	165 582	73 853	74 965	98 401	226 975	42 900	55 454	92 357
Yellowtail	8 058	14 607	13 348	25 634	71 679	81 990	43 299	12 873	46730	15 579	45 111	95 066	24 162	42 428	14 274	48 192	21 298	36 725
Total	406 741	975 721	749 650	776 562	927 216	820 515	968 336	808 448	1 579 134	1 070 395	828 620	694 055	579 734	703 774	285 125	545 198	819 753	828 175
Silky shark	30 124	23 199	27 447	26 786	50 190	44 259	36 819	21 194	21 431	17 979	18 983	16 269	23 088	27 341	25 121	40 146	20 541	27 701
Unid. & Others	8 756	5 198	4 952	5 670	7 408	8 809	6 074	1 406	2 725	3 103	1 641	2 192	634	1 881	1 097	1 112	3 380	3 885
Whitetip shark	2 016	3 940	7 788	8 257	8 443	7 280	5 498	3 018	3 103	894	598	256	74	152	77	62	121	3 034
Hammerhead shark	760	1 875	1 374	1 646	1 742	1 140	1 580	502	1 064	2 258	2 574	2 264	1 256	891	570	583	587	1 333
Total	41 657	34 212	41 561	42 360	67 782	61 488	49 970	26 120	28 323	24 234	23 797	20 981	25 052	30 265	26 865	41 902	24 630	35 953
Mantaray	297	53	73	124	126	77	150	71	65	77	183	80	88	140	126	126	79	114
Stingray	80	140	159	101	106	97	164	104	150	113	94	138	91	153	98	113	70	116
Total	377	193	232	225	232	174	314	175	215	190	277	218	179	293	225	239	149	230
Olive ridley	24	50	66	47	54	66	82	46	51	23	16	8	7	8	6	3	9	33
Unid. Turtle	3	34	24	30	25	26	39	17	22	6	5	4	4	1	7	1	2	15
Green/bjack turtle	2	7	10	11	8	7	5	6	6	3	0	0	1	2	0	0	1	4
Loggerhead turtle	0	0	0	0	1	1	1	2	1	0	0	0	0	1	1	1	0	1
Hawkbill turtle	0	0	0	0	0	3	1	1	1	0	0	0	0	0	1	0	0	0
Leatherback turtle	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	29	93	100	88	88	103	128	72	81	32	21	12	12	12	15	5	12	53

TABLE 18

Capture in numbers, all species in the Eastern Pacific Ocean, 1993–2009 – set types combined

All sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Sailfish	1 919	1 382	932	767	857	1 868	1 392	1 636	2 017	1 131	2 849	1 086	1 411	1 420	1 736	1 263	877	1 444
Blue marlin	777	669	697	619	1 144	1231	1 764	1 160	1 279	1 811	1 648	1 247	1 788	1 491	1 061	1 092	1443	1 231
Black marlin	693	508	546	581	771	842	1 052	752	965	962	1 225	603	865	1 225	667	663	569	793
Stripped marlin	674	306	290	336	333	253	418	208	225	823	387	274	481	621	418	433	268	397
Unid. & Others	866	222	192	222	138	164	226	155	160	129	261	135	146	400	281	328	176	247
Total	4 929	3 087	2 658	2 525	3 243	4 359	4 852	3 911	4 646	4 855	6 369	3 344	4 692	5 158	4 164	3 780	3 333	4 112
Mahi mahi	316 514	615 452	515 571	573 401	461 347	340 742	587 577	571 729	86 6903	657 343	329 536	343 271	290 420	368 778	390 498	333 188	475 505	472 810
Wahoo	85 172	339 470	234 089	149 825	322 891	225 747	150 197	158 906	572 208	289 138	293 075	190 883	211 503	215 094	215 918	127 639	269 906	238 333
Rainbow runner	17 194	15 434	11 054	46517	82 935	180 420	189 753	88 600	103 628	113 927	166 181	73 956	75 385	98 964	227 304	43 126	55 459	93 520
Yellowtail	43 175	20 574	32 832	179 286	79 833	84 922	89 734	29 958	46 825	18 373	45 410	98 595	26 295	94 593	41 356	82 987	22 819	61 033
Total	462 054	990 930	793 546	949 029	947 006	831 831	1 017 261	849 193	1 589 564	1 078 781	834 203	706 704	603 603	777 429	875 076	586 941	823 689	865 696
Silky shark	46 652	34 344	38 518	32 243	60 952	51 583	43 457	26 180	27 722	23 600	24 144	21 839	25 796	29 834	30 898	42 334	22 307	34 259
Unid. & Others	10 451	9 065	7 352	11 178	8 178	9 497	6 685	8 551	3 377	4 365	2 691	3 288	7 266	3 251	2 503	1 768	4 576	5 767
Whitetip shark	2 970	4 426	9 710	8 801	8 982	7 685	5 775	3 483	3 140	1 091	664	274	79	160	79	71	160	3 385
Hammerhead shark	1 725	2 868	1 886	2 643	2 206	1 880	2 473	1 519	1 197	2 620	2 984	3 076	1 604	1 158	826	870	700	1 896
Total	61 798	50 702	57 465	54 866	80 318	70 645	58 389	39 734	35 436	31 676	30 482	28 477	28 745	34 403	34 306	45 043	27 743	45 307
Mantaray	10 490	1 837	2 958	1 994	1 231	10 368	2 193	4 827	1 123	6 736	3 630	2 833	3 010	3 454	2 227	1 545	1 074	3 619
Stingray	2 072	1 851	453	442	1 206	526	718	485	388	325	8 576	263	316	446	285	237	210	1 106
Total	12 552	3 688	3 412	2 436	2 437	10 894	2 911	5 312	1 511	7 061	12 207	3 096	3 326	3 900	2 512	1 732	1 284	4 725
Olive ridley	78	81	91	66	94	108	109	86	66	33	23	13	17	15	10	3	11	53
Unid. Turtle	21	46	34	38	42	41	46	29	41	13	8	6	12	1	9	1	4	23
Green/bjack turtle	15	16	13	12	13	9	11	6	8	3	0	0	2	2	1	0	1	7
Loggerhead turtle	4	2	2	0	5	1	4	2	1	0	0	0	0	1	1	1	0	1
Hawkbill turtle	0	2	0	1	0	3	2	1	1	0	0	0	0	0	3	0	0	1
Leatherback turtle	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	118	148	141	116	153	162	172	123	117	49	31	19	32	19	24	5	16	85

TABLE 19
Bycatch in numbers, all species in the Eastern Pacific Ocean, 1993–2009 – dolphin sets

Dolphin sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Sailfish	384	189	270	244	125	482	210	313	194	321	537	211	230	234	146	159	251	265
Blue marlin	21	20	26	24	7	10	14	18	29	14	44	9	15	22	3	1	8	17
Black marlin	12	9	15	11	1	7	7	5	4	10	6	3	9	2	2	6	11	7
Stripped marlin	83	23	21	63	7	29	9	30	20	27	25	5	10	8	18	3	1	22
Unid. & Others	37	10	35	37	4	8	3	7	6	7	8	0	6	8	1	2	6	11
Total	537	251	367	380	145	535	243	373	253	380	620	228	269	274	170	171	277	322
Mahi mahi	148	74	15 328	267	15	39	44	95	54	113	12	180	183	48	42	92	231	998
Wahoo	34	303	179	14	1 112	10	3	0	3	0	0	5	103	63	8	83	4	113
Rainbow runner	2	1	12	1	0	0	0	11	0	2	0	0	16	7	0	80	0	8
Yellowtail	28	974	11 107	0	3 891	0	0	0	0	0	103	185	0	0	1	0	1	947
Total	211	1 352	26 626	283	5 018	49	47	106	57	115	114	1 770	302	118	51	255	236	2 066
Silky shark	1 742	1 096	3 479	1 488	886	4 660	677	144	1051	212	685	111	265	267	94	166	33	1 101
Unid. & Others	469	378	1 077	3 397	195	204	201	4 532	48	178	224	1	121	72	268	91	62	684
Whitetip shark	267	153	1 075	313	80	88	20	8	10	13	1	16	1	2	0	1	2	120
Hammerhead shark	206	50	288	64	37	111	67	46	26	51	43	1 899	11	41	27	20	5	65
Total	2 684	1 677	5 920	5 262	1 198	5 062	965	4 730	1 135	454	953	511	398	382	389	278	102	1 970
Mantaray	488	355	2 234	369	369	318	473	792	554	1 084	1 309	86	635	989	571	364	773	717
Stingray	132	208	148	173	979	166	151	156	170	153	133	597	173	200	133	99	118	198
Total	620	556	2 381	542	1 348	484	624	949	724	1 237	1 442	2	809	1 189	704	463	891	915
Olive ridley	13	10	11	6	5	18	9	7	4	7	2	0	4	3	3	0	2	6
Unid. Turtle	2	7	7	2	2	6	3	2	5	2	1	0	1	0	2	0	1	3
Green/bjack turtle	0	0	2	0	2	1	4	0	0	0	0	0	0	0	0	0	0	1
Loggerhead turtle	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Hawkbill turtle	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Leatherback turtle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	15	18	20	9	10	25	17	9	9	9	3	2	5	3	5	0	3	10

TABLE 20

Bycatch in numbers, all species in the Eastern Pacific Ocean, 1993–2009 – school sets

School sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Sailfish	619	542	270	152	244	470	42	215	1 186	138	1 036	186	55	33	115	10	7	313
Blue marlin	50	26	26	31	8	15	23	21	28	52	16	19	9	25	7	4	3	21
Black marlin	21	24	15	15	10	5	23	17	5	29	7	6	5	3	28	7	1	13
Stripped marlin	69	7	21	23	6	4	15	13	28	7	89	6	6	9	24	7	0	20
Unid. & Others	44	29	35	46	10	4	13	1	25	4	9	8	30	5	8	7	1	16
Total	802	628	367	267	278	499	116	266	1 272	230	1 158	225	105	76	182	35	12	383
Mahi mahi	8 963	5 310	15 328	5 064	2 068	2 018	1 194	2 102	6 250	2 951	640	1 860	7 515	2 291	12 331	729	753	4 551
Wahoo	4 056	400	179	208	395	48	98	42	490	78	4	49	75	152	27	40	10	373
Rainbow runner	37	30	12	10 041	2 979	156	147	1 535	157	376	68	90	164	3	139	83	0	942
Yellowtail	19 991	2 428	11 107	87 592	811	2 409	3 557	1 330	40	2 439	183	8	946	253	16 006	1 983	500	8 917
Total	33 047	8 168	26 626	102 905	6 253	4 631	4 996	5 009	6 936	5 843	895	2 008	8 699	2 699	28 503	2 834	1 263	14 783
Silky shark	11 398	7 695	3 479	2 850	5 901	1 074	2 887	1 348	1 093	3 269	2 567	2 843	547	910	2 222	136	74	2 958
Unid. & Others	790	2 548	1 077	886	290	136	105	341	159	913	488	573	147	511	502	101	43	566
Whitetip shark	595	283	1 075	174	266	156	115	335	10	90	40	4	0	1	0	0	0	185
Hammerhead shark	430	599	288	594	140	326	71	218	33	172	266	197	153	113	55	62	14	219
Total	13 214	11 125	5 920	4 504	6 597	1 691	3 178	2 242	1. 95	4 444	3 360	3 617	848	1 535	2 786	299	131	3 929
Mantaray	9 273	1 345	2 234	1 423	605	9 941	1 467	3 328	478	5 210	2 071	2 153	2 239	2 289	1 487	1 019	201	2 751
Stingray	1 824	1 480	148	162	103	257	402	213	64	60	8 347	39	52	90	53	24	18	784
Total	11 097	2 824	2 381	1 585	708	10 198	1 870	3 540	542	5 269	10 418	2 192	2 291	2 379	1 540	1 042	219	3 535
Olive ridley	38	17	11	4	25	21	16	25	9	3	4	2	6	4	1	0	0	11
Unid. Turtle	15	2	7	3	15	8	4	9	14	4	0	2	6	0	0	0	1	5
Green/bjack turtle	13	9	2	1	3	1	2	0	2	0	0	0	1	0	1	0	0	2
Loggerhead turtle	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Hawkbill turtle	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Leatherback turtle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	66	32	20	8	43	30	23	34	25	7	4	4	14	4	4	0	1	19

TABLE 21
Bycatch in numbers, all species in the Eastern Pacific Ocean, 1993–2009 – floating object sets

Log sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Sailfish	58	6	31	28	65	4	24	22	27	24	20	21	65	157	7	15	13	35
Blue marlin	171	144	140	147	163	212	325	131	352	183	168	17	51	131	51	63	41	146
Black marlin	115	84	107	92	110	152	274	160	312	229	154	155	99	165	72	56	118	144
Stripped marlin	433	110	59	47	47	38	96	18	38	23	34	35	28	30	27	50	16	66
Unid. & Others	121	54	33	17	13	18	116	24	53	43	30	6	10	22	33	15	15	37
Total	898	397	369	332	399	425	836	355	782	502	406	234	253	505	190	199	204	429
Mahi mahi	201 323	405 206	326 916	375 941	295 672	199 244	422 317	351 784	585 977	407 490	173 258	135 996	88 796	132 074	120 502	199 013	138 797	263 548
Wahoo	49 818	215 206	148 040	94 736	196 993	116 203	110 146	84 123	392 367	128 824	162 254	45 446	49 437	62 202	56 129	30 097	70 232	118 372
Rainbow runner	16 492	14 800	10 609	34 682	72 985	173 946	184 900	82 418	97 726	107 259	163 488	64 805	70 726	93 068	223 167	37 380	51 553	88 236
Yellowtail	4 597	8 430	7 607	14 612	59 490	65 066	27 237	7 607	43 209	10 475	38 029	73 435	16 984	32 649	7 521	31 958	18 152	27 474
Total	272 310	643 643	493 173	519 971	625 140	554 459	744 600	525 932	1 119 279	654 048	537 029	319 682	225 942	319 999	407 319	218 449	278 734	497 630
Silky shark	23 948	18 516	21 825	21 296	32 392	37 739	27 846	16 200	17 299	15 947	17 140	12 478	16 035	16 536	9 708	11 290	10 910	19 241
Unid. & Others	6 777	4 315	3 844	4 432	3 997	8 609	2 894	1 020	1 751	1 721	1 430	568	512	768	797	936	367	2 621
Whitetip shark	1 805	3 562	6 990	7 415	7 467	6 383	4 864	2 583	2 987	824	502	194	72	149	70	46	93	2 706
Hammerhead shark	502	1 253	906	1 086	1 540	967	1 347	369	860	2 113	2 453	2 058	1 066	782	393	344	459	1 088
Total	33 032	27 465	33 564	34 230	45 396	53 697	36 951	20 171	22 898	20 605	21 525	15 298	17 684	18 235	10 967	12 616	11 829	25 657
Mantaray	285	51	70	119	123	77	149	71	61	77	181	79	85	137	125	121	79	111
Stingray	79	137	156	99	106	94	162	102	145	112	93	131	91	152	98	112	67	114
Total	364	189	226	218	229	171	311	173	206	189	274	210	175	289	224	233	146	225
Olive ridley	22	46	61	39	52	63	77	42	49	20	16	8	7	8	6	3	9	31
Unid. Turtle	1	34	23	30	25	26	39	17	22	6	5	4	4	1	7	1	2	15
Green/bjack turtle	1	7	9	8	8	6	2	6	6	2	0	0	1	2	0	0	1	3
Loggerhead turtle	0	0	0	0	1	1	1	2	1	0	0	0	0	1	1	1	0	1
Hawkbill turtle	0	0	0	0	0	2	1	1	1	0	0	0	0	0	1	0	0	0
Leatherback turtle	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	24	89	93	77	86	98	120	68	79	28	21	12	12	12	15	5	12	50

TABLE 22

Bycatch in numbers, all species in the Eastern Pacific Ocean, 1993–2009 – set types combined

All sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Sailfish	1 062	737	572	424	435	956	276	549	1 407	484	1.593	418	349	424	268	184	271	612
Blue marlin	241	190	191	202	178	237	362	170	409	249	228	45	76	178	61	68	53	185
Black marlin	148	117	138	118	120	165	304	182	321	268	168	164	113	171	102	69	130	165
Stripped marlin	585	140	100	134	61	71	120	60	86	57	148	46	43	47	68	60	17	108
Unid. & Others	202	92	102	100	28	31	133	32	84	54	47	14	46	35	42	24	22	64
Total	2 238	1 276	1 103	978	821	1 459	1 195	994	2 308	1 112	2 184	687	628	855	541	405	493	1 134
Mahi mahi	210 434	410 589	357 573	381 272	297 755	201 301	423 555	353 981	59 2281	410 554	173 909	138 036	96 494	134 419	132 875	119 835	139 782	269 097
Wahoo	53 987	215 909	148 397	94 959	198 500	116 261	110 246	84 165	392 859	128 902	162 257	45 500	49 614	62 416	56 164	32 219	70 245	118 859
Rainbow runner	16 531	14 831	10 632	44 724	75 964	174 102	185 048	83 965	97 884	107 636	163 556	64 895	70 906	93 078	223 306	37 543	51 553	89 186
Yellowtail	24 616	11 832	29 822	102 204	64 191	67 476	30 794	8 937	43 249	12 914	38 315	73 443	17 929	32 902	23 528	33 941	18 653	37 338
Total	305 568	653 162	546 424	623 159	636 410	559 140	749 643	531 047	1 126 272	660 007	538 238	321 875	234 944	322 815	435 874	221 538	280 233	514 479
Silky shark	37 088	27 307	28 784	25 634	39 179	43 472	31 411	17 691	19 443	19 428	20 391	17 291	16 847	17 713	12 023	11 593	11 016	23 301
Unid. & Others	8 036	7 061	5 998	8 715	4 482	8 948	3 200	5 892	1 958	2 812	2 141	1252	780	1 351	1 574	1 127	472	3 871
Whitetip shark	2 668	3 997	9 140	7 903	7 814	6 627	4 999	2 926	3 007	928	543	199	73	152	70	47	95	3 011
Hammerhead shark	1 138	1 902	1 482	1 744	1 717	1 404	1 485	634	919	2 336	2 762	2 271	1 230	936	475	425	478	1 373
Total	48 929	40 266	45 404	43 996	53 191	60 450	41 095	27 143	25 327	25 503	25 838	20 814	18 930	20 153	14 142	13 193	12 061	31 555
Mantaray	10 046	1 751	4 537	1 911	1 098	10 336	2 090	4 191	1 093	6 371	3 561	2 743	2 959	3 415	2 184	1 504	1 053	3 579
Stingray	2 034	1 818	452	434	1 188	517	715	472	379	324	8 573	256	316	442	284	234	203	1 096
Total	12 080	3 569	4 989	2 345	2 285	10 852	2 804	4 662	1 472	6 695	12 135	2 998	3 275	3 857	2 468	1 738	1 256	4 675
Olive ridley	73	74	83	49	82	102	102	73	62	30	22	12	17	15	10	3	11	48
Unid. Turtle	18	44	37	35	42	40	46	29	41	12	6	6	11	1	9	1	4	22
Green/bjack turtle	14	16	13	9	13	8	8	6	8	2	0	0	2	2	1	0	1	6
Loggerhead turtle	0	2	0	0	2	1	2	2	1	0	0	0	0	1	1	1	0	1
Hawkbill turtle	0	2	0	1	0	2	2	1	1	0	0	0	0	0	3	0	0	1
Leatherback turtle	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	105	138	133	94	139	153	160	111	113	44	28	18	31	19	24	5	16	78

TABLE 23

Capture in tonnes, all species in the Eastern Pacific Ocean, 1993–2009 – dolphin sets

Dolphin sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Sailfish	20	11	12	13	9	33	22	24	16	23	31	18	28	24	28	32	26	22
Blue marlin		7	8	9	5	7	9	13	13	13	19	14	16	12	11	9	8	11
Black marlin	6	7	6	7	10	9	10	10	9	9	14	8	16	10	9	9	19	10
Stripped marlin	7	3	6	11	6	9	6	4	2	6	9	10	15	12	8	8	7	8
Total	9	32	34	48	33	65	49	57	44	54	78	52	79	63	60	64	67	55
Mahi mahi	55	0	3	0	0	1	1	2	3	1	1	1	1	1	1	3	1	1
Wahoo	1	1	1	0	1	4	0	0	0	0	0	0	0	0	0	0	0	1
Rainbow runner	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellowtail	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	4	4	1	7	6	2	4	4	2	2	3	3	3	4	6	2	4
Silky shark	1	37	161	47	41	170	74	30	53	35	59	75	51	27	41	25	33	59
Unid. & Others	50	14	26	41	8	10	13	166	6	9	15	11	14	18	25	12	32	26
Whitetip shark	20	3	3	4	5	8	5	8	2	4	6	5	4	4	3	3	2	5
Hammerhead shark	7	4	18	12	6	5	2	1	1	1	1	0	0	0	0	0	1	4
Total	9	59	208	104	60	194	94	205	62	49	80	92	68	49	69	41	68	93
Mantaray	86	6	11	6	6	6	6	12	9	19	20	11	17	53	12	11	16	14
Stingray	9	2	1	1	6	1	0	0	1	1	1	0	1	1	0	0	0	1
Total	1	8	11	6	12	7	7	13	10	10	20	11	18	54	13	11	17	14
Olive ridley	9	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 24

Capture in tonnes, all species in the Eastern Pacific Ocean, 1993–2009 – school sets

School sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Sailfish	34	29	15	8	12	25	17	23	44	10	53	12	7	9	20	4	3	19
Blue marlin	14	17	10	10	20	8	18	26	17	50	16	13	15	15	11	12	9	17
Unid. & Others	12	1	4	4	3	2	4	4	3	1	6	2	2	4	8	9	3	4
Black marlin	19	9	9	11	9	10	17	21	7	18	10	8	8	15	10	7	4	11
Stripped marlin	13	9	10	13	14	5	7	8	9	49	14	6	14	23	9	15	2	13
Total	92	65	48	46	57	49	64	81	80	128	99	42	45	67	57	47	21	64
Mahi mahi	14	20	22	18	12	18	4	51	17	8	11	17	75	58	47	19	6	25
Wahoo	11	1	1	1	3	1	0	2	2	1	0	1	1	1	2	1	0	2
Rainbow runner	0	0	0	3	2	0	0	5	0	1	2	0	1	0	1	0	0	1
Yellowtail	35	6	19	153	16	7	46	19	0	9	0	15	3	228	93	36	3	41
Total	80	152	52	306	42	38	110	82	30	21	17	35	89	302	153	62	14	93
Silky shark	363	241	118	105	185	58	98	96	74	139	100	68	41	46	156	27	21	114
Unid. & Others	33	64	33	32	12	21	20	61	13	45	60	37	19	63	40	14	10	34
Hammerhead shark	16	25	14	34	13	24	10	20	3	6	11	15	13	9	9	12	4	14
Whitetip shark	9	5	18	3	6	3	3	5	0	3	0	0	0	0	0	0	0	3
Total	421	335	183	174	216	106	131	182	90	193	172	120	74	118	205	53	36	165
Mantaray	144	23	18	27	13	218	31	67	11	63	40	45	26	42	17	30	5	48
Stingray	9	5	1	1	1	1	1	1	0	0	25	0	0	1	0	0	0	3
Total	152	32	19	28	14	220	32	68	11	63	65	45	26	43	17	30	5	51

TABLE 25

Capture in tonnes, all species in the Eastern Pacific Ocean, 1993–2009 – floating object sets

Log sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
BLUE MARLIN	83	60	71	60	110	134	191	107	133	162	176	133	190	159	117	116	151	127
BLACK MARLIN	63	46	49	51	78	82	99	54	94	85	117	51	81	118	62	68	66	74
STRIPPED MARLIN	45	17	10	5	10	9	24	7	10	20	12	8	13	22	19	10	16	15
UNID. & OTHERS	77	19	10	7	8	9	14	3	5	6	9	7	7	26	11	15	7	14
SAILFISH	3	0	2	1	3	0	3	2	2	2	1	1	7	9	2	3	2	3
Total	271	142	141	125	210	234	331	173	245	275	316	200	298	335	210	211	242	233
MAHI MAHI	707	1 225	1 071	1 312	1 225	816	1 238	1 437	2 202	1 815	894	1 018	972	1 197	1 235	1 093	1 797	1 250
WAHOO	154	475	379	271	475	396	161	277	1 023	571	428	380	420	424	421	243	543	414
RAINBOW RUNNER	16	14	11	28	60	93	110	53	90	94	108	62	66	73	157	39	30	65
YELLOWTAIL	13	19	18	34	69	76	54	29	71	27	44	66	30	91	21	48	23	43
Total	894	1 738	1 482	1 653	1 843	1 414	1 577	1 804	3 395	2 521	1 486	1 543	1 499	1 821	1 847	1 436	24 09	1 786
SILKY SHARK	415	412	439	412	785	661	428	287	371	271	298	235	321	361	316	550	340	406
WHITETIP SHARK	30	81	136	142	160	143	110	66	65	21	13	7	2	5	2	2	4	58
HAMMERHEAD SHARK	19	46	33	43	58	44	44	26	49	93	117	101	70	56	40	35	38	54
UNID. & OTHERS	65	60	79	54	70	63	37	16	25	19	6	14	6	21	17	20	45	36
Total	537	616	693	665	1 091	932	632	404	524	434	450	391	406	450	383	612	31	568
MANTARAY	4	1	1	2	2	2	4	1	2	2	4	2	2	5	2	3	2	2
STINGRAY	0	0	1	0	1	0	1	1	1	0	0	2	0	1	0	0	0	1
Total	4	1	2	2	2	2	5	2	2	2	4	4	3	5	3	3	2	3

TABLE 26

Capture in tonnes, all species in the Eastern Pacific Ocean, 1993–2009 – set types combined

All sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Blue marlin	104	84	87	76	141	151	219	143	159	222	206	155	221	185	137	137	179	153
Black marlin	88	62	67	70	93	100	125	87	115	116	146	72	105	145	83	84	79	96
Sailfish	57	40	28	22	24	59	42	49	63	34	86	32	43	43	49	39	31	43
Stripped marlin	67	29	26	29	30	23	37	19	21	74	36	24	42	57	36	33	25	36
Unid. & Others	101	25	16	20	12	17	20	13	11	11	19	11	12	35	23	29	16	23
Total	418	239	223	218	300	348	443	311	369	457	493	294	423	465	328	323	330	352
Mahi mahi	722	1 245	1 097	1 331	1 237	835	1 243	1 490	2 222	1 825	905	1 037	1 048	1 256	1 283	1 114	1 805	1 276
Wahoo	165	477	380	271	480	400	162	279	1 025	572	428	381	422	426	423	244	544	416
Rainbow runner	16	14	11	30	62	93	110	58	90	95	110	62	67	73	158	39	30	66
Yellowtail	48	26	53	186	87	83	99	48	71	36	44	82	33	320	114	84	26	84
Total	975	1 894	1 538	1 960	1 892	1 457	1 688	1 890	3 429	2 544	1 504	1 581	1 592	2 126	2 004	1 505	2 425	1 883
Silky shark	829	690	717	564	1011	889	600	412	499	445	457	378	413	435	513	602	394	579
Unid. & Others	126	156	144	141	108	115	82	253	58	102	97	96	46	109	89	51	92	110
Whitetip shark	42	74	51	82	76	76	58	54	53	103	134	121	87	69	52	50	45	72
Hammerhead shark	48	90	172	156	172	152	116	72	66	24	14	7	2	5	2	2	5	65
Total	1 045	1 010	1 084	943	1 367	1 231	857	791	676	676	702	603	548	618	657	705	535	826
Mantaray	156	33	29	34	21	227	41	81	22	84	63	57	46	100	31	44	23	64
Stingray	10	8	2	2	8	2	2	2	1	1	26	3	1	2	1	1	1	4
Total	166	41	32	36	29	229	43	83	23	85	89	60	47	102	32	45	24	69

TABLE 27
Bycatch in tonnes, all species in the Eastern Pacific Ocean, 1993–2009 – dolphin sets

Dolphin sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Black marlin	2	2	3	3	1	1	2	2	3	1	4	1	2	3	1	0	2	2
Blue marlin	1	1	1	1	0	1	1	1	1	1	1	0	1	0	1	1	1	1
Sailfish	11	6	6	7	4	15	6	9	6	10	15	6	7	7	4	6	9	8
Unid. & Others	9	3	1	6	1	3	1	3	2	2	2	0	1	0	1	0	0	2
Stripped marlin	3	1	2	3	0	1	7	1	0	1	1	0	1	1	0	0	0	1
Total	22	9	9	16	5	19	7	13	8	12	19	7	8	8	5	7	10	11
Mahi mahi	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wahoo	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Rainbow runner	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellowtail	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1	1	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1
Silky shark	40	28	128	37	14	137	21	5	15	6	20	61	10	8	4	3	1	32
Unid. & Others	14	11	20	32	6	6	8	158	2	6	9	5	7	4	16	4	4	18
Whitetip shark	8	4	16	11	2	3	1	0	0	0	0	0	0	0	0	0	0	3
Hammerhead shark	5	2	2	3	2	5	3	2	0	2	2	1	1	2	1	1	0	2
Total	81	55	187	115	30	157	40	323	19	21	41	71	25	18	36	12	9	73
Mantaray	8	6	10	5	5	6	6	10	9	18	19	10	17	52	11	11	16	13
Stingray	1	2	1	1	6	1	0	0	1	1	1	0	1	1	0	0	0	1
Total	9	8	11	6	12	6	6	10	10	19	19	10	18	53	12	11	16	14

TABLE 28
Bycatch in tonnes, all species in the Eastern Pacific Ocean, 1993–2009 – school sets

All sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. all years
Black marlin	31	23	23	24	22	28	42	21	48	30	26	5	9	21	8	8	7	22
Blue marlin	20	15	16	15	15	20	38	23	40	33	21	21	14	21	13	8	15	20
Sailfish	32	21	15	12	11	31	8	17	45	15	49	13	11	13	8	7	10	19
Unid. & Others	69	16	9	13	7	8	12	6	6	5	9	5	4	4	5	6	1	11
Stripped marlin	20	9	8	9	3	3	11	3	8	5	4	1	4	3	4	2	2	6
Total	171	84	72	73	57	89	111	69	146	88	109	44	41	62	38	31	36	78
Mahi mahi	480	829	729	885	703	426	751	785	1275	938	346	317	295	385	350	327	468	605
Wahoo	105	302	241	172	249	185	102	153	666	240	160	83	92	115	98	50	132	185
Rainbow runner	15	13	11	29	51	85	101	48	80	85	104	54	59	64	152	31	24	59
Yellowtail	27	15	21	106	61	64	35	18	65	26	37	49	20	82	32	24	15	41
Total	627	1 160	1 002	1 192	1 063	760	989	1 005	2 086	1 289	648	503	466	646	631	432	640	890
Silky shark	659	548	570	448	717	708	424	269	365	357	377	290	260	267	226	178	200	404
Unid. & Others	97	120	111	110	80	99	61	204	38	88	83	71	25	55	55	29	14	79
Whitetip shark	43	82	154	141	147	127	101	60	63	21	11	5	2	5	2	1	3	57
Hammerhead shark	28	49	34	54	60	54	41	31	42	92	123	96	69	56	30	26	31	54
Total	827	798	869	753	1.004	989	627	567	508	558	595	462	357	382	313	235	248	593
Mantaray	150	32	28	33	18	226	39	78	21	75	62	56	45	98	31	44	23	62
Stingray	10	7	2	2	8	2	2	2	1	1	26	3	1	2	1	1	1	4
Total	159	39	31	34	26	228	41	80	23	77	88	59	46	100	31	44	23	66

TABLE 29

Bycatch in tonnes, all species in the Eastern Pacific Ocean, 1993–2009 – floating object sets

Log sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. All years
Black marlin	22	18	17	18	20	25	38	16	43	22	20	2	6	15	6	7	5	18
Blue marlin	16	11	13	11	13	19	34	20	39	29	19	19	12	20	10	6	14	18
Sailfish	2	0	1	1	2	0	1	1	1	1	1	1	2	5	0	1	1	1
Unid. & Others	52	13	6	5	5	4	10	2	4	2	3	3	3	3	2	5	1	7
Stripped marlin	14	5	3	2	1	2	9	2	5	4	3	1	1	2	3	1	1	3
Total	83	29	23	19	22	25	54	25	48	36	26	24	18	30	15	13	17	30
Mahi mahi	470	815	712	873	699	420	749	780	1265	932	344	312	270	379	334	324	465	597
Wahoo	97	301	240	172	247	185	101	153	65	240	160	83	91	114	98	50	132	184
Rainbow runner	15	13	11	27	49	85	101	45	79	85	104	54	59	64	152	31	24	59
Yellowtail	7	11	10	18	52	60	31	17	65	19	37	49	19	81	12	22	14	31
Total	593	1 144	976	1 096	1 056	775	989	998	2 082	1 284	652	508	447	652	604	437	644	879
Silky shark	330	329	349	327	578	533	334	229	311	243	275	176	232	232	144	171	196	293
Unid. & Others	57	62	66	54	67	80	40	19	30	41	19	35	10	15	19	20	8	38
Whitetip shark	27	73	122	127	140	122	99	56	62	19	11	5	2	5	2	1	3	52
Hammerhead shark	13	31	22	29	53	34	35	19	41	87	111	91	63	49	28	22	29	44
Total	427	495	558	537	838	770	508	323	444	390	416	307	307	301	192	214	236	427
Mantaray	3	1	1	1	2	2	4	1	1	2	4	2	2	5	2	3	2	2
Stingray	0	0	1	1	1	0	1	0	1	0	0	2	0	1	0	0	0	1
Total	4	1	2	2	2	2	5	2	2	2	4	4	3	5	3	3	2	3

TABLE 30
Bycatch in tonnes, all species in the Eastern Pacific Ocean, 1993–2009 – set types combined

All sets	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Avg. All years
Black marlin	31	23	23	24	22	28	42	21	48	30	26	5	9	21	8	8	7	22
Blue marlin	20	15	16	15	15	20	38	23	40	33	21	21	14	21	13	8	15	20
Sailfish	32	21	15	12	11	31	8	17	45	15	49	13	11	13	8	7	10	19
Unid. & Others	69	16	9	13	7	8	12	6	6	5	9	5	4	4	5	6	1	11
Stripped marlin	20	9	8	9	3	3	11	3	8	5	4	1	4	3	4	2	2	6
Total	171	84	72	73	57	89	111	69	146	88	109	44	41	62	38	31	36	78
Mahi mahi	480	829	729	885	703	426	751	785	1 275	938	346	317	295	385	350	327	468	605
Wahoo	105	302	241	172	249	185	102	153	666	240	160	83	92	115	98	50	132	185
Rainbow runner	15	13	11	29	51	85	101	48	80	85	104	54	59	64	152	31	24	59
Yellowtail	27	15	21	106	61	64	35	18	65	26	37	49	20	82	32	24	15	41
Total	627	1 160	1 002	1 192	1 063	760	989	1 005	2 086	1 289	648	503	466	646	631	432	640	890
Silky shark	659	548	570	448	717	708	424	269	365	357	377	290	260	267	226	178	200	404
Unid. & Others	97	120	111	110	80	99	61	204	38	88	83	71	25	55	55	29	14	79
Whitetip shark	43	82	154	141	147	127	101	60	63	21	11	5	2	5	2	1	3	57
Hammerhead shark	28	49	34	54	60	54	41	31	42	92	123	96	69	56	30	26	31	54
Total	827	798	869	753	1.004	989	627	567	508	558	595	462	357	382	313	235	248	593
Mantaray	150	32	28	33	18	226	39	78	21	75	62	56	45	98	31	44	23	62
Stingray	10	7	2	2	8	2	2	2	1	1	26	3	1	2	1	1	1	4
Total	159	39	31	34	26	228	41	80	23	77	88	59	46	100	31	44	23	66

Data come from the IATTC observer programme and from the national observer programmes that have contributed significantly to the database.

To complete the data summary for the EPO, a brief exploration of trends is done by looking at changes in frequency of occurrence over time. If there are significant trends, then the results should reflect that. Long-term averages are not good descriptors. Figure 58–60, show the frequency of occurrence of the different species in FAD sets, because most of the bycatch happens in these sets. Figure 58 shows the frequency of many of the more common species caught in FAD sets for three time periods (1994–1998, 1999–2003, and 2004–2008) to verify that there were no substantial trends in the data. It shows that the sharks are the group showing clear declining trends, while the others are relatively stable. Frequency of occurrence is a coarse measure of abundance, but readily available. Figures 59 and 60 break the full table down into a more frequent group and a less frequent group in order to show the variability in all the species with more detail. The structure of these communities begins to show in these figures; there are a few very frequent components, present in almost all sets.

FIGURE 58
Capture probability: FAD sets in the Eastern Pacific Ocean

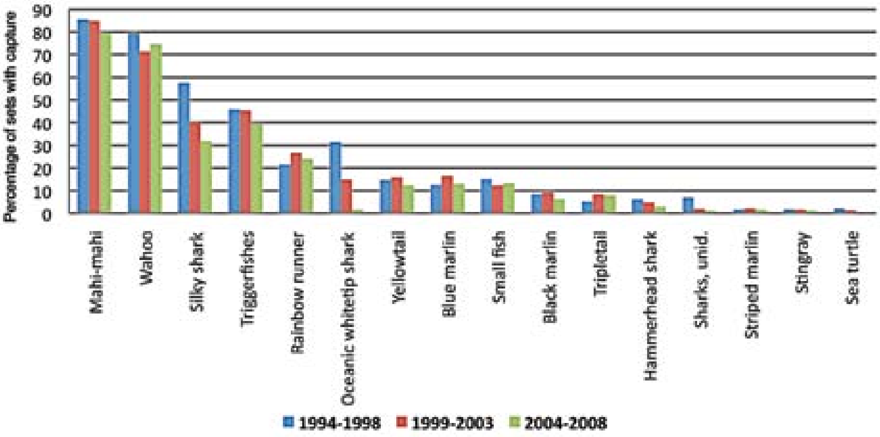


FIGURE 59
Capture probability: FAD sets in the Eastern Pacific Ocean

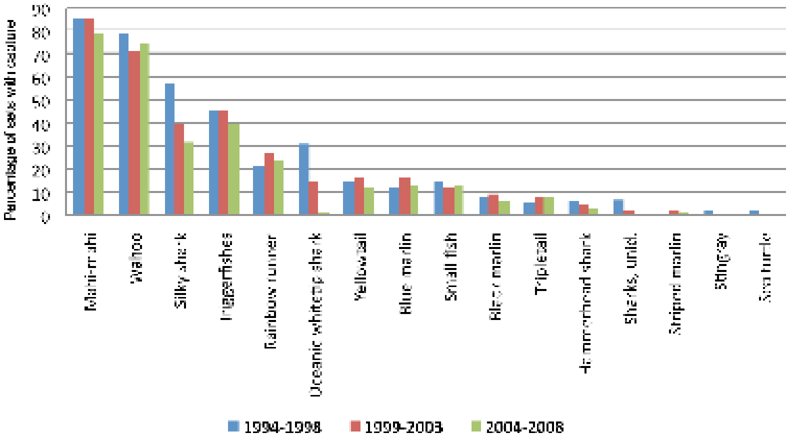
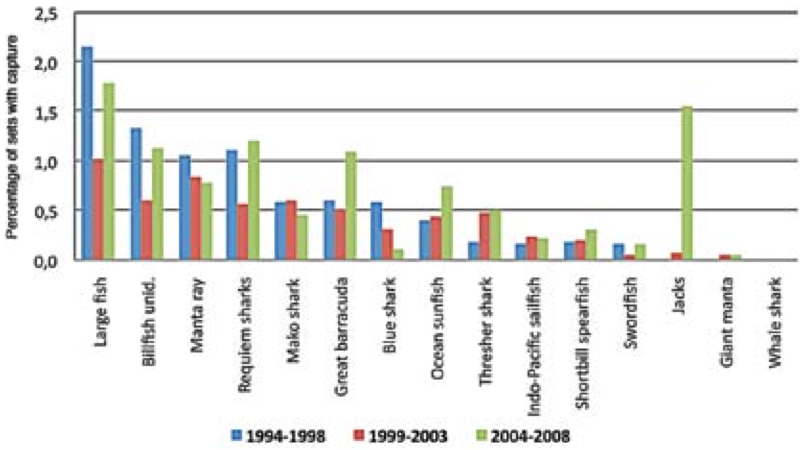


FIGURE 60

Capture probability: FAD sets in the Eastern Pacific Ocean



For other oceans, information from the most recent decade is used where possible. There have been many previous estimates of bycatch for a group, or for a short period, but recently, the different databases available for the Atlantic and Indian Oceans have been merged to produce the most recent complete estimates, making use of all the information from the period. Different attempts to estimate bycatch have been made over the years. With low levels of observer coverage, it was impossible to obtain accurate estimates, and to know whether there were biases, etc.

Several major studies have been carried out on the fisheries on logs and FADs over the years. Stretta *et al.* (1997) produced an important synthesis of the activities of the French and Spanish fleets in both the Atlantic and the Indian Oceans although it was based on a small sample size. Bailey, Williams and Itano (1996) produced a major review for the WPO, followed by very significant and recent contributions from Molony (2007, 2008). Information covering the characteristics of natural and deployed objects, the mode of detection, operational data, and detailed lists of species captured, sizes, etc., have been summarized and analysed to determine the structure of the communities. The fisheries on logs have been the subject of two workshops (Scott *et al.*, 1999; Le Gall, Cayré and Taquet, 2000b).

CATCH AND BYCATCH

The different observer programmes in the tuna fishing regions of the world have provided the only data available on the bycatch of the purse seine fisheries. The observer coverage was initially, and until recently, very low, and did not allow for sophisticated statistical treatments to extrapolate to the total effort (Table 12). Many documents were presented at the different t-RFMOs, and those contain valuable information on limited data sets. To keep the information more or less contemporaneous, data for the last decade have been given more relevance.

As mentioned above, the data have many inconsistencies among the t-RFMOs, because different categories have been considered for set types, units of measurement, etc., and efforts are needed to make the data comparable. In some cases, the differences reflect regional characteristics; payaos are only significant in the WPO, seamounts seem to have more influence in the Indian Ocean, etc. The inclusion and taxonomic aggregation of the estimates is also variable. The IATTC has been working using numbers of individuals as the basic unit, but the other RFMOs have based their statistics on weights. The variables of interest to understand bycatch issues include:

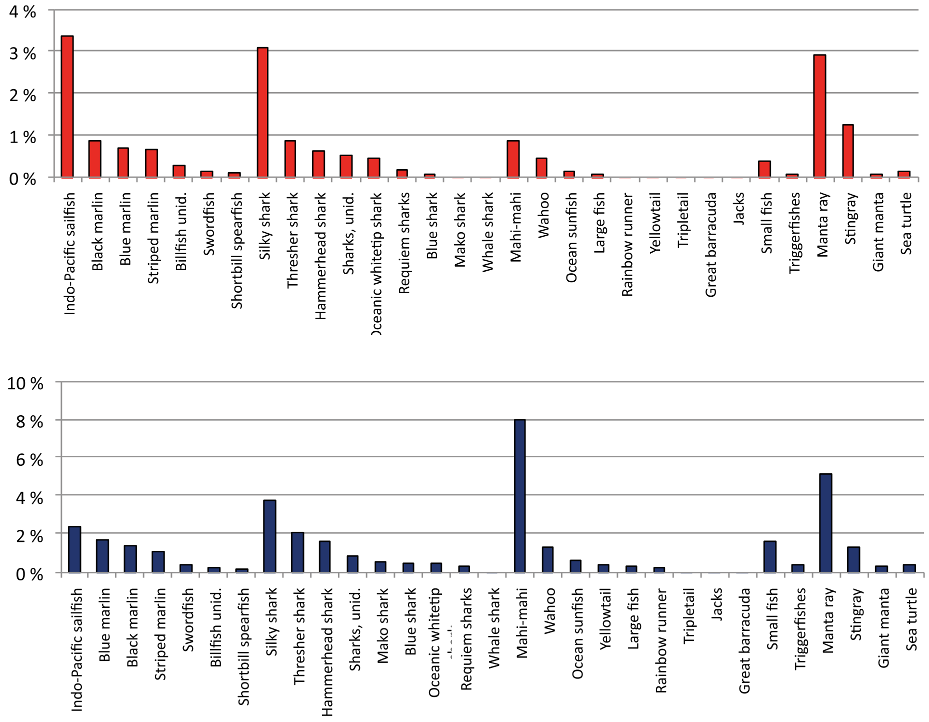
- lists of species present in a region;
- frequency of occurrence;
- capture per set;
- capture or bycatch per tonne of tuna captured;
- capture per positive set;
- capture per tuna positive set;
- bycatch rate;
- utilization rate;
- overall bycatch and utilization rates;
- expression of bycatch as a function of the catch;
- more complex units that reflect the significance of the removals beyond the numbers or weights.

The lists of species present in a region are usually presented by gear and type of operation (e.g. set type, shallow or deep longline sets, fixed or drifting gillnet). For tuna fisheries, there are many such lists (Stretta *et al.*, 1997; Arenas, Hall and García, 1999; Williams, 1999; Castro, Santiago and Santana-Ortega, 2002; Romanov, 2002; Taquet *et al.*, 2007b; Molony, 2008).

Frequency of occurrence, also called incidence in some studies, is the percentage of sets where a species is present, or the probability of encountering a given species in a set taken at random. Figure 61 and 62 show the frequency of occurrence of the more common species by set type in the EPO. The different scales used in the plots reflects the fact that very few individuals are captured in dolphin sets; sailfish, manta rays, and pelagic stingrays are a relatively important component of dolphin sets and practically absent in sets on floating objects. Conversely, mahi-mahi and wahoo are the most frequent species in sets on floating objects, and very rare in dolphin sets. Silky sharks

FIGURE 61

Frequency of occurrence in dolphin (top) and school sets (bottom) in the Eastern Pacific Ocean



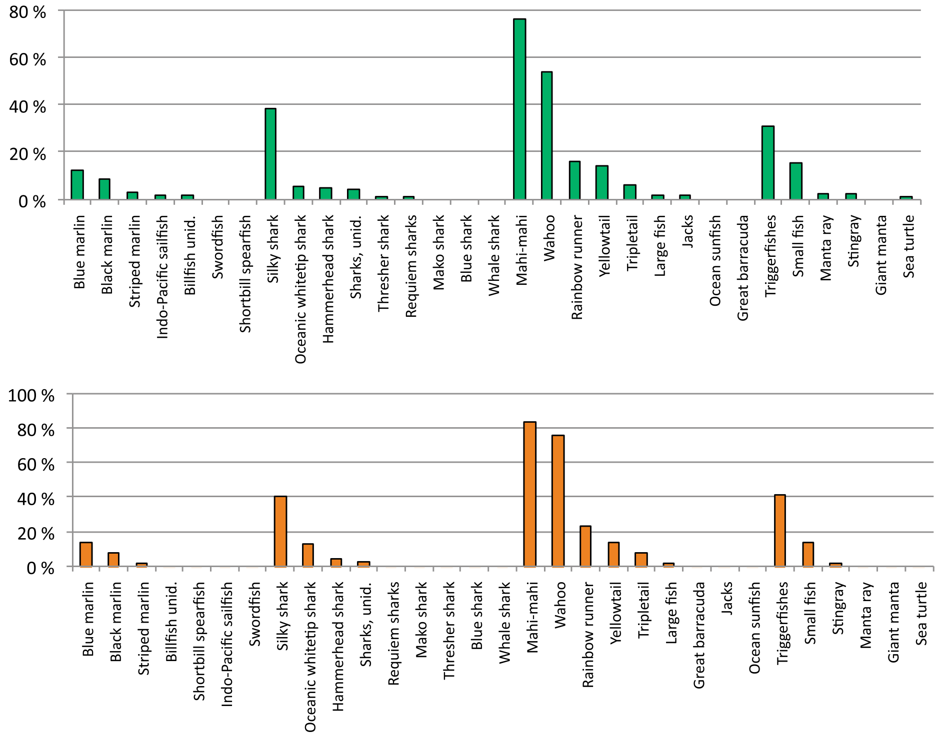
are the dominant species in all types of sets. Dolphin and school sets are more similar to each other than to log or FAD sets. Log and FAD sets appear very similar in the frequency of their components.

Figure 63 shows a similar plot by weight for the WPO in recent years (OFP, 2010a). The concept behind this figure is not the same as the frequency plot. This plot shows the biomass distribution among taxa. However, some features of the communities are visible. School sets have far fewer species than floating object sets, and of these, log sets have the larger biomass of non-tuna species. The rainbow runner replaces the mahi-mahi as the main species in the WPO. Log sets have a much higher biomass of non-tuna species than FAD or payao sets, and all of these are orders of magnitude higher than school sets. In the WPO, log and FAD sets appear much more different from each other than in the EPO, but the units used are different.

Capture per set (CPS) is the number of individuals or tonnage taken in an average set. It is obtained by dividing the total numbers or total tonnage captured by the number of sets. A way to clarify the meaning of this variable would be to use NPS for numbers per set, and WPS for weight per set. This is a measure of the average impact of a set, and it is used for estimation. It is not obvious which the best measure is. For population dynamics studies, the numbers are important, and expressing impacts on turtles, marine mammals, seabirds, etc., in weights is not reasonable. However, it may not be possible to enumerate bycatch of triggerfishes, so estimates of weights are normally used, and from there a conversion is feasible. Whichever is used, it is necessary to specify the choice made, and if possible provide a way to make a conversion if wanted. Bycatch-per-set data facilitate the extrapolation, when the total numbers of sets in

FIGURE 62

Frequency of occurrence in log (top) and FAD sets (bottom) in the Eastern Pacific Ocean, 1994–2009

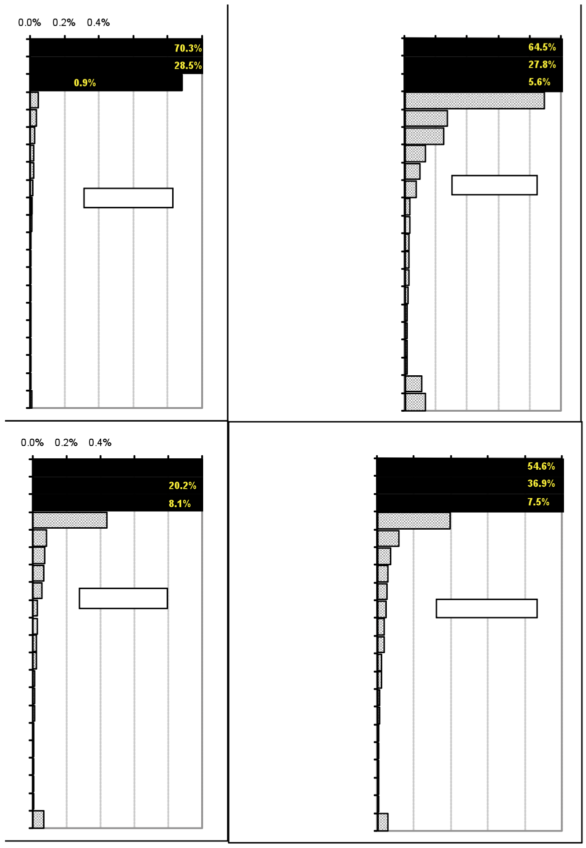


known, and the stratification of the data, given the marked differences between set types.

A generic form of this variable, applicable to all gear types, has been called bycatch per unit of effort (BPUE), understanding that the measure of effort to be used to estimate bycatch is not equivalent to the fisheries effort concept used in CPUE studies. For example, tonnage per hour searching or per day fishing does not connect to the impact of the fishing operation; the incidental mortality is a result of the fishing activity itself resulting in the capture, and the extrapolation unit is the number of sets or other fishing operations (Hall, 1996, Hall, Alverson and Metuzals, 2000). The BPUE may refer to unit fishing operations (e.g. bycatch per set, bycatch per haul) or, whenever possible, it should be standardized by the amount of gear fished (e.g. per number of hooks, per area of a net), and/or by a time unit (e.g. per hour trawling).

FIGURE 63

Percentage composition of 20 main species taken by set type



Note: Percentage by weight in WCP-CA from observer data (2001–07), number of sets = 8 140, 5 743, 5 077 and 6 381, respectively.

Regarding capture or bycatch per tonne of tuna captured, for estimation purposes, it is possible to replace the bycatch per set measure by a ratio estimate with the bycatch in numbers or weights standardized to a measure of tuna tonnage. If the bycatch in a set is correlated to the amount of tuna captured, this measure will be more precise than catch per set (Hammond and Hall, 1983). In the tuna purse seine fisheries, dolphin bycatch per tonne has been used as an alternative to dolphin bycatch per set (Hall and Boyer, 1986).

In the literature, the bycatch is often expressed as x tonnes of a species or group of species per 1 000 tonnes of tuna catch because this produces figures with fewer zeroes before the significant numbers. Examples of this variable are tuna bycatch of 19.2 tonnes/1 000 tonnes of tuna catch, and shark bycatch of 3.6 tonnes/1 000 tonnes of tuna catch (Amandè *et al.*, 2008a). Landings data are then used to extrapolate to the total catch of the fishery. Most probably, the tonnage of tuna captured (rather than the retained portion) will have a stronger correlation to the bycatch, and, therefore, when available, it should produce better estimates. However, the extrapolation factor will be the total capture, and this may require a more complex estimation process than the total catch.

The need to separate what is captured from what is retained is very clear here. Large whales are seldom included in the bycatch tables, but whale sharks are included in some cases, even though they are both released alive. Without certainty about the potential implications of the capture for the survival of those released alive, it becomes important to maintain a record of the number of captures, in case some post-release mortality factor should be applied. In many bycatch studies, it is reported that x percent of a species was released alive, and there remains the doubt on whether they were included in the tabulated figures, or if they had been subtracted from the total capture. This shows the need of a distinction between a "capture per set" and a "bycatch per set", where the latter reflects the mortality component, and the former includes everything released alive, or retained as catch.

Capture per positive set is the average number or tonnage of a species in the sets where it is present. This is a measure of group or school size that is of interest for ecological and behavioural studies. The notation could be numbers per positive set or weight per positive set (WPPS). If the number of negative sets is included, it is possible to transform it into the above variable.

Capture per tuna positive set is a subset of the one above, and a measure of the capture that eliminates the skunk sets, where tuna capture is zero. However, zero is defined as the lack of any capture of the main tuna species. In the majority of cases, these sets will not produce any bycatch either, but it is possible that some bycatch may be retained in the set. In the Atlantic and Indian Oceans, many tuna statistics are expressed in these units, while also including the proportion of null sets, which allows the NPS or WPS to be computed if desired. The problem of this variable is that a set may be a negative set for one tuna species, but not for the other, and the studies of school size must be done on a specific basis.

Bycatch rate (BR) is defined as the ratio of the bycatch of a species (or group of species) to the capture of a species (or group of species). It is a measure of the proportion of those captured that were discarded dead of any target or non-target species or of a group of species (Hall, Alverson and Metuzals, 2000). This is a measure of the level of waste of the fishery. Low BR figures mean that the operation is close to full use of the resource.

The complement of the bycatch rate is the utilization rate, the ratio of the production of the fishery to the biomass extracted from the system from all species: the catch of a species (or group of species) divided by the capture of a species (or group of species).

From the above variables, it is possible to generate a measure of the overall bycatch rate, the ratio of everything discarded dead to all that was captured – and an overall utilization rate in a similar way.

Perhaps more meaningful than the above variables is the expression of bycatch as a function of the catch, the net product of the fishery. Besides the use for estimation, described above, bycatch/catch ratios, such as number or tonnage of a species per 1 000 tonnes of tuna retained (catch), are useful to link impact with production, and therefore to assess the relative ecological costs of different gear types or set types. The tuna catch is the sum of all tuna species retained, or one could use all species retained. Areas and periods with high bycatch/catch ratios are good candidates for spatial or temporal closures, using bycatch reduction curves (Hall, 1996).

More meaningfully, any of the variables used to measure bycatch could be replaced by more complex units that reflect the significance of the removals beyond the numbers or weights. For example, the reproductive value of the individuals, or elasticity analyses taking demographic considerations into account, could be used to provide a statistical weighting to the different numbers (Heppell, 1998; Heppell, Caswell and Crowder, 2000; Gallucci, Taylor and Erzini, 2006; Wallace *et al.*, 2008). This is the direction to pursue in order to obtain an accurate assessment of impacts, and the current estimates of numbers or weights should be considered a simplistic first step.

All these variables provide information of value to estimate and analyse different aspects of bycatch in a fishery, and to compare among types of sets or gear. As far as they are clearly defined, many of them complement each other.

OBSERVER COVERAGE

The data available come from the observer programmes developed in the different regions. The implications of the levels of coverage were discussed in the estimation section. An important source of heterogeneity among RFMOs is the use of definitions of coverage based on different units. Coverage expressed as the percentage of fishing days that were observed makes sense for some fisheries variables (Sarralde *et al.*, 2007; OFP, 2008a), such as the catch per days fishing, etc., but is not the adequate measure of coverage for bycatch estimation that is dependent on the sets themselves. In some cases, the two measures are close enough; for the Spanish fleet in the Indian Ocean, Gonzalez *et al.* (2007) report coverages in fishing days and (in sets): for 2003, 2.4 percent in days (2.4 percent in sets); for 2004, 3.2 percent in days (1.6 percent in sets); for 2005, 3.0 percent in days (2.9 percent in sets); and for 2006, 4.2 percent in days (2.3 percent in sets).

However, for reasons of convenience, sets cannot be sampled at random; hence, the units that are sampled are fishing trips, and this introduces a covariation element – the sets are a cluster, and not independent samples. If the operations and technology are reasonably similar in the vessels fishing in a region, then a given proportion of trips should correlate with a given proportion of sets. Following the same reasoning, if the trips are distributed at random in areas and seasons, then the proportion of trips covered will yield similar proportions of coverage for the different set types (e.g. every trip performs a number of sets of each type that reflect, within the margins of sampling error, the fleet proportions). When the coverage is very dissimilar, then the vessel operated in a "biased" way, and the data may have a spatial, temporal or other bias. Several of the data sets available have this characteristic. Gonzalez *et al.* (2007) show coverage of FAD sets of 3.4 percent of the fleet total, but only 0.5 percent of the school sets, explained by a temporal bias in sampling distribution. In this case, a temporal stratification could have helped if a larger sample size had been available.

In the EPO, the problem of dolphin mortality in the tuna purse seine fishery that had been brought to the public's attention in the late 1960s resulted in the National Marine Fisheries Service of the United States of America starting an observer programme to estimate the mortality. After a few years of very low coverage, by 1972, the passage of the Marine Mammal Protection Act raised the coverage levels, and from then on estimates of mortality improved significantly. The tuna–dolphin issue is discussed below. The IATTC shared the sampling of the United States vessels with the NMFS, and started a programme to sample the fleets from other flags operating in the region that grew rapidly. Subsequently, an international agreement, the Agreement on the International Dolphin Conservation Program (AIDCP) was signed by the fishing countries of the region to reduce dolphin mortality. A critical component of the programme was the assignment of individual vessel mortality limits; every vessel had an annual dolphin mortality limit that if exceeded would require the vessel to stop fishing on dolphins. For this requirement, a 100 percent coverage was required, and the IATTC has been running an observer programme that, combined with several national programmes, has completed coverage of 100 percent since 1993. As a result of this programme, the databases for the period 1993–2009, and available at the IATTC, comprise:

- 125 548 sets on dolphins;
- 71 618 sets on schools;
- 82 417 sets on floating objects.

Besides these sets, there is adequate coverage going back to 1986, and some coverage back to 1979 (Table 12). The coverage for the period 1993–2009 was more than 97 percent, so for all practical purposes, the error of the estimates will be considered negligible. The level of information available allows for many analyses that cannot be performed with other databases, and it is readily available to the authors. Many answers are valid in all oceans, and can inform the discussion for them. Some documents containing estimates of bycatch in the area include: IATTC Annual Reports from (1980–latest), Fisheries Status Report (2003–2010), International Review Panel reports (1998–2002), Executive Reports of the AIDCP (2002–09); Hall and Boyer (1986, 1988); Lennert and Hall (1995, 1996); Wade (1995); Hall (1996, 1998); Hall, Alverson and Metuzals (2000); Hall, Campa and Gómez (2003).

In the Atlantic, observer programmes were enlarged during periods in which a moratorium on setting on FAD was voluntarily adopted by the fleets between 1997 and 2005 (Pallares and Kebe, 2002; Ariz *et al.*, 2005; Ariz *et al.*, 2009; Fonteneau, 2010). The problem with this data set is that it may not be representative of the fishing patterns in a regular year. Recently, the combined data collections for the European fleets, and associated vessels, were analysed for the period 2003–07 (Amandè *et al.*, 2010b), and this is the most comprehensive treatment of the data. In the area, most of the effort has been traditionally applied by the European fleets from France and Spain, with some regional components. During this period, the observer coverage (in number of trips) was 3.0 percent on average, with a range of 1.5–6.2 percent (Table 12). Other recent documents containing bycatch information for the region include: an extensive study by Stretta *et al.* (1997), and several other more recent studies, some of them utilizing special ICCAT programmes, or a voluntary industry moratorium on the fishery on FADs – Santana *et al.*, 1998; Fonteneau *et al.*, 2000; Ménard *et al.*, 2000b; Gaertner *et al.*, 2003; Delgado de Molina *et al.*, 2000, 2010, 2010b; Goujon, 2004a; Sarralde *et al.*, 2004, 2007; Chassot *et al.*, 2009; Pianet *et al.*, 2008, 2009, 2010), and ICCAT documents including the Statistical Bulletins (2010).

In the WPO, a major review of the bycatch in the region was prepared in the mid-1990s (Bailey, Williams and Itano, 1996). Other relevant documents include: Lawson, 1997; Coan *et al.*, 1999; Molony, 2005a; OFP, 2008b, 2009, 2010b). The magnitude of the fleet operating in the area together with the diversity of operations make this area the most challenging to monitor because of: (i) origins (purse seiners from the United States of America, Japan, Taiwan Province of China, the Republic of Korea, Ecuador, etc.), which correlate with technological and operational differences; (ii) habitats covered (open ocean, island systems, coastal habitats, etc.); and (iii) the type of operations including a significant role of payaos; and other sources of heterogeneity. A series of annual updates present the catches of many of the species of interest (e.g. Williams and Terawasi, 2009; OFP, 2010a). The significant contributions of Molony (2005a, 2007) provide one of the best summaries of the biology and ecology of the specie encountered, and of the impacts of the fishery. The observer coverage in the period 1994–2006 ranges from 1.5 percent to 11 percent (Table 12).

In the Indian Ocean, most of the effort has been applied by the French and Spanish fleets. In the 1990s, the former Soviet Union participated in the fishery (Romanov, 2000, 2002). A statistical synthesis was prepared recently, based on observer coverage ranging from 1.4 percent to 8.1 percent for the period 2003–07, with an average of 4 percent (Amandè *et al.*, 2008a). The fishery in this region was heavily disrupted by the piracy problems off the Somali coast (Chassot *et al.*, 2010), and that restricted the fishing areas, and led to movements of vessels to the Atlantic. Recent studies that include information relevant to bycatch estimation, fishing effort, etc. include: Romanov, 2000, 2002; Rajruchithing, Prajakjitt and Siriraksophan, 2005; Sarralde, Delgado de Molina and Ariz, 2006; Viera and Pianet, 2006; Sánchez *et al.*, 2007; Delgado de Molina *et al.*, 2007, 2010a; González *et al.*, 2007; Pianet *et al.*, 2009).

The quality of the data available depends on the quality of the observers training, their dedication, the opportunities to do their job properly (e.g. access to instruments, specimens), the cooperation of the vessel personnel, and the editing and quality controls implemented at the end of the trips.

With the data available, an initial comparative review was possible. The vast majority of the bycatch comes from the main target species. Smaller pelagic species such as many carangids and balistids are sometimes missing from the tables, or probably underestimated, or evaluated without much precision in aggregates; hence, they are not included.

In the following sections, the groups that are covered include:

- small tunas (including small sizes of targets species and other minor tuna species such as *Auxis* sp., *Euthynnus* sp., *Sarda* sp.);
- billfishes (mainly marlins, and sailfish);
- sharks (silky, oceanic whitetip, hammerheads);
- rays: mantas, devil rays, and pelagic stingrays;
- large pelagic bony fishes: rainbow runner, mahi-mahi, wahoo, yellowtail amberjack;
- sea turtles;
- marine mammals.

Many of the references used have been presented at the Scientific Committee meetings, or working groups of ecosystem and bycatch of the t-RFMOs, or included in the annual reports or fisheries statistical bulletins. Traditionally, the major target tuna species, and the billfishes have been the objectives of the RFMOs, and the statistics cover them.

10. Tunas

In all oceans, the vast majority of bycatch in the purse seine fisheries, in numbers or biomass, are tunas, if one sets aside some very difficult to estimate triggerfishes, or other smaller species. The composition of the catch or bycatch includes:

- main tuna target species that are discarded;
- other, usually small, tuna species that may or may not be retained.

Of the major tunas, the bluefin tuna (*Thunnus thynnus*, and *T. orientalis*) and the albacore tuna (*Thunnus alalunga)* are occasionally captured in the tropical tuna fishery. The bluefin tuna is now a target for some purse seine sets to produce stock for tuna ranching operations in some areas of the Pacific Ocean.

BYCATCH OF YELLOWFIN, SKIPJACK AND BIGEYE TUNAS

The most numerous bycatch among the tunas are from the main target species. Usually, they are small individuals that would not be economic to process because of labour costs, and they are returned to the sea, most probably dead after the stress of the capture. Sometimes, a set takes a long time to finish, either because of a large capture, or because of malfunctions, and there is some spoilage of the fish in the net. Occasionally, the vessel storage is completed, and the rest of the capture must be discarded. Bailey, Williams and Itano (1996) compare the reasons for discarding for different types of sets, and find that "Tuna too small" is the cause of 75 percent of all tuna bycatch (Table 31). It amounts to 92 percent of the tuna discards from payao sets, 67 percent from log sets, and 44 percent from school sets. "Vessel fully loaded" results in 31 percent of the discards in school sets, and 9 percent from log sets. "Smashed or soft tuna" is important in school sets (13 percent of discards), and "Wrong species" results in 6 percent of the log set discards, and 3 percent of payao discards. "Wrong species" include frigate tuna and kawakawa. The reasons for discarding tunas in the EPO are shown in Table 32.

TABLE 31
Reasons for discarding (percentage) by set type in the Western Pacific Ocean

	Too small	Wrong species	Other & Fish smashed/soft	Vessel full	Storage problem	Gear malfunction	Unknown
School	44		13	31	8	1	3
Log	67	6	16	9			2
Payao	92	3	4				1

Source: From Bailey *et al.* (1996).

The sizes discarded depend on the price of the fish; high prices reduce the bycatch, and only very small individuals are rejected. The volume of discards is affected by the abundance of the species, and by price issues. Years with high recruitment levels may produce higher discards. The fishers do not benefit in any way from the bycatch of small tunas; they have the additional task of sorting and discarding all the small fish, so they would rather avoid sets with a high proportion of waste.

Tuna sizes and set type

A major cause of differences in the proportion discarded is the type of set where the tuna is caught; there are important differences in the length frequency distributions of the captures. In the WPO, payao sets produce the smallest sizes of tunas, followed by increasing sizes in log sets, FAD sets, and school sets (Williams and Terawasi, 2009; IATTC, 2010). For skipjack tunas, the difference is not large (modal sizes 40–50 cm in associated sets vs 50–65 cm for school sets). For yellowfin tunas, the modes associated with payao sets are 20–40 cm, associated sets go from 75 to 110 cm, school sets and longline captures from 110 to 130 cm. For bigeye tuna, again, the payao sets produce a mode at 20–40 cm, associated (FAD and log sets) at 40–80 cm, school sets at 50–70 cm, and longline captures at 100–140 cm.

Coan *et al.* (1999) report average sizes of skipjack on FADs of 48 cm vs 50 cm in school sets, but for yellowfin the difference is important (64 cm in floating object sets vs 107 cm in school sets).

In the Atlantic, the average weight of tunas yellowfin and skipjack caught in school sets is much larger than those caught in floating object sets (Delgado de Molina *et al.*, 2010b). For the Indian Ocean, Delgado de Molina, Areso and Ariz (2010) and Pianet *et al.* (2009) report average sizes of yellowfin in floating object sets of 4 kg, compared with more than 30 kg in school sets. For skipjack tunas, the averages in floating object sets and in school sets are similar, between 2 and 3 kg. For bigeye tuna, the captures in floating objects produce bigeye of less than 5 kg, compared with more than 25 kg in school sets. The main mode for all species in floating object sets is about 40–50 cm. Yellowfin captured in school sets have this mode, but there are other modes at larger sizes, and the distribution is skewed towards larger sizes.

For the EPO, IATTC (2010) presents a time series of average tuna sizes and distributions by type of set as summarized in Table 33.

TABLE 32
Reasons for tuna discarding in the Eastern Pacific Ocean

Year	Species	Small size	Bad condition	Ripped sack	Full load	Other	No record
1997	Bigeye	436	64	15	23	15	1 108
	Yellowfin	397	48	14	21	13	1 001
	Skipjack	906	131	25	28	19	2 577
1998	Bigeye	1 102	157	2	39	7	
	Yellowfin	1 122	143	14	54	36	
	Skipjack	2 693	382	13	72	36	5
1999	Bigeye	496	237	21	78	7	
	Yellowfin	1 274	287	21	113	30	
	Skipjack	1 725	679	47	189	37	
2000	Bigeye	306	152	25	79	3	
	Yellowfin	1 051	127	19	96	19	
	Skipjack	1 529	405	41	131	15	
2001	Bigeye	385	99	2	29	1	
	Yellowfin	886	189	11	106	28	
	Skipjack	1355	346	12	57	34	
2002	Bigeye	289	66	6	15	8	
	Yellowfin	639	130	13	88	15	
	Skipjack	1 262	639	15	39	7	
2003	Bigeye	375	75	5	37	3	
	Yellowfin	920	141	14	76	7	
	Skipjack	1 766	322	18	89	14	
2004	Bigeye	179	73	3	31	1	
	Yellowfin	340	81	9	51	11	
	Skipjack	1 096	275	12	84	26	1
2005	Bigeye	445	90	1	33	6	2
	Yellowfin	652	119	9	50	15	1
	Skipjack	1 406	451	21	85	33	5
2006	Bigeye	180	120	8	41	10	
	Yellowfin	296	79	13	31	9	
	Skipjack	969	526	20	76	47	
2007	Bigeye	97	70	3	24	2	
	Yellowfin	162	52	7	20	8	2
	Skipjack	632	224	12	51	19	1
2008	Bigeye	34	74	10	36	4	
	Yellowfin	82	75	6	40	12	
	Skipjack	326	399	19	84	40	
2009	Bigeye	46	84	7	29	5	
	Yellowfin	108	61	6	36	7	
	Skipjack	406	405	12	59	46	1

TABLE 33
Modal values of tuna sizes by type of set in the Eastern Pacific Ocean

	Yellowfin	Bigeye
		(cm)
Floating objects sets	40–60	40–50
School sets	45–75	70–120
Dolphin sets	70–90	–
Longlines	110–150	80–150

Major tuna bycatch

Eastern Pacific

Tables 13–14 and Figure 64 show the trends in recent years. The total bycatch rate for the three main tuna species combined (BR all tunas) ranged from a high of almost 10 percent in 1996–97 to less than 2 percent in 2009. The average for the period 1993–2009 is close to 5 percent of the total capture. About 86 percent of all tuna bycatch comes from sets on floating objects, 10 percent from school sets, and 4 percent from dolphin sets. The predominant species in the bycatch is skipjack (71 percent), followed by yellowfin (18 percent), and bigeye (11 percent), the same order as for the capture. The bycatch rates for each species and set type are shown in Tables 13 and 14. Overall, 9.7 percent of the skipjack, 5.1 percent of the bigeye, and 1.8 percent of the yellowfin captured are discarded. The very low yellowfin bycatch comes from the fact that the association with dolphins, and the fishing operation, involving a 15–20 min. chase by speedboats, results in a selection of the sizes of yellowfin that can stay with the group, and if there are smaller/slower individuals or schools, they will not be able to keep up with the tuna–dolphin group moving at flight speed, and in this way they will avoid capture. The slower moving association with floating objects allows all those to remain with the group, and the diversity in species or sizes is much greater.

Bycatch rates are in part determined by prices, but also spatial heterogeneities affect the length frequency distributions of the captures. As an example, Figure 60 shows the proportion small (< 2.5 kg) tuna to all tuna captured for the three main species. For skipjack in the EPO, the proportion of small skipjack increases towards the west. As a result of the expansion of the EPO fishery towards the west, average sizes of skipjack have been declining in recent years (IATTC, 2010).

A large proportion of the skipjack catches in the EPO come from an area where large sizes are common, and the discards are very low, but the expansion of the fishery to the west brings more effort to areas where the sizes are smaller. For yellowfin, the higher proportions of small individuals are found in the coastal area off Ecuador and Colombia. For bigeye, a narrow strip north of the equator has the higher proportion of small ones. The maps show that spatial management of the species is likely to require trade-offs. Closing an area to reduce juvenile bycatch of one species sends additional effort towards areas with impacts on the other species.

FIGURE 64
Catch and bycatch (yellowfin, skipjack, bigeye) in the Eastern Pacific Ocean, 1993–2008

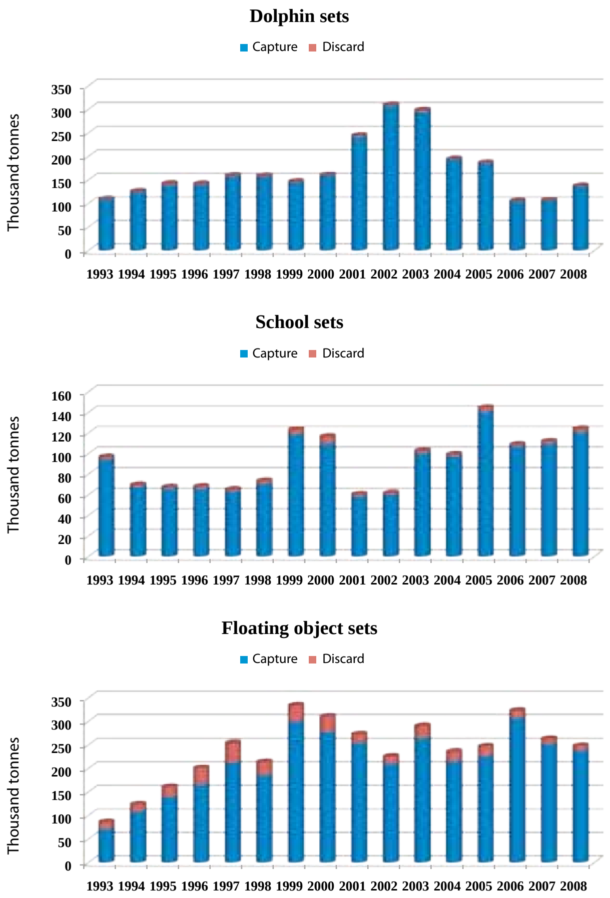
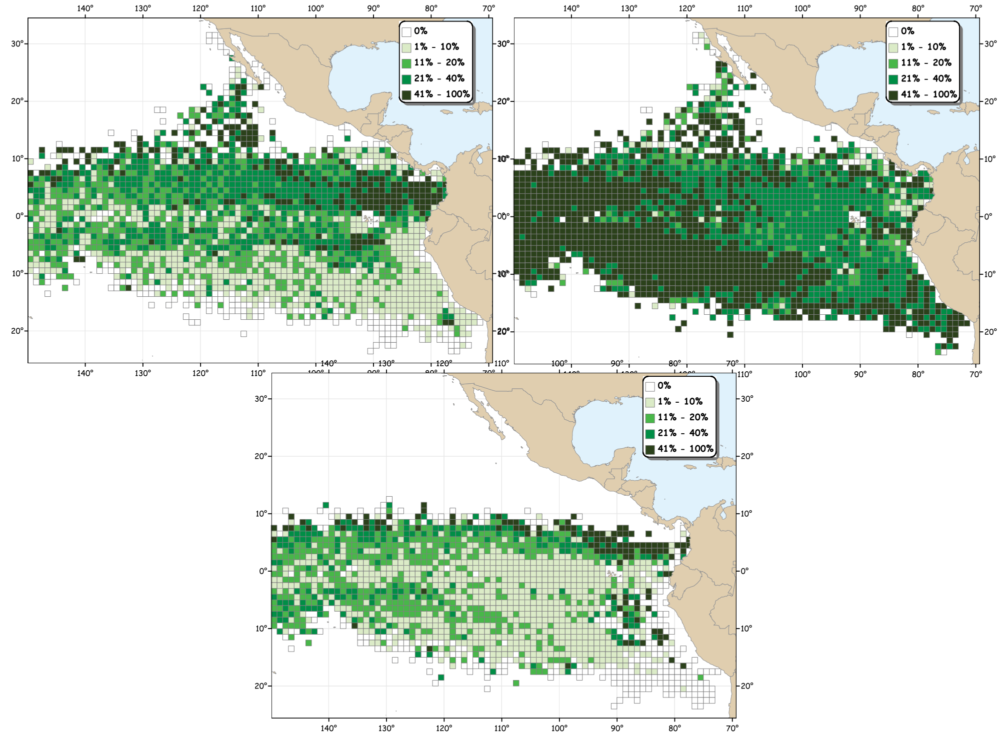


FIGURE 65
Percentage (capture of small tuna species/total tuna species) – sets on floating objects in the Eastern Pacific Ocean, 2001–2009



Furthermore, management actions may affect bycatch rates. The IATTC has passed resolutions mandating full retention of the tunas caught during the period 2001–07, and that may have affected some retention patterns (IATTC, 2010).

Other tuna species present in the EPO captures are Pacific bluefin tuna, caught in school sets, with an average annual capture of about 3 000 tonnes, and practically all retained (part of this connected to sea ranching operations).

Western Pacific

The average discarding for yellowfin and bigeye is about 5 percent, and for skipjack it is 20 percent (Williams and Terawasi, 2009). These figures are similar to the EPO for the first two, but the skipjack rate is double the EPO one. Two possible explanations are: (i) more-demanding buyers for the WPO fish, e.g. if labour is more expensive, etc.; or (ii) the average size of skipjack is smaller.

About 225 vessels participate in this fishery. In the WPO, school sets are predominant with 63 percent of all sets in 2008, followed by an increasing proportion of sets on FADs at 25 percent, and a decreasing proportion of log sets at 11 percent. In 2008, the FAD sets surpassed the log sets for the first time, as had happened in the EPO almost a decade earlier, in 1992. However, the different flags operate in different ways; for example, the fleet of the Republic of Korea relies heavily on school sets, while the fleet of the United States of America is more dependent on FAD sets (Williams and Terawasi, 2009).

The distribution of set types in space is inhomogeneous, and there is a localized section where payaos are extremely important, and other areas where they are absent. This confounding creates difficulties for meaningful comparisons. The skipjack CPUE for FADs is similar to the one for logs, and much higher than the one for school sets.

For yellowfin tuna, the reverse is true. However, the daily production of skipjack is 20–40 tonnes, while that of yellowfin is 2–7 tonnes; hence, the fishery is a skipjack-dominated operation. For comparison, discards in the longline fleet amount to 5 percent of the yellowfin and bigeye, and 20 percent of the skipjack captured (OFP, 2010a).

The OFP (2008b) shows the average bycatch rate for skipjack (4.7 percent), yellowfin (2.9 percent) and bigeye (4.4 percent) for the period 1995–2005. The rates are quite stable over the period, with the ranges being 4.4–5.3 percent for skipjack, 2.5–3.5 percent for yellowfin, and 3.9–4.9 percent for bigeye. An earlier study (Coan *et al.*, 1999) showed bycatch rates of less than 1 percent in log sets, 1–2 percent in FAD sets, less than 1 percent in school sets, and 2.6 percent in sets on payaos. They have some very high values (21–27 percent) but in categories with very few samples.

Atlantic

There have been changes in regulations that may have affected the figures for the years after the change (Romagny *et al.*, 2000). Amandè *et al.* (2010b) report 40 vessels operating in the period 2003–07. The total tuna discards are estimated to be about 6 000 tonnes/year. The composition of bycatch of the main target species is; skipjack 87 percent, yellowfin 9 percent, and bigeye 4 percent. The distribution of bycatch by taxonomic group shows: tunids 83 percent, other pelagic bony fishes 10 percent, billfishes 4 percent, and sharks 1 percent. Practically all the bycatch comes from FAD sets; slightly more than 12 percent of the capture is discarded from FAD sets, versus less than 2 percent in school sets. There is practically no bycatch of the major tuna species in school sets, but 56 percent of all floating object discards are from the main tuna species. The combined bycatch of all species adds up to 76 tonnes/1 000 tonnes of catch, composed of 63.5 tonnes/1 000 tonnes of tunas, 7.8 tonnes/1 000 tonnes of pelagic bony fishes, 3.2 tonnes/1 000 tonnes of billfishes, and 0.9 tonnes/1 000 tonnes of sharks.

Sarralde *et al.* (2007) also report observations made during the moratorium periods, and find that skipjack amounts to 96 percent of the discards in school sets, and yellowfin to the remaining 4 percent of the target species discards. Minor tuna discards are three times the major tuna discards. In floating object sets, the tuna discards consist of 89 percent skipjack, 8 percent yellowfin, and 3 percent bigeye. The fishery is composed of 56 percent of school sets (of which 20 percent are skunk sets), and 44 percent of floating object sets (of which only 1 percent are skunk sets). The discards per set are very low: 0.2 tonnes/set in school sets, and 1.1 tonnes/set in floating object sets. Of the overall discards of the fishery on school sets, 20 percent are skipjack and 1 percent are yellowfin. For the floating object sets, 43 percent of all bycatch is skipjack, and 4 percent is yellowfin. Chassot *et al.* (2009) show, for the French fleet no discards in school sets, and the BR (skipjack in FAD sets) is 4.3 percent, and the one for yellowfin is 0.1 percent of the yellowfin captured in the same sets.

For the Sarralde *et al.* (2007) data set, it is possible to compute the overall utilization rate (the catch of all major tuna species divided by the capture for all major tuna species), and this is 99.7 percent for school sets, and 97.2 percent for floating object sets. From the point of view of the overall BR (the total bycatch all species divided by the total capture all species), it is 1.6 percent for school sets, and 6 percent for floating object sets.

Indian Ocean

Pianet *et al.* (2010) summarize the activities of the European fleets for the period 1991–2008. There were 18 seiners from these flags operating in the fishery. Floating object sets are increasing in proportion, and rose from 32 percent in 1991 to 51 percent in 2008. The species composition of the set types is quite different. The WPPS on floating objects is 66 percent skipjack, 18 percent yellowfin and 13 percent bigeye tuna. In school sets, yellowfin makes up 84 percent of the capture, followed by skipjack (12 percent) and bigeye (2 percent). The WPPS on floating objects is much higher than for school sets 35 tonnes versus 25–30 MY. For all tuna combined, they report bycatch of 2.6 percent in FAD sets, 0.9 percent in school sets, and an overall value of 1.9 percent.

Earlier estimates by Sarralde, Delgado de Molina and Ariz (2006) based on 477 sets from the Spanish fleet show a BR of 2.8 percent for all tunas. Discards in WPPS are reported as 0 for school sets and 0.9 tonnes for skipjack, 0.2 tonnes for yellowfin, and 0.1 tonnes for bigeye. González *et al.* (2007) report for the Spanish fleet in the period 2003–06, based on an observed 535 sets. The coverage of FAD sets is 3.4 percent and the coverage of school sets is 0.5 percent, this difference may bias the results, and it is caused by an imbalance in the temporal distribution of the samples. The BR for the major tuna species for the whole period was less than 2 percent. Skipjack accounts for 40 percent of all discards of all species in floating object sets, and 26 percent in school sets. Yellowfin bycatch was 7 percent of FAD sets and 1 percent of school sets. Bigeye bycatch amounted to 4 percent of FAD bycatch, and 0 percent of school sets bycatch. The BR of tunas in FAD sets was 1.8 percent, and of school sets it was 2.2 percent.

Romanov (2000) summarizes the activities of the former Soviet Union fleet at the end of the 1990s. Bycatch rates for all major species are less than 1 percent, but the data come from a restricted geographical sector of the Indian Ocean. Romanov (2002) data (about 500 sets) show a bycatch per set of 0.5 tonnes/set, or 2.7 percent.

Amandè *et al.* (2008a) report a summary of estimates for the period 2003–07, using all data available (all European seiners in the area), adding up to 1 958 sets. The overall BR is 3.4 percent of the total capture; FAD sets produce a rate of 5.3 percent, and school sets 1.2 percent. The major tunas add up to two-thirds of the total tuna discards in FAD sets (skipjack 53 percent, yellowfin 11 percent, bigeye 2 percent), and 37 percent of all tuna discards in school sets (skipjack 26 percent, yellowfin 7 percent, bigeye 4 percent). Pianet *et al.* (2009) show tuna bycatch rates of 2.6 percent in FAD sets, and 0.9 percent in school sets. Fifty percent of all FAD discards and 79 percent of school set discards are tuna discards.

THE “MINOR” TUNAS

The minor tunas are a group of species present in most ocean areas, and in some cases in large volumes. They are caught by purse seines because they form mixed schools with other tuna species, or because they were being preyed upon by a larger tuna school, or, in some cases they are directly targeted by artisanal or industrial fisheries using different gear types when there is a local market. They are very important to the economy and food security of some regions (e.g. the North African coast [Hattour, 2009], off Sri Lanka [Venkatachalam *et al.*, 2010]), and they are completely discarded in other regions. Reporting is not adequate, and they are frequently lumped in categories. FAO uses pooled frigate and bullet tunas as a statistical unit, and so do some of the t-RFMOs, so the information is not available on a specific basis.

The list of these “other tuna species” is long, but quite similar in all oceans. It includes, among others, those listed below.

The Auxis group

The bullet tunas, *Auxis rochei*, are, according to Collette and Aadland (1996), divided into *A. rochei rochei* in the Mediterranean, and *A. rochei eudorax* in the EPO.

The Mediterranean subspecies reproduces in its third year of life, at 32 cm length. Most of the catch is of sizes 20–46 cm, with a mode at 33–41 cm (Hattour, 2009). The Atlantic stock matures at 35 cm, and 2 years of age (Macías *et al.*, 2006).

The frigate tunas, *Auxis thazard* or *A. thazard thazard*, are mostly found on the continental shelf. Off Sri Lanka, they are target of a significant artisanal fishery with driftnets, and fishers surveys shows some evidence of decline (Venkatachalam *et al.*, 2010), but IOTC data pooling the data for the *Auxis* species shows no trend.

The Euthynnus group

The eastern little tuna or kawakawa or mackerel tuna, *Euthynnus affinis*, is distributed in the Indo-Pacific region. It supports many artisanal fisheries with annual catches of 150 000 tonnes/year. These tunas are mostly caught at about 50–60 cm.

The Pacific black skipjack, *E. lineatus*, is found along the coasts of the Americas, from California (the United States of America) to Peru. It schools with yellowfin and skipjack tunas. Most common sizes in captures are about 60 cm. Female sizes at maturity are 46–50 cm (Schaefer, 1987).

The little tunny, *E. alleteratus* (also called little tuna or Atlantic black skipjack), is found in the Mediterranean. It matures in its second year, at about 42 cm. Modal catches are 50–60 cm (Hattour, 2009). It is more coastal than most other species in the group, lives up to eight years, and forms mixed schools with other species (Valeiras *et al.*, 2008a). It is an incidental capture, and it is retained in the sardine purse seine fishery (Zengin and Karakulak, 2009). It is taken along a long section of the eastern Atlantic coastline (Gaykov and Bokhanov, 2008).

The Sarda group, the bonitos

This group has been reviewed by Orsi Relini *et al.* (2005).

The Atlantic bonito, *Sarda Sarda*, is found in the Atlantic. It matures in its first year of life, at less than 40 cm; in other regions, in its second year (Macías *et al.*, 2006; Hattour, 2009). It lives up to five years and it forms large mixed schools with other tuna species. Most of the catch is of sizes 40–60 cm (Valeiras *et al.*, 2008b).

The striped bonito, *S. orientalis*, is distributed in the Indo-Pacific region but with many gaps. It is a coastal species and schools with other small tunas (Collette and Nauen, 1983).

The eastern Pacific bonito, *S. chiliensis*, matures in its second year of life and reaches a maximum longevity 5–8 years (Campbell and Collins, 1975). *S. chiliensis chiliensis* is found from Ecuador to Chile, while *S. chiliensis lineolata* is found along the west coast of North America, from Baja California to southern Alaska. It is an important species for small coastal and recreational fisheries (Collins and MacCall, 1977; Collette, 1995).

Orcynopsis unicolor is captured at sizes of 31–80 cm, with modal sizes 40–45 cm, and its size at maturity is 44 cm (Hattour, 2009).

The genetic structure of these populations is not well understood, and there appears to be considerable complexity. Cryptic species and genetic differentiation in small areas have been found in several species; hence, it is unlikely that management of these species can be improved without filling the genetic gaps. In the regions where the harvest is intense, such as the Mediterranean with a harvest of 80 000 tonnes (Srour and Di Natale, 2008), or the Atlantic with catches of 8 000–15 000 tonnes (Gaykov and Bokhanov, 2008), there is a need to manage the directed fisheries, together with any actions to reduce bycatch, where they occur.

Catch and bycatch of "minor" tuna species

Eastern Pacific

The main components of the minor tunas group are:

- Black skipjack, with annual captures of about 2 300 tonnes (80 percent in floating objects sets, 18 percent in school sets, 2 percent in dolphin sets); 85 percent of the capture is discarded.

- Bullet tunas, with average annual captures of more than 1 600 tonnes (75 percent in floating objects, 23 percent in school sets, and 2 percent in dolphin sets); 92 percent discarded.
- Eastern Pacific bonito, extremely variable captures in school sets, with an average of 1 600 tonnes, and only 4 percent discarded.

The development of markets in the EPO has not made the retention of these species profitable yet. It is believed that the biomasses of these species are important.

Western Pacific

The most frequent minor tunas occurring in the region are (in percentage of sets with the species; OFP, 2010a):

- Log sets: frigate tuna 3 percent, bullet tunas 1 percent, kawakawa 1 percent.
- Payaos: frigate tuna 12 percent, bullet tuna 5 percent, kawakawa 4 percent.
- FAD sets: bullet tuna 2 percent, frigate tunas 1 percent, kawakawa 1 percent.
- School sets: bullet tuna 4 percent, frigate tuna 3 percent, kawakawa 2 percent.

Similar to the frequencies reported in Coan *et al.* (1999) with 100 percent discarded, Bailey, Williams and Itano (1996), and Lawson (1997). The tonnage of "other tunas' adds up to only 0.2 percent of the bycatch (OFP, 2008b), and the catches of "other fishes" have been about 16 000 tonnes on average over the last three years, but it is not possible to apportion this figure.

Atlantic

The data from the ICCAT (2010) allows the average landings over the most recent three years to be computed, and Amandè *et al.* (2010b), reports the CPS, as summarized in Table 34.

TABLE 34
Average landings of "minor" tuna species in the Atlantic

	Overall catch	CPS
	(tonnes)	
Sarda sarda	22 500	–
King mackerel	10 000	–
Bullet tunas	5 300	780
Frigate tunas	4 200	270
Little tunny	12 600	1 910
Blackfin tuna	1 850	–
Plain bonito	500	–

Of the bycatch in school sets, 64 percent of the tonnage is little tunny, 11 percent is bullet tunas, and 6 percent is frigate tunas. These three species and the sailfish add up to 90 percent of the bycatch in school sets. In sets on FADs, 32 percent of the tonnage is little tunny, 13 percent is bullet tunas, 4 percent frigate tunas, and 2 percent of unidentified *Auxis*. In this type of sets, skipjack shares the dominant position with the little tunny, also with 32 percent (Amandè *et al.*, 2010b). Of the fishes counted during a study covering 2006–08 (Pianet *et al.*, 2010), about 5 percent of the total number of individuals from the purse seine fishery were frigate tunas, and 1.6 percent were little tunny.

In the Atlantic, the purse seine fishery developed a "parallel operation" based on the sale to local buyers of individuals of the main target species not accepted by the canneries, because of size or condition, and of minor tuna catches. This portion of the harvest became known as the "faux poisson" or "faux thons", which translates as "false fish" or "false tunas". The operation was described in the mid-1980s (Bard and Kothias, 1985; Amon Kothias, 1986), and increased in magnitude with the introduction of the FADs in the fishery beginning in about 1991 (Bard and Herve, 1993; Ariz *et al.*, 1999; Ménard *et al.*, 2000b). For many vessels and local participants, it is an important component of the production of the fishery, but it was not well controlled or managed. Menard *et al.* (2000b) reported bycatch of the major tuna species from FAD sets of 6 percent in weight, and of the minor tuna species of 16 percent in weight. Frigate tunas were 28 percent of the discards, and little tuna or black skipjack were 11 percent. The unloading of these catches continued in the 2000s (Konan, Rene and Herve, 2007), and it includes other species such as rainbow runner, wahoo and barracuda. The catches for 2004–05 exceeded 21 000 tonnes, and are more than 20 percent of the overall tuna catch. These catches consist of skipjack (38–51 percent), bullet tunas (16–19 percent), little tunny (10–13 percent), wahoo (5–8 percent), rainbow runner (2–5 percent), and others. Small yellowfin and bigeye tunas are also at a level of 5–8 percent.

This is one case where the "ecosystem utilization efficiency" is very high. Most if not all of the fishes included in this "faux poisson" group may be killed as a result of the capture process, so their utilization in most cases does not add fishing mortality to that already caused by the operation. It is also a way to "diversify the harvest", a concept that has not been explored in fisheries yet (Hall, 1996; Kolding *et al.*, 2010). This concept is important to develop intelligent bycatch management systems, and it questions the premise that highly selective fisheries are a "good" way to harvest an ecosystem, if one of the goals is to maintain its structure and function, and the properties of resilience and others that are so valuable for sustainable use. The alternative would be to develop a diversified harvest scheme, where the impact of the fisheries is distributed horizontally and vertically across the trophic web, while at the same time reducing the excessive pressures applied to a few species and sizes. It entails making decisions on utilization of resources that are not supported by immediate economic objectives – a major innovation. In a way, the utilization of the minor tuna and other species, together with the increased retention of other species such as mahi-mahi and wahoo, could be viewed as an opening to the possibility of steering management in a new and perhaps positive direction.

Indian Ocean

For the Spanish fleet in the period 2003–06, González *et al.* (2007) report tuna discards in FAD sets distributed as follows: skipjack 40 percent, frigate tunas 39 percent, bullets 9 percent, yellowfin 7 percent, and bigeye 2 percent, and a bycatch per sets for all tunas of 1.6 tonnes/set. For school sets, frigate tunas are 68 percent of the discards, followed by skipjack 26 percent, bullets 5 percent, and yellowfin 1 percent, with a total of 2.5 tonnes discarded per set. All bullets and little tunny were discarded, as were 95 percent of the frigate tunas from FAD sets and 88 percent of the frigate tunas from school sets. For FAD sets, the bycatch/capture ratio for the tuna group was less than 2 percent, while for school sets it was about 2 percent. Most of the capture came from FAD sets in their sample.

Amandè *et al.* (2008a) summarize the Indian Ocean data for the period 2003–07, with a total of 2 000 sets observed. The average annual tuna bycatch was almost 5 200 tonnes, which was 54 percent of all the bycatch of all species. The BR can be expressed as 19 tonnes of bycatch discarded per 1 000 tonnes of catch, or 1.9 percent. By set type, it was 26.5 tonnes tuna discards/1 000 tonnes tuna catch in FAD sets, and 9.3 tonnes tuna discards/1 000 tonnes tuna catch in school sets. In FAD sets, frigate tunas are the second-highest with 19 percent of the discards, and bullets rank fourth with 8 percent. In school sets, bullet tunas are the highest tonnage with 37 percent, and the third is frigate tunas with 17 percent – a large volume captured, but with little utilization.

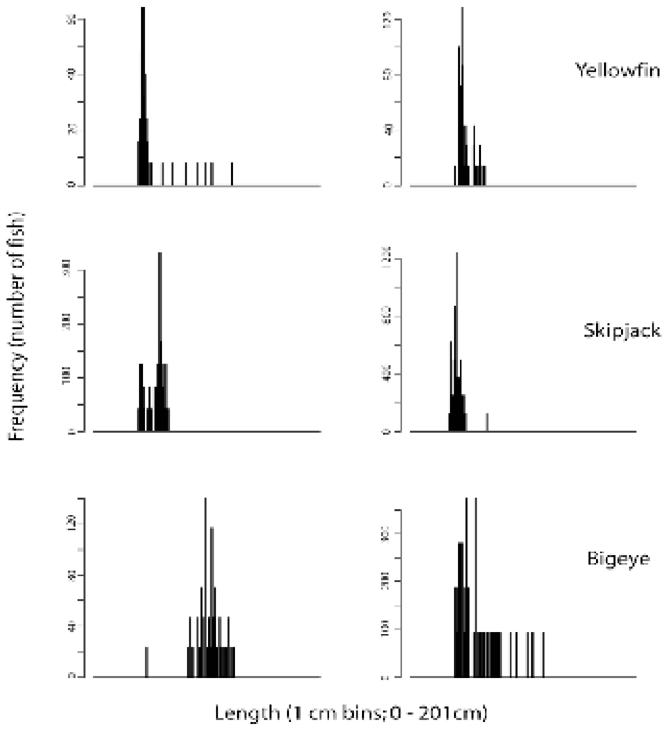
ACTIONS AND CONCEPTS TO REDUCE TUNA BYCATCH

Many of the captures of small individuals of the major species, or of individuals of the minor species, can be retained and utilized. As their survival is questionable, utilization would be a way to reduce fishing effort on the main targets. Where there are markets, as on the west coast of Africa (Romagny *et al.*, 2000), this is what happens in many trips. However, where there are no markets, the unwanted individuals or species are discarded dead, or most probably to die. The issue has three different aspects: (i) the impacts of this bycatch on the tuna populations, especially the major ones; (ii) the waste of a resource; and (iii) the ecosystem implications. When growth rates and natural mortality rates are high, the volume of the bycatch may be insufficient to cause a noticeable impact on the population of the species. This may be the case of the skipjack bycatch in some regions. In this case, the reduction of bycatch is not a high priority for management. However, it remains a waste issue in the perception of the public, and of the fishers themselves.

As the survival of the discarded fish, after being brought on board, is not expected to be high, the main options to reduce bycatch must rely on approaches that avoid capture or release from the net, before the sacking-up process is advanced. However, when a population is showing a declining trend, after the normal reductions to reach the level of the maximum sustainable yield, such as in the case of bigeye tuna in the Pacific, then the issue of capture of juveniles contributes to the negative trend. The development of the FAD fisheries, so productive for skipjack, has resulted in increases in the catches of juvenile yellowfin and bigeye tunas that are also associated with the FAD just before sunrise, when these sets are made. The objective should then be to reduce the catch of bigeye and yellowfin without losing skipjack production – catch, and not bycatch, because the bigeye and yellowfin tunas are retained and sold. For the FAD fishers, the catches of yellowfin and bigeye increase the value of their sets, and they would rather keep them than lose them.

FIGURE 66

The selectivity dilemma: two length frequency samples from sets on floating objects in the Eastern Pacific Ocean



Source: Courtesy of C. Lennert-Cody, IATTC.

The challenge for selectivity work is that the mixtures of sizes in different sets are quite heterogeneous. Figure 66 illustrates the problem, showing two individual sets. In one, the bigeye tuna sizes are significantly larger than the skipjack sizes, in the other, the three species have the same size distribution. The "traditional" selectivity approach is to find the mesh size that allows the smaller fishes to escape from the net, or to avoid capture entirely. However, in the bigeye–skipjack problem, the objective would be an inverse problem: let the larger individuals (bigeye) escape while retaining the smaller ones (skipjack). The second sample illustrates another case, where all the species in the sample have practically the same size distribution, so no sorting process can help, unless there are behavioural differences in the net (e.g. vertical separation). There is no research available on behaviour of the different species and sizes inside the net, which would have been crucial to assess the feasibility of this type of approach.

There are two different objectives with regard to tunas:

1. to reduce the waste of undersized individual of all species;
2. to reduce the capture of juvenile bigeye, and to a lesser extent of yellowfin tuna.

In the present circumstances, with the condition of the bigeye and of some yellowfin stocks being overfished overfished or with overfishing occurring in several regions, Objective 2 has a higher level of priority in those regions, while Objective 1 may be more relevant in areas where there is not much bigeye associated with FADs, or the condition of the bigeye stocks is better. In the EPO, the volume of juvenile bigeye catch in purse seine sets has been steadily growing (Figure 67; IATTC, 2010).

Avoiding the capture of "small"/unmarketable tunas of all species (Objective 1)

Most of these captures come from sets on FAD or payaos.

Spatial or spatial–temporal management

If the areas or periods with high concentrations of small tunas (high ratios of bycatch small tunas/catch of tunas) are known, then spatial–temporal closures are an option. In the EPO (Figure 65), the area with a high proportion of small skipjack tuna is very large for a closure. The incidence and intensity of El Niño events creates problems by altering current systems, and changing the location of suitable condition for reproduction, etc. Fixed areas may have to be placed in locations determined by average long-term bycatch, and they will be effective also in the long term. Monitoring these spatial closures requires high observer coverage, or VMSs, which are already in use in many fleets.

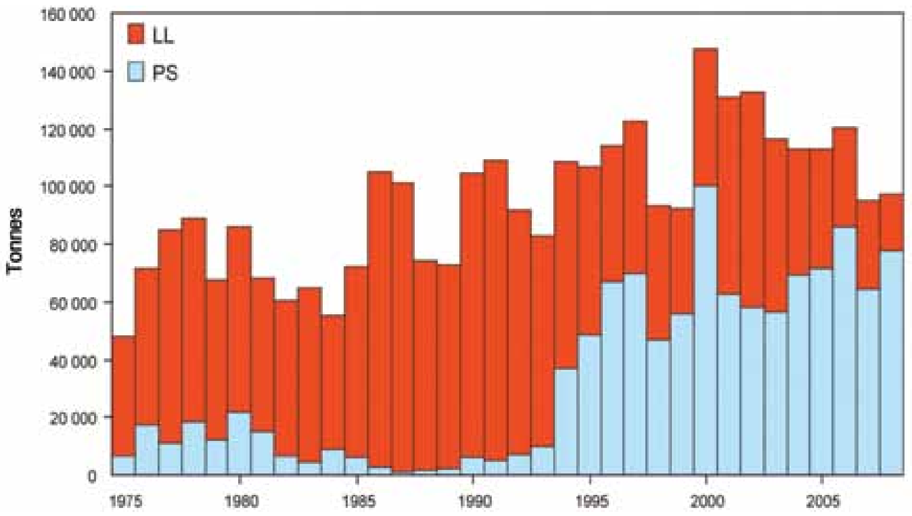
An alternative is the use of fleet communication when an area with a large proportion of small tuna is encountered, in a manner similar to that in use to reduce sea turtle bycatch in the Hawaiian longline fisheries (Gilman, Dalzell and Martin, 2006). Vessels encountering some predefined levels of bycatch communicate to the rest of the fleet the location of the problem spots, which are then avoided by the other vessels. This system is adaptive, and it is very suitable for accommodating to oceanographic changes.

A problem of the spatial closures is that, even if a vessel stays away from an area, its drifting FADs may cross the closed area and aggregate fish that is then captured outside the closure area. This issue must be taken into account in order to put an effective system in place.

Acoustic information

If the fishers knew before making the set that the biomass of small tunas was very high, they might decide to skip the set because of the lower economic payoff. Some FADs have acoustic systems to report to the vessel the biomass underneath, but they do not discriminate sizes (Delgado de Molina *et al.*, 2005b), or they do not provide consistent information matching the vessel echo sounders (Lopez *et al.*, 2010). Moreover, the acoustic signals must go frequently through the biomass of other species that accumulate closer to the FAD. Systems that can report the size distribution or discriminate sizes very well (Moreno *et al.*, 2005, 2007b; Miquel *et al.*, 2006; Moreno, 2008; Morón, 2008) are needed for this task. All acoustic information is affected by sea conditions, but more importantly by thermocline depth, which is very different in different ocean regions (Durand and Delcroix, 2000; Kessler, 2006).

FIGURE 67
Catch of bigeye tuna by gear, 1993–2008

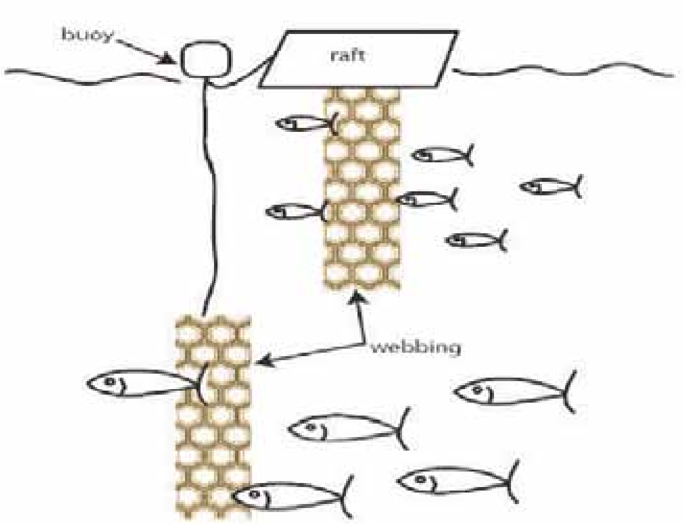


Technological changes

Another suggestion proposed but never tested is a two-part FAD. A floating FAD is connected vertically with another FAD at some depth (Figure 68; Kondel and Rusin, 2007). The deep FAD can be separated from the other one and towed away. If some species of tunas associate with the shallower one, and others with the deeper one, then it may be possible to separate the schools before setting.

Another option proposed by L. Dagorn is the use of two similar FADs at the same depth, relatively close to each other, and verifying acoustically the distribution of targets and non-targets. If all the schools are under the same FAD, there will be no gain, but if there is some splitting of the schools or individuals, captures of unwanted individuals could be reduced.

FIGURE 68
Vertical double FAD

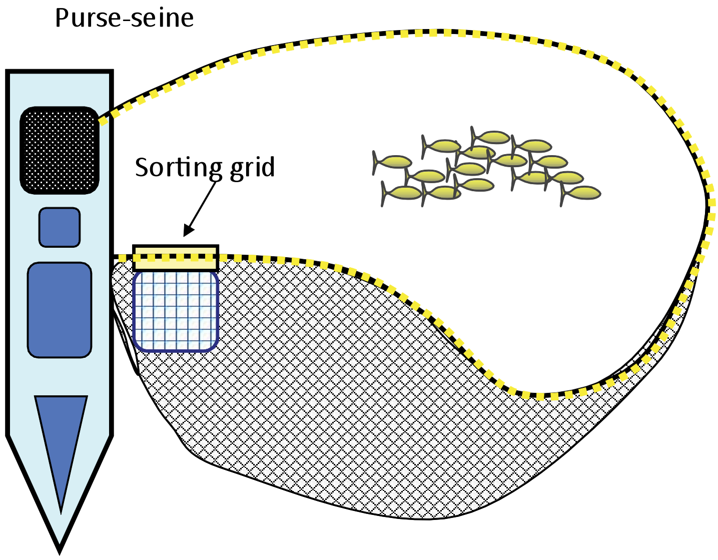


Source: Nelson (2004).

Release from the net

For Objective 1, the problem is a typical selectivity problem, where changes in fishing gear characteristics or operational modes are needed in order to allow the escape of all individuals below a fixed size. This size may be determined through modelling exercises, but much more probably it will reflect the economic conditions at the time (tuna prices, availability of sizes, etc.). Experiments have started to develop a "sorting grid" for tuna purse seines, based on research published by Misund and Beltestad (2000) for Eastern Atlantic purse seine fisheries for mackerel, saithe, etc. Their results were mixed, with only some species surviving the escape. Following their approach, a rigid grid was constructed and tested in Ecuador in a tuna seiner. It proved to be cumbersome, and was not adopted, but a gear expert (A. Arrue) used the concept to develop a flexible grid.

FIGURE 69
Diagram of sorting grid for tuna purse seine and proposed location



The location of this grid in the net is shown in Figure 69. It is installed permanently on the seine, and can be passed through the power block without difficulty (Plate 3). One of its virtues is that it can be raised at will, and it can even have openings of different sizes at different levels of the net that can be replaced at will according to the catch. Plate 4 shows some construction details. The drawback of this flexibility is that skippers choose to submerge different proportions of the grid, making the results of the experiments inconsistent. The experiments are at a very early stage, and the design, construction materials, and form of utilization are evolving rapidly. Other grid designs have been presented as options: Villar's larger mesh grid (Plates 5–7); Nelson's design (Figure 70; Nelson, 2004, 2007); a Canadian design used in small purse seines for salmon fishing (Figure 71); a design by Stephenson (Figure 72), based on the attachment of rigid shapes individually sewn into the net. The need for a frame that is rigid at times but flexible at other times may be solved using a small hose that could be inflated with a pressurized liquid at the right time (Figure 73; Nelson, 2004). Finally, a type of grid designed by K. Zachariassen, the Flexi-Grid to use in trawls (Plate 8) may be of potential application to purse seines.

PLATE 3
Flexible sorting grid going through the power block.

PLATE 4
Arrue's sorting grid – details of construction.

PLATE 5
Work on Villar's sorting grid.

PLATE 6
Villar's sorting grid.

PLATE 7
Villar's sorting grid in the water.

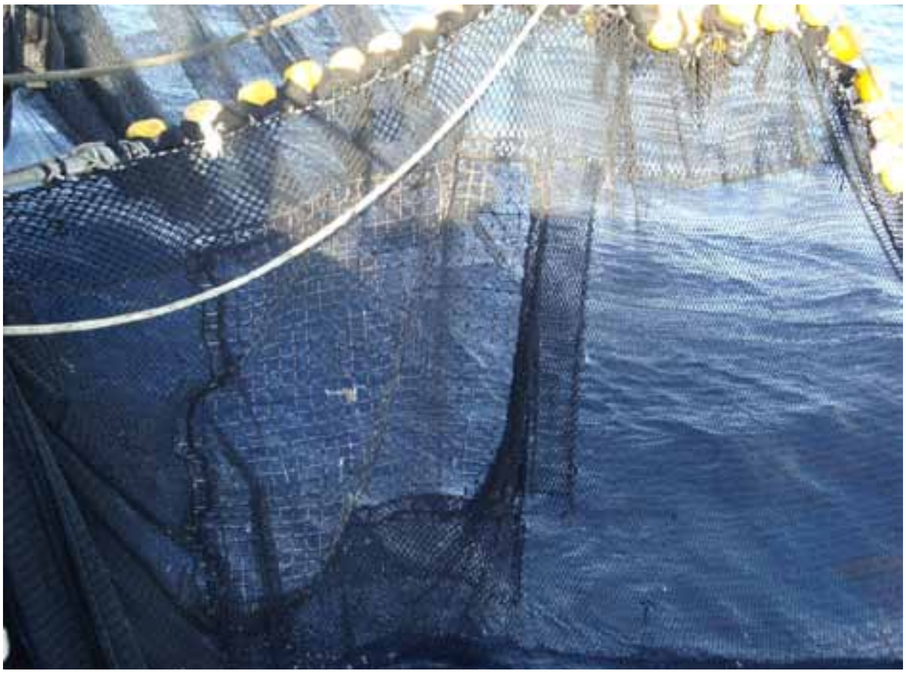


FIGURE 70
Nelson's design – flexible PVC panels

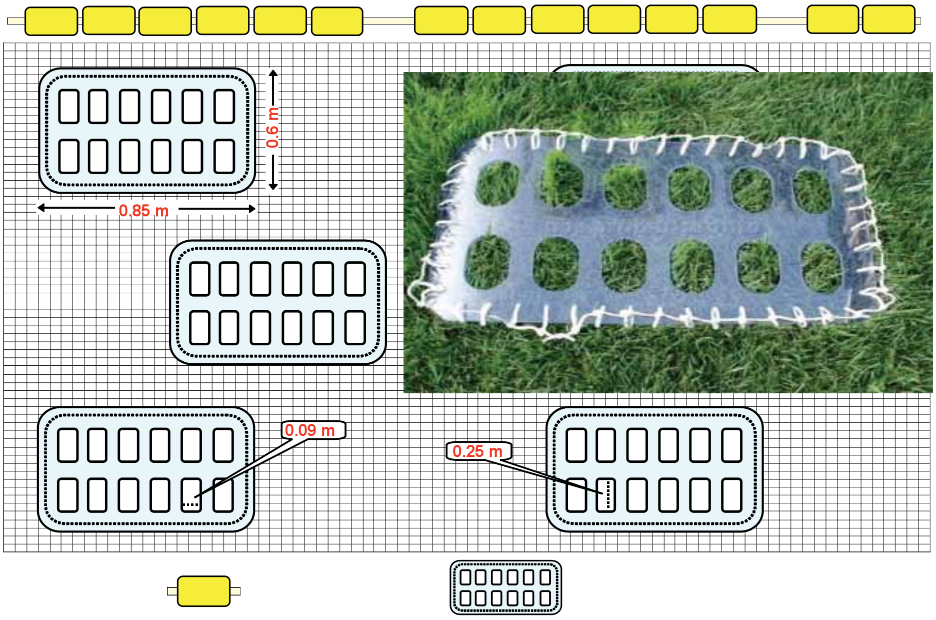


FIGURE 71
Grid design used in Canadian salmon seines

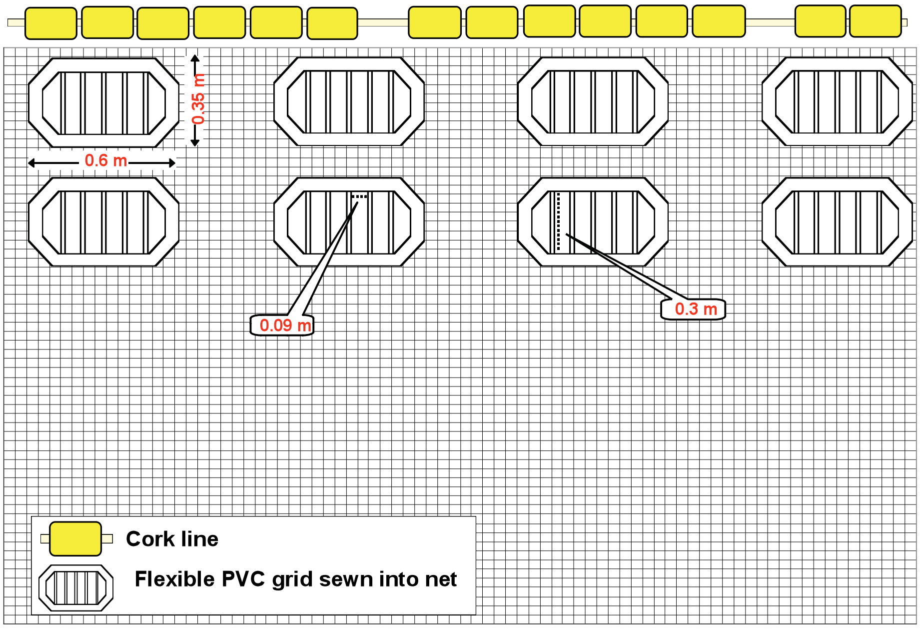


FIGURE 72
Rigid shapes sewn in the webbing

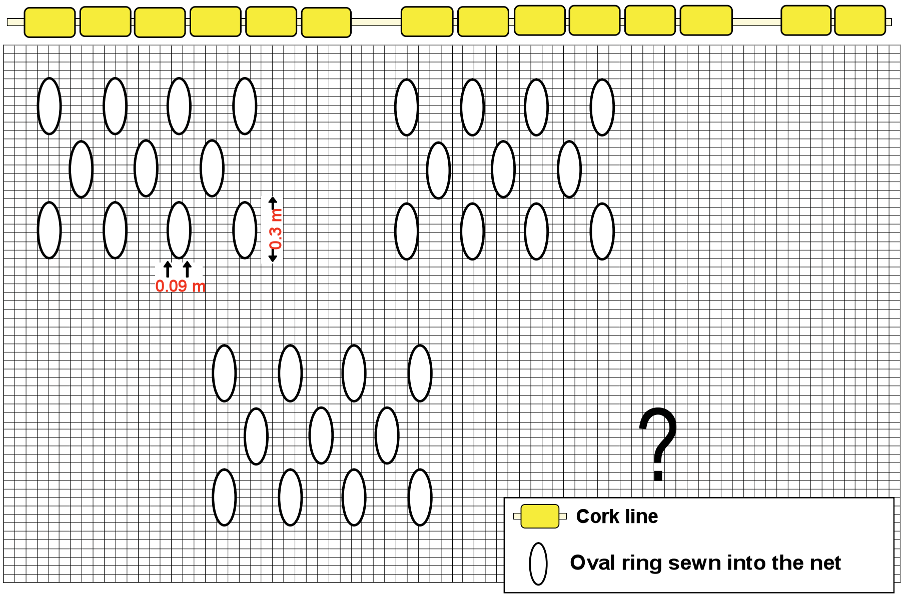


FIGURE 73
Nelson's design: grid framed by high pressure hose

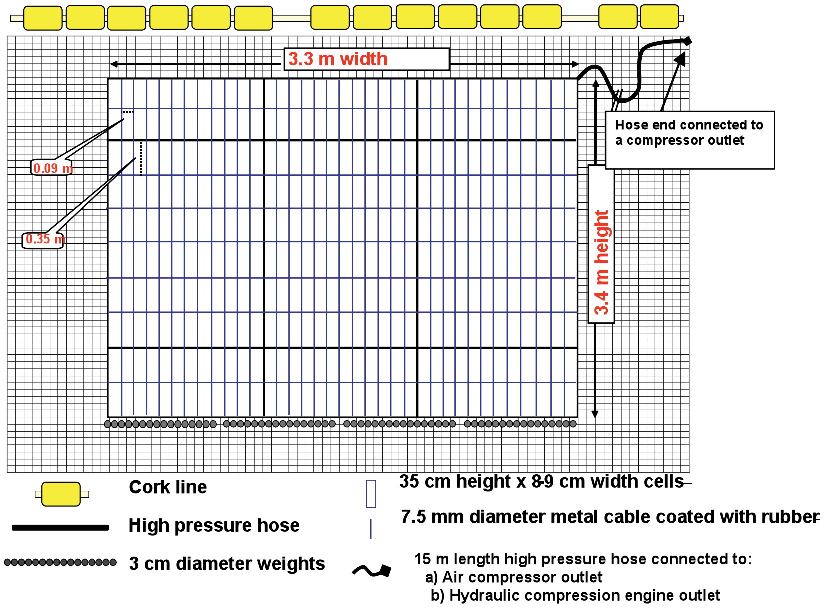


PLATE 8
Zachariassen's grid used in trawls.

Initial results have shown that the number of tunas leaving the net is not very high (less than 6 percent, Table 35), but the experimental conditions were not controlled, and there are not enough replicated samples using a consistent technique. Other locations for the grid in the net are being tested too.

Some researchers believe that a mechanism is needed to "herd" the tunas towards the openings. Recent experiments in Japan (Hasegawa *et al.*, 2010; Oishima, personal communication) have shown that tunas have a strong response to intermittent and continuous light, and it is thought that batteries of lights inside or outside the net may be used to direct the school towards the grid.

Besides these experiments, others will be needed to evaluate the survival of the individuals leaving the net. A limited experiment in Achotines, Panama, showed good

TABLE 35
Percentage escape with sorting grid partially in the water, EPO Capture includes those that escape

		YFT+BET (tonnes)					
		<2,5 kg			>2,5 kg		
% submerged	No. sets	Capture	Escape	% escape	Capture	Escape	% escape
1-25	351	740	7	0.9	4 336	0.5	0.01
25-50	296	727	7	1	3 139	0.8	0.02
50-75	292	205	14	6.7	2 657	3.4	0.13
75-100	222	219	3	1.3	1 814	1.7	0.09

		SKJ (tonnes)					
		<2,5 kg			>2,5 kg		
% submerged	No. Sets	Capture	Escape	% escape	Capture	Escape	% escape
1-25	351	4 548	19	0.4	3 842	0.3	0.01
25-50	296	4 671	48	1	3 121	6	0.19
50-75	292	1 802	78	4.3	3 721	31.6	0.84
75-100	222	1 303	60	4.6	3 380	36.3	1.06

Note: Capture includes those that escape.

survival for tunas crossing a PVC grid in a tank (IATTC, 2000). Field experiments will be necessary to complete the evaluation of this mitigation technique. Costs and practicality are adequate, so it would not be so difficult to adopt the grids if they proved effective, once the evidence is complete (IATTC, 2004a; Nelson, 2007). The sorting grids were effective at allowing some, non-tuna species to escape (Tables 36–38), depending on their sizes and shapes. Whale sharks, manta rays and ocean sunfish (*Mola mola*) will require other procedures. The function of the sorting grids should not be seen as exclusively to release tunas but as a mechanism to facilitate the escape of many unwanted individuals of different species. Many fishers are interested in the release of these other species because of their perception that the more of the fauna left under, the FAD the quicker the recruitment of more tuna. A requisite for this approach to succeed is to avoid crowding tuna in the net, which may cause mortality without any opportunity of release.

TABLE 36
Percentage escape with sorting grid partially in the water in the Eastern Pacific Ocean

		Mahi-mahi			Wahoo			Yellowtail		
% submerged	No. sets	Capture	Escape	% escape	Capture	Escape	% escape	Capture	Escape	% escape
1-25	351	14 547	1 826	12.6	4 931	102	2.1	376	60	16
25.50	296	15 645	6 147	39.3	4 957	171	3.4	219	22	10
50-75	292	13 323	5 665	42.5	6 975	545	7.8	80	28	35
75-100	222	14 330	7 175	50.1	4 745	443	9.3	62	12	19.4

Note: Capture includes those that escape.

TABLE 37
Percentage escape with sorting grid partially in the water in the Eastern Pacific Ocean

		Other large fish			Triggerfish			Other small fish		
% Submerged	No. Sets	Capture	Escape	% escape	Capture	Escape	% escape	Capture	Escape	% escape
1-25	351	992	234	23.6	3 077	1 250	40.6	1 897	207	10.9
25-50	296	999	145	14.5	2 911	1 212	41.6	419	62	14.8
50-75	292	382	40	10.5	968	523	54	135	30	22.2
75-100	222	251	26	10.4	2 449	1 817	74.2	61	0	0
		2 624	445	17.0	9405	4 802	51.1	2 512	299	11.9

Note: Capture includes those that escape.

TABLE 38
Percentage escape with sorting grid partially in the water in the Eastern Pacific Ocean

Species (No. of fish)	Capture	Escape	% escape
Mahi-mahi	14 330	7 175	50.1
Wahoo	4 745	443	9.3
yellowtail	62	12	19.4
Other large fish	251	26	10.4
Triggerfish	2 449	1 817	74.2

Note: Capture includes those that escape.

A mechanism that is in use in some vessels is towing the FAD outside of the seine before it is completely closed. This is being used to release smaller species closely associated with the FAD, but it may also have some value for the release of very small tunas.

Utilization of tunas

In the past, most RFMOs passed conservation measures to reduce the tuna discards, and one of the options chosen was the full retention of the capture. The objective of the measure was to push the vessels towards reducing the discards of small tunas by the economic "sanction" implied in the obligation to retain fish that may have a very low value. By forcing the utilization of the small tunas, it was expected that the fishers would develop the methods to avoid their capture. In the EPO, a clause was included stating that if the fish was not fit for human consumption it could be discarded, and this exception was used by many, rendering the measure ineffective.

It is an incentive system for the vessels to find the solutions to the discard problem themselves. A major drawback is that this measure requires very complete monitoring, either a 100 percent coverage observer programme or electronic monitoring.

In some regions, a fishery has developed to utilize the small tunas, and this may turn the retention into a dangerous expansion of the fishery, capturing sizes well below the optimum (Romagny *et al.*, 2000). However, with very low expected survival of the individuals going through the sacking-up and brailing process, utilization is better than discarding dead fish that may sink to the deep, and remove the biomass from the pelagic ecosystem.

Reducing bigeye capture (Objective 2)

For avoiding capture, the treatment of this option is the same as for Objective 1.

Spatial or spatial-temporal closures

These have been attempted in most regions. In the Atlantic, for many years there was a voluntary moratorium on fishing on FADs during a period each year. Later, this became mandatory by ICCAT Resolution, and was enforced by 100 percent observer coverage (Goujon, 1999; Ariz *et al.*, 2009; Gaertner, 2010). In the EPO, an area called "el corralito" (the little corral) has been closed during part of the year, and another area was closed in the WPO to FAD fishing. The effectiveness of these closures is still subject of debate (Pallares and Kebe, 2002; Goujon, 2004b; Ariz *et al.*, 2005; Hampton and Harley, 2009; Harley, Williams and Hampton, 2010; Harley and Lawson, 2010), and compliance problems, high monitoring costs, or loopholes are common problems (Harley and Suter, 2007). Most comments made in the section for Objective 1 apply here.

Acoustics

In this case, it is necessary to provide the fishers with information on the species composition of a school or schools before a set is made, or on the horizontal and vertical distribution of the species/schools (Moreno *et al.*, 2005, 2007b; Moreno, 2008).

The options then are:

- If the proportions of juvenile bigeye (and/or yellowfin if it were needed to reduce the captures of both species) exceeds some level, or if the tonnage exceeds some acceptable amount, then the set should be avoided.
- If the spatial distribution around the FAD allows some schools to be encircled and others avoided, target the sets more precisely.
- If there is vertical separation, then reduce the depth of the net to limit the captures to the upper layers, assuming that bigeye are in the deeper layers.

The three main tuna species have important differences in their anatomy that influence their target strength to acoustic signals. Skipjack does not have a swim bladder, yellowfin and bigeye do. The swim bladder of the bigeye tuna is much larger than that of yellowfin (Schaefer and Fuller, 2008). These differences are less pronounced in very small yellowfin and bigeye. With these characteristics, and some behavioural and size differences, it may be possible to have an idea of what is going to be captured prior to making the set. However, although some skippers claim that they do know what they are going to capture with some margin of error, many more skippers state the opposite, namely that they do have some idea, but that it is nowhere near the ability to make a quantitative assessment of the proportions of species and sizes. Both groups acknowledge that there are circumstances that improve or impair their assessments, such as the total tonnage in the set, the amount of other species present, the depth of the thermocline, etc.

The first step would be to improve the technology and its use so that the assessment prior to the set becomes much more accurate. This involves electronics, but also software to interpret images, perhaps creating a library of images with data on the captures obtained in each case, etc. For a regulation to be applied to the fleet, it is necessary that those that need to comply with it have the elements needed to assess the situation in the vast majority of cases, including different mixes of species, different tonnages, different thermocline depths, etc. The skills to interpret images develop in the skippers with experience, and they may be transmitted to the new ones. However, a regulation cannot require a very demanding set of skills if it needs to be applied by all vessels.

Adding to the complexity of the first step, the second step is the implementation of a programme mandating the vessels to skip some sets under a given set of conditions. If a vessel has sailed some distance to arrive at a FAD, and it has no time to reach another one, it will be disinclined to skip the set (Moreno *et al*, 2005, 2007b). Researchers from the Mitigating ADverse Ecological impacts of open ocean fisheries (MADE) programme, an initiative from European research groups that has the objective of "mitigating adverse ecological impacts of open ocean fisheries" (Dagorn *et al.*, 2009), are working to develop buoys to be attached to the FADs that can send the information remotely. If the vessel can make a good decision before approaching the FAD, then compliance should be easier (Lopez *et al.*, 2010).

How to monitor compliance, even with 100 percent observer coverage, is not obvious. Observers are not qualified to determine what the acoustic information means, so there should be some type of acoustic logbook recording images prior to a set; a rather complicated process for verification.

An interesting alternative for identifying species that is currently in development is broadband sonar using a split beam to imitate the characteristics of a dolphin sonar (Okamoto *et al.*, 2010).

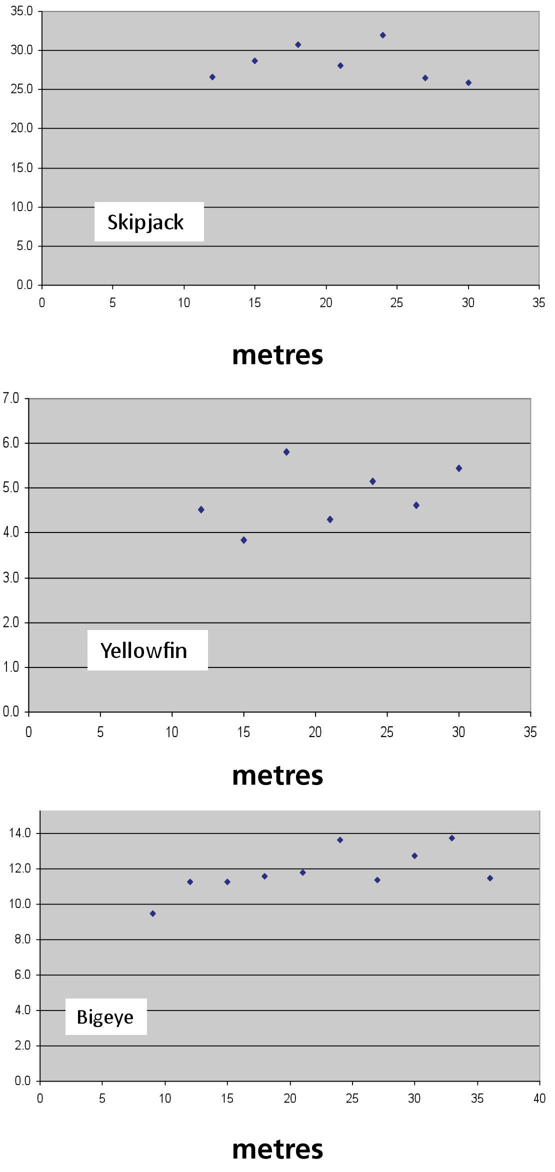
Technological changes

In the case of bigeye, there was an expectation that perhaps a technological solution could reduce the capture. As bigeye inhabits deeper waters than the other two species, it was thought that some modifications of the fishing gear could work. Two options were explored: shorter net depths, and shorter webbing hanging under the FADs (Itano, 2008). Several analyses and experiments were carried out in the different oceans. Lennert-Cody, Roberts and Stephenson (2008) found that there was a higher probability of encountering bigeye under objects with deeper webbing, or fishing with deeper nets, although location variables were much more important. Vessel effects were also significant. However, Satoh *et al.* (2007) and Delgado de Molina *et al.* (2010a) did not find significant differences. Langley (2004) reported that the proportion of FAD sets (with deeper profile) with bigeye was significantly higher than for log sets, but the catches in both types of sets were not different. In some of these studies, the sample sizes are too low, and there are many covariates to consider. Experiments with large sample sizes are needed to answer this question. Figure 74 illustrates in a simplified manner the changes in capture per set with the depth of webbing hanging under the FAD. The distribution for skipjack is flat for all values. For bigeye, it has a lower value for the shortest webbing (about 10 m), but the rest is quite flat. However, there are no values for less than 10 m, and the question is: would there be a difference if webbing were limited to a maximum of 8 or 10 m?

Operational strategies

If the proportions of bigeye in mixed schools change in some circumstances, or if schools separate at some point, it may be possible to select which one to capture, and avoid bigeye. Fishers set just before sunrise because the biomass is maximal at that time. It has been suggested that the fishers could approach a FAD and wait for a skipjack school to separate from the FAD before setting on it. However, doing that loses the major advantage of FAD sets, discussed above, and that is that the schools are “fixed”, and there are very few “skunk” sets, whereas in school sets, the probability of failure reaches 40 percent for some fleets. This would result in a major loss in productivity, and there are other simpler ways to achieve the same goal. Another option, mentioned by Langley (2004), would be to avoid setting during the new moon period, but it is cumbersome to implement. If the proportion of bigeye increases when repeated sets are made on a FAD, then it may be possible to reduce the proportion of consecutive sets on a FAD with some management restrictions.

FIGURE 74
Catch/set vs depth of webbing (in metres) hanging under FADs



Releasing from the net

In this case, the selectivity problem is the inverse – the object is to release the larger species. One option would be to allow the escape of skipjack from the seine to a secondary net, and when all the skipjack have left, release the ortza and free the bigeye. However, there is no information on the behaviour of the different species inside the net that could inform the discussion.

One of the main questions is: Is there any kind of separation/stratification inside the seine that could help? For example, if the bigeye school were near the bottom of the seine, or near the surface of the water, it may allow for some differential release. When swimming speeds decrease in the net, as the set progresses, the larger swim bladders may keep some species from sinking, while others sink. When fishers were asked about bigeye behaviour inside the net, and particularly whether they come close to the surface at some point, the answers were not consistent. Some said that they do come to the surface but with their swim bladders inflated and in bad condition, while others said that they were alive at the surface. These differences may be caused by thermocline depths or school bathymetric differences prior to the set.

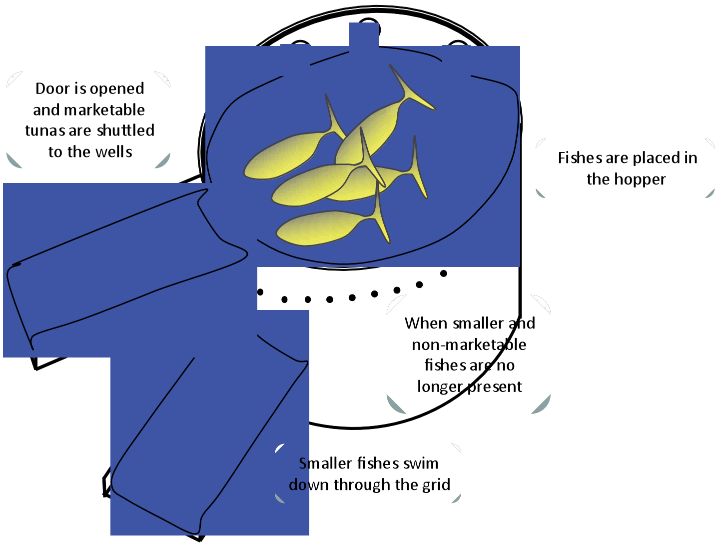
If there is stratification by species, then the sorting grid may be a useful way to release the bigeye. The grid will have larger openings, and after the bigeye have gone, it will be lifted out of the water, or closed with some simple mechanism. The use of lights to manoeuvre schools inside the net is a promising area of research; bigeye tuna seems to escape when exposed to blinking lights, and combined with some escape system (larger mesh, grid, panel), it may overcome the tendency of the fishes not to escape through the net even when the mesh size allows it (Hasegawa *et al.*, 2010).

Another possibility is a "vertical separation by mortality." If skipjack sinks and dies first, then it may be possible to find a way to release the surviving bigeye while retaining the skipjack. This concept has some technical challenges as to how to handle the weight of dead fishes on the net.

Releasing from the deck

An innovative concept to release fishes alive has been advanced by Richard Stephenson (Figure 75–78). The basic, and innovative, idea is that the sacking-up and brailing processes are so stressful that they limit the survival chances for many species. To avoid this, there is a need for a system that does not rely on the usual operation. Reducing the volume of the net would be a first step, but the idea is to allow the schools to stay in motion, and pump air and water inside the net, to maintain oxygen and water temperature at levels that maintain the fish alive and in good condition to survive the process. Fishes will be brought on board with one of two proposed systems: (i) a large diameter pump, similar to those used in other fisheries (Gabriel *et al.*, 2005; www.fao.org/fishery/equipment/fishpump/en; www.miprcorp.com/fishpump.html) or in salmon farms (www.utas.edu.au/docs/aquaculture/salmon/pumps.html); or (ii) a wet brailer, a brailer that will keep seawater inside, and that will operate with smaller numbers of fishes. Once on deck, the fish will be released into a large sorting tank, with circulating seawater, and with different grids to separate the fish that will then be sent via chutes to the wells or back to the ocean. A modification to the net, also proposed by Stephenson, could provide more space for the schools to swim inside it (Figure 80).

FIGURE 75
On-deck sorting tank



Source: Concept by R. Stephenson.

This concept is based on the premise that fishing should not be "killing a number of fishes and then deciding what we want to keep", but rather "capturing live fishes and only killing what is meant to be retained".

FIGURE 76

To reduce stress in the net: aerate the net and use water under pressure to distribute

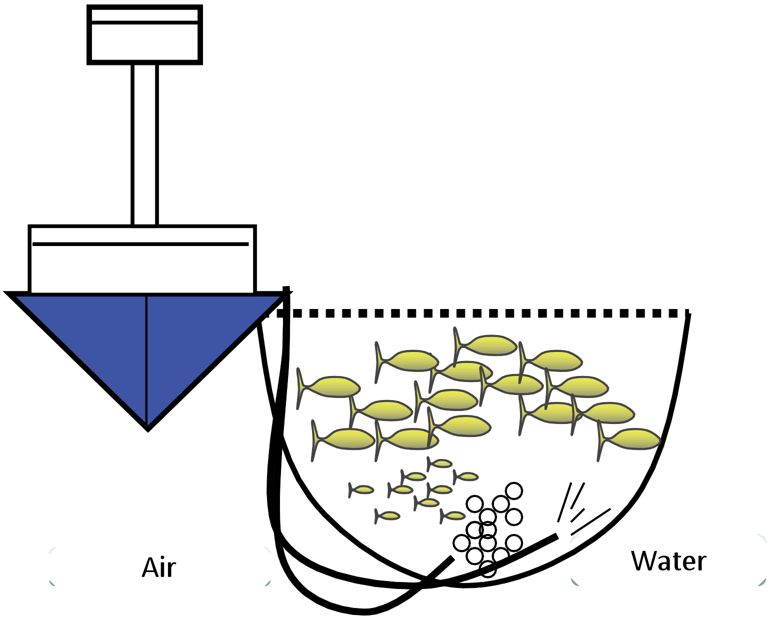


FIGURE 77

Options to place the capture in the hopper

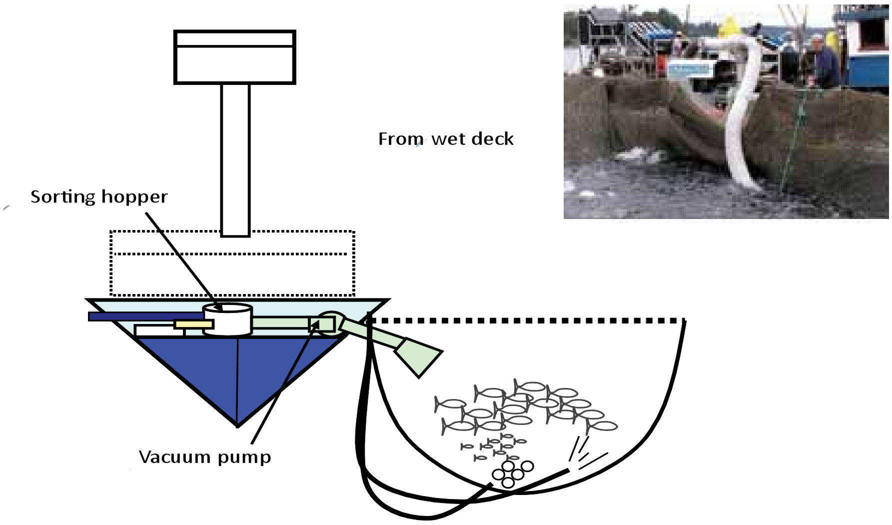


FIGURE 78
Options to bring the capture to the hopper in good condition

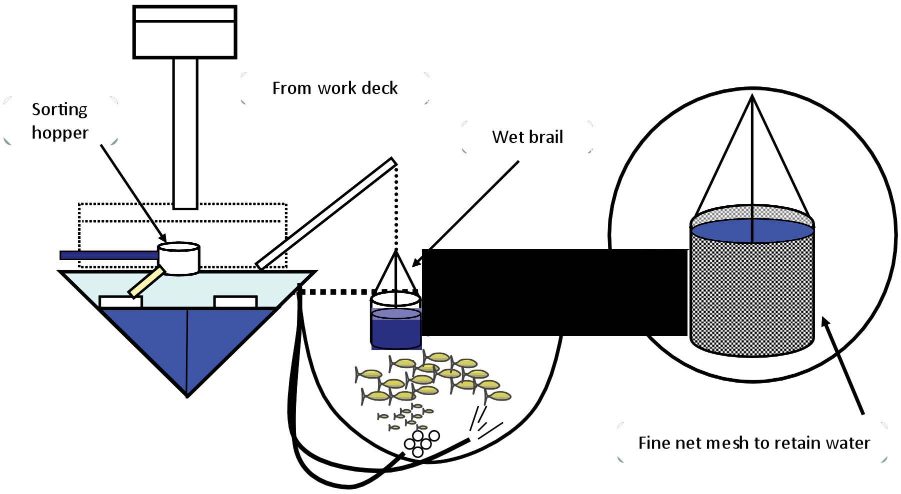
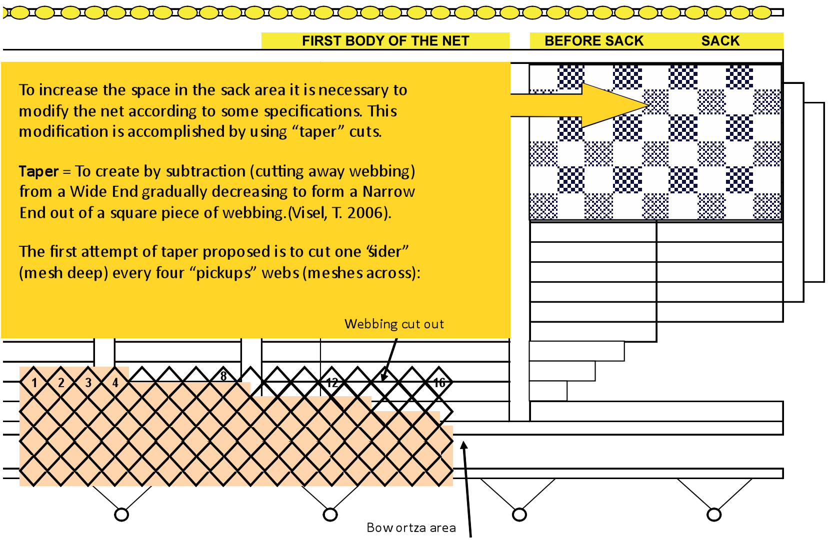


FIGURE 79
Sack area modification to provide space for the school inside the net



To increase the space in the sack area it is necessary to modify the net according to some specifications. This modification is accomplished by using "taper" cuts.

Taper = To create by subtraction (cutting away webbing) from a Wide End gradually decreasing to form a Narrow End out of a square piece of webbing.(Visel, T. 2006).

The first attempt of taper proposed is to cut one "sider" (mesh deep) every four "pickups" webs (meshes across):

Utilization

Once the fishes have gone through the whole process, then mortality is a cautious assumption for their fate. At that point, utilization is better than discarding dead.

Some management options

Different management options have been used to reduce bigeye catch and bycatch in the purse seine fishery in the past, or are in use currently (e.g. Conservation and Management Measure 2008-01 from the WCPFC; IATTC Recommendation C-10-01).

The background paper to the Kobe Bycatch Workshop (IOTC-2010-WPEB-Inf12) lists most of them. Others have been used in the past. Several workshops and reviews have addressed the options available (e.g. IOTC, 2003; Itano, 2005; ICCAT, 2006).

Most measures destined to reduce vessel capacity will probably have a positive impact on bycatch issues, and also, increases in vessel capacity may nullify gains in bycatch reductions attained through other management or technological options.

Spatial and temporal options have already been discussed above, and their application is the most significant effort to reduce bigeye fishing mortality in use today. Spatio-temporal closures are described in CCM-08-01 and C-10-01 cited above. As the number of sets that capture a considerable amount of bycatch is low in some areas (e.g. only 7 percent of sets have more than 5 tonnes of bigeye in the WPO [Langley, 2004]), it is a small target to hit, and the closure needs to be quite large in area and prolonged in time.

Minimum size limits

ICCAT had size limits of 3.2 kg for yellowfin and bigeye for several years and, by 2004, left only the yellowfin one. Given the mixtures of sizes in the sets, the size limit may result in discards. It was difficult to enforce, especially with markets developed for smaller tunas. Species identification problems were present or could be alleged. Lowering the size to 1.5 kg could work for all species, but the difficulties of enforcement make it a complicated scheme.

Juvenile bigeye or overall bigeye catch quotas

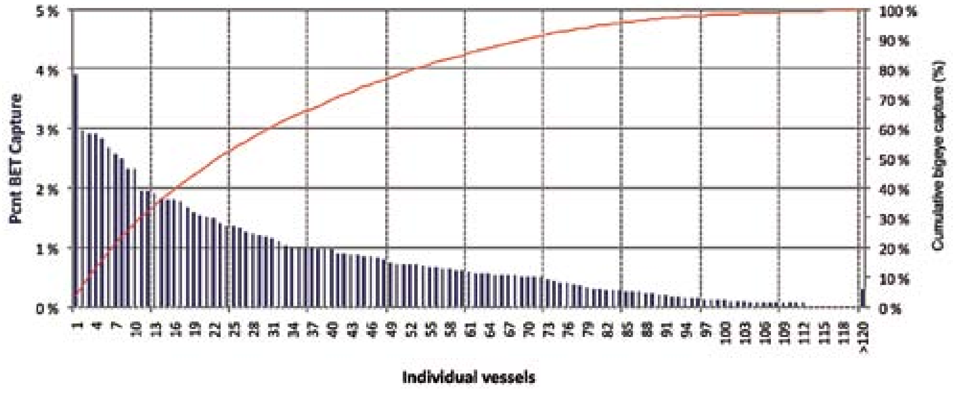
Under this system, a quota will be set every year, based on the condition of the stocks. When the quota is reached, fishing on FADs will be halted. With 100 percent observer coverage, it could be monitored at sea, although this is a complicated and potentially conflictive process – setting observers against captains and crews in some cases. In other cases, it will be monitored in port. Species identification could create problems, so there is an option of setting a joint yellowfin–bigeye quota.

Individual vessel quotas

These could be monitored by observers or port samples. It is a very efficient way to address the issue because several researchers have detected vessel effects (Langley, 2004; Minami *et al.*, 2007), and it is clear that a few vessels capture most of the bigeye (Figure 81), so this measure targets those that generate most of the capture. By calculating a target "acceptable" catch and dividing this figure among participating

FIGURE 80

Proportion of total bigeye capture by vessels in the Eastern Pacific Ocean, 2005–09



vessels, a fair system could be established. The quotas could be traded or not, and they could be reduced gradually to maintain a disincentive until the population has recovered to the desirable status. A major concern would be to avoid causing discards with this measure.

Reducing FAD fishing effort

Given the difficulties of targeting actions precisely on bigeye, one option is to reduce effort on FADs that produce most of the bigeye captures. Some of the spatial–temporal closures are only for FAD sets, and the vessels, with observers may set on schools. There are many options available to achieve this goal:

- Total annual limit on the number of FAD sets: all the fleet will stop setting on FADs when the limit is reached. This variable could be reduced gradually.
- Individual vessel limit on the number of FAD sets: this requires observer coverage of a 100 percent or electronic monitoring. These limits could be traded, and could also be modified as the stock recovers. The individual vessel limit may be a good way to provide an incentive to more judicious decisions on when to set and when not to set. It could be combined with a total retention measure for example.
- Individual vessel limit on number of FADs deployed per year or per trip: much more difficult to control because the deployment may be done from another, unobserved vessel, or another vessel's FAD may be appropriated at sea. An alternative to this could be to limit the number of satellite buoys used per year, or at a given time.
- In spite of some contradictory results, it appears that reducing the depth of the webbing under a FAD to a much shorter length could be effective. Many of the analyses have been performed with a narrow range of options. Ten metres or less could be tested as a way to reduce bigeye captures.

Many other options to reduce vessel efficiency have been suggested (Itano, 2005), but most of these measures are not directly targeted to the objective. In the EPO, the ban on the use of auxiliary vessels is also a measure with the goal of reducing efficiency.

An option proposed by Bailey, Sumaila and Martell (2011) suggests a cooperative sharing system, involving longliners and purse seiners, where the overall rent of the fishery is maximized by a scheme in which longliners make side payments to purse seiners to reduce their effort on FADs. This type of approach has not been tested, but it introduces an economic rationale to the utilization of a resource. To complete the study, analyses are needed of the social consequences for the land-based components of the process of the switch in production. The different national origins of longline and purse seine fleets may add complexity to this approach.

11. Billfishes

The list of species includes, in the different oceans:

- blue marlin (*Makaira nigricans*);
- black marlin (*Istiompax indica*);
- striped marlin (*Kajikia audax*);
- white marlin (*Kajikia albida*);
- sailfish (*Istiophorus platypterus*).

In this section, the nomenclature recently reviewed by Collette, McDowell and Graves (2006) is used for the billfishes. The review focuses on the marlins and sailfish because of their preponderance in most regions. Molony (2005b) summarizes the basic information for the group. Billfishes have been caught and frequently retained over the years, and some species have solid markets. Small individuals, or species with lower value (e.g. sailfish), are sometimes discarded, and by precaution they have been considered dead discards. The volume of the catch is not significant (usually in the low thousands of individuals per year), otherwise they could cause storage problems as they are not well preserved in the brine used for the tunas. The catches are kept in the cold storage where food supplies are kept, and if they exceed this volume, they are kept on the uppermost layer of the wells after filling them. It is necessary to include these impacts in the corresponding stock assessments, both the catch and the bycatch.

BLUE MARLIN (*MAKAIRA NIGRICANS*)

This is a large pelagic species with a broad distribution, and captured in most purse seine fisheries. These large species may be found with tunas because they are exploiting the same resources the tunas are exploiting, or because they are preying on the smaller tunas themselves. It is the dominant species in the whole tropical Pacific (Molony, 2008), and it is believed to be a single stock. It was reported that they could live more than 20 years (Hill, Cailliet and Radtke, 1989), but more recent studies on other marlin species (Kopf, Pepperell and Davie, 2009) suggest that the lifespan of marlins may have been overstated because of difficulties with the techniques. Therefore, caution is needed in the population models used for their management (Kleiber, Hinton and Uozumi, 2003). They may start reproducing before they are five years old (Nakamura, 1985), and there is a very broad range of sizes at first maturity for females (170–205 cm), and less variability for males (145–155 cm). The age issues need to be resolved soon in order to be able to understand the impacts on the populations.

In spite of their economic and ecologic importance, literature on several of these species is limited (Hill, Cailliet and Radtke, 1989; Wilson *et al.*, 1991). It is believed there is at least one stock per ocean, with some low level of mixing (Molony, 2008).

BLACK MARLIN (*ISTIOMPAX INDICA*)

This is another large pelagic predator, although not reaching the sizes of the blue marlin. It has a very broad range of habitats it can occupy (Nakamura, 1985), and is highly mobile, but with no defined migration patterns (Pepperell, 2000). Its maximum longevity is believed to be 18 years, but the ageing issue can also be present here. It has well-defined spawning areas (e.g. in the WPO and the Indian Ocean), and no spawning activity in other large regions (EPO). It has very high fecundity, and is the most coastal of the marlin species (Kaiola *et al.*, 1993. Some of its prey items include the skipjack tuna and the mackerel scad, both species that are common under floating objects (Shimose *et al.*, 2008).

STRIPED MARLIN (*KAJIKIA AUDAX*)

This species inhabits tropical and temperate waters of the Pacific and Indian Oceans. The distribution in the Pacific is complex (Molony, 2008), being absent from equatorial waters in the WPO, but present in the EPO. The spatial patterns in age structure result in fisheries impacts that are not distributed evenly among all age groups (Kopf, Davie and Holdsworth, 2005). There appears to be a single stock in the Atlantic (McDowell, Carlsson and Graves, 2007), but in the Pacific the structure is much more complex (McDowell and Graves, 2008). A recent study (Purcell, 2009) describes four possible stocks in the region. Females mature at 1.5–2.5 years of age, and the males at 1–2 years (Kopf, Pepperell and Davie, 2009), or later according to other authors, at 2–4 years, and at sizes of 140–180 cm (Nakamura, 1985; Bromhead *et al.*, 2004). It has major seasonal movements (Squire and Suzuki, 1990).

WHITE MARLIN (*KAJIKIA ALBIDA*)

Stocks of white marlin raised concerns in the Atlantic, but the most recent stock assessments are somewhat more optimistic. Size at first sexual maturity was estimated by different researchers at 147–160 cm (low jaw–fork length) for females (Oliveira *et al.*, 2007; Arocha and Barrios, 2009). Graves and McDowell (2006) describe only one stock in the Atlantic but with heterogeneities that have not been explored.

SAILFISH (*ISTIOPHORUS PLATYPTERUS*)

It is the species of this group that shows the most aggregation in some regions (Ehrhardt and Fitchett, 2006). They are frequently encountered in groups of 4 – 15 in school sets or in sets on whales (Viera, 2007). They live to be 6–8 years old (Hoolihan, 2006), with fast growth in the first two years. They show little affinity for floating objects, perhaps as a result of a diet specialized in cephalopods (Arizmendi-Rodríguez *et al.*, 2006).

BILLFISH BYCATCH

Blue, black, white and striped marlins are captured in tuna purse seine sets in different ocean areas, usually in sets on FADs or logs, in low numbers. Sailfishes are one of the most numerous billfish species in purses seine captures on school, or dolphin sets in the EPO, and in the Atlantic, but they are rare under FADs. Many billfishes are retained, and form part of the catch. Table 39 and Figure 81 show the evolution of the discarding patterns in the period 1993–2008 in the EPO. In what follows, and on precautionary grounds, it is assumed that mortality follows capture in the purse seine and brailing, lacking evidence to the contrary. There are some possible misidentification issues, especially for small sizes, but they are not believed to distort the statistics in a significant way (Sharples, Brogan and Williams, 2000).

Eastern Pacific

Figure 82 shows the frequency of encounters of the different species over two time periods to compare for changes in relative abundances among the species. Overall, the relative abundances have remained reasonably similar (in particular for the marlins blue > black > striped). Blue and black marlins dominate the captures in FAD sets, while sailfish is by far the most abundant in school and dolphin sets (Tables 15–30). Marlins are usually captured in very small numbers, ones or twos. Occasionally, sailfishes may be captured in groups of tens or more individuals, but these sets are very infrequent. These captures of large numbers do not happen for marlins, or are very rare, which probably reflects the predatory strategy of the different groups (Table 40).

Figure 83 shows a contour map of the effort in the EPO in number of sets, to use as background for the maps showing the distribution of the different species.

TABLE 39

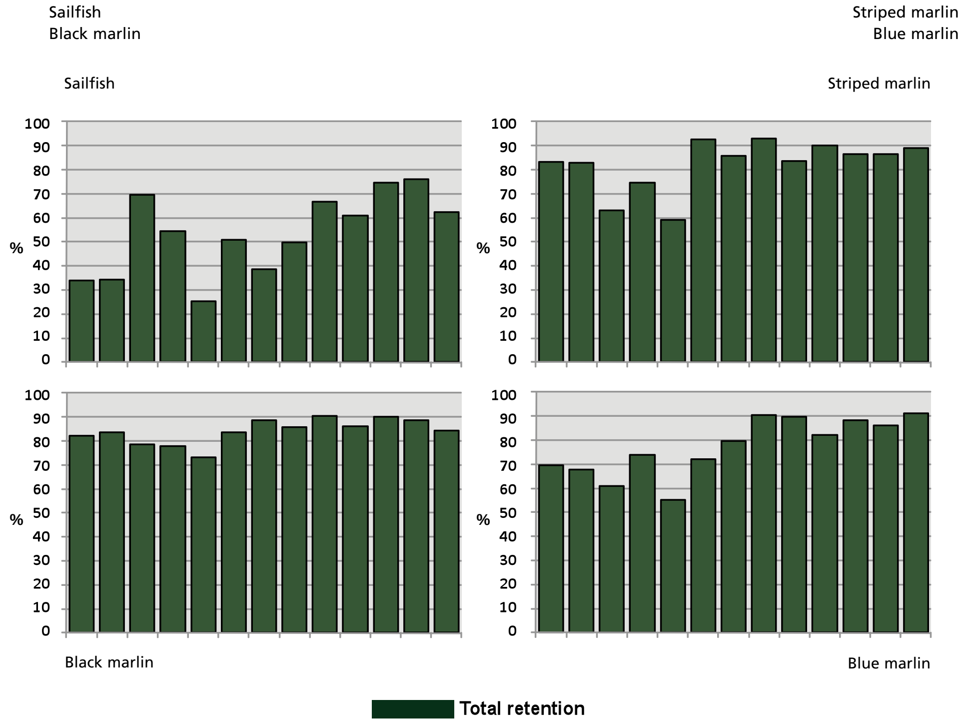
Billfish bycatch – percentage discarded in numbers in the Eastern Pacific Ocean, 1993–2008

Dolphin set	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	1993-2008
Sailfish	55.3	39.1	45.0	29.1	38.4	35.9	42.4	49.3	32.7	23.9	28.4	15.0	15.1	36.0
Black marlin	34.8	14.8	15.7	19.1	13.8	24.6	12.9	25.3	7.9	11.7	25.5	3.7	1.3	18.7
Striped marlin	29.9	5.6	8.1	4.8	14.8	21.1	10.7	7.7	0.2	3.0	5.7	1.1	1.6	10.8
Blue marlin	19.1	0.7	9.1	8.7	6.3	6.2	14.2	5.2	4.4	6.5	2.8	2.6	7.6	8.3
Unassociated set	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**1993-2008**
Sailfish	55.3	57.0	59.9	7.2	28.8	85.5	43.0	60.6	46.4	24.3	11.0	16.2	7.1	50.0
Black marlin	34.8	10.9	17.5	15.8	11.6	40.8	35.1	19.8	28.6	13.0	20.0	9.3	7.8	23.2
Striped marlin	29.9	7.1	7.8	17.5	1.1	27.5	0.7	6.1	12.1	20.6	2.0	8.1	3.8	11.5
Blue marlin	19.1	5.8	7.8	15.8	8.0	3.7	6.7	5.5	5.8	4.4	2.9	29.7	7.3	9.9
Fob set	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**1993-2008**
Sailfish	55.3	60.1	31.3	26.8	29.3	30.0	47.5	38.2	52.3	28.8	53.1	12.7	19.4	41.2
Black marlin	34.8	25.1	30.5	38.9	29.7	45.2	26.0	17.3	3.9	7.7	13.1	10.1	11.4	24.8
Striped marlin	29.9	12.2	18.3	41.9	32.2	50.3	19.9	22.8	7.2	7.0	9.8	16.1	12.5	23.9
Blue marlin	19.1	12.3	14.0	17.8	18.5	29.1	17.5	11	14.4	6.5	12.9	8.2	6.1	14.6

Source: IATTC observer database.

FIGURE 81

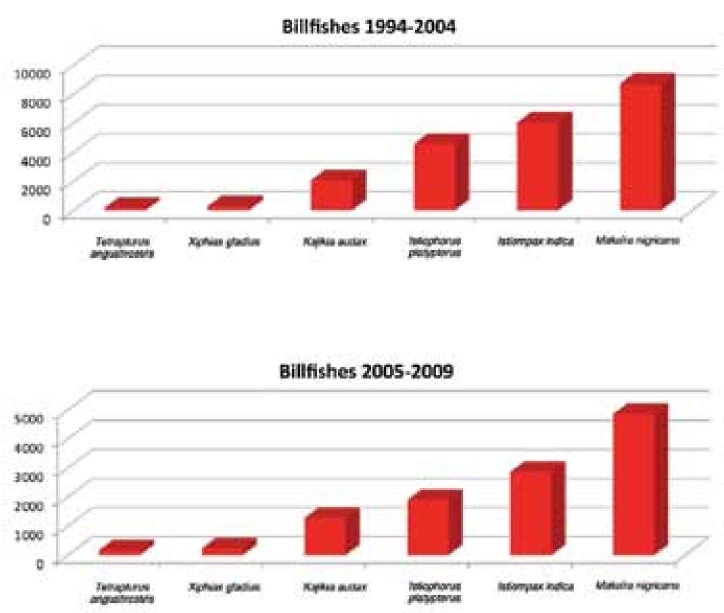
Percentage retained of the billfish captures



Western Pacific

The EPO data are similar in the sequence to the frequency series described in Lawson (1997) for the WPO. For the same area, OFP (2010a) shows that for all types of purse seine sets (including payaos, logs, FADs and school sets), blue marlin is the most frequent, with black as the second.

FIGURE 82
Relative frequency of billfishes in two time periods in the Eastern Pacific Ocean



Indian Ocean

Black and striped marlin have similar levels in school sets, then the sailfish, and the blue marlin (Pianet *et al.*, 2009), while the sequence is black > striped > blue in FAD sets.

Atlantic

The composition of the billfish capture has similar components in general, with a few species replacements in the Atlantic (e.g. white marlin). In this region, the most abundant in school sets is by far the sailfish, similar to the EPO, with the blue marlin a distant second. In sets on FADs, the blue marlin is the most significant by weight and numbers, followed by the swordfish and the white marlin.

ACTIONS AND CONCEPTS TO REDUCE BILLFISH BYCATCH

There appears to be no reason to develop generic mitigation measures for this bycatch in the purse seine fleet on conservation grounds, because of its low magnitude, especially in contrast to the catches of these species in directed fisheries or incidental takes (Figures 84 and 85, Table 41, and IATTC – FSR 2009, www.iattc.org/PDFFiles2/FisheryStatusReports/FisheryStatusReport8ENG.pdf).

FIGURE 83
Fishing effort in number of sets of all types, 1994–2009 – contour map for the Eastern Pacific Ocean

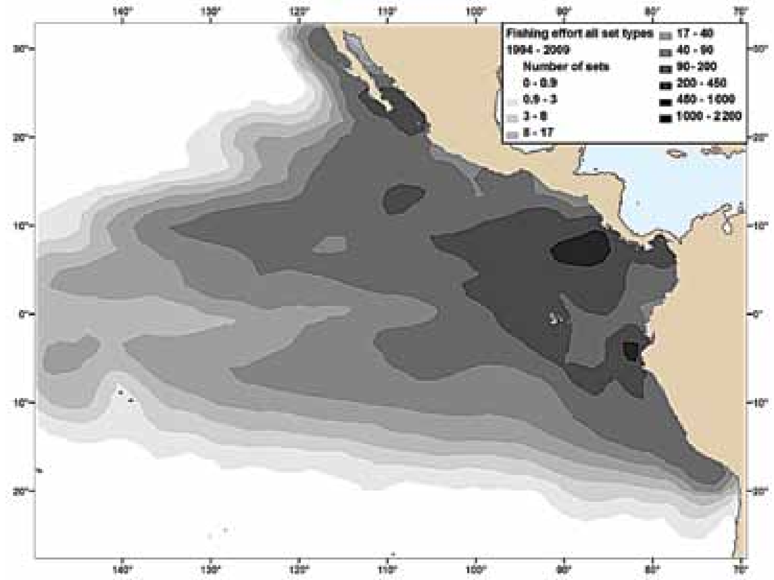


TABLE 40

Number of billfishes caught per set by set type in the Eastern Pacific Ocean, 1994–2009

Blue Marlin				Striped Marlin				Sailfish			
CPS	**Dolphin**	**School**	**F. object**	**CPS**	**Dolphin**	**School**	**F. object**	**CPS**	**Dolphin**	**School**	**F. object**
0	121 472	68 368	73 432	**0**	121 530	68 787	83 150	**0**	118 203	67 912	84 423
1	724	930	7 620	**1**	643	532	1 179	**1**	2 235	804	204
2	84	139	2 423	**2**	75	99	287	**2**	898	319	61
3	23	28	764	**3**	30	40	90	**3**	359	162	24
4	3	9	297	**4**	9	18	32	**4**	215	70	24
5	2	5	132	**5**	8	6	16	**5**	123	37	9
6	1	7	54	**6**	4	4	6	**6**	85	40	5
12	1	28	45	**7**	2	2	2	**7**	45	24	4
				8	2	3	3	**8**	29	19	3
Black Marlin				**9**	1	3	0	**9**	13	12	0
CPS	**Dolphin**	**School**	**F. object**	**10**	1	4	0	**10**	18	14	1
0	121 283	68 586	78 072	**11**	0	0	1	**11**	11	12	0
1	914	788	4 640	**12**	1	2	0	**12**	22	11	2
2	84	94	1 329	**14**	0	0	1	**13**	3	3	1
3	17	21	443	**17**	0	1	0	**14**	2	7	1
4	0	5	177	**20**	0	2	0	**15**	3	7	2
5	5	7	58	**22**	0	1	0	**16**	5	4	0
6	3	6	19	**23**	0	1	0	**17**	2	4	2
7	3	1	14	**30**	0	1	0	**18**	3	2	0
8	0	3	7	**32**	0	1	0	**19**	4	2	0
9	0	1	5	**40**	0	1	0	**20**	5	2	0
10	1	1	2	**46**	0	1	0	**21**	2	1	0
11	0	0	1	**57**	0	1	0	**22**	3	6	0
13	0	1	0	**60**	0	1	0	**23**	3	2	0
				79	0	1	0	**25**	0	2	0
				80	0	1	0	**27**	3	0	0
				160	0	1	0	**28**	0	1	0
								29	1	0	0
								30-105	15	35	1

Source: IATTC observer database.

FIGURE 84

Retained catch of blue marlin by gear type in the Eastern Pacific Ocean, 1979–2007

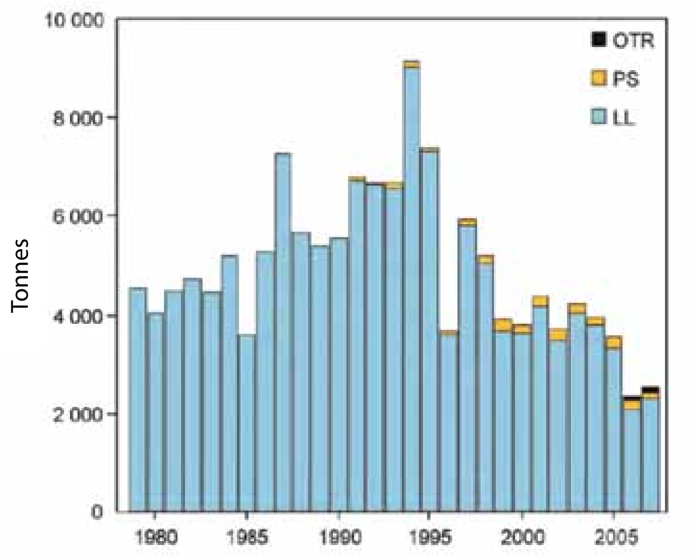


FIGURE 85

Retained catch of striped marlin by gear type in the Eastern Pacific Ocean, 1979–2007

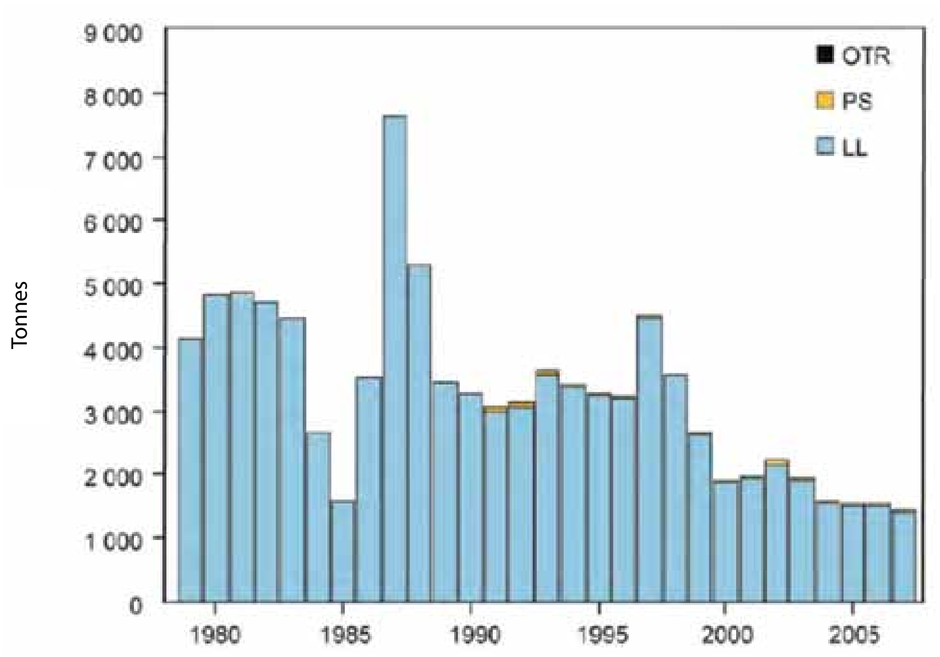


TABLE 41

Captures, bycatch, overall catch (all gears, all fleets), and proportion of captures and bycatch of the overall catch

Species	Ocean	period	Capture	Bycatch	period	Overall catch	%Capture/ catch	%Bycatch/ catch	% of Capture by set type		
									FAD sets	School S.	Dolphin
Blue marlin	EP	1993-2009	154	21	2002-2007	3 600	4%	0.60%	83%	11%	6%
Blue marlin	WP	2007-2009			2005-2009	19 300					
Blue marlin	AT	2006-2008	121		2006-2008	3 140	4%		93%	7%	
Blue marlin	IN	2003-2008	25		2004-2008	9 200	0.30%				
Black marlin	EP	1993-2008	96	23	2002-2007	162	80%	19%	78%	11%	11%
Black marlin	WP				2005-2009	2 400					
Black marlin	AT	2006-2008	4		2006-2008	60	7%		100%		
Black marlin	IN	2003-2008	53		2004-2008	4 500	1%				
Striped marlin	EP	1993-2008	36	6	2002-2007	1 700	2%	0.30%			
Striped marlin	WP				2005-2009	5 000					
White marlin	AT	2006-2008	7		2006-2008	390	2%		66%	33%	
Striped marlin	IN	2003-2008	50		2004-2008	3 000	2%				
Sailfish	EP	1993-2008	44	19	2002-2007	1 200	4%	2%	50%	43%	7%
Sailfish	WP				2005-2009						
Sailfish	AT	2006-2008	38		2006-2008	3 060	4%			100%	
Sailfish	IN	2003-2008			2004-2008	24 400					

Notes: EP = Eastern Pacific; WP = Western Pacific; AT = Atlantic Ocean; IN = Indian Ocean.
Sources: IATTC – 2010 FSR No. 7; WCPFC-SC6-2010-ST-IP-01; ICCAT Stat. Bull 39 – 2010; Amandè *et al.*, 2008; IOTC-2010-WPB-R[E]; Pianet *et al.,* 2009; IOTC-2009-WPEB-21.

However, when a billfish stock needs reductions in fishing mortality to improve its status, there is a possibility of reducing the bycatch first, and eliminating the captures second. It becomes very important at that point to explore the survival of billfishes that have gone through a purse seine set. There is a considerable amount of literature on mortality of animals discarded after capture in fishing gear (for a review, see Suuronen and Erickson, 2010), but the purse seine experience is very limited. However, there are various studies of survival of marlins after release from hooks (Domeier, Dewar and Nasby-Lucas, 2003; Bartholomew and Bohnsack, 2005; Kerstetter and Graves, 2006a, 2006b; Coggins *et al.*, 2007; Graves and Horodysky, 2008; Pine *et al.*, 2008) and sailfish (Kerstetter and Graves, 2008) with encouraging results about the ability of some of these species to endure prolonged stress. Research on survival to the capture operation is critical to determine if releasing from the deck is a viable option. If their survival to the fishing process is low, the options for mitigation should focus on preventing capture, and this is limited for most species because of their capture occurs usually in low numbers (Table 40), and is distributed over large areas. The spatial distribution of bycatch/tuna catch ratios is quite even in space.

When there are some peaks in the ratio, a possible approach to reduce the captures (e.g. of sailfish) in large numbers would be to determine if the high bycatch/catch ratios are predictable in space and time, and produce seasonal closures. Where data are abundant, this possibility can be evaluated. If the crews are capable of determining that they are about to encircle a large aggregation of sailfish, then it would be possible to avoid setting on these aggregations. The same spatial approach could be used for any of these species when spawning areas and seasons are known (e.g. González-Armas *et al.*, 1999). Well-positioned seasonal reserves or other spatial closures may have a significant impact on the mortality, and help reduce the negative interactions with other users, such as recreational fishers (Jensen *et al.*, 2010). In addition, cooperative approaches among vessels can be used to establish the location of these peaks during the season, as proposed by Gilman, Dalzell and Martin, (2006).

The main consideration for billfishes, is that the impacts of the purse seine fisheries (catch or bycatch) must be accounted for in the stock assessments for these species (e.g. IATTC, 2010 – Stock Assessment Report No. 10), and included in the decision-making process.

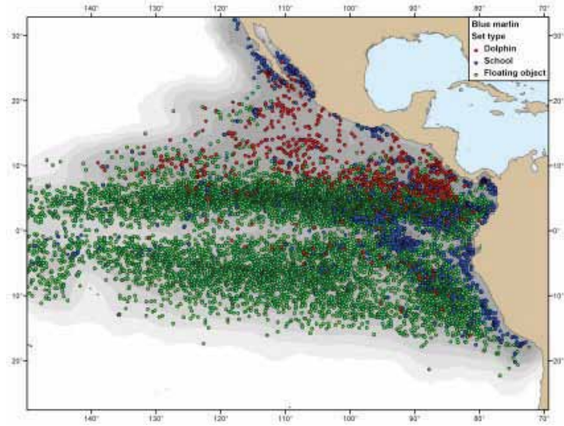
CONCLUSIONS

Table 41 summarizes the impacts in all oceans, based on the most recent estimates of catch and bycatch. Some conclusions can be drawn from the previous tables and figures.

Marlins are mostly part of the catch; their size and good value make them a desirable target (Jensen *et al.*, 2010) unless the size is too small. In the early 1990s, the portion discarded was 20–35 percent, but by 2008 it had dropped to 6–12 percent. For comparison, Spanish longliners kept almost 80 of all billfishes in this group, discarded 15 percent (dead) and released alive 6 percent (Mejuto, Garcia-Cortes and Ramos-Cartelle, 2007). Western Pacific longliners discarded 5 percent of striped marlin, 7 percent of blue marlin, 9 percent of black marlin, 34 percent of sailfishes, 30 percent of swordfish, and 27 percent of spearfish in 2000 (Sharples, Brogan and Williams, 2000).

The annual average capture of the three marlin species ranged from 400 to 1 300 individuals per year, and the bycatch from 60 to 190 individuals per year in the EPO (Tables 15–22). These figures are negligible from the population point of view compared with the catch in directed fisheries, or the bycatch in other fisheries. Capture and discards in weights are shown in Tables 23–30. For the other oceans, Table 41 shows that the marlin bycatch is concentrated in sets on floating objects in all oceans, while that for sailfish tends to be away from logs and FADs.

FIGURE 86
Sets with presence of blue marlin in the Eastern Pacific Ocean, 1994–2009



The distribution of the blue marlin in the EPO is shown in Figure 86. The average annual capture of blue marlin is about 153 tonnes (126 tonnes on floating objects, 26 tonnes on school sets, and 10 tonnes in dolphin sets). Of these, only 20 tonnes are bycatch, mostly from floating objects (17 tonnes from floating objects, 2 tonnes from school sets and 1 tonne from dolphin sets); the rest is retained (Figure 87, Tables 15–30). The EPO catch average is 3 600 tonnes (IATTC, 2009), so the capture in the seiners reaches 4 percent of the overall catch, and the bycatch is 0.5 percent of the overall catch. For the other oceans, Table 41 shows that the capture is frequently less than 5 percent of the overall catch from all fisheries. Captures in the Atlantic are also about 4 percent of the overall catch, and in the Indian Ocean the proportion is only 0.3 percent. As in many cases, bycatch from other fisheries is not accounted for, and there are fisheries not reporting their catches (e.g. IOTC reports of the Working Party on Ecosystems and Bycatch).

FIGURE 87
Blue marlin total annual catch and bycatch by set type in the Eastern Pacific Ocean, 1994–2009

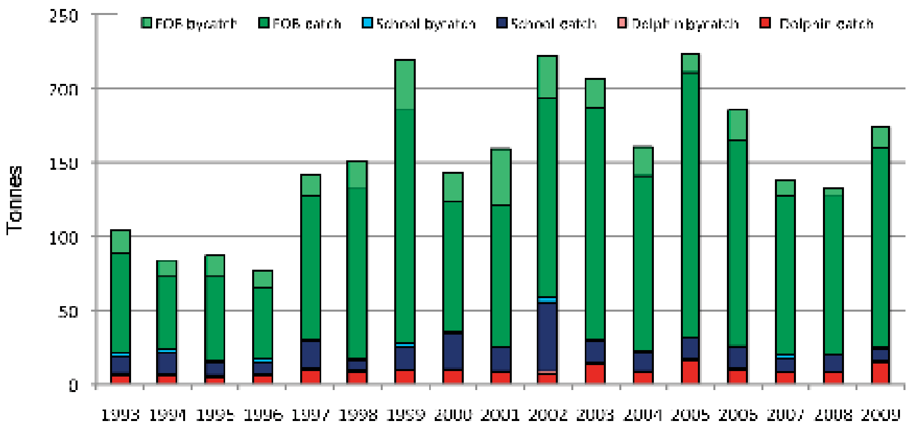
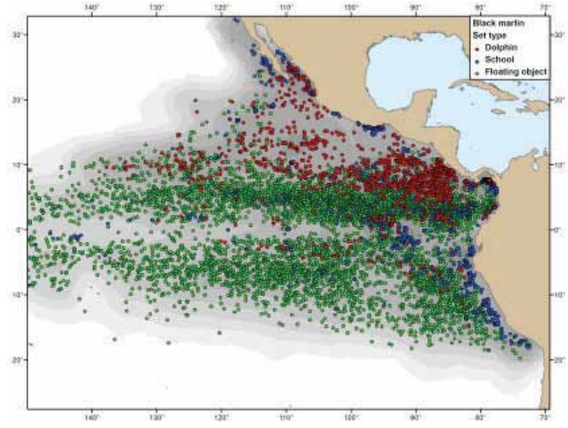


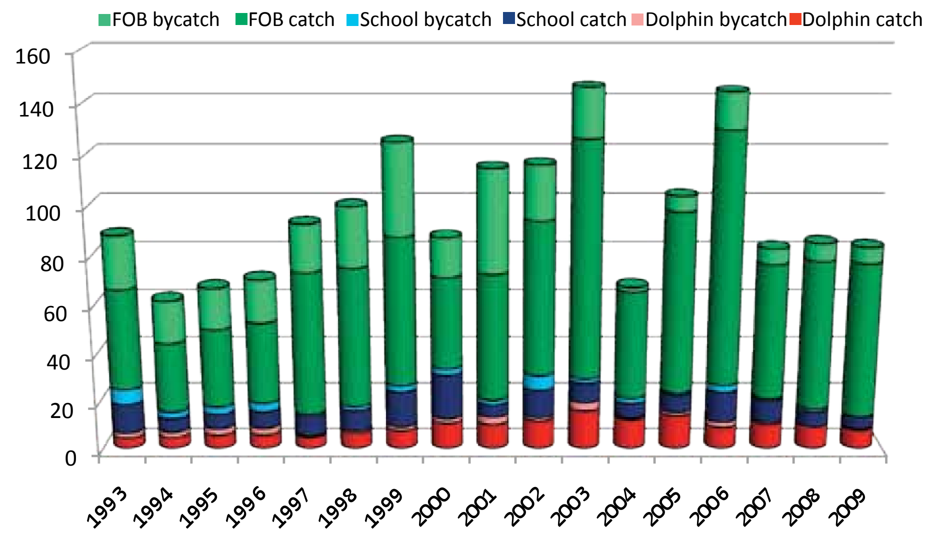
FIGURE 88
Sets with presence of black marlin in the Eastern Pacific Ocean, 1994–2009



The distribution of the black marlin is similar to that of the blue marlin (Figure 88). The average annual capture of black marlin in the EPO is 96 tonnes (74 tonnes from sets on floating objects, 11 tonnes from school sets and 11 tonnes from dolphin sets). This is another case of a strong affinity for floating objects (Figure 89). The bycatch of this species is 22 tonnes/year (17.5 tonnes/year from floating objects, 2.5 tonnes/year from school sets and 2 tonnes/year from dolphin sets). The annual overall catch of this species is only 108–200 tonnes, so this is the only case where the capture in the seiners is a significant proportion of the overall harvest (80 percent). In the Indian Ocean, black marlin is dominant in numbers in school and in FAD sets. The second under FADs is the striped marlin, followed by the blue marlin (Delgado de Molina *et al.*, 2005c; Amandè *et al.*, 2008a). In the Atlantic Ocean, the overall catch is extremely low, and the bycatch accounts for 7 percent of the overall figure, while for the Indian Ocean the bycatch is about 1 percent of the catch.

FIGURE 89

Black marlin total annual catch and bycatch by set type in the Eastern Pacific Ocean, 1994–2009

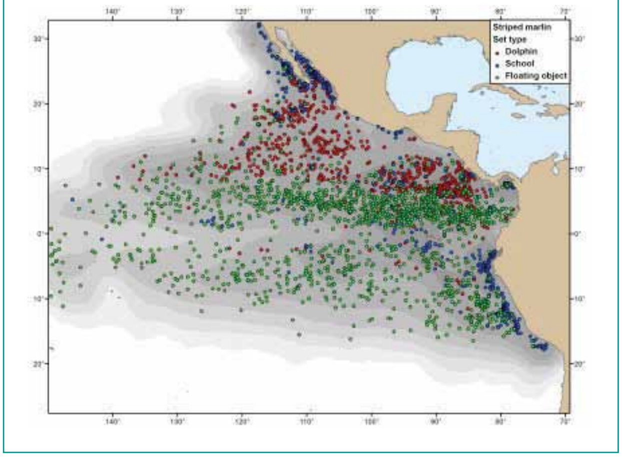


The striped marlin is much less common than the blue marlin, and its distribution is more concentrated (Figure 90). The striped marlin has an average annual capture of 36 tonnes in the EPO (15 tonnes from floating objects, 13 tonnes in school sets, and 8 tonnes from dolphin sets, much more balanced between school and floating object sets than the blue marlin (Figure 91). The bycatch is only 6 tonnes (3 tonnes from floating objects, 2 tonnes from school sets, and 1 tonne from dolphin sets). The overall catches in the EPO have averaged 1 700 tonnes in the past 5 years, so the capture is 2 percent of the EPO catch, and the bycatch is about 0.4 percent of the EPO catch (IATTC, 2009).

The distribution of the sailfish captures shows clear differences from the marlins. It is much closer to the coast, and there is an area with very high densities in the region of the Costa Rica Dome (Figure 92). More than 40 percent of the sailfish are discarded in the EPO (Figure 93). The

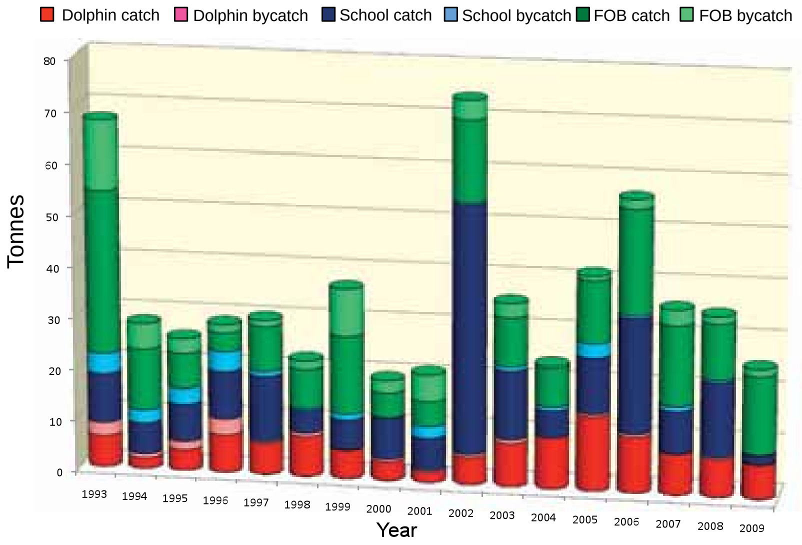
FIGURE 90

Sets with presence of striped marlin in the Eastern Pacific Ocean, 1994–2009



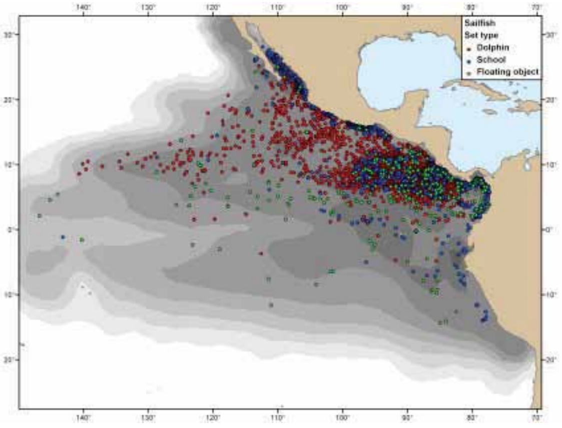
sailfish bycatch add up to about 600 individuals per year (Tables 15–22), divided evenly between dolphin and school sets. This figure is still negligible from the population point of view, and the only issue of interest is that, in some occasional sets, there are catches of dozens of sailfishes, when an aggregation is encircled.

FIGURE 91
Striped marlin total annual catch and bycatch by set type in the Eastern Pacific Ocean, 1994–2009



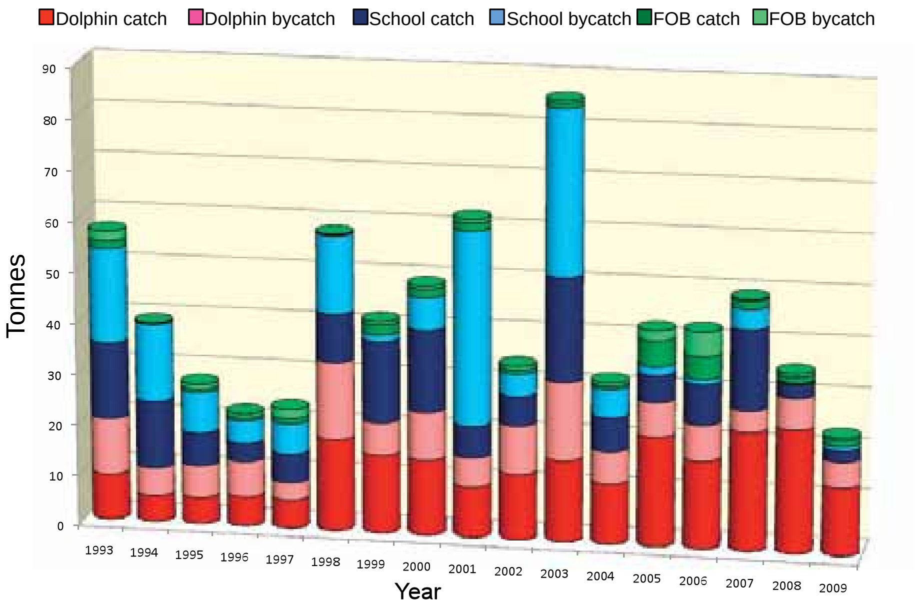
The average annual capture for sailfish in the EPO is 44 tonnes with significant year-to-year variability (3 tonnes from floating objects, 19 tonnes from school sets, and 22 tonnes from dolphin sets), and a bycatch of 19 tonnes (1 tonne from objects, 10 tonnes from school sets, and 8 tonnes from dolphin sets. The sailfish has the opposite distribution to the marlins, and it does not associate much with floating objects (Tables 15–30). The reasons for this difference could be dietary, or perhaps predator avoidance may play a role. The reported catch from different fisheries is of 1 000 tonnes, so the capture amounts to less than 0.5 percent of the overall catch, and the bycatch is less than 0.25 percent. In the Atlantic, the capture is 4 percent of the overall catch. In the Indian Ocean (Amandè *et al.*, 2008a), the capture is a fraction of 1 percent of a much larger catch figure from other fisheries than in other oceans. All marlins are much more common in FAD sets than in school sets (0.18 per set versus 0.09 per set), while the sailfish is evenly distributed in FADs (0.022/set) and schools (0.015/set).

FIGURE 92
Sets with presence of sailfish in the Eastern Pacific Ocean,



Of the three types of sets, dolphin sets have the lowest discards, followed by school sets in the EPO. The percentage discarded ranges from 0 percent to 8 percent in these two types of sets. Floating object

FIGURE 93
Sailfish total annual catch and bycatch by set type in the Eastern Pacific Ocean, 1994–2009



sets discards go from 6 percent to 13 percent. In all oceans, the capture of marlins on floating objects is much higher than in school sets.

The bycatch of shortbill spearfish and swordfish is fewer than a dozen individuals per year in the EPO, and there are the lowest captures in the Indian Ocean, so there is no need for further consideration. In the Atlantic, the swordfish amounts to 5 percent of the capture in FADs, and is absent in school sets (Amandè *et al.*, 2008b).

The utilization level is lower in the Indian Ocean than in the EPO; if the undetermined fraction is ignored, the retention level is 70 percent of the swordfish, 40 percent of the striped marlin, 28 percent of the black marlin, 23 percent of sailfish, 13 percent of the blue marlin, with an overall utilization of almost 22 percent.

12. Shark and rays

The list of the main species includes:

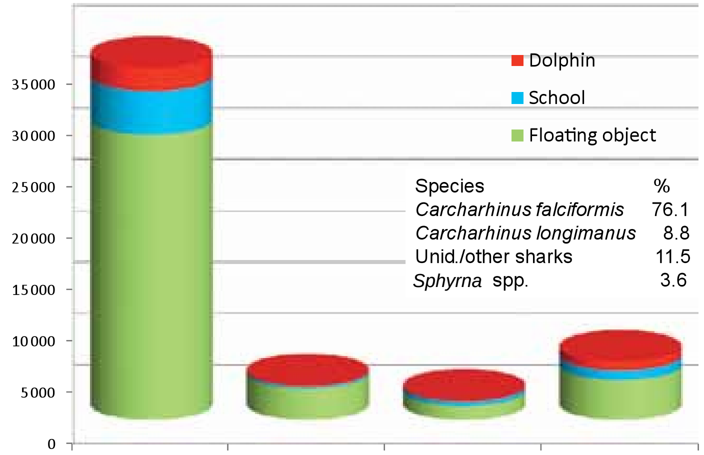
- silky shark (*Carcharhinus falciformis*);
- oceanic whitetip shark (*Carcharhinus longimanus*);
- hammerhead sharks:
  scalloped hammerhead (*Sphyrna lewini*),
  smooth hammerhead (*S. zygaena*),
  great hammerhead (*S. mokarran*).

Sharks and rays are frequently captured in purse seine sets in all oceans. Of the taxa captured incidentally in purse seines, sharks and rays are one of the most vulnerable because of their life-history parameters, and in general, low rates of increase resulting from late maturity, small number of pups and other characteristics of some of the species (Smith, Au and Show, 1998, 2008; Cortés, 2004, 2008a; Frisk, Miller and Dulvy, 2005; Dulvy *et al.*, 2008; Field *et al.*, 2009). Sharks are the main targets of some fisheries, a secondary catch in others, and a bycatch in others; tuna purse seine fisheries include the last two cases. They are discarded or retained depending on the species and sizes. When shark stocks are in a healthy condition, the capture in purse seiners could be retained for utilization, as with the billfishes, when the stock assessments warrant that possibility. When the shark stocks are not in good condition, actions to reduce the capture could be a tool to mitigate the negative impacts. For precaution, the sharks discarded from purse seiners are considered dead in IATTC statistics, lacking evidence of post-release survival. Comparing the frequency of occurrence of different species in three periods in sets on FADs in the EPO, the only ones showing clear declining trends were the sharks (Figure 58).

Although the lists of sharks encountered in purse seine sets are long, the shark capture is concentrated in a few species, with the silky shark comprising more than 75–85 percent of the capture in most cases, followed by 4–10 percent for the oceanic whitetip sharks, and 1–4 percent for hammerhead sharks, mostly the scalloped hammerhead (Figure 94, Tables 15–30; Bailey, Williams and Itano, 1996; Williams, 1999; Molony, 2007, Amandè *et al.*, 2008a, 2010b). Table 42 shows the species encountered in the EPO during a special study to improve the identification of the species, and it provides a more detailed picture of the less frequent species. Tables 15–30 show shark capture and bycatch in the EPO. For the WPO, Table 43 shows the catch in longlines and purse seines, and additional information is available in OFP (2010a). In both cases, silky and oceanic whitetip sharks have declining trends. A comparison of the ratio (silky shark catch/oceanic whitetip catch) in the WPO for two periods with enough data (1998–2000 versus 2006–2008 [Manning *et al.*, 2009]) shows that it has gone from a factor of 2, to a factor of 90. Although many variables are confounding the results, the difference is so large that the signal is not likely to be misleading. For the Indian Ocean, where the time series of data from many fisheries are missing, studies based on fishers surveys also suggest steep declines in the past decade (Anderson and Jauharee, 2009), and longline data seem to agree, but changes in fishing strategy make the data inconsistent (Romanov *et al.*, 2010).

In the EPO, shark retention in the purse seiners is increasing (Figures 95 and 96). The silky sharks bycatch (discarded dead or presumed dead) amounts to less than half of the capture in recent years, while oceanic whitetip discards are 60–70 percent of the capture. Hammerhead sharks show rather stable proportions of discards, about 60–70 percent of the capture, and the group “Other sharks” shows a strong decrease, to

FIGURE 94
Estimated yearly average capture of sharks (numbers), 1993–2009



Source: IATTC observer database.

TABLE 42
Shark catches from Secretariat of the Pacific Community (SPC) for WCPFC
Notes: Excluding domestic fleets of Indonesia, the Philippines, and Taiwan

Species	Common name	Number	Percent
Alopias superciliosus	Bigeye thresher shark	29	1.0
A. pelagicus	Pelagic thresher shark	28	1.0
Alopias spp.	Unidentified *Alopias*	19	0.7
A. vulpinus	Thresher shark	7	0.2
Carcharhinus falciformis	Silky Shark	1 802	63.7
C. longimanus	Oceanic whitetip shark	589	20.8
C. brachyurus	Copper shark	1	0.1
C. galapaguensis	Galapagos shark	6	0.2
C. limbatus	Blacktip shark	5	0.2
C. leucas	Bull shark	2	0.1
C. altimus	Bignose shark	1	0.1
Nasolamia velox	Whitenose shark	2	0.1
Prionace glauca	Blue shark	17	0.6
Isurus oxyrinchus	Mako shark	28	0.9
Rhincodon typus	Whale shark	1	0.1
Sphyrna lewini	Scalloped hammerhead shark	103	3.6
S. zygaena	Smooth hammerhead shark	47	1.7
Sphyrna spp.	Unidentified *sphyrna*	30	1.1
S. mokarran	Great hammehead shark	9	0.3
S. media	Scoophead shark	2	0.1
Unidentified shark		102	3.6
Total		2 830	

Province of China. na = not estimated; * = total based on longline only; ** = total based on purse seine only.
Source: Data from Secretariat of the Pacific Community (2008).

only 20 percent discarded. This "Other sharks" group includes threshers, makos, and other sharks with high economic value. In other regions, the discards are still high; Amandè *et al.*, (2008b) report an 85 percent discard proportion for the Indian Ocean French fleet. Of those discarded, about one-third were released alive, but there was no follow-up to verify their survival. Taking a precautionary approach, this review assumes that all species undergoing the sacking-up operation and the brailing process have a high probability of mortality, in the absence of evidence to the contrary.

The shark association with tuna schools and with floating objects may be based in the search for prey aggregated under or near the objects, or in the tuna schools themselves. The identification of species of sharks and rays made by researchers or observers may be made from some distance in some cases, so improving training, and providing materials to help in the determination is critical to the estimation of impacts. Examples of identification materials, and much of the bibliographic information on the subject of this review, can be found on the Web sites of the different t-RFMOs (e.g. Itano, McGregor and Arcenaux, 2006; Romanov, 2010). The IATTC materials to improve identification of sharks commonly encountered by observers are available at www.iattc.org/Downloads.htm; and Domingo *et al.* (2010) for Atlantic sharks for ICCAT (available at www.iccat.int/Documents/SCRS/Guide_ID_Sharks_ENG-1.pdf).

The silky shark, the oceanic whitetip shark, several species of hammerhead sharks (scalloped hammerhead, smooth hammerhead, etc.), and some thresher sharks (bigeye thresher [*Alopias superciliosus*], pelagic thresher [*A. pelagicus*]) are the more common captures in purse seine sets in the EPO, Figure 94, Tables 15–30.

However, the silky shark is also the most frequent and abundant shark species in purse seine captures in all oceans, followed at a considerable distance by the oceanic whitetip shark (Santana *et al.*, 1998; Amandè *et al.*, 2008a; Román-Verdesoto and Orozco-Zoller, 2005; Molony, 2007, 2008; Sánchez *et al.*, 2007; Bonfil, 2008). These two usually account for more than 90 percent of the shark captures (Amandè *et al.*, 2008a). Many more sharks are taken in association with floating objects than in any other type of set (Tables 15–30; OFP, 2008b; Amandè *et al.*, 2008a, 2010b). In contrast, the blue shark (*Prionace glauca*), which is the most common shark in longline catches in most of the world's oceans (Matsunaga and Nakano, 2005; Molony, 2007; Walsh, Bigelow and Sender, 2009; Clarke, 2010), is seldom captured by purse seiners, and it is very rare in sets on floating objects.

The assessment of the significance of the different shark species in biomass terms needs a clarification concerning the inclusion or not of the whale sharks (*Rinchodon typus*). Some statistical tables include the captures of whale sharks in the computation of the biomass of the shark segment, and this distorts the plots describing the distribution of biomass among the groups. The capture of whale sharks is not frequent in most regions (e.g. 2.5 percent of sets in the Western and Central Pacific Ocean is the highest frequency observed [OFP, 2010a]), but their weights are high, and need to be "guessed" by observers, or estimated from some weight–length conversion. As these sharks are released alive, and some proportion is expected to survive, it is not clear that their inclusion is justified in biomass descriptions; and their inclusion in the tables does not appear to improve the description of the impacts. These

FIGURE 95
Percentage of silky and whitetip sharks discarded in numbers in the Eastern Pacific Ocean, 1993–2009

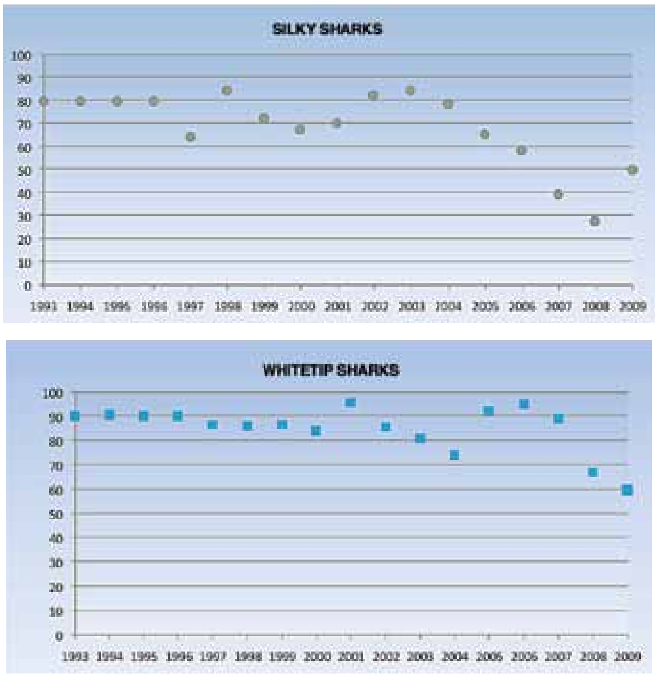


FIGURE 96
Percentage of hammerhead and other sharks discarded in numbers in the Eastern Pacific Ocean, 1993–2009

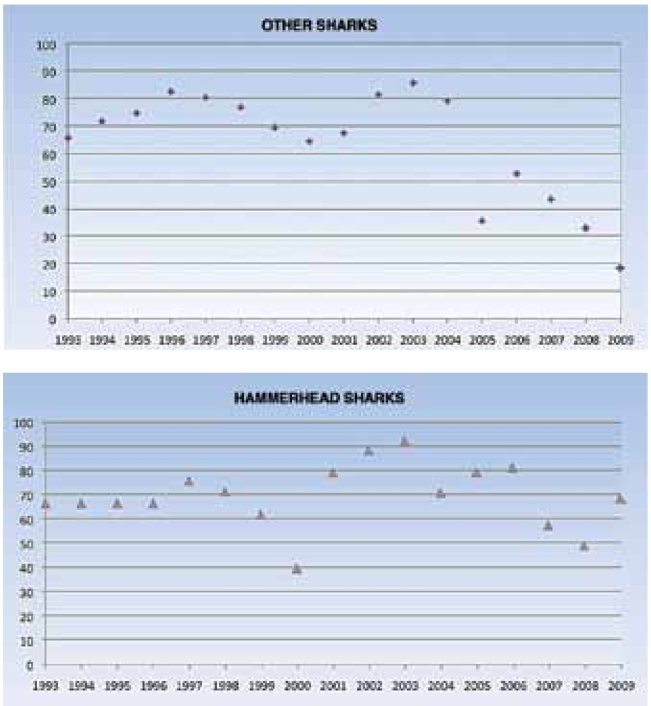


TABLE 43

Shark catches from Secretariat of the Pacific Community (SPC) for WCPFC

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Longline														
Blue	46 854	73 096	69 325	83 112	96 438	110 459	93 076	67 975	53 903	47 346	51 920	41 336	39 556	na
Mako	5 640	6 505	6 493	7 391	8 951	10 664	10 374	9 706	9 081	8 106	6 773	5 257	5 454	na
Oceanic whitetip	10 364	13 999	13 651	11 776	15 338	13 860	12 268	9 054	9 035	6 551	6 124	4 627	3 586	na
Silky	1 080	13 940	11 111	7 603	8 266	10 579	10 487	8 887	8 352	6 863	7 268	6 062	4 993	na
Other	12 654	12 839	8 341	6 120	8 583	10 689	10 633	9 350	8 370	5 929	5 579	7 218	7 308	na
Sub-total	76 592	120 379	108 921	116 002	137 576	156 251	136 838	104 972	88 741	74 795	77 664	64 500	60 897	na
Purse seine														
Silky	na	145	236	427	455	786	685	753	941	944	1 366	1 087	1 060	889
Whale shark	na	166	157	252	285	248	214	272	411	510	636	694	694	781
Other	na	1 361	1 361	1 901	1 115	1 114	734	589	561	404	467	383	274	192
Sub-total	na	1 672	1 754	2 580	1 855	2 148	1 633	1 614	1 913	1 858	2 469	2 164	2 028	1 862
Total	76 592*	122 051	110 675	118 582	139 431	158 399	138 471	106 586	90 654	76 653	80 133	66 664	62 925	1 862**

Notes: Excluding domestic fleets of Indonesia, the Philippines, and Taiwan Province of China. na = not estimated; * = total based on longline only; ** = total based on purse seine only.

Source: Data from Secretariat of the Pacific Community (2008).

sharks are not brailed, and may be released soon after the sacking-up is completed, so their stressors do not include the compression and/or injuries in the brailer and the exposure on deck that others experience. Up to now, there has been no solid basis for estimating the mortality of captured and released individuals. Observer reports from the WPO (OFP, 2010a) estimate mortality as 12 percent of the interactions, and that gives an estimate of mortality of 60 individuals/year for the region. However, this figure should be supported by an experimental approach measuring the survival rates of the released individuals. In the EPO, 0.1 percent of sets involve a whale shark. In other oceans, Romanov (2002), Viera and Pianet (2006), Sarralde, Delgado de Molina and Ariz (2006), Sarralde *et al.* (2007), Sanchez *et al.*, (2007) and González *et al.* (2007) report frequencies of 0.3–1.5 percent of the sets for the Spanish and French fleets in the Atlantic and Indian Oceans; most of them report 100 percent live releases.

The sharks amount to usually 4 percent or less of the capture in weight in all oceans, except for the Indian Ocean, where it is more than 10 percent (Amandè *et al.*, 2008a). The "older" fisheries, the EPO and the Eastern Atlantic, have lower proportions of sharks than the more recently developed fisheries.

In the Western and Central Pacific Ocean, sharks represent close to 25 percent of the longline catches by weight, but only 0.2 percent of the purse seine catch (Molony, 2007). Given the figures for all oceans, the review focuses on the silky and oceanic whitetip sharks, with only passing comments about hammerhead sharks, and less about the other species. This does not mean that all other species are not affected – their abundances are not known and nor are other sources of mortality affecting them. In some coastal regions, impacts on hammerhead sharks or thresher sharks may be significant (Clarke, 1971; Wakabayashi and Iwamoto, 1981; Branstetter, 1987; Stevens and Lyle, 1989; Chen *et al.*, 1990; Amorim, Arfelli and Fagundes, 1998; Castillo-Géniz *et al.*, 1998; Beerkircher, Cortés and Shivji, 2002; Tolentino and Mendoza, 2001; Duncan and Holland, 2006; Piercy *et al.*, 2007).

The bycatch of sharks is much higher in sets on floating objects than in any other type of sets, and the silky shark shows the strongest affinity for them (Tables 19–22 and 27–30; Amandè *et al.*, 2008a, 2010b; OFP, 2008b; Chassot *et al.*, 2009). Little is known about the behaviour of silky sharks about FADs, but research projects are under way as part of the MADE Programme. Some studies have shown that silky sharks remain close to the FADs for days, and make short nocturnal excursions away from the FAD (Filmalter, Dagorn and Bach, 2010; Filmalter, Dagorn and Soria, 2010). Most of the oceanic whitetip shark captures are also from floating object sets (Tables 19–22 and 27–30; Amandè *et al.*, 2008a, 2010b).

The role and significance of sharks in the pelagic ecosystem or in some of its components have been the object of several studies in different ocean basins (Stevens *et al.*, 2000; Heithaus, 2001; Kitchell *et al.*, 2002; Schindler *et al.*, 2002; Myers *et al.*, 2007; Heithaus *et al.*, 2008; Baum and Worm, 2009). However, the ability to research these issues depends, in most cases, on the quality and adequacy of the models utilized (e.g. Plaganyi and Butterworth, 2004). One of the major difficulties to assess this role is that researchers are not witnessing the functioning of pristine communities, but ones that have been altered over several decades in most cases, and the species abundances or composition may have already changed considerably (Graham, Andrew and Hodgson, 2001; Baum *et al.*, 2003; Baum *et al.*, 2005; Burgess, Hehler and Myers, 2005; Frisk, Miller and Dulvy, 2005; Levin *et al.*, 2006).

Reviews of the status of many shark stocks are also available (in addition to the studies cited in the above paragraph, see also Clarke *et al.*, 2006; Dulvy *et al.*, 2008; Camhi *et al.*, 2009b), some with conventional methods, others with risk assessments.

SILKY SHARK (*CARCHARHINUS FALCIFORMIS*)

The biology and ecology of the silky shark has been the subject of recent studies and reviews (Oshitani, Nakano and Tanaka, 2003; Bonfil, 2008; Joung *et al.*, 2008; Molony, 2008; Camhi *et al.*, 2009b). The reproductive biology was reviewed by Snelson, Burgess and Roman (2008). Ranges for age at maturity estimated for the silky shark males go from 4+ to 10 years old, with the more common values of 6–9 years. For females, the range is 7–12 years. Maximum age is 20–25 years, and fecundity is 2–16 pups per litter, with the more common values reported as being 8–11 pups (Branstetter, 1987, 1990; Bonfil, 1990, Bonfil, 2008; Bonfil, Mena and De Anda, 1993; Last and Stevens, 1994; Smith, Au and Show, 1998; Oshitani, Nakano and Tanaka, 2003; Joung *et al.*, 2008; Dulvy *et al.*, 2008), and a mean of 5–6. However, other life-history estimates are provided for the silky shark off Mexico: age at maturity 5, maximum age 13 and mid-

FIGURE 97
Sets with presence of silky sharks in the Eastern Pacific Ocean, 1994–2009

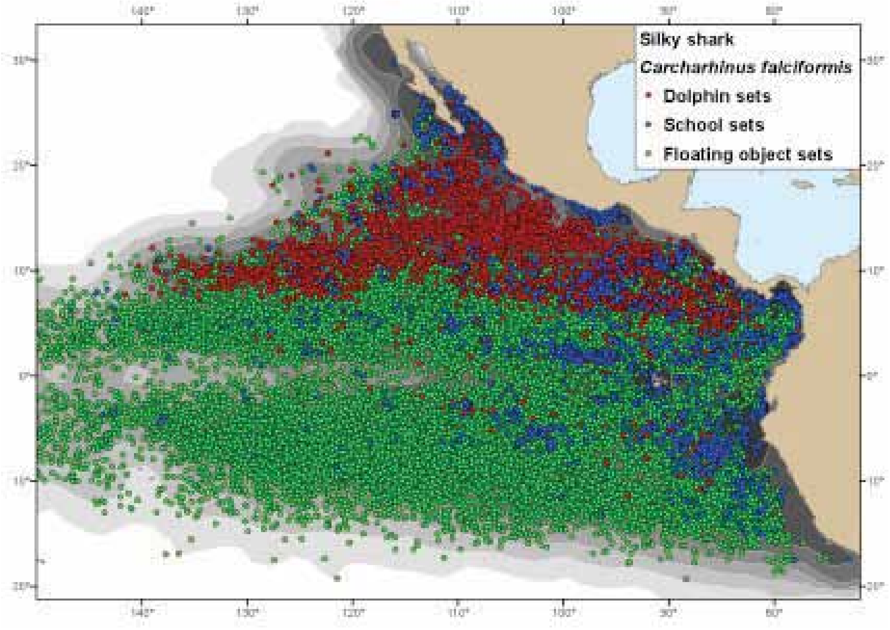
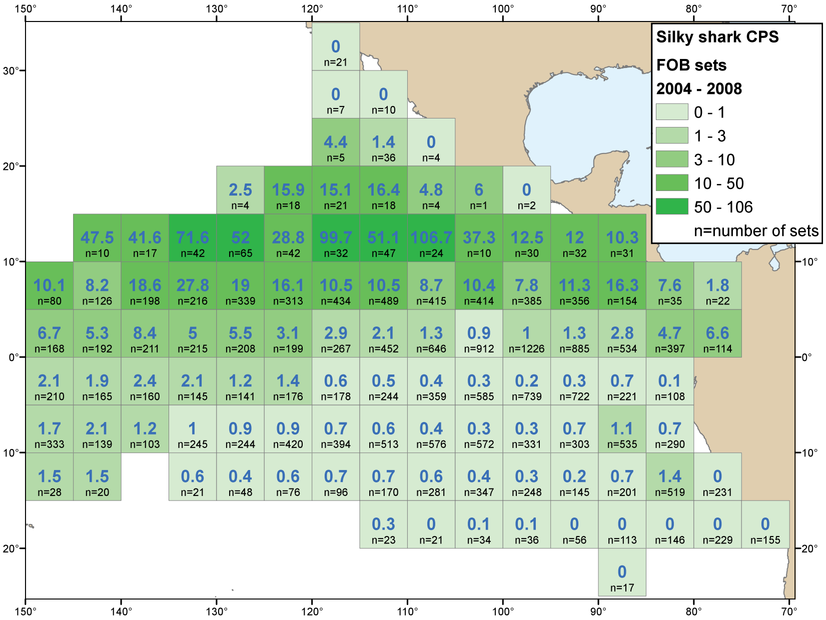


FIGURE 98

Silky shark, numbers per set on floating objects in t he Eastern Pacific Ocean, average 2004–08



point litter size 8 (Bonfil, Mena and De Anda, 1993); and for a population inhabiting waters near Taiwan Province of China: maximum age for males 29 and females 36 (Joung *et al.*, 2008). There seems to be considerable variability in these parameters and in growth rates among the regions, and an additional uncertainty caused by the difficulties in obtaining verification of age readings. It is the most common species caught in purse seines, and one of the most common in longlines, where the blue shark is the leading species (Okamoto and Bayliff, 2003; Matsunaga and Nakano, 2005; Senba and Nakano, 2005; Molony, 2008). The gestation period is close to a year, and there may be a prolonged resting period during the cycle.

Movements are not well known, but Oshitani, Nakano and Tanaka (2003) believe that there are nursery grounds where juveniles concentrate. In the EPO, silky sharks are distributed throughout the fishing area (Figure 97), but there is a region with high capture per set under floating objects, with a predominance of juveniles that supports the concept of a nursery area. Figure 98 shows areas with averages numbers of individuals captured per set of the order of 50–100 silky sharks on floating objects sets, around the parallel 10°N. However, there are very few sets on floating objects in this location, as the figure shows. Figure 99 shows that small individuals are much more abundant in this region than in the core of the floating object fishery, roughly south of 7°N, and Figure 100 shows the length frequency distribution in the different types of sets, with a predominance of juveniles under floating objects. Size selectivity for silky sharks in the different fisheries is also known, and Molony (2008) demonstrates that purse seines capture smaller silky sharks (mode at about 70–100 cm) than longliners (mode at 110–140 cm, and with a heavy tail towards higher values) in the WPO.

The stock structure is not well known, but in the EPO there seems to be evidence of a northern stock and a southern stock (J. Hyde, personal communication). However, within the fishing grounds, there is no other nursery area with high densities of juveniles in the south similar to the area of high density of juveniles described in the northern part of the fishing grounds. There appears to be some high proportion of juveniles

FIGURE 99
Silky shark, proportions of size groups captured in sets on floating objects in the Eastern Pacific Ocean, 1994–2009

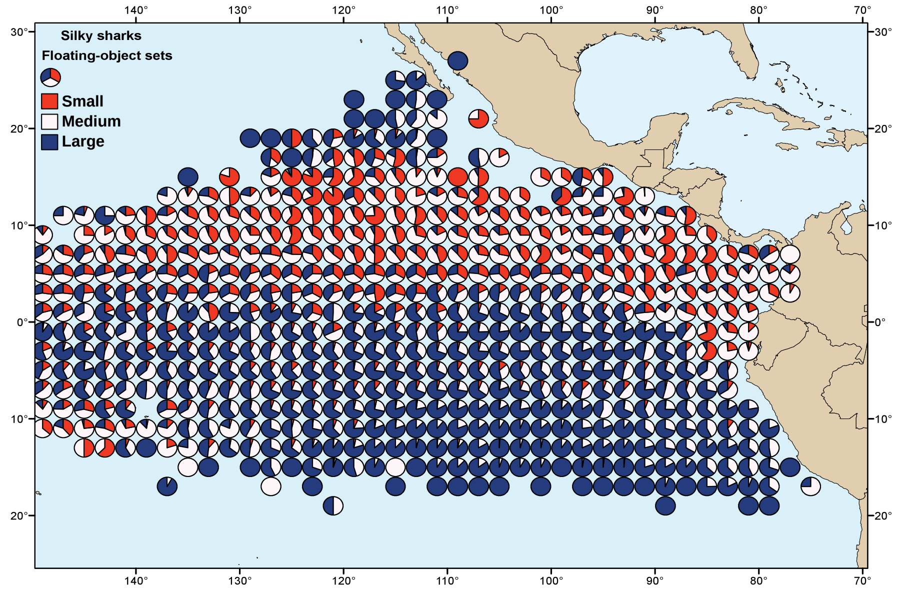
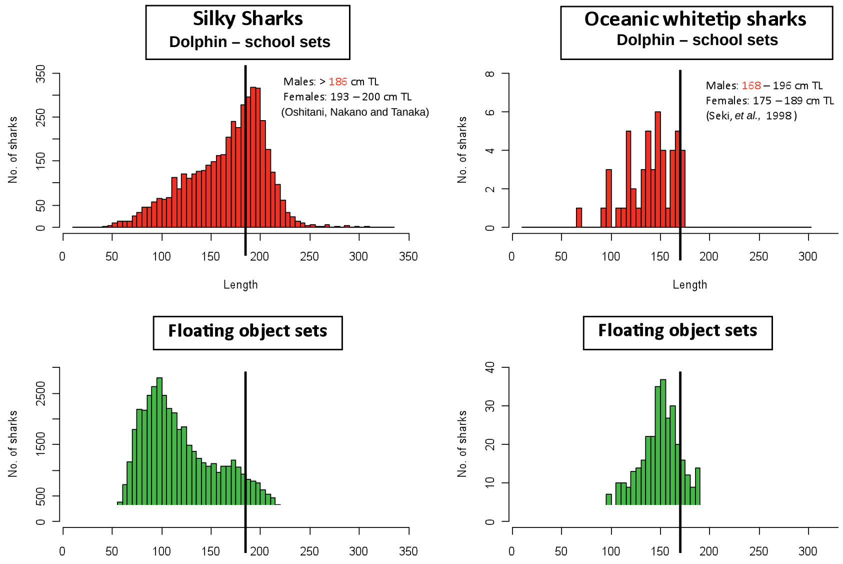


FIGURE 100
Length frequency distribution (in centimetres) for silky and oceanic whitetip sharks caught by set type and size at sexual maturity in the Eastern Pacific Ocean, 2005–09



Source: Courtesy of A. daSilva.

along the Central American coast, and towards the area west of 140°W. With more data and more research, it will become clear if these are other nursery areas. Testing whether there is separation of the stocks in the eastern from those in the western part has not been possible yet because of sample size limitations.

Juvenile silky sharks are especially vulnerable because of their tendency to aggregate under floating objects, which seems to be common in all oceans (Romanov, 2002; Taquet *et al.*, 2007b; Amandè *et al.*, 2008b; Watson *et al.*, 2009). Sharks associated with an object, and marked with acoustic tags, stayed in the association for an average of 5 days, and made excursions away from it lasting 3–9 hours, showing homing behaviour to the FAD (Filmalter *et al.*, 2010). The high densities in the northern areas of the EPO are not associated with the core FAD fishing areas (Figure 51), but with a traditional dolphin-fishing area, where only a limited number of floating objects transported by the California Current System (e.g. kelp patties) are encountered per year. Perhaps the limited number of objects leads to much higher densities on the few available.

Eastern Pacific

Of the identified sharks, the average proportions in numbers over the period 1993–2009 were 84 percent silky shark, 9 percent oceanic whitetip shark, 5 percent several hammerhead shark species, and 2 percent other sharks (Tables 15–30). If only the more recent period 2005–09 is considered, then the proportion of silky sharks is 93 percent, followed by the scalloped hammerhead shark (1.6 percent), and the smooth hammerhead shark (1.5 percent). The changes are the result of the rapid decline in the oceanic whitetip sharks (discussed below). Matsumoto and Bayliff (2008) present a series of longline catches in numbers, and a CPUE series from 1971 to 2003, with a declining trend, but with all shark species aggregated, and there are no data to break down the figures into species. The use of current species proportions to apportion historical data is not advisable, as different shark species have trends with different signs and magnitudes, and the proportions in the past may be quite far from the current ones, as the EPO example above shows. The average annual mortality of silky sharks by the purse seine fleet is about 34 000 individuals/year or about 400 tonnes/year in the period 1993–2009. There are no comparable estimates obtained from observer data for the longline catches at the species level for the EPO (industrial and artisanal fleets).

FIGURE 101
Silky shark catch and bycatch by set type in the Eastern Pacific Ocean, 1993–2009

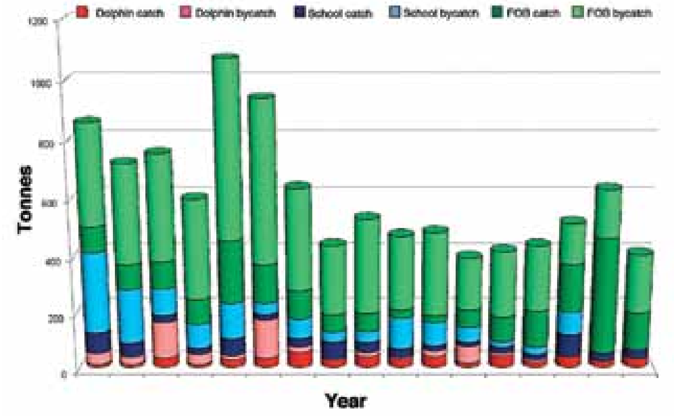
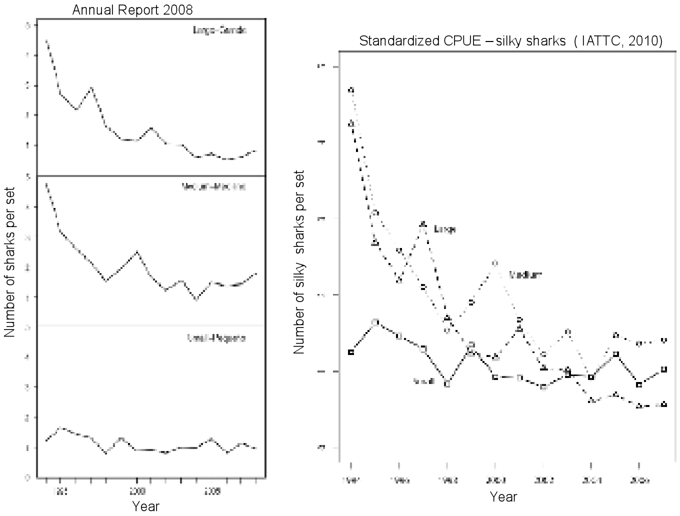


FIGURE 102
Numbers per set by sizes – silky sharks


Annual Report 2008

Standardized CPUE – silky sharks (IATTC, 2010)

Source: IATTC (2008).

FIGURE 103
Sets with silky sharks in four time periods in dolphin and school sets

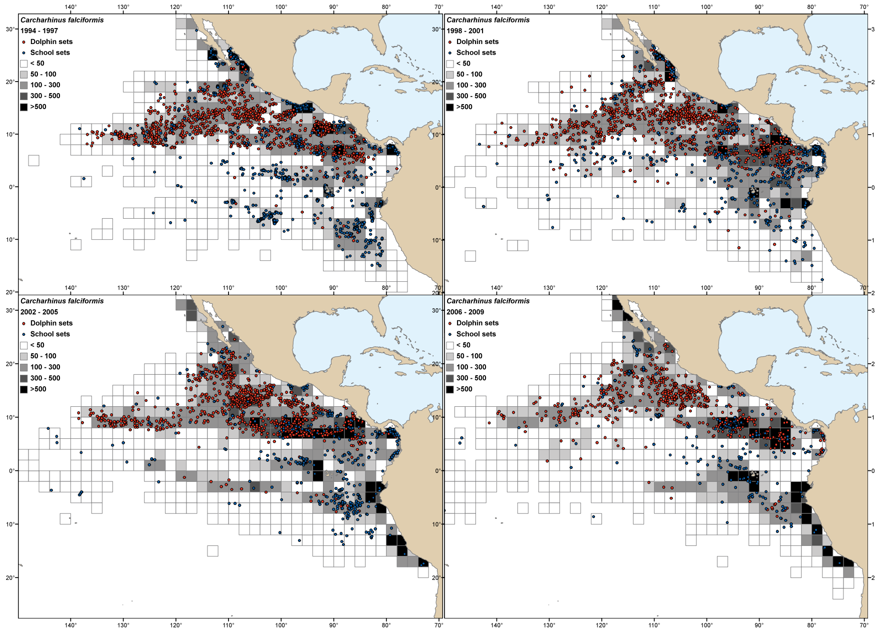
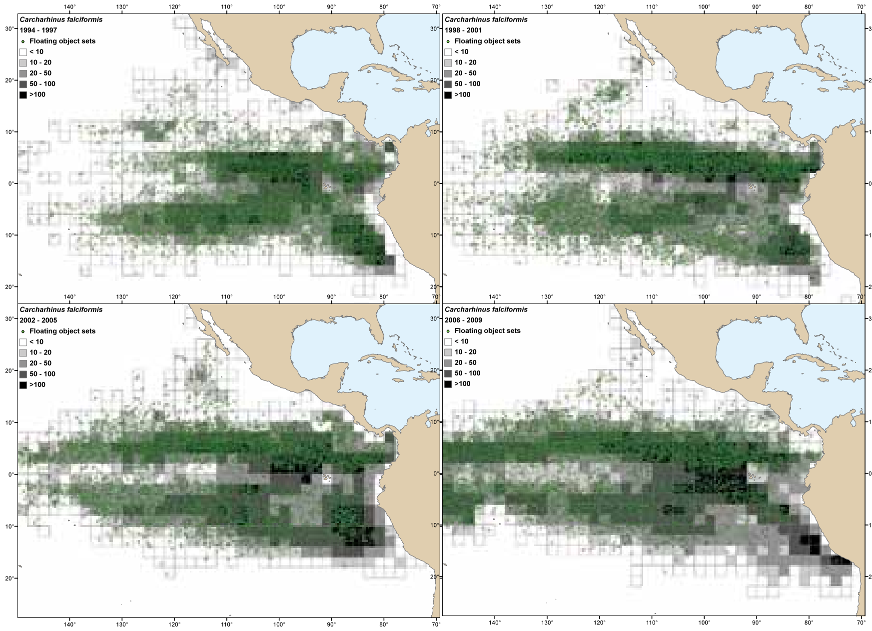
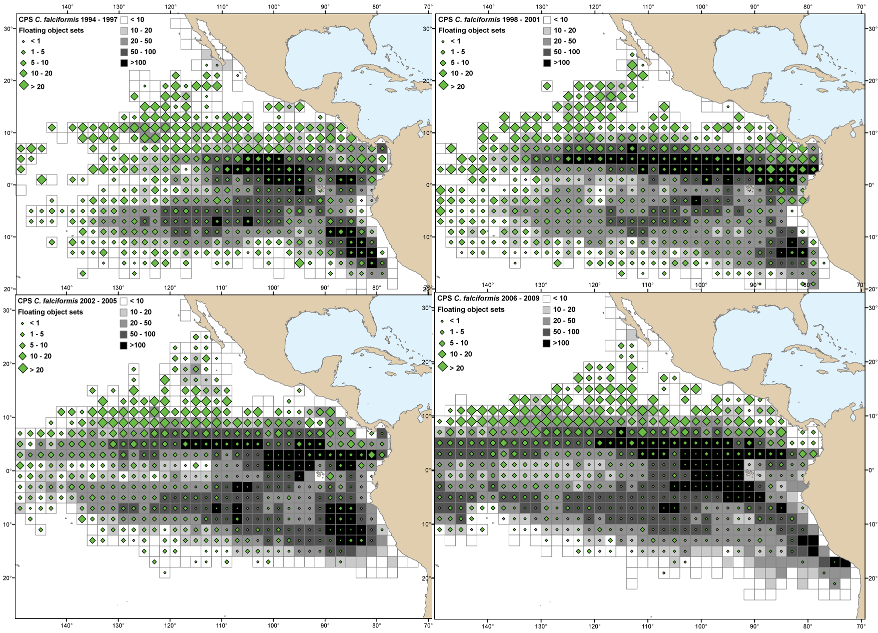


FIGURE 104
Sets with silky sharks in four time periods in floating object sets



Although the data available do not enable a full stock assessment, several pieces of information are available to shed light on the status of the silky sharks. Figure 101 shows the captures of silky sharks in the three types of sets. Catches are down almost 80 percent from the peak in the late 1990s, and the decline is significant (and probably > 70 percent) for the medium and large for all size groups. Figure 102 shows the declines

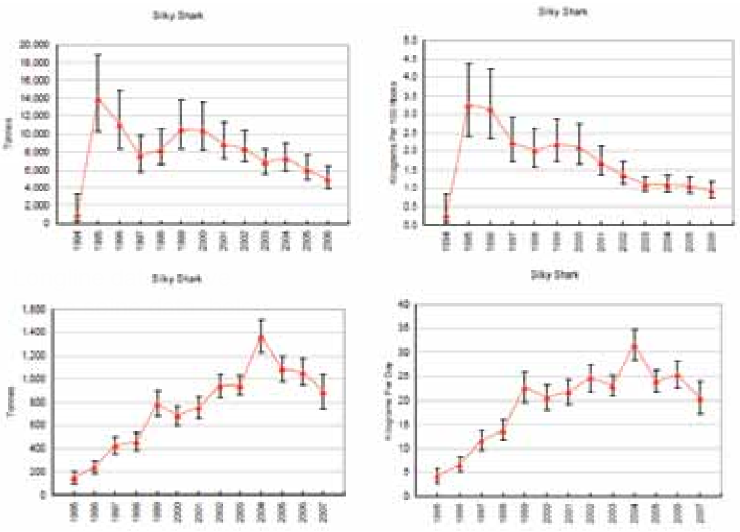
FIGURE 105
Average numbers per set of silky sharks in four time periods in floating object sets



in CPS, and standardized CPUEs for the three size categories (IATTC, 2008, 2010) based on the data from floating object sets. These declines are statistically significant for large (> 150 cm total length) and medium-sized sharks (90–150 cm total length) from 1994 until about 2004, then remain relatively constant. For the smaller sharks (< 90 cm), the trend is rather flat.

To explore the possibility of spatial changes causing the declines, Figures 103 and 104 present simple maps showing the occurrence of shark encounters over periods of four years, from 1994 to 2009 in the EPO, in dolphin and school sets, and in floating object sets. The thinning of the observations is evident in the whole region, and suggests that there have been no shifts in habitat causing the declines. Changes in effort levels in this period are shown in Figure 22. This geographical view allows the consideration of all types of sets, which were not included in the previous analysis. The changes in average NPS in floating object sets for the same periods is shown in Figure 105. The very large group sizes in the north persist over time.

FIGURE 106
Catches and catch rates of silky shark in the Western Pacific Ocean



Note: Longline data (top); purse seine data (bottom).
Source: OFP (2008b) (excluding the domestic fleets of Indonesia and the Philippines).

Western Pacific

The catches of silky sharks has been estimated at 84 000 tonnes in 1994 (Stevens, 2000). More recently, OFP (2006) estimated only 9 000 tonnes in the WCPFC area in 2002, and the most recent figures are 5 000 tonnes in longliners and 1,100 tonnes in purse seiners (Figure 106, Table 43; OFP, 2008b). The wide difference between these figures may reflect a decline in the population, differences in regional coverage, and the inaccuracies of the statistical data available for estimation, especially because some missing data are significant in terms of shark harvests, relating to some of the largest shark producers in the world, especially Indonesia and Taiwan Province of China (Camhi *et al.*, 2009b). In the WPO, in the late 1990s, the retention of silky sharks was 46 percent (Williams, 1999), and more recently it has been slightly higher at 51 percent (OFP, 2010a). For those returned to the sea, the percentage discarded alive from longliners was 81 percent for silky sharks, but there is no long-term verification of survival (Williams, 1999). A study off Hawaii showed recent declines of the order of 54 percent in the CPUEs of silky sharks using data from deep longline sets (Walsh, Bigelow and Sender, 2009).

In the WPO, the proportions captured were 88 percent silky sharks, 10 percent oceanic whitetip, and 2 percent other sharks (Manning *et al.*, 2009). A series of shark catch figures and nominal CPUE figures by species in weight are available for longline and purse seine catches from the WPO (OFP, 2008b, 2009).

Using estimated averages for individual weight for the longline catches (P. Williams, personal communication) an estimate of about 322 000 sharks per year for the period 1994–2006 period was obtained. These estimates are really minimum estimates as they do not include either discards or other important components of the fishing mortality (e.g. domestic fleets Indonesia, the Philippines, Taiwan Province of China). There are alternative, more complete estimates for this region (Clarke, 2009), so the figure used is an underestimate. The estimates for the purse seine fleet for the period 1994–2004 amount to about 40 000 captured sharks/year (Molony, 2005a), with an estimated mortality of 21 000 sharks/year.

Molony (2008) reports catches of silky sharks of 200–1 500 tonnes in purse seine fisheries, compared with 1 500–13 000 tonnes in longline fisheries. The former have been increasing, but the longline catches have suffered major declines. Sharks are mostly taken as individuals or very small groups. Out of more than 29 000 sets included in a study by Molony (2005a), two-thirds had zero captures, and half of the sets with sharks had 1–3 individuals. However, there were 85 sets with captures of more than 35 individuals. The FADs have a much higher frequency of sharks than logs, and much more than payaos.

Atlantic Ocean

Amandè *et al.* (2010b) reports very low catches of 40 tonnes/year based on data for the period 2003–07; silky sharks are 80 percent in numbers of the sharks identified. Chassot *et al.* (2009) show that this species is the most frequently encountered (almost 14 percent of the sets), and the one with the largest numbers and biomass in the captures (80 percent in weight of identified sharks). Their capture happened only in sets on floating objects.

Indian Ocean

The lack of information is a key problem in any attempt to assess the situation. The proportion of sharks reaches more than 10 percent of all the non-tuna bycatch (Romanov, 2000; Amandè *et al.*, 2008a; Pianet *et al.*, 2009). Romanov (2002) reports 0.175 sharks per set, without a specific breakdown. The most recent estimate of captures for the European purse seine fleet, 2005–08 (Amandè, personal communication) is of 424 tonnes of silky sharks per year, and a ratio of 0.1 tonnes/set. Amandè *et al.* (2008a) report a very high frequency of occurrence for the French fleet: 24 percent of the sets captured silky sharks (15 percent of school sets, and 28 percent of FAD sets), with discards of 85 percent of the captures. About one-third of the discarded individuals were alive, but there was no follow-up on survival. For the Spanish fleet, the frequency is 17 percent of the sets (González *et al.*, 2007).

The captures of silky sharks were 86 percent of the total, followed by similar proportions (slightly more than 4 percent) of the oceanic whitetip sharks, the smooth hammerhead, and the scalloped hammerhead shark (Amandè *et al.*, 2008a). In weight and numbers, silky plus oceanic whitetip sharks add up to 90 percent and 94 percent, respectively, of the identified sharks. Smale (2008) points out that the vast majority of the catches in other fisheries from this region are reported in aggregate form, so there is considerable uncertainty (IOTC-2007-WPEB-R[E]). Delgado de Molina *et al.* (2005a) show that, in weight and numbers, the silky shark is the most common species followed by the oceanic whitetip shark, with a clear prevalence in both FAD sets and school sets in numbers.

The silky shark is dominant in catches off Maldives, off Sri Lanka, and very common in most of the Western Indian Ocean (Smale, 2008). Sanchez *et al.* (2007) report capture rates of 1.91 silky sharks per set compared with 0.10 per set for the oceanic whitetip, the second-most abundant species identified (other groups are unidentified, or higher taxa) for the Spanish fleet. This large difference is present in almost all areas. Using visual surveys, Taquet *et al.* (2007b) report 9.5 individual silky sharks versus 0.1 individual for the oceanic whitetip shark.

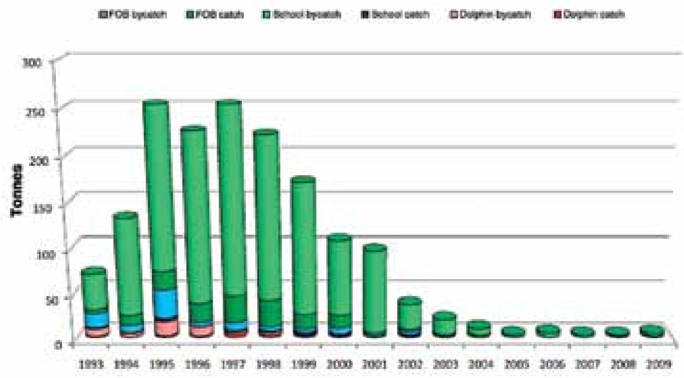
Some shark stocks are showing strong evidence of declines, but in other cases the data presented (John and Varghese, 2009) are aggregated and it is not possible to see species trends. Surveys of fishers from the region show general agreement in the perception of a reduction in the silky shark population, measured through their fishing success (Anderson and Jauharee, 2009), but these types of surveys have the "noise" of the fishers' fears and interests. Romanov *et al.* (2010) show a reduction in nominal BPUE, and on shark diversity in the Indian Ocean, but most of the impacts discussed are based on data from longline fisheries.

Total mortality figures, including catches in directed fisheries and bycatch, in the different ocean basins are hard to obtain because of data aggregation, and lack of adequate coverage in some fleets, but there have been some attempts at obtaining totals for some basins and fleets (Oshitani, 2000; Clarke *et al.*, 2006; Clarke, 2008, 2009). The world catches of silky shark range, according to the method of estimation, from 300 000 to more than 2 million/year.

To put the bycatch figures in perspective would require having abundance estimates of these populations, solid estimates of bycatch in all significant fisheries, and a good understanding of stock structure. Not all this information is available. The data available on mostly incidental captures in industrial longlines, and directed catches in artisanal longlines, show that the role of the purse seine bycatch on the population dynamics of the species is relatively minor, causing less than 5 percent of the mortality resulting from all fisheries (Clarke, 2009). For example, in the WPO, Oshitani (2000) estimated an annual longline catch of silky sharks in the 1990s of 400 000–600 000 individuals per year, compared with 40 000 individuals captured in purse seiners. In the late 1990s – early 2000s (OFP, 2008a), the catches of silky sharks in purse seines were less than 10 percent of the catches in longliners, but in recent years, the steep decline in longline catches, and a more stable level of the purse seine catches have resulted in levels that are now approaching 20 percent of the total catch (Table 43). Estimates of silky shark catches for the Western and Central Pacific using several methods applied to the shark-fin trade volume range from 200 000–600 000 individuals, with the upper boundary of the confidence intervals reaching 600 000–1 200 000 individuals per year (Clarke, 2009). Some of these figures may be affected by the changes in retention proportions that have happened in recent years (Figures 95 and 96); sharks that would have been discarded in the past are now retained, and may appear in the landings statistics, which may allow better species identifications.

FIGURE 107

Oceanic whitetip shark: catch and bycatch by set type in tonnes in the Eastern Pacific Ocean, 1993–2009

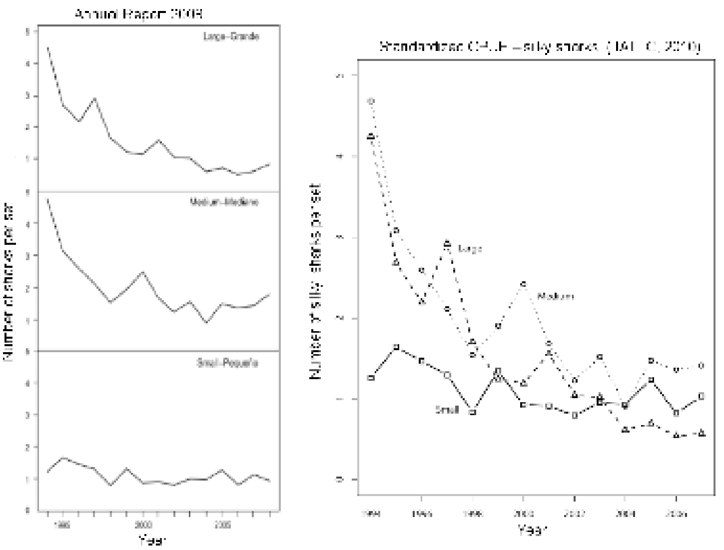


OCEANIC WHITETIP SHARK (*CARCHARHINUS LONGIMANUS*)

Much less is known about the oceanic whitetip shark in spite of a very broad distribution (Bonfil, Clarke and Nakano, 2008). Ranges for age at maturity for the oceanic whitetip shark are 4–5 years old in the Pacific Ocean, with lengths of 120–125 cm (Seki *et al.*, 1998), and 6–7 years old in the Atlantic (Lessa, Marcante Santana and Paglerani, 1999). Maximum age range is 13–17, and fecundity 1–14 young per litter, with common values of 5–8 pups (Snelson, Burgess and Roman, 2008). Gestation period is 9–12 months. There is practically no information on movement, but there appears to be spatial segregation of different reproductive stages (Coelho *et al.*, 2009), and offshore nurseries over continental shelves. This is a species with a relatively high productivity among sharks (Cortés, 2002; Smith, Au and Show, 2008); however, several stocks of this species have been showing steep declines in recent years (Baum *et al.*, 2003; Baum and Myers, 2004; Walsh, Bigelow and Sender, 2009; IATTC, 2009; OFP, 2010a).

FIGURE 108

Year effects from bycatch presence/absence analysis



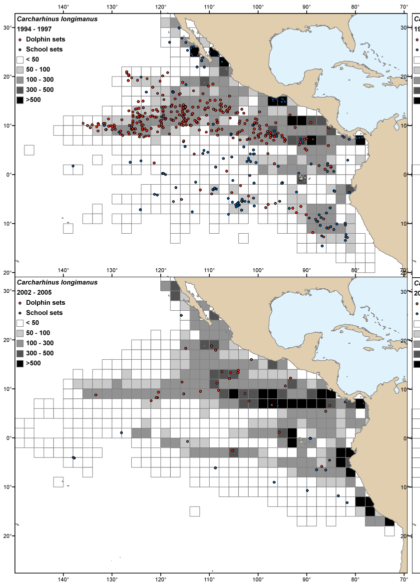
Source: IATTC (2008).

Eastern Pacific

Captures amount to an average of 3 400 sharks/year, or 65 tonnes (1994–2009), of which 3 000 sharks/year are bycatch. Ninety percent of the captures come from sets on floating objects (Tables 15–30). Figure 107 shows a sharp decline in captures after the late 1990s. The proportion retained has been increasing (Figure 95).

Figure 108 reflects the steep declines observed in an analysis based on simple presence–absence, while Figures 109 and 110 show the maps describing the distribution of encounters with oceanic whitetip sharks through four periods, similar to those used for the silky shark above. The signal in this case is impossible to miss – the species has practically disappeared from the fishing grounds, and the progression appears to have been from north to south. Figures 111 and 112 illustrate the decrease in CPS

FIGURE 109
Encounters with oceanic whitetip sharks in dolphin and school sets in four periods



that accompanied the reduction in frequency. To explore the causes of the reduction, Table 44 shows the frequencies of three size groups: < 90 cm, 90–150 cm, > 150 cm. The “small” group, which was close to 10 percent of the captures in the late 1990s, has been less than 2 percent in recent years. This species also shows significant declines in the WPO. Figure 113 describes the progression of catches and nominal CPUE values for

FIGURE 110
Encounters with oceanic whitetip sharks in floating object sets in four periods

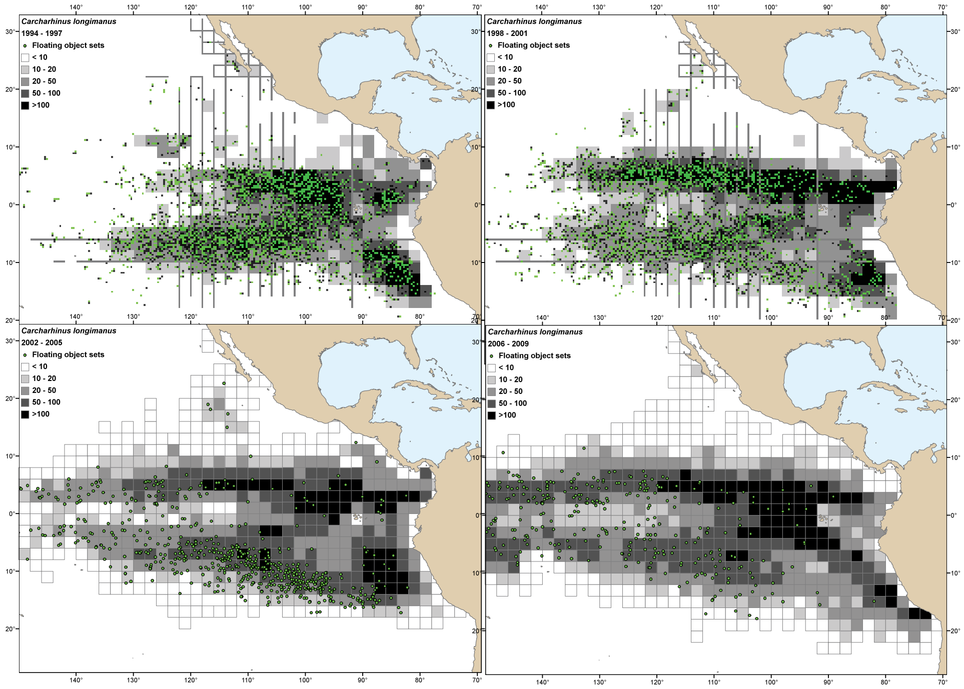


FIGURE 111

Numbers per set of oceanic whitetip sharks in dolphin and school sets in four periods

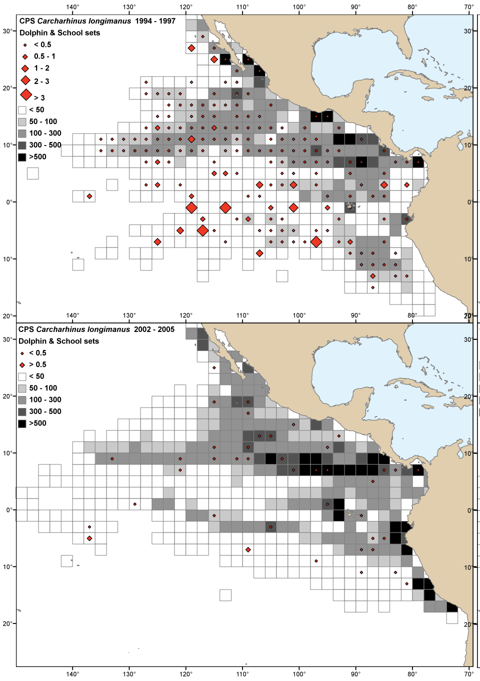


FIGURE 112

Numbers per set of oceanic whitetip sharks in floating object sets in four periods

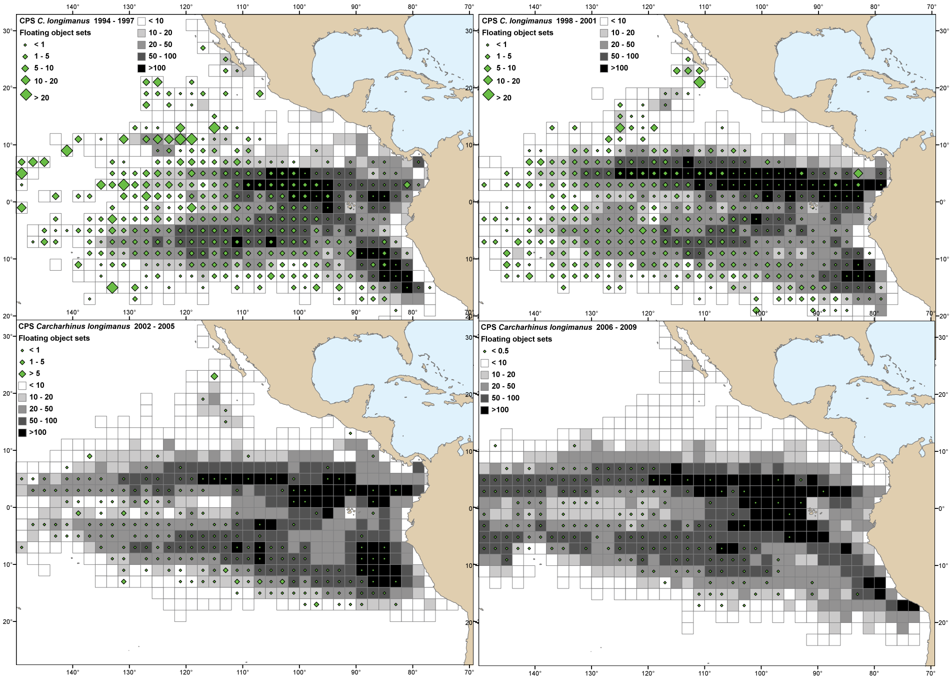
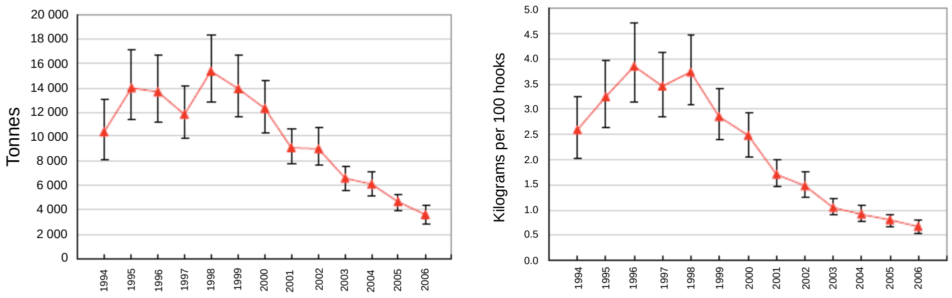


FIGURE 113

Catch and CPUE in longline fisheries of oceanic whitetip sharks in the Western Pacific Ocean



Source: OFP (2008b)

TABLE 44

Capture of oceanic whitetip sharks by size interval in the Eastern Pacific Ocean, 1993–2008

	Number				Percent		
Year	Small	Medium	Large	Total	Small	Med	Large
1993	220	494	310	1 024	21.4	48.3	30.3
1994	95	1 130	1 440	2 665	3.5	42.4	54.1
1995	408	2 984	2 149	5 541	7.4	53.9	38.8
1996	647	2 765	2 483	5 895	11.0	46.9	42.1
1997	592	2 258	2 995	5 845	10.1	38.6	51.2
1998	452	1 862	2 683	4 997	9.1	37.3	53.7
1999	340	1 213	2 210	3 764	9.0	32.2	58.7
2000	18	547	1 426	1 991	0.9	27.5	71.6
2001	80	729	1 252	2 662	3.9	35.4	60.7
2002	15	122	540	677	2.2	18.0	79.8
2003	0	105	266	371	0.0	28.4	71.6
2004	4	38	132	174	2.3	21.8	75.9
2005	1	23	30	54	1.9	42.6	55.6
2006	1	33	48	82	1.2	40.2	58.5
2007	1	18	23	42	2.4	42.9	54.8
2008	0	11	19	30	0.0	36.7	63.3

Note: Small < 90 cm, medium 90–150 cm, large >150 cm.
Source: IATTC observer database.

the WPO region. In both ocean basins, the declines in nominal CPUE or the frequency of occurrence is compatible with a drop of 80–95 percent from the population levels in the late 1990s.

Western Pacific

Catches have been estimated to be high (e.g. 540 000 individuals in the Central and South Pacific, equivalent to 10 800 tonnes) in the mid-1990s (Bonfil, 1994), and another estimate of 52 000–240 000 tonnes (Stevens, 2000) is available for 1994. However, for 2002 (OFP, 2006), the estimate available shows a catch of 7 400 tonnes, although missing some significant fleets from the region. In the WPO, most of the captures in the longline fisheries, and part of the purse seine captures were retained for finning, so mortality was estimated for the longliners at 65 percent of captures (Molony, 2005a).

Camhi *et al.* (2009b) estimate 175 000 tonnes of sharks for the whole Pacific in 2002, and in those years, oceanic whitetip sharks ranked third in order of nominal CPUE in shallow longline sets, and fourth in deep longline sets (Williams, 1999). In purse seine captures, they ranked second in importance in both school and associated sets. Molony (2005a) reports 210 oceanic whitetip sharks killed out of a capture of 3 300 by the purse seine fleet (annual averages 1994–2004), and the longline captures amounted to more than 128 000 sharks with 25 000 mortalities. According to these figures, the purse seine bycatch is less than 1 percent of the longline bycatch.

Other estimates of catches in the WPO (OFP, 2008b) show that the oceanic whitetip purse seine catches amount to about 1.5 percent of the overall catch of the species. Clarke (2009) explores alternative methods to obtain total catch estimates, trying to overcome the lack of data, and other reporting problems. The ranges are wide, but values between 200 000 and 500 000 bracket the core of the different distributions, and are consistent with the more than 320 000 sharks/year obtained by just applying a conversion factor to the catches.

There are clear declines observed in nominal CPUEs for some longline fisheries in the region (Figure 113), reaching a 54 percent decline for the fisheries around Hawaii, using the figures for shallow longline sets, and 78 percent using deep longline sets (Walsh, Bigelow and Sender, 2009). The world catch of the oceanic whitetip sharks ranges from 250 000 to 1.4 million sharks/year (Clarke *et al.*, 2006).

Atlantic

Captures were very low, fewer than a couple of hundred individuals per year, in the 1990s (Cortés, 2008b). Most of the Atlantic shark catches are blue sharks and porbeagle sharks (*Lamna nasus*) coming from longline gear. More recently, less than 600 tonnes was reported for most years in the 1990s (Camhi *et al.*, 2009b). In the Gulf of Mexico, catch rates declined by 99 percent between the mid-1950s and the late 1990s (Baum and Myers, 2004).

Indian Ocean

This species is believed to move north and south of the equator in different seasons (Mejuto, García-Cortés and Ramos-Cartelle, 2005), so its vulnerability to the fishery is seasonal. The most recent estimate was of 80 tonnes/year (Amandè *et al.*, 2008a).

HAMMERHEAD SHARKS (SCALLOPED HAMMERHEAD [*SPHYRNA LEWINI*], SMOOTH HAMMERHEAD, [*S. ZYGAENA*], GREAT HAMMERHEAD [*S. MOKARRAN*])

Several species of the genus *Sphyrna* are caught in purse seine fisheries; the main ones are *S. lewini*, *S. zygaena* and *S. mokarran*. Their fins are highly valued, so they have been targeted for their fins, or the captures are retained for utilization. They sometimes aggregate in large groups (Wakabayashi and Iwamoto, 1981; IOTC, 2007), and these are sometimes targeted by coastal fisheries.

The best known is the scalloped hammerhead. It reaches its age at first maturity at 15 years, lives up to 35 years old, and produces 15–31 pups. These reproductive parameters contrast with the more productive oceanic whitetip and silky sharks, and make them more vulnerable to exploitation. In the Atlantic, another set of parameters shows age at maturity of 6, maximum age of 40, and litter size of 25 (Piercy *et al.*, 2007). This value is similar to the litter size of 14–41, with a median of 25, found in Indonesia and other studies for the Pacific reviewed in White, Bartron and Potter (2008). For the Atlantic, the ranges published are lower (Hazin, Fischer and Broadhurst, 2001). They show no stock structure at the regional level, but studies at larger scales are needed (Ovenden *et al.*, 2009). There seems to be a high level of connectivity along coastlines, and little migration across oceans (Duncan *et al.*, 2006). Adults sometimes aggregate near seamounts, and visit their nursery grounds seasonally, but there is no fidelity to a single nursery ground (Duncan *et al.*, 2006). Coastal, shallow nursery areas are believed to provide refuge from predators (Duncan and Holland, 2006). However, artisanal fisheries are known to target these juvenile aggregations, and in some cases a significant level of effort is deployed towards them.

Although the litter size is larger than for other shark species, and this applies to the great hammerhead, litter size 4–42, and to the smooth hammerhead, litter size 29–37, growth rates and productivity are low, and the proximity of their nursery areas to the coasts in some cases, together with the schooling behaviour of *S. lewini* and *S. zygaena*, puts them within reach of many fisheries, and makes these populations especially vulnerable (Abercrombie, Clarke and Shivji, 2005). Evidence of declines in some regions is clear; Dudley and Simpfendorfer (2006) show declines of 64 percent for the scalloped hammerhead, and of 79 percent for the great hammerhead over a 25year period off the coast of Natal, South Africa. Problems of identification cause a pooling of these species in many statistics, so it is not possible to attribute catch or bycatch to a species or stock. Observer programmes of the t-RFMOs are making efforts to improve the quality of the data collection.

Eastern Pacific

Captures of hammerhead sharks in the EPO are about 1 900 individuals/year, with bycatch of 1 400 individuals/year, averages over 1993–2009, and distributed in dolphin sets (6 percent), school sets (23 percent), and floating objects sets (71 percent) (Tables 15–30, Figures 114 and 115). The most common is the scalloped hammerhead. Captures reached a peak of about 3 000 sharks in 2003–04, and then they declined steeply, with the most current figures being at 700–900/year. Part of the decline is probably due to the effort moving further offshore in recent years, to an area with fewer hammerhead sharks. The rest may be reflecting a real decline. There is considerable effort on these populations from artisanal fisheries using different gear types, and targeting juveniles and adults.

The spatial distribution of *S. lewini* and *S. zygaena* in the different types of sets is shown in Figures 116 and 117. There are important areas for these species around Baja California, on the Peru Current, on the Costa Rica Dome (Fiedler, 2002), and along the northern strip of the FAD fishery extending to the west. Another important concentration occurs north of the equator, between 82°W and 86°W.

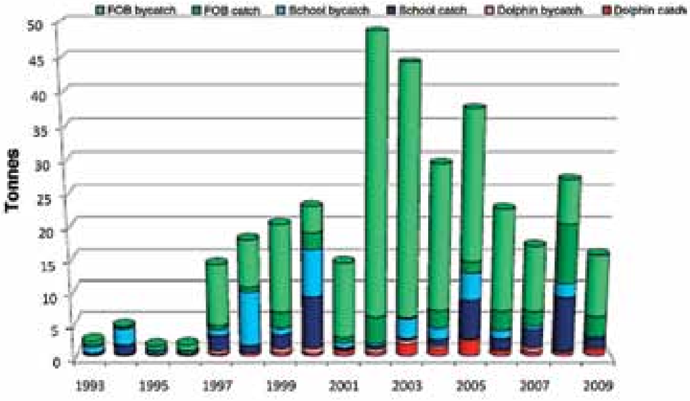
Western Pacific

Hammerhead sharks are included in the "Other sharks" category, so there are no specific values to consider. The category "Other sharks" shows a major decline of more than 90 percent in its nominal CPUE figures from purse seine associated sets. School sets do not have enough data points for analysis. The longline data do not show a clear trend (OFP, 2010a).

Atlantic

The captures are 4.2 tonnes/year of the smooth hammerhead and a similar 3.7 tonnes/year for the scalloped hammerhead in 2003–07. They are the most numerous sharks in school sets, and less common under floating objects. Their frequency of occurrence is 0.5–2 percent of the sets (Sarralde, Delgado de Molina and Ariz, 2006; Chassot *et al.*, 2009; Amandè *et al.*, 2010b).

FIGURE 114
Scalloped hammerhead shark: catch and bycatch by set type in tonnes in the Eastern Pacific Ocean, 1993–2009

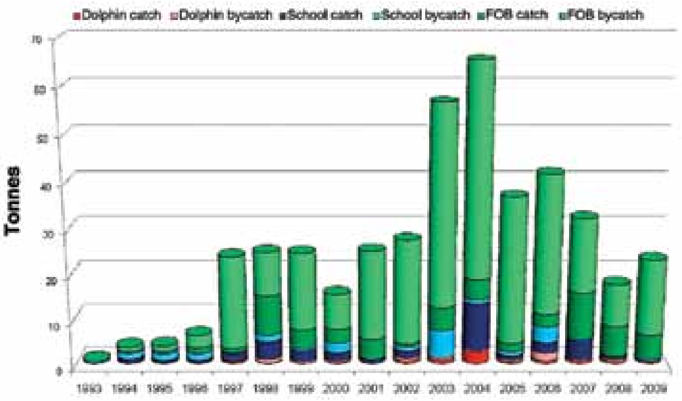


Indian Ocean

The estimated captures were 0.5 tonnes/year with a portion of that without species identification. The frequency of occurrence was less than 1 percent of the sets of both types (Sarralde *et al.*, 2007). The bycatch per 1 000 tonnes of tunas for the pooled hammerheads was 5–6 tonnes/1 000 tonnes in the Réunion–Seychelles area.

FIGURE 115

Smooth hammerhead shark: catch and bycatch by set type in tonnes in the Eastern Pacific Ocean, 1993–2009



Source: IATTC observer database.

ACTIONS AND CONCEPTS TO REDUCE SHARK BYCATCH

Management and technological approaches to reduce shark bycatch have been explored for some years, but they have focused mostly on longline captures (e.g. Patterson and Tudman, [2009] for Australian fisheries). In recent years, the emphasis on the finning issue (McCoy, 2006) has obscured the major issue of the lack of adequate information and effective management at the national and international levels.

Finning restrictions are in place in some countries and in most RFMOs, and so is the obligation to release alive all non-target species, but the option of retention of whole individuals has been available, and full utilization has been increasing (Figures 95 and 96).

FIGURE 116

Occurrence of *S. lewini* (left) and *S. zygaena* (right): dolphin – school sets, 1994–2009

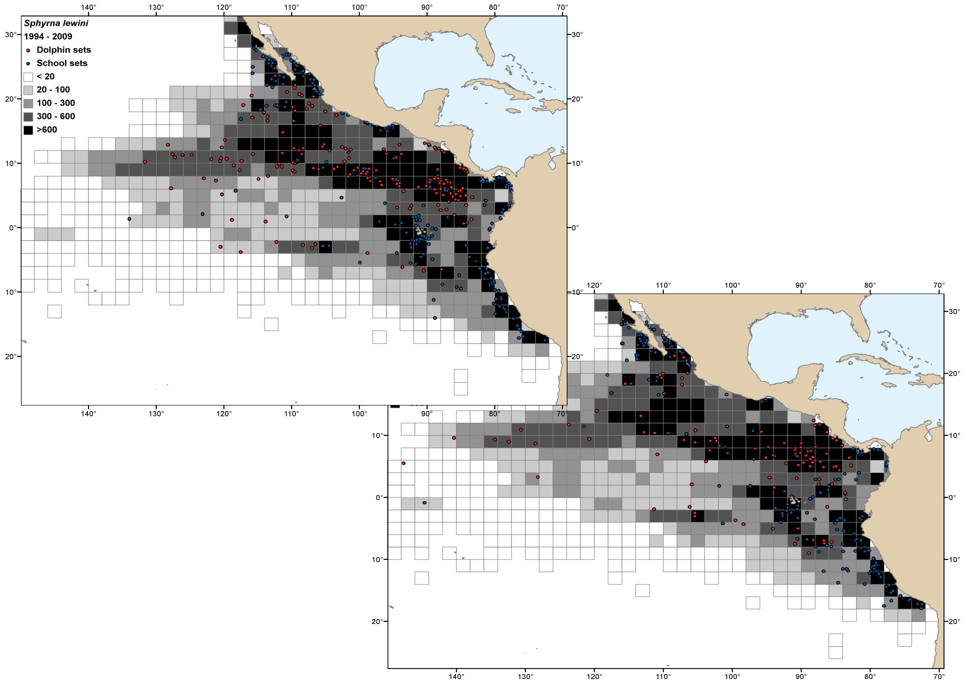
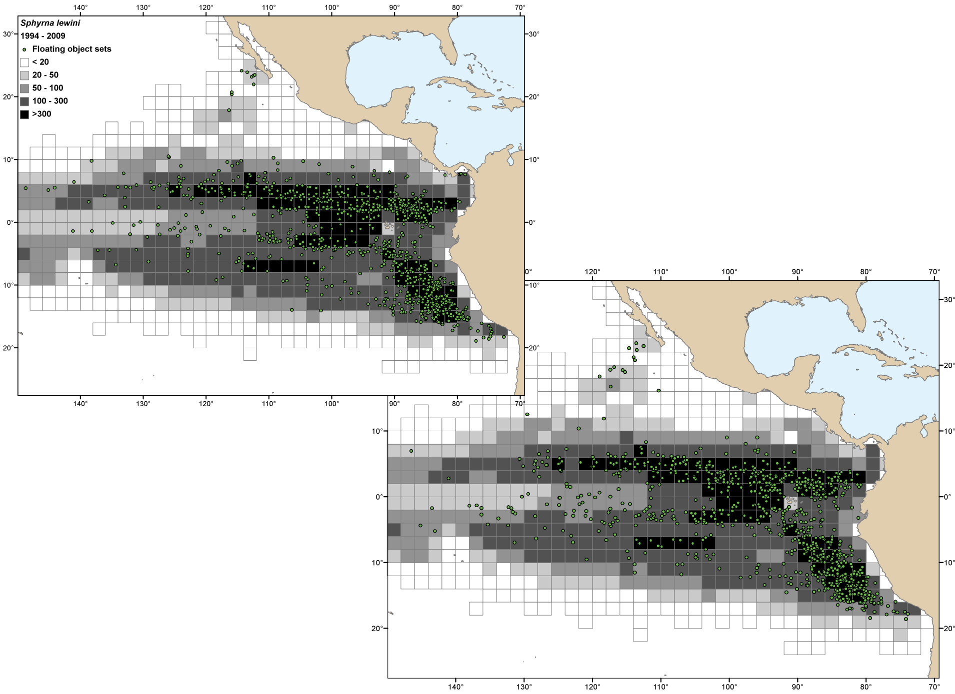


FIGURE 117
Occurrence of *S. lewini* (left) and *S. zygaena* (right): floating object sets, 1994–2009



Options available for shark management in the purse seine fisheries include:

- spatial closure of high density areas such as nursery areas;
- effort controls;
- prohibition of shark landings;
- seasonal closures to protect reproduction;
- shark size limits;
- shark bycatch quotas per vessel;
- mandate to release immediately any shark brought on board;
- setting best procedures for shark handling during release, and training of crews in these procedures.

The recommendations of t-RFMOs and other fisheries organizations with regard to sharks are listed in Lack and Sant (2009). The mixture of actions proposed reflects the diverse nature of the problem; making the utilization sustainable on the one hand, and eliminating the shark bycatch on the other hand. These policies should be applied according to the characteristics of the regional fisheries, and according to the status of the shark species and/or subpopulations involved.

After the more immediate measures have been taken, many additional measures require a solid scientific basis; thus, observer or other monitoring programmes should be a first step when the information is not sufficient. The observer programmes are valuable to estimate the impacts of the fisheries, but they are even more important to understand the causes of bycatch, and to help devise the solutions (Hall, Campa and Gómez, 2003). To provide good estimates, observer coverage levels will be adjusted to the objectives pursued, and to the shark species (frequency, group size, etc.), and in the reliability required of them (Lennert-Cody, 2001; Babcock, Pikitch and Hudson, 2003; Lawson, 2006a; Sánchez *et al.*, 2007; Amandè *et al.*, 2010a). Some of the t-RFMOs have 100 percent observer coverage, or are approaching that level, but others have much lower, but increasing levels of coverage.

Avoiding the capture of sharks

Spatial management

Shark bycatch shows extreme variability in its levels, and with a solid database it is possible to identify areas where the impacts are disproportionate to the production of the fishery. The use of average BPUE (bycatch per unit of effort, in this case bycatch per set), or, better, bycatch/catch ratios, relating the bycatch impacts to the production of a time area stratum, are useful for exploring the data (Hall, 1996; Watson *et al.*, 2009). For example, in the EPO, sets on floating objects in the area north of 8°N produce only 4 percent of the total tuna catch but up to 42 percent of the total silky shark bycatch. Hyde (personal communication) identifies this area as a nursery area for the species, and the juveniles aggregate under floating objects. A closure of this area to floating object sets is a possibility for achieving a substantial reduction in bycatch of this segment of the population. In this region, a small number of sets show average silky shark captures of 90–100 individuals per set, compared with fewer than 0.5 in most of the region (Figure 98). Watson *et al.* (2009), explored systematically different closures to compare their effectiveness to reduce bycatch, and to minimize the negative impacts on the tuna captures. Actions like this can be taken without waiting for additional information. This case shows the value of observer data to generate options to reduce bycatch with the least impact on the fisheries.

Other cases where spatial management could be useful are those involving impacts on breeding and nursery grounds (Castro, 1993; Duncan and Holland, 2006; Heithaus, 2007; Heupel, Carlson and Simpfendorfer, 2007; Kinney and Simpfendorfer, 2009; Salomón-Aguilar, Villavicencio-Garayzar and Reyes-Bonilla, 2009). These nursery grounds are well defined in many cases, so the location of those areas is an important gap to fill.

Once the more immediate actions have been taken, then it should be possible to move on to implement these approaches where a high density of data is required, and one advantage of the observer programmes with high coverage is to allow the quick identification of these problematic regions that cause a disproportionate amount of the problem. They also allow the identification of cases of sexual or size segregation that may distort or nullify the management actions (Mucientes *et al.*, 2009).

Distancing the sharks from the area to be encircled prior to encirclement

Another approach that is being explored is to attract sharks away from the area to be enclosed, or repel them from it (Scott, 2007). A speedboat may tow an “attractor” from the vicinity of the FAD to a location expected to be outside the encirclement. If sharks follow the attractor (and the tuna school does not), then the net can be closed after the sharks have been removed from the area. The challenge is the identification of the proper attractor or attractors that will be effective and selective for the sharks. Given the specialized sensory organs of sharks, it does not seem an impossible task. Shark repellents could have the same effect.

Releasing the sharks from the net

Removing the sharks from the net after encirclement

It has been suggested that towing the FAD out of the net, through the opening between the ortza and the vessel, could help to remove the sharks from the net. Fishers know that towing the FAD through that opening brings many species outside the net, especially those that were more closely associated with the object. This technique is used by skippers who believe that releasing most of the community associated with the FAD will result in improved production of the FAD in the future. There is no evidence of a shark reaction to the towing of the FAD.

Capturing the sharks in the net for release

Given the size of the area encircled, and the usually low number of sharks, it seems a big challenge to attempt to find them and capture them inside the net, unless they can be concentrated in some area of the net. The procedures that should be used to handle the sharks, and that are safe for crews and sharks, are not known.

Releasing the sharks from the vessel

As the capture is being brailed on board, the sharks are set aside for later disposition. In some cases, they will be on the deck of the seiner, in other cases on the well deck (below), and in other cases they will be on a conveyor belt bringing them out of the vessel for release (Plate 1). Some of the sharks are retained for utilization. In the EPO, the proportion retained has been increasing in recent years, from 20 percent in 1993 to more than 70 percent today (Figures 95 and 96).

Those sharks that are going to be discarded are of different species, sizes, sexes, conditions, etc., and experience a variety of stressors, for different periods. For example, sets with a capture of a few tonnes of fish, and sets with a capture of hundreds of tonnes are likely to result in many factors changing for the individuals captured: the duration of the set, the level of oxygen in the net, the probability of injuries inside the net, etc. They also happen in different environmental conditions: water and air temperature, sea state, current speed, etc. It will be difficult to isolate the impact of each one of them, but a comparative exploration of databases in all regions may help in the process. It is possible that one or a few factors are critical for survival, and the identification of these is a major research need. Changes in the fishing process to increase survival of unwanted individuals and species is a promising area of research (Broadhurst *et al.*, 2008).

It is not clear which of these factors are the most significant, and although there are several quality studies of survival to hooking (Moyes *et al.*, 2006; Skomal, 2007; McLoughlin and Eliason, 2008; Campana, Joyce and Manning, 2009; Carruthers, Schneider and Neilson, 2009; Walsh *et al.*, 2009; Heberer *et al.*, 2010; Skomal and Bernal, 2010), and a few ones of survival to net captures (Manire *et al.*, 2001; Mandelman and Farrington, 2007), there are no studies of survival after purse seine sets. A clear research priority is the implementation of a well-planned set of experiments, covering a variety of species, and in well-described and standardized capture conditions (Musyl *et al.*, 2009). The proportions of sharks that are released alive in longlines suggest that some species can handle the capture stresses, although the procedures are very different. Silky, oceanic whitetip and hammerhead sharks are alive at capture in 81–87 percent of the cases, and are released alive in those fisheries.

An important source of information on survival to capture are the studies on tagging of sharks captured with different gear types (e.g. review in Kohler and Turner [2001] and Hussey *et al.*, [2009]).

In vessels with hoppers to sort the fish on deck, the sharks may be set aside on the deck and left there until the brailing is complete. They will be exposed to heat, desiccation, and lack of oxygen for a period that may be up to a few hours. In some vessels, the brailer is lowered on the deck to allow the crew to separate the species not meant to go to the wells. The duration of a set on floating objects is very variable, depending on the tonnage encircled and other factors. Figures 42–44 show the distribution of set durations, and put it as a function of the tonnage. Goujon (2004a) shows a distribution of set durations for the Atlantic.

In vessels where the sorting takes place on the well deck, the sharks will also be set aside for the duration of the set, but it is probable that the conditions are less harsh (e.g. shade and a cooler environment). In vessels that have a conveyor belt in the well deck to return the fish discarded to the water, the conditions should be considerably better, with a much shorter time of exposure to stressors (Plate 1).

In all cases, the sharks will have to be handled for sorting. The most common way to lift a shark is by the tail, but this may result in injury or mortality for the shark. Even those trying to release the shark alive may be causing its death. Training of the crews and perhaps special instruments may be needed to reduce the mortality caused by poor handling, while avoiding risks to the crew. The development of these instruments is a high priority.

In cases where the shark is released back to the ocean, there is no certainty of survival. Some sharks species and sizes are capable of tolerating very harsh conditions, originating in different stressors. A shark arriving to the seiner has been subject to a prolonged period of exposure to high temperatures (close to the surface in tropical seas), to low oxygen (as the biomass inside the net is compressed into a small volume as the set progresses), and to some compression, and perhaps also scraping in the brailer. It is known that different shark species have different tolerances to capture stresses, and research projects should be directed to the different species involved, rather than generalized approaches (Skomal and Bernal, 2010).

Experiments are needed to assess the survival of sharks released under the current conditions. If this figure shows a minimum level of perhaps 20–30 percent of the individuals, then work could be started to improve the conditions during the fishing operations to increase those figures. These changes may include: aeration of the net, modification of the brailing process, acceleration of the release process, improvement in deck conditions (shade, spray), and, in particular, increasing the awareness of the crews of the need to release the sharks alive, and their training to implement it. If the survival levels are very low, then the emphasis should shift to measures that avoid the capture of the sharks, such as those stated above.

Utilization of sharks

For some species, it is possible to reduce the bycatch by utilizing what was previously discarded. If this is done within a sensible, precautionary management scheme, there should be no problem of sustainability. Additional benefits of the retention of species formerly discarded are: (i) reduction in fishing effort, if the vessel occupies well space with other species; and (ii) diversification of the harvest, which may have some positive ecosystem implications. The t-RFMOs have recommended the prohibition of finning sharks, but that leaves the option of retaining the full individual if it is dead. Given the increases in value of shark meat, the practice of full retention of sharks is spreading. In the EPO, the proportion of individuals retained and becoming part of the catch has increased considerably for several species (e.g. silky sharks have gone from 20 percent retained in 1993 to 73 percent retained in 2009). However, the declining trends in several shark populations are showing that their utilization is not sustainable, and live release may be the appropriate action for those populations until they have recovered. For shark species that are not showing declines, a sustainable harvest would be a way to reduce their bycatch.

The normal process of a set results in the sharks being set aside for hours. In most RFMOs, there are bycatch resolutions that mandate the “prompt” live release of non-target species. However, in a fishing vessel, “prompt” means after the basic duties of the crew have been completed (e.g. the catch has been loaded and stored, gear restacked, etc.). By the time the catch has been processed, the sharks, and other species, may be dead. In order to increase shark survival, the release must happen as soon as the crew becomes aware of the capture. The resolutions should specify the desired actions, and research should inform on the best procedures to release the sharks without risks to the crew or the shark.

CONCLUSIONS

Assessing the impacts of the diverse fisheries on sharks is difficult because of the lack of solid population abundances, and the imperfect records of catch and bycatch (absent, imprecise and frequently aggregated over species).

For some species, there are enough data to make at least preliminary assessments (Manning *et al.*, 2009), and to determine priorities for management on the basis of ecological risk assessments that have been performed in most RFMOs. The first stage in some cases is performing the most complete productivity–susceptibility analysis possible, or basing priorities directly on the demographic characteristics of the population, or on the reproductive value of the individuals (e.g. Heppell, Caswell and Crowder, 2000; Gallucci, Taylor and Erzini, 2006; Kirby and Molony, 2006; Aires-da-Silva and Gallucci, 2007; Gedamke *et al.*, 2007; Wallace *et al.*, 2008; Murua *et al.*, 2009; Cortés *et al.*, 2010). In most cases, it is necessary to implement a research and data collection programme to provide solid estimates of bycatch and to aid in the search for effective mitigation actions (Clarke, 2010). The most significant gap is the assessment of total impacts by industrial longline (OFP, 2010a), and by artisanal longline and gillnet fisheries.

The information available on the trends of the main shark populations comes from studies of CPUE series, from longline or purse seine data, with different levels of standardization of the effort units. Almost all of these trends for the silky and the oceanic whitetip sharks show important declines in the past decade (IATTC, 2009; Camhi *et al.*, 2009a, 2009b; Walsh *et al.*, 2009; SPC - OFP, 2009). An additional issue to consider, when judging the impacts of different fisheries, is the possibility of sexual and size segregation in some of these populations, as described for the mako sharks (*Isurus oxyrinchus*) (Mucientes *et al.*, 2009).

The issue of finning has dominated shark management in recent years (McCoy, 2006; Dulvy *et al.*, 2008), and it has drawn attention away from the more basic issue that there is no effective management for a large number of shark fisheries. In some cases, the information is not available; in others, the jurisdiction is not clear. The same shark population may be affected by industrial vessels with high technology and 7m pangas with short longlines or gillnets. International management is needed in most cases, but the heterogeneity of many of these fisheries creates a challenge for existing RFMOs and other subregional organizations.

At this stage of knowledge, it seems clear that there is no need of formal stock assessments to conclude that urgent actions are needed to conserve several shark populations. The combination of impacts from the different fisheries adds up to non-sustainable situations, and steep declines in most ocean areas. Rather than allocating time and resources to refining the databases available, efforts should be targeted towards solutions involving much more effective and immediate management actions, including the reduction of bycatch through research and management, when that could contribute to slowing down and eventually reversing the declines. The data collection efforts should be mounted with a view to improving future actions, but they should not replace the immediate actions required. Although the impact of the purse seine fleet is only a fraction of the impacts of other fisheries, it can still contribute towards the solution, and there is a motivation among some RFMOs and some sectors of the industry to do so (Restrepo and Dagorn, 2010).

RAYS

Manta and devil rays of the genera *Manta* (*M. birrostris*, and possibly *M. alfredi*) and *Mobula* (*M. munkiana*, *M. japonica*, *M. taracapana*, *M. thurstoni*, *M. mobular*, and possibly *M. eregoodootenkee* and *M. kuhlii*) are also taken in purse seine sets (Delgado de Molina *et al.*, 2005c; Romanov, 2010; Amandè *et al.*, 2008a, 2010b). The last two species listed are smaller devil rays, and they may be confused with smaller sizes of the others; in any case, there are no confirmed captures of some of these species. However, there are many aggregated figures over species, and there are difficulties identifying to the species level without the individuals at close range. Some authors (Amandè *et al.*, 2008a) use a different nomenclature. Here, the nomenclature of McEachran and Notarbartolo di Sciara (1995) is followed, so *Mobula coilloti* is called *M. tarapacana*, and *M. rancurelli* is *M. japanica*. The identification of the genera *Manta* and *Mobula* is relatively simple, but the discrimination to species level may not be possible unless the observer has direct access to the specimens.

Manta and devil rays seldom associate with floating objects, but they are sometimes captured in school and dolphin sets. There are some species of the genus *Manta* (*M. birrostris* and *M. alfredi*) and several of the genus *Mobula* that have been mentioned from the bycatch of purse seiners. Some data on disc widths at which they reach sexual maturity is available, which may help assess the impact of the captures. The values in Table 45 are rounded, and are midpoints of intervals when that information was available.

TABLE 45

Disc width of rays at sexual maturity

Species	Disc width at sexual maturity		Maximum disc width	
	Males	Females	Males	Females
		(m)		
***Manta birostris*[1]**	3.6	4	4.9	4.1
***Mobula japanica*[1]**	2	< 1	2.4	2.8
***M. japanica*[2]**	2.1	≈ 2.1	2.4	2.3
***Mobula tarapacana*[1]**	2.5	3.0	3.7	–
***Mobula thurstoni*[1]**	1.5	–	1.8	1.7
***M. thurstoni*[2]**	–	–	1.8	1.8
***M. munkiana*[2]**	–	–	0.9	1.1
***Manta alfredi*[3]**	> 3	≈ 4	–	–
***M. alfredi*[4]**	3.4	2.7	3.0	3.6

[1] White *et al.* (2006).
[2] Notarbartolo di Sciara (1988).
[3] Marshall and Bennett (2010).
[4] Deakos (2010).

The gestation period is close to a year, and they produce one or two young (Notarbartolo di Sciara, 1988; Notarbartolo di Sciara and Hillyer, 1989; Marshall and Bennett, 2010), which offers a sharp contrast with the 2–3 month gestation period for the pelagic stingray.

Eastern Pacific

The species encountered in the region include:

- giant manta (*Manta birostris*) and possibly Alfred's manta (*M. alfredi*);
- Munk's devil ray (*Mobula munkiana*);
- spinetail mobula (*M. japanica*);
- Chilean devil ray (*M. tarapacana*);
- smoothtail mobula (*M. thurstoni*).

Several species seem to coexist in some habitats (e.g. Gulf of California [Notarbartolo di Sciara, 1988]), and the understanding of their niche

FIGURE 118

Catch and bycatch of manta rays by set type in the Eastern Pacific Ocean, 1998–2009

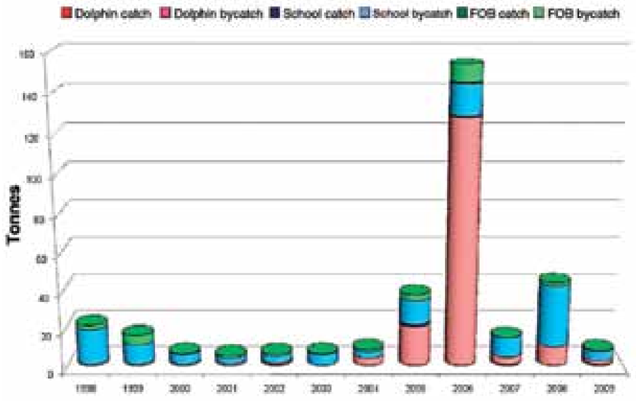
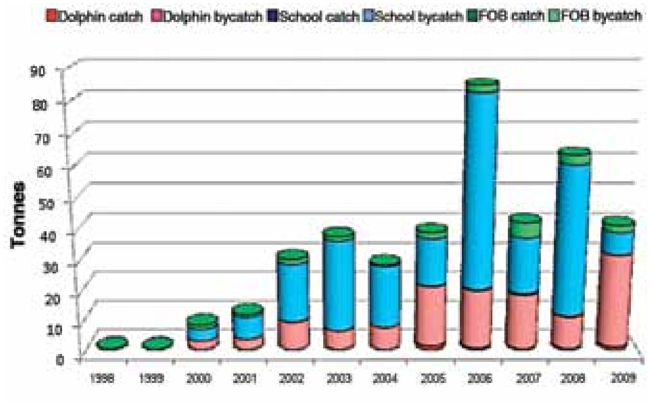


FIGURE 119

Catch and bycatch of devil rays by set type in the Eastern Pacific Ocean, 1998–2009



separation is incomplete. These species have been captured in sets but infrequently. The discrimination in species is tentative, given the difficulties of identification at a distance; thus, the total captures are pooled. They are seldom associated with floating objects, but they rank second in abundance in school sets (Tables 15–30). Figures 118 and 119 show the captures and bycatch, and Figures 120–124 show the spatial distribution of the species from observer records. Figure 125 shows a detail of the concentration of encounters in the Costa Rica Dome (Kessler, 2006). These identifications need further confirmation, but they all point to a strong association of the group with oceanographic features that generate high productivity, in the areas that mostly coincide with those discussed for the hammerhead sharks: Baja California (Montes Dominguez and Gonzalez-Isais, 2007), the Costa Rica Dome, the northern end of the Gulf of Tehuantepec, West of Galapagos, the estuary of the River Guayas, and off central and northern Peru.

Western Pacific

The most abundant bycatch in a purse seine fishery off New Zealand is *M. japanica* (Paulin *et al.*, 1982), and it is by far the most abundant around Indonesia (White *et al.*, 2006). Some pooled capture figures for the WPO area are presented in Table 46.

TABLE 46

Capture production in tonnes of mantas and devil rays in the Western Pacific Ocean, 2000–07

	2000	2001	2002	2003	2004	2005	2006	2007
Species				(tonnes)				
Mantas, devil rays NEI	931	106	110	100	802	635	2 791	3 310

Note: NEI = not elsewhere included.
Source: OFP (2009).

Atlantic

Mobula mobular is the predominant one in school sets in the Atlantic, and *Manta birostris* in FAD sets (Amandè *et al.*, 2010b). In the total bycatch, the order is *M. tarapacana*, *Manta birostris*, *Mobula mobular* and *M. japanica*.

Indian Ocean

Pianet *et al.*, (2009) show that *Manta birostris* and *Mobula* spp. are even in FAD sets, and there is a small edge for *Mobula* spp. in school sets. *Mobula mobular* is the largest biomass captured in school sets (Delgado de Molina *et al.*, 2005a; Sarralde, Delgado de Molina and Ariz, 2006), and the largest ray biomass, followed by *Manta birostris*. The latter is the only one caught under FADs, and not frequently. Amandè *et al.* (2008a) list *Manta birostris* as the larger capture among the large rays, followed by *M. mobular*, *M. tarapacana* (*M. coilloti*), and *M. japanica* (*M. rancurelli*).

Some artisanal fisheries harvest these rays (Alava *et al.*, 2002; Notarbartolo di Sciara, 1988; White *et al.*, 2006), while in other regions there is no utilization.

ACTIONS AND CONCEPTS TO REDUCE MANTA AND DEVIL RAY BYCATCH

Some manta rays appear to spend long periods associated with an area or feature (Dewar *et al.*, 2008), while others are seasonal migrants (Homma *et al.*, 1997; Luiz *et al.*, 2009). Therefore, the possibility of spatial management is an option, if areas can be identified and are persistent in time.

Releasing animals of this size is a complex process. In some cases, the individuals are lifted to the deck and released from there. In others, they are released from the net using improvised instruments to grab the individuals. The hook from the single pulley is used to lift them from the gill opening (Figure 126), or a hole is cut in the pectoral fin to pass a cable through it (Figure 127). Some of these captures and some of the release methods used may result in injuries whose significance is not known (Plate 9). However, it is known that manta rays survive major injuries caused by shark bites. A proposed alternative is described in Plate 10 and Figures 128–130.

Tagging of released individuals would provide the needed information on their survival, and the design of adequate instruments and best practices for their release could improve their survival.

FIGURE 120
Captures of giant manta rays in dolphin and school sets in the Eastern Pacific Ocean

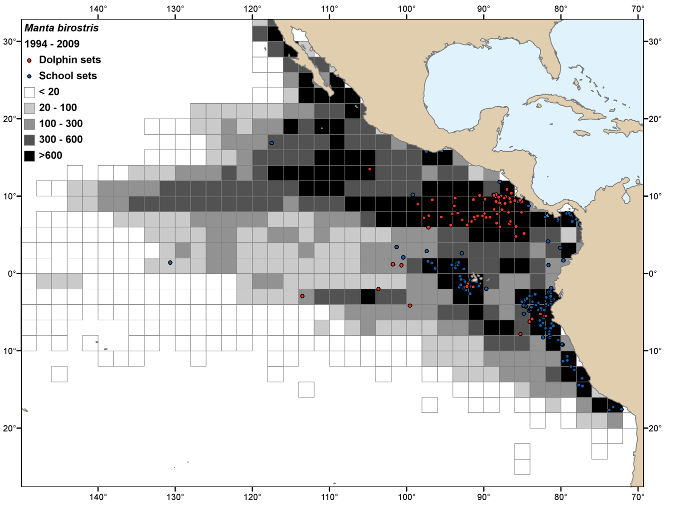
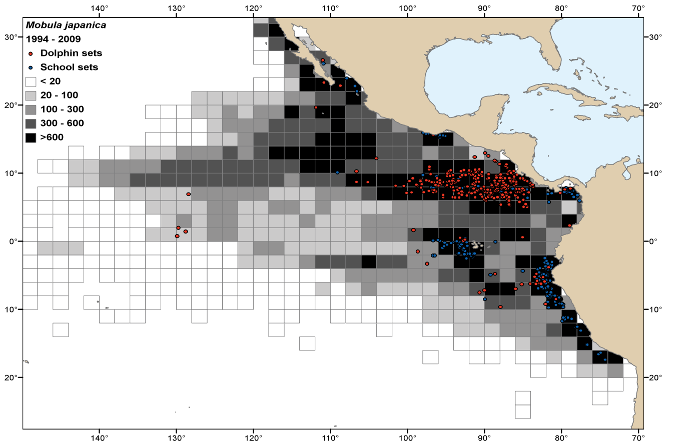


FIGURE 121
Captures of spinetail mobula in dolphin and school sets



THE PELAGIC STINGRAY (*PTEROPLATYTRYGON VIOLACEA*)

The pelagic stingray seems to be the only stingray caught in the purse seine fisheries (Amandè *et al.*, 2008a). It is present in all oceans of the world (Wilson and Beckett, 1970; Mollet, 2002; Akhilesh *et al.*, 2008; Neer, 2008; Ribeiro-Prado and Amorim, 2008). It reaches sexual maturity at 40–50 cm, at an age of 2–3 years, and it lives 7–10 years (Mollet, Ezcurra and O'Sullivan, 2002; Snelson, Burgess and Roman, 2008). It has a short gestation period of 2–3 months, after which it delivers 2–10 pups, with 6 being the most common value. Another study found maturity sizes of 34 cm for males and 45 cm for females off Brazil (Veras *et al.*, 2009).

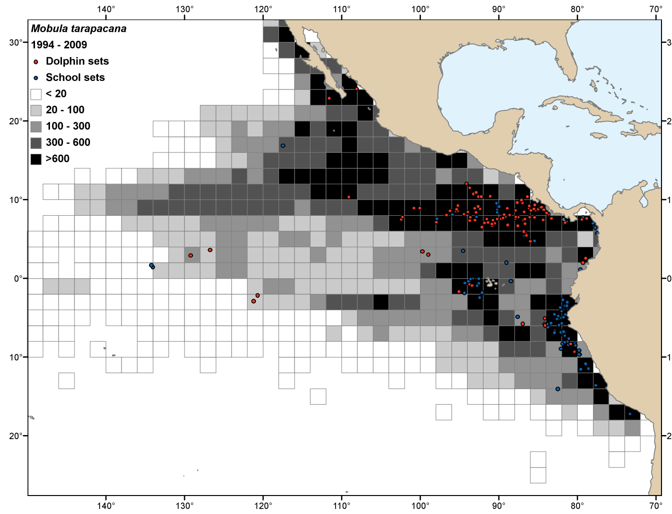
It is believed to undertake seasonal migrations, reproducing in warmer waters in winter, and returning to higher latitudes after giving birth, but the pattern observed for the Pacific is not evident in the Mediterranean population (Mollet, 2002), and Veras *et al.* (2009) did not find any seasonality in their study of the reproductive cycle of this species off Brazil.

Eastern Pacific

The spatial distribution is shown in Figure 131. It is concentrated in high-productivity areas, and it appears more commonly is school sets (71 percent) than in dolphin sets (18 percent) or floating object sets (11 percent). Bycatch is 4 tonnes/year, with 100 percent discards (Tables 15–30). Given the wide distribution and the frequency of encounters in different fisheries, it is unlikely that these impacts are significant.

FIGURE 122

Captures of Chilean devil ray in dolphin and school sets



Western Pacific

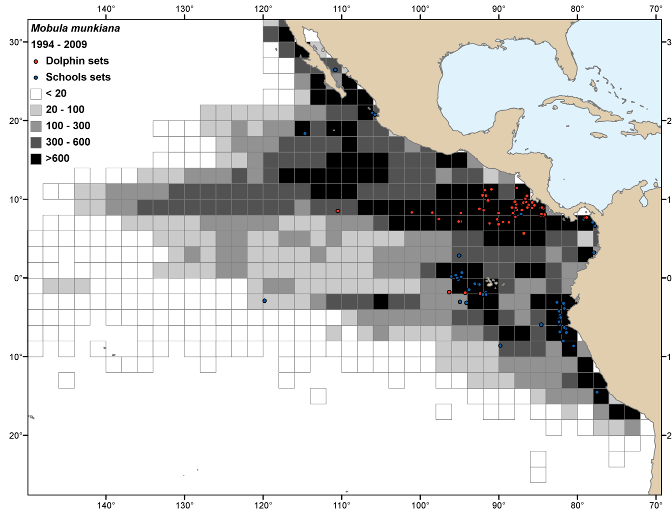
The pelagic stingray is present in less than 1 percent of sets of purse seines (Lawson, 1997; Molony, 2008), but common in shallow longline fisheries (up to 6 percent of captures in some fisheries). Molony (2005a) estimates total captures at more than 100 000 individuals as an average for the period 1990–2004, with more than 6 000 mortalities. The statement probably indicates that 6 000 were encountered dead, and the rest were released alive, without follow-up to confirm survival.

Indian Ocean

It is the most numerous among the ray bycatch in the region (Amandè *et al.*, 2008a), but the total bycatch is less than 1 tonne/year.

FIGURE 123

Captures of Munk's devil ray in dolphin and school sets



Atlantic

It is quite numerous in the captures but infrequent in school sets (< 2 percent), and almost absent in sets on floating objects (Chassot *et al.*, 2009; Amandè *et al.*, 2010b). The annual estimated bycatch is less than 1.5 tonnes (Pianet *et al.*, 2009).

CONCLUSIONS

The impacts of the purse seine captures and bycatch on the population dynamics of the pelagic stingrays are probably negligible. With regard to manta and devil rays, the numbers cannot be placed in perspective because of the lack of population abundances and stock structure information. Although the overall

FIGURE 124
Captures of smoothtail mobula in dolphin and school sets

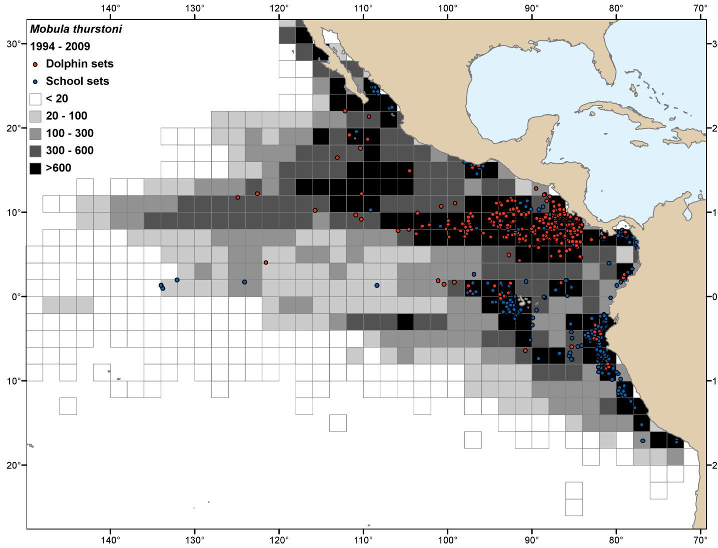


FIGURE 125
Captures of mobulid rays – Costa Rica Dome detail

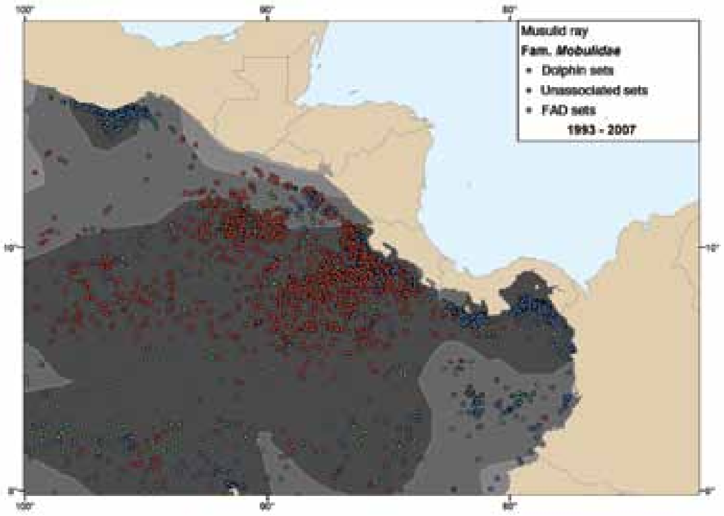


FIGURE 126
Technique used to release manta and devil rays by inserting a hook from a single pulley into gills

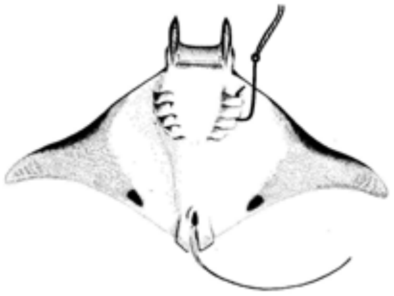


FIGURE 127
Technique used to release manta and devil rays by punching a small orifice in the pectoral fin, and passing a cable through it

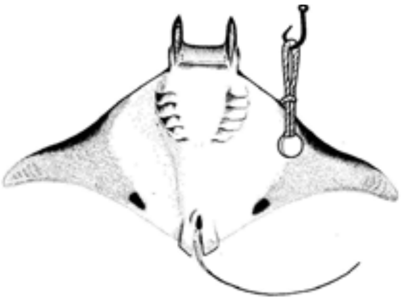


PLATE 9

Techniques used to release manta and devil rays. Difficult handling because of the size and weight of the rays may result in injuries or mortality.

PLATE 10

Proposed technique to release manta and devil rays. The use of a cargo net: it is readily available; it is easy to handle; it allows for a quick manoeuvre and release; and it is less likely to injure the ray.

FIGURE 131
When a manta ray is observed in the brailer, it is placed over a cargo net on the hopper, or directly over the cargo net on the deck

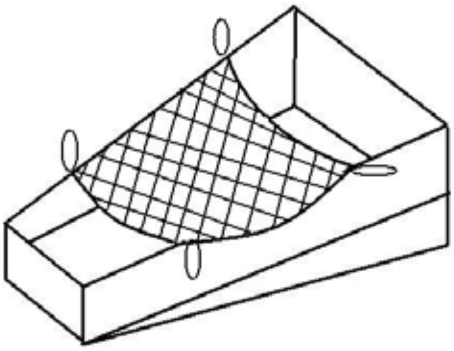


FIGURE 132
The brailer deposits the catch and the manta ray on the cargo net. Tunas are separated

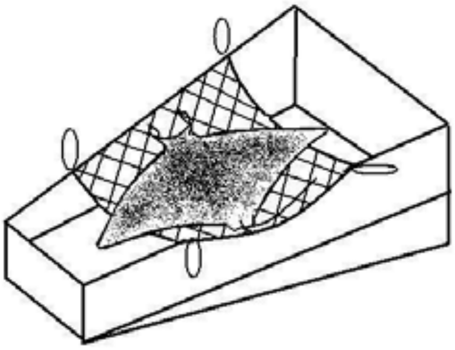
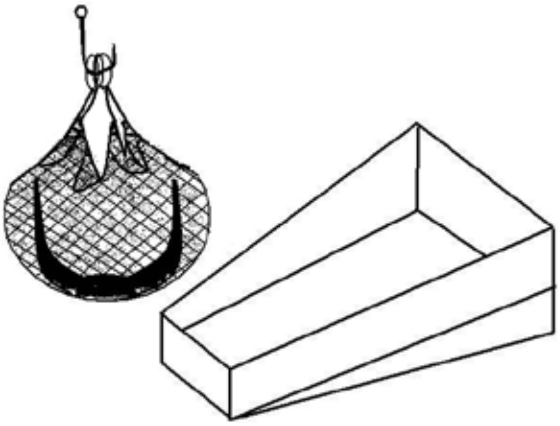
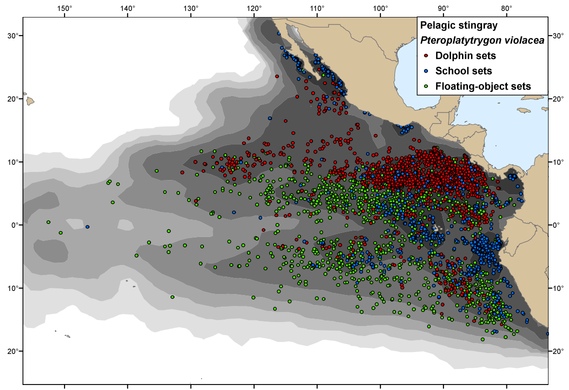


FIGURE 133
The brailer lifts and releases the manta ray



numbers are not large, care must be exercised when the effort concentrates in patches where it may cause localized impacts on subpopulations whose genetic structure is not well known. The development of better techniques to release these species is an important step for eliminating this bycatch.

FIGURE 131
Captures of the pelagic stingray by set type

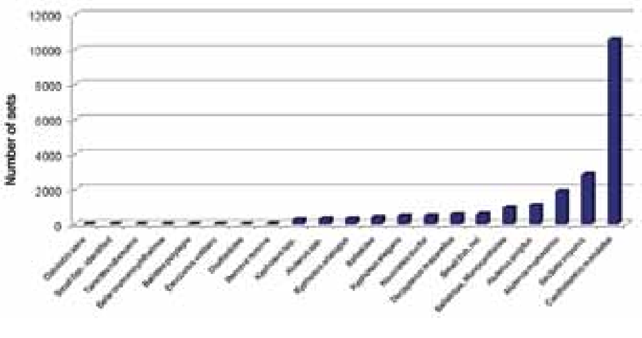


13. Large pelagic bony fishes (other than tunas)

Many fish species other than tunas are captured under floating objects. Figure 132 shows the distribution of the small species of bony fishes in recent years in the EPO to give an idea of the components. Some of them are very common in many oceans (e.g. the ocean triggerfish [*Canthidermis macculata*], the mackerel scad [*Decapterus macarellus*], *Kyphosus* spp., *Aluterus* spp., *Naucrates* spp., and others are reported as pooled taxa where the identification was not available such as “Triggerfish”, Balistidae, etc.), and they may occur in important amounts (Bailey, Williams and Itano, 1996; Stretta *et al.*, 1997). Problems of estimation, identification, escape through the meshes in unknown condition, retention enmeshed in the net or inconsistent treatment by observers and researchers make the data on this group of the smaller species very uncertain, and hard to compare among regions and observer programmes. Therefore, the focus is on the main four species that seem to be recorded more systematically. Only when the smaller species are retained because there is a market do the data become more reliable, but there is not a significant retention in most oceans yet.

In the WPO, the triggerfishes and the mackerel scad are frequent in the sets (OFP, 2010a). In the Atlantic, pooled categories for triggerfishes, barracudas and carangids have important captures (Amandè *et al.*, 2010b; Chassot *et al.*, 2009). In the Indian Ocean, triggerfishes and carangids are presented as aggregate taxa, and both have a significant presence in tonnage among the fishes (Pianet *et al.*, 2009).

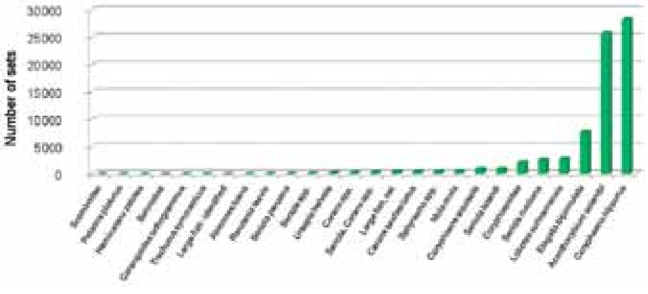
FIGURE 132
Presence of small fish species in the Eastern Pacific Ocean, 2005–09



In Figure 133, the distribution of the larger components of the bony fish group in the EPO is shown for the period 2005–09. The group selected for review here includes:

- a coryphaenid, the dolphin fish or mahi-mahi (mostly *Coryphaena hippurus*);
- a scombroid, the wahoo (*Acanthocybium solandri*);
- two carangids, the rainbow runner (*Elagatis bipinnulata*), and the yellowtail amberjack or kingfish (*Seriola* spp. [*S. rivoliana*, *S. lalandi*, *S. dumerili*).

FIGURE 133
Number of sets with presence of large bony fish species in the Eastern Pacific Ocean, 2005–09



Source: IATTC observer database.

In other oceans, the barracuda (*Sphyraena barracuda*) is more important in tonnage than in the EPO, where it is also present (Amandè *et al.*, 2008a).

After tunas, and excluding the smaller species, the largest captures in most ocean areas in numbers or weight come from this group.

The sequence of importance in numbers is:

- EPO: mahi-mahi > wahoo > yellowtail > rainbow runner (IATTC, 2010 – Stock Assessment Report No. 10);
- WPO: rainbow runner > mahi-mahi > wahoo > barracudas > yellowtail (Williams, 1999; OFP, 2010a);
- Atlantic: rainbow runner > wahoo > mahi-mahi (Amandè *et al.*, 2010b; Chassot *et al.*, 2009).
- Indian Ocean: rainbow runner > mahi-mahi > wahoo in floating object and school sets (Romanov, 2002; Delgado de Molina *et al.*, 2005a).

Comparing the EPO with all other ocean areas, there is a clear reversal of the order. However, the ecological reasons for these differences are beyond the needs of this review.

For simplicity, the common name yellowtail will be used for the Seriola group of species. For the observers, the differentiation between the rainbow runner and the Seriola group is easy from a short distance, but may not be possible from the normal observer location on the vessel, while recording other data.

Problems of storage (e.g. the brine used to preserve the tunas is not adequate to preserve these other species) and lower economic value resulted in discards of the vast majority of these species in the past, but the situation is changing for some. Figure 134 shows the proportion of the capture of the four species that was retained in the recent period in the EPO.

The utilization of mahi-mahi and wahoo has increased considerably, from less than 20 percent of the capture to almost 70 percent. This trend is observed mostly for medium and large sizes (> 30 cm FL, Figure 135). The rainbow runner does not have the same market demand, and the utilization rate has remained stable and low, at below 10 percent. The utilization of the members of the Seriola group is the most variable but

FIGURE 134

Percentage retention of the captures in the of large pelagic bony fishes in the Eastern Pacific Ocean

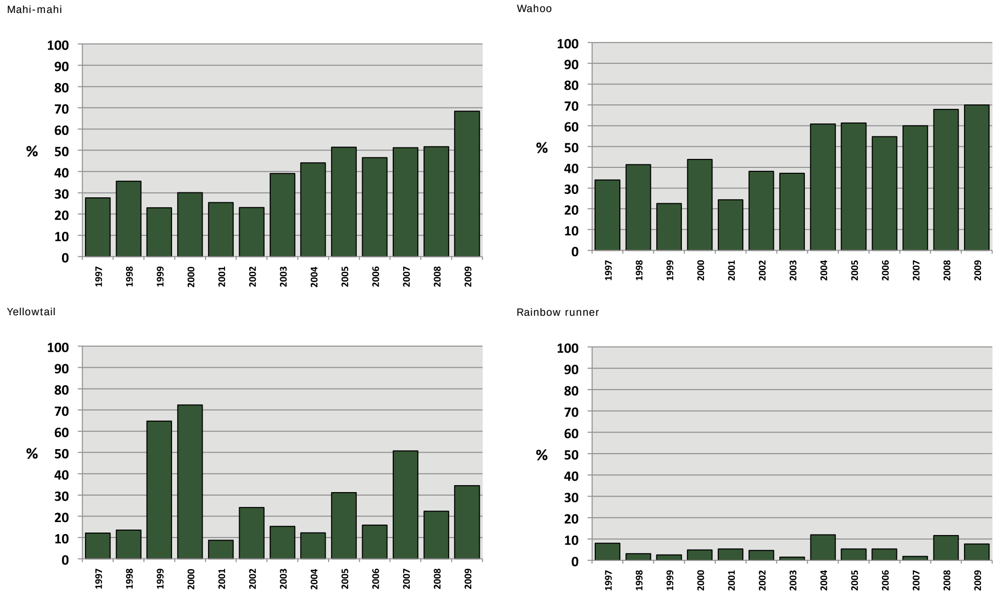
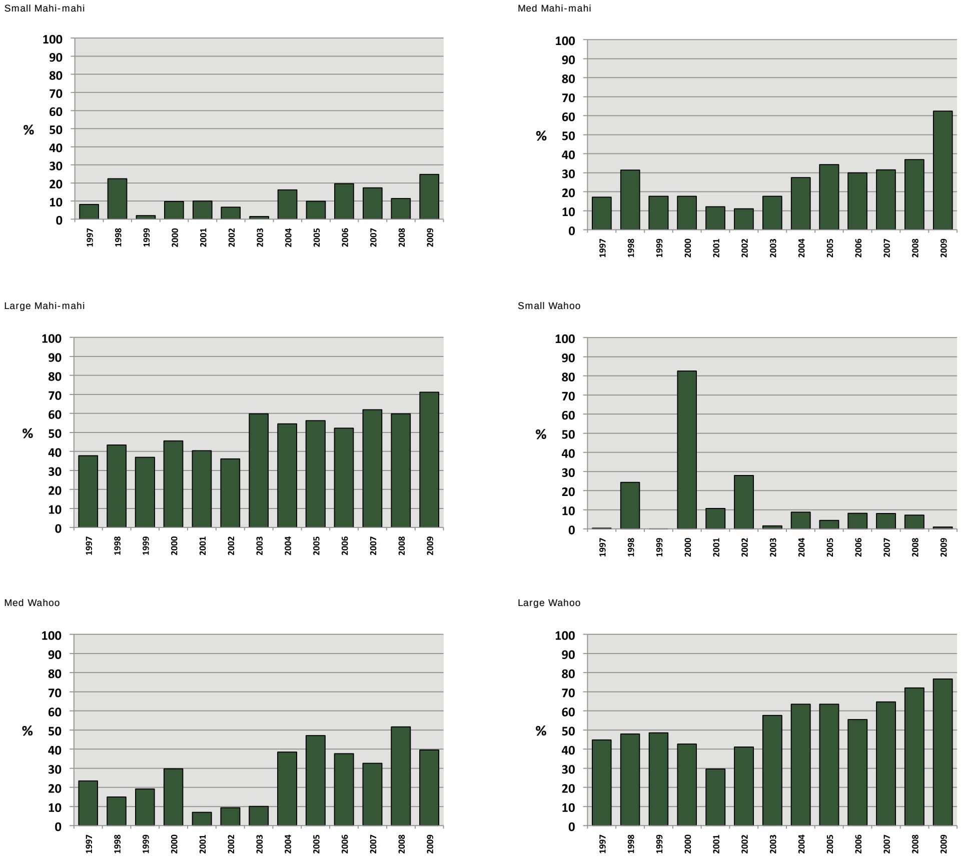


FIGURE 135

Trends in percentage retained by size categories in wahoo and mahi-mahi in the Eastern Pacific Ocean



the overall trend is a slow increase, reaching 30–50 percent in the most recent period. In the late 1990s, Coan *et al.* (1999) reported that the discards in the WPO exceeded 90 percent for the smaller species, but were only 23 percent for the mahi-mahi, and 55 percent for the yellowtail. The triggerfish discards were almost 100 percent.

In the Indian Ocean (Viera and Pianet, 2006), about 95 percent of the mahi-mahi, and 98 percent of the wahoo are utilized, while there is no utilization of the rainbow runners – 34 percent are discarded dead, with no corroborating evidence of survival of the remainder. The rainbow runner is the most abundant in FAD sets, followed by the mahi-mahi, and wahoo, and it is the overwhelming majority of the bycatch in school sets.

These are species with a wide oceanic distribution (Froese and Pauly, 2010), and their tendency to associate with floating objects provides them with a clear means to disperse to new areas, following the currents. The introduction of FADs has resulted in a large increase in the number of objects in some areas, and this may have an impact on the distributions of these species, transporting more schools across the ocean, or to new areas. However, the lack of observations in these open-ocean areas prior to the introduction of the FADs leaves researchers without the baseline information. Were these schools migrating with the currents before the introduction of the FADs, and the FADs have simply made their movements "visible" and the schools vulnerable to capture?

These populations appear to be abundant. They are encountered under most objects, and aggregate rapidly under new objects, which suggests that the densities are high. The hooking rates of mahi-mahi in coastal longline fisheries are frequently more than 100 fish per 1 000 hooks (Largacha *et al.*, 2005). There are no abundance estimates available for any of these populations, but they have high growth rates, early reproduction, and high fecundity. Their residence times under the objects may vary according to environmental conditions (e.g. currents), and predator presence (Dempster, 2005), with *S. lalandi* showing longer residence times than *C. hippurus*.

Bycatch does not seem likely to have a major impact on these populations, but it may produce negative interactions between purse seine and other fleets, especially artisanal ones.

CORYPHAENA SPP.

The mahi-mahi is the dominant non-tuna species in numbers under floating objects in some regions, and very abundant in all regions. It is sexually mature at 4–6 months and produces a large number of eggs (Taquet, 2004; Taquet *et al.*, 2007a; Schwenke and Buckel, 2008; Martínez-Rincón, Ortega-García and Vaca Rodriguez, 2009). It is also one of the fastest-growing marine fishes – estimates in fork length growth range from 4.7 mm/day in the Caribbean (Oxenford and Hunte, 1983) to 3.78 mm/day in its early months off North Carolina, the United States of America (Schwenke and Buckel, 2008), and to 3.6 mm/day off Puerto Rico (Rivera and Appledorn, 2000). A comparison of growth rates in different regions can be found in Rivera and Appledorn (2000). Its lifespan is short, with few individuals reaching 2–3 years of age (Beardsley, 1967; Massutí, Morales and Deudero, 1999; Schwenke and Buckel, 2008). Its presence in anchored FADs is strongly seasonal, and juveniles are the predominant life stage found in some studies (Dempster, 2004). They seem to range much farther away from the FAD than most other species (Dempster, 2005), but according to Taquet *et al.* (2007a) they still remain at less than 365 m from the FAD. In regions with *Sargassum* (*S. fluitans* and *S. natans*) mats, they are closely associated with them (Farrell, 2009). They are visual predators, so they feed during daylight hours, but there is some evidence of night feeding (Massuti *et al.*, 1998).

It is a migratory species (Oxenford and Hunte, 1986; Lasso and Zapata, 1999; Uchiyama and Boggs, 2006), but there is no clear international jurisdiction on the stocks, so management is lacking (Mahon and Oxenford, 1999; Farrell, 2009). It is also one of the main cases where the addition of FADs in a region may alter the spatial distribution and dispersal of a species because of the strength of the association and the large-scale and transoceanic movements of FADs (Taquet *et al.*, 2001; Girard *et al.*, 2007). An issue that is difficult to surmount is the lack of control in the "experiment" of adding thousands of drifting FADs into an area (Kingsford, 1999).

The studies on population structure show mixed results. Results for the Pacific from Rocha-Olivares *et al.* (2006) suggest genetic differences even for localities as close as Hawaii and the Mexican coast. Another study in the Caribbean–Northwestern Atlantic (Oxenford and Hunte, 1983) suggests the existence of two subpopulations in the region through the study of migration patterns. However, Pla and Pujolar (1999) found no significant differences between locations in the Mediterranean and Eastern Atlantic, while Duarte-Neto *et al.* (2008) discriminate two stocks off the Brazilian coasts. The subject of population structure is of a high priority, given the importance of these species to many artisanal fisheries, and the need to manage these resources on an adequate spatial basis.

Another species of the same genus (*C. equiselis*, the pompano dolphinfish) is also present but it appears to be rare in comparison, although it is possible that they are partially confused (Gibbs and Collette, 1959; Pujolar and Pla, 2002). A DNA study from the Mexican Pacific (Rocha-Olivares and Chávez-González, 2008) showed that

2 out of 82 identified *C. hippurus* were *C. equiselis*. These errors are more likely to affect the identification of juvenile fishes, but the figures also showed that the proportions of *C. equiselis* in the catches were very low (< 3 percent). This figure may vary spatially or temporally. The maximum size of *C. equiselis* is 75 cm, while *C. hippurus* may reach 200 cm (Collette, 2010), and that limits the overlap between the species. These species are much appreciated by consumers, and have a high value in the markets.

ACANTHOCYBIUM SOLANDRI

The wahoo is another frequent and important component of the communities associated with floating objects. It has a broad distribution in the oceans of the world (Collette and Nauen, 1983; Oxenford *et al.*, 2003), but it is quite poorly known.

The wahoo begins to reproduce at 7 months of life, and produces a large number of eggs (McBride, Richardson and Maki, 2008; Maki-Jenkins and McBride, 2009). It grows fast but is short-lived, reaching maturity during its first year, and probably living to 5–6 years of age (Hogarth, 1976; Nash, Whiting and Luckhurst, 2002; Oxenford, Murray and Luckhurst, 2003). Females are mature at about 90–100 cm in length, and most mature fish are less than 2 years of age (Brown-Peterson, Franks and Burke, 2000). Based on the data available, it appears to be one of the few vertebrates with a single globally distributed population (Garber, Tringali and Franks, 2005; Theisen *et al.*, 2008).

It is also a species well accepted by consumers, and it has an increasing utilization.

ELAGATIS BIPINNULATA

Outside of the tunas, the rainbow runner (*Elagatis bipinnulata*) is the dominant species in numbers in the WPO (Lawson, 1997) and Indian Ocean regions (Romanov, 2002), but its economic value trails the others, so the utilization level is lower. It is more important in proportion in weight or numbers in school sets than in FAD sets, but it is still the largest biomass under FADs (Delgado de Molina *et al.*, 2005a), or is a close second to the mahi-mahi (Sarralde, Delgado de Molina and Ariz, 2006). Romanov (2002) believes they are the largest biomass among the species captured incidentally in FAD sets in the Western Indian Ocean. Little research has focused on this abundant species. Moreover, there are frequent variations of the spelling, and *Elegatis* and *bipinnulatus* are more common in the literature than the spelling adopted here, following FAO and the World Register of Marine Species (www.marinespecies.org/aphia.php?p=taxdetails&id=126809). It has a broad geographical distribution, but there are few studies of the species (Walsh *et al.*, 2003). Females are sexually mature at 55 cm off Brazil (Barros-Pinheiro, 2004), and at 60–65 cm in the Pacific (Iwasaki, 1991, Iwasaki, 1995), but most other reproductive parameters have been estimated using generic models.

A recent study (Forget *et al.*, 2010) showed that the species remained associated with an object for more than two months, without ever departing for more than a day. It has also a very shallow distribution; hence, its association is quite clear.

SERIOLA SPP.

The species from the genus *Seriola* (Smith-Vaniz, 1984) is another major group of species that associates with FADs and includes, among other species:

- *S. rivoliana* (longfin yellowtail);
- *S. lalandi* (yellowtail amberjack or yellowtail kingfish);
- *S. peruana* (fortune jack);
- *S. dumerili (greater amberjack);*
- *S. quinqueradiata (Japanese amberjack).*

All these species have been found under FADs or are described as associating with floating objects (Gillanders, Ferrell and Andrew, 1997; Sakakura and Tsukamoto, 1997;

Walsh *et al.*, 2003). The taxonomy of these species and their stock and/or subspecies structure are not clear, and several subspecies have been proposed for some of them, but the proposals are still controversial. For the Pacific Ocean, some authors propose the existence of three physically similar but geographically separate populations or subspecies that do not interact: one off California, the United States of America (*S. lalandi dorsalis*), one in Asia (*S. lalandi aureovittata*), and a Southern Hemisphere group (*S. lalandi lalandi*) (Smith-Vaniz, 1984).

Genetic studies have shown differences between the Japanese and Australia–New Zealand populations (Nugroho *et al.*, 2001), but other areas have not been explored. Studies of otolith chemistry suggest some spatial structure in coastal populations from Australia (Patterson and Swearer, 2008), but the association with FADs shows a wide distribution, and probably considerable transport across regions.

There are some age and growth studies available (Mitani and Sato, 1959; Baxter, 1960; Holdsworth, 1994; Gillanders, Ferrell and Andrew, 1997, 1999a, 1999b, 2001; Manooch and Potts, 1997; Thompson, Beasley and Wilson, 1999; Stewart *et al.*, 2001), and they indicate fast growth, but also more longevity in this species than for the previous ones. Stewart, Ferrell and van der Walt (2004) report a life span of more than 20 years for *S. lalandi*, and other species in the genus are believed to live to almost 30 years.

Although *Seriola* and *Coryphaena* share the FAD habitat, some studies in anchored FADs have shown little competition for prey items (Deudero, 2001), and longer residence times for *Seriola* than for *Coryphaena*, without a clear seasonality (Dempster, 2005). In an experiment in the Mediterranean (Deudero *et al.*, 1999), both *Seriola dumerili* and *C. hippurus* were found under FADs with a high frequency, and were absent in control sets in open water, showing their affinity for the objects. Some authors believe that floating objects act as nursery structures for species such as *Seriola* and *Coryphaena* (Deudero *et al.*, 1999), and it is usually juveniles of *Seriola* that aggregate under FADs (Dempster, 2004). Payaos may play a role in the settlement and migrations of some *Seriola* species (Sinopoli *et al.*, 2007). Reef or benthic species may associate with a floating object as a similar habitat to a "substrate" and remain associated for long periods. If the object is drifting, then these species will remain associated in the absence of other habitat options as the objects drift in deep water.

Observer identification to the species level is not easy if observers cannot approach the individuals because of other duties, or operational difficulties; hence, they all are included under a single heading.

BYCATCH ESTIMATES

Eastern Pacific

The annual average capture (with bycatch in parentheses) is 1 280 tonnes (605 tonnes) of mahi-mahi, 417 tonnes (185 tonnes) of wahoo, 84 tonnes (41 tonnes) of yellowtail, and 66 tonnes (59 tonnes) of rainbow runner. However, this figure is a long-term average; in recent years, the proportion discarded is down to 30 percent of the capture for mahi-mahi and wahoo. More than 98 percent of the first three species comes from sets on floating objects. For the rainbow runner, it is close to 50 percent on school sets and 50 percent on floating object sets. Mahi-mahi and wahoo are the two more common species, outside of the tunas, in the EPO in sets on FADs (Tables 15–30 and Figures 61, 62, 132, 133 and 136–139).

Western Pacific

The estimates of catches for this group in recent years are summarized in OFP (2008b). The catches of rainbow runner have been increasing, reaching an average of 8 200 tonnes in 2003–05. The peak in 2004 was almost 11 000 tonnes. Mahi-mahi catches were an average of 750 tonnes. Wahoo catches were 260 tonnes. Trends in nominal CPUE for some of these species for mahi-mahi, wahoo and rainbow runner appear to be stable, in some cases increasing, others variable, but no indication of steady declines. However, as the fisheries have been shifting locations, it may be necessary to perform a more detailed analysis on standardized data.

Atlantic

Amandè *et al.* (2010b) report annual captures of 193 tonnes of the rainbow runner, 102 tonnes of wahoo, and 49 tonnes of mahi-mahi. Chassot *et al.* (2009) show graphically the huge difference in the captures in FAD sets over school sets for these three species; almost 98 percent of the bycatch happens in FAD sets. ICCAT (2010) reports an overall catch of wahoo of almost 2 830 tonnes (average for 2006–08), but the most recent value is the highest in more than 40 years of records, and it doubled the most recent catches.

Indian Ocean

For the Spanish fleet, Delgado de Molina *et al.* (2005a) show a clear predominance of the rainbow runner in school sets, in weights and in numbers, and a less clear predominance in sets on FADs, followed by the mahi-mahi and the wahoo. In other research in the same area on the French fleet (Viera and Pianet, 2006), the rainbow runner is the most abundant in FAD sets, followed by the mahi-mahi and the wahoo, and it is the overwhelming majority of the bycatch in school sets. Retention is high for the mahi-mahi (95 percent), wahoo and barracuda (91–95 percent), while only 2 percent of the rainbow runner is utilized. Although it is believed that 65 percent of this species were released alive at sea, there is no evidence of survival available. The length frequency distributions of mahi-mahi (range 50–108 cm), rainbow runner (range 35–105 cm) and wahoo (range 70–120 cm) are broad. Sarralde, Delgado de Molina and Ariz (2006) show that the frequency of occurrence in FAD sets is much higher for all the species for the Spanish fleet. The rainbow runner and

FIGURE 136

Mahi-mahi: total annual catch and bycatch by set type in the Eastern Pacific Ocean

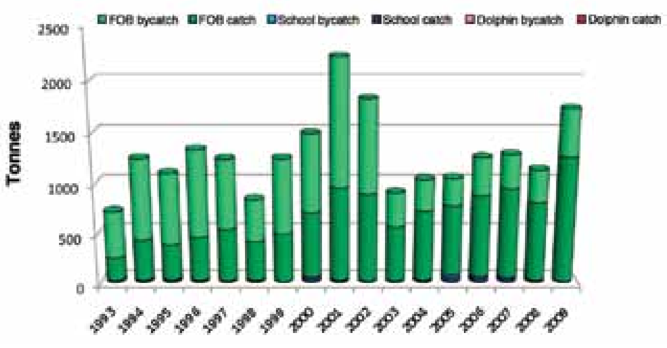


FIGURE 137

Wahoo: total annual catch and bycatch by set type in the Eastern Pacific Ocean

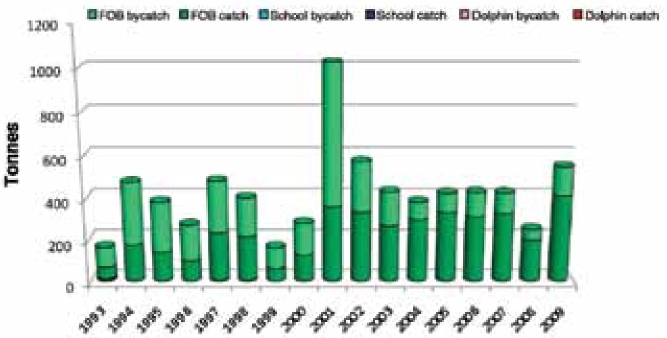


FIGURE 138

Rainbow runner: total annual catch and bycatch by set type in the Eastern Pacific Ocean

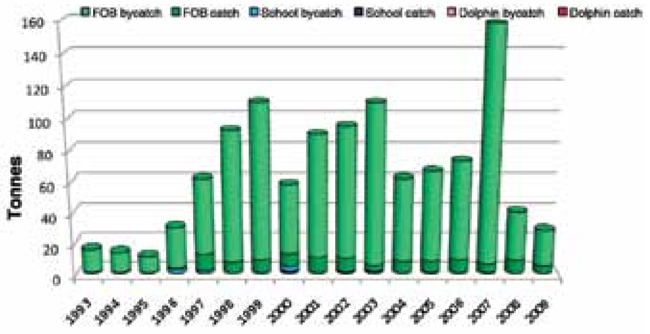
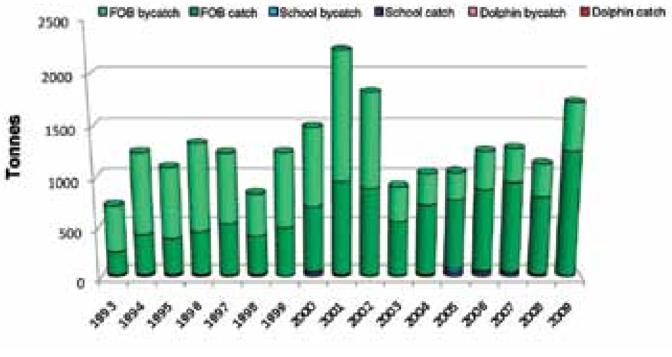


FIGURE 139

Yellowtail: total annual catch and bycatch by set type in the Eastern Pacific Ocean



the mahi-mahi are present in about 75 percent of the sets on FADs and in less than 5 percent of the sets on schools. Wahoo is in 47 percent of the sets on FADs and in 2 percent of school sets. Yellowtail and barracuda are present in 12–14 percent of the FAD sets, and only in 0–1.3 percent of sets on schools. The captures in weight of this group in school sets are dominated by the rainbow runner, with the mahi-mahi being less than one-quarter of the biomass of the rainbow runner. In sets on FADs, the mahi-mahi has a small edge over the rainbow runner, and the wahoo has less than half of these two. The barracuda is present but at a low level. Amandè *et al.* (2008a) report catches of fishes mostly in FAD sets (93 percent), and more than 80 percent of the weight was discarded dead. The species captured are: rainbow runner (1 380 tonnes), mahi-mahi (570 tonnes; including *C. equiselis* and *Coryphaena* unidentified), wahoo (141 tonnes), barracuda (20 tonnes), and yellowtail (3 tonnes).

ACTIONS AND CONCEPTS TO REDUCE BYCATCH OF LARGE PELAGIC BONY FISHES

The first question for this group of species is whether mitigation is needed. The current impacts caused by the fisheries do not seem to be sufficient to affect the population dynamics of most of these species, and the large biomasses that are assumed to be present because of the observed densities in different fisheries. However, many fisheries are having an impact on them, and the sum of the impacts is not known The capture and bycatch in the purse seine fisheries are low in all oceans. As the survival of these species to capture is not known, their utilization makes sense, with the sole condition that such harvest be included in the corresponding stock assessments and management plans. The increase in economic value of most of these species is already changing the fishery towards a full utilization of these captures.

A possible bycatch issue for these species is to reduce or avoid the waste of juveniles without a market. Allowing the escape of juveniles from the seine, through the use of sorting grids or other selectivity devices, could satisfy this objective (Tables 36–38). As these species mostly have fast growth and high natural mortality, it is unlikely that the impact of the low bycatch is meaningful, or that the escape system is a high-priority research item. Nonetheless, it could contribute to improving a fishery that may be having community impacts because of the biomass harvested or removed as bycatch.

However, the major issue here is the lack of definition on what the international framework for their management should be. It is not clear that all the t-RFMOs have jurisdiction on these resources, especially because they are targets of large multispecies fisheries by coastal artisanal fleets, which are not targeting tuna as their main objective.

Avoiding capture

As the components of this group are so frequently associated with floating objects, and the distributions are so widespread, there are no obvious hotspots of density that have been identified in the data yet. It would be very difficult to find ways to avoid capture if that were the goal.

Releasing from the net

Two options have been proposed to release these species from the net. Some tuna skippers have adopted the procedure of towing the floating object outside the net through the space opened between the ortza and the vessel when pursing is being completed. Fishes that are very closely associated with the object will tend to follow it outside the net. Other skippers are concerned with the risk of the tuna escaping, so they use a different manoeuvre to remove the floating object from the net – dragging it over the corkline, which does not allow the escape of the associated fish.

The alternative for releasing these species is the development of a sorting grid (as described for small tunas). The initial experiments, although limited in scope, showed important escapes for some species (Tables 36–38).

Utilization

Except for the rainbow runner, which is not accepted in some regions and has a low level of utilization, the others have significant and growing markets, and high values; thus, the catches are a welcome component of the fishery. Once the storage issues have been resolved by adapting some wells to receive these species without the brine, the proportion utilized is increasing in most oceans where the information is available. The utilization of more components of the capture does not cause additional fishing mortality as probably those individuals would have been discarded dead anyway, and it may reduce the total amount of effort exerted on all stocks. At the same time, it leads to a more diversified harvest that may be a way to maintain ecosystem structure and resilience (Hall, 1996; Kolding *et al.*, 2010).

Research in these cases should aim at providing a solid basis for the assessment of the condition of the stocks, after determining their geographical boundaries, genetic structure, etc. With these elements, the stocks should be managed, adding these harvests to the directed fisheries that target some of them, and the others that capture them incidentally.

14. Sea turtles

Sea turtles have been the subject of attention by international organizations for several years because of their vulnerability and the critical situation of some populations (FAO, 2005, 2009; Gilman, Moth-Poulsen and Bianchi, 2007). Conservation actions at sea and ashore have resulted in some recoveries, while other populations remain at low levels (Balazs and Chaloupka, 2004; Seminoff and Shankar, 2008). The background documents to the Third Joint Meeting of the Tuna Regional Fisheries Management Organizations, Brisbane, 2010 (IOTC, 2010) discuss the status of sea turtle populations of special interest.

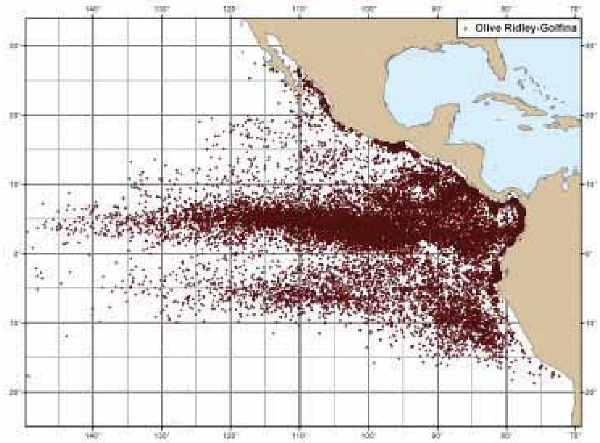
Sea turtles are captured in most types of fishing gear (Lewison, Crowder and Shaver, 2003; Lewison *et al.*, 2004; Lewison, Freeman and Crowder, 2004), and the level of mortality of many of the fisheries where interactions occur is unknown. The long migrations, sometimes transoceanic, of many species bring them into contact with the open ocean tuna fisheries (Luschi, Hays and Papi, 2003; Plotkin, 2003, 2007; Benson *et al.*, 2007; Morreale *et al.*, 2007; Lambardi *et al.*, 2008; Seminoff *et al.*, 2008; Shillinger *et al.*, 2008). In other cases, the purse seining operations may take place near the coast, especially on narrow shelves or near islands, and in some of these coastal habitats, there are high densities of turtles either because they are aggregating in front of nesting beaches or feeding in their internesting habitats. The results are encounters with purse seiners or with FADs (Castroviejo *et al.*, 1994; Anderson *et al.*, 2003; Chanrachkij and Loog-on, 2003). Fishing operations offshore are known to affect the juveniles of some species that forage in open pelagic habitats (Amandè *et al.*, 2008a; Anderson *et al.*, 2009).

When sea turtles are encircled in a purse seine, they may be released by hand, or they may become entangled in the net meshes, usually by their claws. If they are entangled in the net, it is easy to free them when the net is being pulled up from the water towards the power block by a crew member in a speedboat stationed at the right location. If they are not released, and they go up, they may fall on the railings or deck of the vessel, injuring themselves or crew members. The captures can be completely random, as happens in some dolphin or school sets. As turtles are not capable of staying with a fast-moving group of tunas and dolphins, so their capture is a chance event, being at the wrong place at the wrong time. This randomness is tempered in some cases by the fact that the turtles and the tunas may have been attracted to the same location because of a highly productive system, or other favourable environmental conditions that are attractive to both turtles and tunas (Polovina *et al.*, 2001; Saba *et al.*, 2008).

Some species of sea turtles, such as the olive ridley, are attracted to floating objects, perhaps searching for food or shelter, and are captured in sets on FADs or logs. As the FADs usually have webbing hanging below them, the turtle may become entangled in the FAD, and if it is not released it may die.

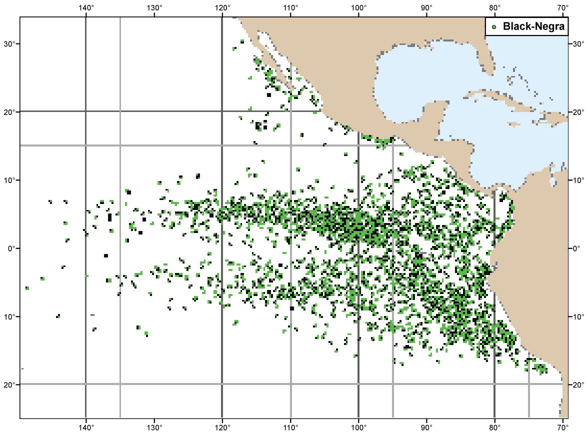
However, turtle captures in purse seines are quite uncommon in most oceans, and the frequency of encounters is usually less than 1 percent of the sets, with captures numbering generally one individual. With low observer coverage, as is the case in most oceans, and those infrequent encounters, it is difficult to produce solid estimates of sea turtle mortality. The numbers captured are usually low, and in the vast majority of the sets, it is possible to release the turtles alive. In the past, there was some retention of sea turtles for consumption or sale, but the practice is an infraction for some t-RFMOs, and it is discouraged in all oceans.

FIGURE 140
Sets with presence of olive ridley turtles in the Eastern Pacific Ocean, 1993–2008



Source: IATTC observer database.

FIGURE 141
Sets with presence of black/green sea turtles in the Eastern Pacific Ocean, 1993–2008



Source: IATTC observer database.

EASTERN PACIFIC

The most common species captured by far is the olive ridley (Figure 140, Tables 15–22), as a result of a combination of being the most abundant species in the region and also having a clear attraction to floating objects. They frequently become entangled in the float lines of longline gear, while approaching the floats to interact with them, another example of their affinity for floating objects (Largacha *et al.*, 2005). These populations are the largest, and are also experiencing significant increases (Eguchi *et al.*, 2007). Of the sea turtle bycatch identified to species, 86 percent were olive ridleys (Tables 15–18).

The next species in order of abundance is the green or black turtle (*Chelonia mydas agassizii*), with 11 percent of the bycatch. This species nests in the Galapagos Islands, Ecuador, and in several continental locations. Given the distribution of the FAD fishing effort shown above (Figure 25), the Galapagos nesting beaches are close to the heaviest concentration of FAD fishing in the EPO. There is also school and dolphin fishing in areas nears the Gulf of Tehuantepec, both sides of the Baja California Peninsula, off Costa Rica, and off the coast of Colombia, all areas with high-density sea turtle concentrations (Figure 141).

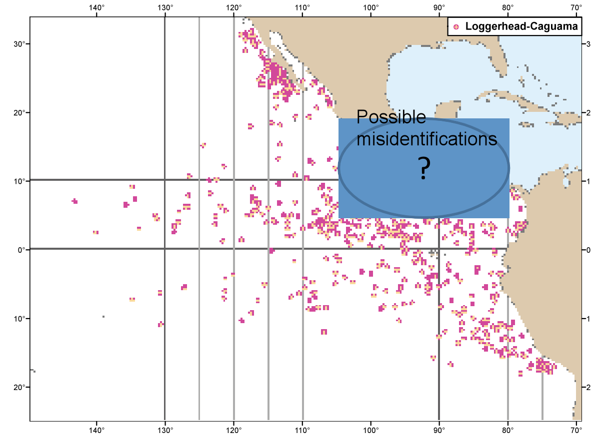
Loggerhead turtles (*Caretta caretta*; Figure 142) and hawksbill turtles (*Eretmochelys imbricata*; Figure 143) follow with about 1–2.5 percent each (Tables 15–18; IATTC, 2004a, 2004b). Juvenile loggerheads spend years in the American continent in Baja California or the Peruvian coast (Boyle *et al.*, 2009), and in some cases they spend a good part of their time in coastal lagoons or habitats where purse seine fishing does not take place, but other fisheries are active there (Peckham *et al.*, 2007). The habitat of the hawksbill turtles is mainly coastal reefs, but they are routinely observed far from the coast, associated with floating objects or not. This is one case where the association of individuals with floating objects may carry them away from their usual habitat, but there is no baseline to compare the current distribution. The hawksbill sea turtle is rare in the Eastern Pacific coasts, and in part, the scarcity of bottom habitats suitable for this species (e.g. coral reefs) may explain this. It is not believed to be a long-distance migrant as loggerheads and leatherbacks are, and it is "less pelagic" than the other species, with affinity for benthic habitats and diets. However, they have been encountered much farther offshore than expected

(Figure 143). This species is usually easy to identify at short distance, and it is well known by the fishers.

Leatherback turtles (*Dermochelys coriacea*) are practically absent from the captures in the EPO (Figure 144). The capture rate of leatherback turtles in the EPO is 0.06 turtles/year, or 1 turtle every 16 years. They are not found in any type of set, but this may be a consequence of the low population levels, as they are caught in sets in other regions. With a diet of gelatinous zooplankton (Houghton *et al.*, 2006), leatherback turtles, may find their food in areas that are not adequate for FAD operations, or for tunas (e.g. current speeds, water temperatures). It is possible than in the EPO the suitable habitat for foraging leatherbacks does not coincide with major purse seine operations (Shillinger *et al.*, 2008), although in their migration route they need to cross the fishing grounds. Pacific leatherback turtles are in a precarious situation (Martínez *et al.*, 2007), so the focus of attention should not be on the numbers of turtles taken, but on the species and sizes taken. However, the impacts in the problematic species in the EPO are extremely low, and the solutions are simple.

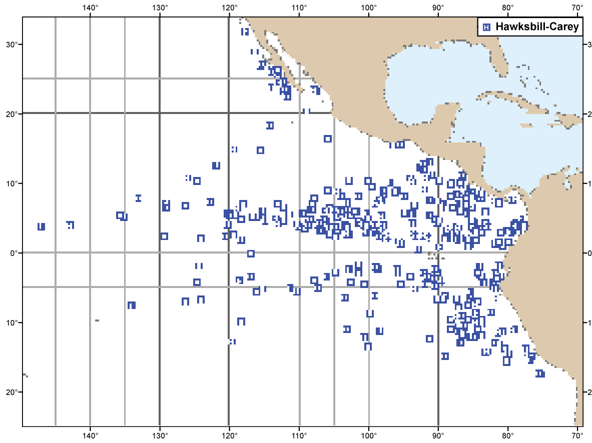
For the EPO, the figures of turtles captured and the mortalities are shown in Figure 145 and Tables 19–22. The mortality levels have been declining since mitigation actions were started through communication with fishers in workshops on bycatch issues – from a peak of 170 individuals in 1998 and 1999, to almost to 20 in 2008, with an average of 79 turtles/year (Figure 145). Sixty-three percent of the captures happened in sets on floating objects, 25 percent in school sets, and the remaining 12 percent in dolphin sets. These last two figures show that the capture is truly incidental (as indicated above); they are not associated with the tunas.

FIGURE 142
Sets with presence of loggerhead turtle in the Eastern Pacific Ocean, 1993–2008



Source: IATTC observer database.

FIGURE 143
Sets with presence of hawksbill sea turtles in the Eastern Pacific Ocean, 1993–2008



Source: IATTC observer database.

WESTERN PACIFIC

The olive ridley turtle is also the most frequent in the captures followed by the hawksbill turtle and the green/black turtle (OFP, 2001). The ratio of these three is 7:4:1, very different from other oceans. The frequency of encounter is shown in Table 47 below, which compares three studies over the years for the Western and Central Pacific Ocean.

TABLE 47

Point estimates for the frequency of turtle encounters in the Western and Central Pacific Ocean

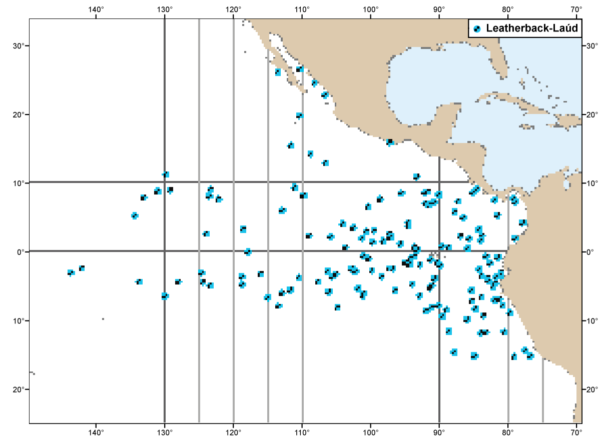
Frequency percentage of sets		1995–2000	1995–2007
School		0.6%	0.1%
Log		0.8%	0.8%
FAD		0.3%	0.1%
Payao		0.6%	0.8%
Animal association		1.1%	1.6%
Nominal CPUE (turtles/100 sets)	**1993–1994**	**1995–2000**	**1995–2007**
School	1.34	0.11	0.61
Log	1.92	0.81	0.78
FAD		0.07	0.28
Payao		0.62	0.78
Animal association		1.11	1.61

Sources: Bailey, Williams and Itano (1996) and OFP (2001) for 1995–2000; Williams, Kirby and Beverly (2009) for 1995–2007.

The confidence intervals are available in the original publications (see Table 47), and are very wide. The point estimates show a few changes that in some cases may reflect the expansion of the fishery to the east (e.g. lower frequency in school sets in open ocean waters, farther away from islands). The proportion of sets on payaos has increased considerably, but this may reflect changes in sampling distribution rather than effort relocation. The ratio of sets on FADs to sets on logs went from 1.41 to 1.13, which is the opposite of the change that has been observed in the frequency of those set types, so the changes probably reflect changes in distribution of observer samples. Comparing the set type distributions, the most recent period shows fewer school sets and more sets on payaos (Figure 56).

FIGURE 144

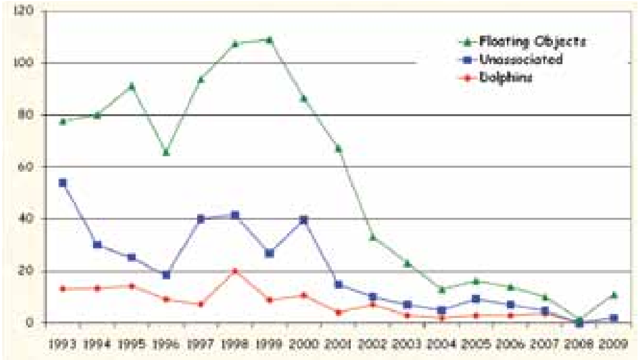
Sets with presence of leatherback sea turtles in the Eastern Pacific Ocean, 1993–2008



Source: IATTC observer database.

FIGURE 145

Incidental mortality of sea turtles in the Eastern Pacific Ocean, 1993–2008



Source: IATTC observer database.

The set type with the highest frequency of occurrence of sea turtles is the animal-associated sets (live whales and whale sharks) but these sets are a small proportion of the total (Williams, Kirby and Beverly, 2009). An estimate of mortality of 500–600 turtles/year for the longline fisheries (OFP, 2001) compared with data showing fewer than 1 encounter per 100 sets for most types of purse seine sets, and estimates of 105 encounters/year. As these encounters in the vast majority result in a live capture (83 percent healthy individuals released in the WPO [OFP, 2001]), then the total estimated mortality from this source is probably fewer than 20 individuals/

year. Molony (2005a) estimated a mortality of fewer than 20 sea turtles per year for the purse seine fleet, given 200 captures, and 90 percent of those released alive, with a frequency occurrence in the study of 0.36 percent.

ATLANTIC

In a report from the mid-1990s, Stretta *et al.* (1997) found that the captures were split 52 percent in school sets and 48 percent in floating objects. They also report that in the Indian Ocean the hawksbill turtle was the most abundant (46 percent of the captures, versus only 9 percent for the Atlantic), while in the Atlantic more leatherbacks were captured (29 percent versus none in the Indian Ocean). More recently, for the Atlantic, Sarralde, Delgado de Molina and Ariz (2006) report frequencies of the different species for the period 2001–06, as shown in Table 48.

TABLE 48

Turtle capture frequency in the Atlantic, 2001–06

	School sets	Floating object sets
	(%)	
Olive ridley	1.3	1.8
Kemps ridley	0.1	0.8
Loggerhead	0.1	0.6
Green	0.4	0.4
Hawksbill	–	0.4
Leatherback	1.1	0.1

As in other regions, leatherbacks do not associate with floating objects.

INDIAN OCEAN

According to Stretta *et al.* (1997) 86 percent of sea turtles were captured in floating objects, and 14 percent in school sets. In a recent study, Amandè *et al.* (2008a) show the olive ridley turtle as the prevalent species with more than 50 percent of the identified individuals, followed by the green turtle and the hawksbill turtle. The interpretation of these differences between this study and the previous one from the same region should take into account the spatial extent of the fishery in the different periods. As the fisheries expand offshore, with the use of FADs, the "more pelagic" species predominate. More than 90 percent of the turtles captured were released alive, and 95 percent of the turtles were captured in sets on floating objects. A rough estimate of mortality per year in the period 2003–07 was 60 individuals per year. Most of the mortality was among juveniles, with sizes between 30 and 50 cm of curved carapace length. Even with this addition, the figures are not likely to be significant in the population dynamics of the main species, although the sizes of the hawksbill turtle populations are frequently unknown. However, there could be important spatial components in these distributions. Delgado de Molina *et al.* (2006) found a large majority of hawksbills in an experiment with a very small sample size, so there could be areas and periods where the local proportions could be very different from the global figures. A regional workshop report (FAO, 2006) describes gillnetting, longlining and trawling as the major threats to turtles in the southwest Indian Ocean.

In the Indian Ocean, there are very large nesting concentrations of olive ridleys along the coast of Andhra Pradesh (India), and on islands near the Indian subcontinent. These are away from the core of the purse seine effort, but foraging habitats could be far from the nesting beaches, and the pre-reproductive individuals may concentrate in offshore areas (Amandè *et al.*, 2008a).

In the Atlantic and Indian Oceans, the conditions of the leatherback turtle populations are considerably better than in the Pacific (Saba *et al.*, 2008), and the populations are, in some cases, recovering from previous impacts. The impacts of the different fisheries of the Benguela Current System on sea turtles are discussed by

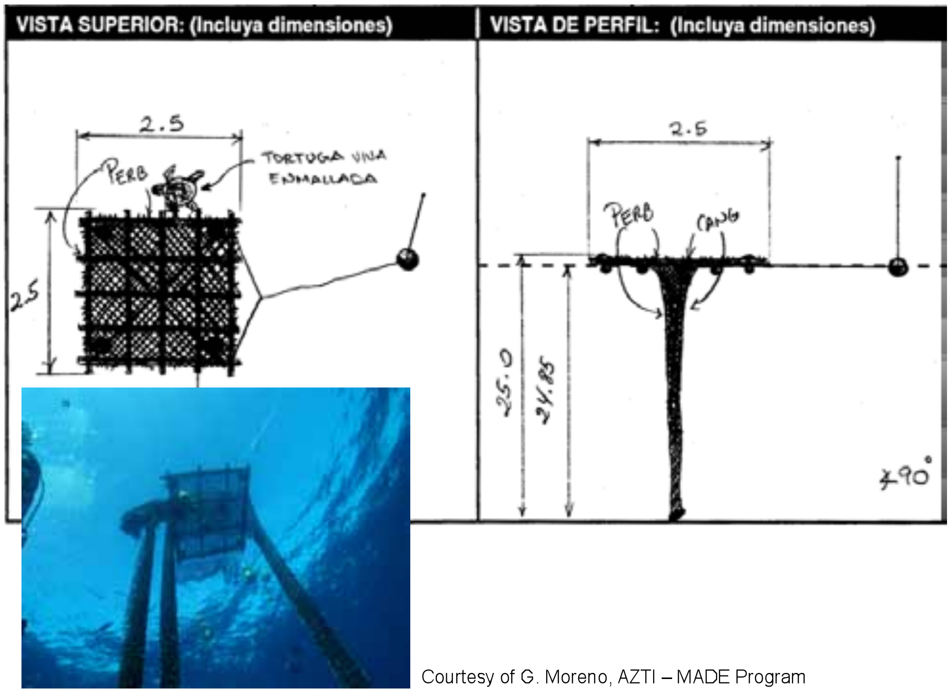
Honig, Petersen and Duarte (2008), and it appears that the direct purse seine impact is a minor one in relative terms. High-use areas have been identified in the Atlantic for leatherback turtles (Eckert, 2006).

In all these indices, there is a confounding effect because changes in sea turtle abundance and in fleet (or sampling) spatial distribution may affect the figures, and it will be necessary to account for all these possibilities in the analyses.

SEA TURTLE ENTANGLEMENT IN FADS

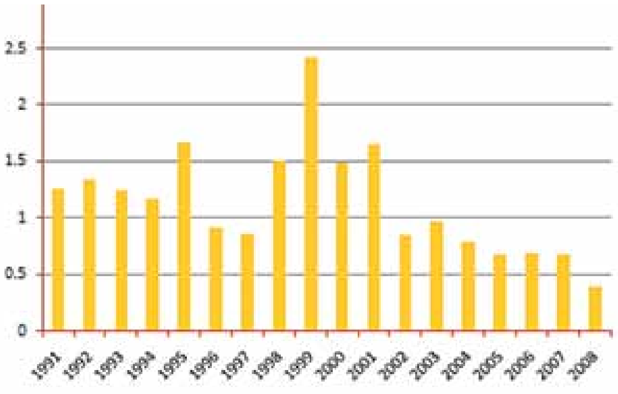
An additional risk factor for sea turtles is the entanglement in the netting materials that the fishers use to wrap around and under the FADs (Figure 146). These pieces of old nets are added to increase the attraction of the FADs, and in some cases they are long in the vertical dimension, perhaps to attract schools from deeper waters. In the EPO, most of them reach 10–30 m in depth (Table 10), and about 1 percent of the FADs sighted have entangled turtles (Figure 147). Some proportion of these are alive, and can be released, so the total maximum additional impact from this source could be in the order of 80–100 sea turtles per year in the EPO, as the number of FADs deployed has been

FIGURE 146
Observer diagram of entangled turtle, and photograph of webbing under the FAD



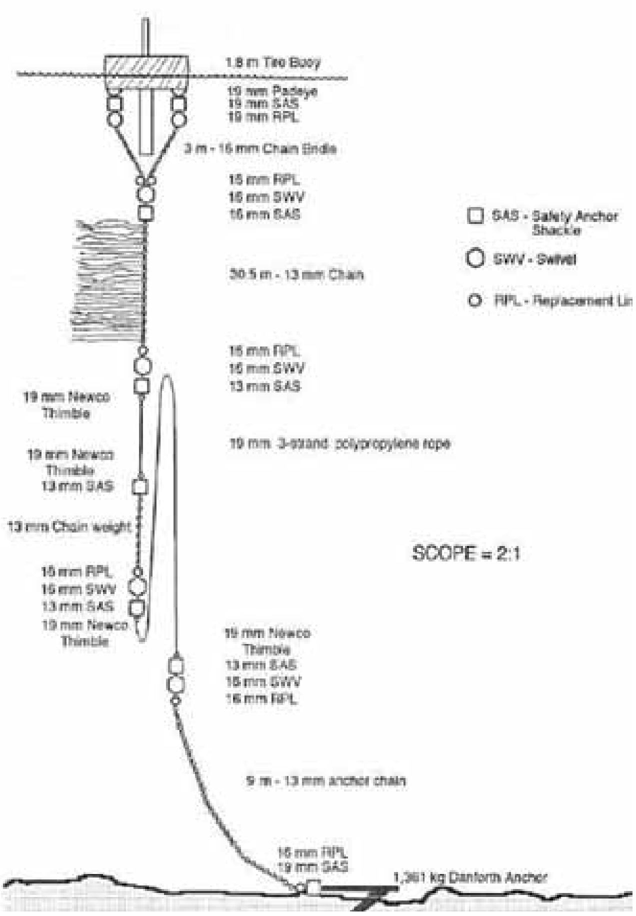
Courtesy of G. Moreno, AZTI – MADE Program

FIGURE 147
Percentage of floating object sets with at least one entangled turtle in the Eastern Pacific Ocean, 1991–2008



8 000–10 000 in recent years. The uncertainty about these estimates is large because observer data are not adequate to estimate these impacts. Moreover, lost FADs may drift closer to nesting locations (Shanker *et al.*, 2004; Tripathy, Choudhury and Shanker, 2002; Tripathy *et al.*, 2009; Tripathy, Shanker and Choudhury, 2003), and those impacts, when the FAD becomes ghost fishing gear, may not be observed. The issue of reducing entanglements of turtles in the netting under FADs may be significant, even in the absence of enough observations to produce solid estimates of impact levels.

FIGURE 148
Vinyl strips



Source: K. Holland (personal communication).

ACTIONS AND CONCEPTS TO REDUCE SEA TURTLE BYCATCH

Different resolutions have been passed by the t-RFMOs to reduce sea turtle bycatch, and they are reviewed in Gilman, Moth-Poulsen and Bianchi (2007). The background paper presented at the "Kobe II" Bycatch Workshop of the Joint Tuna RFMOs is available as IOTC-2010-WPEB-Inf11 and the Report at (WCPFC-SC6-2010/EB- IP-05). Many of those actions address longline bycatch, considered to be the most significant by far. For purse seiners, there are obligations:

- to provide information on bycatch;
- to develop observer programmes;
- to follow the FAO Guidelines;
- to release sea turtles alive and help in their recovery;
- to disentangle turtles from the netting under FADs;
- to train crews in release methods;
- to deploy a speedboat in the place where the seine is lifted from the water in order to release entangled turtles;
- to use dipnets to handle sea turtles;
- to release sea turtles entangled in the netting that is added to the frames in the construction of the FADs.

FAO organized a series of workshops and technical consultations on sea turtles that resulted in the publication of a set of Guidelines to reduce sea turtle mortality in fishing operations (FAO, 2004a, 2004b, 2005, 2009; Gilman, Moth-Poulsen and Bianchi, 2007), but the major focus has been on the longline fleets. Other regional organizations such as the Indian Ocean–South East Asian Marine Turtle Memorandum of Understanding (IOTC-2008-WPEB-INF05a) and the Inter-American Sea Turtle Convention (www.iacseaturtle.org) coordinate and monitor efforts at the regional scale, in cooperation with RFMOs.

In the EPO, the IATTC management actions included a recommendation to deploy a speedboat in the area where the net is lifted from the water to release the sea turtles as soon as they are seen. The impact of this resolution has been a considerable decline in sea turtle mortality (Figure 145). In particular, the requirement that the vessel stops net roll when a turtle is seen entangled, and that the turtle is disentangled and released before continuing the set has been effective (e.g. IOTC Resolution 09/06). This procedure is inexpensive, and relatively simple, so the only issue is implementation, and it should be extended to other ocean areas. A resolution asked fishers to release turtles seen entangled in the netting under FADs, even if the FAD does not belong to the vessel making the observation, and even if there is no intention to set on that FAD. This basically requires that the seiner stops, lowers a speedboat and performs the release, interrupting the fishing operations. There are many reports of this type of action taking place, which is a sign of growing awareness on the part of skippers and crews.

The resolution mentions the avoidance of high-density areas, and in some cases there are obvious options open for spatial management. Nesting beaches during sea turtle "arribadas', massive simultaneous arrivals of females to nest, create a situation where the densities offshore are so high that any fishing operation could cause a large impact. The protection of the internesting habitat, where females spend the days between nesting events (which are several per season), is another valuable opportunity to protect reproductive females, one of the most important segments of the population.

Migration corridors (Morreale *et al.*, 2007; Shillinger *et al.*, 2008), when they are well-defined in time and space, offer another possibility for adaptive closures, following the migratory movements. High-use foraging habitats are less well known (Eckert, 2006), and they may change with oceanographic conditions such as El Niño events; occasionally, these areas are also important fishing areas, so the ratios of bycatch to catch are important (Hall, Alverson and Metuzals, 2000), or enforcement will become a weak link in the process.

Every time a closure is proposed, the overall impact of the potential displacement of the effort should be considered, to avoid "unispecific", unwise choices (Hall, 1998). Spatial measures could be effective if there is adequate control and monitoring.

A hazard to sea turtles from the FAD fishery that could be mitigated is the entanglement in the netting that fishers hang under and around the FAD (Figure 146; Anderson *et al.*, 2009). As fishers believe that the netting plays an important role in the attraction of fish, it would not be easy to eliminate it. A replacement that could fill the same role and without entanglement has been the target of some research projects (Delgado de Molina *et al.*, 2005b, 2006; Franco *et al.*, 2009), and there are also some suggestions from skippers and others that could be viable (Plates 11–13 and Figures 148–150).

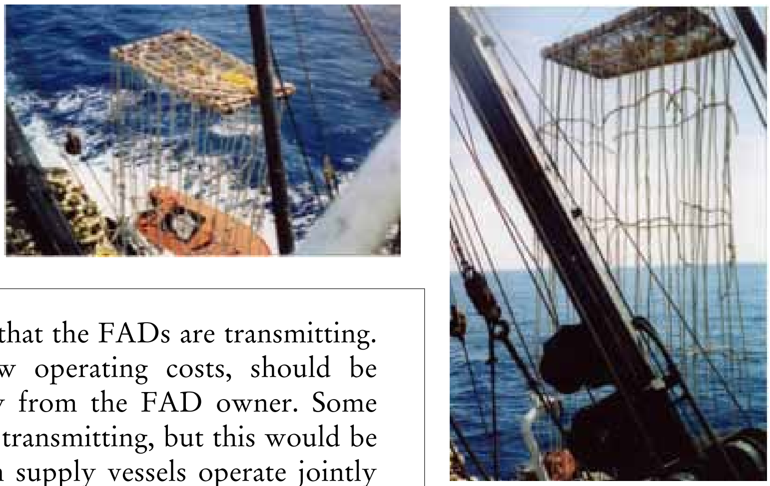
The Working Party on Ecosystems and Bycatch from the IOTC recommended:

- "Complete conversion to Ecological FADs be completed as soon as possible".
- "Purse seine FADs be constructed from biodegradable materials".
- "IOTC guidelines on releasing sea turtles be developed, and that these be made freely available to fishers".

A conflict appears because the fishers are placing valuable instruments on the FADs, and there is an interest on their part in retaining the FADs for a long period, using them repeatedly, and eventually recovering their instruments, and re-deploying the FAD when it is drifting outside the fishing grounds. This requires FADs with long-term buoyancy, and if biodegradation occurs rapidly, then it will go against the other objective. However, FADs are becoming a component in the increase in marine debris that pollutes oceans and beaches, and this creates a source of friction with other interests (e.g. tourism). Most t-RFMOs have expressed interest in the recovery of FADs. At the level of a single vessel, if one or a few FADs drift to a distant area, it may not be cost-effective for the seiner to sail several days to retrieve them, spending in fuel and fishing time much more than the cost of the lost equipment. However, at the fleet level, it may be possible to implement a system based on a "fleet service vessel", stationed strategically, and recovering FADs from all vessels, based on the positions that the FADs are transmitting. This vessel, selected with low operating costs, should be compensated by each recovery from the FAD owner. Some FADs would still sink, or stop transmitting, but this would be a much smaller fraction. When supply vessels operate jointly with a seiner, some of these functions could be executed by them, but they are banned in some ocean areas.

PLATE 11

Rope structure to attract tunas.



Resolution 09-06 from the IOTC is available at: www.iotc.org/English/resolutions/Resolution_09_06.pdf.

Some of the options to make FADs with lower possibilities of entanglement are:

- Dick Stephenson's ropes: Mr. Stephenson, a creative tuna boat skipper, devised a simple system based on ropes, which he tested briefly. Plate 11 shows its structure. It is cheap and simple to construct. Its effectiveness to attract tunas should be studied with an adequate sample size.
- McIntosh Sea-Kites (www.reefix.com/mcintoshP2.htm): This is a commercially available product that could be attractive to tunas, and it does not appear likely to entangle any species (Plate 12). Testing is also needed.
- The "Holey sock" (Instituto Español de Oceanografia): This concept was tested in the Indian Ocean, and the results were encouraging (Plate 13; Delgado de Molina *et al.*, 2006, 2007). It is a tubular structure made of sailcloth, so there is no mesh to cause entanglements, with holes to facilitate water circulation and reduce the drag. Other designs have also been tested in this experiment.
- "Hawaiian style strip attractors": In anchored FADs around the Hawaiian Islands, fishers utilize vinyl strips tied to the links of the anchoring system. K. Holland suggested this alternative (Higashi, 1994). It has never been tested (Figure 148).
- Korean style (Atlantic): There is another style of FAD, used by Ghanaian flag vessels handled by skippers from the Republic of Korea in the Atlantic, that is much less likely to entangle turtles. Its

PLATE 12

McIntosh Sea-Kites

PLATE 13
Tuna attractive system. No entanglement experimental FAD (Instituto Español de Oceanografía).

submerged portion is made of a single piece of netting (~ 45 m) with transversal bamboo canes every few metres until reaching the lower end of the netting. The bamboo keeps the netting open and makes the netting taut, reducing the risk of entanglement (G. Moreno, personal communication).

MADE models

MADE (Mitigating ADverse Ecological impacts of open ocean fisheries) is a programme supported by the European Union, and carried out by research teams from France and Spain (Dagorn *et al.*, 2009). One of its goals has been the development of "ecological FADs", defined as:

- FADs should not have hanging panels of nets with large mesh size that can cause entanglements of animals.
- FADs should not be covered by several layers of netting where turtles can be trapped, or should have surface structures on which turtles cannot climb.
- FADs should be made of biodegradable materials as much as possible.

Figures 149 and 150 show two of the designs that are being tested (Franco *et al.*, 2009). The idea of building FADs that will not start appearing in beaches all over the world makes sense, as it will reduce the marine debris problem and many negative interactions.

As the FADs are increasingly carrying valuable equipment, the fishers have a strong incentive to recover them. The first figures available for the EPO show that, of the thousands of FADs deployed each year, a large majority are recovered. The numerical difference between deployed and recovered includes FADs that are currently at sea and are fully functional, and others lost or sunk.

On the subject of replacing the netting under the FADs, there seem to be plenty of options that are quite economic and practical to build with common materials. The main issue is for the fishers to experiment with the different designs in order to test that there are no negative impacts

FIGURE 149
FAD with only biodegradable materials

FIGURE 149
FAD with only biodegradable materials

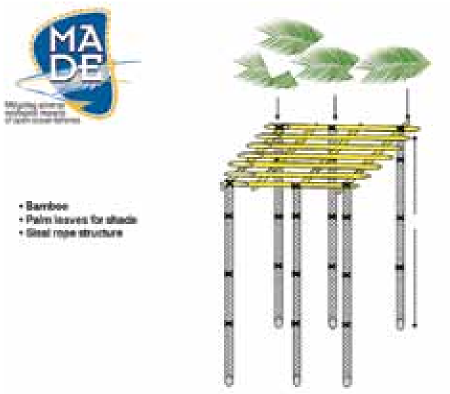


FIGURE 150
FAD with mostly biodegradable materials

FIGURE 150
FAD with mostly biodegradable materials

on the productivity of the FADs, and then adopt any of the alternatives. There are several plastic netting materials with characteristics that would make entanglements much more difficult, and a compromise would be to use plastic fencing material, or so-called poultry netting, of a mesh and stiffness that would eliminate entanglements, but of a material sensitive to light that would degrade in a reasonable amount of time.

CONCLUSIONS

In all oceans, the situation of sea turtles appears to be similar:

- very low captures in numbers;
- much lower bycatch, with a magnitude in the tens;
- much of the impact for some of the species is centred on juveniles;
- almost 90 percent of individuals are found, and can be released alive;
- with a cryptic mortality caused by the webbing on the FADs, presumably low.

The types of resolutions already passed, and the increasing awareness by fishers of the need to release the sea turtles, are eliminating what is a minor impact, and the issue of captures in purse seines is being resolved. The issues of sea turtle entanglement in FADs is not a major problem in view of the information currently available, but the issue of the generation of marine debris need to be addressed.

15. Marine mammals

Four types of sets involve marine mammals: (i) sets on dead whales, pinnipeds, etc. are considered log sets; (ii) sets on live whales; (iii) accidental sets (i.e. a school or FAD set that captured a marine mammal accidentally); and (iv) sets on dolphins;

Sets on live whales were discussed above. They are infrequent, and the whales escape unharmed in the majority of the sets according to the observer reports. Accidental sets are also very infrequent. Occasionally, a rough-toothed dolphin (*Steno bredanensis*) is captured in a FAD set. This is the only dolphin species with affinity for logs and FADs.

Tunas also associate with dolphin herds, but this phenomenon is only common in the EPO. It has been observed in many other locations (Donahue and Edwards, 1996), but not as a frequent and consistent practice, utilized routinely as in the EPO. In recent years, dolphin sets have fluctuated between 9 000 and 12 000 per year (Figure 22). The main species involved in the association are yellowfin tunas, with modal sizes about 70–90 cm, and the spotted dolphin. Eastern spinner dolphins are also encountered with tunas, but usually in mixed herds with the spotted dolphin. To a much lesser extent, yellowfin also associates with common dolphins. The discovery of this association by fishers led to the development of a technique that consisted in detecting the dolphin schools, much more visible than the tuna schools, and surrounding them with the seine after a chase by speedboats lasting about 15–20 minutes. In the earlier years of this fishery, in the 1950s, the encirclement of the dolphin group resulted in the capture of both the dolphin group and the tuna school, and the fishers had no way to release the dolphins from the net (Perrin, 2004). The dolphin groups were composed of several hundred individuals, and occasionally thousands.

Mortalities in the 1960s and early 1970s were high, perhaps reaching several hundreds of thousand dolphins per year, but the estimates for this period are poor; data for only four trips were available for more than a decade of fishing operations (Figure 151). Two of those were voluntary reports by concerned crew members, and there was no sampling design of any kind in the period (Lo and Smith, 1986). Almost 50 percent of the mortality affected two stocks of dolphins, the northeastern stock of spotted dolphins (*Stenella attenuata*) and the eastern stock of spinner dolphins (*S. longirostris*) (IATTC, 2008). The NMFS started a more formal observer programme following the passage of the Marine Mammal Protection Act of 1972. In the United States of America, a Committee set up by the National Academy of Sciences reviewed all the information available and concluded that the mortality estimates prior to 1973 “had little or no statistical value” (Francis *et al.*, 1992). However, the numbers have been used consistently to assess the status of the dolphin populations. Those high figures produce an estimate of K prior to the fishery impacts that is very high, and the result is that the current status is depleted (Wade *et al.*, 2007), and, therefore, the theoretical recovery rates should be much higher than those observed in the population (Reilly and Barlow, 1986). Those theoretical rates have never been observed in nature, but the number of studies where that is possible is limited. Several studies considered different hypothesis to explain what the authors called the ”non-recovery” of the dolphin stocks (Gerrodette and Forcada, 2005), but the possibility of overestimates in early years mortality was never included among the possibilities, an omission that left out of consideration one of the most likely explanations (Wade *et al.*, 2007). Every other year, new studies have addressed all potential sources of non-recovery, including: mother–calf separation (Archer *et al.*, 2001, 2004; Edwards, 2006), foetal mortality (Perrin, Chivers and Archer, 2003); declines in reproductive output (Cramer, Perryman and

Gerrodette, 2008); and stress caused by fishery interactions (Myrick and Perkins, 1995; Curry, 1999; Archer *et al.*, 2010).

Dolphin mortality is estimated as a product of the number of dolphin sets multiplied by the average mortality of dolphins per set. These two variables are shown in Figure 152, and illustrate the fact that the improved ability and commitment of fishers to release the dolphins has been the driver of the change.

Dolphin abundance estimates produced from surveys organized by the National Oceanographic and Atmospheric Administration of the United States of America have steadily increased over the years (Gerrodette *et al.*, 2008), and the point estimate for eastern spinners in the most recent survey in 2006 was the highest in 25 years (Figure 153). The best model to explain the trajectories of abundance with the mortality figures estimated was developed at a technical workshop (AIDCP, 2006), and is shown in the same figure, together with an exploration of the most likely values for ‘r’ for this stock (Figure 154), the intrinsic rate of increase. For the spotted dolphin, the abundance series also shows an increasing trend in recent years (Figure 155). Using the best-fit model, the estimates of ‘r’ are shown in Figures 156 and 157.

The first step towards a solution was the development by tuna fishers of a manoeuvre called the “backdown”. As soon as the net has encircled the group of dolphins, the vessels goes into reverse and pulls the net. The net becomes elongated and forms a channel. The water resistance causes the corkline to sink a few metres at the opposite end. The dolphins have remained close to the surface, while the tunas are lower in the net, so the dolphins can exit the net through the opening. When all dolphins have escaped,

FIGURE 151
Total dolphin mortality, 1959–2008

FIGURE 152
Total dolphin mortality, 1986–2008

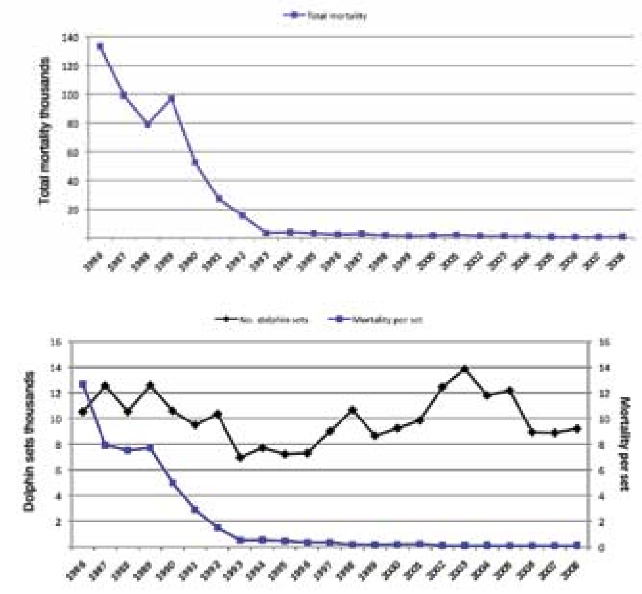
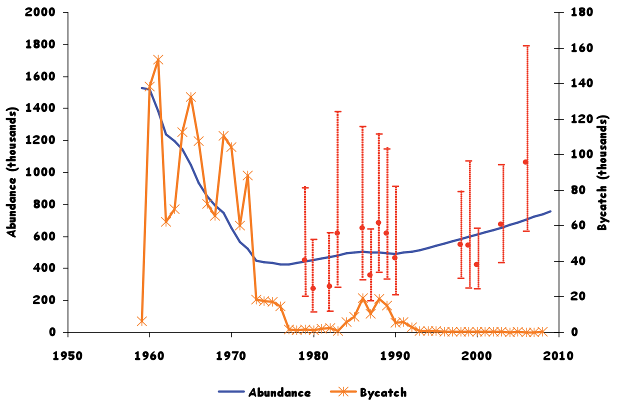


FIGURE 153
Spinner dolphin (Eastern stock)



the backdown stops, and the seining operation is completed. A small mesh panel, called a Medina panel (named so after its creator), is placed at the end of the backdown channel to increase resistance to the water flow, and increase sinking of the corkline. Other measures include placing a raft with a rescuer inside the net, and using the speedboats pulling the net to keep it open. Most of these developments have come from creative fishers, and have been tested by them in vessels (Francis *et al.*, 1992; Hall *et al.*, 2007; Hall, Campa and Gómez, 2003).

The initial observer programme by the NMFS focused mainly on estimating mortality; starting in 1979, the IATTC shared the observer programme with the NMFS. As the fleets flagged outside the United States of America increased, the IATTC share of the sample increased, as it took all samples from those other flags. The focus of the programme was expanded to identify factors that were causing or increasing mortality. A series of fishers workshops was used to improve communication with them, build awareness and smooth the adoption of all mitigation measures available (Hall *et al.*, 2007). Since 1986, more than 150 fishers workshops have been organized.

FIGURE 154
Spotted dolphin (Northeastern stock)

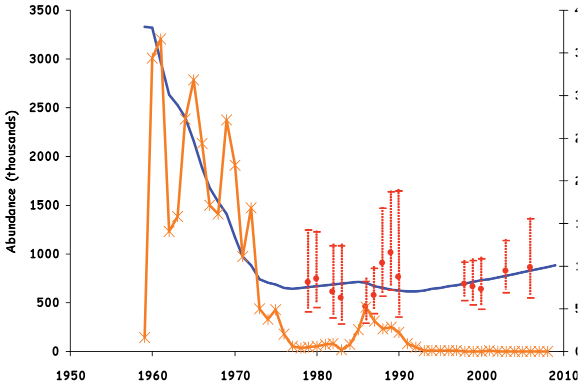
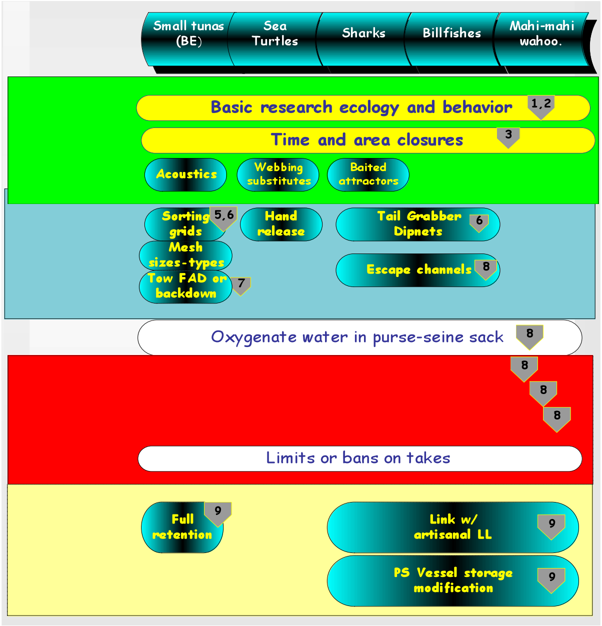


FIGURE 158
Strategies available to develop technical and operational mitigation measures



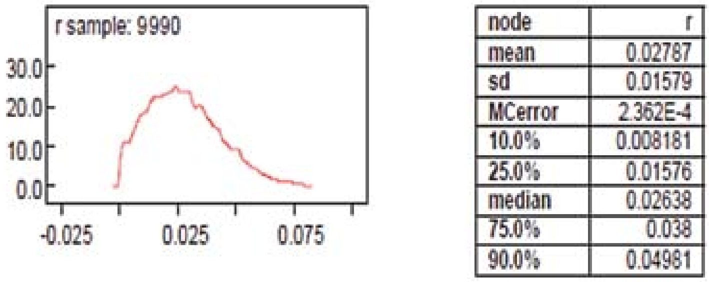
MANAGEMENT ACTIONS

On the management side, an agreement was signed in La Jolla in 1989, and expanded by the AIDCP (www.iattc.org/IDCPENG.htm; Joseph, 1994; Hedley, 2001). These agreements: regulated the equipment the vessels should carry; established a system based on an overall dolphin mortality limit, complemented with individual vessel dolphin mortality limits; raised observer coverage to 100 percent; instituted a captain training system; promoted research on gear and techniques to reduce dolphin bycatch; promoted research on alternative ways of caching tunas; and established a tuna-tracking system.

Dolphin-safe labels

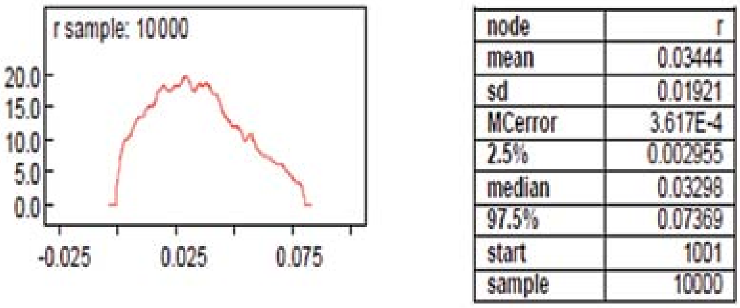
In 1990, some tuna canneries adopted, at the urging of the Earth Island Institute (a dolphin-protection organization), a dolphin-safe policy. This policy stated that the canneries would not buy tuna caught during trips where dolphins had been encircled. Its current definition of dolphin-safe is the following (www.earthisland.org/dolphinSafeTuna/consumer/):

FIGURE 156
Estimates of 'r' for northeastern spotted dolphins



node	r
mean	0.02787
sd	0.01579
MCerror	2.362E-4
10.0%	0.008181
25.0%	0.01576
median	0.02638
75.0%	0.038
90.0%	0.04981

FIGURE 157
Estimates of 'r' for eastern spinner dolphins



node	r
mean	0.03444
sd	0.01921
MCerror	3.617E-4
2.5%	0.002955
median	0.03298
97.5%	0.07369
start	1001
sample	10000

- No intentional chasing, netting or encirclement of dolphins during an entire tuna fishing trip;
- No use of drift gill nets to catch tuna;
- No accidental killing or serious injury to any dolphins during net sets;
- No mixing of dolphin-safe and dolphin-deadly tuna in individual boat wells (for accidental kill of dolphins), or in processing or storage facilities; and
- Each trip in the Eastern Tropical Pacific Ocean (ETP) by vessels 400 gross tons and above must have an independent observer on board attesting to the compliance with points (1) through (4) above.

This policy initially pushed the United States fleet to develop the fishery on FADs as an alternative to the fishery on dolphins. The ecological consequences of the change have been presented (Hall, 1998) and they include significant increases in most bycatch, increasing captures of juvenile yellowfin and bigeye tunas, etc. When this policy was adopted, dolphin mortality had already declined by about 60 percent from the 1986 peak and was on a downward trend (Figure 151). It has been mentioned that mortality has two components: the level of effort (number of sets on dolphins); and the average mortality per set. The dolphin-safe policy intended to reduce dolphin mortality by eliminating effort on dolphins. That did not happen (Figure 152). Dolphin effort dipped for a few years, but then climbed again as the fleets found their new markets, and now the number of dolphin sets it is at the same level as when the policy was passed. The only value of the policy was to add pressure to the system initially, but it did not achieve its goal. Dolphin mortality declined because the fishers continued fishing on dolphins but reduced the average mortality per set in a continuous manner for years.

The failure of the Earth Island Institute's dolphin-safe policy to eliminate effort on dolphins was perhaps fortunate. If the 10 000 sets on dolphins had switched to sets on FADs in addition to the current level of effort, the bycatch impacts and the catches of juvenile tunas described in this report would have been much higher (Hall, 1998). The participants in the AIDCP programme established an alternative label; their definition of dolphin-safe tuna is: "tuna that has been caught in sets without mortality or serious injury to dolphins". This definition allows the setting on dolphins, and it provides an incentive to produce sets without mortality (www.iattc.org/DolphinSafeENG.htm).

The IATTC–AIDCP programme has reduced dolphin mortality to low levels, and maintained them there for almost two decades (Figure 151). The current levels of mortality are a small fraction of the population abundance, estimated by scientists of the National Oceanic and Atmospheric Administration of the United States of America based on periodic surveys (Gerrodette *et al.*, 2008). Table 49 shows the relationship between abundance and mortality; all stock mortalities are several times below a precautionary level.

The issue has been the subject of many studies because of the development of international environmental legislation, and its connection to the developing free trade agreements. A sampler of Web pages discussing the different angles of the tuna–dolphin issue follows:

- World Trade Organization: www.wto.org/english/tratop_e/envir_e/edis04_e.htm
- General Agreement on Tariffs and Trade: www1.american.edu/ted/TUNA.HTM
- International Centre for Trade and Sustainable Development: http://ictsd.org/i/publications/3470/
- International Economic Law and Policy Blog: http://worldtradelaw.typepad.com/ielpblog/2010/09/the-tunadolphin-nafta-panel.html
- bilaterals.org: www.bilaterals.org/spip.php?article18211
- Legal Planet: http://legalplanet.wordpress.com/2009/05/15/dolphins-and-tuna-mix-it-up-again/
- www.bibliojuridica.org/libros/1/143/21.pdf
- Journal of Environmental Law: http://jel.oxfordjournals.org/content/12/3/293.abstract
- Bizcovering: http://bizcovering.com/international-business-and-trade/reconcilability-between-international-free-trade-and-environmental-protectionhow-has-the-united-states-responded-to-the-tunadolphin-decision/

TABLE 49

Incidental dolphin mortality estimates, population abundance, and relative population mortality in the Eastern Pacific Ocean, 2009

Stock	Incidental mortality	Population abundance	Relative mortality (%)
Offshore spotted dolphin			
Northern/eastern	264	911 177	0.03
Southern/western	254	911 830	0.03
Spinner dolphin			
Eastern	288	790 613	0.04
Withe belly	222	711 883	0.03
Common dolphin			
Northern	109	449 462	0.02
Central	30	577 048	<0.01
Southern	49	1 525 207	<0.01
Other dolphin	23	2 802300	<0.01
Total	1 239		

Source: Gerrodette *et al.* (2006).

It is also a favourite subject for environmental studies classes to develop students' critical thinking and an understanding of the trade-offs involved in all decisions on resource use (Vaca Rodriguez and Enriquez-Andrade, 2006):

- FOR SEA Institute of Marine Science: www.forsea.org/TUNASTUD.HTML
- University of California, Berkeley: http://are.berkeley.edu/courses/EEP131/old_files/studentpresentations05/Tuna percent20Dolphin percent20Case.pdf
- University of Maryland: www.arec.umd.edu/libcomp/Areclib/Publications/Working-Papers-PDF-files/00-05.pdf
- The topic also appears frequently in the media, as it is one of the best-known controversies:
- Forbes.com: www.forbes.com/2008/07/24/dolphin-safe-tuna-tech-paperplastic08-cx_ee_0724fishing.html
- All About Wildlife: www.allaboutwildlife.com/dolphins-whales/the-disturbing-facts-about-dolphin-safe-tuna/4298
- *The Telegraph*: www.telegraph.co.uk/earth/earthnews/3349460/Dolphin-friendly-tuna-may-not-be-environmentally-friendly.html
- *The Times*: www.timesonline.co.uk/tol/news/environment/article4517778.ece

Social scientists have also been interested in this problem, and in the interactions between fishers, scientists, managers, and others (Orbach, 1977; Jenkins, 2007) – an aspect that cannot be ignored in bycatch reduction programmes (Campbell and Cornwell, 2008).

The complexity of the case defies reduction to a slogan, and it has troubled many individuals and organizations (Joseph, 1994; Gosliner, 1999). It has illustrated the evolution of society in the connection between trade and environmental concerns in the international arena, and it brings up ethical and ecological approaches to conservation that may be in conflict with each other. When the "save the dolphins" proponents were forced to consider the ecological costs of the alternatives, they split into a "dolphin-centred" sector and a more ecologically minded sector. The controversy has had educational value for most involved.

16. Impacts of the development of the FAD fishery on fishing operations

Fishing on floating objects has existed since the beginning of the purse seine fishery, and the association of some tuna species with objects most probably originated because it conferred some evolutionary advantage to the species involved. However, the association is not necessary for the tunas – they can exist and thrive without it, as they do in some regions. The evolutionary advantages may or may not persist in the association with FADs, and in fact, the association may turn out to be maladaptive as it increases vulnerability to the fishery, a significant predator. The spatial distribution of FADs is not the same as that of natural objects, and the ecological conditions around FADs are different (e.g. in much more pelagic regions, without continental inputs). The development of the fishery on FADs brought several significant changes to the overall fishery, besides the described bycatch impacts:

- It made available a large skipjack resource that could be harvested sustainably and without problems, if the negative impacts of the harvest could be addressed.
- It extended the range of the fishery, reducing the spatial density of the harvest that could lead to concentrated local impacts.
- It reduced search time, and improved the fuel efficiency of the operation.
- It reduced the number of “skunk sets.”

Some of these advantages may become truly positive aspects when the issue of excess capacity has been dealt with. A review by Bromhead *et al.* (2000) outlined the major issues early on. Building on that list, it is possible to suggest some of the major changes resulting from the use of FADs:

The fishing areas shifted following the drift and distribution of the FADs. In the EPO, for example, effort in the coastal areas was reduced, as the vessels moved offshore following the FADs. In the Eastern Atlantic, effort also shifted west (Ariz *et al.*, 1999). In the Indian Ocean, the monsoon system gives a more complex picture (Murtugudde and Busalacchi, 1999), but FAD extended effort towards the north (Figure 27).

In some areas, the introduction of large numbers of FADs (Figure 33) may have reduced the number of unassociated schools to be set on, in this way affecting the species and size composition of the catch, and increasing the vulnerability of the fish (Fonteneau *et al.*, 2000). However, there is no evidence to substantiate this. The numbers of FADs active at any given time in each ocean area are not easy to estimate, but there are some figures available on the number of FADs deployed and recovered per year from the Eastern Pacific (Table 50). The difference between the numbers deployed and the numbers recovered includes FADs currently in operation, and also FADs that have strayed out of the fishing grounds, FADs that have lost their transmitting system, FADs that have sunk, etc. For the Indian Ocean, Moreno (2008) estimates there are about 2 100 FADs active at any given time.

It shifted the distribution of effort, concentrating it in the areas with adequate conditions for FAD fishing (fast currents).

As the FADs were very productive and reliable, they began to determine the fishing strategies of the vessels, and the searching areas used. This affected other ways of fishing, and sets on tunas associated with dolphins or other animals or schools began to take place in, or close to, the FAD fishing areas because that was where the vessels were.

As most sets on FADs were made very early in the morning, beginning before the sun was up, only one FAD set could be made per day, and that limited the increases in effort.

Instead of searching, the vessels had a set of options with known locations, and as technology developed the information on what was available under a FAD improved, and the effectiveness of the vessels increased.

Sets on FADs have a very high percentage of success (i.e. they produce an acceptable catch) because the fishers know what is under the FAD, and because catching it is simple compared with school sets, which frequently fail to produce because of school avoidance, etc.

TABLE 50

Number of FADs deployed and recovered by year in the Eastern Pacific Ocean

	2005	2006	2007	2008	2009
FADs deployed	4 455	8 003	8 390	9 594	10 771
FADs recovered	4 069	6 070	7 457	7 994	8 781

The targets of the fishery changed with the new strategy. As large yellowfin and large bigeye were not commonly found under FADs, the fishery concentrated on skipjack and smaller yellowfin and bigeye.

From the point of view of the stock assessment of the tuna populations, this change interrupted the time series of CPUE data based on search effort, and created a major problem to connect the indices obtained from this fishery with those from previous or different sources.

Trends in the effort on FADs shows increases in all oceans in recent years (Figures 54 and 55), and also a gradual replacement of the fishery on logs by a fishery completely based on FADs deployed by the vessels. It is not clear if the fishery on FADs will attract the vessels to areas where, for example, they are too far from payaos to use a mixed strategy, or if the vessels will specialize in some combination of sets.

ECOLOGICAL IMPACTS OF THE DEVELOPMENT OF THE FAD FISHERY OTHER THAN CAPTURES AND BYCATCH

As a result of the location of deployment, and of current patterns, in the EPO, the FADs move predominantly in a northwest or southwest direction from the initial equatorial deployment, and after a while, they seem to take a clearly westward drift. To show the drift patterns in a synthetic way, Figure 36 shows, as an example, a set of vectors for a year, but the patterns are similar in most non-El Niño years observed to date. The origin represents the location of deployment, and the end of the vector is the location of the first set on that FAD. The length of the vector is the straight line distance covered by the FAD (unit vector in Figure 36 is 600 nm). These figures show a very clear western drift for the vast majority of the FADs. They also cover considerable distances before being set on. The vectors show the drift of the FAD, not of any species associated with it. In the Eastern Atlantic, the prevailing currents also result in a drift westwards. In the Indian Ocean, the monsoon system makes it more difficult to define the situation in terms of one pattern.

Therefore, the question is: When FADs are deployed in the ocean, and many species associate with them for varying periods, do FADs “transport” those individuals and/or schools in the direction of the drift? There are several cases to consider:

- If currents are very slow, or the association is only for a small fraction of the time (e.g. a couple of hours per day, or a few days per month), the movement of the individuals and/or schools when they are away from the FAD may determine whether there is directionality or not, and the effect of the drift would not be noticeable.

- If the currents are fast, and/or the association is for prolonged periods, and if the movements of the individuals and/or schools are not "compensatory" (opposite to the drift), when they are away from the FAD (e.g. they forage in random directions in different days), then there will be some directional movement caused by the FAD association – a resultant vector whose magnitude will depend on current speed, and duration of association. Over time, this component may become a significant displacement.
- If currents change directions, or form eddies, then there will be no directionality vector arising from the association.
- If the individuals and/or schools have compensatory mechanisms (e.g. vertical migrations to a layer with a different direction of drift), these may cancel the drift.
- In the absence of FADs, e.g. prior to their introduction and in areas without many floating objects, would the individuals and/or schools have drifted in the currents anyway? Maybe the FADs only make vulnerable to fishing the schools that were already in the area but were not easy to detect, moving or migrating with the currents.

The influence of the association with the FAD on the movements and migrations of the species then ranges from null to determinant. The set of species associated with FADs is diverse, and there are probably species across all this range of possibilities. As the currents in the EPO weaken considerably to the west, towards 180°W, the circulation of FADs becomes much more complex, and less directional.

Given the local complexity of oceanic currents, and the swimming abilities and habitat utilization of many of the species of interest, the answers to the basic question is likely to be very complex, too. If, as a result of the association with the FADs in an area where there were no, or few, floating objects before, an individual or school experiences some displacement of a few hundred to a few thousand miles, then there could be impacts on several aspects of their ecology, biology (growth, natural mortality, and reproduction) and behaviour.

For example, the current systems in the Indian Ocean have their monsoon components with all the changes involved, so the persistence of the currents will be different. In the Eastern Atlantic, the Benguela Current System and the shape of the continent limit the direction of drift along the coast. Each ocean presents a variation of the situation, so there will probably be different answers according to the region. In some cases, the drift is offshore, away from the continents; in other cases, it is towards land masses.

If they are within the same water mass, it is not relevant if the individuals return to the same FAD, or if they switch their association to any other FAD in the area.

Many of these questions are key to implementing successful management programmes for the target species. Hallier and Gaertner (2008) demonstrated that FAD-associated tunas had a directional movement different from those not associated, besides other differences in condition. A hypothesis suggested that the association of tunas with FADs traps the tunas in low-productivity areas, the "Ecological Trap Hypothesis" (Fonteneau *et al.*, 2000; Marsac, Fonteneau and Ménard, 2000; Ménard *et al.*, 2000b; Dagorn *et al.*, 2010). In the EPO, it is not obvious that the FADs circulate in a low-productivity region.

Regardless of the productivity issue, another question of ecological significance is whether the introduction of FADs affects the ecology of the pelagic communities (distributions, relative abundances, etc.), and, potentially, the migration patterns of the species associated with the FAD (Marsac, Fonteneau and Ménard, 2000). Are there ecological consequences for the pelagic communities as a result of the FAD association, and of this directional drift? For the species involved, this addition may even modify genetic patterns (Duncan *et al.*, 2006) by increasing connectivity and genetic exchange between populations that were isolated before.

When the FADs were introduced, they were new, additional attractors in regions that in some cases had few or no floating objects. Floating objects attract some species and sizes, not all. For example, the rough-toothed dolphin is the only dolphin species that associates with some frequency with floating objects, although many dolphin species are abundant in the region. Manta rays are seldom captured on FADs, but they are captured in school sets in the same region. Blue sharks are very abundant in longline catches in most regions (Nakano and Seki, 2003; Lawson, 2004b, Joung *et al.*, 2005), but very rare under FADs, while silky sharks are a very frequent component of the fauna under FADs. The effort on FADs has added a new selectivity component to the fishery, which not only selects by species and sizes, as do all nets, but also by the associative behaviour of the members of the community; species associated with the FADs are selectively removed, while those that do not associate are not, or are less vulnerable to the fishery. Thus, the FAD fishery may be causing competitive disadvantages to some species. As fishing mortality increases, the ecological and even genetic implications of the harvest are probably significant.

Different species associate with the FADs for different periods; some remain a few hours, while others may spend days associated. The residence times of tunas on FADs appears to be a few days at a time, about 3–10 days. In some studies with drifting objects, yellowfin has been the longest resident, followed by skipjack, and bigeye (Govinden *et al.*, 2010), and most of the arrivals of bigeye and yellowfin to FADs happen between 18.00 and 05.00 hours, with another peak of activity after 19.00 hours, with both arrivals and departures. For skipjack, the peaks also exist, but the distribution is much flatter, and the activity is scattered throughout the day. The three tuna species have shallower distributions during the night, making them more vulnerable to the early morning sets, although the bigeye that goes deeper during the day. The dimensions of the net cover their depth distribution. However, most of the information comes from anchored FADs. There are not enough data on behaviour of the different species with regard to drifting objects, and it is dangerous to extrapolate from other situations (e.g. anchored FADs), or from different regions (e.g. deep vs shallow thermoclines). Interesting approaches are being tested, such as comparing conditions (Marianne, Dagorn and Jean-Louis, 2010).

Around payaos, the average residence time of yellowfin and bigeye tunas was estimated at 5–8 days, with a maximum of more than 2 months; there was also some site fidelity, with tunas tending to return to the original FAD where they were released (Dagorn, Holland and Itano, 2007). They are capable of finding their orientation from up to 10 km (Girard, Benhamou and Dagorn, 2004). The tuna schools are shallower at night than during the day in most studies carried out with anchored FADs (Holland, Brill and Chang, 1990; Cayre, 1991; Josse, Bach and Dagorn, 1998; Brill *et al.*, 1999).

In any case, the picture of the dynamics of these communities is not yet complete, and most of the information on residence times, area of influence of the FADs, etc., comes from anchored FADs (Dempster and Taquet, 2004; Dagorn, Holland and Filmalter, 2010).

Some questions are: Is a significant biomass of a number of species being shifted in the direction of the drift of the FADs? Or was that happening prior to the introduction of the FADs? Are schools that would have migrated otherwise being retained under payaos?

What proportion of the biomass in an area is associated with FADs? If only a small fraction of the biomass of the different species is associated with FADs, then there will be no significant impact from a directional drift. However, if a high proportion of the biomass in an area is associated, then the thousands of FADs being deployed every year may act as a conveyor belt, shifting biomass in the direction of drift. In the Pacific and Atlantic Oceans, the drift will be in a general east–west direction; in the Indian Ocean, the circulation is more complex. If the species that are "shifting" have migratory patterns, then the drift of the FADs may disrupt the timing or alter the distance of their migrations.

However, FADs certainly increase the number (density) of floating objects in an area (Figure 33), and the likelihood of tunas and other species encountering floating objects. This may have impacts on the populations in terms of changes in diet, condition, etc. as discussed by Marsac, Fonteneau and Ménard (2000); Stehfest and Dagorn (2010); Marianne, Dagorn and Jean-Louis (2010); and Jaquemet, Potier and Menard (2011).

Do average group sizes decrease when many objects "compete" for the same schools, as would be predicted if the "meeting point" hypothesis is true? Perhaps additional tests of the meeting point hypothesis can be carried out by analyses of group sizes in areas with different FAD densities (Soria *et al.*, 2009). Some of these group size changes may affect natural mortality, predation rates, etc.

This subject brings to the fore a very important research gap that needs to be filled in order to increase understanding of the behaviour of the different species around the FADs: the density of FADs in a region is an important variable that is not available. Some t-RFMOs have research programmes in the pipeline to identify and track individual FADs. These programmes are expensive, but the benefits could be obtained much less expensively if the vessels could contribute their satellite records of deployment, tracks, and sets on each FAD carrying a satellite buoy. This would allow the reconstruction of the FAD history, the local density, and other information that could help improve the data available for fisheries and bycatch studies. The level of information available today on FAD characteristics (Flotsam Information Record of the IATTC, and similar data from the WCPFC) is adequate for standardization of their characteristics, and research on the effect of those characteristics on catch and bycatch. Alternatively, drift models are being explored to predict distributions of FADs when the deployment points are known.

Some of these answers may have impacts on the stock assessments of tunas, and they may also affect bycatch estimates. If higher FAD densities result in smaller captures, smaller group sizes, and reduced biomass inside the seines, then the probability of survival of some species may improve. However, smaller schools may have higher predation rates.

An ecological impact that needs to be addressed is the ghost fishing by the webbing hanging under the FADs, and the creation of marine debris from lost FADs. Systems of FAD recovery, perhaps regional efforts, can be implemented with RFMO coordination.

Another ecological impact that is seldom discussed is the fate of the discards. Two issues are relevant here:

- the fate of those individuals released alive but without follow-up experiments to determine the survival rate; and
- the fate of the biomass discarded dead or dying, that presumably will sink to the bottom in its majority.

With regard to the second aspect, although the total biomass discarded is not too large, it is frequently discarded in ocean areas in waters with depths of several thousand metres. There are no studies in this fishery of the fate of the discards, but in other cases, it has been shown that only a small proportion of the discards is consumed in the descent through the water column (Hill and Wassenberg, 1990). Therefore, several tens of thousands of tonnes of fish may be sinking to the bottom. What happens to those discards and their impacts on the benthic habitats are unknown (Dayton *et al.*, 1995; Smith and Baco, 2003; King, Bailey and Priede, 2007; Fonseca *et al.*, 2011), and this is another significant gap in the knowledge of the impacts of fisheries. If they mineralize slowly in depth and then circulate on bottom currents, they may take centuries to be recycled to the surface waters.

In any case, FADs increase the vulnerability of schools that were not easily detected before. In order to understand these potential ecological impacts of the FAD fisheries, a series of experiments will be needed. Their significance cannot be assessed at present, but on precautionary grounds they should not be dismissed without a concerted research effort to explore them.

CONCLUSIONS AND CHALLENGES FOR BYCATCH MANAGEMENT AND REDUCTION

Comparison of bycatch rates across different fisheries

Updating the comprehensive study by Alverson *et al.* (1994) on bycatch in world fisheries, Kelleher (2005) produced some tables that allow a comparison of the bycatch rates by different types of fisheries, gear types and regions (Table 51).

TABLE 51
Comparison of bycatch rates

	Bycatch/capture (%)
Shrimp trawl	62.3
Tuna and highly migratory species longline	28.5
Dredge	28.3
Mobile trap/pot	23.2
Demersal finfish trawl	9.6
Demersal longline	7.5
Tuna purse seine	5.1
Mid-water (pelagic) trawl	3.4
Handline	2.0
Small pelagics purse seine	1.2
Gillnet (surface/bottom/trammel)	0.5
Tuna pole and line	0.4

The overall bycatch rate for the tuna purse seine fishery was about 5 percent when Kelleher's review was made. These estimates are based on bycatch/capture. For the most recent years (2007–09) in the EPO, the rate was 2.6 percent. The most recent figures are 1–4 percent for all oceans. The growing utilization of the large pelagic bony fishes such as the mahi-mahi and the wahoo will probably reduce this figure even more. In comparative terms, the purse seine fishery has a low proportion of bycatch.

The different ocean basins have much in common. The species composition, the preferences for FADs or logs, and even the relative proportions are similar. Because of their high mobility, these communities have spread throughout the oceans, and their adaptations to life in tropical oceans have been successful everywhere. Tunas of the main target species amount to 64–86 percent of the captures (Tables 23–30; Amandè *et al.*, 2008a, 2010b). The next group in biomass is the billfishes (5 percent) in the Atlantic, and the large pelagic bony fishes in the Eastern Pacific and Indian Oceans (14–26 percent). There is a low biomass of sharks in the Atlantic (1 percent), and a bit higher (7 percent) in the Eastern Pacific and Indian Oceans. The opposite is true for the billfishes; the biomass in the Atlantic (5 percent) is higher than in the Eastern Pacific and Indian Oceans (2 percent). These figures are affected by the inclusion or not of many smaller species that present difficulties in assessing their biomass or numbers, and of the whale sharks, which can distort the shark biomass. However, the picture is clear – tunas are the vast majority of the bycatch in all oceans, and the group of large pelagic bony fishes is the next in importance globally. Of this bycatch, only the juvenile bigeye tunas require some action to reduce the magnitude in some ocean basins. For the others, a combination of utilization and reducing the mortality of very small individuals that are not to be retained would address the issue.

17. Final conclusions

The traditional approach to bycatch reduction has been the technical development of more selective gear and the improvement of operational practices, and it continues to be one of the clear ways to achieve many of the desired goals without the disruption of the economic activity, loss of employment, and impoverishment that follows the closure of fisheries. At a global level, the resources dedicated to these efforts are minimal, and the number of gear experts that could interact with the fishers to accelerate the testing and adoption process is limited.

When there is a technical solution, the adoption of bycatch mitigation gear and procedures is the next hurdle. In some countries, command-and-control, top-down approaches based on strict and detailed regulations are the procedure of choice. These require an extensive and costly enforcement system, and usually evolve into very rigid regulations. They also stifle creativity because changes are sanctioned, and testing requires a long process of authorization. In most of the world, the political weight of the fisheries agencies and the will of the governments to develop these type of strict programme are often lacking. In the experience of the authors of this review, a bottom-up approach where fishers play a role in finding practical solutions that are economically viable has been the best approach (see several case studies in Hall *et al.*, 2007). Learning to communicate and interact with the fishing community is a characteristic of successful programmes; scientists and managers should acquire the necessary skills, and join forces with social scientists to optimize the use of resources, and maintain a fluid connection with the community (Campbell and Cornwell, 2008). The first step towards the solution of a bycatch problem is to accept that there is one. The second is to change the perception by some fishers that scientists and managers are the enemy.

To be successful, it is necessary to adopt integrated approaches, addressing the problems in their different stages. For species such as sea birds or sea turtles, protecting nesting areas is a necessary component of a solid conservation approach. When fisheries bycatch is a significant issue, it should be tackled in the different fisheries, being aware of its relative importance. Intelligent priority-setting will make for more efficient use of resources.

ECONOMIC AND OTHER INCENTIVES

Incentives are needed, and here is an area in development, exploring new options connecting the users with the impacts caused and increasing participation of all stakeholders in the definition of the management approach (Hilborn, 2004; Ferraro and Gjertsen, 2009; Gjertsen, Hall and Squires, 2009; Gjertsen and Niesten, 2010; Pascoe *et al.*, 2010; Gutierrez, Hilborn and Defeo, 2011). The range of potential incentives is broad, from the threat of embargoes and economic sanctions, to rewards for performance. Some of these have been used to push the adoption of turtle excluder devices and dolphin mitigation techniques (Jenkins, 2002, 2006).

Among the promising approaches to reduce bycatch are:

- Rewards for innovation: Awards and/or economic rewards to fishers and other innovators for concepts that improve fishing gear and contribute to the reduction of bycatch are a positive way to encourage people to propose and test new ideas. The Smart Gear Award, organized by the World Wildlife Fund is an example (www.smartgear.org/).

- Lower the costs of gear replacements: Eliminate import tariffs and taxes when products are not built in a nation. Governments or organizations can subsidize the construction or purchase of the equipment needed. They could also offer trade-ins of old gear for new gear. Bulk purchases may lower the costs of materials and instruments.
- Waive permits or other fees for vessels adopting the improved technology.
- Increase the cost of capture of unwanted species or individuals: A tax may be assessed by tonne captured on an unwanted species when observers are witnessing the operations. Alternatively, the cost of the fishing license may be determined with a sliding scale depending on the capture of the unwanted species.
- Subsidies to undertake programmes researching catch storage and food technology, to broaden the range of products retained, are another option. Marketing actions would also favour the utilization of more species, and the reduction of impacts on those overfished.
- Add a licence fee per FAD deployed or per FAD set, to control the expansion of the effort, or waive fees to those deploying a number below a predetermined threshold.
- Restrict fishing from some areas to vessels with large bycatch, the equivalent of a closure but only for vessels not meeting some standards. Or apply longer closures to those not meeting the standards.
- Conservation investments: In this modality, those causing an impact make a contribution to some conservation activity as a way to offset the impact. For example, vessels with high mortality of some species fund the research projects on ways to reduce bycatch, or pay for the development and construction of instruments to improve handling of the capture. Some examples with sea turtles are provided by Ferraro and Gjertsen (2009), Janisse *et al.*, (2009), and Gjertsen and Niesten (2010). For some species such as sea turtles, it is easy to find actions to protect nesting habitats, but for other pelagic species such as sharks, it will require more creativity.

The options mentioned above are only selection of what broad set of options. In some cases, it may be difficult to find an investment to match the impacts, or to identify the level of responsibility of the different sources of impacts. An important factor in determining the success or failure of this approach is that the activities identified are clearly and directly targeted to the conservation outcome desired. If these investments become a source of funding for researchers pursuing a broader agenda of knowledge, then the approach will not be effective.

A powerful combination of approaches would be linking the incentive or conservation investment programme to a more refined definition of the value of each individual, based on population dynamics or reproductive value, or a function of both (Heppell, 1998; Heppell, Caswell and Crowder, 2000; Gallucci, Taylor and Erzini, 2006; Wallace *et al.*, 2008; Pascoe *et al.*, 2010). For example, fishers willing to operate in an area with a concentration of highly valuable individuals will have higher costs for their licences.

SPATIAL MANAGEMENT, MARINE PROTECTED AREAS AND BYCATCH REDUCTION

In many of the above sections, spatial management has been considered as an alternative to reduce effort in areas with high density of the different species. There are some obvious cases, such as the proximity of turtle nesting beaches during the season when thousands or tens of thousands of turtles are in a limited area. In these cases, the significance of the location is obvious, and the area is well defined. In other cases, in the pelagic ecosystems, the areas tend to be much larger (Alpine and Hobday, 2007), and the impact is more diffuse, so the delimitation is more complex (Martin *et al.*, 2007;

Miller, 2007; Game *et al.*, 2009, 2010; Kaplan *et al.*, 2010). In other cases, oceanographic changes may affect the location of the areas to protect, and adaptive closures are more complex, unless a fleet information system is implemented (Gilman, Dalzell and Martin, 2006), or real-time oceanographic data can help determine the boundaries of a marine protected area (MPA). Fonteneau (2007) reviews the application of the concept of MPAs specifically to tuna fisheries, taking into account the different types of movements of tunas, from real migrations to other types of movements, and the peculiarities of these widespread pelagic fisheries. Some of the concepts apply to bycatch issues.

For some, MPAs are the cureall of fisheries management. They are prescribed for every disease, with the idea that they may produce a miracle cure, and that they probably will not have negative side-effects. They are a good component in the toolbox available for fisheries management, and where used intelligently, and in combination with several other tools, they are an effective instrument (Jennings, 2009; Gutierrez, Hilborn and Defeo, 2011).

The option of spatial management was mentioned in several of the sections above, to achieve bycatch reduction goals. However, most of those options were not concordant. The area to close for protection of nesting leatherbacks is different from the area to close for protection of juvenile silky sharks, etc. When an area is closed, effort will increase in other areas, so protection of some species may be achieved at the expense of added impacts on others.

Besides those impacts on other species, the search for the ideal location for these areas should consider the negative impacts on the production of the fishery (Watson *et al.*, 2009) in order to facilitate compliance, and increase acceptance.

The provision of funding to maintain an adequate level of implementation of the MPA system, including monitoring and enforcement, is difficult, especially for countries with acute social problems, widespread poverty, etc. This is another area where participation of fishers is crucial for the success of the process.

What is more complicated is to harmonize all the management measures into a condensed structure (Jennings, 2009; Robb *et al.*, 2010). The possibility of the ocean defined as a mosaic of open and closed areas is attractive to many. Integrating all the conservation measures into a coherent unit will not be easy; some priorities will be easy to decide, but there will be cases of conflicts in the evaluation of different impacts, as the tuna–dolphin issue demonstrated (Hall, 1998).

The difficulties of implementation of MPA should not deter managers from their utilization (Game *et al.*, 2009, 2010). However, the task is not a simple one (Kaplan *et al.*, 2010), and understanding that MPAs alone cannot fix all problems is a significant step for managers and stakeholders.

THE HUMAN COMPONENT OF BYCATCH MANAGEMENT

Most successful programmes to reduce bycatch have been the result of a mixture of components that range from solid leadership in the different participants in the process, intelligent pressures to break the inertia and keep the process moving, and creativity from all sectors.

Successful programmes bring together talents and strengths from all stakeholders, and develop a cooperative framework. In some developed countries, command-and-control, top-down systems may be the way chosen to implement a programme, but in most of the world, this is not an option. Instead, systems with strong participation are the best choice, and frequently the only ones that will ensure a good level of compliance.

Intelligent leadership from non-governmental organizations, from the fishing sector, fishers unions and cooperatives, and conservation organizations is also crucial. Realistic and pragmatic leaders that do not lose sight of the objectives are also needed.

Scientists and managers that can communicate well with fishers and other stakeholders are another critical component. Pressures to publish reduce the time available for the type of informal contacts that build relationships with the fishers. The usual university training of fisheries scientists does not include communications skills, except perhaps to communicate in scientific meetings, etc. The needs of this type of communication are different, and perhaps some social sciences training could help improve this. It is not only shedding the unnecessary jargon, but learning to understand the motivations and expectations from a variety of participants. Scientists also need to be motivated to find solutions to the problems that do not eliminate the activity or make it economically unviable.

The approaches to dealing with bycatch problems have evolved considerably, from the very rough interactions between stakeholders that could not find common ground on the tuna–dolphin problem (Hall, 1998; Hall and Donovan, 2002; Perrin, 2004) in the 1970s and 1980s, to the different success stories in recent years (Kennelly and Broadhurst, 2002; Hall, Campa and Gómez, 2003; Hall *et al.*, 2007).

A major step forward has been to understand that bycatch is, in most cases, a technical problem that should be tackled with a patient, and methodical, scientific approach (Dagorn, Dagorn *et al.*, 2006b, 2009; Dietrich, Parrish and Melvin, 2009), with practical solutions developed in cooperation with the fishers and their communities, and with the participation of the groups interested in conservation (Melvin, Parrish and Conquest, 1999; Melvin and Parrish, 2001; Kennelly and Broadhurst, 2002; Hall and Mainprize, 2005; Largacha *et al.*, 2005; Sridhar, 2005; Hall, Vogel and Orozco, 2006; Hall *et al.*, 2007, 2008; Kennelly, 2007; Gilman, Kobayashi and Chaloupka, 2008; Laporta *et al.*, 2008). Figure 158 maps the options for bycatch reduction programmes for the different taxa, highlighting the opportunities available in each "line of defence". The diagram emphasizes the sequential approach that is followed to define the strategies to tackle bycatch problems. There is a series of opportunities that may be taken advantage of, and the objective may be achieved by small gains in several lines of defence, rather than a single, complete solution.

Furthermore, the multiple objectives of management and even of bycatch mitigation programmes should be considered in a holistic manner in order to avoid repeating past errors (Hall, 1998; Vaca Rodriguez and Enriquez-Andrade, 2006). The lessons of the past have not been wasted, and the experience has been incorporated into the modern strategies to implement bycatch mitigation programmes (Hall and Mainprize, 2005).

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Appendix 1

COMPARISON OF VARIABLES FROM OBSERVER PROGRAMMES

TABLE A1.1
Trip data

	IATTC	FFA	Spain	France
Trip Number	●	●	●	●
Vessel Number	●	●		●
Vessel Name	●	●	●	●
Observer Name	●	●		●
Flag	●	●		
Depart Date	●	●		
Arrive Date	●	●		
Capacity	●	●		
Depart Port	●	●		
Arrive Port	●	●		
Net Length	●	●		
Net Depth	●	●		
Net Mesh Size	●	●		
Safety Panel Type	●			
Safety Panel Length	●			
Safety Panel Depth	●			
Safety Panel Mesh Size	●			
Number Speedboais	●	●		
Bow Thruster present	●			
Aircraft present	●	●		
Sonar present	●	●	●	●
Ring Stripper present	●			
Number of Screws	●			
Power Block Size	●			
Raft present	●			
High Intensity Floodlight present	●			
Blind Radar present	●	●		
Diver Equipment present	●			
Quality Codes	●			
Captain Information	●	●		
Observer Information	●	●		
Vessel registration number		●		
Fishing permits license number		●		
Radio Call sign		●		
Vessell Owner		●		
Work with tender vessel		●	●	●
Skiff date		●		
Helicopter information		●		
power Block Details		●		
Winch details		●		
Brall Capacity		●		
Electronics details		●		
Crew details		●		
Well configuration details		●		
Safety equipments details		●		
Communication equipment details		●		

TABLE A1.2

Sets data

	IATTC	WCPFC	ICCAT/IOTC	
	IATTC/Nat. Programs	SPC/FFA	Spain	France
All types of sets:				
Set Number	Yes	Yes	Yes	Yes
Set Type	Yes	Yes		
Set Date	Yes	Yes	Yes	Yes
LetGo time	Yes	Yes	Yes	Yes
RingsUp time	Yes	Yes	Yes	Yes
Endset time	Yes	Yes	Yes	Yes
Strong Currents present	Yes			
Malfunction information	Yes	Yes		
Well loading data	Yes	Yes	Yes	Yes
Begin/end pursing		Yes		
Begin/end brailing		Yes		
Tuna catch of set	Yes	Yes	Yes	Yes
Tuna discards of set	Yes	Yes	Yes	Yes
Cumulative tuna catch		Yes		
Tuna estimation before the set			Yes	Yes
Sonar tuna readings			Yes	Yes
Net depth at rings up			Yes	Yes
Reason a set is not made		Yes	Yes	Yes
Marine Mammal sets:	Yes	Yes		
Dolphin school composition estimations	Yes	Yes		
Dolphin school size estimations	Yes	Yes		
Explosives use (seal bombs)	Yes			
Dolphin behavior (during chase, set, backdown)	Yes			
Dolphin rescue effort by the crew	Yes			
Backdown times	Yes			
Fish lost during backdown	Yes			
Dolphin mortality by spp. and cause	Yes	Yes		
Dolphin injury	Yes	Yes		
Number of bow bunches pulled	Yes			
Presence of net canopies and/or collapses	Yes			
Use of High Intensity Floodlights after sundown	Yes			
Use of speedboats to tow the net during backdown	Yes			
Net configuration sketches	Yes			
Dolphins in net during malfunctions				
Marine Mammal sightings:	Yes	Yes		
Dolphin school composition estimations	Yes	Yes		
Dolphin school size estimations	Yes	Yes		

TABLE A1.3

Effort data

	IATTC	FFA	Spain	France
Vessel mode (in port, search, run, drift)	●	●	●	●
Observer on duty	●	?		
Position durig the day	●	●	●	●
Marine mammal sighting information	●	●		
Crew search activity	●	●	●	●
Vessel speed	●	●	●	●
Environmental (SST, Wird speed)	●	●	●	●
Environmental (Cloud cover, Visibility)	●			
Helicopter/plane assistance	●	●		
Cue to set	●	●		
Distance to cue	●	?	●	●
UTC time		●		
Helicopter take-off/landing times		●		
Transhipment activities		●	●	●
Code group fishing activity			●	●

TABLE A1.4

Capture and bycatch

	IATTC	FFA	Spain	France
Tuna tonnage caught and loaded by spp. and size	●	●	●	●
Reason for tuna discard	●	●	●	●
Bycatch by spp. And number	●	●	●	●
Billfish, shark, turtles: identification characteristic	●	●		
Non-tuna spp. Siza measurements	●	●	●	●
Utilization of bycatch (discarded, treated as catch, etc)	●	●		
Tag information (turtles, tuna, fish)	●	●		
Specimen collection	●	●		
Tuna size measurements		●	●	●
Other fauna size measurements (fish, turtles, cetaceans)		●	●	●

TABLE A1.5

Floating objects

	IATTC	FFA	Spain	France
Object number	●	●	●	●
Object Count	●	●		
Set Number	●	●		
Date and Time	●	●	●	●
Position	●	●		
Object origin	●	●	●	●
Object type	●	●	●	●
Object disposition (eg. Left in water, removed)	●	●	●	●
Locate method	●	●	●	●
Object soak time			●	●
Hanging net information	●	●		
Bait information	●			
Turtle presence	●		●	●
Turtle Entanglement	●		●	●
Other spp. Presence	●		●	●
Size and depth of the object	●	●		
Water clarity	●			
Percent of object covered in flora	●			
Components making up the object	●	●		
Location equipment attached	●	●	●	●
Transmission capabilities of location equipment	●			

This report provides a review of our knowledge of the bycatches, defined as discarded dead, from the tropical tuna purse seine fisheries of the world. The major fishing grounds involved (eastern and western Pacific, eastern Atlantic, and western Indian Oceans) share the gear, the ways of fishing, and the structure of the pelagic communities. Because of that, the species taken in association with tuna schools tend to be the same in all regions.

After describing the gear and fishing operations, it discusses the reasons why bycatches happen, and explores the options to mitigate them.

The types of sets used to capture tunas and the detection methods used to locate the schools are a major factor to determine which are the catches and the bycatches. The main bycatches are tunas, sharks and rays, pelagic bony fishes, billfishes, and sea turtles. The total discards amount to one to five percent of the total tonnage captured, and tunas of the species targeted amount to over 90–95 percent of those bycatches. The silky shark is the most common shark species by far, followed by the oceanic whitetip sharks. Marlins and sailfishes are also taken but in reduced numbers. Olive ridley sea turtles are the most common turtle captured, but the majority of them are released alive and unharmed. Rainbow runners, mahi-mahis, wahoos and amberjack yellowtail are the major pelagic bony fishes taken with the tunas. They are being retained in increasing numbers for utilization.

Besides discussing problems of estimation, the report presents most of the ideas proposed or in different stages of testing, to mitigate those bycatches, including ways to avoid the captures, or to release the individuals from the net or from the deck.

Finally, the known or potential ecological impacts of the rapidly increasing fishery on fish aggregating devices (FADs) are reviewed, emphasizing some of the uncertainties that still prevail.