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Killer whale (*Orcinus orca*) interactions with the tuna and swordfish longline fishery off southern and south-eastern Brazil: a comparison with shark interactions

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Depredation by cetaceans and sharks on longline fisheries is a global issue that can have negative impacts on both animals and fisheries and has concerned researchers, managers and the fishing industry. Nevertheless, detailed information on depredation is only available for a few regions where the problem exists. With the purpose of evaluating killer whale depredation on longline-caught tuna (*Thunnus* spp.) and swordfish (*Xiphias gladius*) in the waters off southern and south-eastern Brazil and comparing it to shark depredation, data sheets were distributed to the captains of tuna vessels in Santos, south-eastern Brazil, between 1993 and 1995. Data on the catch per unit effort (CPUE) of tuna and swordfish and some records of interactions were also obtained from fishing vessel logbooks. Dockside interviews with fishermen and with researchers on board tuna vessels provided additional information. Killer whale and shark interactions were analysed per longline set and per trip. Killer whale interactions occurred from June to February, mainly between June and October, while shark interactions occurred year round. The number of sets and trips involving shark interactions was significantly higher than the number of sets and trips involving killer whale interactions. However, when depredation occurred, the proportion of fish damaged by killer whales was significantly higher than by sharks. Furthermore, killer whales removed or damaged significantly more hooked swordfish than hooked tuna, whereas sharks damaged significantly more hooked tuna than swordfish. This study also shows that cetacean by-catch is experienced by the tuna and swordfish longline fishery in Brazilian waters.

INTRODUCTION

Killer whales (*Orcinus orca* Linnaeus, 1758) have been known to interact with fishing operations in many regions of the world. Sivasubramaniam (1964) reported that in the Indian Ocean killer whales attacked tuna caught on pelagic longlines, and together with sharks, were responsible for the loss of at least 4% of the total annual catch, by weight, of tunas and related species by the longline fleet. Killer whale depredation on longline-caught tuna has also been reported to occur in northern and southern Pacific equatorial waters (Iwashita et al., 1963) and in the North Atlantic (Dahlheim, 1988). In the north-eastern Pacific Ocean, killer whale depredation on bottom longline-caught black cod, *Anoplopoma fimbria*, has been reported in the south-eastern Bering Sea and Prince William Sound, Alaska (Matkin et al., 1986; Dahlheim, 1988; Matkin, 1988; Yano & Dahlheim, 1995). In Icelandic waters, fishermen reported killer whale depredation on longline-caught Greenland halibut, *Reinhardtius hippoglossoides* (Christensen, 1982; Bloch & Lockyer, 1988). In the North Atlantic, killer whales were also reported interacting with the Atlantic mackerel, *Scomber scombrus*, purse-seine fishery and with the Atlantic herring, *Clupea harengus*, fishery (Bloch & Lockyer, 1988), indicating that killer whales may also

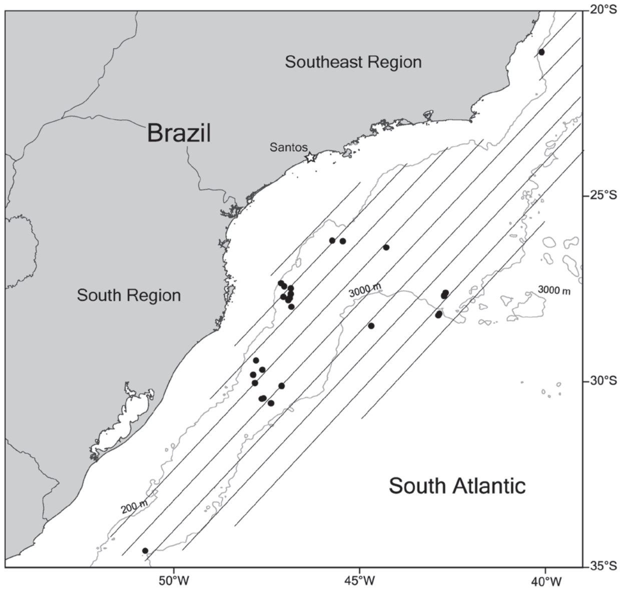

Figure 1. Fishing area of the tuna and swordfish longline fleet from the Port of Santos (lines) and the location of some killer whale/longline fishery interactions (dots) off southern and south-eastern Brazil.

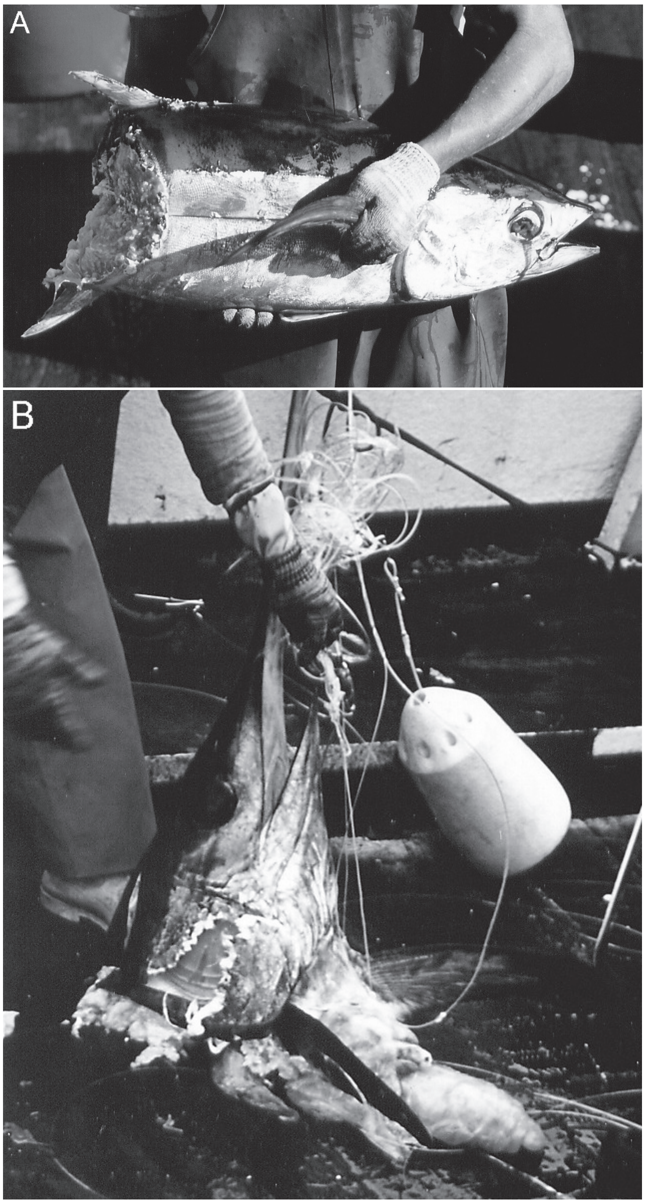

Figure 2. (A) Albacore, *Thunnus alalunga*, eaten by a shark. Sharks leave relatively small bite marks with clear-cut edges. Photograph: E.R. Secchi; (B) swordfish, *Xiphias gladius*, eaten by a killer whale. Killer whales tear the body of the fish, leaving bites with ragged borders and often just the head of the fish on the hook. Photograph: F. Costa.

learn to depredate other types of fisheries. In the Southern Ocean, killer whales were reported depredating longline-caught Patagonian toothfish, *Dissostichus eleginoides* (Ashford et al., 1996; Hucke-Gaete et al., 2004; Purves et al., 2004; Kock et al., 2006), and in New Zealand waters, they were reported taking bluenose, *Hyperoglyphe antarctica*, and school shark, *Galeorhinus galeus*, off the longlines (Visser, 2000).

Depredation by killer whales on pelagic longline-caught swordfish, *Xiphias gladius*, and tuna, *Thunnus* spp., has been reported off southern and south-eastern Brazil (Amorim & Arfelli, 1984; Secchi & Vaske Jr., 1998). However, no quantitative assessments of this depredation have been made to date.

While reports on killer whale depredation are widespread, very few studies have addressed shark depredation on longline catches (e.g. Sivasubramaniam, 1964; Nishida & Shiba, 2005).

The tuna longline fishery in Brazil was started by commercial vessels from Japan in 1957, off the north-east region (Wise & Le Guen, 1969; Zavala-Camin & Tomás, 1990). The Japanese fleet continued to operate off Brazil until 1965 (Barros, 1965; Zavala-Camin & Antero da Silva, 1991). In 1969, the Brazilian longline fleet, based in the port of Santos, south-eastern Brazil, started fishing off the southern and south-eastern regions of the country (Zavala-Camin & Tomás, 1990). In 1977, Japanese and Korean vessels leased by Brazilian companies from the port of Rio Grande, southern Brazil, initiated longlining off the north-eastern and, mainly, southern regions of the country (Antero da Silva, 1992).

In waters off southern and south-eastern Brazil, the Santos tuna longline fleet operates year round. According to Amorim & Arfelli (1984), the Brazilian tuna vessels operate in the area between 20° and 33°S and between 39° and 50°W. Until 1979, these vessels fished south of parallel 25°S from May to October and north of 27°S during the rest of the year. In 1979, they changed the seasonal distribution of fishing effort, but still following the same general pattern.

This work describes killer whale interactions with the tuna and swordfish longline fishery off southern and south-eastern Brazil and briefly evaluates the losses due to killer whale and shark depredation.

MATERIALS AND METHODS

Study area and the longline fleet

During the present study, vessels from Santos fished mainly in the area from 20° to 35°S and from the shelf break seaward across the continental slope, and occasionally further offshore (Figure 1). In the warmer months, fishing occurred in the south as well as in the south-east, whereas in the colder months it occurred predominantly in the south. From early 1993 to July 1995, the longline fleet from Santos consisted of 13 or 14 national vessels and two or three leased foreign vessels, totalling 16 to 17 vessels belonging to three different companies. After 1994, monofilament longline gradually replaced the traditional cotton-cable longline in the fisheries. For each trip, usually 12 to 15 sets took place with one set per day and between 1500 and 1800 hooks per set (about 8 sets and 700 hooks per set when monofilament line was used).

Longline fishery interactions

Aiming to obtain information on depredation by killer whales and sharks on longline catches, data sheets were distributed to captains or fishing masters of tuna vessels based in Santos from early 1993 to 1995. These questionnaires requested data about the vessel, fishing effort (number of hooks set per day and number of operations, or sets, per trip), fish catch and interactions (number and species of fish damaged by killer whales and by sharks, location and water temperature).

Data on catch per unit effort (CPUE) for the target fish and some records of interactions were also obtained from the logbooks of fishing vessels and were provided by the Instituto de Pesca, a state government agency located in Santos. Additional information about interactions was

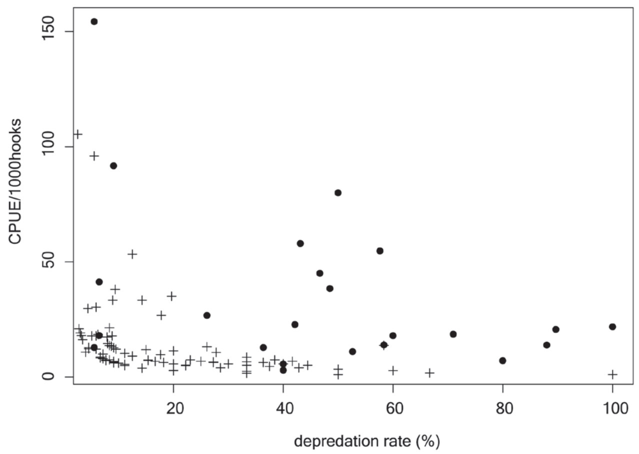

Figure 3. Relationship between the depredation rate by killer whale (•, N=23) and by shark (+, N=93) per set, and the respective CPUE (catch per unit effort of target fish).

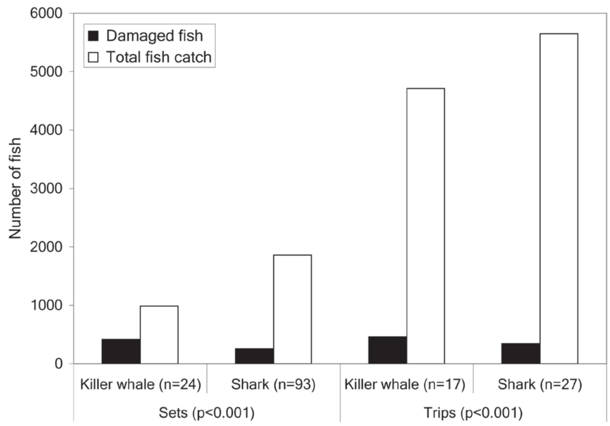

Figure 4. Proportion of damaged fish and total fish catch for sets and trips with killer whale depredation and with shark depredation.

obtained from researchers on board tuna vessels and from dockside interviews of fishermen at the Port of Santos.

The fish damaged by killer whales were distinguished from those damaged by sharks by the size and border type of the bites. According to Secchi & Vaske Jr (1998), blue, *Prionace glauca*, hammerhead, *Sphyrna* spp., shortfin mako, *Isurus oxyrinchus*, and requiem, *Carcharhinus* spp., sharks, all of which commonly damage longline-caught fish, leave relatively small bite marks with clear-cut edges (Figure 2A), while killer whales tear the body of the fish, leaving bites with ragged borders and often just the head of the fish on the hook (Figure 2B). These authors verified the distinction from on-board observations of both types of interactions, when sharks were seen depredating or when killer whales were seen nearby longline sets that had several fish damaged. They also concluded that experienced fishermen were able to differentiate between depredation by killer whales or sharks, even when the predators were not seen.

Data analysis

In the analysis of the interaction data only the target species were considered, which were: swordfish, yellowfin tuna, *Thunnus albacares*, albacore, *T. alalunga*, and big-eye tuna, *T. obesus*. For the purpose of analysis, the three species of tuna were combined into a single sample class.

Killer whale and shark interactions were analysed per longline set and per trip. Only the sets and the trips involving interactions were considered in the analysis of the proportion of the total catch that was damaged per set and per trip, respectively. For this reason, caution is necessary when interpreting the depredation rates, as they do not represent overall losses to the fleet, but only the loss during trips that experienced depredation.

The returns of the questionnaires were not consistent, data came from different sources, and some were incomplete. As a consequence, the sample size varied in different analyses.

In the trips where depredation by sharks but not by killer whales was registered, it was assumed that there was no depredation by killer whales. However, in the trips where depredation by killer whales but not by sharks was registered, the information on sharks was considered incomplete, instead of considering it zero, and it was not included in the analysis of shark depredation. This approach was used because the fishermen tended to record only important losses and, since losses caused by sharks during each operation were usually relatively small, the fishermen often failed to record them.

In the analysis of the proportion of fish damaged by killer whales, the fish damaged by sharks were not included in the total catch and vice versa, because it was assumed that once a fish was damaged by a predator, it was no longer available to the other predator.

The depredation rate was defined as the percentage of the total catch of target fish that was damaged per set or per fishing trip. Depredation rates were plotted against CPUE, defined as the number of target fish caught per thousand hooks, in order to better understand the extent of damage caused by both killer whales and sharks.

In order to determine which type of predator was responsible for a higher proportion of fish damage in relation to the total catch, both per set and per trip, the two-proportion z-test (Sheskin, 2000) was used. This test was also used to determine whether the predators exhibited significant preferences for swordfish or tuna. The chi-square test (Zar, 1999) was used to compare the frequency of interactions by killer whales and by sharks.

RESULTS

Killer whale interactions (Figure 1) occurred from June to February, mainly between June and October, while shark interactions occurred year round. Twenty-seven longline sets in 15 trips were recorded to have killer whale depredation and 93 sets in 16 trips were recorded to have shark depredation. The number of sets with shark interactions was significantly higher than the number of sets with killer whale interactions (χ^2=36.3, df=1, P<0.001). Of 27 trips with shark depredation, seven also had killer whale depredation. The number of trips with shark interactions was significantly higher than the number of trips with killer whale interactions (χ^2=11.76, df=1, P<0.001). The tuna vessel 'Taihei Maru #3', the most reliable for its systematic returning of data sheets during 1994, returned nine completed data sheets (117 sets) from practically consecutive trips. Killer whale interactions were

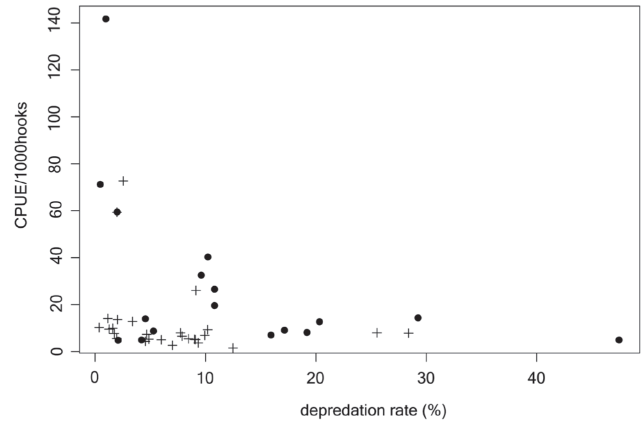

Figure 5. Relationship between the depredation rate by killer whale (•, N=17) and by shark (+, N=27) per trip, and the respective CPUE.

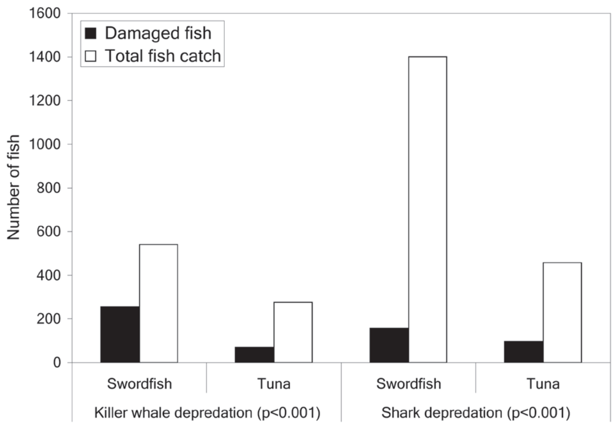

Figure 6. Difference in the proportion of swordfish and tuna damaged by killer whale and by shark.

reported in seven sets on four trips, while shark interactions were reported on all nine trips, involving 44 sets.

In the sets with killer whale depredation, from 1 to 53 and a mean of 17.33 target fish were damaged (N=24, SD=13.92). The depredation rate varied from 5.56 to 100% ($\bar{X}$=45.28%, N=24, SD=27.78, Figure 3). In the sets with shark depredation, from 1 to 14 and a mean of 2.72 target fish were damaged (N=93, SD=2.18). The depredation rate per set varied from 2.53 to 100% ($\bar{X}$=20.74%, N=93, SD=17.34, Figure 3). The proportion of the total catch that was damaged in the sets with killer whale depredation was significantly higher than in the sets with shark depredation (z=17.03, *P*<0.001, Figure 4).

In the trips with killer whale depredation, from 0.48 to 47.46% and a mean of 12.38% of the total catch of target fish was damaged (N=17, SD=12.10, Figure 5). The number of fish damaged per trip ranged from 2 to 91 ($\bar{X}$=27.24, N=17, SD=24.03). In the trips with shark depredation, from 0.38 to 28.40% and a mean of 7.13% of the total catch of target fish was damaged (N=27, SD=6.69, Figure 5). The number of fish damaged ranged from 1 to 60 ($\bar{X}$=12.85, N=27, SD=14.61). The depredation rate for the trips with killer whale depredation was also significantly higher than that of the trips with shark depredation (z=6.96, *P*<0.001, Figure 4).

When fish catches were high, depredation rates by sharks tended to reduce considerably, both per set and per trip, but for killer whales this trend was not so conspicuous (Figures 3 & 5).

On 20 sets, killer whales damaged 256 of 540 swordfish that were caught and 69 of 276 tuna. On 93 sets, sharks damaged 156 of 1401 swordfish and 97 of 457 tuna that were caught. Killer whales damaged significantly more swordfish than tuna (z=6.19, *P*<0.001), whereas sharks damaged significantly more tuna than swordfish (z=5.46, *P*<0.001) (Figure 6).

Killer whale depredation on white marlin, *Tetrapturus albidus*, blackfin tuna, *Thunnus atlanticus*, and sharks (not identified) was reported only once per species.

Incidental captures

In July 1994, a female killer whale was captured incidentally by the tuna vessel 'Toshin Maru 106' during its second trip using monofilament longline (Figure 7). The whale escaped alive when the hook bent open (B. O'Connel, personal communication).

Figure 7. A female killer whale captured incidentally by a tuna vessel using monofilament longline in July 1994. According to fishermen, the whale escaped alive when the hook bent open. Photograph: B. O'Connel.

DISCUSSION

Fishermen reports on shark depredation may not accurately reflect its true frequency of occurrence, because they often do not take small losses (e.g. one or two fish per set) into account. For instance, of 18 trips with killer whale depredation, seven also reported shark depredation.

However, all of the information gathered on interactions, including that obtained from interviews with fishermen, seems to indicate that depredation by sharks occurs on practically all trips (but not all sets), as it was observed for the tuna vessel 'Taihei Maru #3' on all nine of its monitored trips.

The lack of a measure of observer reliability precluded us from quantifying potential biases in the dataset. However, biases from missing records or under-reporting of shark depredation were minimized by analysing only trips with reported depredation and comparing proportions for each predator. As a consequence, we were unable to estimate the absolute frequency of the interactions and to assess overall losses to the fleet. Bias from incorrect identification of the predator by fishermen seems unlikely. Japanese longliners operating worldwide have also been assumed to correctly differentiate, through years of experience, between bite marks of sharks and cetaceans (Sivasubramaniam, 1964; Nishida & Shiba, 2005). And besides, fish damaged by sharks tend to be found distributed at random along the longline set, while fish damaged by killer whales tend to be distributed in an orderly manner (Sivasubramaniam, 1964; Secchi & Vaske Jr, 1998), facilitating differentiation.

The high variability in the extent of damage caused by killer whales may be explained by variation in the size of groups. Although adult males are sometimes solitary, killer whales are known for their high degree of social organization (Bigg et al., 1990; Ford et al., 2000). Groups composed of many individuals may learn to take advantage of group size and spread themselves over relatively large areas in order to improve their search for longline sets and to maximize feeding efficiency. For this reason, depending upon the number of whales that engage in depredation, the depredation rate could be relatively high even during fishing operations with high fish catches. Furthermore, if fishing continues in the same area, the depredation tends to continue and may even increase after the first day of interaction; this has been observed by Sivasubramaniam (1964) in the Indian Ocean. Dahlheim (1988) and Secchi & Vaske Jr (1998) reported that leaving the area where the interactions occurred is not always an efficient strategy to avoid depredation, since the killer whales may simply follow the boats.

Sivasubramaniam (1964) observed that besides the direct damage from killer whale depredation, significant losses might be caused by the decline in tuna catch rates when this predator was present at the fishing grounds and by the expenditure of time, fuel, and food (for the fishing crew) during the search for another fishing area. Dahlheim (1988) reported a decline in the catch rate of black cod on demersal longlines in Alaska when killer whales were present. Our data do not allow us to determine whether a similar decline in catch rates occurs off southern and south-eastern Brazil, although some of the fishermen claimed that it does.

According to fishermen, the longline catches are very occasionally depredated by another cetacean species, which based on their descriptions (e.g. all black and smaller than the killer whale) and their confirmation after looking at illustrations, is believed to be the false killer whale, *Pseudorca crassidens* (L. Dalla Rosa, unpublished data). Thus, the possibility cannot be ruled out that some of the losses attributed to depredation by killer whales were actually caused by false killer whales.

The predominant depredation on swordfish by killer whales and on tuna by sharks may be indicating a feeding preference by at least one of the predators. The probability of this result being biased is decreased by the fact that swordfish are usually caught in greater numbers than tuna. Also, given that killer whales and sharks may be found all over the fishing grounds, it seems unlikely that this difference is due to spatial patterns in the distribution of predators or fish catches. Selective foraging by fish-eating killer whales has been documented in British Columbian waters (Ford & Ellis, 2006).

Although the mean loss caused by killer whales, both per set and per trip where depredation occurred, was higher than the loss caused by sharks, the frequency of sets and trips with shark depredation was higher. Therefore, it is unclear from the data which type of predator may be responsible for the higher total annual loss to the entire fleet. It may be similar for both, and it is even possible that the losses caused by sharks are greater. It should be noted, however, that the shark species responsible for depredation are also caught in the longlines and become a source of revenue for the industry.

Depredation rates in our study are relatively similar to those reported for the Indian Ocean. When killer whales and sharks depredated the catch on a longline set, an average of 55% and 11% of the total catch was damaged, respectively (Sivasubramaniam, 1964). The frequency of shark depredation is also higher than cetacean depredation in the Indian Ocean. Of 1564 depredation events reported in 2000–2004, 58% were attributed to sharks, 40% to killer whales and false killer whales and 2% to others (Nishida & Shiba, 2005).

Estimates of depredation rates from systematic on-board monitoring are required to evaluate the frequency of killer whale and shark interactions and to better quantify the impact on the fisheries in Brazilian waters.

Incidental captures

Since monofilament longline was introduced in the tuna fleet from south-eastern Brazil in mid 1994, several incidents involving cetacean by-catch (in addition to the killer whale capture mentioned earlier) have come to our attention. In June 1994, a hooked Risso's dolphin, *Grampus griseus*, was released by cutting the line, and in March 1995, a hooked false killer whale was released. Dalla Rosa (unpublished data) also reported the capture of a Risso's dolphin in September 1996. The animal became entangled by its peduncle and was freed by cutting the line. Although none of these incidents was known to have resulted in the death of the cetacean, they demonstrate that by-catch does occur and it is reasonable to assume that in some cases the event can result in debilitation or death of the animal. We believe that the change in the longline from traditional cotton-cable to monofilament has increased the number of cetaceans caught incidentally because the latter is less visible and fished closer to the surface of the water. The problem of by-catch by longlines needs to be investigated more rigorously to determine if conservation measures are to be urged.

CONCLUSIONS

Our data demonstrate that: (1) the frequency of longline sets and trips with shark interactions is higher than the frequency of sets and trips with killer whale interactions; (2) the mean loss of fish due to killer whales, both per set and per trip that experience depredation, is higher than the loss caused by sharks; (3) depredation by killer whales occurs predominantly on swordfish, while depredation by sharks is mostly on tuna; and (4) cetacean by-catch is experienced by longline fisheries in Brazilian waters.

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