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KILLER WHALE PREDATION ON SPERM WHALES: OBSERVATIONS AND IMPLICATIONS

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ABSTRACT

In October 1997 we observed a herd of approximately 35 killer whales (*Orcinus orca*) attack a pod of nine sperm whales (*Physeter macrocephalus*) 130 km off the coast of central California. During the four hours we watched, adult female killer whales, including some with calves, attacked in waves of four to five animals in what was apparently a "wound and withdraw" strategy. Adult male killer whales stood by until the very end when one charged in and quickly killed a seriously wounded sperm whale that had been separated from the group. The sperm whales appeared largely helpless: their main defensive behavior was the formation of a rosette ("marguerite"—heads together, tails out). When the killer whales were successful in pulling an individual out of the rosette, one or two sperm whales exposed themselves to increased attack by leaving the rosette, flanking the isolated individual, and leading it back into the formation. Despite these efforts, one sperm whale was killed and eaten and the rest were seriously, perhaps mortally, wounded. We also present details of two other encounters between sperm whales and killer whales that we observed. Although sperm whales, because of various behavioral and morphological adaptations, were previously thought to be immune to predation, our observations clearly establish their vulnerability to killer whales. We suggest that killer whale predation has potentially been an important, and underrated, selective factor in the evolution of sperm whale ecology, influencing perhaps the development of their complex social behavior and at-sea distribution patterns.

Key words: sperm whale, *Physeter macrocephalus,* killer whale, *Orcinus orca,* predation.

Killer whales (*Orcinus orca*) are the most widespread carnivores in the world (excluding humans); they occur in all oceans where they feed on practically every large vertebrate that lives in the sea, including nearly every known

species of marine mammal. There are, however, remarkably few recorded observations of attacks on cetaceans, especially large whales (Jefferson *et al.* 1991).

Jefferson *et al.* (1991) reviewed reports of killer whale predation on marine mammals and specifically noted that there were no documented accounts of successful predation on sperm whales (*Physeter macrocephalus*), although there have been incidences of calves and wounded adults being attacked. This lack of evidence has led to the widely held belief that because of their large size, effective communication, herding behavior, deep diving habits, powerful toothed jaws, and sometimes aggressive demeanor, sperm whales are largely immune to killer whale predation (*e.g.,* Jonsgård 1968, Rice 1989, Jefferson *et al.* 1991). Sperm whale authority A. A. Berzin concluded, "As a matter of fact, the sperm whale has no enemies in the ocean (besides man)" (Berzin 1972:261). This idea of sperm whale invincibility recently received support from three separate, detailed accounts of attacks on sperm whales by short-finned pilot whales (*Globicephala macrorhynchus*; Weller *et al.* 1996), false killer whales (*Pseudorca crassidens*; Palacios and Mate 1996), and killer whales (Arnbom *et al.* 1987). In each of these cases, although the sperm whales received some minor injuries, their behavioral responses were ultimately successful in warding off the attackers.

But there are other observations that suggest that killer whale attacks on sperm whales are not all that rare, and perhaps not always unsuccessful. Shevchenko (1975) reported that 65% of sperm whales taken by whalers in Antarctica had killer whale teeth marks on them. Rice (1989) discredited this last report saying that it would be difficult to distinguish tooth marks of killer whales from those of other sperm whales, but Shevchenko (*op. cit.*) found the same tooth marks on fin, sei, and minke whales (*Balaenoptera physalus, B. borealis,* and *B. acutorostrata,* respectively). Also, it seems unlikely that an experienced cetologist like Shevchenko would mistake the very different tooth size and placement, and jaw configuration of a killer whale with that of a sperm whale.[1] Yukhov *et al.* (1975) mentioned an attack on a herd of female sperm whales with calves, and also reported sperm whale remains in the stomachs of killer whales from the Southern Hemisphere. Best *et al.* (1984) examined a dead sperm whale calf that had wounds apparently inflicted by killer whales, and Brennan and Rodriguez (1994) reported that a killer whale bit a sperm whale behind the dorsal hump and drew blood, although the sperm whale subsequently dove and presumably escaped.

These records suggest that killer whales may regularly test sperm whales, and although sperm whales are probably successful in fending off attackers in most cases, they may also be vulnerable at times. In this paper we describe three separate encounters we observed between killer whales and sperm whales, including an attack in which a large, presumably adult, female sperm whale was killed and eaten. We suggest that the threat of killer whale predation

[1] Peter B. Best, Whale Unit, % South African Museum, P. O. Box 61, Cape Town 8000, South Africa; e-mail December 1999.

may have been a significant factor in shaping some of the life history traits of sperm whales.

Methods

All of our observations were recorded during dedicated cetacean survey cruises in the eastern Pacific Ocean while aboard the 60-m NOAA Research Vessel *David Starr Jordan.* Observations were made from a platform 10 m above the sea surface using two or three pairs of 25 × 150-mm mounted spotting binoculars and 8 × 50-mm handheld binoculars. The use of high-powered binoculars allowed us to make detailed observations of whales at distances of over 1 km. The number of observers present during the sightings varied from six to eight. For Sighting 1, Pitman and Ballance recorded details of their observations within an hour after the event. For Sightings 2 and 3, all eight observers present (including all of the authors) independently recorded their observations and impressions immediately after the sighting, and these were used to compile the narrative that follows.

Results

Sighting 1—The event happened on 21 August 1989 at 9°06′N, 105°50′W, approximately 1,100 km southwest of Acapulco, Mexico, in water 3,700 m deep. Initially, we saw a mixed herd of approximately 65 short-finned pilot whales and 15 bottlenose dolphins (*Tursiops truncatus*) charging through the water at high speed (the pilot whales were porpoising). A few minutes later, a group of approximately six killer whales came into view 2–3 km ahead of them. The pilot whales made several abrupt turns, still traveling at full speed. Approximately five minutes later, a group of eight sperm whales (including at least one calf) appeared between us and the pilot whales; they were lying close together at the surface in a line, "shoulder-to-shoulder." As we turned to approach the sperm whales, the pilot whales and bottlenose dolphins started heading toward them also. The sperm whales then formed a "rosette" (or "marguerite," Nishiwaki 1962), consisting of a circle of animals at the surface with their heads together and tails pointed out (see Fig. 1). The pilot whales moved in among them, sometimes within 2 m, and milled about, while the bottlenose dolphins remained in a tight group off to the side.

The sperm whales remained in a rosette until we approached within 50 m of them, then they suddenly all rolled over and dove. Several minutes later the pilot whales and bottlenose dolphins bolted and were once again leaping out of the water. The killer whales reappeared in the distance directly in front of the charging herd although not heading in its direction. The pilot whales and dolphins stopped abruptly, came about-face, and returned to the sperm whales which had just resurfaced. This time the sperm whales did not form a rosette. Instead, they formed a tight but irregular group while the pilot whales milled among them. As we passed within 50 m of the sperm whales they

Figure 1. Geometry for an unselfish herd? Sperm whales form a rosette with their heads toward the center and their tails out during a killer whale attack on 21 October 1997 (Sighting 2, see text).

dove once again. At this time the entire scene was obscured by rain and we terminated observations.

Weller *et al.* (1996) reviewed our field notes from this event and concluded that the sperm whales probably formed a rosette in response to the pilot whales. Our interpretation at the time, however, was that the pilot whales and bottlenose dolphins may have been seeking refuge among the sperm whales from the killer whales and that the sperm whales were reacting to the presence of killer whales also. Either way, the sperm whales' response to threatening mammals was different than their response to our vessel, *i.e.*, they submerged when we got too close.

Sighting 2—This event occurred on 21 October 1997, at 35°06′N, 122°14′W, approximately 130 km WSW of Morro Bay, California. The water depth was 4,400 m. At 0705 (first light) a bridge officer reported killer whales attacking sperm whales in front of our drifting vessel. Although we began observations immediately, it was apparent that the attack was already underway because the sperm whales were in rosette formation (Fig. 1) and there was a large slick of blood and oil on the water around them. We watched from a distance of 0.5–1 km for four hours while the killer whales attacked repeatedly. At 1100 one of the sperm whales was killed; the killer whales dragged it approximately 1 km from the site and began to feed on it. We stayed with the killer whales and photographed them as they fed until 1300,

after which we went back to look for surviving sperm whales, but were unable to locate them. Details of this event are given below.

Group sizes and composition—Throughout our observation, groups of killer whales numbering from one to six individuals were scattered throughout our range of view, up to 3 km from the sperm whales. At no time during the episode did we see all of the killer whales form a single group. Although we initially estimated there were approximately a dozen, the number seemed to grow as the hours passed, so that by the end of our observations we estimated that there may have been as many as 35.

Nancy Black[2] reviewed all of our killer whale photos from this episode and identified a minimum of 17 individuals, including 2 adult males, 11 "female types," 2 juveniles and 2 calves. She could not find any matches with individuals in a recently completed catalog of 268 individually identified killer whales from California and western Mexico (Black *et al.* 1997). Black[2] also stated that she had never before seen killer whales with the black dots/circles in the pale area behind the dorsal fin (the "saddle") evident on most of these animals. Neither are these circles present on any individuals in a catalog of "transient" killer whales that occur from Alaska to Washington (Ford and Ellis 1999). These circles are almost certainly healed scars from bites of cookiecutter sharks (*Isistius* sp.) (Jones 1971). These sharks inhabit deep water (Castro 1983) and we suggest that the killer whales in Sighting 2 belong to a far offshore population that normally occurs seaward of the continental shelf.

We estimated that there were nine sperm whales present in the rosette when we began our observations. The sperm whale pod appeared to be comprised of adult females based on size (lengths from 7 to 10 m), and one of the largest animals (the animal that was killed) was determined to be a female from a genetic analysis of a skin sample we salvaged. However, we saw no callosities on the dorsal humps of any of individuals we photographed (usually present on adult females; Kasuya and Ohsumi 1966), so it is possible that this was a group of large subadults. We saw no calves but, since the attack was well underway at first light, calves could have been present and killed before we began observations.

Attack strategy—The killer whales attacked in waves. Initially, and for the first few hours, subgroups of four to five charged in from several hundred meters distance, often lunging high out of the water, side-by-side as they approached. Then they dove and resurfaced just outside the rosette, swimming rapidly around it. Almost immediately they attacked one or more sperm whales, striking them perpendicularly well below the water line, usually mid-body, along the side. Immediately following each of these attacks, we usually saw fresh blood rise to the surface. After a few minutes the killer whales retreated and apparently dispersed, sometimes for 10 min or so, before attacking again. Although this "wound and withdraw" strategy gave the sperm whales time to rest and regroup, seriously bleeding individuals progressively

[2] Nancy Black, P. O. Box 52001, Pacific Grove, CA 93950, U.S.A., undated letter, *ca.* December 1997.

weakened over time. During the last hour before the kill, the attacks became more frenzied, the number of attacking killer whales increased to twelve or more, and the interval between raids was reduced to one or two minutes. We observed a minimum of 16 separate attacks. It was not possible to determine if the same individual killer whales were involved in each of the attacks although this was our impression at the time (for example, one cow with a very small calf was often present in the attacking parties).

The sperm whales appeared to have very tough hides because, when the killer whales bit into them, they had difficulty removing the flesh. We observed killer whales using at least three different methods in their attempts to wrench off mouthfuls of flesh. Sometimes a killer whale would bite into a sperm whale and shake its head violently side-to-side, like a shark. The dorsal fins of these killer whales (especially the adult male) wobbled wildly during these vigorous efforts. Another method was for the biting killer whale to spin on its horizontal axis; this was usually evident as a flashing black and white pattern underwater as an animal exposed its black dorsal and white ventral surfaces in rapid succession. Another method was to bite into a victim, then use the flukes and large, paddle-shaped pectoral fins to try to back away from the animal. It was not clear in these latter cases whether the attacking killer whale was attempting to remove flesh or trying to pull a sperm whale out of the rosette (see below).

The killer whales were clearly interested in breaking up the rosette. This became increasingly evident as the sperm whales started weakening. When the rosette was intact, killer whales appeared to attack animals at random, but on the several occasions when a sperm whale was pulled out of formation, it was immediately set upon from all sides by most or all of the killer whales present. This continued until the isolated whale found its way (or was led, see below) back into the rosette.

Throughout the event, only adult female and immature killer whales were involved in the attacks. Although at least three adult male killer whales were present from the start, they were always in the distance (100–2,000 m), and did not join the attack until it was almost over. Throughout the attack, two young killer whale calves accompanied adult females (presumably their mothers). When cows with calves were away from the immediate area of the rosette, the calves traveled close by their mother's sides, but when the cows were attacking, the unattended young usually circled around, just outside the rosette. During the last hour of the attack however, the calves joined in, biting into the sides of the sperm whales alongside their mothers.

Defense strategy—The main defensive strategy of the sperm whales appeared to be in maintaining the rosette formation. During some of the attacks the killer whales succeeded in breaking up the pattern briefly, but the sperm whales always regained the formation when the killer whales withdrew. Sometimes an individual appeared to be moved toward the center of the rosette. This may have been due simply to the jostling during the attacks, but we cannot rule out the possibility that a seriously injured individual was deliberately positioned in a more central position for protection. During most of

the attacks, however, all of the sperm whales, even some of the more badly injured individuals, took equal positions in the formation.

The only other formation that we saw was when our vessel drifted within 150 m of the group. At that time the rosette opened up on one side and became a phalanx with members shoulder-to-shoulder. This may have been done so the herd could swim away from us although, because this only happened late in the attack, it is possible that the group was trying to protect more severely wounded individuals. When they were in this formation and the killer whales attacked, the exposed animals on the ends received the brunt of the attack, and a rosette was quickly reformed.

One of the most striking features of the attack was the apparent helplessness of the sperm whales. We never saw them deliberately strike at the killer whales, nor did we see any attempt to escape by diving, even during the many times when the killer whales withdrew from the attack. A potential defense behavior by the sperm whales was tail-slapping. We saw sperm whales lift their tails out of the water fairly often, both during and between attacks, but most of the time when they raised their tails they were limply waving around with no obvious intent, or held at odd angles as though the whale was being dragged down. Most of the tail-slaps had no real force behind them; the few strong tail slaps we did see seemed to be merely reflexive, they did not appear to target individual attackers, and they did not appear to deter them.

Apparent altruism—The strength of the sperm whales' drive to maintain the rosette pattern was never more apparent than when the killer whales succeeded in pulling a sperm whale out of the formation. Two hours into the episode the killer whales dragged one of the sperm whales out of the rosette; it was immediately attacked by four to five killer whales biting and pulling on it as fresh blood colored the surface. Within less than a minute, one of the larger sperm whales in the rosette left the formation and swam over beside its companion. It was immediately attacked as it assumed a position parallel to the first animal. The pair moved slowly back into the rosette, the second whale apparently leading the way. On each of the several occasions when killer whales pulled a sperm whale out of the rosette, one or sometimes two others left the formation almost immediately, and, despite the vicious attacks this brought upon themselves, they flanked the isolated animal, and led it back into the formation.

Injuries—Near the end of the attack it appeared that most, if not all, of the sperm whales were injured, several seriously. One sperm whale rolled over next to the ship and a huge flap of blubber (approximately 2 m × 1.5 m) opened up, exposing the underlying flesh. Another individual had a large chunk of flesh ripped out of its back below the dorsal hump exposing what appeared to be ribs. One individual had its intestines floating beside it and draped over its dorsal hump. Another individual that spy-hopped had a broken jaw that jutted off laterally at a 90° angle at about the mid-point. (We do not know for certain that this was a result of the attacks.) We suspect that at least three or four of the survivors eventually died from wounds they received, and it is quite possible that the entire herd died as a result of injuries from the attack.

Killing and feeding behaviors—At 1100, attacking killer whales broke up the rosette and isolated two sperm whales. One of these rolled over on its side and appeared to be nearly dead. At that moment, an adult male killer whale charged in and slammed into it. The male took the sperm whale in its jaws and shook it violently from side-to-side. He then spun it around at the surface, throwing huge sprays of water into the air in an immense display of power not shown by any of the females at any time during the attack. Several other killer whales also came in to attack this individual when another sperm whale came out from the rosette and attempted to lead it back to the formation. In the confusion that followed, it was not clear which of these two animals was killed, but shortly afterward the adult male killer whale swam off carrying a large dead sperm whale with him.

Several minutes later a group of four to five killer whales were carrying the sperm whale carcass backwards through the water with its flukes projecting up over their heads. Shortly afterward the carcass apparently sank to a depth of neutral buoyancy because the killer whales were milling and diving at the same spot for over an hour and apparently feeding. As we photographed the killer whales we saw several large chunks of skin and blubber float to the surface including a piece approximately 0.5 m^2 and weighing approximately 20 kg that we collected. Another one square meter chunk of blubber floating at the surface was taken by an adult female killer whale accompanied by a calf. The traveling pair surfaced directly in front of the chunk and the female took it in her mouth as she dove; the piece was gone when they resurfaced a couple of minutes later.

Sighting 3—This event was recorded on 26 October 1997 at 35°24′N, 122°27′W, approximately 83 km west of Pt. Lopez, off the central California coast. The water depth was approximately 3,800 m.

At 0845 we sighted a group of five sperm whales, possibly including a calf. They were active at the surface and for 30 min, as we monitored their respiration rates, we saw several full body breaches and 40–50 tail slaps. While observing this group another group of five sperm whales, including a calf, surfaced approximately 1 km away from the first group.

At 0930 we first saw a group of five killer whales, including an adult male and at least one adult female, approximately 1 km beyond the second sperm whale group and headed toward them. Those sperm whales then submerged, for less than a minute, leaving the calf at the surface. We think they may have sounded an alarm call at this time because immediately afterward the first sperm whale group bunched up and started traveling rapidly toward the second group. When the second group resurfaced it was joined almost immediately by several other sperm whales that surfaced around and among them, and by the time the two original groups merged there were approximately 15 individuals present. The sperm whales appeared agitated: several had the anterior portion of their heads raised out of the water and were facing in different directions. Others rolled over on their sides exposing their flippers and flukes, and some slapped the surface with their tails.

At 0947 a single adult female killer whale left her traveling group and

approached the sperm whales, while her group continued traveling in their original direction. After several arching dives by the killer whale, sometimes within 3 m of the sperm whales, an oily slick formed at the edge of the sperm whale cluster suggesting that one or more had been bitten, although no blood was visible.

As their numbers increased to approximately 20, the sperm whales formed a raft at the surface, all facing the same direction. At that time we noticed that they were blowing more forcefully and more rapidly. At least four other groups of sperm whales in the distance were charging toward the core group at full speed, pushing waves with their heads as they plowed through the water. The converging animals initially included separate groups of eight, five, and two animals, and a large, lone individual that appeared to be an adult male. The farthest incoming group that we saw was approximately 7 km away when first sighted.

As the sperm whale numbers continued to grow they coalesced into a "spindle" formation, from one to four or five animals wide and 12 to 15 animals long, and all facing the same direction. In this formation they came about-face several times, usually all turning in the same direction, at the same time, along the long axis of the formation. On one occasion both halves of the group were facing the middle for several seconds. One observer noted that the change of direction was always clockwise, with the animals in the front apparently initiating the direction change.

While the killer whale was busy in the slick area for several minutes it drifted approximately 50 m away before moving back in among the sperm whales, once again causing much agitation. At this time, without lifting their flukes, all but two or three of the sperm whales submerged for almost a minute. When they resurfaced approximately 30 were present, and they formed a staggered chorus-line formation with the entire group lined up, facing the same direction, side-by-side, apparently touching each other, and each animal ¼–⅓ of body length behind the animal to its right. (This remarkably precise formation is possibly formed when a line of sperm whales swimming shoulder-to-shoulder makes a slight turn to the left or right.) The formation lasted less than one minute, then the herd reverted to the spindle formation which it maintained throughout most of the event. Other sperm whales continued to join the herd until by 1010 an estimated 50 were present, including several calves. By this time the female killer whale had apparently lost interest and was traveling almost 2 km away, toward her group.

By 1025 the killer whales had all left the area and we saw no more sperm whales arriving. We put a launch in the water and attempted (unsuccessfully) to radio tag one of the sperm whales, but whenever we approached within 100 m of them they broke up into smaller subgroups and submerged (without raising flukes). Shortly afterward, the whole herd broke up into several subgroups and we followed one group of about 20 animals (seven cow/calf pairs and six other individuals) as it traveled north at high speed for the rest of the day.

Discussion

These observations clearly establish for the first time that killer whales are predators of sperm whales (Jefferson *et al.* 1991). Although it has long been suspected that they at least occasionally challenge sperm whales to check for vulnerable individuals (*e.g.,* Arnbom *et al.* 1987, Dufault and Whitehead 1995), the lethal attack we witnessed (Sighting 2) involved a herd of healthy, adult female-sized sperm whales and the entire herd appeared to be at risk. The attacking behavior was well coordinated and efficient, and it did not appear that this was the first time that the killer whales had preyed upon sperm whales. This is supported by the fact that we saw another attack five days later and only 42 km away (although we do not know if the same killer whales were involved in Sightings 2 and 3).

The prolonged and episodic nature of the attack in Sighting 2 was presumably a deliberate attempt to decrease the possibility of injury to the killer whales as they pursued a large and potentially dangerous prey (see also Ford and Ellis 1999). The apparent "wound and withdraw" strategy may have had exsanguination as its ultimate goal because each new attack resulted in large amounts of fresh blood at the surface. A similar attack strategy has been hypothesized for white sharks (*Carcharodon carcharius*): when they target large prey, they reportedly bite their victims, then withdraw, and return to feed only after the victim has bled to death (Tricas and McCosker 1984, Barlow 1996, but see Klimley *et al.* 1996).

The role of the adult male in killer whale predation, especially on large cetaceans, is not clear (Jefferson *et al.* 1991) because there are published accounts of them participating (Hancock 1965, Whitehead and Glass 1985), being peripherally involved (Tarpy 1979, Arnbom *et al.* 1987), standing by (Silber *et al.* 1990), or being absent during attacks on large whales (Cummings *et al.* 1972). Vidal and Pechter (1989) reviewed the literature and concluded, "It appears that marine mammals are successfully attacked and eaten mainly by the larger, usually adult male killer whales," and that attacks on larger whales involving only females and immatures were largely unsuccessful. Similarly, Budylenko (1981) stated that, "Initially, the prey is attacked by the large and strong killer whale males and afterwards, when the prey grows weak, the attacks are continued by the females and young of both sexes." Our observations do not support these assertions. The attacking females and young in Sighting 2 nearly decimated an entire herd of sperm whales without any help from adult males. In fact, the male killer whale waited until most of the work was done before moving in to finish off a critically wounded sperm whale. In a possibly analogous situation, Schaller (1972) reported that male lions (*Panthera leo*) usually waited for lionesses to make a kill, then they moved in and used their larger size to appropriate the prey. More observations will be necessary to determine the specific role the adult male, with his much larger size, plays in killer whale predation.

Although it has generally been assumed that sperm whales rely mainly on their deep and prolonged diving abilities to escape predators (*e.g.,* Rice 1989),

Berzin (1972) identified three separate fright reactions of sperm whales: diving, aggregating at the surface, and flight. Berzin (*op. cit.*) did not comment on the circumstances under which these behaviors might occur, but our observations, combined with those of other researchers, suggest that each of these responses are context dependent. Specifically, sperm whales dive if a vessel approaches (Sightings 1, 3); aggregate at the surface if there is an immediate threat from predatory cetaceans (Sightings 1–3; Arnbom *et al.* 1987, Palacios and Mate 1996, Weller *et al.* 1996), and flee from an area after an encounter with predators (Sighting 3; Caldwell *et al.* 1966, Arnbom *et al.* 1987). We should also point out that *what* sperm whales are responding to may not always be apparent. For example, it was not clear in Sighting 1 whether sperm whales formed a rosette in response to the immediate presence of pilot whales or the acoustic detection of distant killer whales, and without high-powered binoculars we would not have even known that killer whales were in the area.

When sperm whales do form defensive aggregations at the surface, they are of two main types, apparently depending on their group size. They form rosettes when the group is small; for example, eight animals (Sighting 1), 9 (Sighting 2), and 12, including two calves (Weller *et al.* 1996). In a terse, secondhand report, Nishiwaki (1962) mentioned a group of 20–30 sperm whales forming a rosette but his accompanying photograph shows only a dozen or so animals. Perhaps more telling is the account of Palacios and Mate (1996) who reported that a group of 20–25 sperm whales formed two separate rosettes. When larger numbers of individuals are present, for example, 31 animals (Arnbom *et al.* 1987) and 50 (Sighting 3), they form a tight flotilla. Clearly the larger group offers more protection, especially for vulnerable individuals that can go in the middle (Best *et al.* 1984), but a rosette may be the best option when there are no more than 10–15 individuals present.

It is evident from Sighting 2 that forming a rosette is an "all or none" strategy that does not always work to the best interests of sperm whales. For example, most of the time rosette formation probably has the advantage of providing equal protection for each member of the group, and it may also allow the whales to selectively provide additional shielding for calves or seriously injured individual, by positioning them in the middle of the formation (*e.g.,* Weller *et al.* 1996). But in Sighting 2, *because* individuals in the rosette were equally exposed to attack, killer whales attacked individuals randomly instead of focusing on a specific individual. This meant that most or all of the sperm whales were severely injured. And the killer whales quit attacking the rosette and departed once they had killed one of the sperm whales. If the sperm whales had not continued to lead separated individuals back into the rosette and instead let the killer whales have one of their number, the rest of the herd might have been spared. Although altruistic behavior likely serves sperm whales well in most cases, in this instance it meant most, if not all, of the herd was sacrificed in efforts to protect individual members (see also Dufault and Whitehead 1995).

Although never demonstrated, it has long been suspected that sperm whales can sound a long distance alarm/summons call when threatened (Caldwell *et*

al. 1966, Arnbom *et al.* 1987). During Sighting 3, after a small group of sperm whales was harassed by a killer whale, using high-powered binoculars we saw that every sperm whale within at least a 7-km radius immediately charged toward the threatened group at high speed and joined them in a defensive formation. Although it may never be known if their intention was to come to the aid of threatened conspecifics or to seek protection themselves (or both), there can be little doubt but that they were responding to a very specific and powerful acoustic signal.

Recently, Corkeron and Connor (1999) suggested that baleen whales undertake breeding migrations to lower latitudes in order to reduce the risk of killer whale predation on their calves. We suspect that killer whales could have a similar influence on the overall pattern of distribution and movement of sperm whales. The sperm whale is the most sexually segregated animal species in the world: females and young occur in the tropical and subtropical oceans, while (non-breeding) adult males occur mainly in polar regions. It may be that killer whale predation pressure forces females and young to inhabit only lower latitudes, where killer whales are much less common (Dahlheim and Heyning 1999). Even the structured social organization of sperm whales may have evolved as a defense against predators (Best 1979, Whitehead and Weilgart 1990). The cumulative ecological effects of killer whales—large, intelligent, pack-hunting predators, roaming the world's oceans—has never been fully evaluated. We suggest that killer whales, through their predatory habits, represent a much more important selective force in shaping life history traits of individual marine mammal species, and in structuring their communities, than has generally been acknowledged.

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