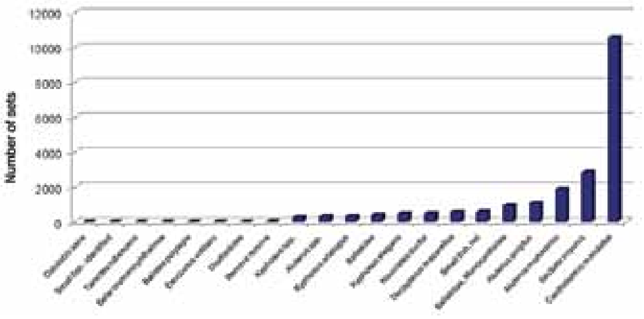
13. Large pelagic bony fishes (other than tunas)

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).

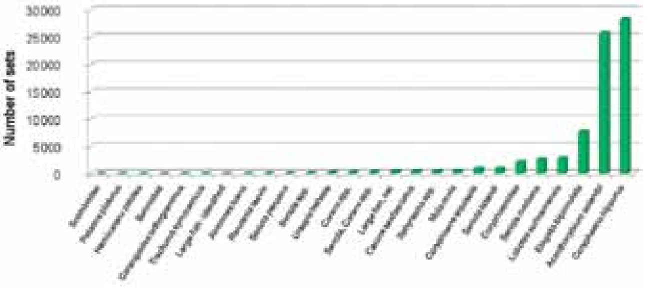
FIGURE 132
Presence of small fish species in the Eastern Pacific Ocean, 2005–09



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

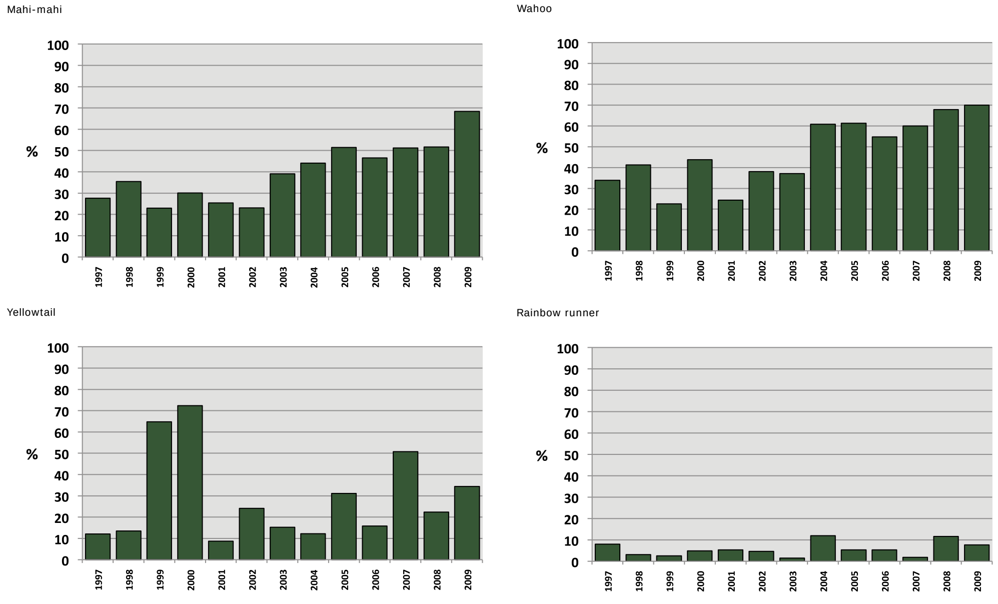
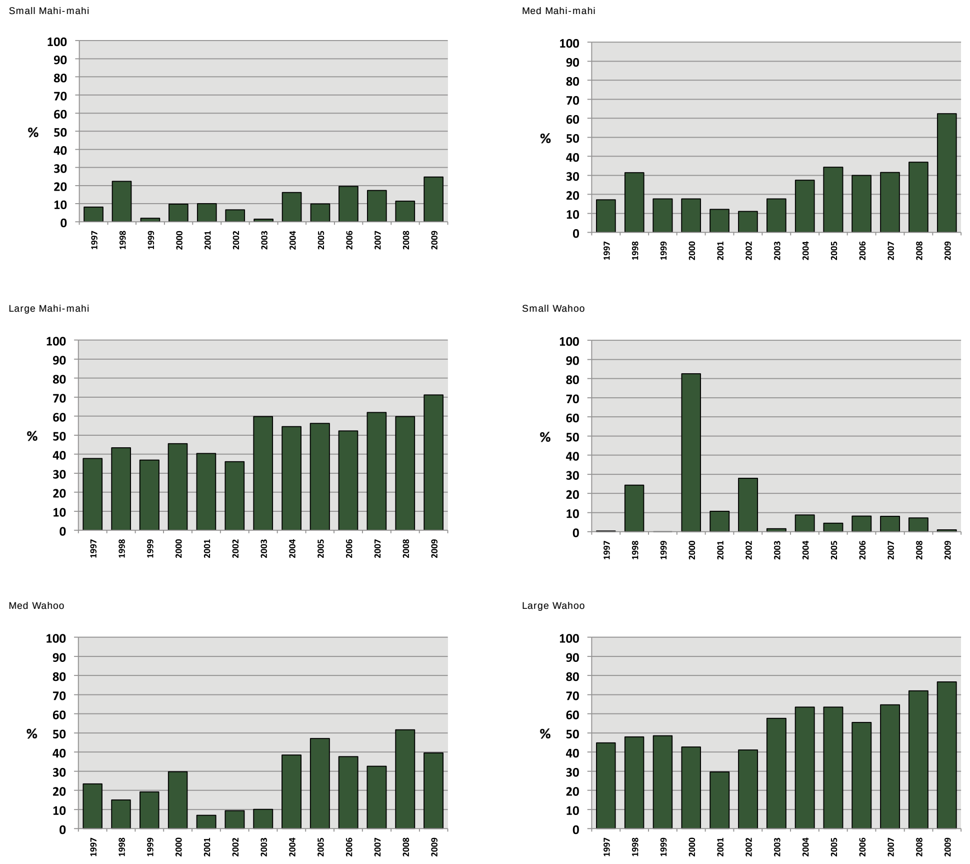


FIGURE 135

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.

FIGURE 136

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

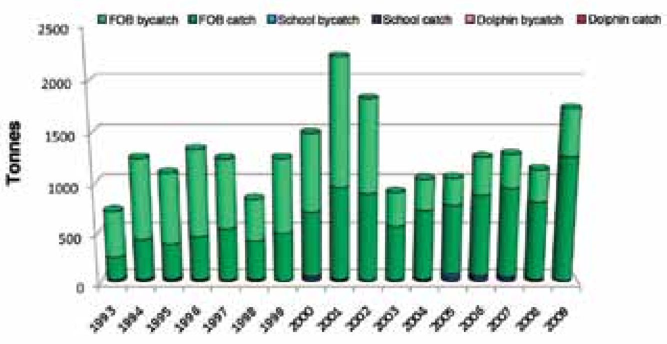


FIGURE 137

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

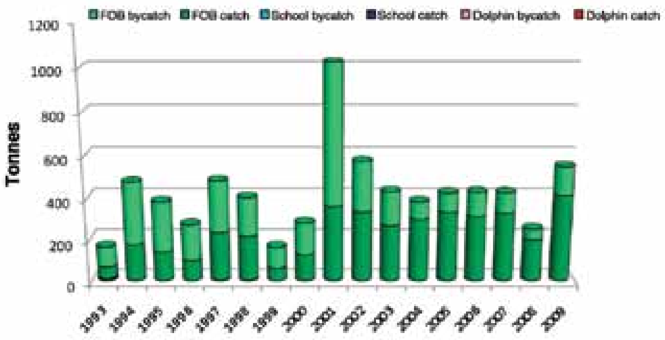
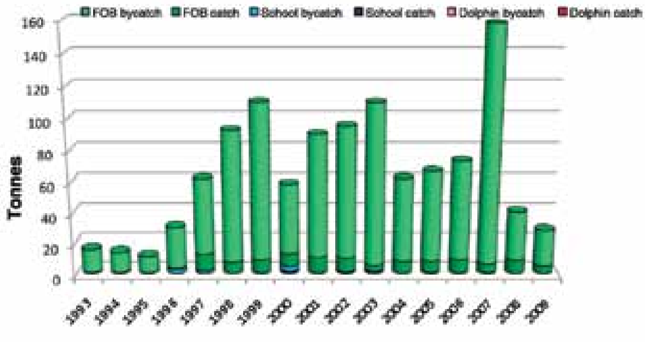


FIGURE 138

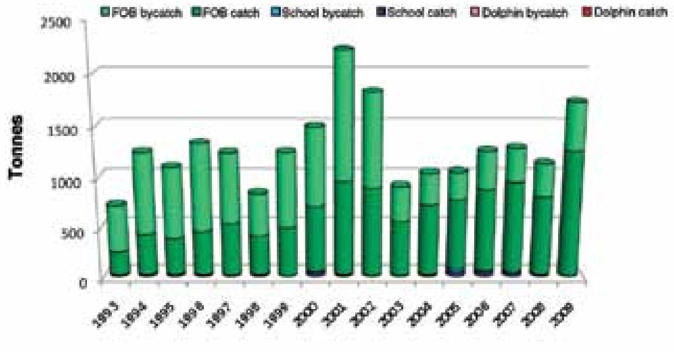
Rainbow runner: total annual catch and bycatch by set type in the Eastern Pacific Ocean



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 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.

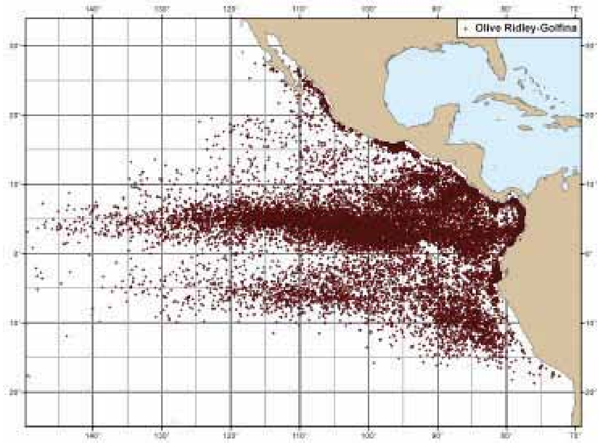
Sea turtles are captured in most types of fishing gear (Lewison, Crowder and Shaver, 2003; Lewison *et al.*, 2004; Lewison, Freeman and Crowder, 2004), and the level of mortality of many of the fisheries where interactions occur is unknown. The long migrations, sometimes transoceanic, of many species 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.

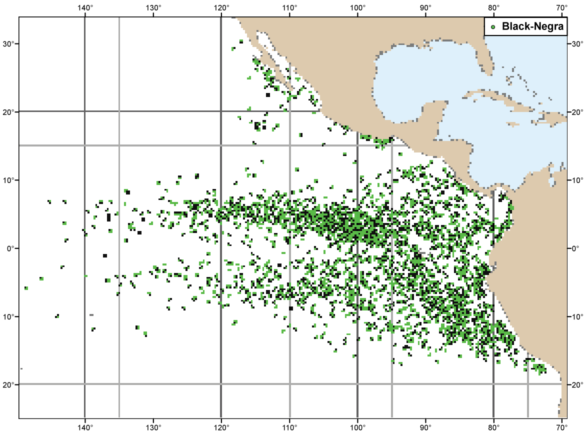
However, turtle captures in purse seines are quite uncommon in most oceans, and the frequency of encounters is usually less than 1 percent of the sets, with captures numbering generally one individual. With low observer coverage, as is the case in most oceans, and those infrequent encounters, it is difficult 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.

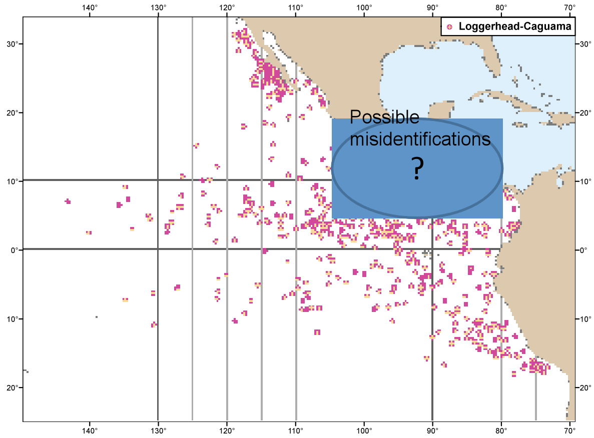
EASTERN PACIFIC

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).

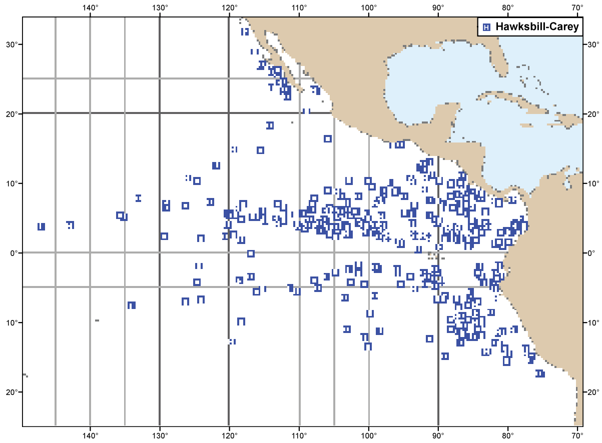
Loggerhead turtles (*Caretta caretta*; Figure 142) and hawksbill turtles (*Eretmochelys imbricata*; Figure 143) follow with about 1–2.5 percent each (Tables 15–18; IATTC, 2004a, 2004b). Juvenile loggerheads spend years in the American continent in Baja California or the Peruvian coast (Boyle *et al.*, 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 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.

(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.

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

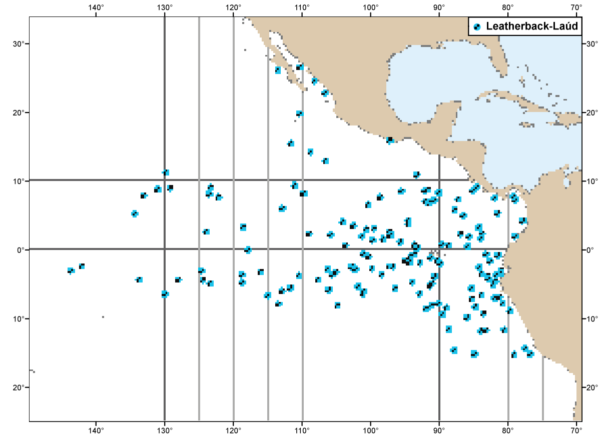
Sources: Bailey, Williams and Itano (1996) and OFP (2001) for 1995–2000; Williams, Kirby and Beverly (2009) for 1995–2007.

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).

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/

FIGURE 144

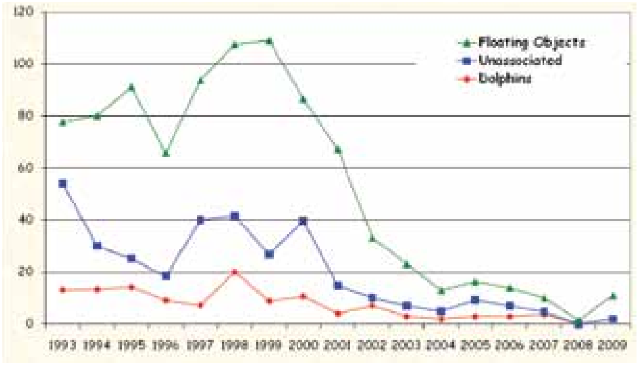
Sets with presence of leatherback sea turtles in the Eastern Pacific Ocean, 1993–2008



Source: IATTC observer database.

FIGURE 145

Incidental mortality of sea turtles in the Eastern Pacific Ocean, 1993–2008



Source: IATTC observer database.

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).

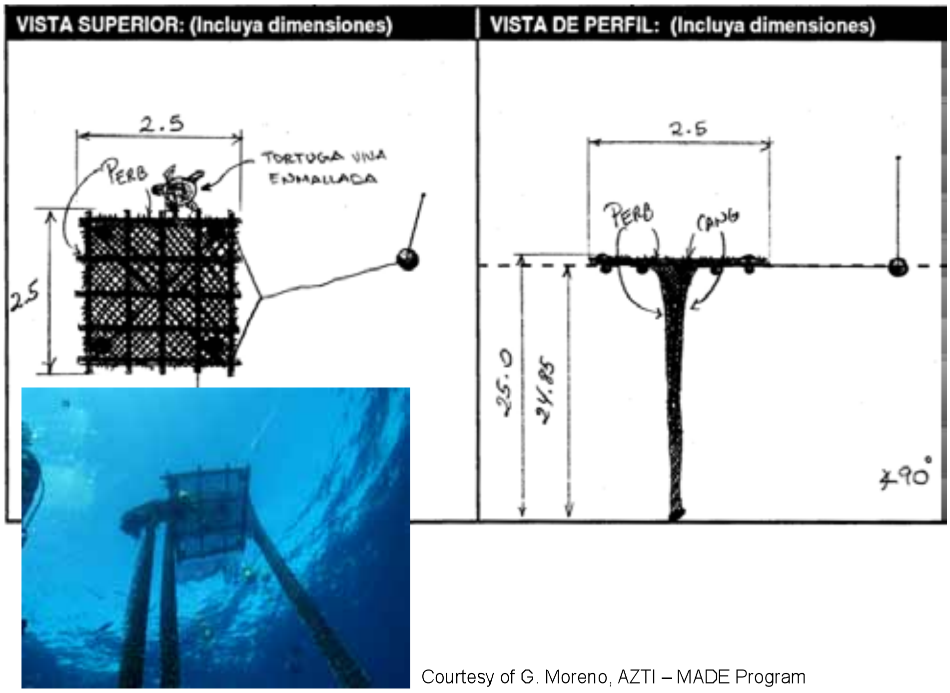
In all these indices, there is a confounding effect because changes in sea turtle abundance and in fleet (or sampling) spatial distribution may affect the figures, and it will be necessary to account for all these possibilities in the analyses.

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

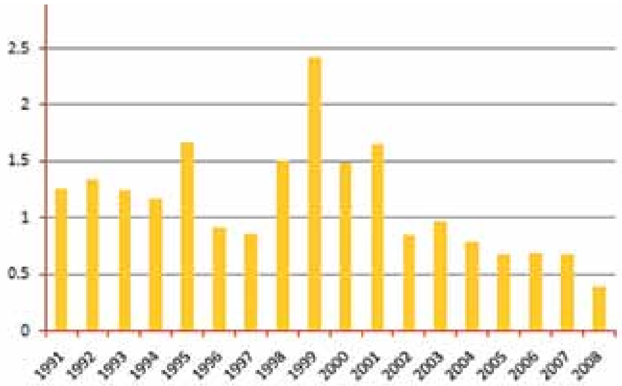
Observer diagram of entangled turtle, and photograph of webbing under the FAD



Courtesy of G. Moreno, AZTI – MADE Program

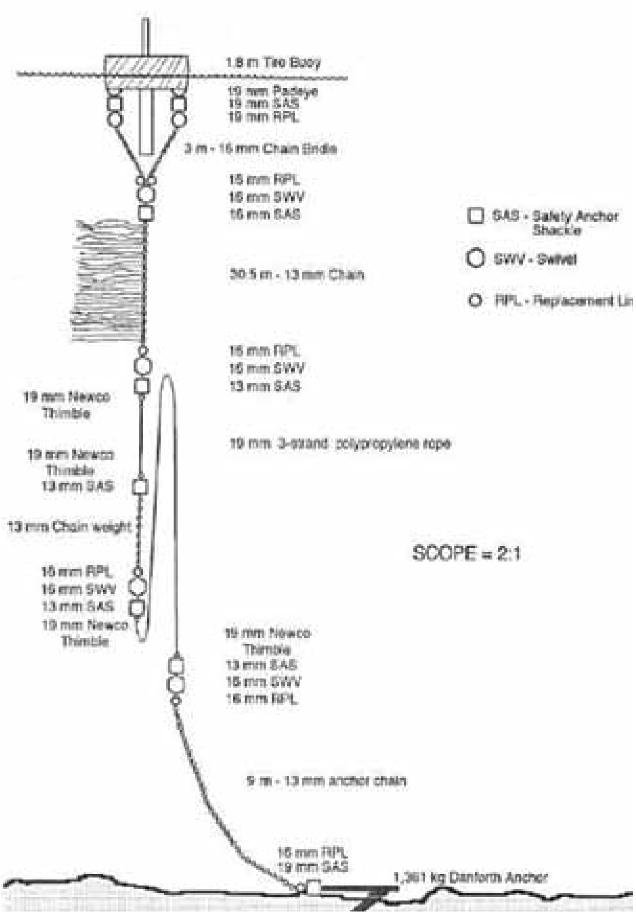
FIGURE 147

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.

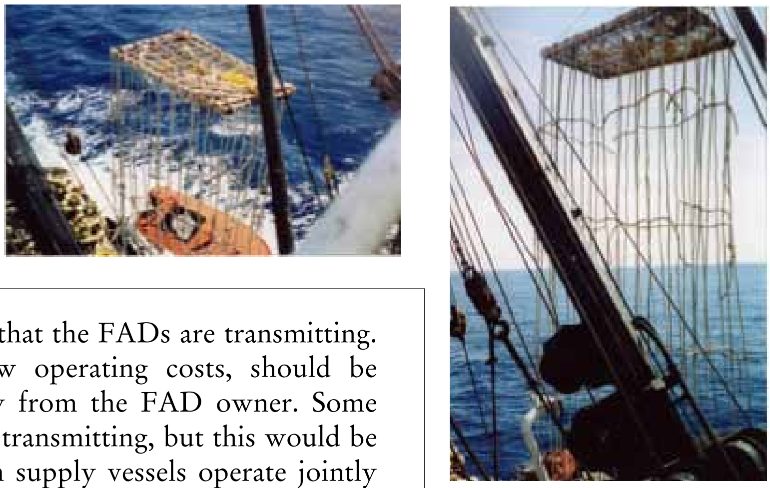
A hazard to sea turtles from the FAD fishery that could be mitigated is the entanglement in the netting that fishers hang under and around the FAD (Figure 146; Anderson *et al.*, 2009). As fishers believe that the netting plays an important role in the attraction of fish, it would not be easy to eliminate 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

PLATE 11
Rope structure to attract tunas.



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.

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

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).

PLATE 13
Tuna attractive system. No entanglement experimental FAD (Instituto Español de Oceanografía).

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.

FIGURE 149
FAD with only biodegradable materials

FIGURE 149
FAD with only biodegradable materials

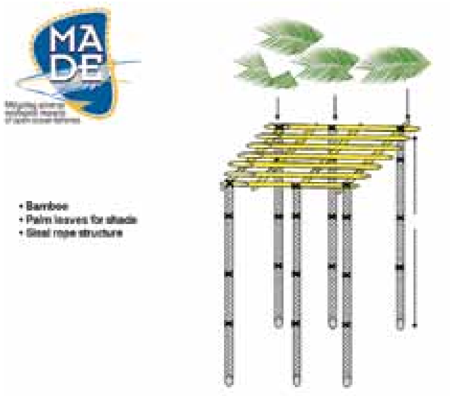


FIGURE 150
FAD with mostly biodegradable materials

FIGURE 150
FAD with mostly biodegradable materials

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 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

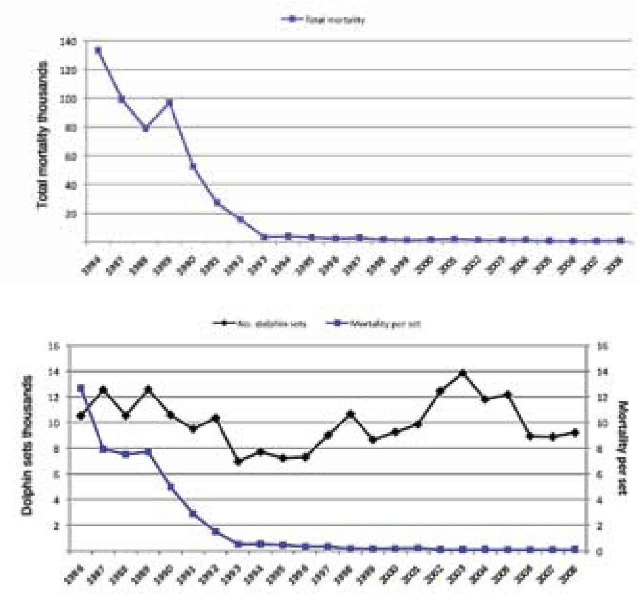
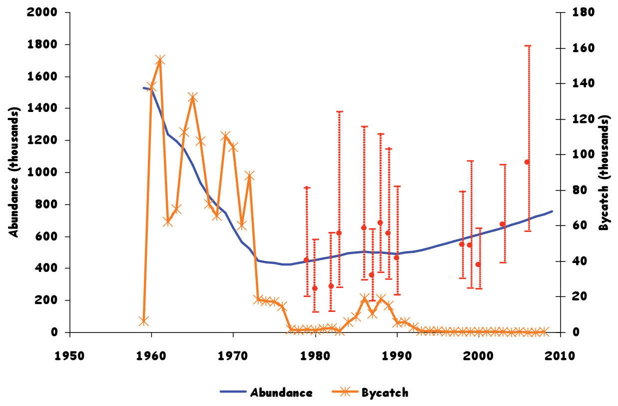


FIGURE 153
Spinner dolphin (Eastern stock)



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)

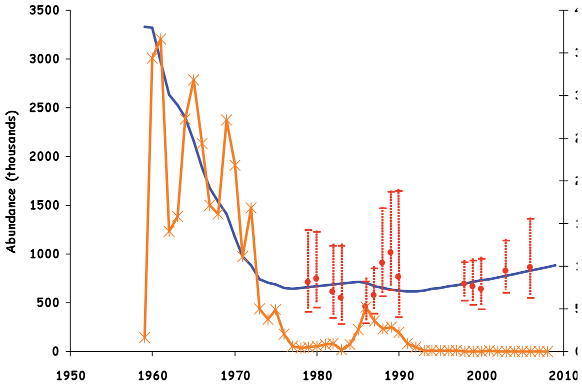
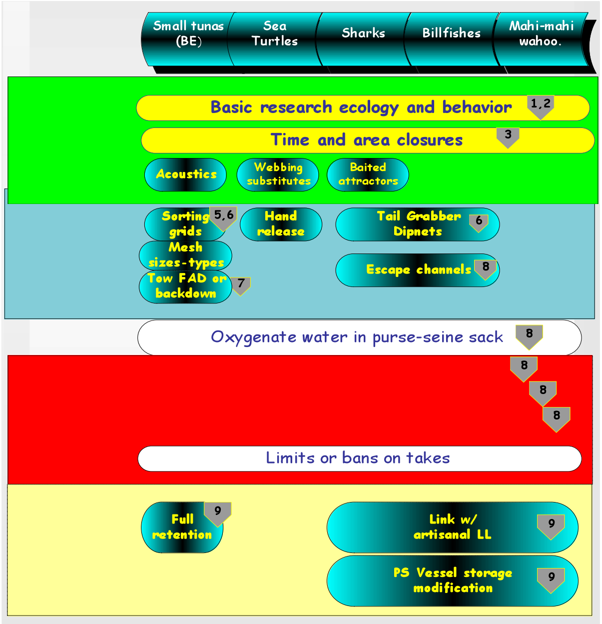


FIGURE 158

Strategies available to develop technical and operational mitigation measures



MANAGEMENT ACTIONS

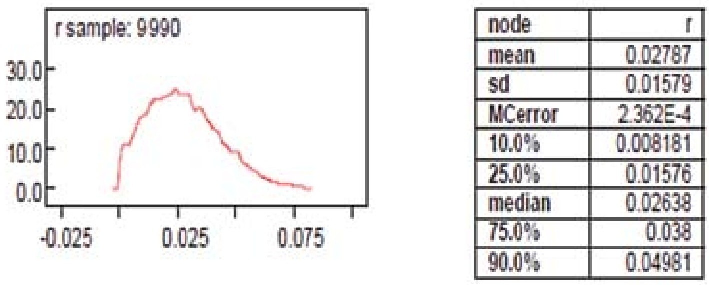
On the management side, an agreement was signed in La Jolla in 1989, and expanded by the AIDCP (www.iattc.org/IDCPENG.htm; Joseph, 1994; Hedley, 2001). These agreements: regulated the equipment the vessels should carry; established a system based on an overall dolphin mortality limit, complemented with 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

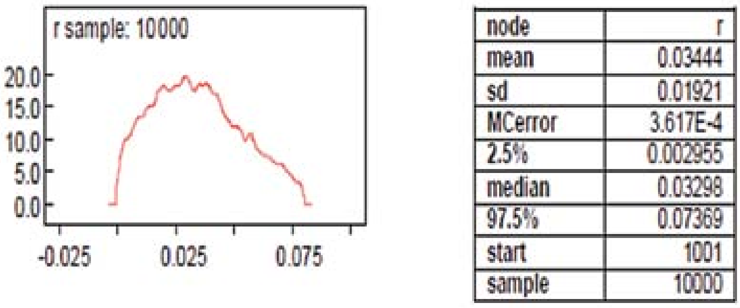
Estimates of 'r' for northeastern spotted dolphins



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).