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Killer whales (*Orcinus orca*) in the Canadian Arctic: Distribution, prey items, group sizes, and seasonality

JEFF W. HIGDON

Department of Environment and Geography,
University of Manitoba,
501 University Crescent,
Winnipeg, Manitoba R3T 2N6, Canada
and
Fisheries and Oceans Canada,
Central and Arctic Region,
501 University Crescent,
Winnipeg, Manitoba R3T 2N6, Canada
E-mail: jeff.higdon@gmail.com

DONNA D. W. HAUSER¹

78 Marine Drive,
Logy Bay, Newfoundland A1K 3C7, Canada

STEVEN H. FERGUSON

Fisheries and Oceans Canada,
Central and Arctic Region,
501 University Crescent,
Winnipeg, Manitoba R3T 2N6, Canada
and
Department of Environment and Geography,
University of Manitoba,
501 University Crescent,
Winnipeg, Manitoba R3T 2N6, Canada

ABSTRACT

Killer whales (*Orcinus orca*) have a global distribution, but many high-latitude populations are not well studied. We provide a comprehensive review of the history and ecology of killer whales in the Canadian Arctic, for which there has previously been little information. We compiled a database of 450 sightings spanning over 15 decades (1850–2008) to document the historical occurrence, distribution, feeding ecology, and seasonality of killer whales observed throughout the region. Sighting reports per decade increased substantially since 1850 and were most frequent in the eastern Canadian Arctic. The mean reported group size was 8.3 (median = 4, range 1–100), but size varied significantly among regions and observed prey types. Observations of predation events indicate that Canadian Arctic killer whales

¹Current address: LGL Limited environmental research associates, PO Box 13248 Station A, St. John's, Newfoundland A1B 4A5, Canada.

prey upon other marine mammals. Monodontids were the most frequently observed prey items, followed by bowhead whales (*Balaena mysticetus*), phocids, and groups of mixed mammal prey. No killer whale sightings occurred during winter, with sightings gradually increasing from early spring to a peak in summer, after which sightings gradually decreased. Our results suggest that killer whales are established, at least seasonally, throughout the Canadian Arctic, and we discuss potential ecological implications of increased presence with declining sea ice extent and duration.

Key words: distribution, abundance, climate change, predation, sea ice, seasonal movements, Inuit traditional ecological knowledge, marine mammals, sightings.

Killer whales (*Orcinus orca* Linnaeus, 1758) are among the most widely distributed cetaceans, occurring in all oceans from the Arctic to the Antarctic (Ford *et al.* 2000). The ecology of some populations is poorly understood, others are among the most studied cetaceans. In the northeast Pacific Ocean, populations of sympatric fish-eating and mammal-eating killer whales can be distinguished based on diet, acoustics, behavior, genetics, and morphology (*e.g.*, Baird and Stacey 1988, Bigg *et al.* 1990, Ford *et al.* 2000). Four different “forms” occur in Antarctic and subantarctic waters, with apparently different foraging specializations (Pitman and Ensor 2003, Pitman *et al.* 2010). Although diet specializations and associated behavior appear to be common characteristics for the species among known populations, there is little information about the presence and ecology of killer whales in some areas (Forney and Wade 2006), and this is particularly true for arctic regions.

Use of the Canadian Arctic by killer whales has largely been considered sporadic, though little directed scientific research has been conducted in the region (Reeves and Mitchell 1988, Baird 2001). A recent review of population status in Canada considered killer whales in the eastern Canadian Arctic and Atlantic Ocean of “Special Concern” largely due to limited knowledge of the population (COSEWIC 2008). Furthermore, climate change is predicted to be particularly pronounced in arctic regions, with decreased ice extent expected throughout the northern hemisphere (Parkinson and Cavalieri 2002, Overpeck *et al.* 2005). Portions of the Canadian Arctic are also predicted to have the greatest rate and degree of climatic warming (Comiso 2003), and the extent and duration of seasonal sea ice has already declined in most areas (Parkinson and Cavalieri 2002). Negative effects of such large-scale ecosystem transformations have already been documented for some ice-dependent species of arctic seabirds and marine mammals (Post *et al.* 2009). Declines in sea ice extent and duration may be coupled with marine mammal range expansions and changes in abundance (Tynan and DeMaster 1997, Laidre *et al.* 2008). Killer whales in the Canadian Arctic are generally considered to be pagophobic, avoiding heavy ice conditions (Heide-Jørgensen 1988, Higdon 2007, Matthews *et al.* 2011). Thus, seasonal species that are typically only present during ice-free conditions, such as killer whales, may occupy more northerly latitudes and remain longer as conditions continue to warm (Moore and Huntington 2008).

Within the Hudson Bay region of the eastern Canadian Arctic (Fig. 1), Higdon and Ferguson (2009) described a punctuated advancement in killer whale distribution that was attributed to the opening of areas that have historically been blocked by ice. As these areas have increasingly been ice-free for longer periods, killer whale presence in Hudson Bay exponentially increased over the last 50 yr, and they are now regularly seen each year. The ecological implications of increased killer whale occurrence may

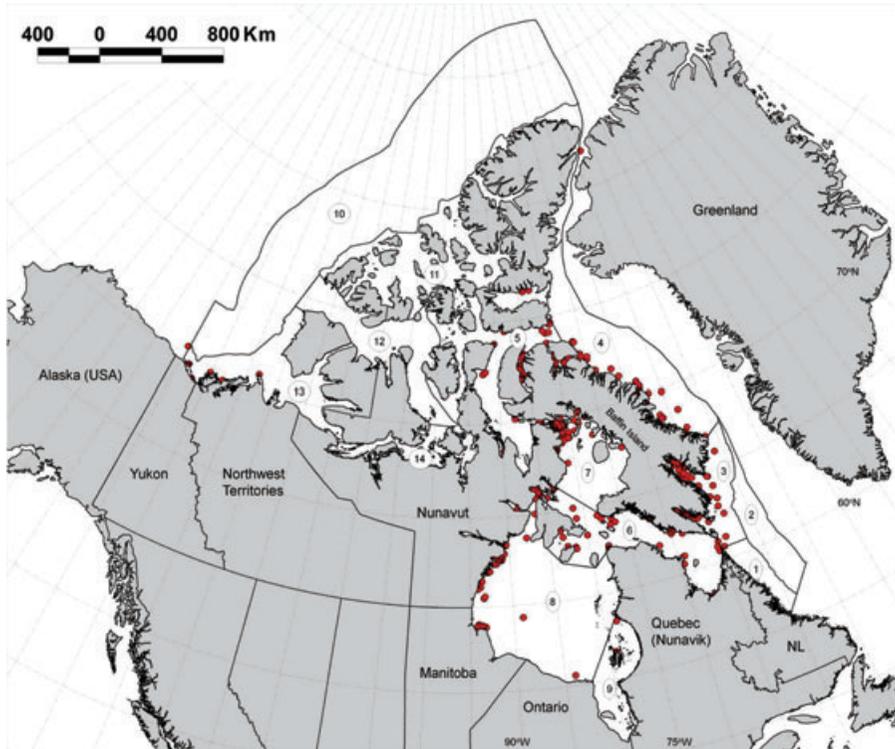


Figure 1. Canadian Arctic killer whale sighting locations (red circles, high spatial quality only, $n = 172$) within Canadian Arctic ecoregions. Numbers correspond to the following ecoregion names, with the total number of sightings and percent of total database ($n = 450$): 1—northern Labrador (not included in study); 2—Labrador Sea north (not included in study); 3—southern Baffin Island (86, 19.1%); 4—Davis Strait-Baffin Bay (33, 7.3%); 5—Lancaster Sound (109, 24.2%); 6—Hudson Strait (64, 14.2%); 7—Foxy Basin (54, 12%); 8—Hudson Bay (83, 18.4%); 9—eastern Hudson Bay-James Bay (2, 0.4%); 10—Arctic Basin (no records); 11—high Arctic Archipelago (1, 0.2%); 12—Viscount Melville (no records); 13—Beaufort Sea-Amundsen Gulf (18, 4%); 14—Queen Maude Gulf (no records).

be profound, either as a competitor or predator that has been implicated in trophic cascades and ecosystem modification (Estes *et al.* 1998, Springer *et al.* 2003, 2008, but see DeMaster *et al.* 2006, Mizroch and Rice 2006, Trites *et al.* 2006, Wade *et al.* 2007).

Given the current climatic trends and predictions as well as the potential ecological implications of increasing killer whale presence, there is a need for information on the history and ecology of this species in the Canadian Arctic. We used a database of observations from 1850 to 2008 to assess current and historical distribution, seasonal presence, preferred prey, and group sizes of killer whales in the region. Over 400 sightings were compiled and included reports from literature, researchers, and northern residents as well as dedicated traditional ecological knowledge (TEK) interviews in Inuit communities in Nunavut. This information facilitated a general understanding of killer whale presence and ecology in the Canadian Arctic.

Table 1. Summary of nine Nunavut communities visited to collect Inuit TEK (or *Inuit Qaujimaqatuaqangit*) on killer whales, with dates of visit and number of semidirected interviews conducted.

Community	Date visited	Number of interviews
Repulse Bay	July–August 2007	17
Igloolik	February–March 2008	16
Hall Beach	February–March 2008	7
Rankin Inlet	March 2008	10
Arviat	March 2008	5
Pangnirtung	January 2009	11
Kimmirut	February 2009	5
Arctic Bay	April 2009	11
Iqaluit	April–May 2009	7
Total	July 2007–May 2009	89

METHODS

Database

A comprehensive review of available literature on killer whale sightings was conducted and included peer-reviewed literature (*e.g.*, Reeves and Mitchell 1988), consulting reports, newspapers, and government documents (see Higdon 2007 for a complete review of data sources). Scientists and technicians with the Canadian Department of Fisheries and Oceans (DFO), independent arctic researchers and consultants, university staff and students, tour operators, conservation officers, staff at Makkovik Corp. (managers of the Nunavik [northern Quebec] Land Claim), community hunters and Trappers Organizations, and local residents were also contacted for reports of killer whale sightings. Additional sightings were acquired during semidirected interviews (Huntington 1998) with Inuit hunters and elders conducted in nine Nunavut communities from 2007 to 2009 (Table 1).

Ultimately, the database included information regarding killer whale sighting date, behavior, location, movement direction, estimated group size, observer or information source, observations of predation events including predator–prey behavior, associations with other species, and an indication of group composition or sex. Time, location, and group size were reported as a range for some records. For the purposes of our group size analysis, a single value was estimated for each sighting that included a report of the number of individuals. The median value (rounded-up) was used whenever a sighting included a range (*e.g.*, 5–10 animals), while the lower number of individuals was used when a range of two numbers (*e.g.*, 5–6 animals) was reported.

Data Analysis

Each record was assigned to one of 12 ecoregions (Fig. 1) as defined by Powles *et al.* (2004), with modifications to the Hudson Bay region suggested by Stewart and Lockhart (2005) (also see Higdon 2007). Records were also evaluated for killer whale identification, spatial, and temporal reliability and quality before analysis. Only sightings with credible killer whale identifications were used for analyses, such that each record was either supported by photographic evidence,

Table 2. Season definitions used for the present study, based on seasons described by Inuit in Nunavut, Canada (NWMB 2000).

Season	Inuktitut name	Descriptive characteristics (NWMB 2000)	Inclusive months in killer whale database
Winter	Ukiaq	Early January to mid-March; extensive sea ice, continues to thicken and coalesce; snow on land and ice; short daylight, sun returning; very cold.	January to March
Early spring	Upirngassaaq	Mid-March to late May; maximum sea ice cover and thickness; snow on land and ice; daylight period long and increasing.	April and May
Spring	Upirngaaq	Late May to mid-July; progressive snowmelt on land; widening of ice leads, disappearance of ice; 24-h daylight.	June and July
Summer	Aujaq	Mid-July to early September; open water, some drifting ice; daylight period long, but decreasing.	August
Early fall	Ukiassaaq	Early September to late October; open water, ice starting to form late in season along the shore; snow on land; lake ice; daylight period short and decreasing.	September and October
Fall	Ukiaq	Late October to early January; new ice thickens and hardens to form extensive areas of land-fast or drifting pack ice; snow on land and ice; 24-h darkness.	November and December

made by a trained biologist, naturalist, skilled Inuit hunters or fishermen, published in a scientific journal, or made by an untrained observer offering a supportive killer whale description (*e.g.*, coloration pattern, dorsal fin size). Location quality varied among records, and many of the locations in Figure 1 are approximate, although all records could be accurately assigned to an ecoregion for further analysis.

Temporal information also varied among records. Full day, month, and year data were only available for a subset of sightings, so analyses of the annual trends and seasonal distribution of sightings proceeded by considering year and high Arctic season, as available. The definition of each high Arctic season was based on the perception of annual seasons by Nunavut Inuit, largely as a measure of sea ice conditions, amount of daylight, and snow (Table 2; described in NWMB 2000). One

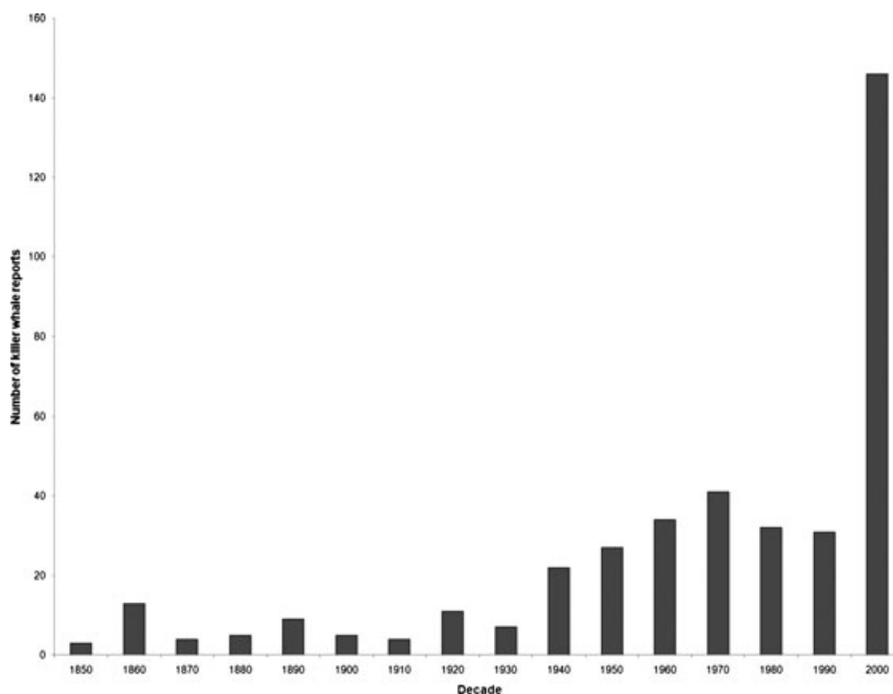


Figure 2. Number of reported killer whale sightings per decade, 1850–2008 (excludes 56 sightings with no date information).

of these six seasons (*i.e.*, winter, early spring, spring, summer, early fall, and fall) was assigned to all records for which month was reported.

Prey species were categorized into groups for records that included an observation of a predation event. Prey species were grouped as “monodontid” for beluga whale (*Delphinapterus leucas*) or narwhal (*Monodon monoceros*) predation events, “bowhead whale” for bowhead whale (*Balaena mysticetus*) predation events, “phocid” for harp seal (*Pagophilus groenlandicus*), ringed seal (*Pusa hispida*), bearded seal (*Erignathus barbatus*), harbor seal (*Phoca vitulina*), or unidentified seal predation events, and “multiple prey groups” for observations that described a combination of cetacean and phocid predation or a combination of bowhead whale and monodontid predation. In the case of multiple prey group predation events, sometimes one record included observations of the same group of killer whales that occurred over multiple days.

A number of factors were evaluated to describe the presence of killer whales in the Canadian Arctic, including trends in the number of killer whale sightings, the distribution of sightings, mean group sizes, predation on different prey groups, and seasonal presence. Comparisons of median killer whale group sizes among ecoregions and prey groups were made using Kruskal–Wallis tests and chi-square tests, respectively. To portray seasonal patterns of prey selection (multiple prey events excluded), a Gaussian model (Platt and Sathyendranath 1988) was used to fit the sighting data due to the graphic resemblance to a symmetric “bell curve” shape that quickly falls off similarly during spring and fall.

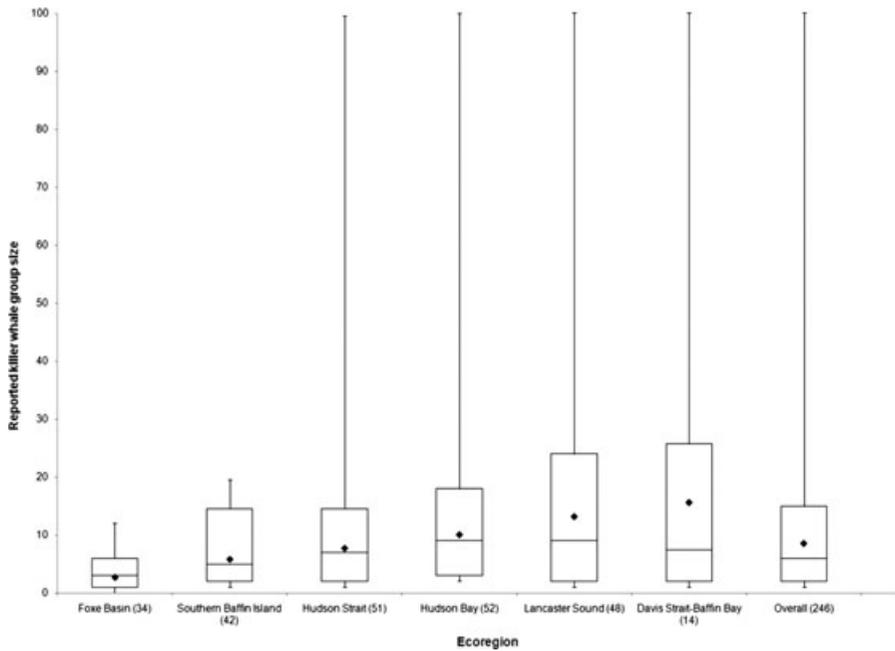


Figure 3. Whisker-box plots of reported killer whale group size in different ecoregions in the eastern Canadian Arctic. Point data are the mean group size, and the box plot represents median and 25th/75th percentile values. Whiskers represent minimum and maximum values (range), with maximum reports of “100” killer whales from four ecoregions. The overall mean and median number of individuals ($\bar{x} = 8.3$; median = 4, $n = 246$) includes sightings from the following ecoregions, not shown due to small sample sizes: eastern Hudson Bay/James Bay ($n = 2$), Beaufort Sea/Amundsen Gulf ($n = 2$), and the high Arctic Archipelago ($n = 1$).

RESULTS

A total of 450 sightings of killer whales were compiled following our identification criteria, including records occurring from 1850 to 2008. The number of reported sightings has increased considerably over time across the entire region (Fig. 2). Sightings ranged throughout the Canadian Arctic, but reports were most frequent in eastern ecoregions, with few observations in the central Arctic or the Canadian Beaufort Sea (Fig. 1). Sightings were most frequent in the Hudson Bay, southern Baffin Island, and Lancaster Sound ecoregions (18.4%, 19.1%, and 24.2% of 450 sightings, respectively; Fig. 1). Of the 246 records that included estimates of group size, mean group size was 8.3 animals. Group size distribution was highly skewed and nonnormal (skewness = 4.813, Shapiro–Wilks test statistic = 0.472, $P < 0.01$), ranging from 1 to 100 animals with a median of four killer whales (Fig. 3). Four reports estimated 100 killer whales, much higher than other sightings that ranged from 1 to 60. There was a significant difference in median group size among ecoregions (Kruskal–Wallis, $df = 5$, $H = 22.6$, $P < 0.001$), with smallest group size in Foxe Basin (median = 2, $O = 2.7$) and largest group sizes in Lancaster Sound (median = 8, $O = 13.2$) and Davis Strait-Baffin Bay (median = 6, $O = 15.6$; Fig. 3). Observations from the eastern Hudson Bay–James Bay ($n = 2$), Beaufort

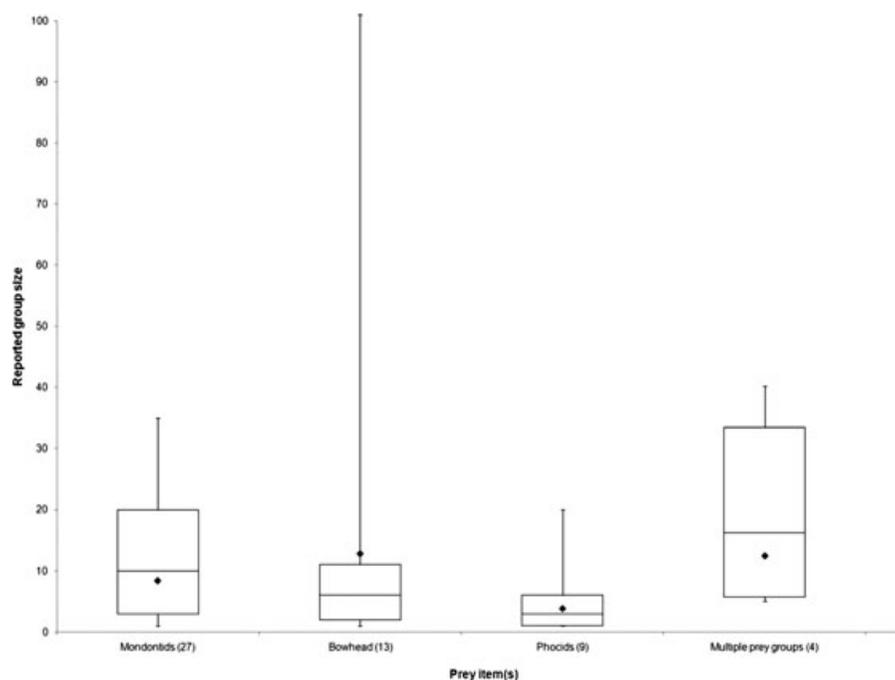


Figure 4. Whisker-box plots of reported Canadian Arctic killer whale group size in relation to reported predation events (prey species and sample sizes in parentheses). The point data are mean group size, boxes represent median and 25th/75th percentiles, and whiskers represent overall range of reported group sizes.

Sea-Amundsen Gulf ($n = 2$), and high Arctic Archipelago ($n = 1$) ecoregions were excluded from the Kruskal–Wallis test due to small sample sizes.

One quarter ($n = 111$) of killer whale sightings included a report of a predation event. Reports of monodontid predation ($n = 57$) occurred significantly more often than predation on bowhead whales ($n = 35$), phocids ($n = 13$), or multiple prey groups ($n = 6$; chi-square, $df = 3$, $\chi^2 = 56.89$, $P < 0.001$). The greatest proportion of predation events were recorded in Lancaster Sound ($n = 29$), followed by Hudson Bay ($n = 24$) and Foxe Basin ($n = 20$), with all three prey groups (monodontids, bowhead, and phocids) reported in each ecoregion. Reports of monodontid predation events were most common in Hudson Bay and Lancaster Sound, with bowhead whale predation events most frequently reported in Foxe Basin and Davis Strait-Baffin Bay. Monodontids (only beluga whale observations) were the only reported prey item in the Beaufort Sea-Amundsen Gulf ecoregions.

There were 52 records that included an estimate of killer whale group size as well as a predation observation. Sample sizes were small, but median killer whale group size was significantly different among prey groups (Kruskal–Wallis, $df = 3$, $H = 10.017$, $P = 0.018$; Fig. 4). Median group size was lowest for bowhead whale (4, $n = 13$) and phocid predation events (2, $n = 9$) and highest for monodontid (7, $n = 27$) and multiple prey group (11, $n = 4$) events. However, the range in observed group size was large, particularly for bowhead whale predation events, for which reported group sizes ranged from 1 to 100 animals, skewing mean group size (12.9;

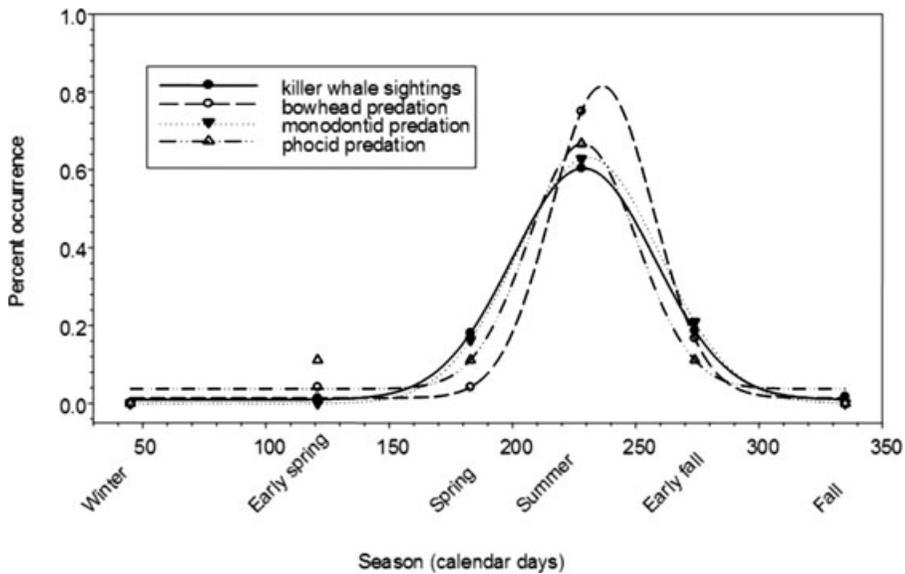


Figure 5. Percent occurrence of Canadian Arctic killer whale sightings ($n = 305$) and predation events (43 monodontid, 24 bowhead, and 9 phocid) with season (see Methods for definitions). Observed predation events were distributed similarly to killer whale sightings with monodontid predation events distributed in an almost identical fashion as killer whale sightings across seasons. However, bowhead whale predation events were most frequent in summer and least frequent in spring.

if the report of 100 killer whales is excluded, mean group size for bowhead predation events is 5.6 [range = 1–22, median = 4]).

Of the 305 records that included enough information to categorize season (see Table 2), no observations occurred during winter. Most ($n = 184$, 60.3%) killer whale sightings occurred during summer, with fewer spring and early fall sightings (ca. 18%). Less than 2% of the records occurred in either early spring ($n = 4$) or fall ($n = 5$). Seasonal patterns in sighting frequency were similar throughout different ecoregions in the eastern Canadian Arctic. Predation records followed a similar seasonal pattern (81 predation records could be categorized by season). Monodontids comprised the largest proportion of summer predation observations, followed by bowhead whales, but monodontid predation also occurred in spring and early fall. Proportionally more bowhead whale predation events occurred during summer relative to other seasons; whereas monodontid predation events occurred in proportion to killer whale sightings across seasons (Fig. 5).

DISCUSSION

The occurrence and ecology of killer whales in the Canadian Arctic is of increasing interest given current climate predictions for decreased sea ice duration and extent and the potential impact of the species on arctic marine food webs. Killer whales have been present in portions of the Canadian Arctic (Davis Strait and Baffin Bay) since at least the 1800s (Reeves and Mitchell 1988), although the number of reported sightings

has dramatically increased since the 1950s. A similar trend was recently described in the Hudson Bay region as a progression from authors reporting no evidence (Degerbøl and Freuchen 1935), sporadic occurrence (Davis *et al.* 1980), occasional and possibly annual use (Reeves and Mitchell 1988), to annual use (Ferguson *et al.* 2010a). Higdon and Ferguson (2009) described an exponential increase of killer whale sightings in the Hudson Bay region that they attributed to punctuated decreases in sea ice and, therefore, greater access to available open water habitat. Indeed, the significant negative correlation between sea ice concentration and killer whale sighting frequency described by Higdon and Ferguson (2009) corroborates the importance of ice in driving distributions in these areas (Tynan and Demaster 1997).

Effort

The largest caveat associated with our database is a lack of quantified observation effort. Killer whale sighting reports have increased dramatically, although a number of changes have occurred that have affected observation effort since the 1800s. Chief among these are technological advances in travel methods and changes in seasonal land use, residency, and movement patterns. A recent increase in the arctic human population (the population of Nunavut increased from 4,166 to 29,474 residents from 1961 to 2006; Nunavut Planning Commission 2008) may be partially offset by associated increases in wage employment that effectively reduce the number of hunters on the water (NWMB 2000). Inuit moved into permanent settlements in the 1960s, and observations are clustered around communities (local hunting and fishing areas). Research effort has increased, with active soliciting of sighting reports starting in 2006 (Higdon 2007), including the semidirected interviews conducted (2007–2009) throughout Nunavut (Table 1). Some bias in reporting effort is likely; although interviews with Inuit hunters, particularly elders, consistently indicate the perception of increased presence of killer whales throughout Nunavut.² However, we do acknowledge the opportunistic nature of the sighting database and the limitations of recall ability (Bradburn *et al.* 1987), and the caution, thus, required in interpreting temporal trends.

Observation effort is also not equal throughout all regions of the Canadian Arctic. Few sightings around the central high Arctic Archipelago may be related to limited observer effort, but the presence of multiyear sea ice and reduced productivity may preclude killer whale presence, at least historically. Sightings were also less frequently reported in the western Canadian Arctic, which may reflect a lower incidence of killer whales reaching the Canadian Beaufort Sea. During interviews to collect traditional knowledge of beluga whales in 1993–1994, only 15% of hunters and elders in the communities of Tuktoyaktuk, Aklavik, and Inuvik (Northwest Territories) had ever seen killer whales (Byers and Roberts 1995). Hartwig (2009) conducted TEK mapping workshops with 128 participants in six western Arctic communities in 2007 and only identified eight killer whale observations. There is presently renewed and extensive oil and gas exploration activity in the Canadian Beaufort Sea, with associated vessel-based and aerial marine mammal surveillance programs (2006–2010), but no killer whales have been sighted during any of these efforts.³ Additionally, killer

²S.H. Ferguson, Fisheries and Oceans Canada, unpublished data, 2007–2010.

³Personal communications from Ross Harris, LGL Limited, King City, ON, Canada, May 2010 and Lois Harwood, Fisheries and Oceans Canada, Yellowknife, NWT, Canada, May 2010.

whales have only occasionally been recorded in the adjacent Alaskan Beaufort Sea (Lowry *et al.* 1987, George and Suydam 1998). In contrast, killer whale sightings occur with some regularity along the west Greenland coast, where the species is occasionally harvested (Heide-Jørgensen 1988). Thus, all of the available information suggests that killer whale presence is more frequent in the eastern Arctic than it is in the west. However, biases in observer effort (concentrated around communities) preclude any rigorous analyses or conclusions on distribution or relative abundance of killer whales throughout different regions of the Canadian Arctic.

Ultimately, killer whale sightings remain relatively rare during standardized surveys of the Arctic (*e.g.*, aerial surveys) or by vessels that regularly transit portions of the Canadian Arctic (*e.g.*, Canadian Coast Guard vessels, shipping and supply vessels, and those associated with oil and gas exploration activities). Killer whales have only been recorded on a few occasions despite thousands of kilometers of aerial and ship-based surveys, which indicates that numbers are too low to make aerial surveys an effective way to measure population size (Higdon 2007). For example, during extensive bowhead surveys of the eastern Arctic (>11,000 km flown 2002–2003; Dueck *et al.* 2007) no killer whales were observed. However, other research methods, including use of TEK (Ferguson, unpublished data; this study), photo-identification (Young *et al.*, in press), and satellite tagging and focal follows (Matthews *et al.* 2011), are all providing important information on killer whale ecology in the Canadian Arctic.

Prey Preferences

A number of studies have noted a strong seasonality to killer whale predation on various prey items (Hoelzel 1991, Baird and Dill 1995, George and Suydam 1998, Ford and Ellis 2006). We discerned limited seasonal trends in preferred prey groups. Generally, the proportion of predation on each prey group remained constant relative to proportion of killer whale sightings across seasons. One exception was bowhead whales, with a greater frequency of predation events observed during the summer season relative to the spring season. Bowhead calves are born between April and early June, peaking in May (Nerini *et al.* 1984), with most births possibly occurring as females migrate through Hudson Strait (COSEWIC 2009). Bowhead whales arrive at the floe edge in northern Foxe Basin by late June (NWMB 2000), a nursery ground occupied by cow–calf pairs and juvenile whales (NWMB 2000, Cosens and Blouw 2003). Prior to break-up in July, the open water (polynya) in northern Foxe Basin is separated by hundreds of kilometers of heavy (9/10+) pack ice. Killer whales often target calves and smaller baleen whales rather than adults (Ford and Reeves 2008), and the sea ice in Foxe Basin may provide a refuge from predation during spring (Ferguson *et al.* 2010b, Higdon and Ferguson 2010). During the summer period, when sea ice habitat is reduced, bowhead calves and juveniles are more vulnerable and killer whale predation activities more successful.

Sample sizes for seal predation events were small, but events were relatively more abundant in early spring (April–May). Springtime predation events on phocid seals were mostly reported from more open regions, such as Davis Strait and Baffin Bay *vs.* enclosed or inland areas, such as Hudson Bay and Foxe Basin, possibly related to ice conditions. Eastern Arctic killer whales appear to generally avoid heavy ice (Heide-Jørgensen 1988, Reeves and Mitchell 1988), in contrast to those in other regions (*e.g.*,

Lowry *et al.* 1987, Pitman and Ensor 2003). However, they are occasionally observed in the vicinity of light to moderate ice (also see Lawson *et al.* 2007). Antarctic type “B” killer whales utilize a sophisticated group technique to hunt seals on ice floes in partially ice-covered waters (2–5/10 ice cover) (Visser *et al.* 2008, Pitman and Durban 2011). Inuit have described similar behaviors in the eastern Canadian Arctic (southern Baffin Island): one interviewee in Kimmirut and two in Pangnirtung described killer whales washing seals off the ice floes (Ferguson, unpublished data). On northern Baffin Island, hunters have observed killer whales surround an ice floe while one whale pushes up from underneath, to break up the ice and force the seal back into the water (Brody 1976). Killer whales in the eastern Canadian Arctic, while avoiding heavy, consolidated ice (see Matthews *et al.* 2011), have apparently developed techniques to hunt pagophilic seals in moderate ice conditions.

Marine mammals were the only definitively reported prey of killer whales in the Canadian Arctic. However stomach contents of killer whales harvested in Disko Bay, west Greenland, have contained fish (species not given in one case, Heide-Jørgensen 1988, and lumpsucker fish, *Cyclopterus lumpus*, in another, Laidre *et al.* 2006). Greenland killer whales have also been reported to prey on Greenland halibut (*Reinhardtius hippoglossoides*) and cephalopods (Degerbøl and Freuchen 1935, Vibe 1990, in Jensen and Christensen 2003). Predation on various fish species has also been recorded further south in the northwest Atlantic (*e.g.*, Newfoundland and Labrador) (Lawson *et al.* 2007). Numerous records of marine mammal predation also occur in these regions, and observational biases in the database preclude any rigorous conclusions regarding possible ecotypes of killer whales in the region. In general, it is much more likely to observe killer whale predation on marine mammals than fish because of the large prey body size, surface-based pursuit and consumption, duration of predation events, and surface-active behaviors associated with marine mammal consumption (*e.g.*, Laidre *et al.* 2006). Large salmonid species are consumed and sometimes shared at or near the surface by individuals among fish-eating killer whales in the northeastern Pacific (Ford and Ellis 2006, Hanson *et al.* 2010), but compared to marine mammals, consumption of fish is likely less obvious to observers.

Killer Whale Group Sizes

Killer whale group sizes observed in the Canadian Arctic are also more typical of mammal-eating populations. In the coastal temperate northeastern Pacific, fish-eating killer whales are found in long-term stable matrilineal groups (pods) typically comprised of 10–25 individuals, and temporary associations of several matrilines sometimes result in larger groups (Ford *et al.* 1998). Fish-eating killer whales in Antarctica (“Type C”) are observed in large groups, ranging from 10 to 100 and averaging 46.1 individuals (Pitman and Ensor 2003). Group sizes of mammal-eating killer whales are typically smaller than those of fish-eaters. Mammal-eating killer whale group sizes theoretically maximize per capita energy intake (Baird and Dill 1996), and in other regions, mean group sizes range from 3.8 individuals for whales feeding on harbor seals and 5.0 individuals for groups foraging on small odontocetes in the northeastern Pacific (Ford *et al.* 1998) to 13.6 individuals for “Type A” killer whales feeding on Antarctic minke whales (Pitman and Ensor 2003). Median killer whale group size for bowhead predation events was low (four individuals), although Jefferson *et al.* (1991) found a similar result, with most reported attacks on large

whales made by small groups of one to five killer whales. The number of killer whales involved in attacks on large whales is, however, quite variable (Ford and Reeves 2008), and group size may also increase during the course of an attack (Pitman and Chivers 1998).

Killer Whale Distribution and Predation

Most killer whale sightings occur during ice-free or decreased ice periods of the year. Occurrence in arctic regions is thought to be limited by the presence of pack ice in winter months (Reeves and Mitchell 1988), although reduced observer effort during this season may also be a factor (Gill and Thiele 1997). Killer whales may migrate northwards in the spring along the Labrador coast from the northwest Atlantic and into more open portions of the Arctic (Sergeant and Fisher 1957). The whales observed during the summer presumably migrate south in autumn, ahead of the advancing winter ice. Along north Baffin Island, killer whales are usually seen in July and August but occur as late as October (Reeves and Mitchell 1988, Laidre *et al.* 2006), and this is supported by a satellite-tagged killer whale in Admiralty Inlet in August 2009. The whale avoided heavy ice (>50% coverage), but did navigate through pack ice of *ca.* 30% coverage to exit Lancaster Sound and reach the open waters of Baffin Bay in early October, and then rapidly moved southwards into the North Atlantic (Matthews *et al.* 2011). The abundance and distribution of killer whales throughout the Canadian Arctic is likely related to the distribution and abundance of prey items. Marine mammals in the eastern Canadian Arctic have predictable fall and spring migrations as well as summering grounds, but spend winter months within the pack ice or recurring polynyas (Stirling and Cleator 1981). Each cetacean species has documented concentration areas during the summer (*e.g.*, NWMB 2000, Richard *et al.* 2001, Dietz *et al.* 2008, Ferguson *et al.* 2010*b*). Such predictable and dense prey aggregations will likely also concentrate predators such as killer whales.

Implications

Killer whale sightings occur throughout the Canadian Arctic on an annual basis, and sightings are increasing in many regions (also see Higdon 2007, Higdon and Ferguson 2009). We have summarized predation observations, and reported that prey items were exclusively marine mammals (although predation on fish cannot be discounted). Changing climatic conditions are expected to result in the redistribution of ice-adapted species (Tynan and Demaster 1997, Laidre *et al.* 2008), coupled with range expansions of temperate species (Moore and Huntington 2008, Higdon and Ferguson 2011). Killer whales can be expected to extend their duration in the Arctic and possibly expand their use of areas, where they have been less frequently observed. An increased abundance of mammal-eating killer whales may, in turn, affect existing and future marine mammal community dynamics, though the extent remains unclear (Ferguson *et al.* 2010*a*).

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