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PREDATION ON A WHITE SHARK (*CARCHARODON CARCHARIAS*) BY A KILLER WHALE (*ORCINUS ORCA*) AND A POSSIBLE CASE OF COMPETITIVE DISPLACEMENT

We observed an adult killer whale (*Orcinus orca*) kill and partially ingest a 3–4-m white shark (*Carcharodon carcharias*) near Southeast Farallon Island (37°42.0′N, 123°0.1′W) off San Francisco, California. The following account is based on field notes and a review of photograph and video documentation of the event.

At 1015 on 4 October 1997 a fishing vessel reported two killer whales approaching Southeast Farallon Island (SEFI) from the north. One of the whales was reported as being slightly larger than the other. At approximately 1100 another fishing vessel reported two killer whales killing and partially consuming an adult male California sea lion (*Zalophus californianus*) just to the west of SEFI. Again, one of the killer whales was reported to be slightly larger than the other. The two whales travelled with the partially consumed carcass 1 km northwest of the island, where they stopped and continued feeding at 1120.

At 1140 a whale-watching vessel located two killer whales in approximately the same location as last reported 20 min earlier. The rarity of killer whales near SEFI, the proximal time and location of the sightings, and the fact that intensive searching with 10× binoculars and a 20× scope from the lighthouse atop SEFI during this time period recorded no other killer whales within 10 km of the island, convinces us that these were the same individuals that killed the sea lion. Two of us (MJS and CK) were aboard the whale-watching vessel. The two killer whales were seen intermittently for the next 20 min. The seas were Beaufort 3–4 at this time.

At 1200 a 3–4-m white shark was observed next to the whale-watching boat, swimming along the surface and away from the vessel. When the shark was approximately 15 m from the vessel, one of the killer whales swam directly at the shark and contacted it underwater. The whale then came to the surface holding the shark by its back, proximal to the shark's dorsal fin. For the

following 15 min, the killer whale transported the shark along the surface such that the shark's ventral surface and jaw were clearly visible. The shark was motionless during this period. No blood or bite marks were noted on the shark, indicating that it may have died due to the impact from the killer whale. It is also possible that the shark entered a state of tonic immobility when it was upside down (Henningson 1994), allowing the killer whale to asphyxiate it through immobilization during this 15-min period. The shark was identified as a white shark based on the diagnostic combination of large size and white undersides with black-tipped pectoral fins.

At 1218, PP arrived at the scene, 0.5 km to the north of SEFI, in a 5.6-m Boston Whaler with an underwater Sony Hi-8 video camera. About 200 seabirds, primarily western gulls (*Larus occidentalis*), California gulls (*L. californicus*), sooty shearwaters (*Puffinus puffinus*), and northern fulmars (*Fulmarus glacialis*) were attracted to a large slick that had formed on the water. A female killer whale, estimated 5.4–6.0 m in length as directly compared with the Boston Whaler, was observed to the south of the slick, and a smaller female killer whale (estimated 4.7–5.3 m) that had distinctive white scarring on the head was holding the shark in its mouth. This killer whale continued to carry the shark until 1223, when it dropped it to feed on a large section of the liver that had separated from the rest of the carcass. The rostrum of the whale was chafed and stained with a small amount of blood. At 1233 SDA arrived in another Boston Whaler and observed one of the killer whales lifting its head above the surface and emitting a loud squeal of 2–3 sec duration. The seabirds were actively feeding on pieces of the shark's liver at this time. By 1238 the whales stopped feeding and swam toward the north.

Field notes, photographs, and videotape suggest that the smaller killer whale with the distinct scarring on the head was the same individual that killed, transported, and partially consumed the shark. This individual has been identified as "CA2," an adult female of the "LA Pod" recorded between Baja California and Monterey Bay from 1982 to 1995[1] (see Black *et al.* 1997). No photographic or video documentation of the larger whale was obtained, so it was not individually identified; however, on 17 October 1997, CA2 and another larger female killer whale were photographed (by SDA) 0.5 km south of SEFI. The larger female on this date has been identified as "CA6," the primary companion of CA2 within the LA Pod[1] (see Black *et al.* 1997). CA2 and CA6 were also photographed together off Monterey on 23 and 30 October 1997.[1] It is thus likely that the larger killer whale accompanying CA2 during the shark predation was CA6.

The habits and diet of killer whales off California are poorly known. Off British Columbia and Washington, "transient" killer whales feed primarily on marine mammals and birds, "resident" killer whales feed primarily on fish, and "offshore" killer whales are poorly known but appear to be primarily piscivorous (Ford *et al.* 1994, in press). No data on diet are available for killer whales off California. That we observed members of the LA Pod feeding on both a sea lion and a shark is of interest and may indicate that some California groups regularly feed on both fish and marine mammals.

Killer whales are known to prey on several species of sharks (reviewed by Fertl *et al.* 1996), but this is the first documented occurrence of predation upon a white shark. White sharks, although common around SEFI, are rarely seen swimming at the surface unless attracted by a decoy or a pinniped killed by another shark (Klimley *et al.* 1992, Anderson *et al.* 1996, Pyle *et al.* 1996). More typically, white sharks swim near the bottom around SEFI (Goldman *et al.* 1996). We suspect that the white shark killed by the killer whale may have been attracted to the surface by the carcass of the recently killed California sea lion, or the slick caused by its consumption by the whales.

The size of the white shark corresponds with that of the smallest of adults documented around SEFI, which range from 3 to 6 m in length (Klimley and Anderson 1996). The shark could not be identified from the documentation as any of up to 35 known, naturally marked individuals cataloged from SEFI (Klimley and Anderson 1996; Anderson and Pyle, unpublished data).

Killer whales are not common around SEFI. During year-round, daily censusing for cetaceans from SEFI between 1973 and 1996 (see Pyle and Gilbert 1996), killer whales were observed on only 30 d. During September–November, when white sharks are most abundant at SEFI (Pyle *et al.* 1996), killer whales have been observed on only 9 of 2,184 d during 1973–1996. It thus appears that killer whales rarely frequent SEFI waters in autumn, despite the presence of an abundant prey resource. White sharks are known to prey upon small to medium-sized cetaceans (Long and Jones 1996), and this may account for the general avoidance of this area by killer whales.

Of significant interest, however, was a nearly complete disappearance of white sharks around SEFI immediately following the predatory event on 4 October through 1 December 1997 when observations for white sharks from the island concluded. Attacks by white sharks on pinnipeds and other sightings of white sharks from SEFI (Pyle *et al.* 1996) were observed at approximately average rates through 3 October 1997, when one attack and one sighting were recorded (Fig. 1). Between 4 October, when the predation by the killer whale occurred, and 1 December, only two sightings were observed (predatory attacks on 15 October and 23 November). This represents a significant paucity of sharks during this period (Fig. 1), one that cannot be explained by prey abundance or environmental factors. Both pinniped abundance and mean sea surface temperature at SEFI (15.8°C), were slightly higher than is normal for this period. Similar evidence for this paucity of white sharks around SEFI during this period included (1) a significant lack of visits by sharks to decoys (Anderson *et al.* 1996: mean 0.58 ± 0.08 [SE] interactions/h in 1989–1996, 0.69 interactions/h during 3 September–3 October 1997, and 0.0 interactions/h in 33.6 h from 4 October–1 December 1997) and (2) a significant lack of shark-bitten northern elephant seals (*Mirounga angustirostrus*; see Long *et al.* 1996) recorded from 4 October–1 December 1997 (none, as compared with a mean of 8.63 ± 0.82 during this period in 1989–1996).

Killer whales were observed four more times from SEFI: on 14 October (a male and two females), 17 October (CA2 and CA6), 26 October (two males and four females or immatures), and 31 October (two females). These obser-

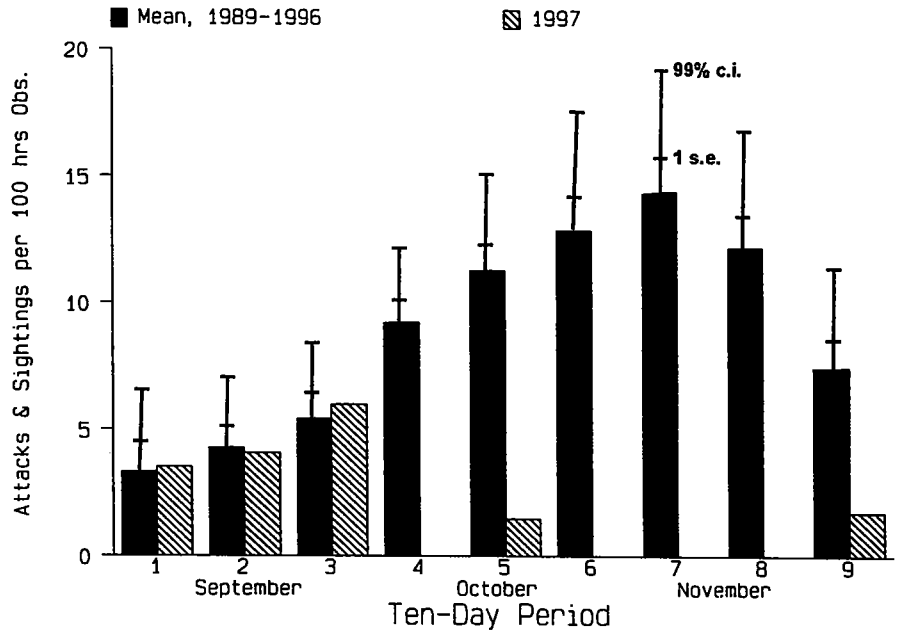

Figure 1. Mean number of sightings of white sharks (including attacks on pinnipeds) observed from SEFI (see Pyle *et al.* 1996) in 1989–1996, as compared with 1997. Ten-day periods defined according to the predatory event by the killer whale; thus, Period 3 includes 24 September–3 October, Period 4 includes 4–13 October, *etc.* Note that frequency of attacks and sightings observed falls well below 99% confidence limits (based on 1989–1996 data) during 4 October through 1 December 1997 (periods 4–9). Paucity of sharks in 1997 highly significant during these periods (multiple ANOVA, $F_{(1,6)} = 55.96$, $P < 0.0001$, adjusting for ten-day-period).

vations and those from Monterey Bay indicate that the LA Pod may have remained in the area through much of the 1997 season following the predatory event. We are unable to speculate on where the seasonally resident sharks at SEFI, including many seen during multiple and consecutive years (Klimley and Anderson 1996; Anderson and Pyle, unpublished data), may have been during the fall of 1997.

While little-understood or unknown, large-scale marine patterns or other factors may have caused this paucity of white sharks at SEFI, the significant and unprecedented nature of this paucity and its precise correspondence in timing with the predatory event has led us to speculate that the killer whales may have displaced the white sharks for the duration of the 1997 season. Confirmation of this and a mechanism for such competitive displacement or predator avoidance awaits further study.

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