Reactions of Narwhals, *Monodon monoceros,* to Killer Whale, *Orcinus orca,* Attacks in the Eastern Canadian Arctic

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A Killer Whale attack on Narwhals was observed at Kakiak Point in Admiralty Inlet, Nunavut, Canada, in August 2005. Behavioral responses of both Narwhals and Killer Whales were documented by direct observation. Data collected from Narwhals instrumented with satellite-linked transmitters 5 days prior to the arrival of Killer Whales were used to examine changes in Narwhal movement patterns (e.g., dispersal and clumping) five days before the attack, during the attack, and five days after Killer Whales left the area. A minimum of four Narwhals were killed by 12-15 Killer Whales in a period of 6 hours. Narwhals showed a suite of behavioral changes in the immediate presence of Killer Whales including slow, quiet movements, travel close to the beach (<2 m from shore), use of very shallow water, and formation of tight groups at the surface. These behavioral changes are consistent with Inuit accounts of Killer Whale attacks on Narwhals. During the attack, Narwhals dispersed broadly, the groups were less clumped (standard deviation of inter-whale mean latitudes and longitudes), Narwhal space-use doubled from pre-attack home ranges of 347 km^2 to 767 km^2 (kernel 50% probability), and Narwhals shifted their distribution further south of the attack site. After the disappearance of Killer Whales, north-south dispersal of Narwhals contracted and was similar to pre-attack levels, total space use decreased slightly (599 km^2), yet west-east dispersal remained high. Narwhals were distributed significantly ($P < 0.001$) more broadly offshore in areas not used before the occurrence of Killer Whales. In general, short-term reactions of Narwhals to Killer Whale presence were obvious; yet normal behavior (as observed from shore) resumed shortly after Killer Whales left the area. Long-term (five day) Narwhal behavioral responses included increased dispersal of Narwhal groups over large offshore areas. This is among the few reports of eyewitness Killer Whale attacks on Narwhals in the high Arctic and is the first time changes in Narwhal behavior have been documented in response to a predation event through the use of satellite telemetry.

Key Words: Killer Whale, *Orcinus orca*, Narwhal, *Monodon monoceros*, predation, satellite telemetry, Admiralty Inlet, Nunavut, Canada.

Killer Whales (*Orcinus orca*) occur widely in Arctic waters, yet their abundance, movements, site fidelity, and specific distribution are poorly known (Forney and Wade 2006). Generally, Killer Whales are sighted during ice-free months and often near areas with high densities of other marine mammals, such as summering grounds for Belugas (*Delphinapterus leucas*) and Narwhals (*Monodon monoceros*). In the eastern Canadian High Arctic, this includes eastern Lancaster Sound and associated inlets or fjords around Baffin Island (e.g., Eclipse Sound, Admiralty Inlet, and Prince Regent Inlet) (Markham 1874; Reeves and Mitchell 1988).

Few eyewitness accounts are available of Killer Whale attacks on Narwhals (Steltner at al. 1984). This is because Killer Whales occur over large, sparsely inhabited Arctic areas and the timing and location of attacks are unpredictable. Thus, the majority of descriptions, both of Killer Whale attacks themselves and of the response of Narwhals, come from Inuit observations (Degerbøl and Freuchen 1935; Freuchen and Salomonsen 1961) or from scattered opportunistic reports (Campbell et al. 1988). Generally these accounts made by locals are limited in that observations extend only as far as what can be observed from shore and generally cover short time scales (hours). Also, Inuit observations of Killer Whale occurrence or Killer Whale attacks may not always be reported. There is little information about the natural mortality of Narwhals and generally, Killer Whales are assumed not to significantly depress Narwhal populations (Davis et al. 1980). Furthermore, the extent to which Killer Whales affect the behavior of Narwhals (e.g., movement patterns) is unknown.

In August 2005, a Killer Whale attack on Narwhals was observed from a camp operating a month-long Narwhal satellite tagging operation in Admiralty Inlet, Canada. Several kills of Narwhals by Killer Whales were inferred from vigorous surface and diving activity of Killer Whales within large oiled areas on the surface and congregations of seabirds. In combination with eyewitness observations of behavior of Narwhals and Killer Whales, data collected from satellite tags deployed on Narwhals up to five days before Killer Whales arrived in the area were used to examine clustering and dispersal of Narwhals prior to and following the predation events. These are the first quantitative movement data obtained from Narwhals subjected to Killer Whale predation.

Visual Observations of Attack

Killer Whales were reported by Inuit hunters in a camp about 3 km north of Kakiak Point (72°31'N 86°38'W), in Admiralty Inlet, Nunavut, Canada, on 19 August 2005. On 20 August, we witnessed a Killer Whale predation event on Narwhals just offshore of Kakiak Point. Approximately 12-15 Killer Whales arrived in a single group at Kakiak Point at 12 noon local time. At least several hundred Narwhals had been seen daily in the area for at least two weeks preceding the arrival of the Killer Whales and also on the morning of 20 August. On several occasions thousands of Narwhals had been seen moving past Kakiak Point over periods of 2-3 hours.

The Killer Whale group consisted of one adult male, 7-10 adult females, and several juveniles of undetermined sex. Narwhals were attacked less than 1 km from shore. At least two Narwhals were killed during the first observed attack between 12:00-13:00 local time. After this event, the Killer Whales left the vicinity of Kakiak Point for approximately 3 hours and returned at 16:00, when at least two more Narwhals were killed ~0.5 km from the coast. Killer Whales were not seen or reported again in the area until 25 August. Active subsistence hunting for Narwhals was practiced at several hunting camps along the shore north and south of the research camp.

The four independent kill events occurred over a 6 hour period in daylight hours. Narwhal kills were inferred from large oil/blubber slicks at the surface, congregations and diving of Fulmars (*Fulmarus glacialis*) in surface waters, and focal movements of Killer Whales diving in the center of oiled areas for 15-30 minutes at a time (Figure 1). No body parts or pieces of Narwhals were directly seen.

Narwhal Movements

Narwhal satellite tagging operations were ongoing prior to the Killer Whales' arrival at Kakiak Point. Narwhals were captured using nets set perpendicular to the shoreline 50-100 m from shore (details described in Dietz et al. 2001) and instrumented with SPOT4 and SPOT5 satellite tags made by Wildlife Computers (Redmond, Washington). Tags recorded daily geographic positions based on Doppler shift of tag transmissions received by polar orbiting satellites through Service Argos (Harris et al. 1990). Transmitters were attached to Narwhals on the dorsal ridge with three 6-10 mm polyethylene pins. The Narwhals were usually released after less than 30 minutes (Table 1).

Only data collected from Narwhals instrumented prior to the Killer Whales' arrival were used in the analysis to control for differences in sample size (number of individuals monitored before and after the predation event). Since the Narwhals were instrumented and released on different occasions, they were assumed to represent different groups or pods. Average daily geographic positions were calculated for each Narwhal based on good quality Argos locations (location quality >=0). Average daily positions for each whale were averaged to create inter-whale means. The standard deviation of daily average inter-whale positions was calculated for each of three time periods: five days before Killer Whales arrived (14–18 August), during the immediate Killer Whale observations or attacks (19–20 August), and five days after the Killer Whale attack (21–25 August) when no Killer Whales were seen in the area. Narwhals were distributed along a north-south gradient along the west coast of Admiralty Inlet; therefore the variation in latitude was interpreted as coastwise dispersion and the variation in longitude was interpreted as inshore-offshore dispersion. Narwhal space-use patterns were quantified in each of the three time periods with a kernel home range polygon (probabilistic measure of space use) [ArcView 3.1 Environmental Systems Research Institute] based on average daily positions from each whale.

Results

Pre-attack Narwhal behavior (> 5 days)

Narwhals observed passing Kakiak Point before the Killer Whale attack moved in groups of 3-8 whales at a distance of 20-200 m from the beach. Most whales were heading south. Between 14 and 17 August, seven Narwhals were instrumented with satellite tags before the Killer Whales arrived in the vicinity of Kakiak Point (Table 1). These Narwhals moved along the western side of Admiralty Inlet south of Kakiak Point and less than 1-2 km from shore. No tagged Narwhals were located in the center or eastern side of the inlet and the linear home range along the west coast was <100 km.

TABLE 1. Seven Narwhals instrumented with satellite transmitters prior to Killer Whale occurrence and attack at Kakiak Point, Admiralty Inlet, Canada, 2005. Calf accompanying female on 17 September 2005 was not tagged.

ID	Tagging date	Time of release	Sex	Body length (cm)
20685	14 September 2005	15:06	F	360
20686	14 September 2005	15:56	M	483
20689	17 September 2005	06:25	F	360
37235	17 September 2005	10:45	F + calf	358
37236	17 September 2005	21:20	F	380
37280	17 September 2005	21:27	F	380
37282	17 September 2005	21:45	F	364

FIGURE 1. Oil film on the surface created by Killer Whales feeding on Narwhals in Admiralty Inlet, Canada, August 2005. Large aggregations of Fulmars appeared in the area shortly after each kill. Photo by M. P. Heide-Jørgensen.

The standard deviation of average daily positions indicated that dispersal of Narwhal groups varied approximately 19.9 km north-south, and 13 km west-east before Killer Whales arrived (Table 2). The core of the pre-attack kernel home range (50% probability area) was concentrated just offshore of Kakiak Point and distributed along the west coast of the inlet encompassing 347 km^2 (Table 2).

Immediate Reactions of Narwhals to Killer Whale Attack

On 19 August, Killer Whales were reported by Inuit hunters north of the camp, yet no detailed observations of predation events or behavior were collected. On that day, we observed Narwhals passing very close to the shore (within the surf zone approximately 2-3 m from land) and remaining still at the surface in large groups.

TABLE 2. Dispersal of Narwhals before, during, and after a Killer Whale attack in August 2005 as measured by the distance between average daily satellite positions obtained from seven Narwhals instrumented at Kakiak Point prior to the arrival of the Killer Whales. The standard deviation (SD) in latitude and longitude is reported and also converted to north-south dispersal and west-east dispersal with distance units of km.

	Latitude SD	Longitude SD	N-S dispersal (km)	W-E dispersal (km)	Kernel core (50%) km^2
Before attack (5 days)	0.18	0.12	19.9	13.0	347
During attack (2 days)	0.33	0.29	36.4	32.8	767
After attack (5 days)	0.18	0.25	19.7	27.6	599

FIGURE 2. When Killer Whales arrived in the vicinity of Kakiak Point, Narwhals formed tight groups and remained close to the shore lying still. Photo M. P. Heide-Jørgensen.

On 20 August, Killer Whales were visually observed arriving at Kakiak Point traveling a northbound route along the west side of the inlet. Narwhals were already present in the coastal area (<500 m from the shore) around Kakiak Point and in a small bay just behind the point. When the Killer Whales were within 2-4 km, Narwhals suddenly moved closer to the shore in shallow water (<2 m). Some Narwhals formed tight groups and others moved slowly or lay very still at the surface (Figure 2). One Narwhal stranded on a flat gravel beach (<0.5 m of water) and made violent tail thrashes for >30 seconds (Figure 3), either as a warning signal or in attempts to remove itself from the beach.

Satellite telemetry data indicated instrumented Narwhals clearly responded to the presence of Killer Whales (Figure 4). During the attack, both the north-

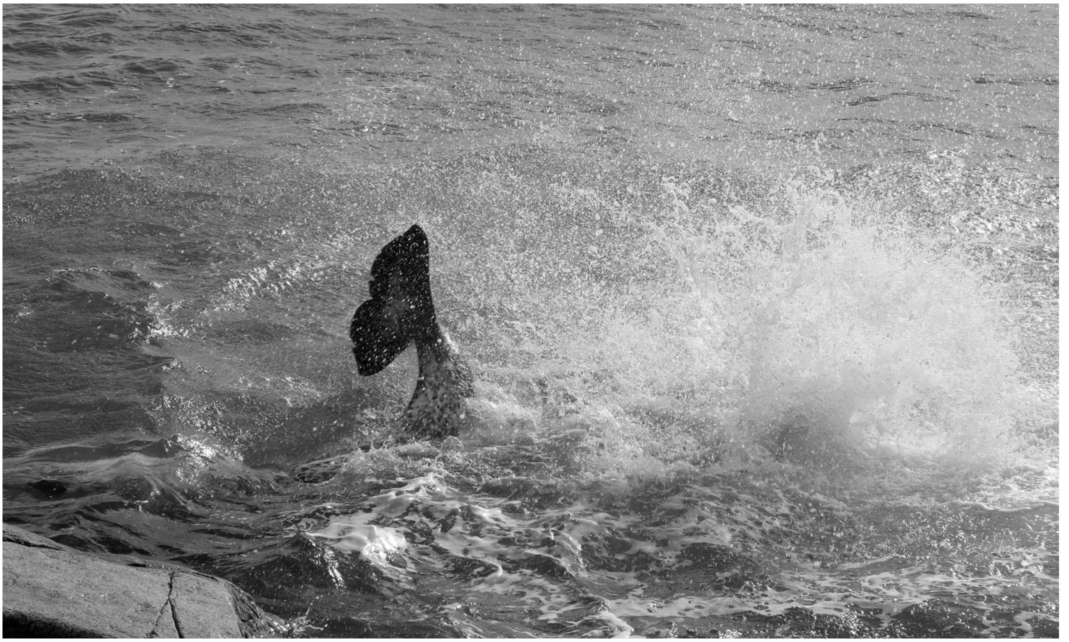

FIGURE 3. During the Killer Whale attack, Narwhals beached themselves in sandy areas and made tail slaps. Coastline can be seen in lower left. Photo by K. L. Laidre.

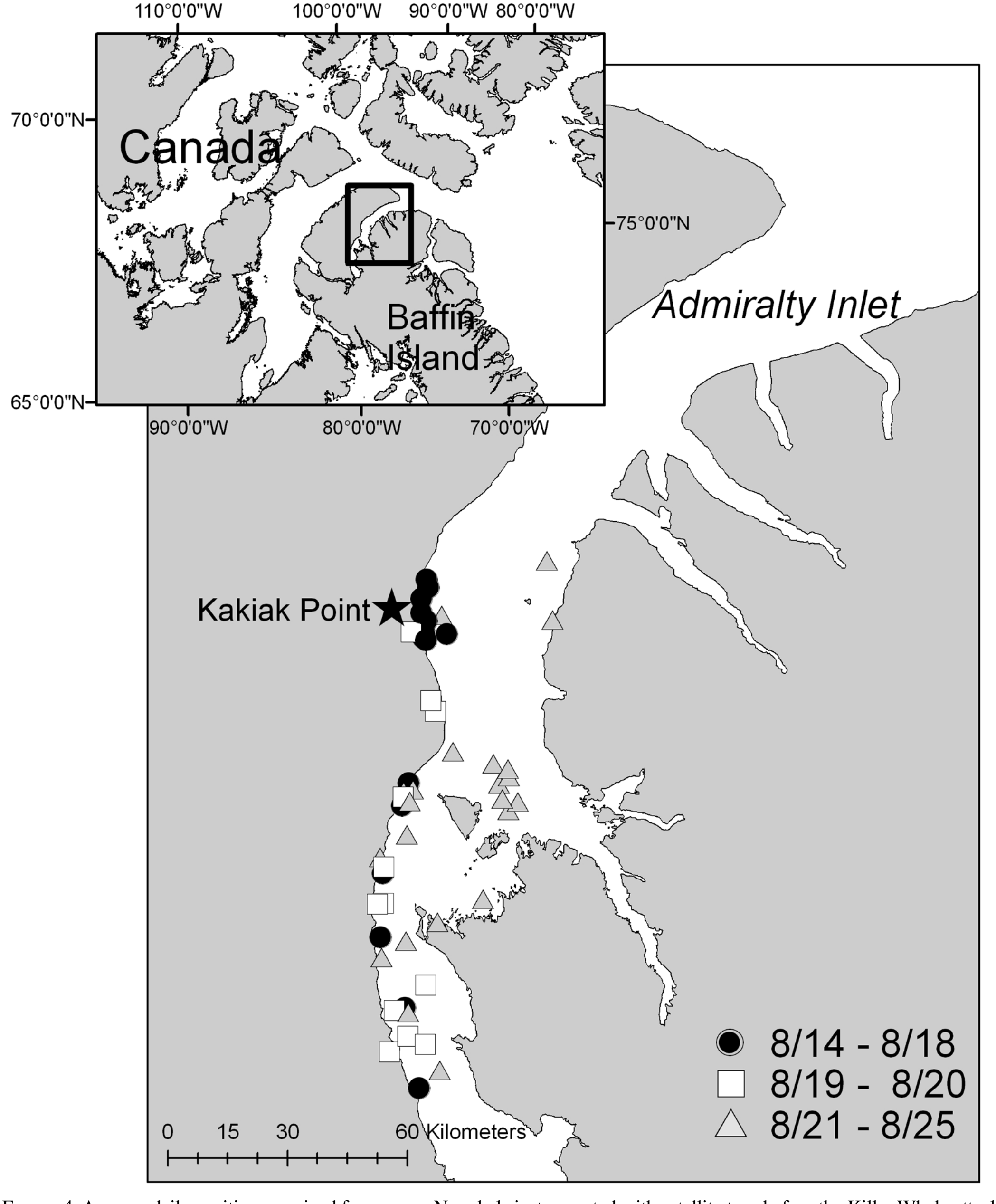

FIGURE 4. Average daily positions received from seven Narwhals instrumented with satellite tags before the Killer Whale attack. Average positions are shown in 3 time periods: the five days prior to Killer Whale arrival (14-18 August), the two days Killer Whales were observed (19-20 August), and the five days after the Killer Whale departure (21-25

south and west-east dispersal (as measured by inter-whale mean latitude and longitude standard deviations) doubled (Table 2). When Killer Whales were in the area, the core kernel home range shifted south by approximately 80 km and doubled in size (767 km^2) (Figure 5, Table 2). Generally, the groups of Narwhals were more widely dispersed in all directions during the attack than before the Killer Whales arrived.

Post-Attack Narwhal Behavior (>5 days)

Narwhals resumed their normal swimming behavior and distance from the coast within an hour after the Killer Whales left the locality. No whales were observed closer than 20 m from the beach and tight groups at the surface broke-up and dispersed.

The instrumented Narwhals moved offshore and utilized a wider area after the attack (ANOVA on longitude, $F_{2,9}$=17.6, $P < 0.001$). Standard deviations of the mean inter-whale latitude (19.7 km) were reduced by half after the departure of the Killer Whales and were nearly identical to pre-attack values (19.9 km), demonstrating a contraction of the north-south dispersal (Table 2). The mean inter-whale longitude standard deviation was slightly lower than during the Killer Whale attack (27.6 km), yet did not return to pre-attack value, indicating a general inshore-offshore dispersal from the attack site.

Post-attack kernel home range core area (599 km^2) was less than that during the attack, yet the core area was located east of the pre-attack core in the center of Admiralty Inlet extending across to the eastern shoreline (Figure 5, Table 2). In general the Narwhal groups maintained a wider offshore dispersal and ranged more widely than before the Killer Whale attack.

Discussion

Narwhals exhibited clear reactions to the immediate presence of Killer Whales. Their suite of behaviors included slow, quiet movements, travel very close to the beach in the surf zone, movement into very shallow water less than 2 m, and formation of tight groups at the surface. All of these observations are consistent with Inuit accounts. Within an hour after the Killer Whale attack and when Killer Whales had left the area, direct observations suggested Narwhals resumed normal behavior (e.g., distances from the coast increased and tight groups dispersed).

Satellite telemetry data revealed long-term (multiday) observations of Narwhal movements before and after the attack, in addition to observations during the attack. Average daily positions indicated that Narwhal groups were more dispersed during and after the Killer Whale attack. Dispersal primarily increased in the offshore (west-east) direction as measured by longitude standard deviations and home ranges. Cores of area use calculations demonstrated that the range of Narwhal movements increased two-fold during the Killer Whale attack, shifted south in a direction away from the attack point, and then expanded to offshore areas afterwards (where Narwhals had not been observed previously in 2005).

Later in the season, Killer Whales were reported in "fairly large numbers" in Admiralty Inlet and vicinity (especially Adams Sound) until October 2005 (Niore Annie Iqalukjuak, Arctic Bay, personal communication). The exact location and movements of these Killer Whales between August and September are not known, nor is it known whether other attacks on Narwhals occurred. Satellite tagging data showed that Narwhals remained in Admiralty Inlet until the third week of October, after which the southbound fall migration was underway. Thus, it appears that even on longer time scales (~2 months) Narwhals do not alter their site fidelity to the summering grounds (see Heide-Jørgensen et al. 2003) or depart early in response to the presence of Killer Whales.

Killer Whales were also reported in Admiralty Inlet in late August 2004 but no data or specific observations were available. It is unknown if the occurrence observed in 2004 involved the same group of Killer Whales as observed in 2005. On 25 August 2004, one of the authors (J.R.O.) observed a young Bowhead Whale (*Balaena mysticetus*) killed by Killer Whales at Kakiak Point, and bones were found on the beach less than 1 km away from the attack site the following year in 2005. Furthermore, on the same date as the attack reported here, several Killer Whales were observed attacking Narwhals in Repulse Bay, Hudson Strait, Canada (Joani Kringayark, personal communication). Therefore, at least two separate groups of Killer Whales feed on Narwhals on their summering grounds in the eastern Canadian Arctic in August.

When Killer Whales attacked Narwhals, there was limited action at the surface with no struggle or splashing observed. Killer Whales consumed the Narwhals below the surface of the water, and made multiple dives in the center of oiled areas (presumed kills) for 15-20 minutes. An eyewitness account of a Killer Whale attack on Narwhals in Inglefield Bredning, West Greenland in August 2004 noted Killer Whales jumping on top of Narwhals and holding them under the surface until they drowned (Gretchen Freund, personal communication).

If the predation level observed at Kakiak Point (4 Narwhals over 6 hours) is representative of the daily predation level of a similar sized pod of Killer Whales in the High Arctic, then consumption of Narwhals during a two-month stay in Admiralty Inlet would amount to approximately 200-300 Narwhals. A photographic survey estimated 5,556 (CV=0.22) Narwhals in Admiralty Inlet in 1984 (Richard et al. 1994). If the photographic survey results are corrected for whales that were diving using a correction factor of 0.38 (0.06) developed by Heide-Jørgensen (2004), then the abundance would have been in the order of 14,621(0.23). A mortality of 200-300 Narwhals from Killer Whale predation would represent <3% of this abundance estimate. It is possible that predation constitutes a larger proportion of the annual natural mortality of Narwhals than previously expected; however, it is not known if this natural mortality is fully compensatory. In this case, a continued high level of Killer Whale predation in combination with a population reduction by subsistence harvest could reinforce a decline. Killer Whale predation has been responsible for the decline of sea otters in Alaska (Estes et al. 1998; Doroff et al. 2003) and has been hypothesized as the driver for a decline of other top predators in the North Pacific (Springer et al. 2003).

The reason Narwhals occupy deep and narrow fjords during summer is unknown and it has been hypothesized that their summer distribution may be related to

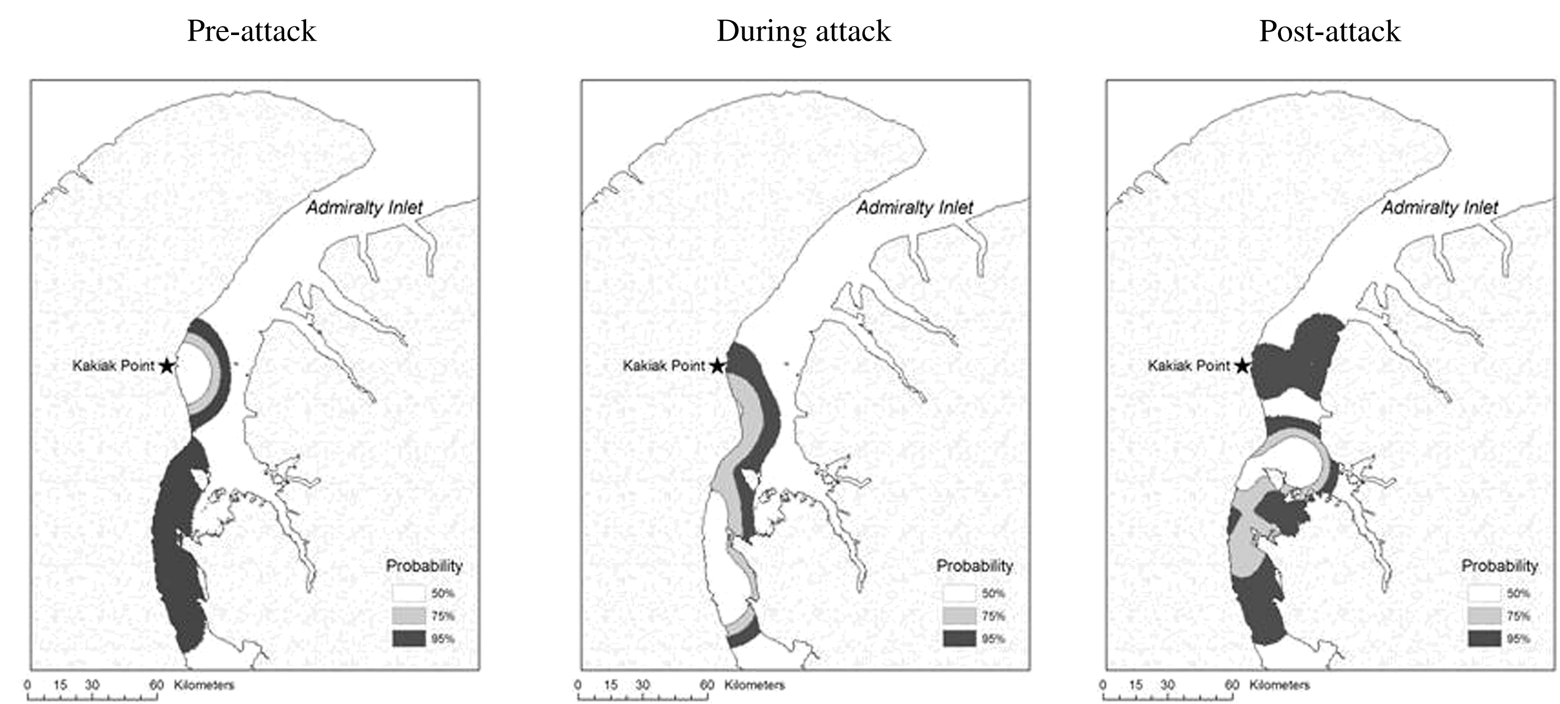

FIGURE 5. Narwhal space-use patterns before, during, and after the Killer Whale attack estimated with kernel home range polygons (50% is white). Home ranges were calculated for three time periods: The five days prior to Killer Whale arrival (14-18 August), the two days Killer Whales were observed (19-20 August), and the five days after the Killer Whale departure (21 August-25 August). The Killer Whale attack was observed at Kakiak Point (star symbol) on the west coast.

potential predation by Killer Whales (Kingsley et al. 1994). Narwhals feed very little during the summer season (Laidre and Heide-Jørgensen 2005a), and summering grounds do not appear to be related to calving needs given calves are born in the spring. The summer refuge from Killer Whales hypothesis lacks conclusive evidence as Narwhal distribution in other seasons is clearly driven by biological needs, such as sea ice formation, open water, or access to prey resources (Laidre and Heide-Jørgensen 2005b) and Narwhals did not seek refuge or depart early in response to the observed attack. Little is known about what proportion of different types of Killer Whales occurs in Arctic waters (i.e., mammal-eating vs. fish-eating). Stomach contents of 30 Killer Whales harvested in Disko Bay, West Greenland in February 2003 contained only Lumpsucker fish (*Cyclopterus lumpus*), despite the fact these Killer Whales were taken in an area with a large abundance of Bowhead Whales, Ringed Seals (*Phoca hispida*), Narwhals, Belugas, and other potential marine mammal prey items (Greenland Institute of Natural Resources, unpublished data).

Few observations have been collected of Killer Whales during winter in Arctic ice conditions. It is generally assumed that Killer Whales avoid the Arctic pack ice (Heide-Jørgensen 1988) despite the fact many Killer Whales occur and thrive in the dense pack-ice of the Antarctic. It is possible that changes in sea ice (lighter sea ice cover and earlier break-up) will alter (or have already altered) the occurrence of Killer Whales in Arctic waters. These changes may facilitate increased or longer visits by Killer Whales to ice-free Arctic areas.

The predicted reduction of annual sea ice, together with a longer open water season, will likely lead to an increase in Killer Whale predation on Narwhals. At the same time, reduced sea ice will also decrease the probability that Narwhals succumb in ice entrapments (also known as Sassats), another important source of natural mortality (Laidre and Heide-Jørgensen 2005b). It is unclear how the interplay between these two elements of natural mortality will evolve under changing sea ice regimes.

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