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SHORT NOTE

Satellite tracking of a killer whale (*Orcinus orca*) in the eastern Canadian Arctic documents ice avoidance and rapid, long-distance movement into the North Atlantic

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Abstract Killer whales (*Orcinus orca*) occur in the eastern Canadian Arctic during the open-water season, but their seasonal movements in Arctic waters and overall distribution are poorly understood. During August 2009, satellite transmitters were deployed onto two killer whales in Admiralty Inlet, Baffin Island, Canada. A whale tracked for 90 days remained in Admiralty and Prince Regent Inlets from mid-August until early October, when locations overlapped aggregations of marine mammal prey species. While in Admiralty and Prince Regent Inlets, the whale traveled 96.1 ± 45.3 km day^{-1} (max 162.6 km day^{-1}) and 120.1 ± 44.5 km day^{-1} (max 192.7 km day^{-1}), respectively. Increasing ice cover in Prince Regent Inlet in late September and early October was avoided, and the whale left the region prior to heavy ice formation. The whale traveled an average of 159.4 ± 44.8 km day^{-1} (max 252.0 km day^{-1}) along the east coast of Baffin Island and into the open North Atlantic by mid-November, covering over 5,400 km in approximately one month. This research marks the first time satellite telemetry has been used to study killer whale movements in the eastern Canadian Arctic and documents long-distance movement rarely observed in this species.

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Introduction

During late summer months, killer whales (*Orcinus orca*) enter bays and inlets in the eastern Canadian Arctic in pursuit of prey such as narwhal (*Monodon monoceros*), beluga (*Delphinapterus leucas*), and bowhead whales (*Balaena mysticetus*), as well as seals (Reeves and Mitchell 1988a; Higdon et al. 2010). Summarized accounts indicate a broad seasonal distribution extending from the High Arctic south to Hudson Bay, encompassing the Lancaster Sound region, the east coast of Baffin Island, and Hudson Strait, Hudson Bay, and Foxe Basin (Reeves and Mitchell 1988a; Higdon et al. 2010). Seasonal patterns in killer whale occurrence are similar throughout their eastern Canadian Arctic range, where numbers increase gradually through spring (June to July), peak in summer (August), and decline through early fall (September to October) (Higdon et al. 2010). Sighting records suggest regular, possibly annual killer whale occurrence in the Lancaster Sound region west to Prince Regent Inlet (Reeves and Mitchell 1988a). Observations around Pond Inlet peak in July and August, but killer whales have been seen there as late as October. A similar seasonal distribution pattern exists in nearby Admiralty and Prince Regent Inlets, where killer whales are seen from August to October (Reeves and Mitchell 1988a).

Killer whales observed in the eastern Canadian Arctic during summer are thought to undertake seasonal migrations to overcome limitations imposed by pack ice (Sergeant and Fisher 1957; Reeves and Mitchell 1988a). Reeves and Mitchell (1988a) speculated killer whales

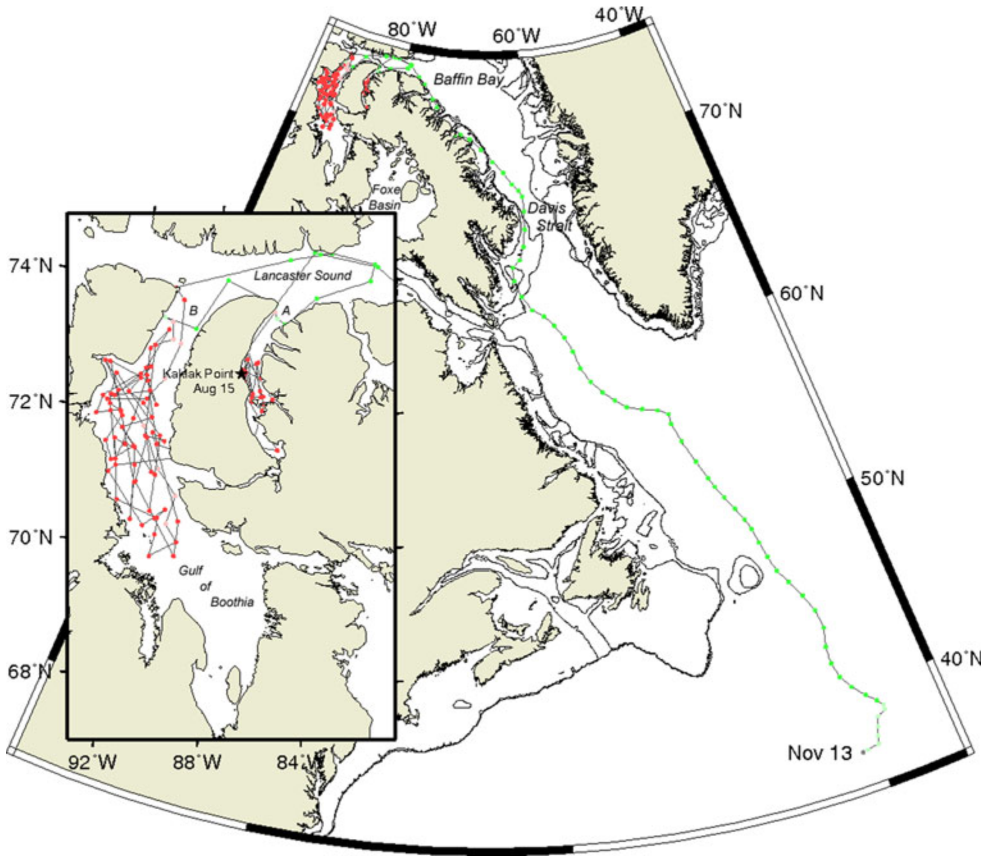

Fig. 1 Track for female or immature male killer whale satellite tagged off Kakiak Point (inset, *black star*) from August 15 to November 13, 2009, as estimated by a state-space model (SSM). Resident behaviors (*red circles*) were aggregated in Admiralty Inlet (*A*) and Prince Regent Inlet (*B*)/Gulf of Boothia, while movements between the two inlets and southward track into the open North Atlantic were detected as 'traveling' (*green circles*). Light red and light green circles denote locations with uncertain behavior categorization. *Contour lines* represent the continental shelf. Raw Argos locations not shown

migrate from Arctic waters to offshore portions of the Labrador Sea, the open Atlantic east of Newfoundland, or along the North American coast as far south as the Caribbean Sea (see also Katona et al. 1988). Their winter range may also include the west and southwest coasts of Greenland, where killer whales occur throughout the year, although in reduced numbers during winter months (Heide-Jørgensen 1988). Although there is no evidence to suggest year-round killer whale presence in the eastern Canadian Arctic (Higdon et al. 2010), killer whales have been observed using leads and polynas to disperse deep within Antarctic winter sea ice (Gill and Thiele 1997; Pitman and Ensor 2003), and also within ice fields of the northwest Atlantic (Lawson et al. 2008) and Bering Sea (Lowry et al. 1987). The extent to which sea ice constrains killer whale distribution in the eastern Canadian Arctic is therefore uncertain.

Recent increases in killer whale sightings in the region, along with range expansions associated with decreasing ice cover (Higdon and Ferguson 2009), have highlighted a need for further research on Arctic killer whale movements and distribution. In August 2009, we deployed satellite transmitters onto killer whales in Admiralty Inlet, Baffin Island, to (1) determine seasonal movements in the eastern Canadian Arctic and (2) identify distribution in the North Atlantic.

Materials and methods

Study site and tagging procedures

Shore-based surveys for killer whales were conducted from a field camp at Kakiak Point, Admiralty Inlet, Baffin Island (Lat. 72.683°, Long. −86.689°) (Fig. 1). Immediately upon sighting, researchers set out by boat and slowly approached the whales to within ~10 m before transmitter deployment was attempted. SPOT5 location-only satellite transmitters (Wildlife Computers, WA) surface-mounted with two 6-cm titanium darts (Andrews et al. 2008) were deployed using a 150-lb draw weight crossbow (Excalibur Vixen, Kitchener, ON, Canada). Whales were targeted at the base of the dorsal fin/saddle patch area, where the barbed darts penetrated dermal/blubber tissue upon contact. Tags were programmed for 300 transmissions each day between 00:00 and 23:00 GMT and were scheduled to transmit daily during the first 2 months of deployment (August to October), every second day during the third month (October to November), and every third day from then on. Battery life under this duty cycle was estimated at approximately 6 months. Polar-orbiting satellites received transmission signals within their reception field and relayed location data through the Argos system. Encountered whales were photographed using either a Canon (EOS 1DS Mark II, EOS 1D Mark II, and EOS 1D Mark II N models) or Nikon D90 camera fitted with either a 400-mm fixed or a 70–200-mm lens for identification purposes.

Data analysis

Because locations were observed with error, and at irregular intervals, we fit a two-state (nominally resident and traveling) 'switching' state-space model (SSM; described in detail in Jonsen et al. (2005) and Breed et al. (2009) to Argos locations to estimate the most probable path of the whale. Argos assigns each location to one of the following seven quality classes, in decreasing order: 3, 2, 1, 0, A, B, and Z, for which errors in both dimensions of the plane have been determined, except for class Z (Vincent et al. 2002). Therefore, locations of class Z were removed prior to fitting the model. The model implicitly assumes that the movement process occurs on a regular time series, where the true unobserved locations are estimated via Markov Chain Monte Carlo simulations, accounting for errors in observed locations. Behavioral states at each time step of the track were determined from changes in speed and turning angles of the killer whale, which are quantified by a parameter in the SSM model (Breed et al. 2009). 'Resident' behavior refers to slower movements with frequent turns, while 'traveling' is characterized by faster, straight-line movements. We used a 12-h step to construct a regular time series of location estimates, which represents a compromise between temporal resolution in the output-modeled whale track and avoiding simple interpolation between observed locations due to lack of data.

Results and discussion

Killer whales were sighted on four occasions from August 10 to 19, 2009. Group size varied with each sighting from 8 to 20 individuals. Subsequent analysis of photo-identified individuals indicated sightings on different days were of the same whales (G. Freund, pers. comm.), although not all identified whales were observed during each encounter. Satellite tags were deployed onto two adult female or juvenile male killer whales on August 12 and 15. The individual tagged on August 12 was tracked for a total of 2 days in an area where both narwhals and harp seals (*Phoca groenlandica*) were observed (data not shown). The tag deployed on the second individual transmitted until November 13 (90 days total). This whale remained in Admiralty Inlet for 2 weeks (August 15–29) after tag deployment and then moved into Prince Regent Inlet/Gulf of Boothia via Lancaster Sound by late August, where it remained until October 9 (Fig. 1). Mean net distances traveled while in Admiralty Inlet and Prince Regent Inlet/Gulf of Boothia were 96.1 ± 45.3 km day^{-1} (max 162.6 km day^{-1}) and 120.1 ± 44.5 km day^{-1} (max 192.7 km day^{-1}), respectively. Increasing ice cover in late September and early October was avoided (Fig. 2a,b,c,d). The whale left Prince Regent Inlet in early October prior to heavy ice formation in the area (Fig. 2e), traveling an average of 159.4 ± 44.8 km day^{-1} (max 252.0 km day^{-1}) along the east coast of Baffin Island and into the open North Atlantic (Lat. 37.728°, Long. −40.701°) by mid-November (Fig. 1). The SSM indicated the killer whale switched between 'resident' swimming behavior in Admiralty Inlet and Prince Regent Inlet/Gulf of Boothia, and 'traveling' while crossing Lancaster Sound (from Admiralty Inlet to Prince Regent Inlet) and during the southward component of the track (from Prince Regent Inlet to final transmitted location) (Fig. 1).

Time spent in Admiralty and Prince Regent Inlets (mid-August to early October) agrees well with the summarized accounts of killer whale sightings in the region, which peak during the late summer months (Reeves and Mitchell 1988a; Higdon et al. 2010). Locations in Admiralty Inlet and Prince Regent Inlet (Fig. 1) overlapped with seasonal aggregations of potential killer whale prey, including narwhals and bowhead whales. Narwhals aggregate in the central, deeper waters of Admiralty and Prince Regent Inlets, where they number in the thousands until late September/early October (Dietz et al. 2008; Richard et al. 2010), and Prince Regent Inlet is a nursery area for female bowheads with calves during July–September (Reeves et al. 1983; Finley 2001). Beluga are generally uncommon in Admiralty Inlet during July to late September (Richard et al. 2010), and aggregations of belugas in Prince Regent Inlet during July–August have largely left the area for summer locations further west in Peel Sound by September (Smith and Martin 1994; Richard et al. 2001). Other potential killer whale prey in Admiralty and Prince Regent Inlets include harp seals, which migrate into the area in late spring and summer as sea ice recedes, and ringed (*Pusa hispida*) and bearded seals (*Erignathus barbatus*), which are resident year-round.

Ice cover was avoided while in Prince Regent Inlet/Gulf of Boothia during the final weeks of September and early October (Fig. 2a,b,c,d), and departure from Prince Regent Inlet preceded the formation of heavy (>50%) ice cover in the area by just days (Fig. 2e). In a recent compilation of killer whale sightings across the eastern Canadian Arctic, Higdon et al. (2010) found no winter observations within 305 records with sufficient information to categorize season. Although our data support the general belief that killer whales avoid sea ice in the eastern Canadian Arctic, the tagged whale navigated pack ice of ∼30% cover while crossing Lancaster Sound to reach the ice-free waters east of Baffin Island (Fig. 2e).

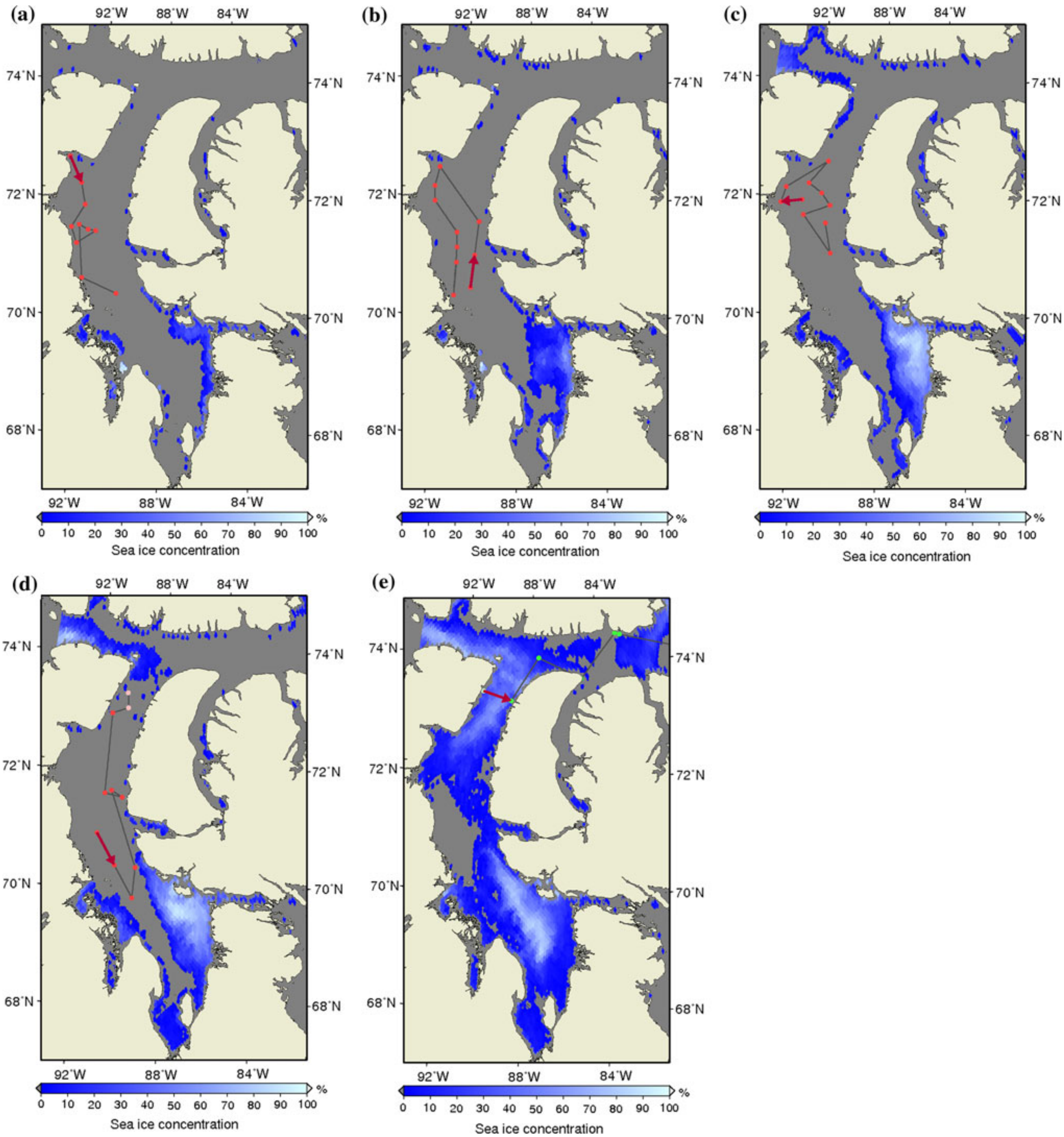

Fig. 2 Killer whale movements (modeled data) relative to sea ice cover indicate the whale never entered areas of ice cover in Prince Regent Inlet/Gulf of Boothia during September 18–22 (**a**), September 23–27 (**b**), September 28–October 01 (**c**), and October 02–08 (**d**). Departure from Prince Regent Inlet through ~10–30% sea ice cover occurred prior to heavy ice cover (>50%) formation during October 08–12 (**e**). *Red arrows* indicate first segment within each movement sequence. Ice data source: Canadian Ice Service (http://ice-glaces.ec.gc.ca)

Once in Baffin Bay/Davis Strait, prolonged directed swimming persisted despite passing known aggregations of bowhead and beluga whales in areas such as Isabella Bay and Cumberland Sound at that time of the year (Finley 1990; Richard and Stewart 2008). Distance traveled from Lancaster Sound to final transmitted locations (>5,400 km) is among the longest documented for killer whales. Offshore killer whales in the eastern North Pacific are known to frequently travel long distances. Two offshore killer whales photo-identified in both Alaska and California traveled straight-line distances (i.e., a minimum estimate) of 4,435 and 4,345 km (Dahlheim et al. 2008). Goley and Straley (1994) documented a linear distance of 2,660 km traveled by a North Pacific transient killer whale, also between Alaska and California. Guerrero-Ruiz et al. (2005) reported linear distance of 5,535 km traveled by a male killer whale between Mexico and Peru, although the validity of this photographic match has been questioned (Dahlheim et al. 2008). The short period within which the whale traveled from Lancaster Sound to the mid-North Atlantic (~1 month) is also noteworthy, as previous reports of long-distance movements by killer whales have been inferred from photo-identification matches separated by periods of several months (e.g., Dahlheim et al. 2008) to years (e.g., Goley and Straley 1994).

Transmissions did not last long enough to determine the winter range of the tagged whale, and interpretation of its movement within the context of the greater North Atlantic is constrained by limited knowledge of killer whale distribution patterns in the region. Summaries of killer whale sightings from the eastern Canadian Arctic (Reeves and Mitchell 1988a; Higdon et al. 2010), western Greenland (Heide-Jørgensen 1988), and Newfoundland and Labrador (Mitchell and Reeves 1988; Lawson et al. 2008) indicate killer whale movements in the North Atlantic are complex, but provide no clear indication of seasonal distribution patterns. Final locations of the tagged whale in the mid-North Atlantic correspond with areas of concentrated killer whale sightings by nineteenth-century American whalers on the 'Western Ground' (the open North Atlantic between the Azores and Bermuda) from March through September (Reeves and Mitchell 1988b). Reeves and Mitchell (1988b) concluded whales observed on the Western Ground did not represent the wintering or southern component of a north–south migration given sightings occurred during the summer months. Current killer whale sightings around the Azores occur between February and August (ICES 2010; Annette Scheffer, The Mid-Atlantic Orca Project, pers. comm.), but the seasonal distribution and overall range of these whales is unknown.

The remarkable, directed, long-distance movement from Arctic waters at the onset of ice formation in early October suggests killer whales seasonally inhabiting the eastern Canadian Arctic have a large overall range within the North Atlantic. Whether seasonal visitations to the Arctic are annual or repeated by the same whales remains to be determined through continuing research efforts using satellite telemetry, photo-identification, and chemical analysis of tissues. Future research will assist in clarifying seasonal movement patterns and overall distribution of eastern Canadian Arctic killer whales, which will provide a better understanding of their influence on Arctic ecosystems.

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