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SHORT NOTE

Unusual narwhal sea ice entrapments and delayed autumn freeze-up trends

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Abstract Sea ice entrapments of narwhals (*Monodon monoceros*) occur when rapid changes in weather and wind conditions create a formation of fast ice in bays or passages used by whales. Between 2008 and 2010, four entrapments of narwhals were reported in Canada and Greenland. In each case, large groups (40–600 individuals) succumbed in the sea ice at three separate summering localities, two of these where entrapments had never before been reported. We examined long-term trends in autumn freeze-up timing (date when sea ice concentration rises above some threshold) on the 6 largest narwhal summering areas using sea ice concentration from satellite passive microwave data (1979–2009). We found strongly positive and significant trends ($P < 0.001$) in progressively later dates of autumn freeze-up in all summering areas. Autumn freeze-up occurs between 0.5 and 1 day later per year, or roughly 2–4 weeks later, over the 31-year time series. This indicates that sea ice conditions on narwhal summering areas are changing rapidly. The question remains whether entrapment events on summering areas are random or whether narwhals are adapting to changes in sea ice freeze-up by prolonging their summer residence time.

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Introduction

The life histories, behaviors, and feeding patterns of Arctic marine mammals are temporally associated with sea ice parameters which, in some cases, make them vulnerable to changes that are sudden, unidirectional, or large (Laidre et al. 2008). Two approaches for gaining insight into the effects of climate alterations include (1) long-term monitoring of population metrics, life history, or behavior in combination with environmental time series and quantitative modeling (e.g., Regehr et al. 2010; Rode et al. 2010) or (2) documenting unusual or rare phenological or behavioral observations in concert with altered environmental conditions (e.g., Amstrup et al. 2006; Cooper et al. 2006). Although not corrected for effort, unusual observations offer insights into how species may react to changes in their physical environment.

Roughly 80,000 narwhals (*Monodon monoceros*) use Baffin Bay and at least 7,000 inhabit the Greenland Sea (Heide-Jørgensen et al. 2010; Richard et al. 2010). There are approximately 10 summering stocks or aggregations of narwhals in the Canadian Arctic and West and East Greenland which supply whales to multiple subsistence harvest localities (DFO 2010; Heide-Jørgensen et al. 2010). These stocks range widely in population size, with some stocks >27,000 animals (Richard et al. 2010; Heide-Jørgensen et al. 2010). Numerous satellite tracking studies have documented the seasonal movements of narwhals (Heide-Jørgensen et al. 2003; Dietz et al. 2008). Typically, narwhals move out of coastal summering areas into offshore winter areas in the autumn when fast ice forms. In many areas, the disjunct seasonal distributions are connected by autumn and spring migrations over 1,000 km long which last up to 2 months (Laidre et al. 2008).

Although narwhals are known to regularly occupy heavy pack ice habitats with less than 3% open water in winter (Laidre and Heide-Jørgensen 2005, 2011), ice entrapments are a source of natural mortality. These events occur when a sudden change in weather and wind creates a rapid formation of fast ice in bays or passages used by whales over the course of hours or days. Most previous narwhal ice entrapments have been reported during stable high-pressure periods in winter, especially February and March. Furthermore, most entrapments have been reported in narwhal wintering areas, especially around Disko Bay, West Greenland, where the largest entrapment of >1,000 narwhals occurred in 1915 (Porsild 1918).

We report on four recent narwhal sea ice entrapments that occurred in the winters of 2008, 2009, and 2010 in the vicinity of three narwhal summering areas. Ice entrapments have not previously been documented in two of these localities. We also investigated large-scale changes in sea ice patterns on six of the largest narwhal summering areas (based on absolute population size) by calculating trends in the autumn freeze-up date (the date when sea ice concentration rises above some threshold) using satellite-based sea ice data, 1979–2009. We discuss how these recent narwhal sea ice entrapments may be linked to changing Arctic conditions.

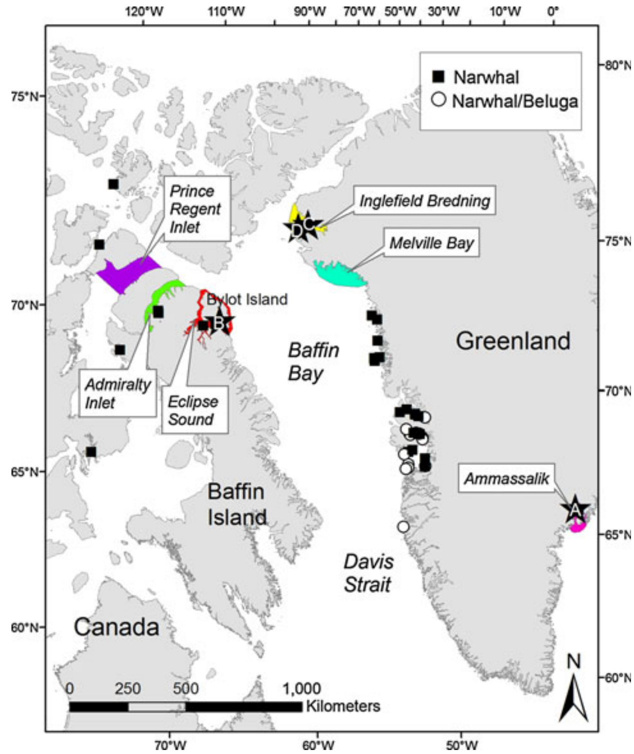

Fig. 1 Map of all reported narwhal sea ice entrapments in Canada and Greenland (1912–2010). Some ice entrapments were comprised of both narwhals and belugas. *Stars* indicate locations of the four recent sea ice entrapments discussed in this paper (labeled *A*, *B*, *C*, and *D*). The six narwhal summering areas used for sea ice analyses are shown in *different colors*

Methods

We compiled information on date, weather, sea ice conditions, and numbers of whales in four recent ice entrapments in Greenland and Canada between 2008 and 2010 and integrated them into the existing record of all narwhal ice entrapments reported between 1912 and 2010 (Fig. 1, Siegstad and Heide-Jørgensen 1994; Heide-Jørgensen et al. 2002).

We calculated long-term trends in sea ice on 6 summering areas in Canada and Greenland: Prince Regent Inlet (PRI), Admiralty Inlet (ADM), and Eclipse Sound (ECL) in Canada, Inglefield Bredning (ING) and Melville Bay (MEL) in West Greenland, and Ammassalik (AMM) in East Greenland. We used daily (after 1987) and every-other-day (before 1987) sea ice concentration values from satellite passive microwave data available from the National Snow and Ice Data Center (NSIDC) (Cavalieri et al. 1996). A time series of daily mean sea ice concentration on each summering area was calculated, and a 5-day running median filter was applied to reduce noise in day-to-day concentration. The autumn freeze-up date was defined as the date in the fall when the mean sea ice concentration rose above a threshold of 65% and remained above the threshold for at least 2 weeks. A threshold of 45% was used for the Ammassalik region due to generally lower sea ice concentrations on account of its low latitude relative to the other regions. Standard least-squares regressions of autumn freeze-up date versus year (1979–2009) were calculated for each region (Table 1) to determine the trend in autumn freeze-up date over the last 30 years.

We tested the sensitivity of the trends in autumn freeze-up date versus year to the choice of sea ice concentration threshold. The sea ice concentration data are provided on a grid with approximately 25-km pixel size. According to NSIDC, the accuracy of the concentration values is ±5% to ±15% depending on conditions. By averaging over all the pixels in a region, the random error of the mean ice concentration is reduced by a factor of $\sqrt{N}$ where N is the number of pixels in the region. Using the worst-case uncertainty of 15% and the smallest summering area ($N = 7$ pixels), the random error of the daily mean ice concentration is slightly above 5%. Therefore, we varied the thresholds by ±5% and re-calculated trends in each area.

We also computed the slope of autumn freeze-up day versus year using the standard least-squares method in a

Table 1 Regression results for autumn freeze-up day between 1979 and 2009 in 6 narwhal summering regions (see Fig. 2)

Region	Slope (days/year)	STD slope (days/year)	R^2	STD residuals (days)	Significance
PRI	0.66	0.16	0.39	7.45	$P = 0$
ADM	0.75	0.14	0.49	6.77	$P = 0$
ECL	0.45	0.13	0.29	6.34	$P = 0.002$
ING	1.14	0.32	0.31	15.30	$P = 0.001$
MEL	1.11	0.33	0.28	16.04	$P = 0.002$
AMM	1.48	0.66	0.16	29.98	$P = 0.03$

The West Greenland/Baffin Bay regions are reported for a 65% sea ice threshold and the East Greenland (AMM) region at a 45% threshold. Slope is the slope of the linear fit, *STD* Slope is the standard deviation of the slope, R^2 is the squared correlation of the linear fit, *STD* Residuals is the standard deviation of the residuals of the linear fit, and significance is the *P* value computed from the *F* test

sliding 15-year window to assess changes in slope at each summering area over the 31-year period.

Results

Narwhal sea ice entrapments (2008–2010)

In mid-February 2008, approximately 30–40 narwhals were discovered by hunters entrapped at Amanga Island in the Sermilik Fjord, Ammassalik, East Greenland (Fig. 1, site A). All entrapped whales were taken in a subsistence harvest. The nearest weather station, at Kulusuk airport on the coast 80 km SSE of Amanga Island, was too far away to provide reliable wind data for the entrapment site. The air temperature at Kulusuk was −12°C to −18°C in the first 12 days of February.

On November 15, 2008, a large entrapment of several hundred narwhals along a pressure ridge was discovered 17 km from the town of Pond Inlet, Canada (Fig. 1, site B). It was determined that the animals had no chance of escaping to open water (approximately 50 km away), and a harvest of 629 narwhals occurred between 19 November and 2 December. Of these, 566 animals were assessed by the hunters according to size (68 calves, 210 juveniles, and 288 adults). In early November, the air temperature hovered between −23°C and −12°C at the weather station at Pond Inlet. The temperature dropped from November 13 to November 24 to −32°C with wind consistently blowing at 2–3 m/s from the south.

On November 23, 2009, approximately 50–100 narwhals were discovered entrapped in Inglefield Bredning, West Greenland, approximately 15 km southwest of Qaanaaq (Fig. 1, site C). The air temperature in Qaanaaq was about −19°C from November 13 to November 25, and the wind speed was close to zero. About 38 whales were harvested (M.O. Kristiansen, Qaanaaq, Pers. Comm).

On February 5, 2010, a sea ice entrapment of narwhals was reported approximately 500 m northeast from the easternmost point of Herbert Island, Inglefield Bredning, West Greenland (Fig. 1, site D), <10 km from the 2009 event. Approximately 30–100 whales were reported entrapped. Whales were swimming between 3 and 4 large ice floes covering approximately 2 km. The nearest open water was estimated to be 30–40 km away. The air temperature at Qaanaaq was about −18°C to −23°C during the preceding 2 weeks, except for a brief warming on February 2–4 reaching highs of +3°C. During the subsistence hunt on February 6, approximately 35 whales were secured and more lost under the ice.

Autumn freeze-up timing in summering areas

We found that the autumn freeze-up date occurs later in all six narwhal summering areas, with strong significant trends (Table 1, Fig. 2). The slopes were not sensitive to sea ice threshold in any summering area. When thresholds were adjusted by ±5%, the change in the trends was <0.1 days/year and all trends remained significant. There were differences in the rate of change of autumn freeze-up date between western and eastern Baffin Bay. Summering areas in the Canadian high Arctic (Prince Regent Inlet, Admiralty Inlet and Eclipse Sound) froze up later in the fall by approximately 1/2–3/4 day per year, or roughly 2–3 weeks later over the 31-year period. In contrast, summering areas in West Greenland (Inglefield Bredning and Melville Bay) froze up later in the fall by about 1 day per year, or roughly 4 weeks later over the 31-year period. The summering areas in Canada experienced more-or-less linear increases in freeze-up day, whereas the summering areas in West Greenland had almost no trend during the first half of the record and a large significant trend during the second half of the record (Fig. 3). The summering areas in West Greenland also displayed larger year-to-year variability (Table 1; Fig. 2, 3). The autumn freeze-up dates at Ammassalik occurred later in the fall compared with the five other areas because of its lower latitude. Linear trends were all significant (Table 1); however, Ammassalik demonstrated high variability and trends were strongly influenced by conditions in 2001–2004.

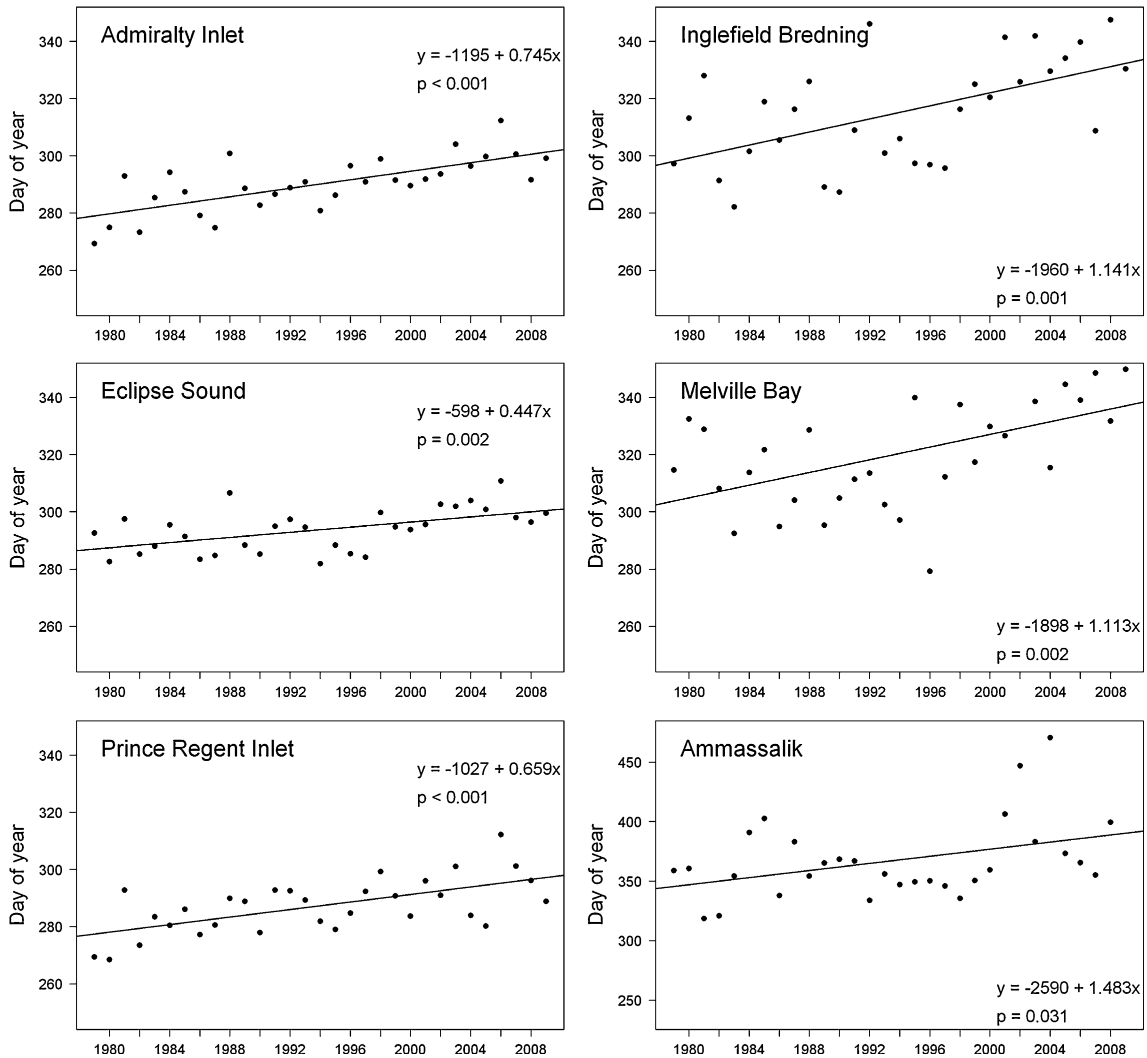

Fig. 2 Time series of the day of year of autumn freeze-up in narwhal summering areas (1979–2009), derived from the 65% threshold of sea ice concentration (Ammassalik 45% threshold). All trends are significant at $P < 0.05$ and insensitive to choice of threshold

Discussion

The ice entrapments reported here are the first documented entrapments in Greenland since 1994 and the first in Canada since 1979. Entrapments are typically observed and reported by Inuit hunters and, after the situation is determined to be irreversibly lethal, management authorities may give permission to harvest whales for humane purposes. Recorded ice entrapments date back to the early 1900s (Fig. 1); however, since ice entrapments depend on human observation in remote areas, it is difficult to estimate trends in their frequency.

Notably, all four ice entrapments occurred in the vicinity of narwhal summering areas, thus whales had delayed their departure from these areas into the late fall and winter. The Pond Inlet event was the second largest sea ice entrapment of narwhals in Canada (Heide-Jørgensen et al. 2002) and occurred during a November marked by an exceptional number of narwhals in the area according to Inuit observations. In West Greenland, no entrapments have been documented in the summering area of Inglefield Bredning (NW Greenland) despite year-round observer effort by Inuit hunters (Heide-Jørgensen et al. 2002). The entrapment in Ammassalik was also the first ever reported in East Greenland. All prior reported ice entrapments in Greenland have occurred between Upernavik and Disko Bay on the west coast (69–74°N, Siegstad and Heide-Jørgensen 1994).

In three of the four events for which reliable weather data were available, there was a general absence of wind combined with cold temperatures. In ice-covered waters, open water is generally created by ice-fracturing events caused by strong winds. In the absence of wind, little new open water can be created. This limits narwhals to existing open water on which ice grows rapidly. For example, in

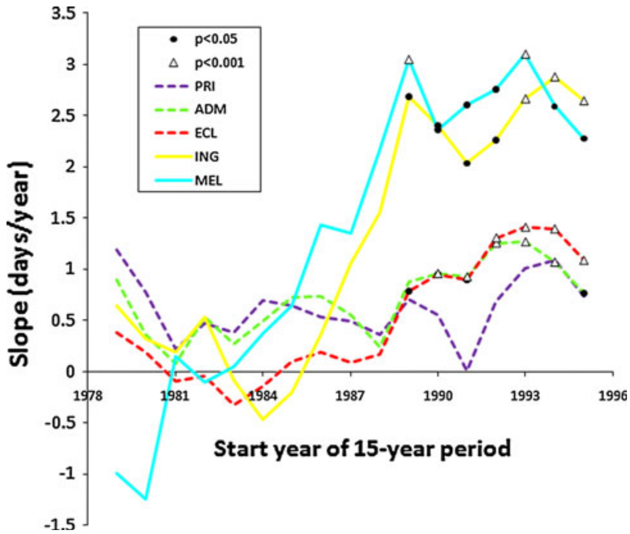

Fig. 3 Slopes of sliding 15-year least-squares fits for western and eastern Baffin Bay narwhal summering areas. The slope of the least squares line is plotted for each 15-year period. Canadian summering areas are shown as *dashed lines*

3 days of −19°C air temperature, ice would grow to be 14 cm thick (Maykut 1986), beyond the limit of narwhal ice-breaking ability.

There were significant trends in later autumn freeze-up day over the entire primary summer range of the narwhal in Arctic Canada and Greenland. These trends are consistent with the larger physical changes reported for these areas, with sea ice declines of approximately 9% per decade in Baffin Bay and 10% per decade in East Greenland (Perovich and Richter-Menge 2009). The autumn freeze-up trends were linear in Canada while in Greenland they followed a step change. The three Canadian sites had less year-to-year variability in autumn freeze-up dates than the three Greenland sites (Table 1 and Fig. 2). The Canadian sites are relatively sheltered from the influence of ocean currents and winds as they are tucked into inlets and passages between islands. In contrast, the Inglefield Bredning region is heavily influenced by its proximity to the North Water Polynya, whose formation depends on wind, upwelling, and a highly variable ice bridge in Smith Sound (Barber et al. 2001). Melville Bay is influenced by the large-scale, wind-driven circulation of Baffin Bay, where a cyclonic feature in the northeast part of the bay carries sea ice northward into Melville Bay (Kwok 2007). Finally, the Ammassalik region is highly influenced by the strong East Greenland Current that flows southward along the coast. Thus, compared with the Canadian sites, the Greenland sites are subject to advection of sea ice from surrounding regions by wind and currents, which accounts for the greater variability around the date in the fall when the sea ice concentration reaches a given threshold. However, it is difficult to link the differences in variability with narwhal behavior.

The question still remains whether the four recent ice entrapments are due to random variation in narwhal residence time in summer areas, or whether there is an actual trend in prolonged summer residence time as narwhals adapt to a longer open water season. Most climate models predict increased variability in climate extremes and increased frequency and intensity of extreme weather events (IPCC 2007). Given that rapid changes in weather and ice conditions do not always trigger narwhals to move into open water areas, careful documentation of future entrapments is needed to assess the relationship between incremental and unidirectional changes in autumn freeze-up and narwhal vulnerability.

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