10. Tunas

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

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

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

BYCATCH OF YELLOWFIN, SKIPJACK AND BIGEYE TUNAS

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

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

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

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

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

Tuna sizes and set type

A major cause of differences in the proportion discarded is the type of set where the tuna is caught; there are important differences in the length frequency distributions of the captures. In the WPO, payao sets produce the smallest sizes of tunas, followed by increasing sizes in log sets, FAD sets, and school sets (Williams and Terawasi, 2009; IATTC, 2010). For skipjack tunas, the difference is not large (modal sizes 40–50 cm in

TABLE 32
Reasons for tuna discarding in the Eastern Pacific Ocean

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

associated sets vs 50–65 cm for school sets). For yellowfin tunas, the modes associated with payao sets are 20–40 cm, associated sets go from 75 to 110 cm, school sets and longline captures from 110 to 130 cm. For bigeye tuna, again, the payao sets produce a mode at 20–40 cm, associated (FAD and log sets) at 40–80 cm, school sets at 50–70 cm, and longline captures at 100–140 cm.

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

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

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

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

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

Major tuna bycatch

Eastern Pacific

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

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

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

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

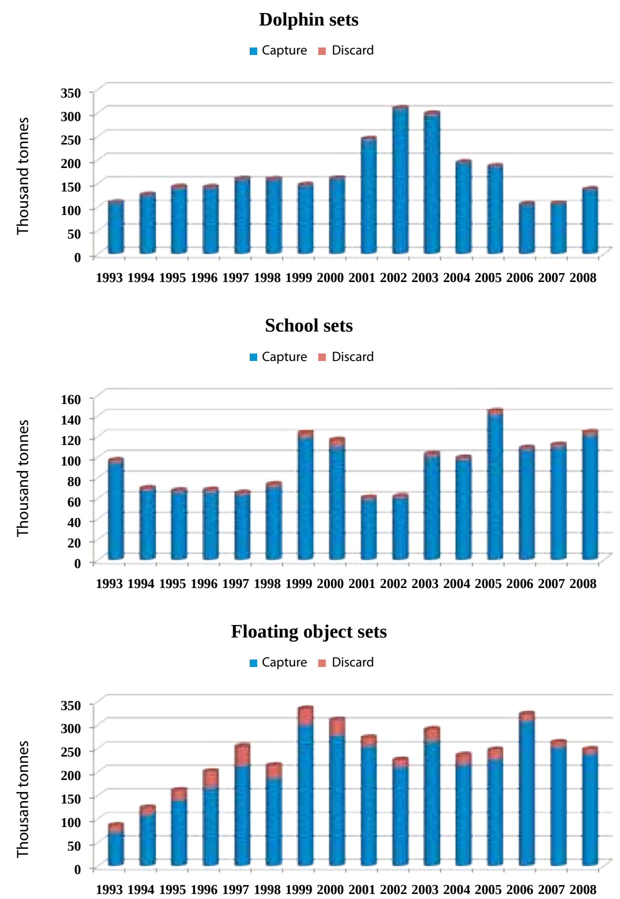
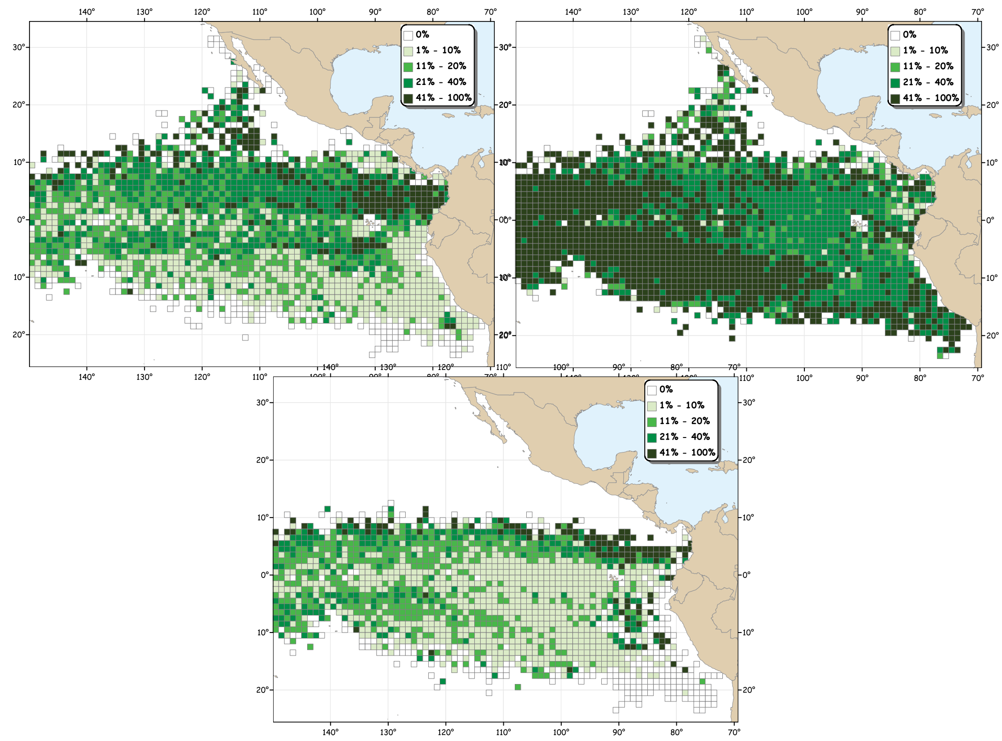


FIGURE 65
Percentage (capture of small tuna species/total tuna species) – sets on floating objects in the Eastern Pacific Ocean, 2001–2009



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

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

Western Pacific

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

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

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

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

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

Atlantic

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

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

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

Indian Ocean

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

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

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

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

THE "MINOR" TUNAS

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

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

The Auxis group

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

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

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

The Euthynnus group

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

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

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

The Sarda group, the bonitos

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

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

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

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

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

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

Catch and bycatch of "minor" tuna species

Eastern Pacific

The main components of the minor tunas group are:

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

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

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

Western Pacific

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

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

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

Atlantic

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

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

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

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

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

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

Indian Ocean

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

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

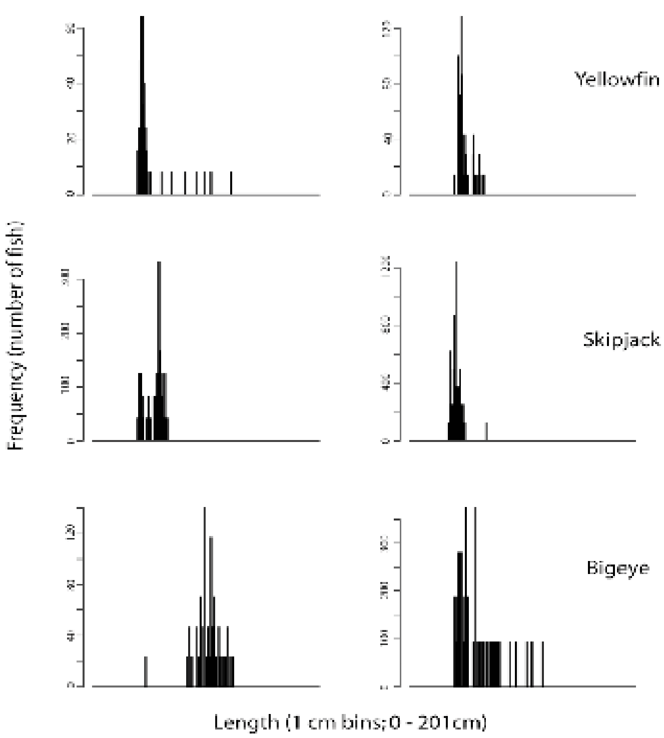
ACTIONS AND CONCEPTS TO REDUCE TUNA BYCATCH

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

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

FIGURE 66

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



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

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

There are two different objectives with regard to tunas:

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

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

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

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

Spatial or spatial–temporal management

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

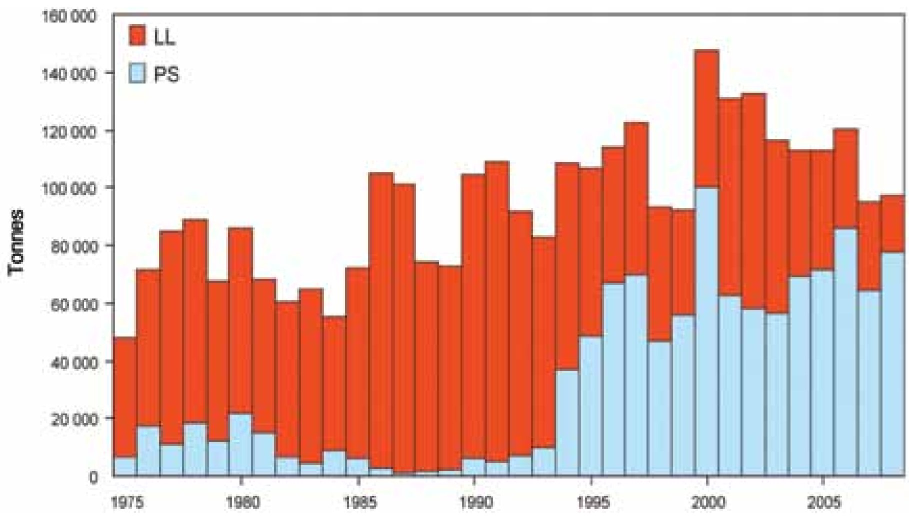
An alternative is the use of fleet communication when an area with a large proportion of small tuna is encountered, in a manner similar to that in use to reduce sea turtle bycatch in the Hawaiian longline fisheries (Gilman, Dalzell and Martin, 2006). Vessels encountering some predefined levels of bycatch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

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

Acoustic information

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

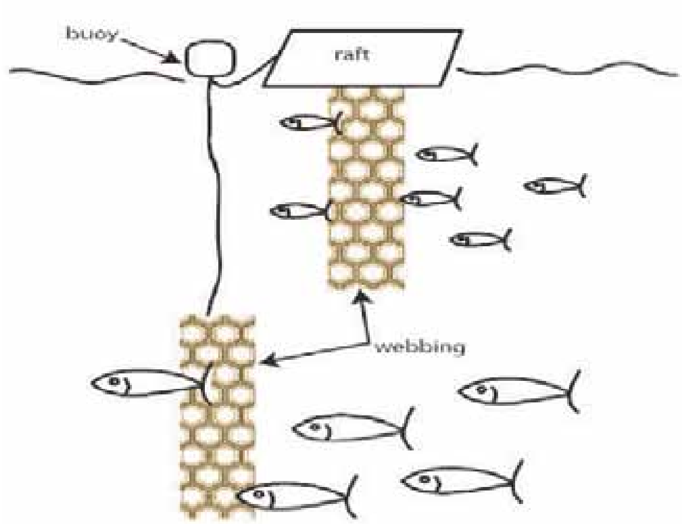
FIGURE 67
Catch of bigeye tuna by gear, 1993–2008



Technological changes

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

FIGURE 68
Vertical double FAD



Source: Nelson (2004).

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

Release from the net

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

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

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

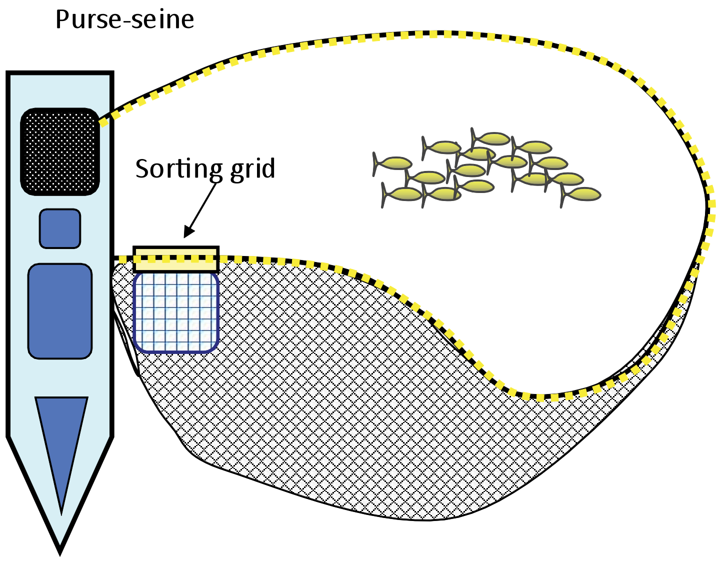


PLATE 3
Flexible sorting grid going through the power block.

PLATE 4

Arrue's sorting grid – details of construction.

PLATE 5

Work on Villar's sorting grid.

PLATE 6
Villar's sorting grid.

PLATE 7
Villar's sorting grid in the water.

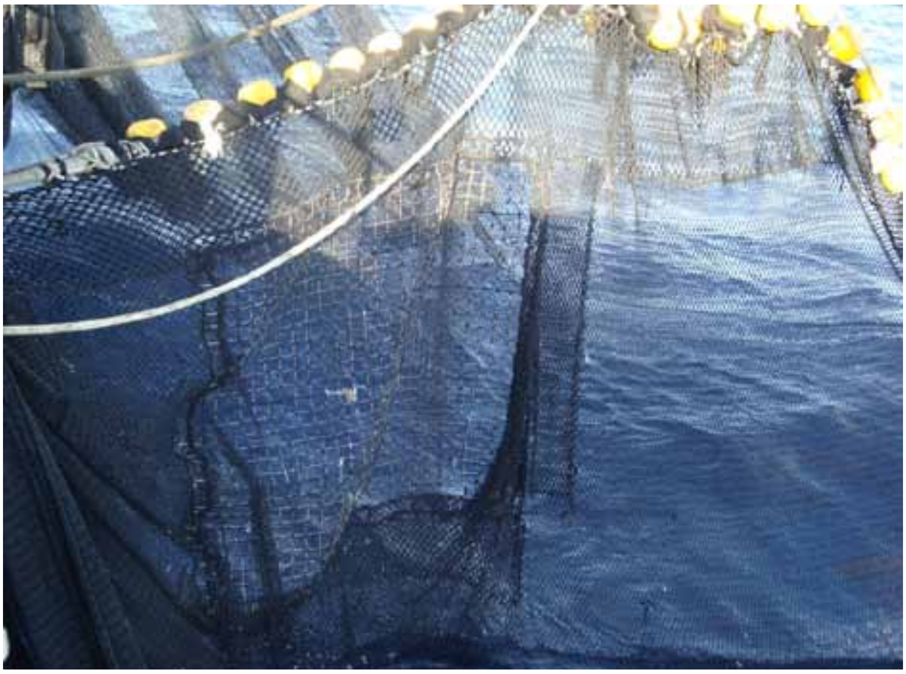


FIGURE 70
Nelson's design – flexible PVC panels

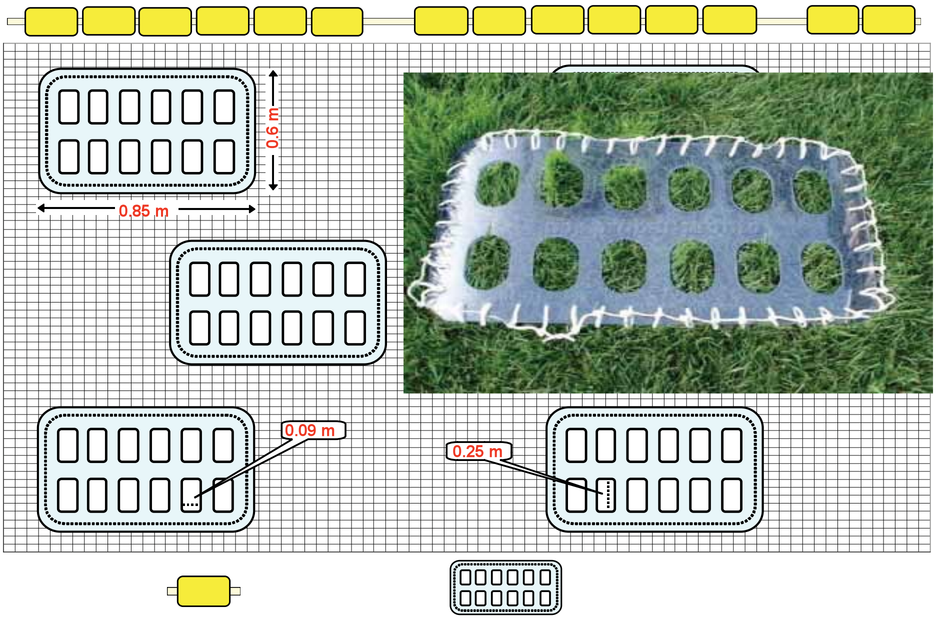


FIGURE 71
Grid design used in Canadian salmon seines

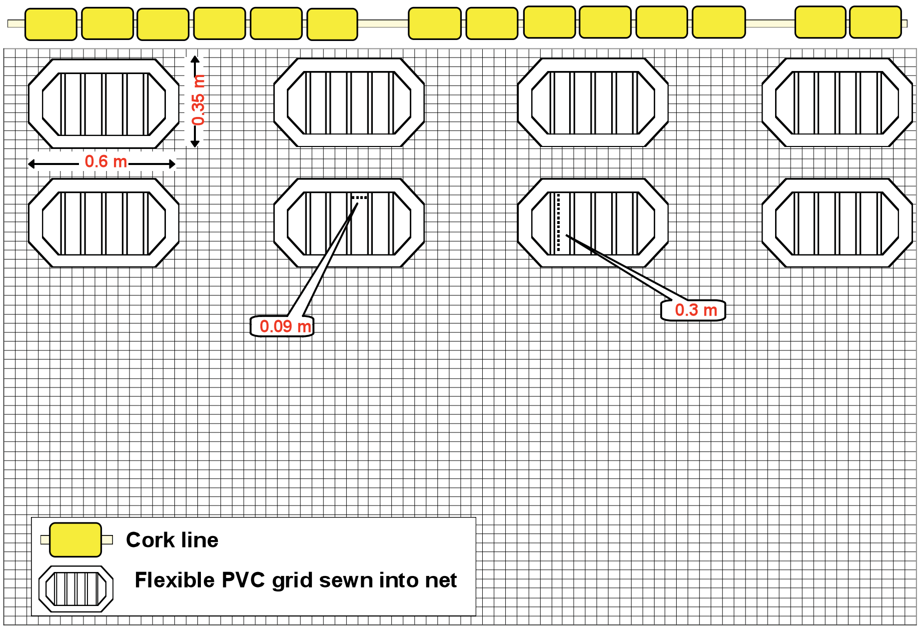


FIGURE 72
Rigid shapes sewn in the webbing

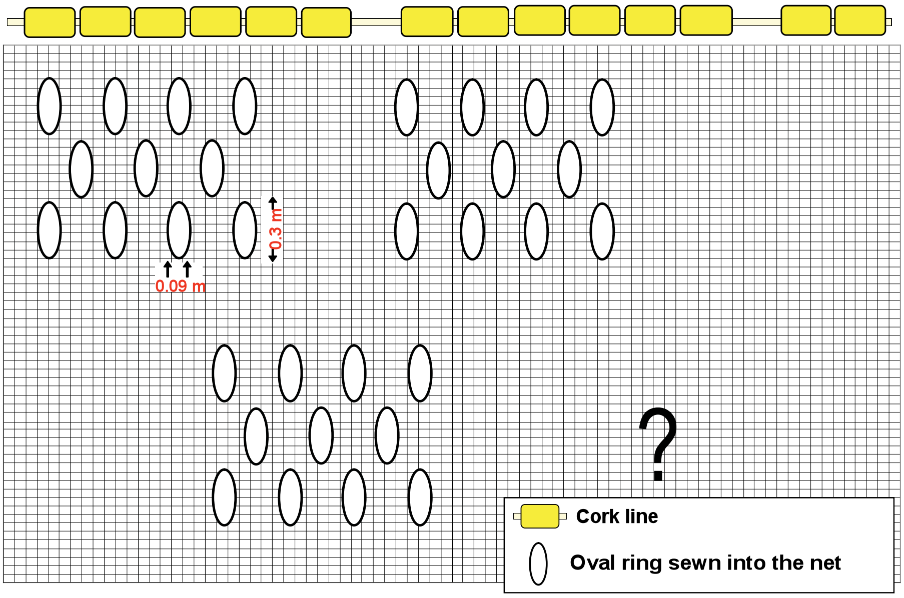


FIGURE 73
Nelson's design: grid framed by high pressure hose

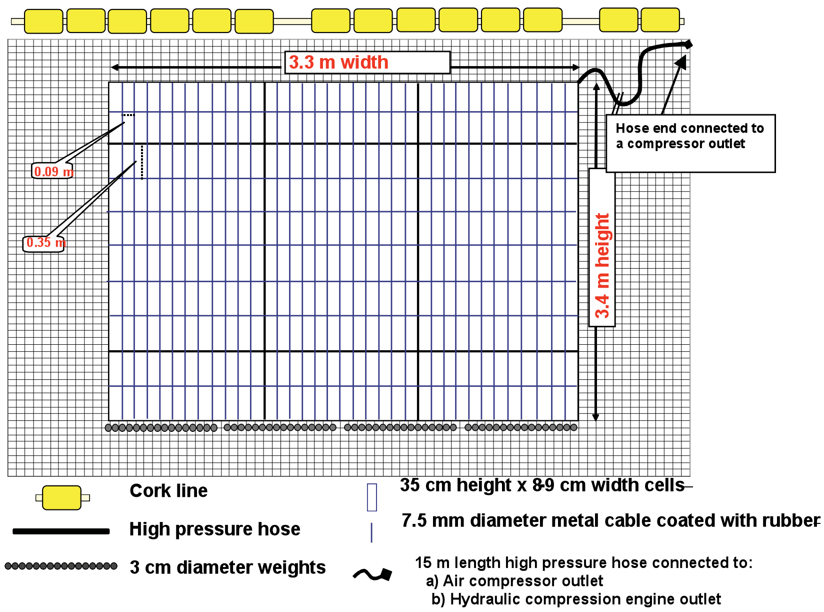


PLATE 8
Zachariassen's grid used in trawls.

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

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

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

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

		YFT+BET (tonnes)					
		<2,5 kg			>2,5 kg		
% submerged	No. sets	Capture	Escape	% escape	Capture	Escape	% escape
1-25	351	740	7	0.9	4336	0.5	0.01
25-50	296	727	7	1	3139	0.8	0.02
50-75	292	205	14	6.7	2657	3.4	0.13
75-100	222	219	3	1.3	1814	1.7	0.09

		SKJ (tonnes)					
		<2,5 kg			>2,5 kg		
% submerged	No. Sets	Capture	Escape	% escape	Capture	Escape	% escape
1-25	351	4548	19	0.4	3842	0.3	0.01
25-50	296	4671	48	1	3121	6	0.19
50-75	292	1802	78	4.3	3721	31.6	0.84
75-100	222	1303	60	4.6	3380	36.3	1.06

Note: Capture includes those that escape.

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

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

		Mahi-mahi			Wahoo			Yellowtail		
% submerged	No. sets	Capture	Escape	% escape	Capture	Escape	% escape	Capture	Escape	% escape
1-25	351	14547	1826	12.6	4931	102	2.1	376	60	16
25.50	296	15645	6147	39.3	4957	171	3.4	219	22	10
50-75	292	13323	5665	42.5	6975	545	7.8	80	28	35
75-100	222	14330	7175	50.1	4745	443	9.3	62	12	19.4

Note: Capture includes those that escape.

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

		Other large fish			Triggerfish			Other small fish		
% Submerged	No. Sets	Capture	Escape	% escape	Capture	Escape	% escape	Capture	Escape	% escape
1-25	351	992	234	23.6	3077	1250	40.6	1897	207	10.9
25-50	296	999	145	14.5	2911	1212	41.6	419	62	14.8
50-75	292	382	40	10.5	968	523	54	135	30	22.2
75-100	222	251	26	10.4	2449	1817	74.2	61	0	0
		2624	445	17.0	9405	4802	51.1	2512	299	11.9

Note: Capture includes those that escape.

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

Species (No. of fish)	Capture	Escape	% escape
Mahi-mahi	14330	7175	50.1
Wahoo	4745	443	9.3
yellowtail	62	12	19.4
Other large fish	251	26	10.4
Triggerfish	2449	1817	74.2

Note: Capture includes those that escape.

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

Utilization of tunas

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

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

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

Reducing bigeye capture (Objective 2)

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

Spatial or spatial-temporal closures

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

Acoustics

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

The options then are:

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

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

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

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

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

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

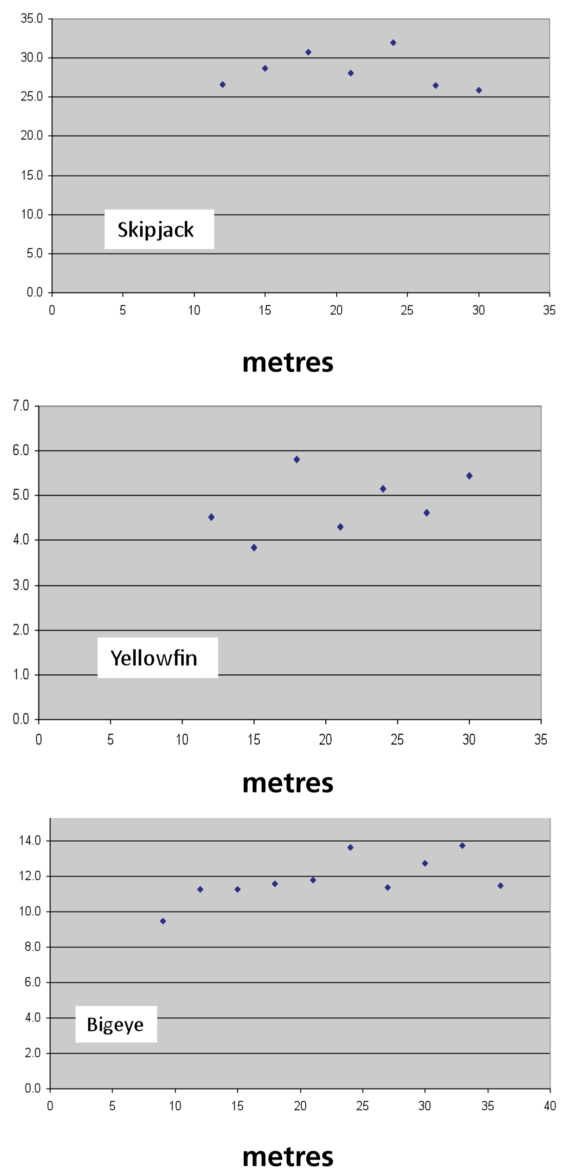
Technological changes

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

Operational strategies

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

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



Releasing from the net

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

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

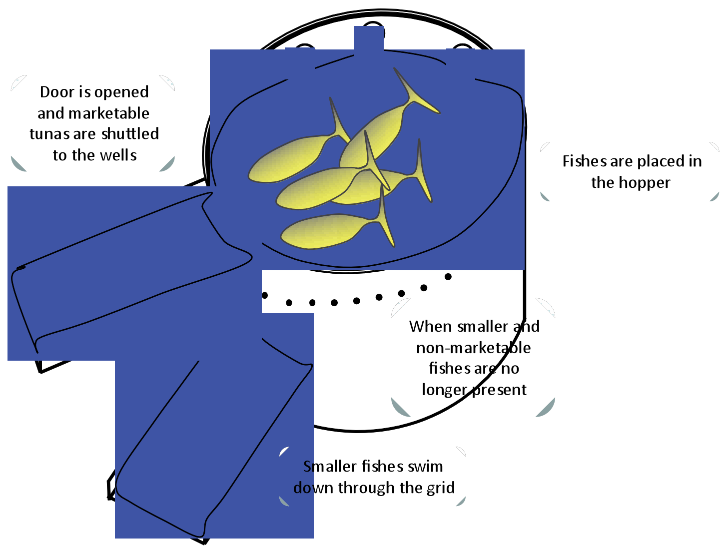
If there is stratification by species, then the sorting grid may be a useful way to release the bigeye. The grid will have larger openings, and after the bigeye have gone, it will be lifted out of the water, or closed with some simple mechanism. The use of lights to manoeuvre schools inside the net is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

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

Releasing from the deck

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

FIGURE 75
On-deck sorting tank



Source: Concept by R. Stephenson.

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

FIGURE 76
To reduce stress in the net: aerate the net and use water under pressure to distribute

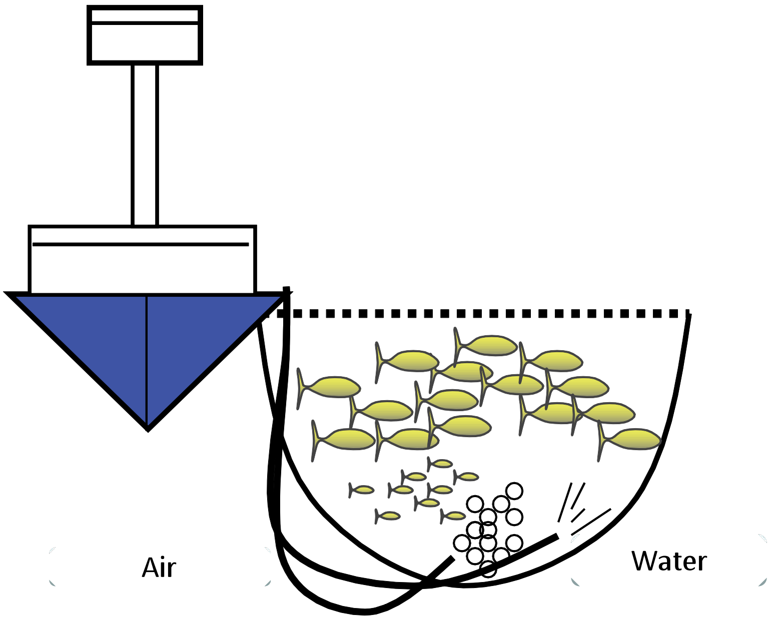


FIGURE 77
Options to place the capture in the hopper

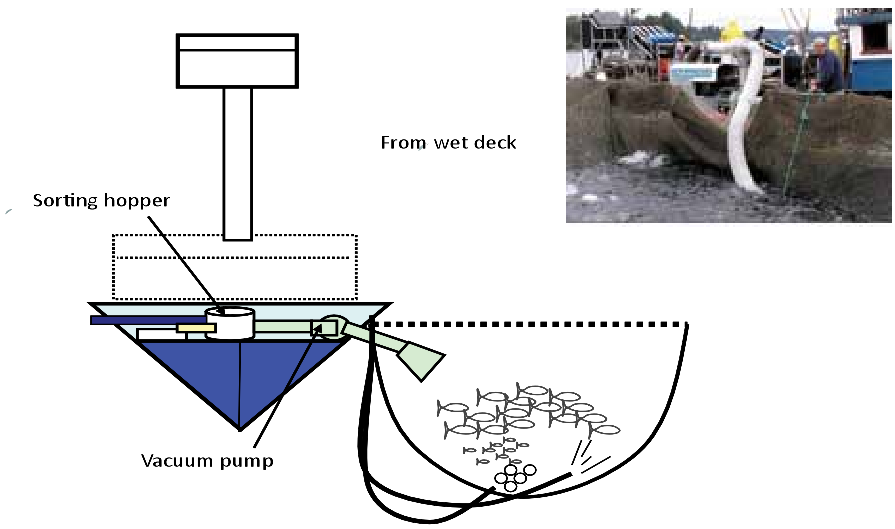


FIGURE 78
Options to bring the capture to the hopper in good condition

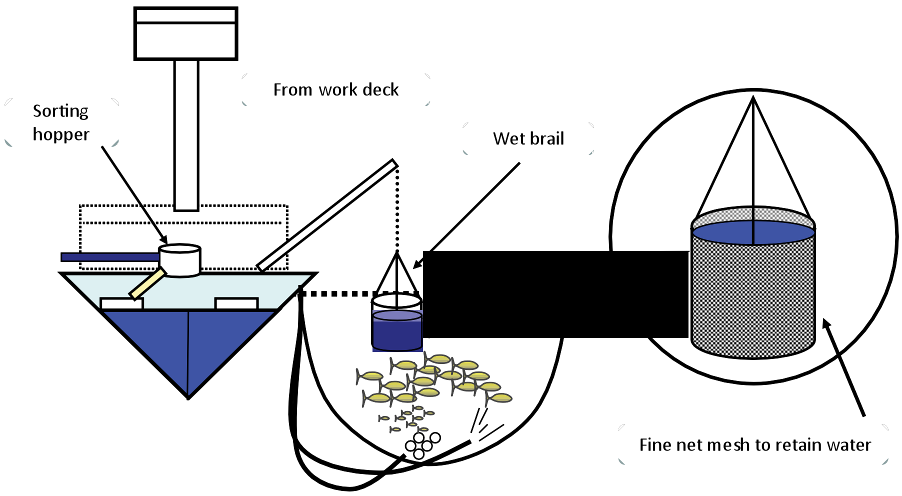
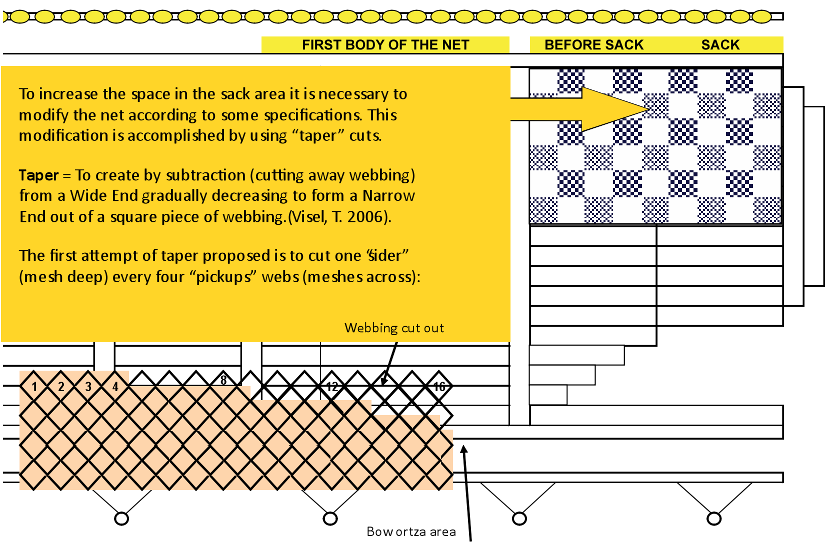


FIGURE 79
Sack area modification to provide space for the school inside the net



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

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

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

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

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

Minimum size limits

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

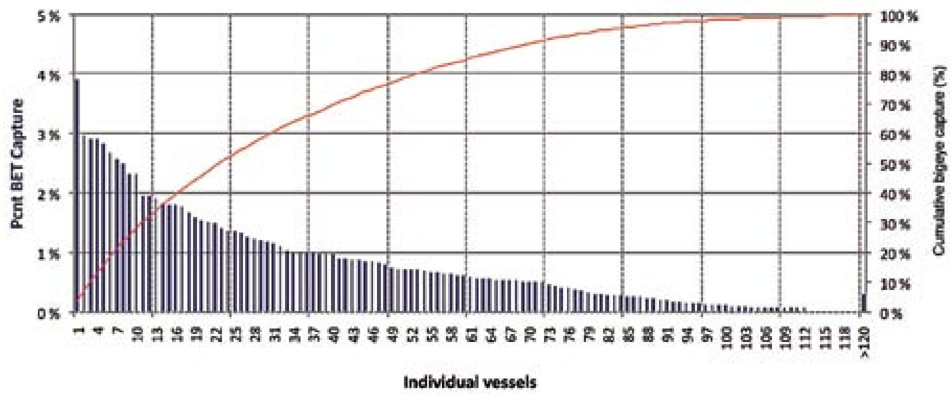
Juvenile bigeye or overall bigeye catch quotas

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

Individual vessel quotas

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

FIGURE 80
Proportion of total bigeye capture by vessels in the Eastern Pacific Ocean, 2005–09



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

Reducing FAD fishing effort

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

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

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

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

11. Billfishes

The list of species includes, in the different oceans:

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

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

BLUE MARLIN (*MAKAIRA NIGRICANS*)

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

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

BLACK MARLIN (*ISTIOMPAX INDICA*)

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

STRIPED MARLIN (*KAJIKIA AUDAX*)

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

WHITE MARLIN (*KAJIKIA ALBIDA*)

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

SAILFISH (*ISTIOPHORUS PLATYPTERUS*)

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

BILLFISH BYCATCH

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

Eastern Pacific

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

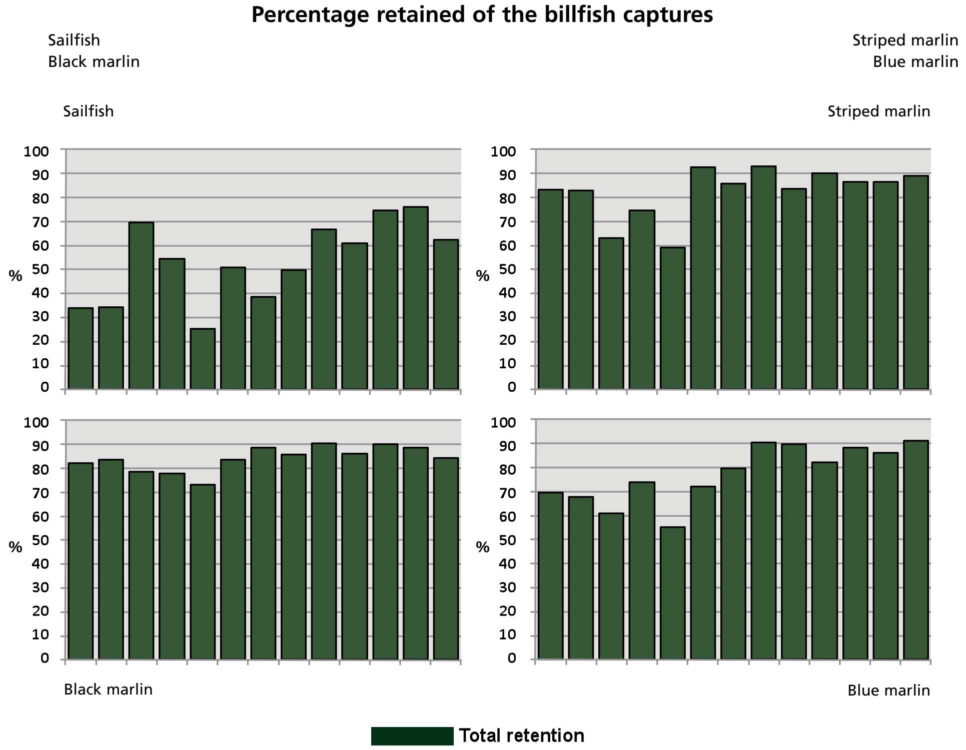
Figure 83 shows a contour map of the effort in the EPO in number of sets, to use as background for the maps showing the distribution of the different species.

TABLE 39
Billfish bycatch – percentage discarded in numbers in the Eastern Pacific Ocean, 1993–2008

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

Source: IATTC observer database.

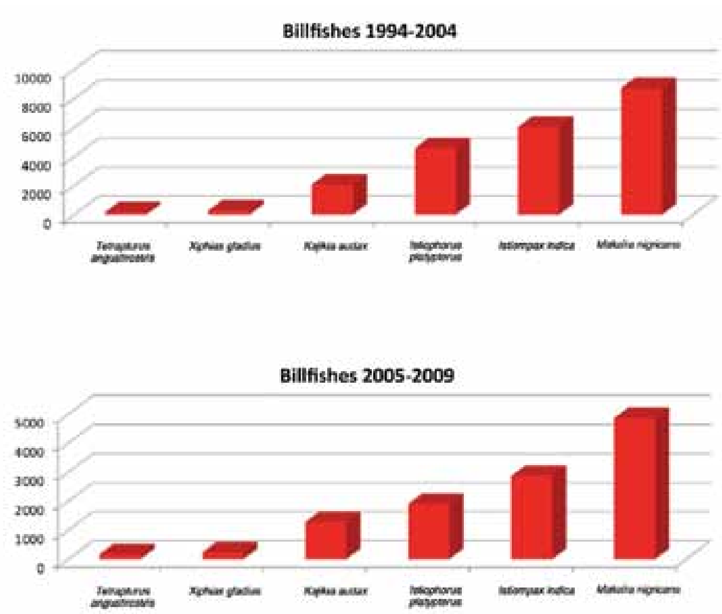
FIGURE 81
Percentage retained of the billfish captures



Western Pacific

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

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



Indian Ocean

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

Atlantic

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

ACTIONS AND CONCEPTS TO REDUCE BILLFISH BYCATCH

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

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

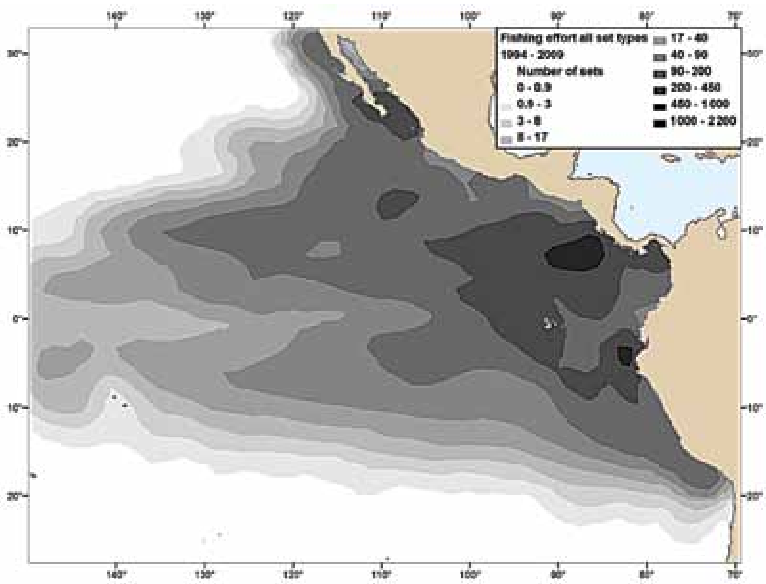


TABLE 40
Number of billfishes caught per set by set type in the Eastern Pacific Ocean, 1994–2009

Blue Marlin			
CPS	**Dolphin**	**School**	**F. object**
0	121 472	68 368	73 432
1	724	930	7 620
2	84	139	2 423
3	23	28	764
4	3	9	297
5	2	5	132
6	1	7	54
12	1	28	45

Black Marlin			
CPS	**Dolphin**	**School**	**F. object**
0	121 283	68 586	78 072
1	914	788	4 640
2	84	94	1 329
3	17	21	443
4	0	5	177
5	5	7	58
6	3	6	19
7	3	1	14
8	0	3	7
9	0	1	5
10	1	1	2
11	0	0	1
13	0	1	0

Striped Marlin			
CPS	**Dolphin**	**School**	**F. object**
0	121 530	68 787	83 150
1	643	532	1 179
2	75	99	287
3	30	40	90
4	9	18	32
5	8	6	16
6	4	4	6
7	2	2	2
8	2	3	3
9	1	3	0
10	1	4	0
11	0	0	1
12	1	2	0
14	0	0	1
17	0	1	0
20	0	2	0
22	0	1	0
23	0	1	0
30	0	1	0
32	0	1	0
40	0	1	0
46	0	1	0
57	0	1	0
60	0	1	0
79	0	1	0
80	0	1	0
160	0	1	0

Sailfish			
CPS	**Dolphin**	**School**	**F. object**
0	118 203	67 912	84 423
1	2 235	804	204
2	898	319	61
3	359	162	24
4	215	70	24
5	123	37	9
6	85	40	5
7	45	24	4
8	29	19	3
9	13	12	0
10	18	14	1
11	11	12	0
12	22	11	2
13	3	3	1
14	2	7	1
15	3	7	2
16	5	4	0
17	2	4	2
18	3	2	0
19	4	2	0
20	5	2	0
21	2	1	0
22	3	6	0
23	3	2	0
25	0	2	0
27	3	0	0
28	0	1	0
29	1	0	0
30-105	15	35	1

Source: IATTC observer database.

FIGURE 84
Retained catch of blue marlin by gear type in the Eastern Pacific Ocean, 1979–2007

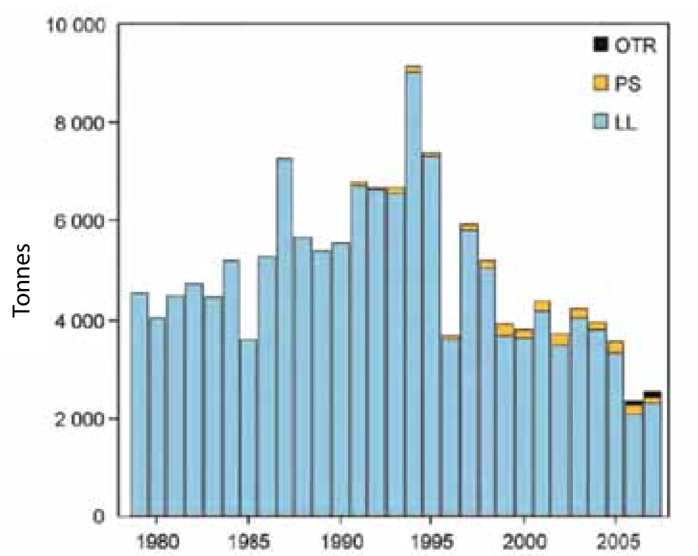


FIGURE 85
Retained catch of striped marlin by gear type in the Eastern Pacific Ocean, 1979–2007

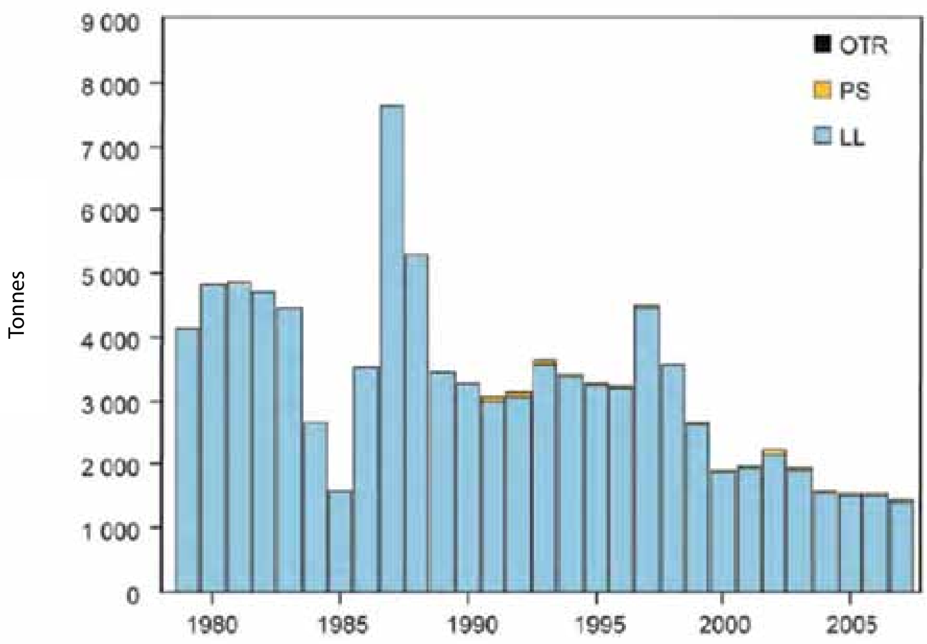


TABLE 41
Captures, bycatch, overall catch (all gears, all fleets), and proportion of captures and bycatch of the overall catch

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

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

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

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

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

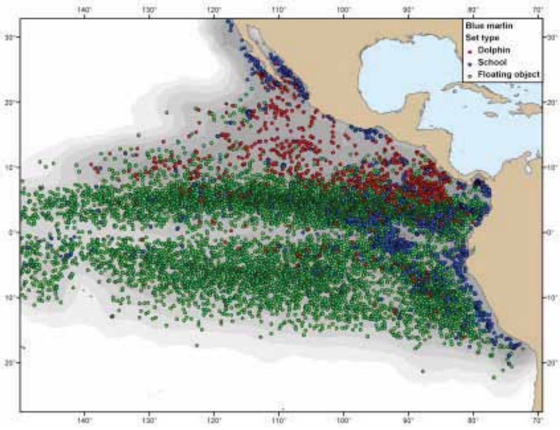
CONCLUSIONS

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

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

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

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



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

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

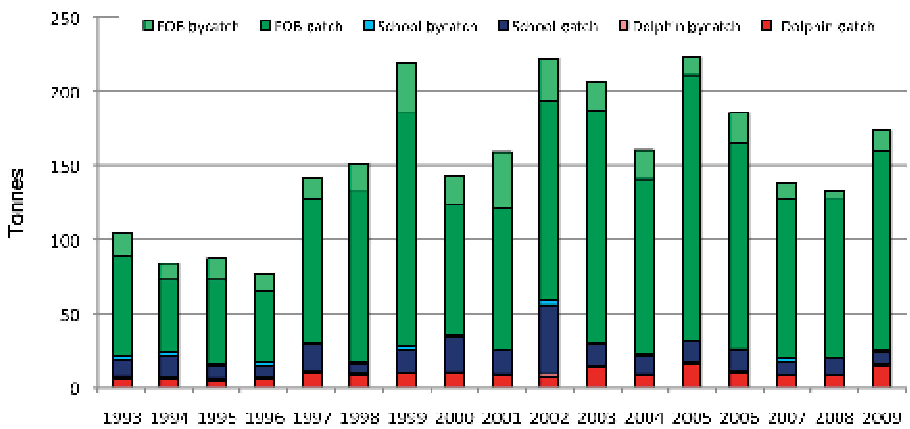
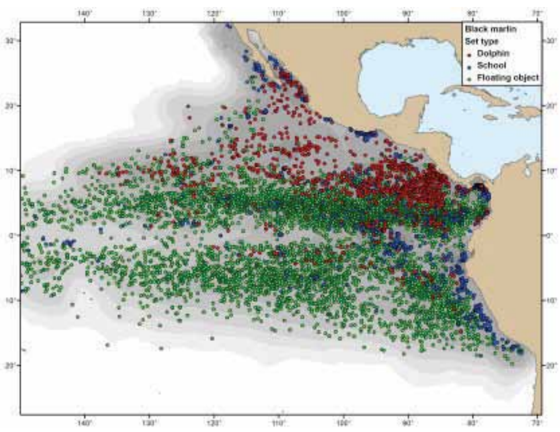
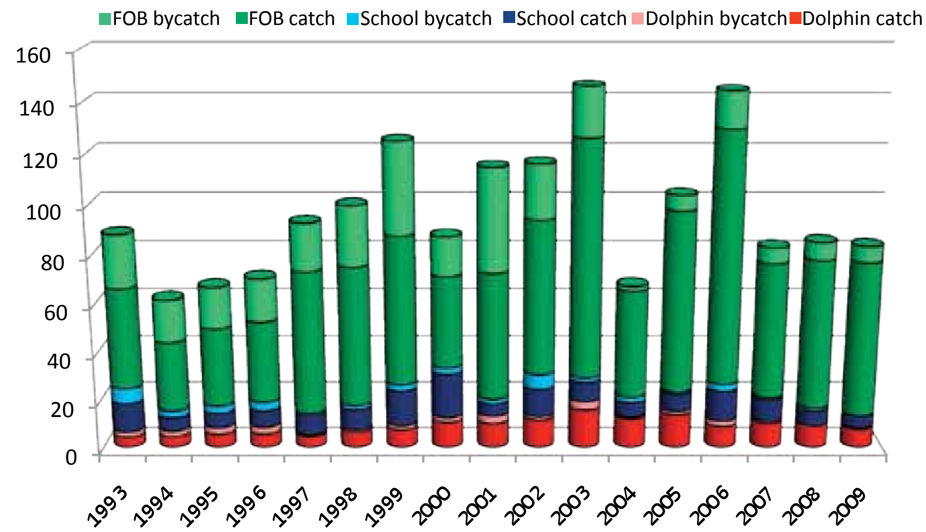


FIGURE 88
Sets with presence of black marlin in the Eastern Pacific Ocean, 1994–2009



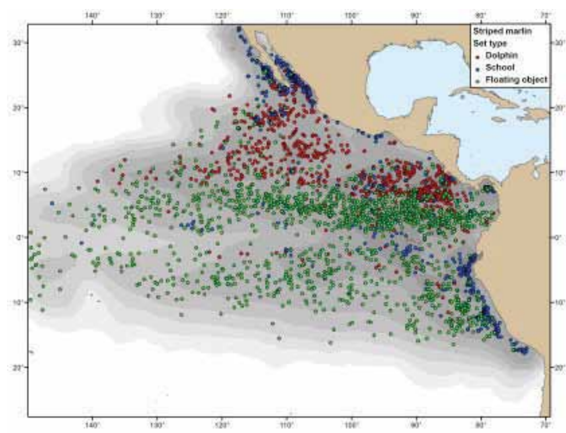
The distribution of the black marlin is similar to that of the blue marlin (Figure 88). The average annual capture of black marlin in the EPO is 96 tonnes (74 tonnes from sets on floating objects, 11 tonnes from school sets and 11 tonnes from dolphin sets). This is another case of a strong affinity for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

FIGURE 89
Black marlin total annual catch and bycatch by set type in the Eastern Pacific Ocean, 1994–2009



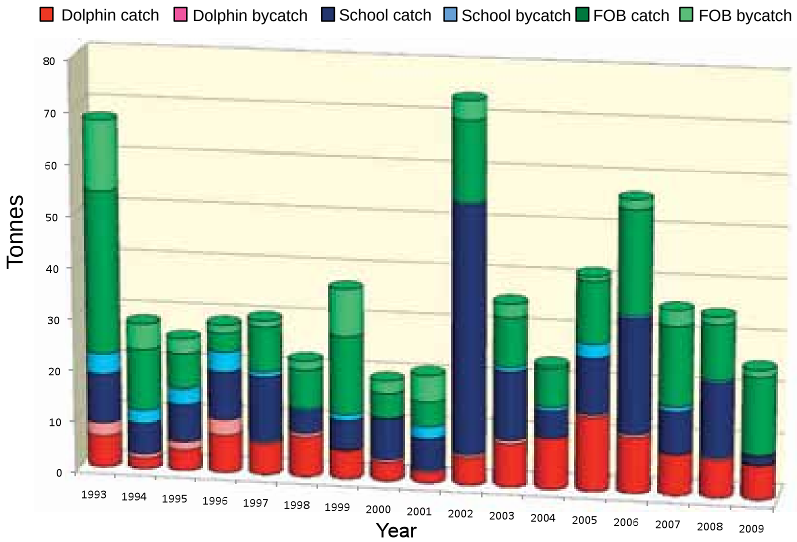
The striped marlin is much less common than the blue marlin, and its distribution is more concentrated (Figure 90). The striped marlin has an average annual capture of 36 tonnes in the EPO (15 tonnes from floating objects, 13 tonnes in school sets, and 8 tonnes from dolphin sets, much more balanced between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

FIGURE 90
Sets with presence of striped marlin in the Eastern Pacific Ocean, 1994–2009



The distribution of the sailfish captures shows clear differences from the marlins. It is much closer to the coast, and there is an area with very high densities in the region of the Costa Rica Dome (Figure 92). More than 40 percent of the sailfish are discarded in the EPO (Figure 93). The sailfish bycatch add up to about 600 individuals per year (Tables 15–22), divided evenly between dolphin and school sets. This figure is still negligible from the population point of view, and the only issue of interest is that, in some occasional sets, there are catches of dozens of sailfishes, when an aggregation is encircled.

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



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

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

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

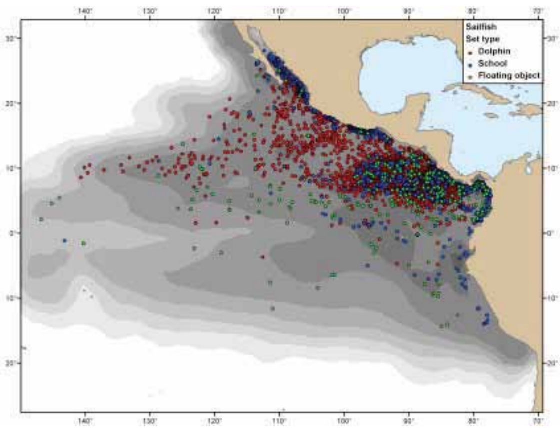
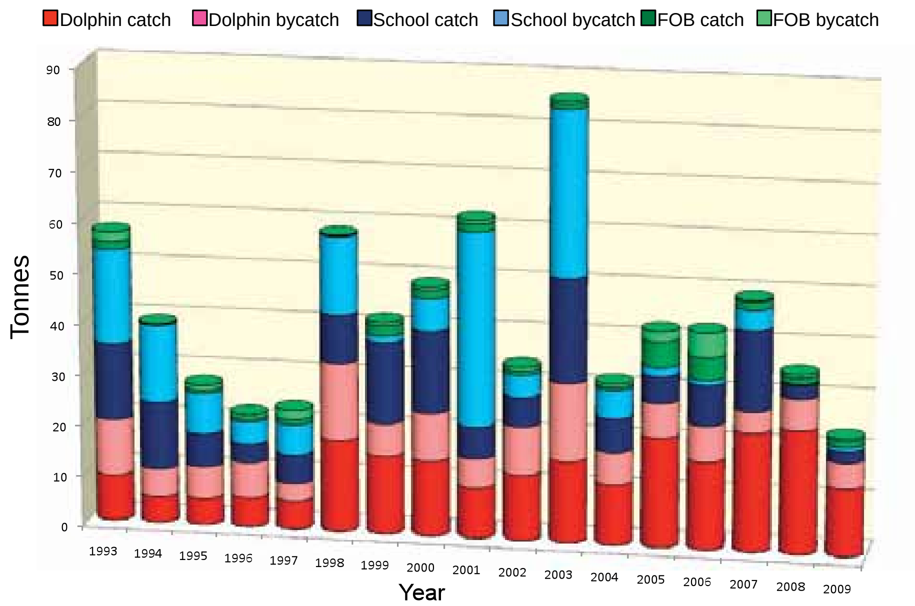


FIGURE 93
Sailfish total annual catch and bycatch by set type in the Eastern Pacific Ocean, 1994–2009



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

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

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