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CO-ORDINATED ATTACK BEHAVIOR AND PREY SHARING BY KILLER WHALES AT CROZET ARCHIPELAGO: STRATEGIES FOR FEEDING ON NEGATIVELY-BUOYANT PREY

Killer whales are known to prey on a wide array of species, including fish, seabirds, and marine mammals (Scammon 1874, Jefferson *et al.* 1991). At Crozet Archipelago (southern Indian Ocean, 46°E 25′S, 51°E 45′E) the same killer whales have been observed attacking fish, penguins, pinnipeds, and large cetaceans (Guinet 1991, 1992). Here, we describe the attack and kill of a minke whale (*Balaenoptera acutorostrata*) calf and the sharing of a young elephant seal carcass (*Mirounga leonina*) by killer whales at Crozet, based on both surface and underwater observations. To our knowledge, this is the first description by divers of the underwater behavior of killer whales feeding on marine mammals. The observations led us to consider the problems that killer whales face when feeding on large, negatively buoyant prey, and we discuss possible mitigating strategies.

Both events described here were observed from a 5.5-m inflatable boat powered by twin 50-hp outboard engines. The minke whale attack was also observed from shore, using binoculars. Still photographs were taken from shore during the minke attack using a 35-mm SLR camera equipped with a 180-mm lens and 400 ISO black-and-white film. The minke whale and elephant seal predations were filmed by divers using a Sony Betacam video camera in a waterproof housing and a Sony underwater digital video camera fitted with a hydrophone, respectively. Individual killer whales were identified from the photographs and video footage by pigmentation and scar patterns, and by the shape and relative size of the dorsal fin (Bigg *et al.* 1987). Each individual was assigned an alpha-numeric identifier. All speeds and distances given are estimates.

The predation of the minke whale calf took place on 23 November 1998 at Possession Island, Crozet Archipelago and was observed by C.G. and L.B-L. from a 10 m-high bluff, 20–300 m from the whales. At 1330 a group of six killer whales comprising two adult males, two adult females, and two juveniles were observed swimming at 5–7 km/h along the seaward side of a kelp bed, 300 m offshore, near the eastern end of Baie Americaine. The whales were approached to a distance of 200 m and then followed by B.L and others in the inflatable boat. Three previously photo-identified killer whales were present: two females (B2 and G2) and a male (F1) that were first identified in 1984, 1988, and 1983 respectively. G2 was with a large juvenile or a female (possibly G3, identified in 1988). The sixth animal was an adult male (possibly F3, identified in 1988). This group associated consistently throughout our study period in 1998 (11 November–20 December).

At 1334 one of the killer whales breached 300 m offshore. This was im-

mediately followed by porpoising surfacings of two other killer whales. The entire group accelerated to 25–30 km/h and swam towards the mouth of a creek flowing into the bay. A minke whale calf was seen to surface slightly ahead of the killer whales. At 1337 the calf stranded on a sand bar in the mouth of the creek in 20–40 cm of water, followed a few seconds later by an adult female killer whale. The calf was approximately 3 m in length, dark grey with white pectoral flippers. The other killer whales grouped up and remained 4–5 m off the creek mouth. The stranded killer whale immediately seized the minke whale calf behind its pectoral flipper and held it crossways in its jaws. The killer whale then re-entered the water with a series of strong strokes of its partially submerged tail and side-to-side body motions, still holding the minke calf. As the two whales moved off the sand bar the calf escaped. Several tightly grouped killer whales then forced it away from the beach until it was approximately 50 m offshore. The minke made three more lunging head-first surfacings but appeared to be held by the left pectoral flipper by a male killer whale. During these surfacings two to three female and juvenile killer whales rolled their bodies over the minke whale's head. The minke was last seen at the surface at 1343. The whales moved slowly (4 km/h) offshore, frequently pausing and changing direction, and surfacing asynchronously at short intervals. At 1349 blood was seen just below the surface, and a killer whale surfaced with a large piece of flesh in its mouth.

At 1402 the whales stopped and began to dive repeatedly, and a diver (B.L.) entered the water. At 1405 a second group of killer whales approached from offshore, swimming relatively rapidly (12–15 km/h), and joined the first group. The second group comprised five individuals including two adult males, and three females and/or juveniles of which two males (M1 and M3) and one female (M2) had been previously identified, all in 1989. The groups joined for approximately one minute, then all of the first group except for one male, probably F3, departed. A third group of three killer whales approached rapidly (12–15 km/h) from the north at 1411 and joined the second. This third group comprised an adult male, a female, and a juvenile. We believe that the male and female were A1 and A2, first identified in 1972, and the juvenile appeared to be A4, an offspring of A2 first identified in 1986. These three whales regularly associated with M1, M2, and M3 in November and December 1998.

The diver located the carcass of the minke whale and began filming several minutes after he entered the water. The carcass had been stripped of skin, blubber, and viscera and was lying on sand on the bottom at a depth of 25 m. Little soft tissue remained other than muscle and connective tissue attached to the ventral side of the vertebral column. While the carcass lay on the bottom several whales of each group including adults of both sexes and juveniles slowly approached it in head-down, vertical positions, closely inspecting it and gently pulling at the remaining soft tissue. No rapid movements by the killer whales were seen, and some individuals were seen rubbing their sides and backs on the sand. Periodically the carcass was picked up and moved several meters by one of more of the whales, and dropped again. It sank rapidly

each time it was released. This behavior continued to at least 1503, when the cameraman left the water. A few quiet killer whale calls were heard by the diver while he was filming.

The second incident occurred on 18 December 1998 in Baie la Hébé, about 4 km from the site of the minke predation. The same six whales that attacked the minke were sighted approximately 500 m offshore. They were approached and followed at a distance of 100 m by B.L and others in the inflatable boat. The whales appeared to interrupt a long dive by surfacing sooner than expected, and then milled at the surface. Two divers (B.L. and L. Guenoun) entered the water 50 m from the milling whales. They filmed a young male and a female killer whale swimming slowly side by side holding the bleeding carcass of a young elephant seal. The male and the female killer whales tore the carcass into two pieces by arching their bodies away from each other and shaking their heads. The whales then separated and swam off, each holding pieces of the carcass in their mouths. Twenty seconds later a juvenile female killer whale swam towards the cameraman carrying another part of the carcass in its mouth. It released the piece 5–8 m in front of the diver. Ten seconds later the whale took the remains back in its mouth. As this whale swam off, it was joined by a second female or juvenile whale, and the two tore the remains into two parts in the same manner seen previously. Approximately 10 min after the whales began to mill, a group of five to six unidentified whales approached rapidly from offshore waters and joined them. It is not known if this second group had access to any remains of the prey. Many calls were recorded throughout the filming.

The group of killer whales that initiated each hunt consisted of six whales that had previously been assigned to three different pods (Guinet 1991), using the criteria of Bigg *et al.* (1990). The observations reported here suggest that group structure is more flexible at Crozet Island than previously thought (Guinet 1991), and that association patterns between individuals may change over time. This flexibility in association patterns bears more resemblance to the mammal-eating transient form of killer whale in the Northeast Pacific than to the fish-eating residents of the same area (Bigg *et al.* 1990, Ford and Ellis 1999).

A common aspect of both events was that the killer whales that initiated the hunt were joined within 10–15 min by other groups of killer whales. It is unlikely that the joining groups obtained a significant fraction of the prey in either case. No instances of intergroup prey sharing has been reported during 31 observations of killer whale predation of elephant seals at Possession Island, suggesting that pods of killer whales compete for this prey species (Guinet 1992). Pods may also compete for small cetaceans that can be rapidly consumed, such as the minke calf described here. In contrast, large cetacean prey are often shared between groups of killer whales (Silber *et al.* 1990, Guinet 1991, Goley and Straley 1994, Ford and Ellis 1999, Pitman and Chivers 1999). Assuming a sustained travelling speed of 12–15 km/h for rapidly moving killer whales, the times we reported here suggest that the joining groups travelled from distances of 4–8 km. In the Silber *et al.* (1990) account,

the authors described attacking killer whales being joined by other individuals up to more than 75 min. after the attack started. This time lag suggests that the killer whales travelled at least 15–19 km to join the attackers. In the Pitman and Chivers (1999) account, the number of killer whales increased from three or four to 40–50 over a 3-h period.

During attacks of large cetaceans it is likely that the probability of success increases with killer whale group size. However, the encounter rate of prey per killer whale will decrease with group size, particularly if prey are widely dispersed. Killer whales could, in theory, maximize both attack success and encounter rate by searching for prey in small groups and joining up to attack them. In reality, the vocal behavior of mammal-hunting killer whales is constrained by the risk of alerting prey (Barrett-Lennard *et al.* 1996), and long-distance acoustic communication prior to an attack seems unlikely. An optimal strategy for small groups may be to attack and cripple a large cetacean or trap it at the surface as rapidly as possible after detecting it before signalling to other killer whale groups. This strategy accords with accounts by Silber *et al.* (1990) and Pitman and Chivers (1999) in which small groups of killer whales apparently incapacitated larger cetaceans before they were joined by other groups of killer whales.

We suggest that large group sizes may have a second important advantage for killer whales that are feeding on large cetaceans. Rorqual (*Balaenopteridae*) whales usually sink when killed (Scammon 1874). The fact that the minke whale carcass described here sank rapidly when released and was retrieved several times from the sea floor suggests that when killer whales feed on a large cetacean in deeper water, they may lose the carcass before they are satiated unless they actively prevent it from sinking beyond reach. Pitman and Chivers (1999) reported that killer whales dove repeatedly after killing a sperm whale (*Physeter macrocephalus*) in deep water, and at one point dragged it briefly to the surface, suggesting that they were indeed preventing it from sinking. A group of killer whales that have killed a large cetacean may benefit from the joining of other groups if their presence helps prevent the carcass from sinking and ensures a longer feeding period. A group effort to prevent sinking would require that individuals divide their time between feeding and pushing the carcass upward. Such a trade-off would only be an evolutionarily stable strategy (Maynard Smith 1982) if individuals realize greater long-term advantages from participating in the group effort than they would from feeding rapidly without participating. We will explore in a future paper the possibility that such advantages are social in nature, and that cetacean-hunting killer whale groups belong to larger coalitions with shared behavioral conventions.

Additional strategies that killer whales may use to prevent whale carcasses from sinking beyond reach are (1) feeding on crippled whales while they are still alive, as described by Tarpy (1978) for a blue whale (*Balaenoptera musculus*), and Whitehead and Glass (1985) for humpback whales (*Megaptera novaeangliae*), (2) driving cetacean prey into shallow areas before attacking them, or (3) simply hunting as much as possible in shallow areas.

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