12. Shark and rays

The list of the main species includes:

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

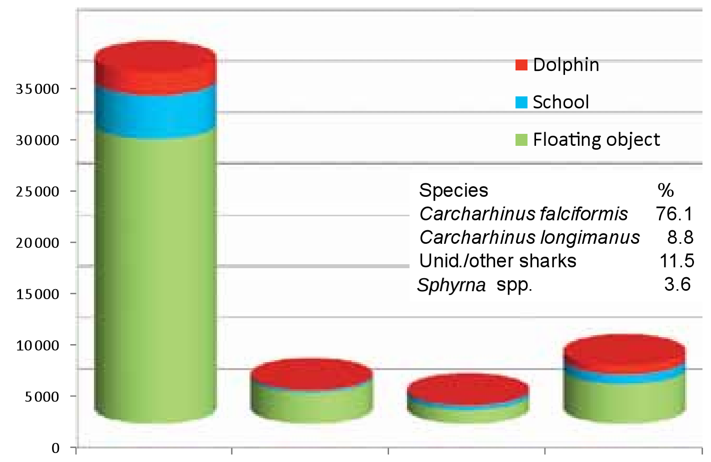
Sharks and rays are frequently captured in purse seine sets in all oceans. Of the taxa captured incidentally in purse seines, sharks and rays are one of the most vulnerable because of their life-history parameters, and in general, low rates of increase resulting from late maturity, small number of pups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

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

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

FIGURE 94

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



Source: IATTC observer database.

TABLE 42

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

Notes: Excluding domestic fleets of Indonesia, the Philippines, and Taiwan

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

Province of China. na = not estimated; * = total based on longline only; ** = total based on purse seine only.

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

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

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

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

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

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

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

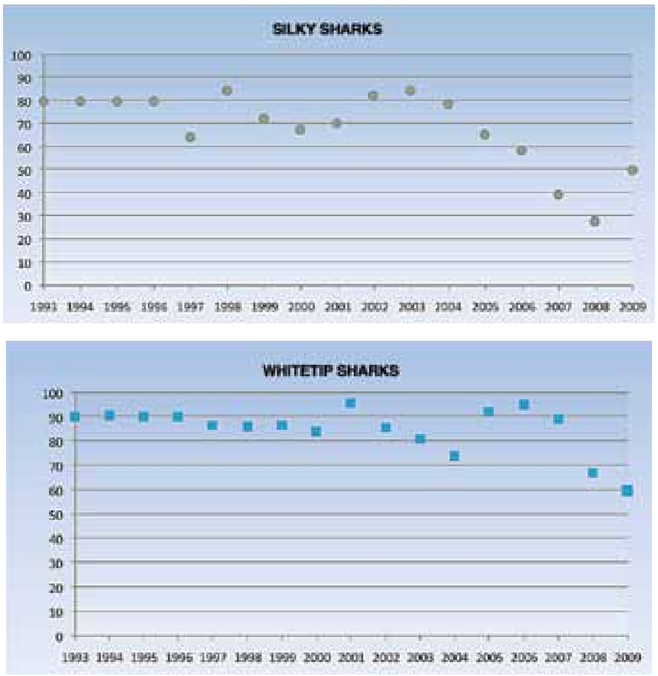


FIGURE 96
Percentage of hammerhead and other sharks discarded in numbers in the Eastern Pacific Ocean, 1993–2009

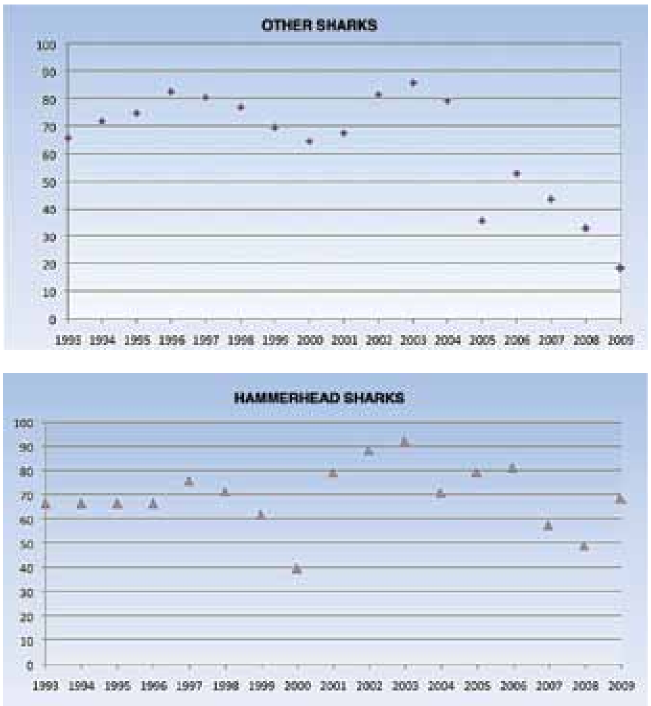


TABLE 43
Shark catches from Secretariat of the Pacific Community (SPC) for WCPFC

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Longline														
Blue	46854	73096	69325	83112	96438	110459	93076	67975	53903	47346	51920	41336	39556	na
Mako	5640	6505	6493	7391	8951	10664	10374	9706	9081	8106	6773	5257	5454	na
Oceanic whitetip	10364	13999	13651	11776	15338	13860	12268	9054	9035	6551	6124	4627	3586	na
Silky	1080	13940	11111	7603	8266	10579	10487	8887	8352	6863	7268	6062	4993	na
Other	12654	12839	8341	6120	8583	10689	10633	9350	8370	5929	5579	7218	7308	na
Sub-total	76592	120379	108921	116002	137576	156251	136838	104972	88741	74795	77664	64500	60897	na
Purse seine														
Silky	na	145	236	427	455	786	685	753	941	944	1366	1087	1060	889
Whale shark	na	166	157	252	285	248	214	272	411	510	636	694	694	781
Other	na	1361	1361	1901	1115	1114	734	589	561	404	467	383	274	192
Sub-total	na	1672	1754	2580	1855	2148	1633	1614	1913	1858	2469	2164	2028	1862
Total	76592*	122051	110675	118582	139431	158399	138471	106586	90654	76653	80133	66664	62925	1862**

Notes: Excluding domestic fleets of Indonesia, the Philippines, and Taiwan Province of China. na = not estimated; * = total based on longline only; ** = total based on purse seine only.
Source: Data from Secretariat of the Pacific Community (2008).

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

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

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

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

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

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

SILKY SHARK (*CARCHARHINUS FALCIFORMIS*)

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

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

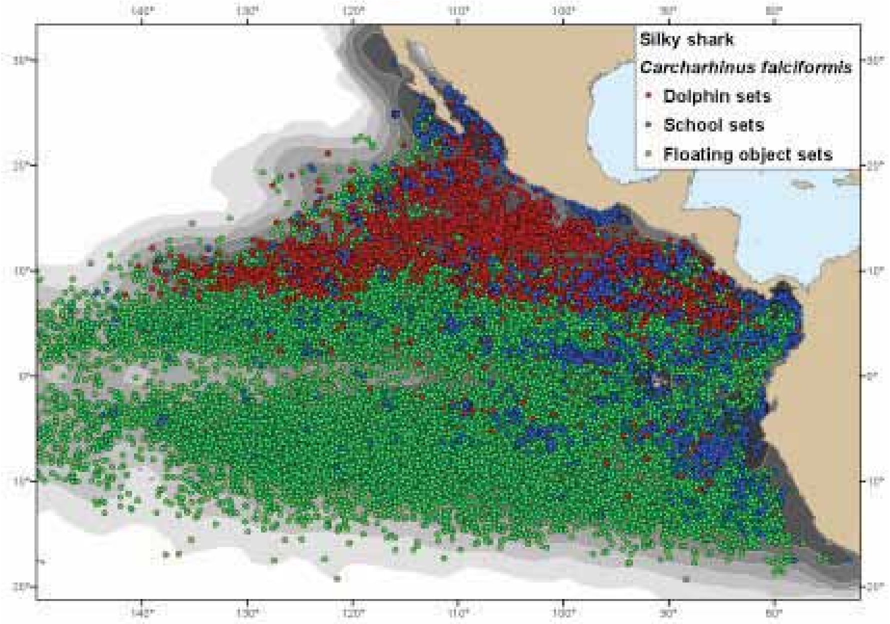
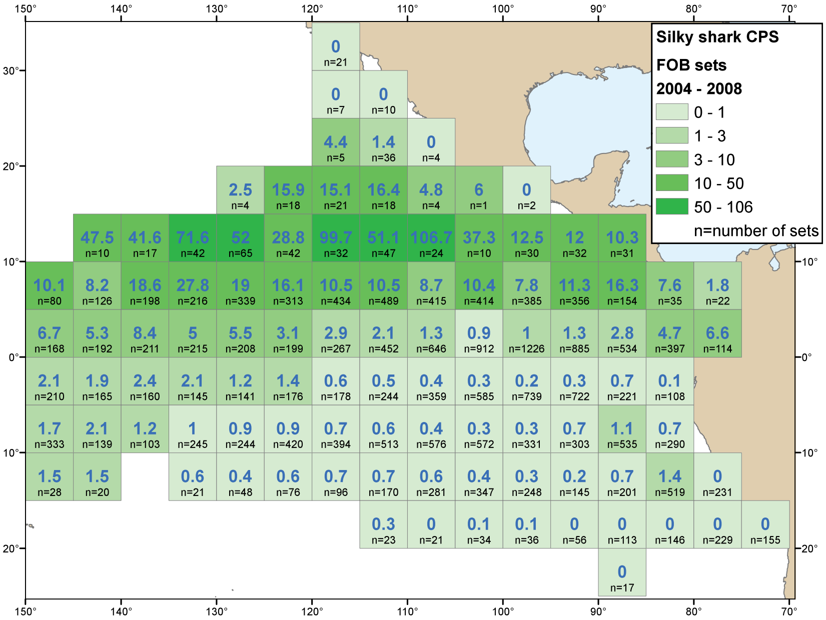


FIGURE 98
Silky shark, numbers per set on floating objects in t he Eastern Pacific Ocean, average 2004–08



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

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

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

FIGURE 99

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

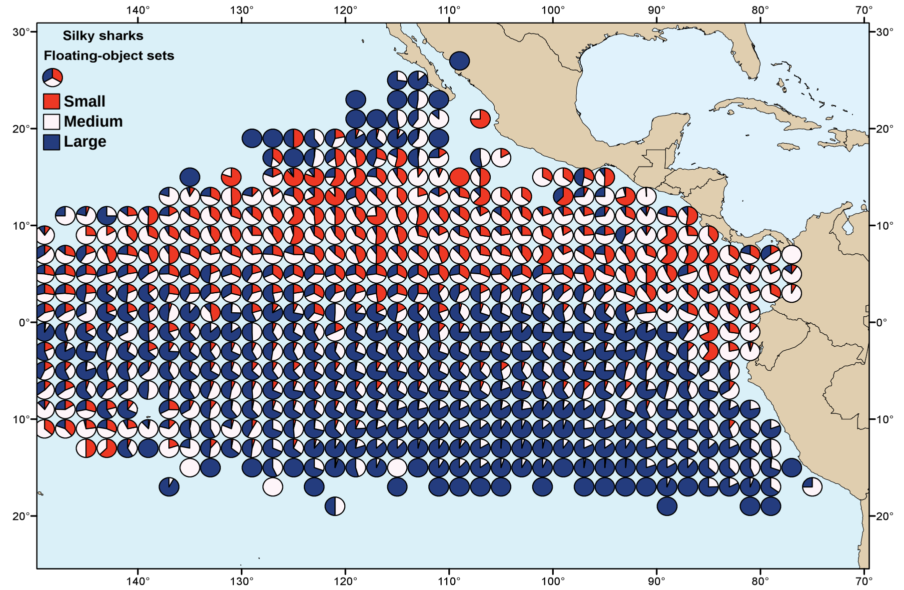
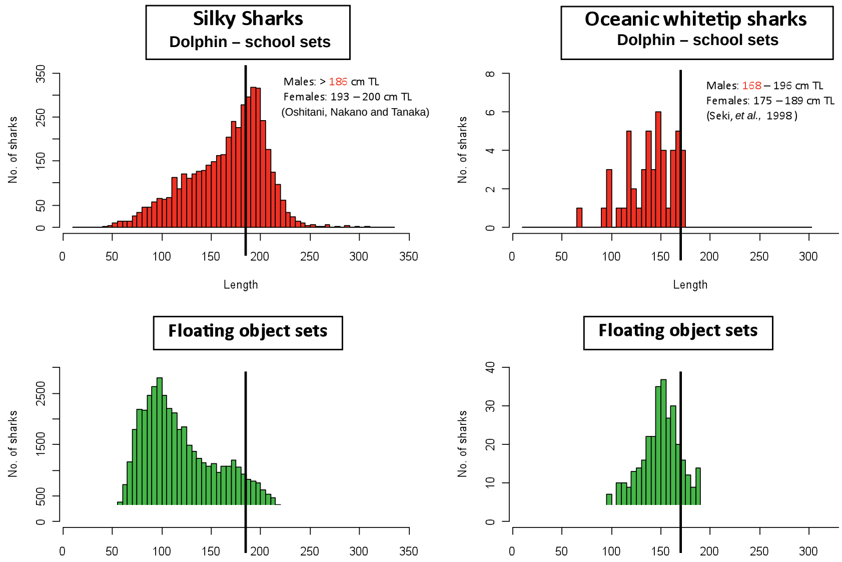


FIGURE 100

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



Source: Courtesy of A. daSilva.

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

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

Eastern Pacific

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

FIGURE 101

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

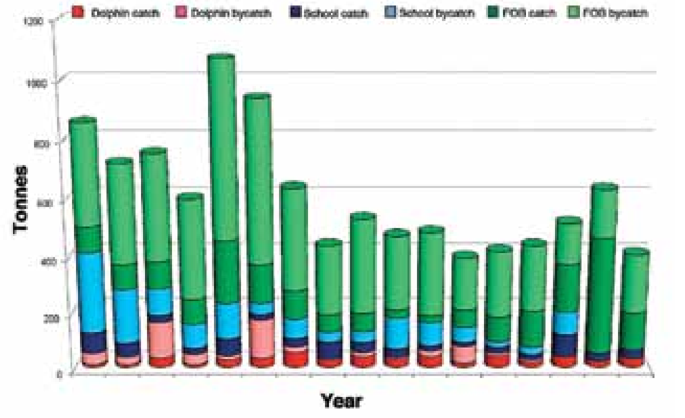
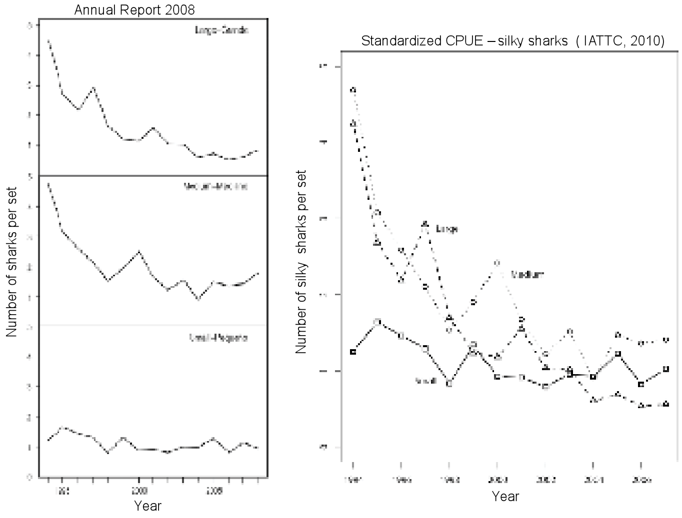


FIGURE 102

Numbers per set by sizes – silky sharks



Source: IATTC (2008).

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

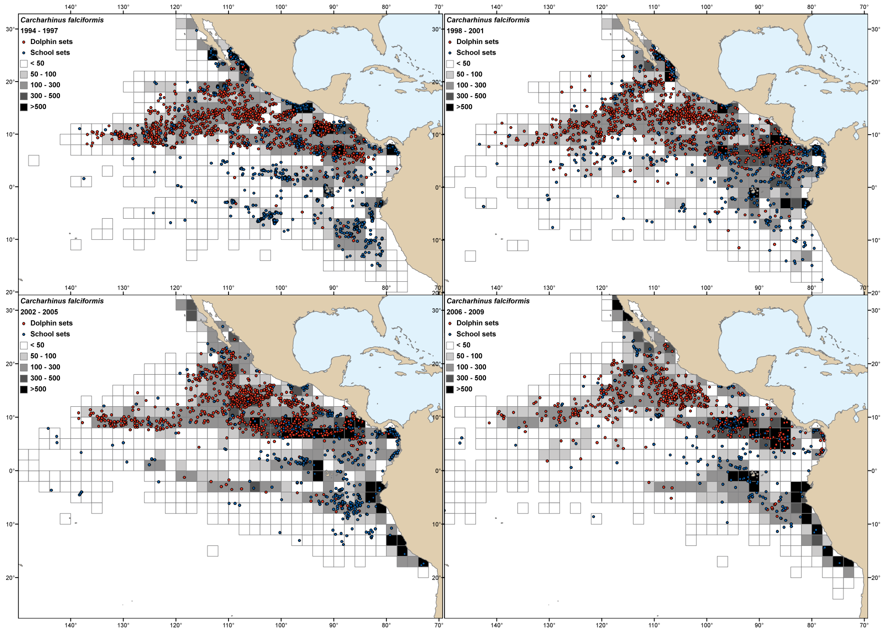
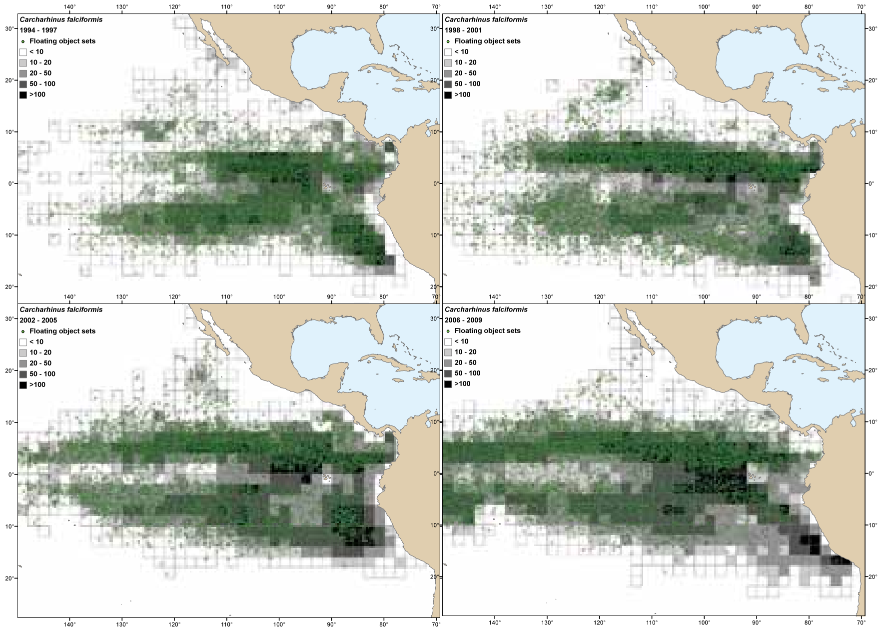


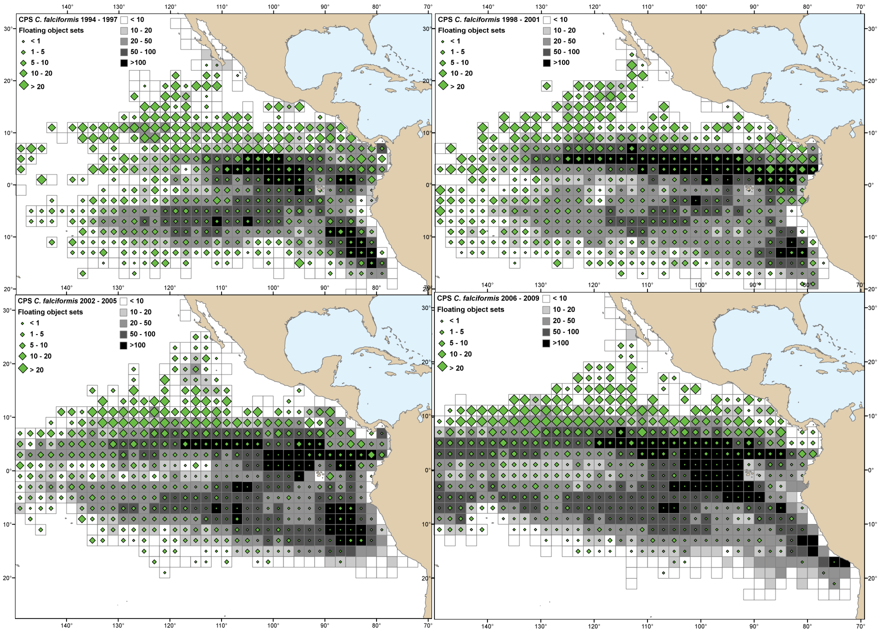
FIGURE 104
Sets with silky sharks in four time periods in floating object sets



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

FIGURE 105

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

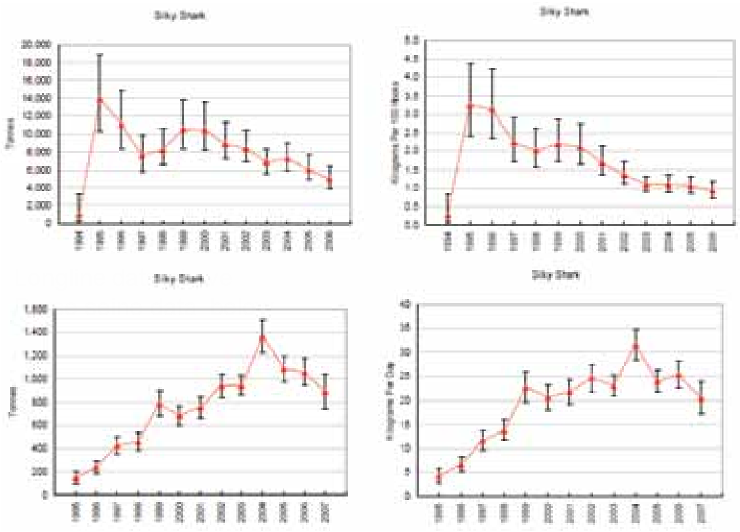


in CPS, and standardized CPUEs for the three size categories (IATTC, 2008, 2010) based on the data from floating object sets. These declines are statistically significant for large (> 150 cm total length) and medium-sized sharks (90–150 cm total length) from 1994 until about 2004, then remain relatively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

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

FIGURE 106

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



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

Western Pacific

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

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

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

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

Atlantic Ocean

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

Indian Ocean

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

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

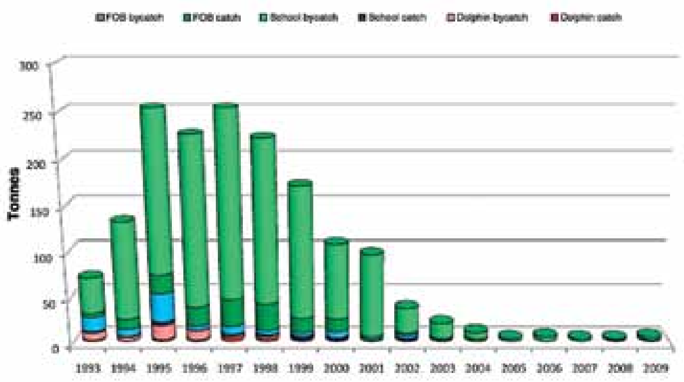
The silky shark is dominant in catches off Maldives, off Sri Lanka, and very common in most of the Western Indian Ocean (Smale, 2008). Sanchez *et al.* (2007) report capture rates of 1.91 silky sharks per set compared with 0.10 per set for the oceanic whitetip, the second-most abundant species identified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

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

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

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

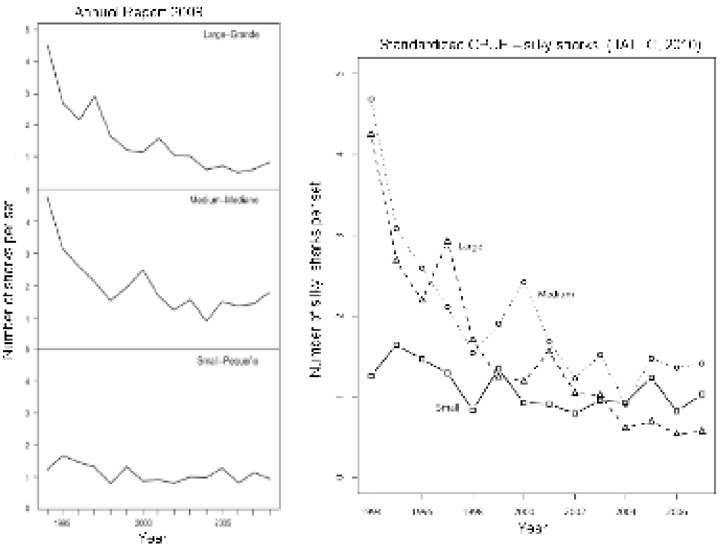
FIGURE 107
Oceanic whitetip shark: catch and bycatch by set type in tonnes in the Eastern Pacific Ocean, 1993–2009



OCEANIC WHITETIP SHARK (*CARCHARHINUS LONGIMANUS*)

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

FIGURE 108
Year effects from bycatch presence/absence analysis



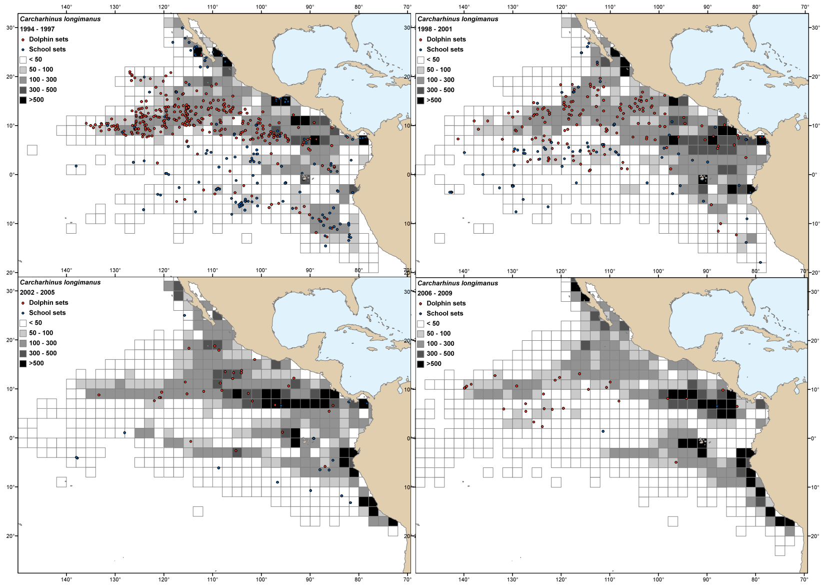
Source: IATTC (2008).

Eastern Pacific

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

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

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



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

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

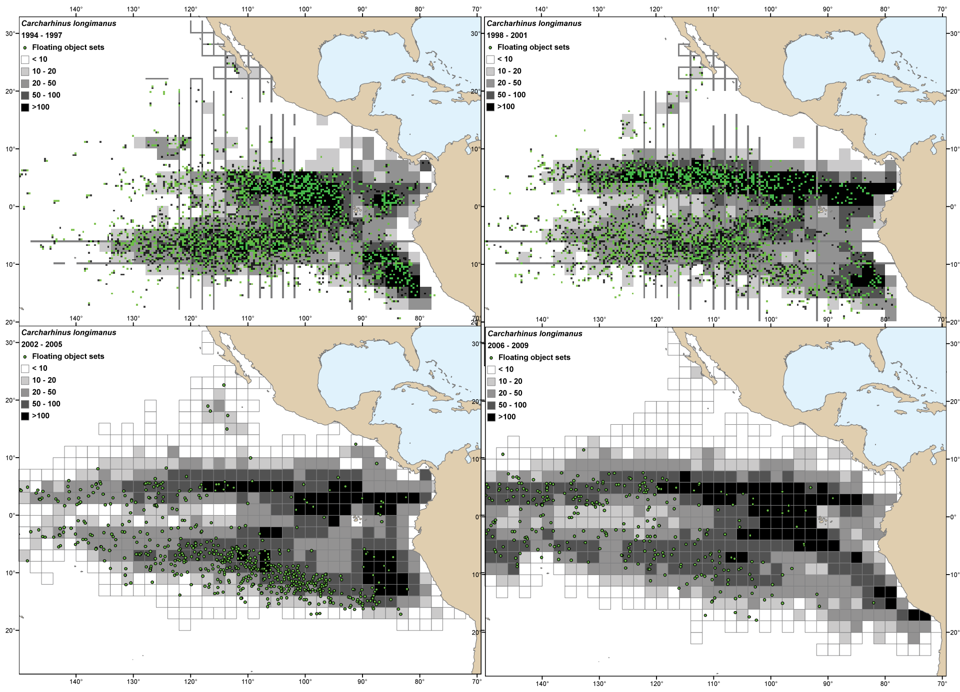


FIGURE 111

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

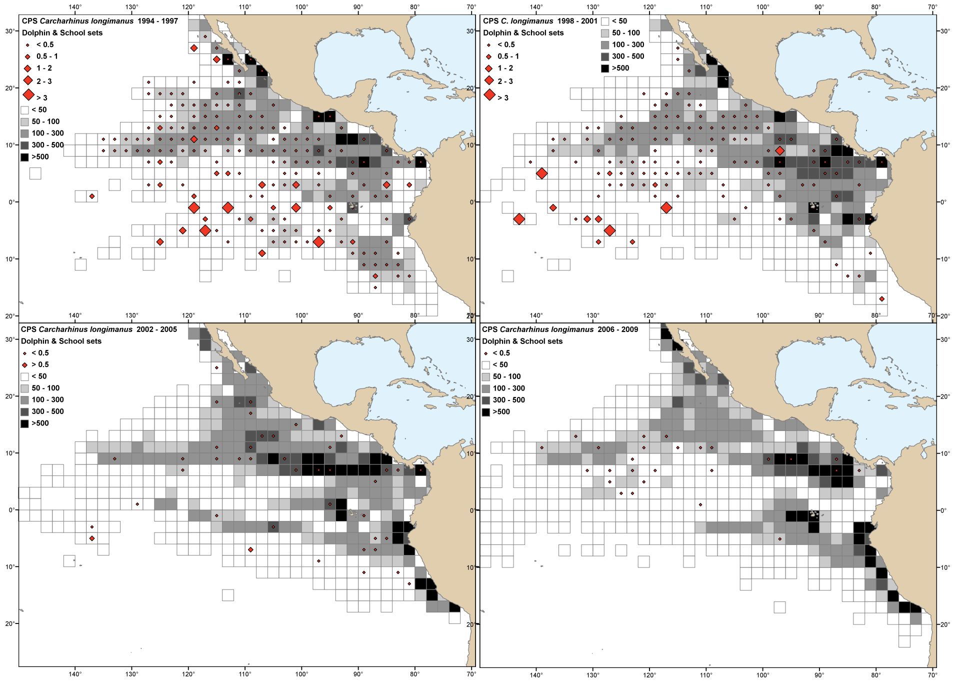


FIGURE 112

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

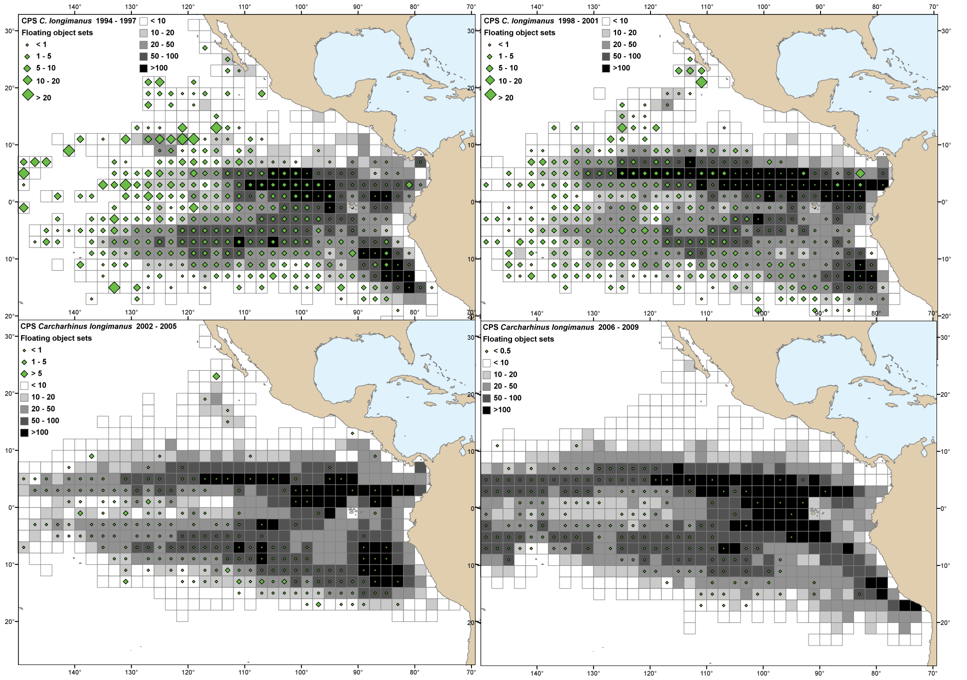
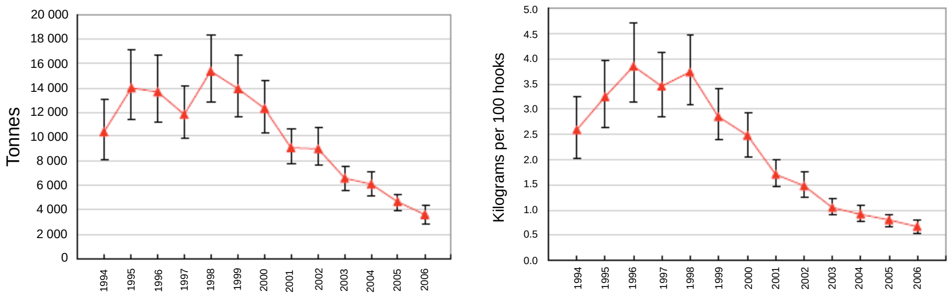


FIGURE 113
Catch and CPUE in longline fisheries of oceanic whitetip sharks in the Western Pacific Ocean



Source: OFP (2008b)

TABLE 44
Capture of oceanic whitetip sharks by size interval in the Eastern Pacific Ocean, 1993–2008

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

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

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

Western Pacific

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

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

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

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

Atlantic

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

Indian Ocean

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

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

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

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

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

Eastern Pacific

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

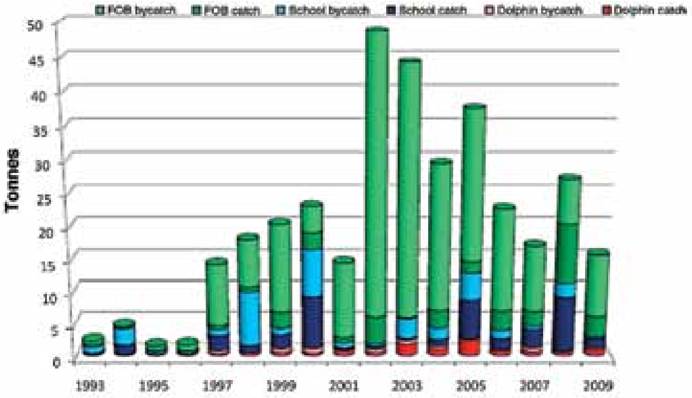
The spatial distribution of *S. lewini* and *S. zygaena* in the different types of sets is shown in Figures 116 and 117. There are important areas for these species around Baja California, on the Peru Current, on the Costa Rica Dome (Fiedler, 2002), and along the northern strip of the FAD fishery extending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

Western Pacific

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

FIGURE 114

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



Atlantic

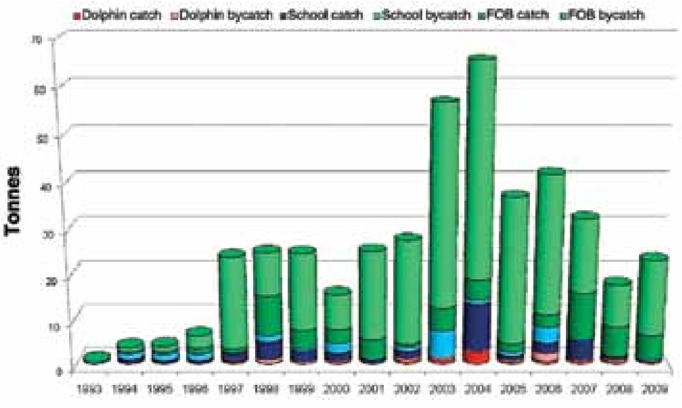
The captures are 4.2 tonnes/year of the smooth hammerhead and a similar 3.7 tonnes/year for the scalloped hammerhead in 2003–07. They are the most numerous sharks in school sets, and less common under floating objects. Their frequency of occurrence is 0.5–2 percent of the sets (Sarralde, Delgado de Molina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

Indian Ocean

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

FIGURE 115

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



Source: IATTC observer database.

ACTIONS AND CONCEPTS TO REDUCE SHARK BYCATCH

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

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

FIGURE 116

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

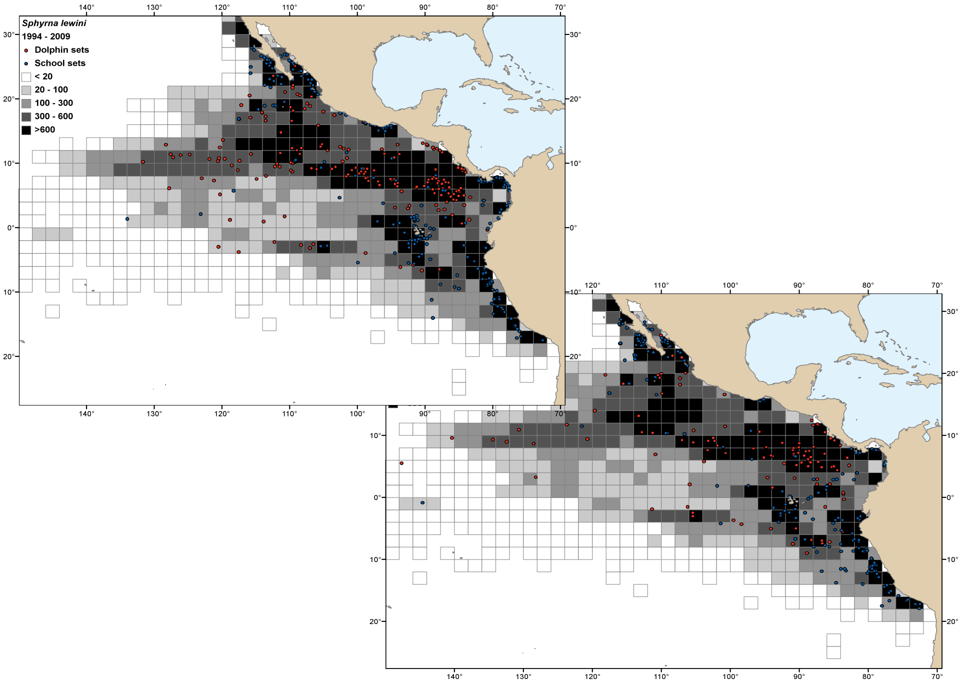
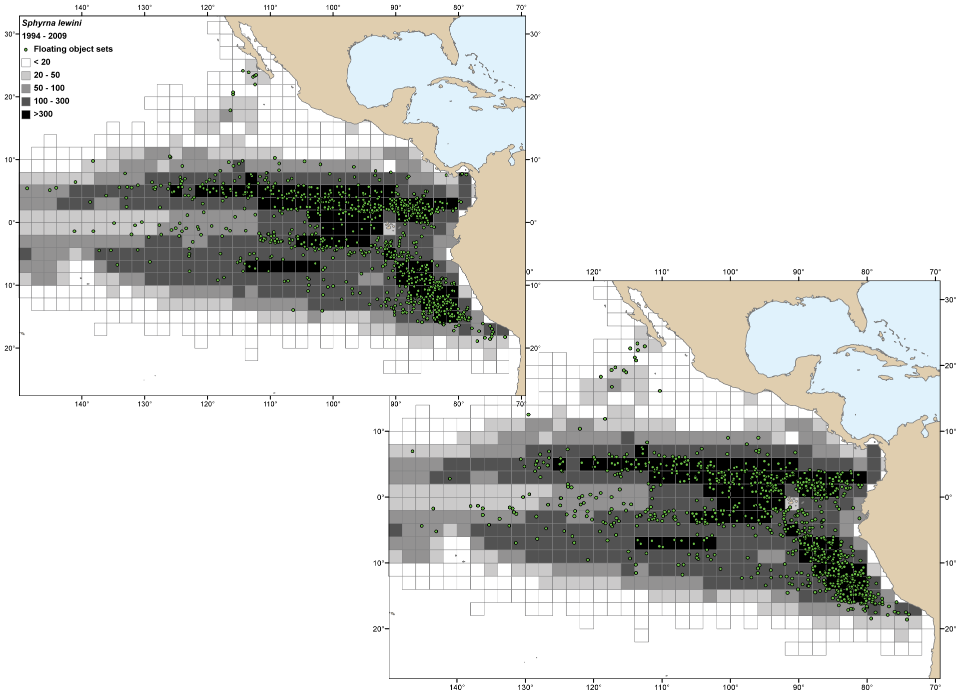


FIGURE 117

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



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

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

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

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

Avoiding the capture of sharks

Spatial management

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

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

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

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

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

Releasing the sharks from the net

Removing the sharks from the net after encirclement

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

Capturing the sharks in the net for release

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

Releasing the sharks from the vessel

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

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

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

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

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

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

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

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

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

Utilization of sharks

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

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

CONCLUSIONS

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

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

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

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

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

RAYS

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

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

TABLE 45

Disc width of rays at sexual maturity

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

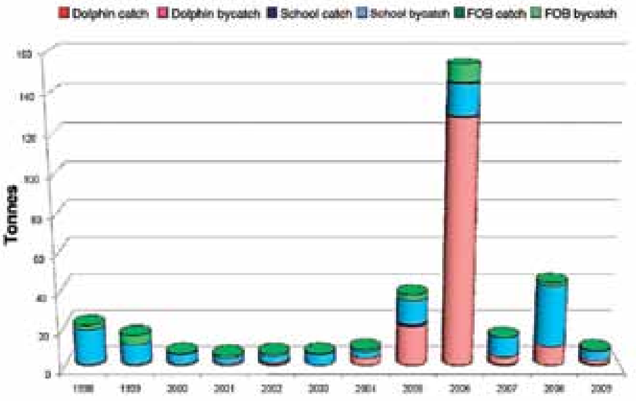
[1] White *et al.* (2006).
[2] Notarbartolo di Sciara (1988).
[3] Marshall and Bennett (2010).
[4] Deakos (2010).

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

Eastern Pacific

FIGURE 118

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

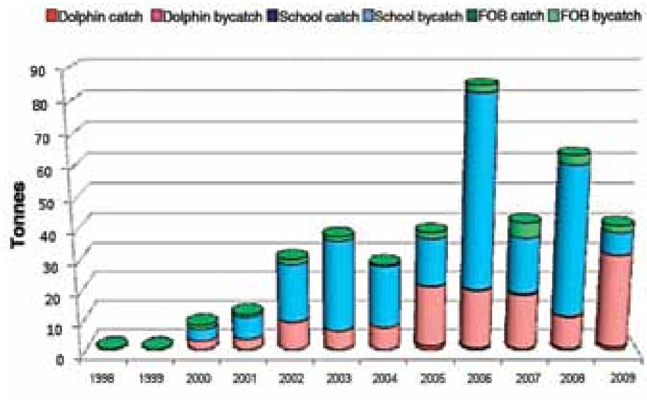


The species encountered in the region include:

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

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

FIGURE 119
Catch and bycatch of devil rays by set type in the Eastern Pacific Ocean, 1998–2009



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

Western Pacific

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

TABLE 46
Capture production in tonnes of mantas and devil rays in the Western Pacific Ocean, 2000–07

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

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

Atlantic

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

Indian Ocean

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

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

ACTIONS AND CONCEPTS TO REDUCE MANTA AND DEVIL RAY BYCATCH

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

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

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

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

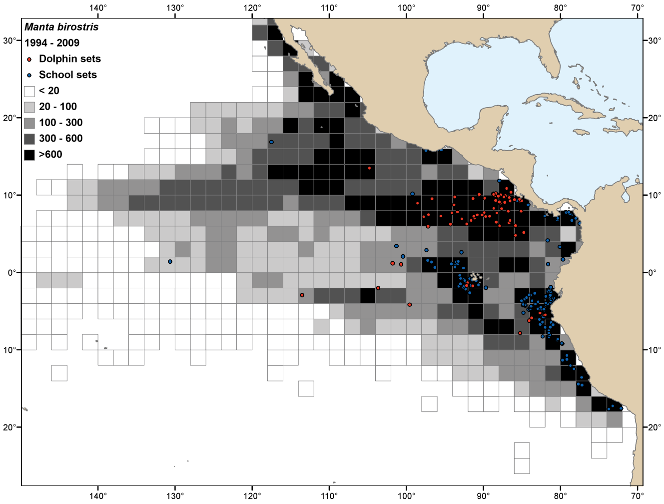
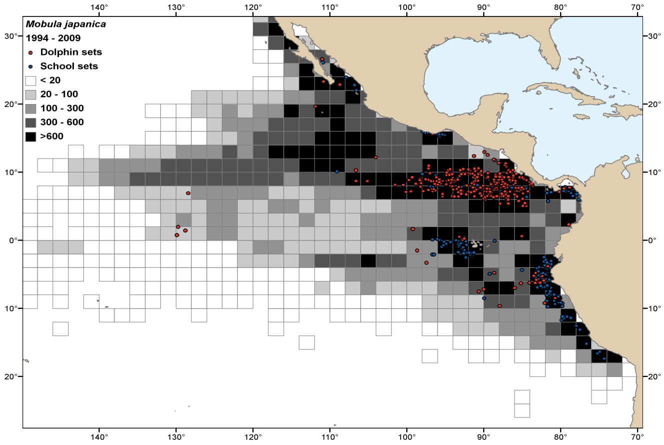


FIGURE 121
Captures of spinetail mobula in dolphin and school sets

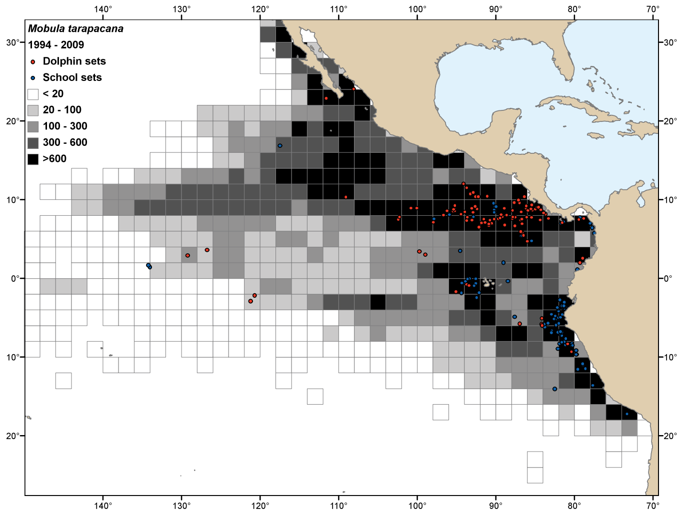


THE PELAGIC STINGRAY (*PTEROPLATYTRYGON VIOLACEA*)

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

It is believed to undertake seasonal migrations, reproducing in warmer waters in winter, and returning to higher latitudes after giving birth, but the pattern observed for the Pacific is not evident in the Mediterranean population (Mollet, 2002), and Veras

FIGURE 122
Captures of Chilean devil ray in dolphin and school sets



et al. (2009) did not find any seasonality in their study of the reproductive cycle of this species off Brazil.

Eastern Pacific

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

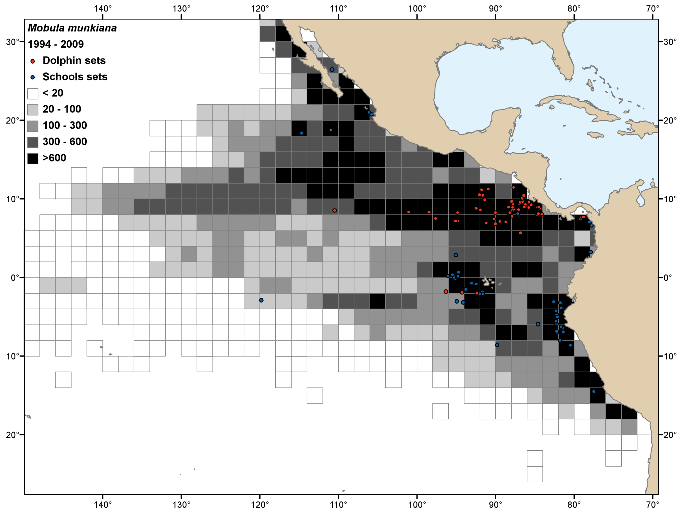
Western Pacific

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

Indian Ocean

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

FIGURE 123
Captures of Munk's devil ray in dolphin and school sets



Atlantic

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

CONCLUSIONS

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

FIGURE 124
Captures of smoothtail mobula in dolphin and school sets

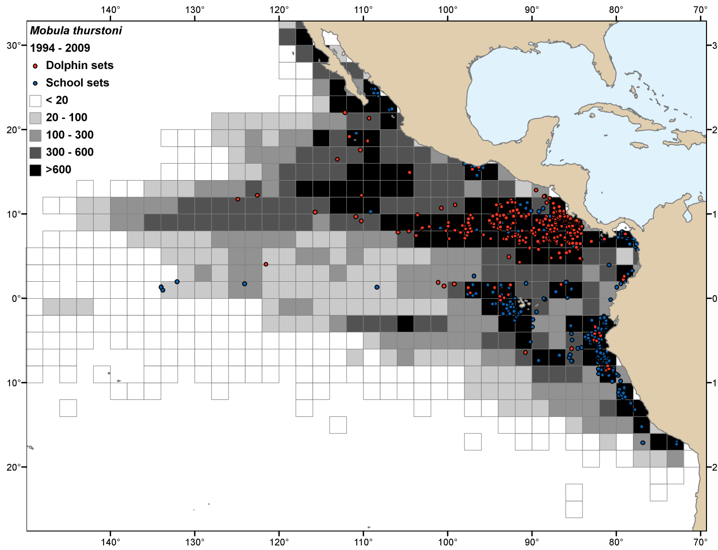


FIGURE 125
Captures of mobulid rays – Costa Rica Dome detail

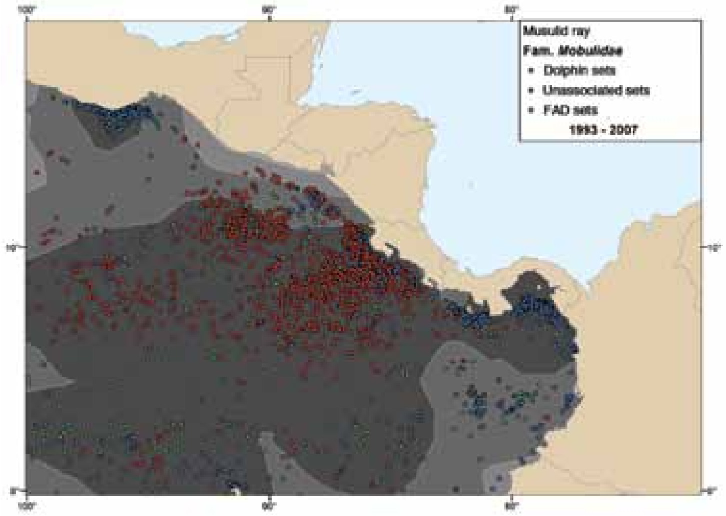


FIGURE 126
Technique used to release manta and devil rays by inserting a hook from a single pulley into gills

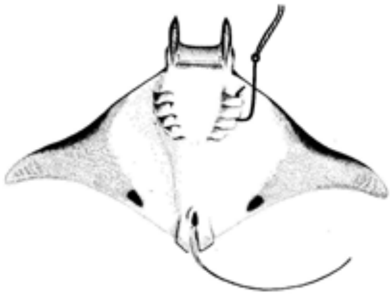


FIGURE 127
Technique used to release manta and devil rays by punching a small orifice in the pectoral fin, and passing a cable through it

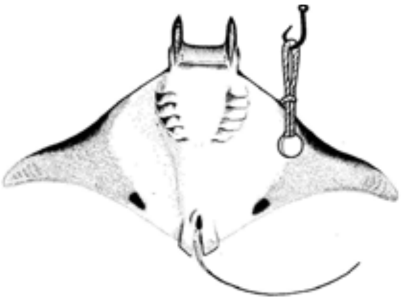


PLATE 9

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

PLATE 10

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

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

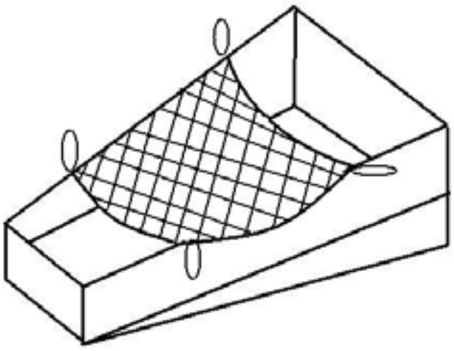


FIGURE 132
The brailer deposits the catch and the manta ray on the cargo net. Tunas are separated

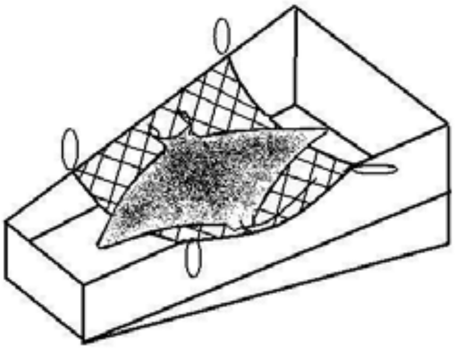
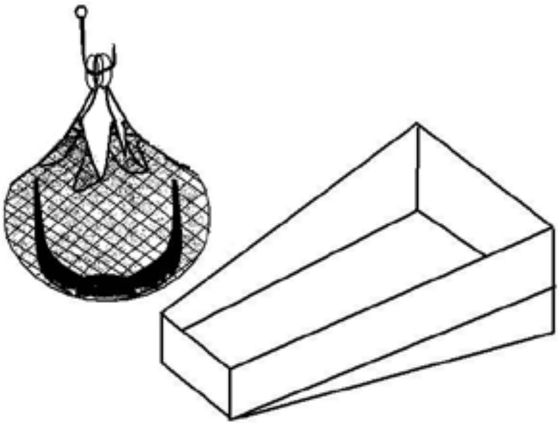


FIGURE 133
The brailer lifts and releases the manta ray



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

FIGURE 131
Captures of the pelagic stingray by set type