SHORE-BASED MONITORING OF NARWHALS AND VESSELS AT BRUCE HEAD, MILNE INLET, 2016

Prepared by

LGL LIMITED
environmental research associates

for

Baffinland

LGL Report FA0089-1

28 February 2017

SHORE-BASED MONITORING OF NARWHALS AND VESSELS AT BRUCE HEAD, MILNE INLET, 2016

Prepared by:

Heather R. Smith, Valerie D. Moulton, Scott Raborn,
Patrick Abgrall, Robert E. Elliott, and Mark Fitzgerald

LGL Limited, environmental research associates
P.O. Box 280, King City, Ontario L7B 1A6
1-905-833-1244 vmoulton@lgl.com

for

Baffinland Iron Mines Corporation
2275 Upper Middle Road East, Suite 300
Oakville, Ontario L6H 0C3

LGL Report FA0089-1
28 February 2017

Suggested format for citation:

Smith, H.R., V.D. Moulton, S. Raborn, P. Abgrall, R.E. Elliott, and M. Fitzgerald. 2017. Shore-based monitoring of narwhals and vessels at Bruce Head, Milne Inlet, 2016. LGL Report No. FA0089-1. Prepared by LGL Limited, King City, Ontario for Baffinland Iron Mines Corporation, Oakville, Ontario. 87 p. + appendices.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

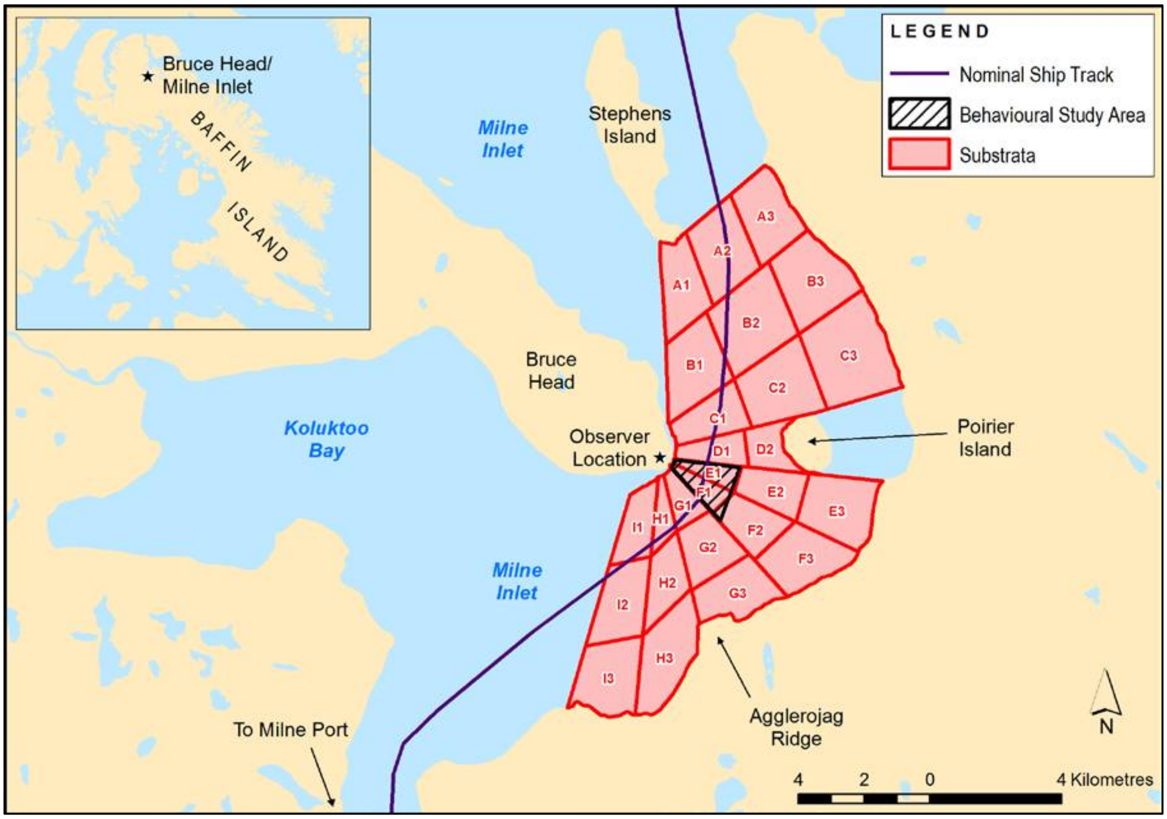
LIST OF ACRONYMS

AANDC	Aboriginal Affairs and Northern Development Canada
AIS	Automatic Identification System
ASL	above sea level
BSA	behavioural study area
CCGS	Canadian Coast Guard Ship
CITES	Convention on International Trade in Endangered Species of Wild Flora and Fauna
CPA	closest point of approach
CV	coefficient of variation
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DFO	Fisheries and Oceans Canada
DSLR	digital single lens reflex (camera)
DWT	dead weight tonnage
EDT	Eastern Daylight Time
EEM	Environmental Effects Monitoring (plan)
ERP	Early Revenue Phase
FEIS	Final Environmental Impact Statement
GLM	generalized linear model
GLMM	general linear mixed model
GPS	Global Positioning System
GT	gross tonnage
IMO	International Maritime Organization
LGL	LGL Limited, environmental research associates
LNA	low noise amplifier
MEWG	Marine Environment Working Group
MMSI	Maritime Mobile Service Identity
MV	motor vessel
NGS	National Geodetic Survey (U.S.)
NIRB	Nunavut Impact Review Board
QIA	Qikiqtani Inuit Association
RAD	relative abundance and distribution
SARA	*Species at Risk Act*
SSA	stratified study area
TALC	total allowable landed catch
VBA	Visual Basic for Applications®
VHF	very high frequency

SUMMARY OF APPROACH AND KEY FINDINGS

The 2016 open-water season marked the second year of operational shipping for the Early Revenue Phase (ERP) of Baffinland's Mary River Project and the fourth year that the shore-based study of narwhal response to shipping occurred in Milne Inlet (see map below). From late July to early October 2016, there were 38 round-trip voyages by ore carriers that shipped about 2.7 million tonnes of ore from the port at Milne Inlet. A team of marine biologists and Inuit observers collected data on narwhals and shipping from an observation site on Bruce Head (see photo below) from 30 July to 30 August 2016; the team collected data on narwhals during 18 ore carrier and 2 cargo vessel one-way transits.

The approach taken to investigate narwhal response to shipping in 2016 was very similar to the approach taken in 2014 and 2015. Three primary types of narwhal data were collected: relative abundance and distribution (RAD) data, group composition data, and behaviour data. Additionally, all observers made general observations (*ad lib*) of narwhal activity. Besides data on shipping, ancillary information about tide, weather, and other anthropogenic activity, particularly hunting, were also collected. (Narwhal hunting is conducted regularly at the base of Bruce Head.) Data on the ancillary variables were used to investigate their influences on narwhals and to help in distinguishing effects of ore carriers from those of other factors influencing local numbers and distribution of narwhals.



Study area for shore-based observations of narwhals at Bruce Head, 2014 to 2016. Also shown are the stratified study area (SSA) for relative abundance and distribution counts, the smaller behavioural study area (BSA), and the usual ship track for ore carriers.

The observation platform at Bruce Head, Milne Inlet, 2016. The south end of Poirier Island can be seen in the photo.

In 2016, there was a total of 301.6 hours of observation effort over the course of 27 days at the observation site from 30 July to 30 August 2016. This is similar to effort in 2015 (307 hours of observation effort over the course of 30 days) and almost double the effort achieved in 2014 when weather was quite severe (181.2 observation hours conducted over the course of 24 days).

Narwhal General Distribution and Habitat Use

Although the focus of this study is the effects of Baffinland shipping on narwhals, the data also provide important information about narwhal general distribution and habitat use in southern Milne Inlet. Again this year, thousands of narwhals were recorded during RAD counts of the SSA. In 2016, we recorded 27,888 narwhals (including repeat sightings) over the 30 July to 30 August study period. Daily totals ranged from 0 to 3764 narwhals, and totals exceeded 1000 narwhals on 11 days. There were five days when no narwhals were observed.

General Distribution

In 2016, as observed in 2013–2015, most narwhals during RAD counts of the SSA were consistently observed in the south (strata G, H, I), i.e., near Koluktoo Bay (see map above), and were more often observed in the eastern and middle portions of the SSA. The northernmost portion of the SSA was often observed to contain no narwhals. During *ad lib* observations, narwhals were frequently observed south of the SSA in the general vicinity of Koluktoo Bay and the entrance to Assomption Harbour (and Milne Port). A similar distribution was observed during aerial surveys conducted over 25 years ago and it is thought that Koluktoo Bay may serve as a refuge for narwhals.

Based on data from 2014 to 2016, numbers of narwhals counted in the SSA were significantly (statistically) related to tide, time of day, and date. Relatively more narwhals were observed in the SSA during ebb tides. *Ad lib* observations made in 2015 and 2016 corroborate this finding. On several occasions in 2016, narwhals were observed to move north into the SSA, usually from Koluktoo Bay, and then reverse direction and head south again for no obvious reason. Examination of daily tidal flow in the area revealed that some of these movements and direction reversals coincided with the tide. During the three summers, narwhal numbers began increasing around 11 August, peaked at about 22 August, and began decreasing about a week later. This finding is in general agreement with observations made during systematic aerial surveys of the same area conducted by Baffinland. Highest counts of narwhals in the SSA occurred around 14:00 EDT.

Habitat Use

Most narwhals in the SSA and adjacent waters were travelling when observed. However, narwhals have also been observed engaged in nursing, rubbing, tusking, foraging, and mating behaviour—illustrating the many uses of the inlet by narwhals.

As in previous years, in 2016, narwhal calves were often observed in the SSA and adjacent areas, lending further support for the hypothesis that the area is important for calf rearing. During 2013–2016, groups with calves or yearlings accounted for 39.7 % of the groups of known composition. Further support that southern Milne Inlet is a calf-rearing area comes from observations of nursing behaviour in 2016 (four occasions) and 2015 (two occasions). On 11 August 2016, the birth of a narwhal calf off Bruce Head was observed. To the best of our knowledge, this is the first time that such an event has been documented in the wild, and adds support to the suggestion by previous researchers that Milne Inlet is used for calving in addition to calf-rearing.

In 2016, narwhals were observed foraging on arctic cod schooling close to the Bruce Head shore on 9 days during the first half of August. Mother-calf pairs were observed to engage in foraging behaviours although the majority of these feeding groups did not include calves or yearlings. Based on an analysis of narwhal stomach contents in the 1960s, narwhals have been previously shown to consume arctic cod in the area. However, most narwhal foraging is thought to occur during winter in Davis Strait.

Narwhals and Large Vessels

In 2016, narwhals were exposed to 36 one-way transits by ore carriers (typically 225 m in length) during the 30 July to 30 August study period. That was more than double the number of ore carrier transits during the first year of operational shipping in 2015. The findings concerning effects of large vessels on narwhal relative abundance and distribution, behaviour and group composition are interpreted below based on combined data from 2014, 2015, and 2016.

Relative Abundance and Distribution

As described above, the numbers and local distribution of narwhals in the SSA are influenced by “natural” factors like tide, time of day, and date as well as human activities like hunting. It is important to account for the influences of natural factors and human activities on narwhals when investigating the effects of large vessels. We used a statistical analysis called a generalized linear mixed model (GLMM) on the combined 2014, 2015 and 2016 relative abundance and distribution (RAD) data to accomplish this. This analysis examined the effects of ore carriers on narwhal numbers in defined areas (substrata) within the SSA; the analysis accounted for the influences of natural variables (date, time of day, tide, sighting conditions, location within the SSA, year) and one other type of human activity (hunting) on narwhal numbers in those areas. The results of this analysis showed that narwhals responded differently to ore carriers depending on the direction of travel by the vessels through the inlet.

For **ore carrier transits northward** through the SSA (i.e., exiting the inlet), results from the GLMM analysis indicated that significantly higher numbers of narwhals (on average ~2.8× higher) were observed when an ore carrier was headed north through the SSA and approaching a given substratum versus periods when no ore carriers were present. The numbers of narwhals were significantly lower (on average ~1.8× lower) during periods after a northbound ore carrier had departed from a given substratum versus periods when no ore carriers were present. This indicates that at least some narwhals exhibited a localized avoidance response to northbound carriers. *Ad lib* observations were variable but generally supported the model results (i.e., number of narwhals were significantly lower after a northbound ore carrier departed an area vs. periods with no ore carriers present). For example, immediately after the passage of the *Golden Saguenay* on 21 August, many narwhals were observed travelling south and out of the SSA. However, in some cases, *ad lib* observations did not seem to support the model results; for example, hundreds of narwhals were observed resting and slowly travelling north in the southernmost strata shortly after the passage of the *Golden Pearl* on 19 August.

For **ore carrier transits southward** through the SSA (i.e., entering the inlet), the GLMM analysis indicated that narwhal numbers in the observation areas tended to be lower, but not significantly so, than numbers when no ore carriers were present; this occurred regardless whether the ore carrier was approaching or departing a given counting area (substratum). *Ad lib* observations were made during two southward ore carrier transits and these supplement the GLMM results. Narwhals were observed heading south toward Koluktoo Bay in advance of the *Nordic Orion* entering the inlet on 11 August 2016, and again heading south out of the SSA in advance of the *Golden Bull* entering the inlet on 14 August 2016. These responses appeared to be short-term as narwhals were observed to return to the SSA within several hours. Given the narrow shape of southern Milne Inlet, and the nearby location of Koluktoo Bay away from the shipping route, it is not surprising that some narwhals would move into Koluktoo Bay in response to ore carriers.

Despite increased shipping traffic during the ERP and localized movements of narwhal groups in response to ore carriers, there were no significant annual differences in narwhal numbers within the SSA in 2014, 2015, and 2016.

Behaviour and Group Composition

Based on analysis of combined 2014, 2015, and 2016 data, we had sufficient sample size to investigate the effects of large vessels (ore carriers plus other vessels >100 m in length, e.g., sealift and ecotourism vessels) on narwhal behaviour and group composition. During periods when a large vessel was present in the SSA, narwhals were more inclined to swim close to shore (<300 m vs. >300 m), and at a faster speed. The presence of a large vessel was also related to narwhal group formation; during a large vessel transit, proportionally more narwhals occurred in a loose (and fewer in a tight) formation, and proportionally more in circular (and fewer in parallel) formation. Narwhal group sizes were not found to differ significantly in the absence (average = 3.9) vs. presence (average = 5.1) of large vessels. Similarly, large vessels did not seem to affect narwhal group composition; there was no statistically significant difference in the proportions in narwhal groups with and without calves/yearlings during periods with and without large vessels in the SSA.

Narwhals and Hunting Activity

The rocks at the base of the cliff at Bruce Head, immediately below the observation site, are commonly used by local Inuit for hunting narwhals and seals. Most of the hunting (i.e., shooting) activity observed during the shore-based studies at Bruce Head was conducted from the shore. In 2016, the hunting camp at the base of Bruce Head was observed to be occupied on 22 days (vs. 16 days in 2015).

During each year of this shore-based study, narwhals have been observed to respond to shooting by diving and increasing their swim speed. Despite repeatedly being shot at from the same location, narwhals were always observed to return to the area at the base of Bruce Head, though the time until they returned was variable (30 minutes to >5 hours). The GLMM analysis supports observations made by the study team at Bruce Head—a significant "time since shooting" effect was found. Following a shooting event, narwhal counts tended to be zero or low during the first 2–3 hours, when narwhals left the area, but counts subsequently tended to increase as narwhals returned 4 to ~9 hours after a shot was fired.

Summary

The shore-based study at Bruce Head sampled a small but important portion of narwhal summering habitat (~82.5 km^2 for the SSA) during the season of peak narwhal abundance and allowed for detection of changes in narwhal local relative abundance, distribution and behaviour related to shipping.

In 2016, despite increased shipping traffic, narwhals were regularly observed in the SSA and adjacent areas of Milne Inlet throughout the 30 July–30 August study period. This was also the case in 2014 and 2015. Results of our analyses on narwhal relative abundance, distribution, and behaviour in southern Milne Inlet indicated narwhals responded to ore carrier transits by exhibiting temporary and localized displacement and related changes in behaviour. However, there was no overall decrease in the abundance of narwhals in the area.

This page left blank intentionally.

1 INTRODUCTION

This document is a technical report presenting results of shore-based monitoring of narwhals (*Monodon monoceros*) and vessels in Milne Inlet, northeast Baffin Island, during the 2016 open-water season. Certain analyses incorporate data on narwhals from comparable observations collected during the 2014 and 2015 shore-based monitoring studies.

1.1 Background

Baffinland Iron Mines Corporation (Baffinland) is developing an open pit iron mine on northern Baffin Island, Nunavut Territory. The Nunavut Impact Review Board (NIRB) granted a Project Certificate for Baffinland's Mary River Project (the "Project") in 2012. The originally approved project included year-round shipping of ore from a port in Steensby Inlet, Foxe Basin, along a southern shipping route through Foxe Basin and Hudson Strait to international markets in Europe. The originally approved project also included shipping of construction supplies and oversized equipment to Milne Port along a northern shipping route through Baffin Bay and Milne Inlet during the open-water season. In January 2013, Baffinland informed the NIRB that it was proposing to make changes to the initial development stages of the Project due to various business drivers. The proposed changes, termed the Early Revenue Phase (ERP), were amended and approved by NIRB in March 2014, and then modified and approved by Aboriginal Affairs and Northern Development Canada (AANDC) in April 2014. The ERP includes shipping up to 4.2 million tonnes per year (Mt/a) of ore via Milne Port during the open-water season (late July to late October), and the deferral of ore shipments from Steensby Port. During the ERP, shipment of the ore to market will occur via chartered ore-carrier vessels. Shipping of ore from Milne Inlet during the open-water period began in 2015 (i.e., the first year of the ERP Operations Phase), and is expected to continue for the life of the Project, about 25 years. During the first year of ERP Operations, Baffinland shipped ~900,000 tonnes via 13 ore carrier voyages. The amount of ore shipped increased substantially in 2016 with 38 ore carrier voyages shipping ~2.7 million tonnes. During the peak of the Operations Phase, approximately 50 to 70 vessel voyages (i.e., 100 – 140 one-way transits) inclusive of ore carriers, sealifts and tankers, will occur each open-water shipping season.

An Addendum to the approved Final Environmental Impact Statement (FEIS) assessing potential effects of the ERP was submitted to the NIRB in June 2013. A key concern that was identified during the FEIS process, including during local stakeholder consultations, was the potential effects of shipping on marine mammals—notably narwhals. The shipping route to Milne Port occurs in key summering habitat for narwhals and this species is an important resource for local hunters. The FEIS addendum did not predict significant effects of shipping on narwhals but it was recognized that there was much uncertainty around this effects prediction. There is a paucity of information about narwhal responses to shipping, particularly exposure to repeated ore carrier traffic. Baffinland contended that with a rigorous monitoring program and an adaptive management approach these uncertainties could be addressed and effects on marine mammals could be minimized.

The shore-based study of narwhals, which commenced in 2013, is one component of Baffinland's Marine Environmental Effects Monitoring (EEM) Plan for marine mammals (SEM and LGL 2016). In 2014 and 2015, the shore-based study was complemented by aerial surveys conducted in Milne Inlet, Eclipse Sound, and Pond Inlet as well as an acoustic study of ship sounds, ambient noise levels, and marine mammal vocalizations. The aerial and acoustic monitoring studies were not undertaken in 2016. In 2016, Fisheries and Oceans Canada (DFO) undertook an aerial survey of the region and Baffinland entered into a data sharing agreement with DFO.

The primary component of the 2016 program to monitor shipping effects on narwhals is the shore-based study described in this report. This study began as a Pond Inlet community-led initiative, which received the support and guidance of the Qikiqtani Inuit Association (QIA). Baffinland committed to supporting this shore-based study of narwhals in conjunction with the QIA. LGL Limited (LGL) was contracted to manage the study, conduct planning, prepare data collection protocols, provide marine biologists to conduct narwhal observations, train Inuit observers, and report on findings. A pilot study was conducted during summer 2013 (Thomas et al. 2014) and residents of Pond Inlet were an integral part of the study team. The pilot study was critical in allowing Baffinland and LGL to identify logistical issues and refine data collection protocols prior to the expected increase in shipping activity associated with the ERP. The shore-based study continued in 2014, 2015, and 2016 with a study period and team size that were doubled compared to the 2013 pilot phase to increase the amount of data collected (Smith et al. 2015, 2016).

The following subsections provide the objectives of the shore-based study as well as background information on narwhals in the study area.

1.2 Objectives of the Shore-based Study

The primary objective of the shore-based study is to determine if there are changes in the distribution, relative abundance, or behaviour of narwhals in Milne Inlet, as observed from Bruce Head, in response to shipping traffic for the Mary River Project. If changes are found, the length of time over which these changes persist will be examined to determine whether habituation occurs. Baffinland committed to conduct the shore-based study for a minimum of three years during the ERP (see NIRB Project Certificate Conditions 99 and 101). The Marine Environment Working Group (MEWG) established for the Mary River Project was to have direct input into determining whether the shore-based study would continue beyond three years.

In order to understand how narwhal relative abundance, distribution, and behaviour relate to shipping traffic (i.e., the presence of large vessels), it was also necessary to identify any natural or other anthropogenic factors that might be related to observed variability in narwhal numbers, distribution or behaviour. Examples of such factors include tides, wind, time of day, the presence of small vessels, and subsistence hunting. It was anticipated that these types of data would need to be collected over multiple years so that sample sizes would be sufficient to identify anthropogenic effects in the presence of natural variability.

Participation of Pond Inlet residents was deemed critical to the success of this study. Therefore, an important objective of this study was to ensure that Inuit observers received technical training in data collection protocols and that these observers were integrated into the study team. A related objective was to provide opportunities to Pond Inlet residents to develop the capacity to plan, participate in, and lead community-based monitoring projects.

1.3 Narwhals in Milne Inlet

Two tentative populations of narwhals have been identified in Canadian waters, based largely on summer distribution: the Hudson Bay population and the Baffin Bay population. However, narwhals in Baffin Bay are currently assessed as a single population by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The narwhal is designated “special concern” by COSEWIC (2004), but has no status under the *Species at Risk Act* (SARA). The subsistence harvest of narwhals is a priority fishery for Fisheries and Oceans Canada (DFO 2015).

Strong evidence from genetic, contaminant and satellite tracking data has been used to define at least four management stocks that summer entirely in Canadian waters: the Somerset Island, Admiralty Inlet, Eclipse Sound, and East Baffin Island stocks (Richard et al. 2010). It is the Eclipse Sound stock that primarily occurs along the northern shipping route. In August 2013, DFO undertook a broad scale aerial survey program called the High Arctic Cetacean Survey, whose objective was to produce new abundance estimates for the Baffin Bay narwhal population (and the Eastern Arctic–West Greenland bowhead whale population; DFO 2015). Surveys were conducted in Eclipse Sound, Milne Inlet, Pond Inlet and Navy Board Inlet on 18–19 August. Based on these aerial survey data, narwhal abundance was estimated to be 142,000 for the entire Baffin Bay population, and 10,489 (coefficient of variation (CV) 0.24) for the Eclipse Sound stock (Doniol-Valcroze et al. 2015). Narwhal abundance in the Canadian High Arctic was previously estimated to be in excess of 63,000 narwhals, with an estimated 20,211 summering in the Eclipse Sound and Milne Inlet area (NAMMCO 2010). Doniol-Valcroze et al. (2015) discussed how the stock estimates for the 2013 surveys in Admiralty Inlet (~35,000 narwhals) and Eclipse Sound (~10,000 narwhals) differ substantially from previous survey estimates of the same stocks (~18,000 for Admiralty Inlet in 2010 and ~20,000 for Eclipse Sound in 2004). They noted that the combined estimate for Admiralty Inlet and Eclipse Sound (~45,000) is similar to the total of previous abundance estimates, and that documented movements of individual narwhals between Eclipse Sound and Admiralty Inlet raise the possibility of some degree of exchange between the two summering areas. They also noted that differences in survey design and estimation procedures may also have contributed to the very different estimates for 2004, 2010, and 2013.

Narwhals typically exhibit site fidelity for the same fjords and bays each summer (Heide-Jørgensen et al. 2003, 2015; Laidre et al. 2004), though recent evidence suggests mixing between summering areas does occur (Dietz et al. 2001; Heide-Jørgensen et al. 2002; Watt et al. 2012, 2017). The reason for such site fidelity to Milne Inlet is equivocal. Mansfield et al. (1975) examined stomach contents of 62 narwhals captured in Koluktoo Bay (at the south end of Milne Inlet) in summer, and few were found to contain food despite extensive runs of Arctic char (*Salvelinus alpinus*) in the area. Similarly, Finley and Gibb (1982) examined stomach contents of 73 narwhals from Pond Inlet and Eclipse Sound, and found little evidence of feeding in the fjords in the summer. In contrast to this, foraging behaviour (i.e., fish chases and underwater blows) was observed in Milne Inlet in 2013 (Thomas et al. 2014) and a recent study by Watt et al. (2017) identified Eclipse Sound as an important foraging area for narwhals during summer based on information on diving profiles. Site fidelity to Milne Inlet is likely tied to its suitability for calving or rearing calves (Remnant and Thomas 1992), as evidenced by numerous observations of mother-calf pairs in the area (Mansfield et al. 1975; Kingsley et al. 1994; Marcoux et al. 2009; Thomas et al. 2014; Smith et al. 2015, 2016). Site fidelity to Milne Inlet may also be related to its suitability as a refuge from predators; narwhals have been observed sheltering from killer whales (*Orcinus orca*) in the shallows of Koluktoo Bay (Campbell et al. 1988).

Narwhals are social and are usually seen in small groups, but are sometimes encountered in groups of many hundreds (Strong 1988; Kingsley et al. 1994; Marcoux et al. 2009; Elliott et al. 2015; Thomas et al. 2015a). Observations from Bruce Head (where the present shore-based study was conducted) indicated that narwhals travelled in groups that averaged 3.5 individuals (range: 1 to 25), and that average group size was larger when they entered the inlet than when they exited (Marcoux et al. 2009).

The arrival and departure time of narwhals from their summering areas is variable and depends on ice conditions. Narwhals typically arrive in Eclipse Sound and Milne Inlet in late July as the ice breaks up and depart for their wintering area in Baffin Bay in September before ice forms (Finley and Gibb 1982; Dietz et al. 2001; Watt et al. 2012, 2017). This pattern has also been documented during aerial surveys conducted as part of Baffinland's baseline data collection program and the marine mammal monitoring program for the ERP.

Considerable aerial survey effort was focused on Eclipse Sound and Milne Inlet and nearby bays and inlets during the open-water periods in 2007 and 2008 as part of the Project's baseline data collection program in support of the FEIS. In addition, aerial surveys were conducted along and adjacent to the northern shipping route in August to October of 2013 and 2014 to address data gaps in spatial and temporal coverage and serve as a basis for future monitoring of marine mammals (Elliott et al. 2015; Thomas et al. 2015a,b). Narwhals were present in relatively high densities in Milne Inlet and Koluktoo Bay in late July/early August to mid-September in 2007, 2008, 2013, and 2014, with numbers peaking during mid to late August. During the August to mid-September period, numbers observed during a typical survey often were in the thousands and varied considerably from day to day. During the 2013 and 2014 aerial surveys, by late September, narwhal densities decreased substantially in Koluktoo Bay and Milne Inlet and increased in Eclipse Sound, with a subsequent increase in densities in Pond Inlet by mid-October. These local changes in narwhal densities reflect narwhal migration out of their summering area.

1.4 Narwhal Response to Vessels

Prior to the shore-based study of narwhals and vessels that began at Bruce Head in 2013 (Thomas et al. 2014; Smith et al. 2015, 2016), there had been no systematic study of narwhal response to shipping traffic during the open-water season. However, narwhal response to icebreaking ships had been investigated and documented. The most comprehensive studies of narwhal response to icebreaking ships were undertaken during June of 1982, 1983, and 1984 in Lancaster Sound (LGL and Greeneridge 1986; Finley et al. 1990a). In each study year, the MV *Arctic*, an icebreaking ore carrier of 20,000 dead weight tonnage (DWT), was accompanied by the Canadian Coast Guard Ship (CCGS) *John A. MacDonald* (1982, 1983) or the CCGS *Louis S. St-Laurent* (1984) in Lancaster Sound as it approached the landfast ice-edge and then moved through the fast ice enroute to the Nanisivik mine in Admiralty Inlet. Narwhals at ice edges waiting to continue their migration to summering areas responded to oncoming vessels and periodic icebreaking by 1) demonstrating a "freeze" response, typically lying motionless or swimming slowly away (as far as 37 km along the ice edge), 2) huddling in groups, and 3) ceasing sound production. After initially being displaced in response to relatively low levels of noise (~101 to 105 dB re 1 µPa in the 20–1000 Hz band in 1983) from the approaching ship, narwhals sometimes returned 1–2 days later when icebreaker noise levels were still as high as 120 dB in the 20–1000 Hz band (LGL and Greeneridge 1986; Finley et al. 1990a) and engaged in diving and foraging behaviour.

Finley et al. (1990a) also observed the behavioural responses of belugas (*Delphinapterus leucas*) to the approaching vessels and ice-breaking activity. During the same study, belugas were found to display very different responses than narwhals: belugas along ice edges typically moved rapidly away from approaching vessels, formed herds, undertook long dives while travelling, and vocalized (presumably with "alarm" calls). The responses of belugas and narwhals observed during the 1982–1984 study were generally similar to responses they make to predators (i.e., killer whales) as described by Inuit hunters (Finley et al. 1990a).

Cosens and Dueck (1988) conducted helicopter surveys of leads in the ice across the mouth of Admiralty Inlet during May to July 1986, and examined the effects of icebreaker traffic on the relative abundance, distribution, activity, and orientation of narwhals and belugas. They classified narwhals and belugas as being disturbed when ships were within 130 km of the floe edge. Cosens and Dueck (1988) found that disturbed narwhals were in larger groups, swam more slowly and with fewer changes in direction, and rested less than when vessels were absent. Narwhals were also found to change orientation when ships were ~50 km away. When ships were less than 50 km away, a greater proportion of narwhals were oriented away from the ship (~64 %) than were oriented toward it; when the ship was more than 50 km away, a greater proportion of narwhals were in a neutral orientation (53 %) as compared to when the ship was close (13 %). Cosens and Dueck (1988) did not observe the "freeze" response observed by Finley et al. (1990a), and provided two possible explanations—the heavy pack ice in Admiralty Inlet provided cover for narwhals and narwhals had possibly habituated to shipping traffic. Disturbed belugas were observed to show less directed movement, less resting, and more circling than when vessels were absent.

The strong responses of narwhals (and belugas) at long ranges are unique in the literature of vessel noise responses by marine mammals. Possible reasons suggested by LGL and Greeneridge (1986) are the fact that the whales were concentrated along the ice-edge as the ships approached, the whales' lack of previous experience with ships in the High Arctic in spring, and good sound propagation conditions. The strong response of narwhals to icebreaking ships seems at odds with the findings of Baffinland's shore-based study of narwhal response to large vessels during the open-water seasons of 2013–2015 (Smith et al. 2016; see *Discussion* of this report). Data collected in 2016 (i.e., the second year of ERP Operations), when ore carrier traffic increased to 38 voyages from 13 voyages in 2015, provides a more robust sample size with which to assess the effects of ore carrier traffic on narwhal relative abundance, distribution and behaviour.

1.5 Subsistence Harvest of Narwhals

Narwhals are a significant source of food and income for the residents of Pond Inlet. During the open-water period, harvesting of narwhals by Pond Inlet residents occurs in Milne Inlet, Eclipse Sound, and Pond Inlet (Volume 4, Section 10 *in* Baffinland 2012). More specifically, narwhal harvest locations have primarily been identified in Koluktoo Bay, in Tremblay Sound, near Pond Inlet, along the west shore of Milne Inlet, and near Bruce Head during summer and autumn, and at the Pond Inlet ice-edge during late spring or early summer. Based on the Nunavut Wildlife Harvest Study (1996–1999), August is the month with the largest harvest of narwhals, followed by July and September (Priest and Usher 2004). Hunting has frequently been observed in August during this shore-based study of narwhals at Bruce Head (Smith et al. 2016). The rocks at the base of the cliff at Bruce Head are well used by local Inuit for hunting narwhals and less frequently seals. This method of shore-based hunting (i.e., shooting from the shoreline at the base of Bruce Head vs. from a small vessel) is practiced during the open-water season at a number of locations in Eclipse Sound (Finley and Miller 1982). In 2015, most of the hunting (i.e., shooting) activity observed from Bruce Head was conducted from the shore, though shooting was also occasionally observed from small vessels (Smith et al. 2016).

In Canada, the narwhal hunt is co-managed by Inuit, DFO, and the Nunavut Wildlife Management Board. Recently, a Narwhal Integrated Management Plan was approved that sets quotas based on Total Allowable Landed Catch (TALC) based on estimates of stock size. The current TALC limit for the Eclipse Sound stock is recommended to be 134 (Doniol-Valcroze et al. 2015). A robust management system for the narwhal hunt is necessary to meet the requirements of the Convention on International Trade in Endangered Species (CITES). The narwhal is listed in Appendix II of CITES. To export narwhal products (i.e., tusks) internationally, a CITES export permit is required, and a prerequisite for issuance of a permit is a non-detrimental finding from the DFO Scientific Authority.

1.6 Bruce Head Study Approach, 2016

The approach taken to investigate narwhal response to shipping in 2016 was nearly identical to the approach taken in 2014 and 2015. Three primary types of narwhal data were collected:

- **Relative abundance and distribution (RAD)** — data were collected to investigate potential changes in narwhal relative abundance, distribution, and travel direction in Milne Inlet in response to the presence of large vessels. This dataset allows narwhal response to large vessels (and other sources of disturbance) to be investigated at a relatively large geographical scale (§ 2.3.4).

- **Group composition** — data were collected to investigate potential changes in narwhal group size and composition in response to the presence of large vessels. This dataset allows for greater insight into individual narwhal groups but is restricted to a much smaller spatial scale than the RAD dataset (§ 2.3.5).
- **Behaviour** — data were collected to investigate potential changes in narwhal behaviour in response to the presence of large vessels. Data collection protocols allowed for the investigation of nearshore travel behaviour of passing narwhals, and the calculation of metrics to characterize behaviours observed over longer periods of time (§ 2.3.5). As with the group composition data, behaviour data were collected on a smaller spatial scale than RAD data.

As in 2015, all observers were encouraged to make *ad lib* observations of narwhal activity, including activity not systematically documented in the three primary types of data, with a particular focus on narwhals south of the stratified study area (SSA; see Figure 2 later). Narwhals were frequently observed in this area in previous years, though they were too far away to be included in the existing data collection protocols. In 2016, modifications were made to the *ad lib* data sheet to allow for a semi-quantitative analysis of these data.

Daily visual observations were made to cover the longest continuous stretches of time feasible (nominally 16 hours during the first four weeks, and eight hours during the last two weeks of the study) to increase our ability to document the duration of narwhal response to large vessel activity. Environmental and other anthropogenic activity data were collected to investigate, and to account for, additional sources of variability in narwhal relative abundance, distribution, and behaviour. Baseline data collected in the absence of large vessels are valuable and necessary for the investigation of narwhal response to any type of disturbance.

2 METHODS

2.1 Study Team and Training

In 2016, the study team was divided into early and late shifts so that daily observation effort would cover 16 continuous hours of daylight at the start of the field season. As in 2014 and 2015, each shift originally consisted of three marine biologists from LGL, two Inuit observers and an Inuit polar bear monitor. Baffinland selected and hired the Inuit study team members. Many of the study team members had previous experience on this project: four of the LGL biologists had 2 to 3 years of experience, two of the Inuit observers had 2 years of experience, and one Inuit polar bear monitor had one year of experience: all other team members joined the project in 2016. On 10 August 2016, the early shift decreased in size when one of the original polar bear monitors unexpectedly needed to leave Bruce Head and polar bear monitor duties were assumed by one of the existing Inuit observers. The study team was further reduced to a single shift of five team members (three LGL biologists, one observer, and one observer/polar bear monitor) on 23 August because there was no longer enough daylight to require the two shifts.

A formal data collection training session in Pond Inlet, as had been held immediately prior to departing for Bruce Head in each of 2013 to 2015, was not held in 2016 because inclement weather repeatedly delayed the travel, and ultimately changed the routing, of the LGL biologists to Nunavut. The biologists departed Toronto on the morning of 21 July 2016 and finally arrived in Nunavut (direct to Mary River) on the evening of 26 July 2016. The biologists and Inuit study team members met in Mary River on 27 July 2016 and received orientation and safety training from Mary River staff immediately prior to departing for Bruce Head. Observer handbooks, which included detailed descriptions of data collection protocols, were provided to all study team members after arrival at Bruce Head. Data collection protocols were briefly described following an in-camp orientation and safety training session, and hands-on training occurred during the initial visit to the observation platform with the entire 12-person study team. Hands-on training continued as the biologists mentored the Inuit study team members during the initial days of data collection.

2.2 Study Area(s)

Milne Inlet is a narrow fjord in Nunavut's Qikiqtaaluk Region. Its entrance is between Ragged Island and Athole Point, at the confluence of Navy Board Inlet and Eclipse Sound. It extends in a south-southwesterly direction for ~65 km to its head, where Baffinland's port site is located on a fjord-head delta.

Bruce Head is a high rocky peninsula that extends from the western shore of Milne Inlet ~40 km inland of the entrance. There are two islands in Milne Inlet close to Bruce Head: Stephens Island to the north and Poirier Island to the east. Koluktoo Bay extends westward ~16 km along the southern shore of Bruce Head Peninsula. The head of Milne Inlet, south of the entrance to Koluktoo Bay, is identified on some maps as Assomption Harbour (Figure 1).

The portion of Milne Inlet surrounding Bruce Head is ~6 km wide on average, generally characterized by waters 100–360 m deep, and surrounded by steep headlands. Nearshore waters along Bruce Head drop off steeply, reaching depths >100 m within 200 m of shore. The eastern side of the inlet does not drop off as steeply, and in many places the water depth is <100 m at a distance of 1 km from shore. The deepwater channel used by transiting ships runs along the centre of the inlet, passes between Bruce Head and Poirier Island, and then between Stephens Island and the western shore of the inlet (see Appendix A for maps of specific ship tracks during this study). This portion of the deepwater channel is ~200–360 m deep where it passes Bruce Head, and becomes progressively shallower to the south towards Assomption Harbour. The maximum tidal range at Bruce Head is ~2.1 m, according to the WebTide Tidal Prediction Model (v0.7.1) (http://www.bio.gc.ca/science/research-recherche/ocean/webtide/index-eng.php).

Three study areas have been defined for this project. The three areas overlap in the waters of Milne Inlet adjacent to Bruce Head, but differ in size and extent of area included. A different study area was defined for each of the three narwhal data collection protocols (§ 2.3.4–2.3.5).

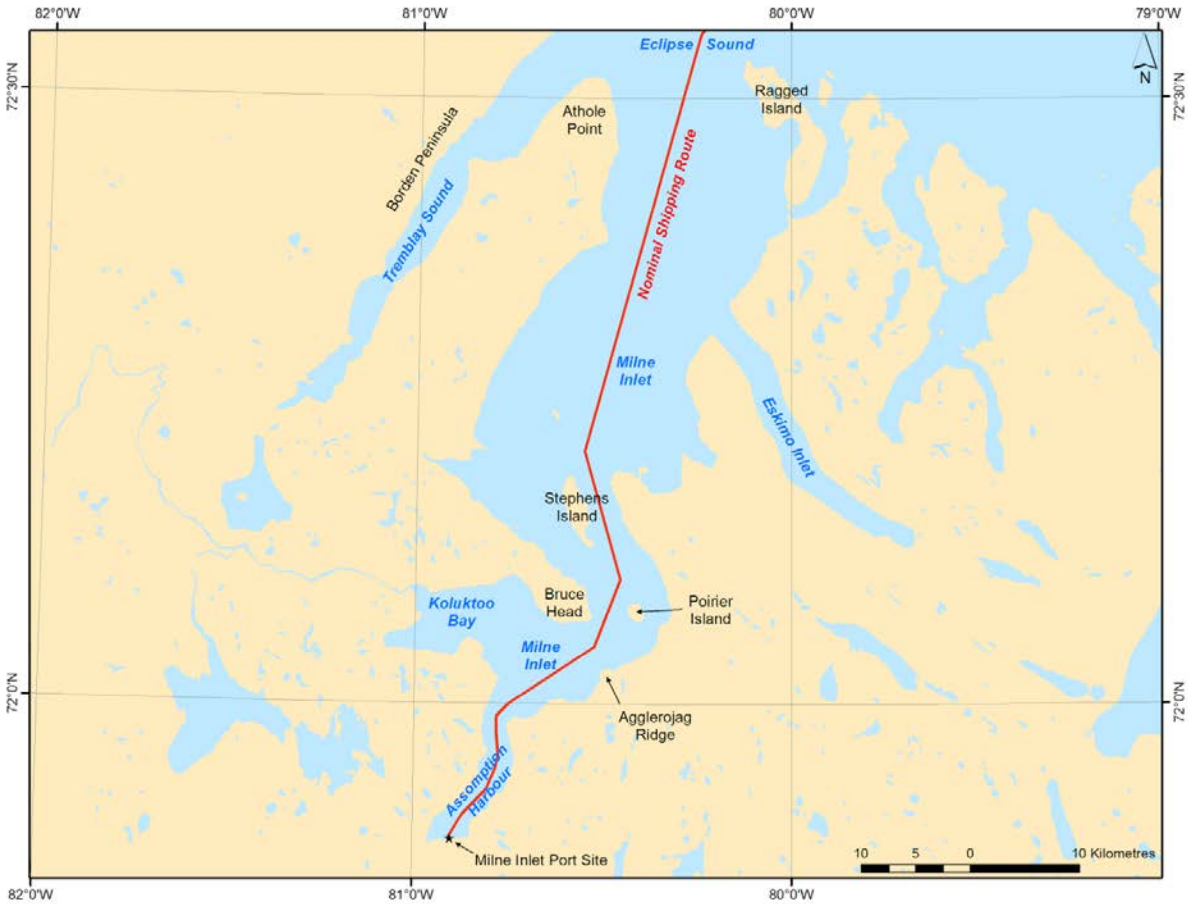


FIGURE 1. Map of the area for shore-based narwhal study at Bruce Head, showing place names mentioned in the text and nominal shipping route to Milne Port.

2.2.1 Stratified Study Area (SSA)

The SSA was used for the collection of RAD data. The SSA covers a total observed area of 82.5 km^2, and was divided into 26 substrata (Figure 2). Natural landmarks on the opposite shore of the inlet were used to define the limits of each stratum, and boundary lines between strata were visually approximated running from the east shore to the observation site on Bruce Head. The nine strata were not equal in size because the available natural landmarks were not equally spaced (Table 1). The boundaries for the substrata were visually estimated in the field. The purpose of establishing these substrata was to facilitate the collection of RAD data, and enabled narwhals to be spatially referenced (§ 2.3.4). The same substrata boundaries have been used since 2014.

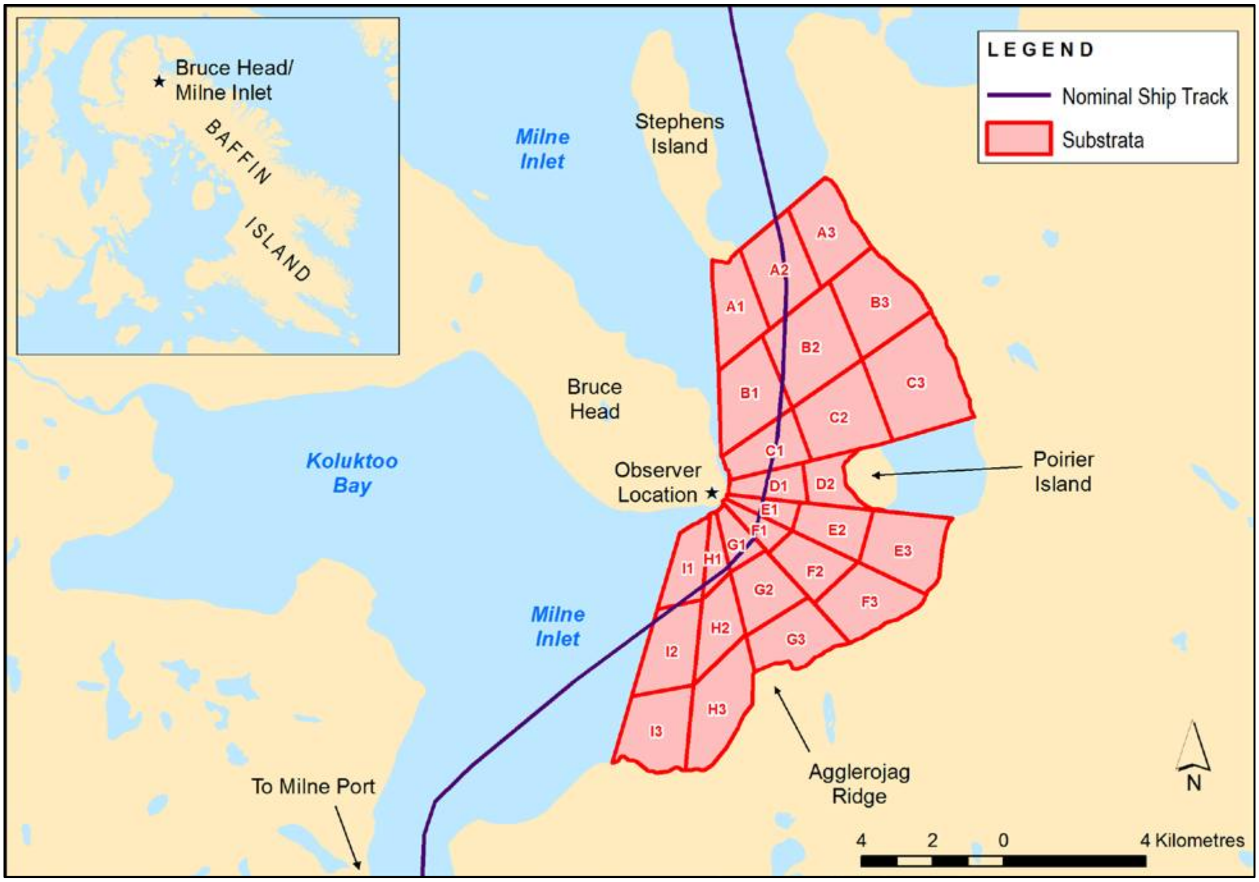


FIGURE 2. The stratified study area (SSA) for shore-based observations of narwhal relative abundance and distribution at Bruce Head, 2014 to 2016.

TABLE 1. Size (km^2) and approximate location (distance from the observation platform) of geographic strata used during the shore-based narwhal study at Bruce Head, 2014 to 2016.

Stratum	Area (km^2)	Distance from Observation Location (km)		
		Min	Max	Centroid
A	11.15	3.42	9.38	6.55
B	14.22	1.03	8.19	5.03
C	14.05	0.59	7.96	4.79
D	3.45	0.41	4.98	2.63
E	7.46	0.41	6.77	4.14
F	7.33	0.38	6.64	3.99
G	7.41	0.44	5.72	3.44
H	7.82	0.55	7.84	4.48
I	9.66	0.60	8.09	4.71
Total	82.54	-	-	-

2.2.2 Behavioural Study Area (BSA)

Data on group composition and behaviour were collected from narwhals in the behavioural study area (BSA). The BSA covered portions of strata E and F that were within ~1 km of the western shore of the inlet and immediately in front of the observation site (Figure 3).

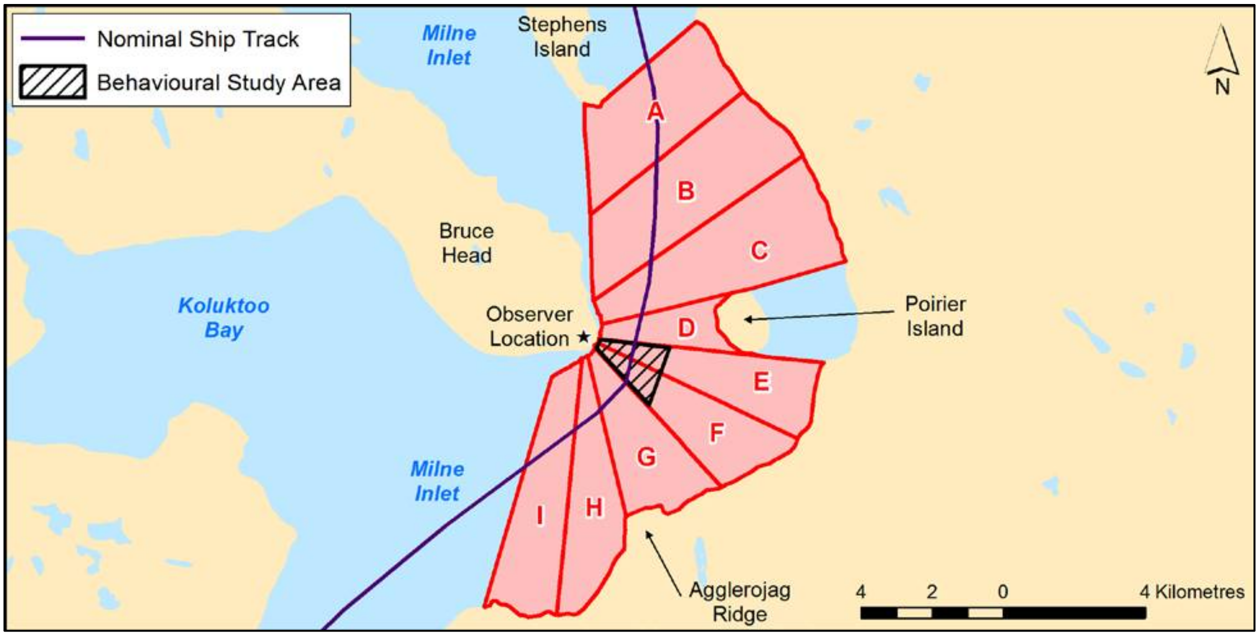


FIGURE 3. Approximate boundaries of the behavioural study area (BSA) for the shore-based narwhal study at Bruce Head, 2014 to 2016.

2.2.3 Observation Site

All observations were made from a shore-based site on Bruce Head (N 72° 4′ 17.76″, W 80° 32′ 35.52″) at an elevation of ~215 m above mean sea level. The observation site afforded views of Milne Inlet from the south end of Stephens Island in the north, to the embayment south of Agglerojaq Ridge in the south (see Figure 2). A wooden observation platform built on the cliff edge overlooking Milne Inlet had waist-high walls to prevent observers from falling off the platform and a partial roof that offered some protection from the elements. The platform was anchored to the rock with steel bolts. A plywood "survival" shack immediately behind the observation platform (Figure 4) provided space for gear storage and was occasionally used for shelter by the study team during observation periods with inclement weather. Observations were made by observers stationed either on the platform or at specified locations adjacent to the platform (§ 2.3.4–2.3.5; two protocols are described in 2.3.5)

2.2.4 Campsite

Camp was mostly set up prior to the arrival of the study team at Bruce Head on 27 July 2016, and had some improvements and modifications from 2015. There was a kitchen tent and five sleeping tents; all were insulated prospector-style tents on plywood platforms. Running water was made available at the kitchen tent via a gravity-fed system, i.e., water pumped into a cistern located on the small hill between camp and the nearby lake (Figure 5), and a door was put on the plywood shower stall. Baffinland hired a camp manager and assistant camp manager to run the camp. Resupply was via helicopter from the Milne Inlet port site (25 km away) and the Mary River mine site (94 km away).

FIGURE 4. Observation platform on Bruce Head, Baffin Island, 2016 (Poirier Island in the background).

FIGURE 5. Campsite on Bruce Head, Baffin Island, 2016 (Stephens Island in the background).

The campsite was 366 m above sea level and located about 1 km northwest of the observation site (Figure 6). On average, it took each study team about 30 minutes to hike the rough terrain from the camp to the observation site.

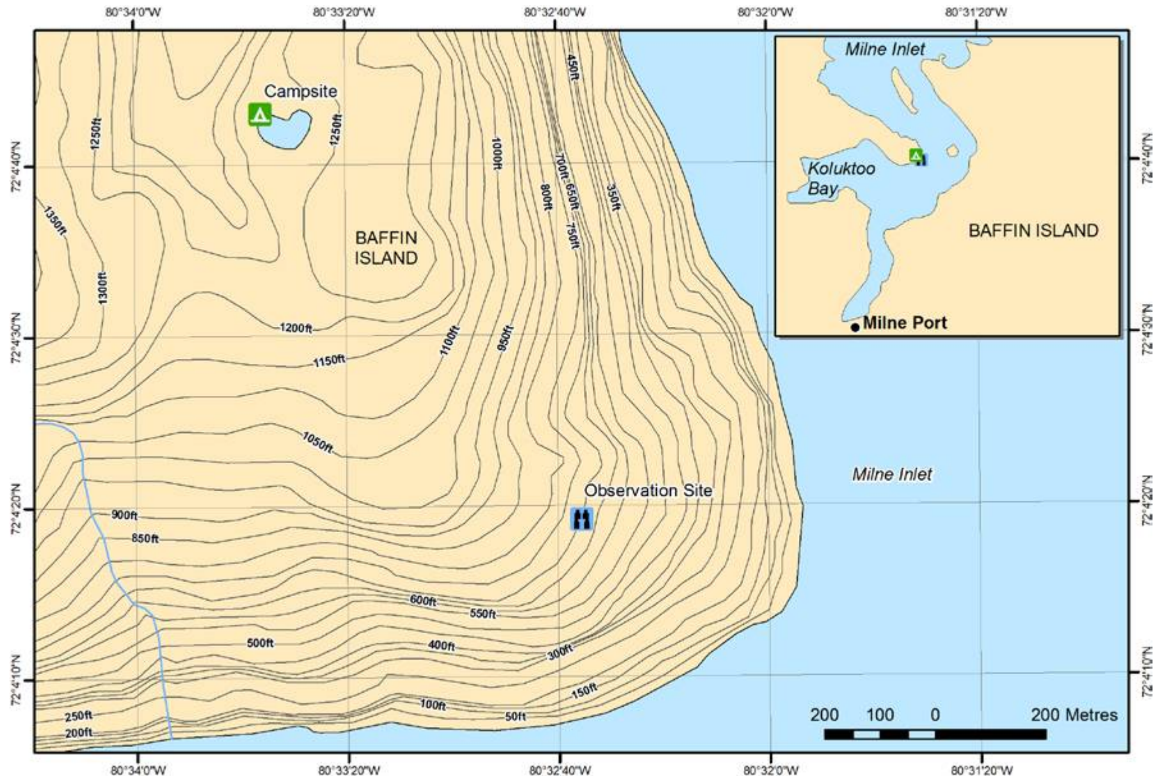


FIGURE 6. Locations of campsite and observation site on Bruce Head, Baffin Island.

2.3 Data Collection

In 2016, data were collected from 30 July to 30 August. Three primary types of data were collected from the Bruce Head observation site: (1) relative abundance and distribution (RAD), (2) group composition, and (3) behaviour. *Ad lib* observations of narwhal activity, with a particular focus on narwhals south of the SSA or in the presence of anthropogenic activity, were also collected. Additional data were collected on environmental conditions, vessel passages and other anthropogenic activities, and marine mammals other than narwhals. Different types of equipment and data collection protocols were used to collect each of the types of data; these are detailed below.

In order to make daily observations over 16 continuous hours of daylight during the first four weeks of the field season, the study team was divided into early and late shifts. The early shift made observations from 06:00 to 14:00 and the late shift made observations from 14:00 to 22:00. All times are Eastern Daylight Times (GMT-4 hr). Scheduled shifts were occasionally extended in order to collect data during large vessel transits. On 23 August, the study team was decreased in size because only a single shift was needed to cover the diminishing number of daylight hours suitable for observation during the latter part of the field season. Weather permitting, observations were made every day during the field season.

During each shift, the observers split into two small teams. A team of two observers was responsible for collecting and recording RAD data. A team of three observers was responsible for collecting and recording data on narwhal group composition and behaviour, environmental conditions, anthropogenic activity, and other marine mammals. As much as possible, observers rotated through the various team roles from day to day, so that everyone had the opportunity to participate in the collection and recording of the different types of data.

All field data, except for theodolite fixes (§ 2.3.5) and measurements made by the weather station (§ 2.3.2), were recorded on customized paper datasheets. At the end of each observation shift, datasheets were checked for completeness and accuracy and photographed to create a digital backup; and data logger files and photos were downloaded onto the project laptop computer back at camp. Data from hardcopy datasheets were entered into Microsoft® Excel® spreadsheets and were later reviewed for completeness and accuracy. All files were backed up onto hard drives on a daily basis while in the field.

2.3.1 Observation Equipment

Several types of equipment were used to collect data on narwhals and vessels in the study area:

- "Big Eye" binoculars (Fujinon 25 × 150 MT-SX) – Big Eye binoculars are large format instruments designed for clear, long-distance viewing (see Figure 9 later). The Big Eyes were used to determine the group composition (e.g., age, sex) and behaviour of narwhals. The Big Eyes were also used to observe vessels and other marine mammals in the study area.
- Theodolite (Sokkia CX-105 Total Station (electronic theodolite), with telescope magnification of 30 ×) – An electronic theodolite was used to take location fixes on narwhals. A fix consisted of sighting the target through the theodolite telescope and storing (using the data logger) the horizontal and vertical angles measured by the theodolite while the telescope was pointed at the target. During each observation period, the theodolite was pointed at the horizontal "north" reference point to set the origin prior to taking fixes. The theodolite was also used to take fixes on vessels transiting through the study area and on other marine mammals. The use of a theodolite to monitor the location and movement patterns of cetaceans is well-established (reviewed by Samuels and Tyack 2000), and has been effective for monitoring cetacean responses to human activities in various coastal environments, e.g., for gray whales (*Eschrichtius robustus*, Gailey et al. 2007), and killer whales (Williams et al. 2009).
- Data logger (Mesa Rugged Notepad from Juniper Systems, MAGNET Field data collection software) – The data logger was connected to the theodolite and enabled observers to collect fixes on marine mammals and vessels quickly and accurately.
- Binoculars (Nikon Monarch 7: 10 × 42) – Binoculars were used primarily during RAD counts, but were also used to supplement the use of the Big Eyes in determining narwhal group composition and behaviour.
- Digital single lens reflex (DSLR) camera (Nikon D610 with AF-S Nikkor 80-400 mm f/4.5-5.6G ED VR lens) – The DSLR was used to photograph narwhals so that group composition could be verified.
- Global Positioning System (GPS) unit (Garmin GPSMap76Cx) – The GPS unit was used to determine the geographic locations of the theodolite and reference points used to convert theodolite fixes into latitude and longitude coordinates.

2.3.2 Environmental Conditions

Environmental condition data were recorded for the SSA and the BSA during each observation shift. Environmental conditions were recorded every hour and whenever conditions changed. The following data were collected for the SSA: ice cover (%), precipitation type (rain, fog, snow, or none), cloud cover (%), glare (presence/absence of light or severe glare for each stratum), and sightability (subjective judgement of overall viewing conditions classified as being excellent, good, moderately impaired, severely impaired, or impossible). The following data were collected for the BSA: Beaufort Scale, glare (severe, light, or none), and sightability. A subset of environmental data (Beaufort Scale, glare, and sightability) was recorded for each substratum during each RAD count.

In 2016, a weather station was mounted to the roof of the observation platform as was done in 2015 (Figure 7). It consisted of a temperature probe (Campbell Scientific Model 109) protected by a radiation shield plus a wind monitor (RM Young Model 05103L). Both instruments were connected to a data logger (Campbell Scientific Model CR200X) programmed to record measurements at five minute intervals throughout the field season. The data logger was programmed using PC200W and Short Cut software (available at http://www.campbellsci.ca/datalogger-software). It was stored inside the survival shack behind the observation platform, and data were backed up in the field.

FIGURE 7. The weather station mounted to the observation platform at Bruce Head in 2015 and 2016.

Tide elevation estimates for Bruce Head were obtained using the WebTide Tidal Prediction Model (v0.7.1; § 2.2). These estimates were needed to convert theodolite fixes to geographic locations because the height of the theodolite above sea level must be accurately determined for each fix to estimate distance accurately (Gailey and Ortega-Ortiz 2002). Tide elevation values were also included as a categorical variable in the analysis of RAD data.

2.3.3 Vessel Passages and Other Anthropogenic Activities

All anthropogenic activity in the SSA was recorded during each observation period. Activities were classified as follows: large vessel (>100 m in length), medium vessel (50–100 m), small vessel (<50 m), fixed-wing aircraft, helicopter, and hunting. When feasible, multiple theodolite fixes were taken for individual vessels to track their movements in the study area. Additional notes were made to record the general locations of all anthropogenic activity, identifying characteristics of vessels and aircraft, and target species and duration of hunting activity.

Alerts about large vessels transiting through the study area were received from both Baffinland and LGL personnel; Baffinland personnel relayed estimated arrival and departure information from vessel charter companies, and LGL personnel based their alerts on commercially available ship location data (§ 2.3.3.1). Alerts were received a few hours to many days in advance of large vessel transits, and information was primarily used during the latter portion of the field season to optimize observation effort around large vessel transits when there was a single observation shift per day.

2.3.3.1 Vessel Track Logs

Vessel track logs were compiled from three sources and merged into a single dataset. The three sources consisted of the following:

1. Automatic Identification System (AIS) data collected via low-altitude satellites operated by a commercial data provider (exactEarth Ltd., Cambridge, ON). AIS data are broadcast by vessels equipped with appropriate transponders, which are mandatory for all vessels >300 gross tonnage (GT) engaged in international voyages, cargo ships >500 GT, and all passenger ships irrespective of size (IMO 2016). Many smaller vessels that frequent commercial shipping lanes also use AIS transponders to inform other vessels of their presence. Some vessels (e.g., sailboats, Navy, Coast Guard) turn their AIS transponders off periodically to evade detection by AIS receivers or to save power. Vessels are identified using some combination of: vessel name, call sign, Maritime Mobile Service Identity (MMSI) number, and International Maritime Organization (IMO) number. Data were downloaded daily using exactAIS Viewer software; data were downloaded for all vessels along and adjacent to Baffinland's northern shipping route.
2. AIS data collected via shore-based receiver station at the campsite. A long-range, high-sensitivity AIS receiver (ShineMicro, Inc., Port Ludlow, WA) was connected to a low noise amplifier (LNA) and a very high frequency (VHF) antenna. The LNA and VHF antenna were affixed to a wooden mast attached to the kitchen tent at an elevation of ~366 m above sea level (Figure 8). The line-of-sight range for the antenna was ~100 km, and some vessel locations were received from as far north as the southern end of Navy Board Inlet, and as far south as Milne port. AIS signals were not received when vessels went behind hills, did not have an AIS, or elected not to broadcast their AIS locations. A computer attached to the AIS receiver (located inside the kitchen tent) logged all AIS data received 24 hours a day during the field program. Vessel tracks were recorded by the shore-based AIS from 30 July to 3 September 2016. The AIS antenna station was dismantled on 3 September 2016.
3. Theodolite fixes taken by the study team.

FIGURE 8. Antenna for the Automatic Identification System (AIS) was mounted on a wooden mast attached to the kitchen tent at the Bruce Head camp.

The merged dataset contained some errors (e.g., vessels crossing land, unbelievable vessel speeds or changes in direction) which were corrected prior to using these data for analysis. These corrections are described in Appendix B, and were made for all large vessel transits from 2014 to 2016.

2.3.4 Relative Abundance and Distribution of Narwhals

RAD data were collected on narwhals in the SSA from two positions at the observation site. Position #1 afforded an optimal view of strata A to F, and position #2 afforded an optimal view of strata G to I (see Figure 2). The two positions were ~15 m apart. RAD data were collected by a team of two observers employing survey and scan sampling protocols (Mann 1999). Mann (1999) describes behavioural data collection in terms of follow protocols and sampling method. Survey refers to encountering groups or individual animals and briefly staying with them to assess the variables (e.g., identification, location, behaviour) of interest. Scan sampling refers to taking an instantaneous sample of the behaviour or location of an individual/group before moving to the next individual/group and doing the same. One person used 10 × 42 binoculars to survey all narwhals visible at the water's surface, and called out the data (e.g., group size) to the second person, i.e., the data recorder.

The hierarchy of sampling effort is defined as follows: a count comprises observational effort across all nine strata; a stratum-level count comprises effort across all component substrata in a single stratum; and a substratum-level count comprises effort in a single substratum only. For each nominal count, there were nine stratum-level counts and 26 substratum-level counts possible. During some counts, portions of the SSA could not be seen by observers because of extremely poor sighting conditions (i.e., fog, snow). Data were not collected for a stratum that could not be observed in its entirety.

Data were collected in each stratum consecutively, and a minimum of three minutes was spent surveying each stratum during each count. This ensured that search effort was consistent across strata. Group size, direction of travel, and substratum were recorded for each sighting. A group was defined as all narwhals within one adult body length of each other (Kingsley et al. 1994; Asselin et al. 2012). During each count, observers also recorded environmental conditions within each substratum (e.g., A1, A2, etc.) and the type and location of any anthropogenic activity that occurred within the SSA.

Counts were made at the start of each observation period for each shift; every hour, on the hour, during the observation period; just prior to a large vessel entering the SSA at either the northern or southern edge ("Pre" count); when a large vessel was immediately in front of observation site, roughly in the centre of the SSA ("Centre" count); and just after a large vessel exited the SSA after transiting through all nine strata ("Post" count). Counts usually began in the stratum closest to the large vessel's point of entry into the SSA (i.e., when a vessel entered the SSA from the south end of Milne Inlet, stratum I was counted first). When narwhals were present in the SSA, strata were observed in the order opposite in direction to that of the majority of narwhal travel (i.e., when the majority of the narwhals were travelling to the south, stratum I was counted first) in order to avoid double-counting narwhals.

2.3.5 Narwhal Group Composition and Behaviour

Data on group composition and behaviour were collected on narwhals that swam through the BSA (see Figure 3) and passed within ~1000 m of shore. Observers were stationed on the wooden platform at the observation site. The wooden platform was oriented to face the BSA, and the Big Eye binoculars were mounted on a stand at the front of on the wooden platform which afforded a good view of the BSA (Figure 9).

2.3.5.1 Group Composition and Nearshore Travel Behaviour of Passing Narwhals

Data on group composition and nearshore travel behaviour of passing narwhals were collected by a team of three observers employing survey and scan sampling protocols (Mann 1999). One person observed the narwhals through the Big Eye binoculars and called out all information on group composition, and the second person recorded the data. The third person assisted either by using 10 × 42 binoculars to observe passing narwhals, or by photographing passing narwhals when light and sea surface conditions were favourable. Photographs were examined later to verify or augment data recorded in the field.

FIGURE 9. Big Eye binoculars were used to determine narwhal group composition.

Data on group composition and nearshore travel behaviour of all passing narwhals were collected only on narwhals within ~1000 m of shore to ensure that observed narwhals would be close enough that the following could be determined for each group:

1. Time of passage: On occasions when multiple groups of narwhals passed by too quickly for individual group passage times to be recorded, sightings were grouped into five-minute bins.
2. Group size (including group size 1).
3. Number of narwhals with tusks: present, absent, and unknown (e.g., because head not visible). Narwhals were categorized as having tusks present or absent because that was determined to be a more reliable means of classification than assigning sex in the field. The majority of tusked narwhals are males, whereas female narwhals typically do not have tusks (Silverman 1979; Hay and Mansfield 1989; Roberge and Dunn 1990). Though some experienced Inuit study team members were confident in their identification of narwhals as being male or female regardless of whether or not a tusk was present, the majority of study team members did not possess the experience needed to determine sex accurately.
4. Number of narwhals in the age categories adult, juvenile, yearling, and calf. Age categories were assigned based on size and colour: large narwhals that were mostly white or with black and white spotting on their backs were categorized as adults; juvenile narwhals were slightly smaller than adults (~85% as long), generally dark grey in colour, and showed no or light spotting on their backs; yearlings were light to dark grey, and approximately two thirds the length of accompanying females. Calves were approximately half the length of the adult females, whitish

to slate grey in colour, and were usually close to a female in the “baby” or “echelon” position (Mansfield et al. 1975; Hay 1984; Koski and Davis 1994; Mann and Smuts 1999).

5. Spread (tight: narwhals ≤ 1 body width apart, loose: narwhals > 1 body width apart).
6. Formation (linear, parallel, circular, non-directional line (i.e., adjacent animals oriented in different directions), no formation; see Table 2).
7. Direction of travel (compass directions: N, S, E, W).
8. Speed of travel (slow, medium, fast).
9. Distance away from shore (inner: within ~300 m of shore, outer: > 300 m from shore).

To maximize the amount of data on group composition and nearshore travel behaviour collected, survey periods covered as much of each observation shift as possible (Appendix C). However, these data were not collected when groups of narwhals swam back and forth in front of the observation platform (to avoid counting the same groups more than once), nor when narwhals swam past Bruce Head so quickly that observers were unable to determine group size or composition.

2.3.5.2 Narwhal Group Focal Follows

Narwhal group focal follow data were collected by a team of three observers employing modified group-follow and predominant group activity sampling protocols (Mann 1999). Group-follow is defined as monitoring a group of animals for >30 min; predominant group-activity is defined based on the assessment of the activity engaged in by >50 % of group (Mann 1999). One person tracked the focal groups (i.e., individual or groups of narwhals) using the theodolite. The theodolite was set up on a tripod immediately adjacent to the Big Eyes on the observation platform (Figure 10). Fixes were taken on the focal groups approximately every 10 seconds, regardless of whether or not travel direction or behaviour changed. The second person observed the focal groups through the Big Eye binoculars and called out information on group composition and behaviour. The third person recorded and saved all theodolite fixes using the data logger, and recorded all data on group composition and behaviour. Focal groups were photographed opportunistically when an additional study team member was available to assist: photos were taken when members of the two-person team were not actively collecting RAD data. Focal groups were photographed so that group composition could later be verified.

To avoid biasing the selection of focal groups towards large and/or “interesting” groups, the first single or group of narwhals to enter the BSA after the initiation of a follow period was selected as the focal group. A follow period was defined as the duration of time over which a single focal group was followed, and was initiated either at the start of the behavioural observation period, or ~2 minutes after the termination of the previous follow period. Focal groups were followed while they were in the BSA. Follows were terminated when focal groups left the BSA, focal groups could no longer be followed with confidence (e.g., because the focal group was swimming and interacting with other groups of narwhals in the BSA), or focal groups dove and did not resurface for five minutes. A brief 2–3 minute “rest” was taken upon the termination of each follow to allow the study team time to review the datasheets and ensure that they were completely filled out. A new follow period was initiated immediately after this brief rest period. If a focal group split into smaller subgroups during a follow, the time of the split was recorded, and the largest subgroup was followed. If the subgroups were of equal size, the group closest to shore was followed. Only a single focal group was followed at any one time.

TABLE 2. Groups of narwhals were categorized as swimming in one of five formations described by Funk et al. (2005). The bottom row depicts orientation of individuals swimming in groups of 5.

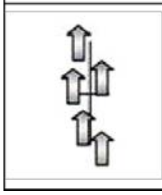
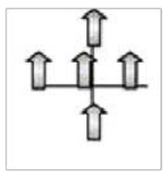
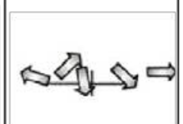
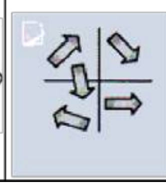
Linear	Parallel	Circular	Non-directional Line	No Formation
Directional Line	Directional Line	Directional	Non-directional	Non-directional
Stretched Longitudinally	Stretched Laterally	Lateral = Longitudinal	linear distribution	non-linear
Head to Tail > Side to Side	Side to Side > Head to Tail	Head to Tail = Side to Side	Head to Tail Versus Side to Side Unclear	Equal spread with no clear orientation
				

FIGURE 10. The theodolite was used to take location fixes on narwhals, other marine mammals, and vessels in the study area.

On occasion, focal groups were selected with the intention of gathering data to characterize a particular behaviour of interest (e.g., fish chases). These follows were selected in a biased manner, and were thus excluded from some analyses.

The following data were recorded for each fix:

1. Local time: each fix was automatically time stamped by the theodolite.
2. Location: horizontal (azimuth) and vertical (declination) angles were measured by the theodolite and were used to triangulate geographic locations of focal groups.
3. Group size (including group size 1).
4. Number of narwhals with tusks: present, absent, and unknown.
5. Number of narwhals in the age categories: adult, juvenile, yearling, calf, and unknown.
6. Group spread (tight or loose).
7. Group formation (linear, parallel, circular, non-directional line, no formation).
8. Primary behaviour:
    i. travelling (directed movement),
    ii. milling (non-directed movement),
    iii. resting with back exposed, and
    iv. resting submerged.
9. Secondary behaviour:
    i. side swimming,
    ii. back swimming,
    iii. diving,
    iv. tusking,
    v. tail slap,
    vi. fish chase,
    vii. fish catch,
    viii. porpoising,
    ix. rolling,
    x. rubbing (against another narwhal),
    xi. petting (touching another narwhal with front flippers),
    xii. bubble rings,
    xiii. nursing, and
    xiv. mounting.

Primary and secondary behaviours were used to describe the behaviour of the entire group; when all group members were not engaged in the same behaviour, we recorded the behaviour exhibited by the majority of group members. Primary behaviours described broad and mutually exclusive types of behaviour in which all narwhals could be classified as engaging. Secondary behaviours described more specific activities/actions (e.g., rolling) in which individual narwhals may or may not have also engaged. The lists of primary and secondary behaviours were based on descriptions of the behaviour of free-ranging narwhals (Cosens and Dueck 1988; Finley et al. 1990a; Dietz et al. 2007), ethograms for other cetaceans (Smith, T.G. et al. 1994; Dolphin Communication Project 2011), and behaviours observed at Bruce Head during the pilot study in 2013 (Thomas et al. 2014). Behavioural terminology that implied function was purposefully avoided, following the example of Smith et al. (1994).

2.3.6 Other Marine Mammals

The times and locations of other marine mammal sightings in the study area were recorded, and location fixes were taken with the theodolite when possible. Marine mammals were identified to species when possible, and behaviour was noted. Because narwhal sightings were given priority, it was not possible to document the presence of all other marine mammals, particularly seals, in the SSA.

2.4 Data Analysis

Investigating the effects of shipping traffic on narwhal abundance, distribution, and behaviour is the primary objective of this study, in particular, the effects of ore carrier traffic. Data from 2014 to 2016 were combined to the extent possible in order to maximize the size of the dataset. When sample sizes for a particular analysis allowed, the effects of ore carrier traffic alone were examined (see § 2.4.1). When sample sizes were small, the effects of all large vessels in combination, i.e., ore carriers combined with sealift and ecotourism vessels, were examined (§ 2.4.2 and 2.4.3). The size of the combined 2014–2016 dataset allowed hunting to be taken into account in the analyses in a more comprehensive manner than previously possible. More specifically, the RAD analysis included a continuous variable to account for hunting activity (§ 2.4.1), and the effects of hunting on narwhal group composition and nearshore travel behaviour were examined separately from the effects of vessel presence (§ 2.4.2).

2.4.1 Relative Abundance and Distribution of Narwhals

Changes in relative abundance of narwhals with respect to various categorical variables of interest (e.g., large vessel presence, geographic stratum, time of day, tide flow) were analyzed using the statistical model described below. These analyses provide information concerning the veracity of the following null hypotheses:

- narwhal abundance does not change during various ore carrier presence scenarios,
- narwhal abundance is constant across geographic strata,
- narwhal abundance does not change with time of day,
- narwhal abundance does not change with tide flow,
- narwhal abundance does not change when hunting occurs.

For null hypotheses that proved to be inconsistent with the data, the nature of the relationship between narwhal abundance and the relevant factor (ore carrier presence, stratum, time, etc.) was characterized.

2.4.1.1 Modelling Narwhal Abundance

A modelling approach was used to test the general hypothesis that, during 2014–2016, narwhal abundance in the study area did not change in the presence of ore carriers. The statistical model and output presented in § 3.3.1 was based on the 2014–2016 combined data. These new results are considered more definitive than the related results for 2014–2015 data reported by Smith et al. (2015, 2016) due to increased sample size in general, and occurrence of more ore carrier transits under more varied conditions in 2016. The 2013 pilot data were not included in this analysis. During 2013, counts were made at the stratum-level, but not the substratum-level. Likewise, in 2013 there were no “Centre” counts during individual vessel transits (Thomas et al. 2014).

Narwhal count data were modelled using a generalized linear mixed modelling (GLMM) approach, with a discrete probability distribution, as described below under “Modelling Approach and Specification”. In this analysis, narwhal abundance was the response variable; specifically, total numbers of narwhals observed in each substratum were used as the units of observation. Various “independent” (i.e., predictor) variables measured for the substratum and time in question were included in the analysis to allow for and to characterize their effects, if any, on narwhal abundance. These predictor variables included presence of ore carriers and other variables suspected to be related to the number of narwhals seen.

2.4.1.2 Independent (Predictor) Variables

The primary variable of interest as a potential predictor of narwhal number was disturbance by ore carrier presence. Hourly counts were made during the absence of ore carriers; three sets of counts were made during ore carrier presence: (1) "pre-counts" = just prior to an ore carrier arriving in the SSA at either the northern or southern edge; (2) "centre-counts" = when an ore carrier was immediately in front of observation site, roughly in the centre of the SSA; (3) "post-counts" = just after an ore carrier left the SSA after transiting through all nine strata. The effect of ore carrier presence was potentially different depending on whether the vessel was entering or exiting Milne Inlet and whether the count was made as the vessel was approaching the centre of each stratum or as it was departing. Thus, our characterization of ore carrier presence was labeled "ore carrier scenario" and was defined by direction of transit and vessel location relative to a given substratum. Data were categorized as follows: (1) no ore carrier present, (2) ore carrier entering Milne Inlet and moving toward (approaching) the closest point of approach (CPA) for a substratum, (3) ore carrier entering the Inlet and moving away from (departing) a substratum CPA, (4) ore carrier exiting the Inlet and approaching substratum CPA, and (5) ore carrier exiting Inlet and departing substratum CPA.

One of the greatest challenges in any field study, including the Bruce Head study, is to account for confounding environmental influences on the response variable of interest. Extraneous variables are defined as those forces that are partially confounded with the levels of the factor of interest. For example, sightability would be an extraneous confounding variable if it happened to be poor on days with ore carrier activity, but good in the absence of this disturbance. An improper experimental design and/or model specification could falsely attribute changes in narwhal numbers associated with such a variable to impacts from vessel transits.

Nuisance variables refer to those that are not confounding, but merely add variability to responses, and therefore lower the power to detect effects from the factor of interest. Accounting for these variables was challenging given the inherent natural variability in narwhal behaviour and movements within Milne Inlet.

In addition to "ore carrier scenario", other variables that were likely to have affected the counts of narwhals and that we could measure included:

- Beaufort Scale (levels = 0–6)
- glare (none, light, moderate, and severe)
- sightability (excellent, good, and poor)
- tide (ebb, low slack, flood, and high slack)
- spatial stratum (A-I)
- substratum (i.e., each stratum divided into thirds: 1, 2, and 3)
- presence of small vessel
- Julian date
- hour of the day
- time since shooting occurred in the SSA during a count.

Some special considerations applied to certain of these predictor variables. "Sightability" was largely affected by and incorporated Beaufort Scale and glare; as such, only sightability was used and Beaufort Scale and glare were excluded from the final model. "Tide" elevation estimates were available at 5 min intervals, and the difference in elevation between consecutive intervals was calculated. The tide levels, low slack and high slack, were categorized as such if this difference was ≤0.01 m on either side of the lowest/highest elevation level for a given cycle. This process assigned about 28% of the counts into low or high slack categories and 72% of the data into ebb or flood tide categories. The "time since shooting" variable ranged from 0 to 11.9 hours (5,743 records), and there were an additional 13,701 substratum counts when hunting was not recorded to have occurred before or during counts on that day (i.e., no shot was observed in the period of continuous observation prior to that record). Recall that observation coverage was not continuous (i.e., 24 hours a day). We reasoned that the most appropriate missing value estimate for "time since shooting" for all records when that was unknown was 12.5 hrs, slightly longer than the longest record of time since shooting (i.e., 11.9 hr). This adjustment allowed "time since shooting" to be modelled as a single continuous variable, an improvement over the dummy variable approach (i.e., hunting occurred/did not occur). Finally, the effect of small vessels could not be addressed in the analysis as hunting was sometimes observed to take place from these boats; hence, this variable would have sometimes been collinear with the variable "time since shooting".

2.4.1.3 Modelling Approach and Specification

Narwhal count data were modelled using a generalized linear mixed modelling (GLMM) approach, with a discrete probability distribution. This approach involved three basic steps:

1. Constructing a model with parameters of interest to predict the counts for all observations;
2. Multiplying the predicted counts from Step (1) by the sampling effort (called an effort offset) to obtain the predicted (expected) number of individuals comparable to the observed counts; however, in the current case all experimental units were treated as though they were consistent with respect to effort (see § 2.3.4);
3. Computing the likelihood of the observed counts given the expected counts assuming some discrete distribution.

The negative binomial regression was selected, which accounted for overdispersion and used the log link function to portray the predicted counts:

$$\log_e\left(\lambda_i \cdot \omega_i\right) = \mu + x_i\beta + z_i b \tag{1}$$

where λ_i = predicted number of narwhals for the i^{th} substratum, ω_i = effort offset (assumed constant for this study), μ = overall mean, x_i = the vector of fixed effects, β their corresponding vector of coefficients, and z_i and b represent the random effects and coefficients. This two-parameter discrete distribution is commonly used for analyses of this type of data to handle overdispersion and the typically high frequency of zero counts for marine mammals (e.g., Boveng et al. 2003; Ver Hoef and Boveng 2007) and fisheries (e.g., Terceiro 2003; Minami et al. 2007; Arab et al. 2008; Shono 2008; Dunn 2009).

A generalized linear mixed model (GLMM) was used instead of a generalized linear model GLM due the former's flexibility in handling complex data structures. "Mixed" indicates that the model incorporates some predictors as "fixed" terms and some as "random" terms. Fixed terms are used mostly when the researcher is interested in how the mean response differs across only the specified levels of the factor. Random terms are used when the only interest is removing variation due to a factor and generalizing the results across all possible levels. For instance, in the GLMM used here the variable "ore carrier scenario" was modelled as a fixed term.

Non-independence of spatial strata was accounted for with a random term. Experimental units consisted of substrata 1 to 3 within the larger strata A to I, all of which were spatially adjacent. Because narwhals exhibit a non-random spatial distribution (as do most animals), numbers recorded in strata near one another in space tended to be correlated. This artifact is known as spatial autocorrelation and can cause confidence intervals to be underestimated if the covariance structure is not properly specified (Stroup 2013). To prevent this bias, the covariance structure across strata was modelled with a coefficient

ρ that estimated the average correlation among strata by substratum on a given date. The time difference between consecutive stratum counts was about 3 min (0.05 hrs), but was not always consistent. To account for varying distances (i.e., time differentials) among stratum counts, the correlation coefficient between two strata was raised to the power of the difference in times when strata were counted. The overall trend across strata was estimated, and accounted for, by the addition of stratum as a fixed effect.

Correlation across consecutive hours within each day may have been a source of temporal autocorrelation, but both processes (correlation across hours and correlation across strata within each hourly survey) could not be accounted for in the same model. Modelling spatial correlation across strata took priority because the multiple strata created replication of levels (i.e., Pre, Centre, and Post) within each ore carrier transit event. Any correlation unaccounted for across strata would have increased the probability for a Type I error with respect to the ore carrier effect. Correlation across hours had less effect, if any, on the assessment of ore carrier effects (i.e., the statistical significance of the disturbance) because transits mostly occurred on separate days or were separated by several hours on days when two transits occurred.

Categorical fixed terms included ore carrier scenario, year, stratum, tide and sightability. Hour of the day and Julian date were entered as continuous variables (covariates) and their functional form modeled as 2nd order polynomials. Time since shooting was continuous as well, but modeled as a 3rd order polynomial. Observations of ore carrier transits only occurred between the hours of 05:00 and 21:00. Fixed effects (without subscripts or parameters) used to model the number of narwhals were given as follows:

$$\begin{aligned}\text{Number of narwhals} = {} & \text{ore carrier scenario} + \text{year} + \text{stratum} + \text{tide} + \text{sightability} \\ & + \text{hour} + \text{hour}^2 + \text{Julian date} + \text{Julian date}^2 \\ & + \text{time since shooting} + \text{time since shooting}^2 + \text{time since shooting}^3\end{aligned} \quad (2)$$

This specification formed the $x_i\beta$ part of Equation (1) in the GLMM. Maximum likelihood parameters were estimated using the Laplace approximation in the GLIMMIX Procedure of the statistical software SAS 9.4 (SAS Institute, Inc. 2012). This SAS code is available from the authors upon request. Model fit was assessed using a moving sum residual plot.

2.4.1.4 Data Filters

Counts during transits of large vessels that were not ore carriers were excluded from the analysis of narwhal distribution and abundance; these vessels included sea lift and ecotourism vessels. Also, there were no RAD counts during ore carrier transits outside the 04:00–22:00 hour time window. Accordingly, counts obtained between 23:00 and 04:00 in the absence of ore carriers were not used to make undisturbed and disturbed counts more comparable. Furthermore, all counts on the following dates were excluded because multiple large vessel transits within several hours of one another on these days may have confounded data: 15 Aug 2014, 2 Aug 2016, and 29 Aug 2016.

2.4.2 Group Composition and Nearshore Travel Behaviour of Passing Narwhals

Analyses of data on group composition and nearshore travel behaviour of passing narwhals were performed in R 3.3.1 (R Core Team 2016) using RStudio v0.99.903 (RStudio Team 2016). Results were deemed significant at $\alpha = 0.05$.

Data on group composition and nearshore travel behaviour of passing narwhals collected during 2014 to 2016 were categorized by “type” of anthropogenic activity present. An observation (i.e., a single sighting) was categorized as having a type of anthropogenic activity present if that activity occurred at the time of the sighting or in the 15 minutes prior to the observation. Anthropogenic activity types were defined according to the presence or absence of vessels of all sizes (large, medium, and small) and shooting in the SSA. Large vessels were primarily ore carriers, though sealift and ecotourism vessels were included here in order to have adequate sample size for analysis. Low sample sizes for some types of anthropogenic activity (e.g., large vessel present <u>and</u> shooting) limited the analysis to four types: none, large vessel only, small vessel only, and shooting.

Group characteristics (i.e., group size, spread, formation, direction of travel, speed, and distance from shore) were described for all groups, and tested across types of anthropogenic activity. Group size was investigated using a one-way ANOVA and *post-hoc* tests on trimmed means using the WRS2 package (Mair et al. 2016) functions `tn1way()` and `lincon()`, respectively. These robust methods were used because the data did not conform to standard parametric assumptions. Categorical group characteristics (e.g., spread, formation) were investigated using Pearson's Chi-squared statistic. When the omnibus Chi-squared statistic was significant, differences among all pairs of groups were tested using the FIFER package (Fife 2014) function `chisq.post.hoc()` with p-values adjusted using the Bonferroni method. These analyses addressed variations on the hypothesis: narwhal group characteristic "x" does not change with type of anthropogenic activity. Some types of anthropogenic activity were excluded from the analysis when sample sizes were < 5.

Groups with known composition (i.e., all individuals in the group were classified by age and presence/absence of a tusk) were categorized according to group membership. Groups were initially placed into 48 categories (see Appendix J); these were combined to form six broad categories of composition:

1. No tusks (adults or juveniles without tusks), no calves or yearlings.
2. No tusks (adults or juveniles without tusks), yes calves or yearlings.
3. Mixed tusks (adults or juveniles, with and without tusks), no calves or yearlings.
4. Mixed tusks (adults or juveniles, with and without tusks), yes calves or yearlings.
5. Yes tusks (adults or juveniles with tusks), no calves or yearlings.
6. Yes tusks (adults or juveniles with tusks), yes calves or yearlings.

The presence of calves and tusked animals in groups were examined with respect to type of anthropogenic activity using Pearson's Chi-squared statistic and Bonferroni-adjusted *post-hoc* tests as described above. These analyses addressed the following null hypotheses:

- presence of calves in groups does not change with level of anthropogenic activity.
- presence of tusked narwhals in groups does not change with level of anthropogenic activity.

On a number of occasions, large numbers of narwhal groups were observed to pass quickly in front of the observation site. Though it was not possible to collect group composition data on all passing groups, observations were recorded during each of these events, and were summarized.

2.4.3 Narwhal Group Focal Follows

The first step in analyzing the narwhal group focal follow data required that theodolite fixes be converted to geographic locations (Appendix D) so that tracklines for each of the focal groups could be created. Metrics commonly used in the analysis of marine mammal trackline data (e.g., Gailey and Ortega-Ortiz 2000) were then calculated for each track of a narwhal focal group. Calculations were done in Microsoft Excel; distances between two points were calculated using the inverse Vincenty formula (Vincenty 1975) in VBA. The following metrics were calculated for each track:

1. Total number of fixes

2. Track duration (minutes)
3. Track distance (m)
4. Track speed (kt)
5. Individual leg speeds between successive fixes (kt)
6. Linearity - a measure of straightness of the trackline. Values range between 0 and 1, and values close to one indicate a straight trackline. Linearity was calculated by dividing the net distance travelled (i.e., straight-line distance between first and last fix) by the total track distance (Batschelet 1981).

Primary and secondary behaviours were summarised for all focal follows made during 2014 to 2016. Trackline metrics were compared between years (GLM with lognormal distribution for track duration and total distance and beta distribution for linearity; Tukey *post-hoc* tests). Trackline metrics were also compared for focal follows in the absence vs. presence of large vessels.

2.4.4 Ad lib observations

Ad lib observations were summarised into broad categories based on what was observed and whether or not anthropogenic activity was present.

3 RESULTS

3.1 Observation Effort and Environmental Conditions

There was a total of 301.6 hours of observation effort over 27 days at the observation site from 30 July to 30 August 2016. The observation period was shortened in 2016 on account of very poor weather. The study team arrived at Bruce Head the evening of 27 July 2016, three days later than originally scheduled because poor weather hampered travel north. They departed Bruce Head on 5 September, one day earlier than anticipated, after observation shifts were repeatedly cancelled and concern grew about demobilizing the field camp in increasingly stormy conditions. Total daily observation effort averaged 11.2 hours (range: 0.9–16.6 hours; Figure 11). Observation shifts were expected to last for eight hours, but were sometimes cut short due to inclement weather or extended to observe a large vessel transit (see Appendix E for details). Observations were not possible on 11 days during the study period because it was either not safe for the study team to hike out to the observation site, or because sighting conditions were so poor (e.g., high winds and Beaufort Scale) that the quality of observations would have been seriously compromised. The study team also spent time at the observation site at the start and end of the field season to set-up and then dismantle equipment; data were not collected on these days (Appendix E).

The study area was primarily ice-free for the duration of the 2016 observation period. Though icebergs were commonly sighted in the study area (single icebergs sighted on 15 of the 27 observation days), they were relatively small in size (Figure 12) and did not affect sighting conditions.

Observations were primarily conducted when Beaufort Scale was 1, 2, or 3 (Table 3). Though observations were occasionally conducted during periods of high Beaufort Scale (4 to 6) in an effort to collect as many data as possible during periods when large vessels were present in the study area, the majority of data were collected during good or excellent sightability conditions, across all levels of ore carrier presence.

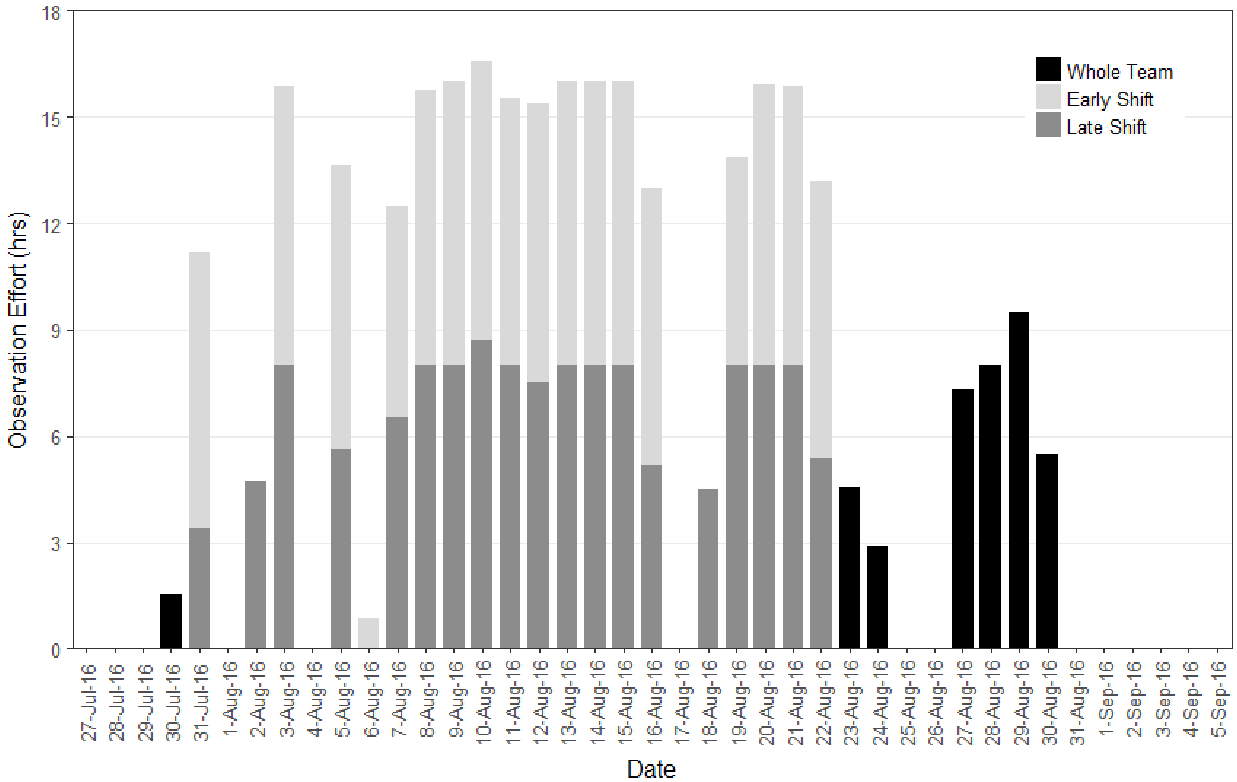


FIGURE 11. Number of hours of observation effort, by day and study team, during the shore-based study of narwhals at Bruce Head, 2016.

FIGURE 12. Icebergs were commonly present in the study area during the shore-based study of narwhals at Bruce Head from 30 July to 30 August, 2016. This photo was taken on 14 August 2016.

TABLE 3. Observation effort categorized according to Beaufort Scale in the behavioural study area (BSA) for the shore-based narwhals study at Bruce Head, 2016.

Beaufort Scale[1]	0	1	2	3	4	5	6
% of Observation Effort	2.9 %	33.0 %	28.5 %	23.7 %	7.0 %	3.9 %	1.1 %

[1] Beaufort Scale could be quite variable at any given time throughout the entire stratified study area (SSA). Conditions in the BSA are considered to be roughly equivalent to the "mean" value for the SSA.

There was very little precipitation during observation periods (primarily because observations were purposely not made during such periods)—there were occasional periods of light rain during ~1.2 % of the observation effort.

Based on the consideration of glare and other relevant environmental factors, the overall sightability in the SSA for observations was judged as excellent, good, moderately impaired, or severely impaired during 14.9 %, 58.3 %, 21.5 %, and 5.3 % of observations, respectively.

The air temperature measured at the observation site ranged from -1.8 to 16 °C over the course of the 2016 study period. The mean daily temperature remained below 3 °C from 31 August onwards (Figure 13; Appendix F).

Wind speed measured at the observation site ranged from 0 to 25.3 m/s (91.1 km/h) over the course of the 2016 study period. Daily mean wind speed was 10 m/s (36 km/h) or greater on six days; observations were made on all of these days (Figure 11), though individual observations shifts were sometimes cancelled or shortened because of poor sightability.

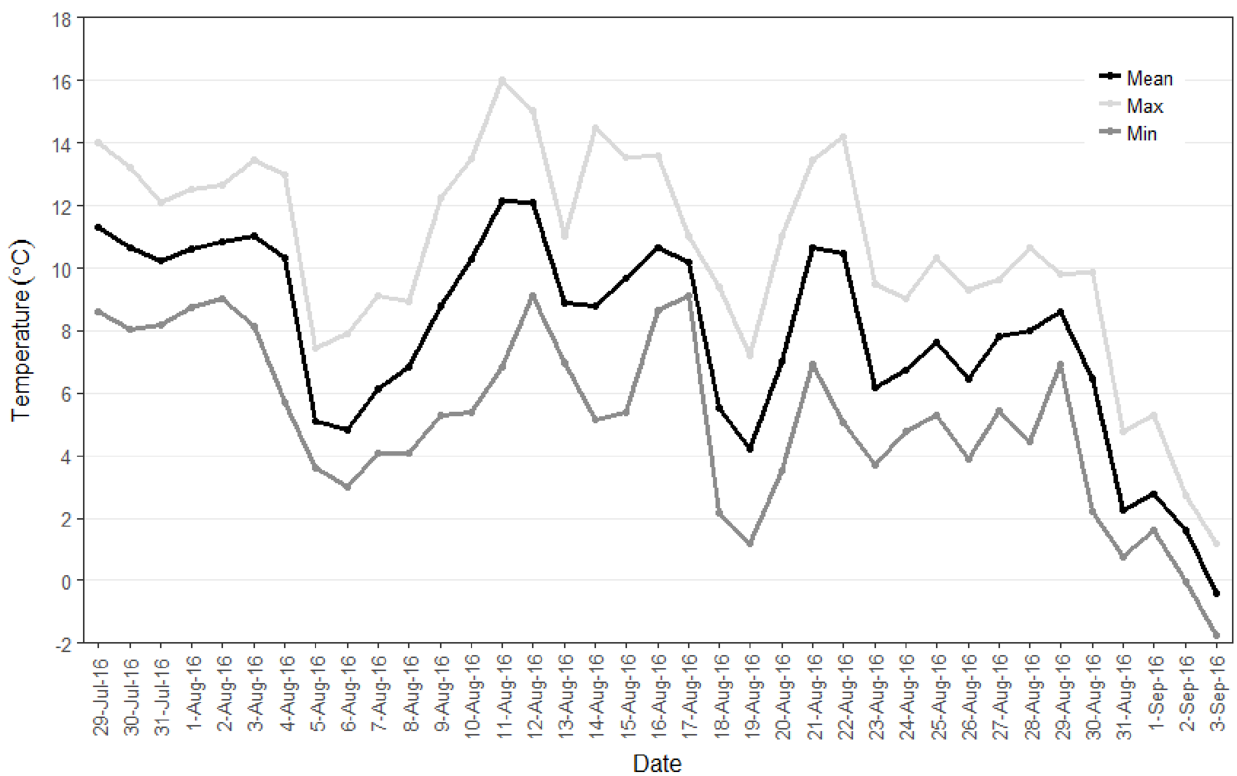


FIGURE 13. Daily air temperatures recorded at the observation platform during the shore-based study of narwhals at Bruce Head, 2016.

3.2 Vessel Passages and Other Anthropogenic Activities

The following text summarizes the observations of large vessels chartered by Baffinland as well as observations of other large vessels. Other anthropogenic activities, notably small vessel traffic, narwhal hunting, and aircraft overflights, are also summarized. It should be noted that for periods when observers were not at the observation site, data on small vessel and other anthropogenic activity are unavailable.

3.2.1 Baffinland Vessels

Eighteen ore carrier and two cargo vessel transits (i.e., 20 one-way transits) through the study area involving vessels chartered by Baffinland were observed in the SSA from 30 July to 30 August 2016 (Table 4, Figure 14). There were no observations of an additional 17 ore carrier and three cargo vessel transits, chartered by Baffinland, because these occurred during periods of poor weather, darkness, or were outside times of scheduled observation effort (Table 4). Photos and maps showing approximate tracklines of Baffinland vessels are found in Appendix A.

3.2.2 Other Large and Medium Vessels

Two additional large vessels, both operated by ecotourism operators, were observed in the study area in 2016 (Table 4; Appendix G). The MV *National Geographic Explorer* is a 112 m ice-class expedition ship operated by National Geographic Expeditions, and was observed to briefly enter the northernmost stratum (i.e., A) at approximately 09:00 on 19 August 2016. The MV *Silver Explorer* is a 107.9 m ice class luxury expedition cruise ship operated by Silversea Expeditions, and was observed travelling south and north through the study area during the afternoon of 29 August 2016.

The three types of large vessels observed in the study area may be distinguished from one another in terms of mean travel speed and trackline followed. Ore carriers traveled considerably slower than sealift and ecotourism vessels (Table 5). Ecotourism vessels were observed to take a more circuitous path through the study area in comparison to ore carriers and sealift vessels, and often spent time in Koluktoo Bay (Appendix A; Smith et al. 2015, 2016).

Two medium vessels were observed in the study area during the 2016 field season. The *Rosehearty*, a 56 m luxury sailing yacht, was observed heading south through the study area on 3 August at approximately 14:30 to 15:10; it exited the area and headed north through the study area on 4 August 2016 at approximately 14:40 to 15:10. The *Galileo G*, a 55 m luxury motor yacht, travelled south through the study area at approximately 20:30 to 21:25 on 5 August; it was then observed passing back through the study area, heading north, at approximately 09:40 to 10:20 on 6 August 2016. A third medium vessel, a sailboat, was observed in Koluktoo Bay early in the morning (before 06:00) of 9 August 2016. It was not observed, or recorded by the AIS, passing through the study area at any time during the field season.

3.2.3 Small Vessels

Small vessels were observed in the study area on 19 days (Appendix G). Small vessels were typically aluminum skiffs with 1 or 2 outboard motors, though some small vessels were voyageur canoes (also with outboard motors; see photos in Appendix A). The majority of these small motorized vessels appeared to be operated by Inuit, and many of these small vessels spent time anchored at the shoreline immediately below the observation site (Figure 14).

No small sailing vessels were observed in the SSA during the 2016 field season.

TABLE 4. Large vessel (> 100 m) presence in the stratified study area (SSA) at Bruce Head, 30 July to 4 September 2016. Rows shaded in grey indicate large vessel transits during which shore-based visual observations were made. All large vessels with the exception of the *National Geographic Explorer* and the MV *Silver Explorer* were chartered by Baffinland. Also included is information on hunting activity that was recorded during observations.

Date/ Time[1] in the SSA (2016)	Vessel Name (type)	Travel Direction	Vessel Speed[1] (kt)	Notes
30 July, 13:06–13:49	MV *NS Energy* (ore carrier)	North	9.3	First count made during moderate to good sightability. Sightability deteriorated during the second count, which was stopped early because of rain. Two shots fired immediately prior to transit[2]. No shots during transit.
30 July, 20:46–21:40	MV *Nordic Odyssey* (ore carrier)	South	7.8	No observations – shift ended early because of rain.
1 August, 00:32–01:17	MV *Arkadia* (ore carrier)	North	9.0	No observations – vessel transit outside scheduled observation hours.
1 August, 16:05–16:55	MV *Nordic Oshima* (ore carrier)	South	8.0	No observations – shift cancelled because of rain and fog.
2 August, 18:16–19:01	MV *Nordic Oasis* (ore carrier)	North	9.1	Observations made during mostly excellent sightability. No shots fired prior to, during, or after transit.
2 August, 20:59–21:44	MV *Nordic Odin* (ore carrier)	South	8.6	Observations made during mostly excellent sightability. No shots fired prior to or during transit.
4 August, 11:46–12:42	MV *Nordic Odyssey* (ore carrier)	North	7.1	No observations – shift cancelled because of fog and high winds.
4 August, 20:53–21:39	MV *Nordic Olympic* (ore carrier)	South	8.9	No observations – shift cancelled because of fog and high winds.
6 August, 00:16–01:04	MV *Nordic Oshima* (ore carrier)	North	8.6	No observations – vessel transit outside scheduled observation hours.
6 August, 14:57–15:51	MV *Golden Diamond* (ore carrier)	South	7.8	No observations – shift cancelled because of high winds.
7 August, 23:12–23:59	MV *Nordic Odin* (ore carrier)	North	8.5	No observations – vessel transit outside scheduled observation hours.
8 August, 13:13–13:52	MV *Golden Strength* (ore carrier)	South	10.6	Observations made during mostly moderate to good sightability. No shots fired prior to or during transit. Shots fired after transit at 16:22 and 17:43.
9 August, 05:44–06:24	MV *Nordic Olympic* (ore carrier)	North	10.2	Observations made during mostly moderate to good sightability. No shots fired during transit. Shots fired after transit (five shots from 16:00 to 16:43; four shots fired from 21:20 to 21:38).

TABLE 4 (continued).

Date/ Time[1] (2016)	**Vessel Name**	**Travel Direction**	**Vessel Speed[1] (kt)**	**Notes**
9 August, 10:23–11:15	MV *Golden Ice* (ore carrier)	South	7.6	Observations made during mostly good sightability. No shots fired prior to or during transit. Shots fired after transit (five shots from 16:00 to 16:43; four shots fired from 21:20 to 21:38).
10 August, 21:15–22:04	MV *Golden Diamond* (ore carrier)	North	9.0	Observations made during mostly moderate to good sightability. Shots fired prior to (6 shots from 11:15 to 19:52), during (21:30), and after (22:30) transit.
11 August, 17:08–18:00	MV *Nordic Orion* (ore carrier)	South	8.3	Observations made during good to excellent sightability. Shots fired prior to (three shots from 16:02 to 16:48), during (17:27, 17:37), and after (18:36, and ~11 shots from 19:16 to 19:29) transit.
13 August, 10:00–10:34	MV *Golden Strength* (ore carrier)	North	11.9	Observations made during mostly good sightability. No shots fired prior to or during transit. Shots fired after transit at 13:19, 15:40, and 19:18.
14 August, 03:53–04:29	MV R*osaire A. Desgagnés* (cargo)	South	12.0	No observations – vessel transit outside scheduled observation hours.
14 August, 19:30–20:16	MV *Golden Bull* (ore carrier)	South	8.6	Observations made during mostly good sightability. Shots fired prior to (seven shots from 07:00 to 17:18) transit. No shots fired during or after transit
14 August 23:37–15 August 00:36	MV *Golden Ice* (ore carrier)	North	7.0	No observations – vessel transit outside scheduled observation hours.
16 August, 03:22–04:24	MV *Golden Pearl* (ore carrier)	South	6.8	No observations – vessel transit outside scheduled observation hours.
16 August, 15:51–16:20	MV R*osaire A. Desgagnés* (cargo)	North	13.2	Observations made during mostly moderate to good sightability. Five shots fired prior to (06:14 to 07:19) transit. No shots fired during or after transit.
16 August, 18:07–18:51	MV *Nordic Orion* (ore carrier)	North	10.0	Observations made during good and moderate sightability; sightability deteriorated as rain started. Five shots fired prior to (06:14 to 07:19) transit. No shots fired during transit.
17 August, 00:44–01:37	MV *Golden Saguenay* (ore carrier)	South	7.7	No observations – vessel transit outside scheduled observation hours.
18 August, 01:22–02:03	MV *Golden Bull* (ore carrier)	North	9.7	No observations – vessel transit outside scheduled observation hours.

TABLE 4 (continued).

Date/ Time[1] (2016)	**Vessel Name**	**Travel Direction**	**Vessel Speed[1] (kt)**	**Notes**
19 August, 08:56–09:06	*National Geographic Explorer* (ecotourism)	South & North	16.1	No RAD counts. Vessel briefly entered northernmost substratum (A2).
19 August, 12:35–13:22	MV *Golden Pearl* (ore carrier)	North	8.6	Observations during mostly excellent sightability. No shots fired prior to or during transit. Shot fired after transit at 17:23.
21 August, 07:13–08:07	MV *Golden Saguenay* (ore carrier)	North	7.3	Observations during mostly moderate to good sightability. No shots fired prior to transit. Shots fired during (07:17) and after (five shots from 12:01 to 12:54) transit.
22 August, 17:48–18:39	MV *Golden Opportunity* (ore carrier)	South	8.1	Observations during mostly severely impaired sightability. No shots fired prior to, during, or after transit.
23 August, 05:03–05:50	MV *NS Energy* (ore carrier)	South	8.9	No observations – vessel transit outside scheduled observation hours.
23 August, 11:25–12:13	MV *Golden Brilliant* (ore carrier)	South	8.4	Observations during mostly moderate to severely impaired sightability. Observations began after vessel had transited through the SSA. No shots fired after transit.
24 August, 03:22–04:04	MV *Golden Opportunity* (ore carrier)	North	9.7	No observations – vessel transit outside scheduled observation hours.
24 August, 08:42–09:31	MV *NS Yakutia* (ore carrier)	South	8.5	Observations during mostly moderate to severely impaired sightability. No shots fired during or after transit.
25 August, 10:01–10:47	MV *NS Energy* (ore carrier)	North	9.0	No observations – shift cancelled because of rain and fog.
25 August, 16:14–16:59	MV *Nordic Oasis* (ore carrier)	South	9.3	No observations – shift cancelled because of rain and fog.
26 August, 17:40–18:25	MV *Golden Brilliant* (ore carrier)	North	9.5	No observations - shift cancelled because of fog and unsafe hiking conditions.
26 August, 21:32–22:20	MV *Nordic Odyssey* (ore carrier)	South	8.2	No observations – no shift because of fog, unsafe hiking conditions, and late hour of vessel transit (i.e., low light conditions and likely severely impaired sightability).

TABLE 4 (concluded).

Date/ Time[1] (2016)	**Vessel Name**	**Travel Direction**	**Vessel Speed[1] (kt)**	**Notes**
28 August, 07:48–08:40	MV *NS Yakutia* (ore carrier)	North	8.0	Observations during mostly good sightability. No shots fired during or after transit.
29 August, 12:18–12:36	MV *Silver Explorer* (ecotourism)	South	13.3	Observations in mostly moderately impaired sightability. No shots fired prior to, during, or after transit.
29 August, 14:26–14:58	MV *Anna Desgagnés* (cargo)	South	12.3	Observations in mostly moderate to good sightability. No shots fired prior to, during, or after transit.
29 August, 15:35–16:25	MV *Nordic Oasis* (ore carrier)	North	8.6	Observations in mostly good to excellent sightability. No shots fired prior to, during, or after transit.
29 August, 16:45–17:03	MV *Silver Explorer* (ecotourism)	North	13.5	Observations in mostly moderate to good sightability. No shots fired prior to, during, or after transit.
29 August, 23:17–23:50	MV *Anna Desgagnés* (cargo)	North	12.8	No observations – vessel transit outside scheduled observation hours (and during low light conditions)
31 August, 16:14–17:06	MV *Golden Ruby* (ore carrier)	South	8.7	No observations – shift cancelled because of high winds and snow.
01 September, 08:13–09:00	MV *Nordic Oshima* (ore carrier)	South	8.9	No observations – shift cancelled because of gusting winds and snow squalls.
01 September, 15:54–16:43	MV *Nordic Odyssey* (ore carrier)	North	8.1	No observations – shift cancelled because of gusting winds and snow squalls.
01 September, 18:26–19:14	MV *Arkadia* (ore carrier)	South	8.6	No observations – shift cancelled because of gusting winds and snow squalls.
02 September, 17:52–18:26	MV *Sarah Desgagnés* (cargo)	South	13.5	No observations – shift cancelled because of gusting winds, snow squalls, and ice on ground.
03 September, 18:16–19:09	MV *Golden Ruby* (ore carrier)	North	7.8	No observations – shift cancelled because of high winds. Camp demobilization begins.
04 September, 06:25–07:09	MV *Nordic Odin* (ore carrier)	South	8.9	No observations – camp demobilization.

[1] Time (EDT) and speed are estimated from vessel tracks generated from AIS data (See § 2.3.3.1).

[2] For the purpose of summarizing hunting activity here, a transit is equal to the time during which the vessel was in the SSA. Our ability to comment on hunting activity prior to and after transits is constrained by observation effort.

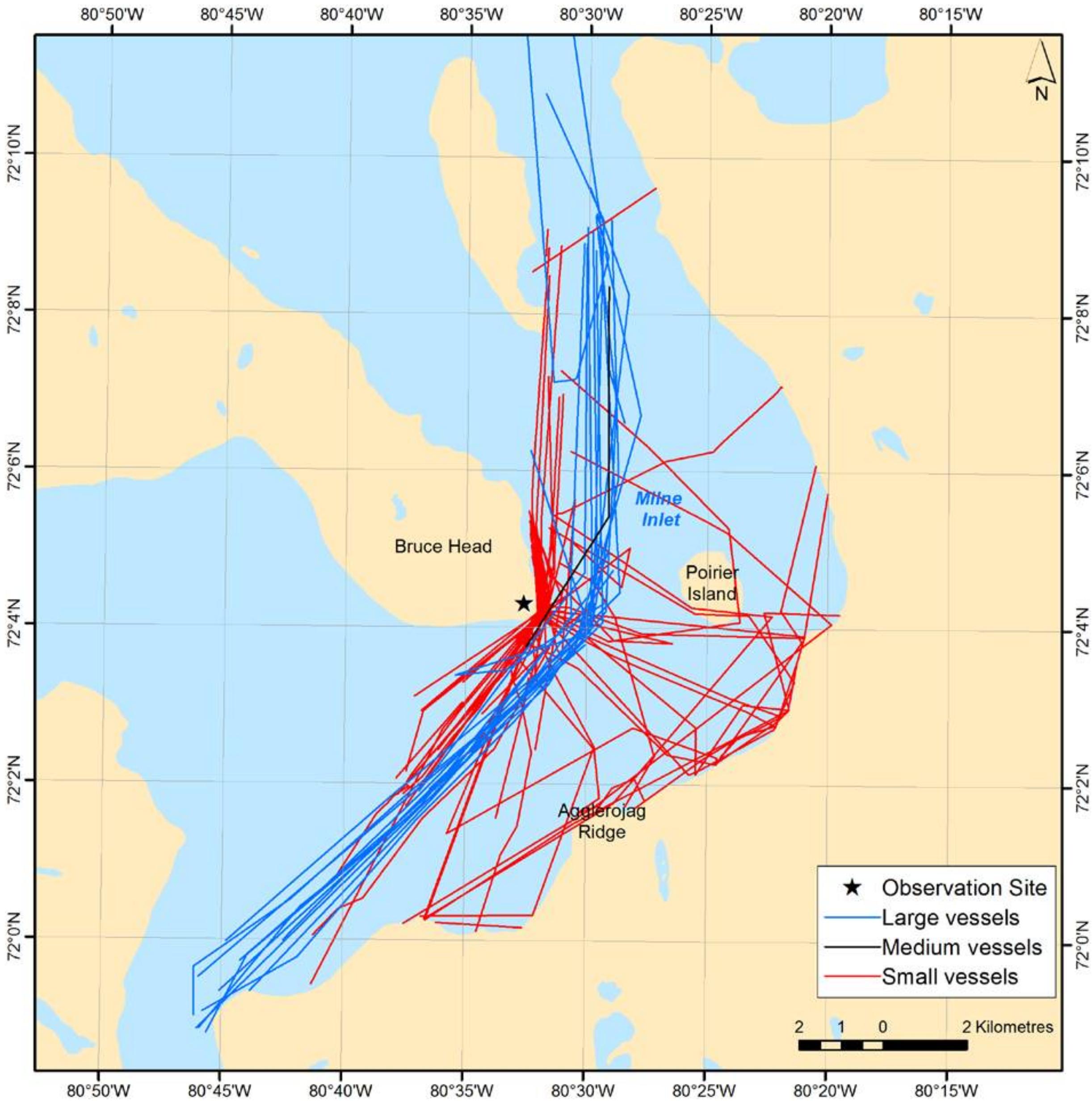


FIGURE 14. Vessel tracks for large, medium, and small vessels observed (n = 18, n = 1, and n = 82, respectively) and recorded by AIS or theodolite during the shore-based narwhal study at Bruce Head, 30 July – 30 Aug, 2016.

TABLE 5. Mean large vessel speed through the stratified study area (SSA) at Bruce Head, 30 July – 4 September 2016. Speed was estimated from vessel tracks generated from AIS data.

Travel direction	**Large vessel type**		
	Ore carrier	Sealift (cargo)	Ecotourism[1]
South	8.4 kt (n = 21)	12.6 kt (n = 3)	13.3 kt (n = 1)
North	8.9 kt (n = 21)	13.0 kt (n = 2)	13.5 kt (n = 1)

[1] Excludes the MV *National Geographic Explorer* because this vessel was only very briefly present in the northernmost portion of the study area on one occasion.

3.2.4 Other Anthropogenic Activity

The observation site was located directly above a hunting camp used by local Inuit for hunting marine mammals. This camp was observed to be occupied on 22 of the 27 observation days over the course of the 2016 study period. Much of the small vessel traffic in the study area occurred when hunters arrived and departed this hunting camp (Figure 14). Hunting activity did take place during some of the observation periods. Hunting activity was observed on 18 separate days from 30 July to 27 August, and comprised 71 shooting events. A shooting event was defined as one or multiple shots fired at the same target species in a short period of time; hunting events were generally only several seconds in length. In 38 of the recorded shooting events, the target species was narwhal. Seals and birds were the target species in 11 and 5 of the shooting events, respectively, and target species was not determined for the remaining 17 shooting events.

Hunting activity was predominantly observed to take place from the shore, though hunting from small vessels was also observed or very likely to have occurred on three occasions. Boat-based hunting was observed in substratum H2 on 3 August and in substratum F3 on 13 August; boat-based hunting was also very likely to have occurred near the entrance to Koluktoo Bay on 3 August.

Small vessels were observed deploying, maintaining, or retrieving a narwhal set net on numerous occasions from 15 to 27 August. The set net was approximately 15 m in length and was set perpendicular to the shoreline in stratum E1, within easy view of the observation platform. A narwhal was caught in the net the morning of 16 August, and was shot five times by the hunters between 06:14 and 07:19 prior to being removed from the net. Inuit using a small vessel were also observed retrieving fish from the net on 21 and 22 August.

Air traffic also occurred over the study area (i.e., SSA). We observed 17 helicopter and 13 small fixed-wing aircraft overflights during observation periods within the 2016 field season. Helicopters were generally estimated to be flying at altitudes of 2000–5000 ft above sea level (ASL), while fixed-wing aircraft were generally estimated to be at 1000–2500 ft ASL.

3.3 Relative Abundance and Distribution of Narwhals

A total of 320 RAD counts were made during 27 days from 30 July to 30 August 2016, resulting in an average of 12 counts per day (range: 1–19 counts; Table 6). The majority of RAD counts were "complete" counts, consisting of counts for all nine strata. Three partial counts were made; two counts were cut short in order to begin a large vessel count, and one count was cut short due to deteriorating weather conditions. Large vessels were present during counts on 15 days (Table 6; Figure 15).

TABLE 6. Relative abundance and distribution (RAD) effort for the shore-based narwhal study at Bruce Head, 2016. These totals include all complete and partial counts made during all sighting conditions. Days highlighted in grey include count effort associated with the presence of large vessels.

Date	Start Time[1] of First Count	Start Time of Last Count	Number of Counts[2]	Number of Large Vessel Counts[3]		
				Pre	Centre	Post
30-Jul	12:39	13:21	2	1	1	0
31-Jul	06:01	21:01	11	0	0	0
02-Aug	17:49	21:56	6	2	2	2
03-Aug	06:05	21:00	16	0	0	0
05-Aug	06:07	19:00	13	0	0	0
06-Aug	10:04	10:04	1	0	0	0
07-Aug	08:05	20:00	13	0	0	0
08-Aug	06:10	21:00	17	1	1	1
09-Aug	05:55	21:00	19	1	2	2
10-Aug	06:19	22:12	18	1	1	1
11-Aug	06:24	21:00	17	1	1	1
12-Aug	06:07	21:00	16	0	0	0
13-Aug	06:05	21:00	17	1	1	1
14-Aug	06:01	21:30	17	1	1	1
15-Aug	06:02	21:00	15	0	0	0
16-Aug	06:08	18:28	15	2	2	1
18-Aug	16:00	20:00	5	0	0	0
19-Aug	08:13	21:00	15	1	1	1
20-Aug	06:05	21:00	16	0	0	0
21-Aug	06:09	21:00	17	1	1	1
22-Aug	06:19	18:53	14	1	1	1
23-Aug	12:27	16:01	5	0	0	1
24-Aug	09:16	11:01	3	0	1	1
27-Aug	09:12	16:00	8	0	0	0
28-Aug	09:00	16:00	8	0	0	1
29-Aug	09:01	17:56	11	2	4	2
30-Aug	11:31	16:02	5	0	0	0
Totals			**320**	**16**	**20**	**18**

[1] EDT

[2] Data were collected by two shifts of observers from 30 July to 22 August; observation shifts were rarely separated in time during a given day such that daily counts usually cover a continuous block of time.

[3] Large vessel counts comprise “Pre” counts made prior to a large vessel entering the SSA; “Centre” counts made when a large vessel was in the centre of the SSA (i.e. in stratum D or E), and “Post” counts made after a large vessel had exited the SSA.

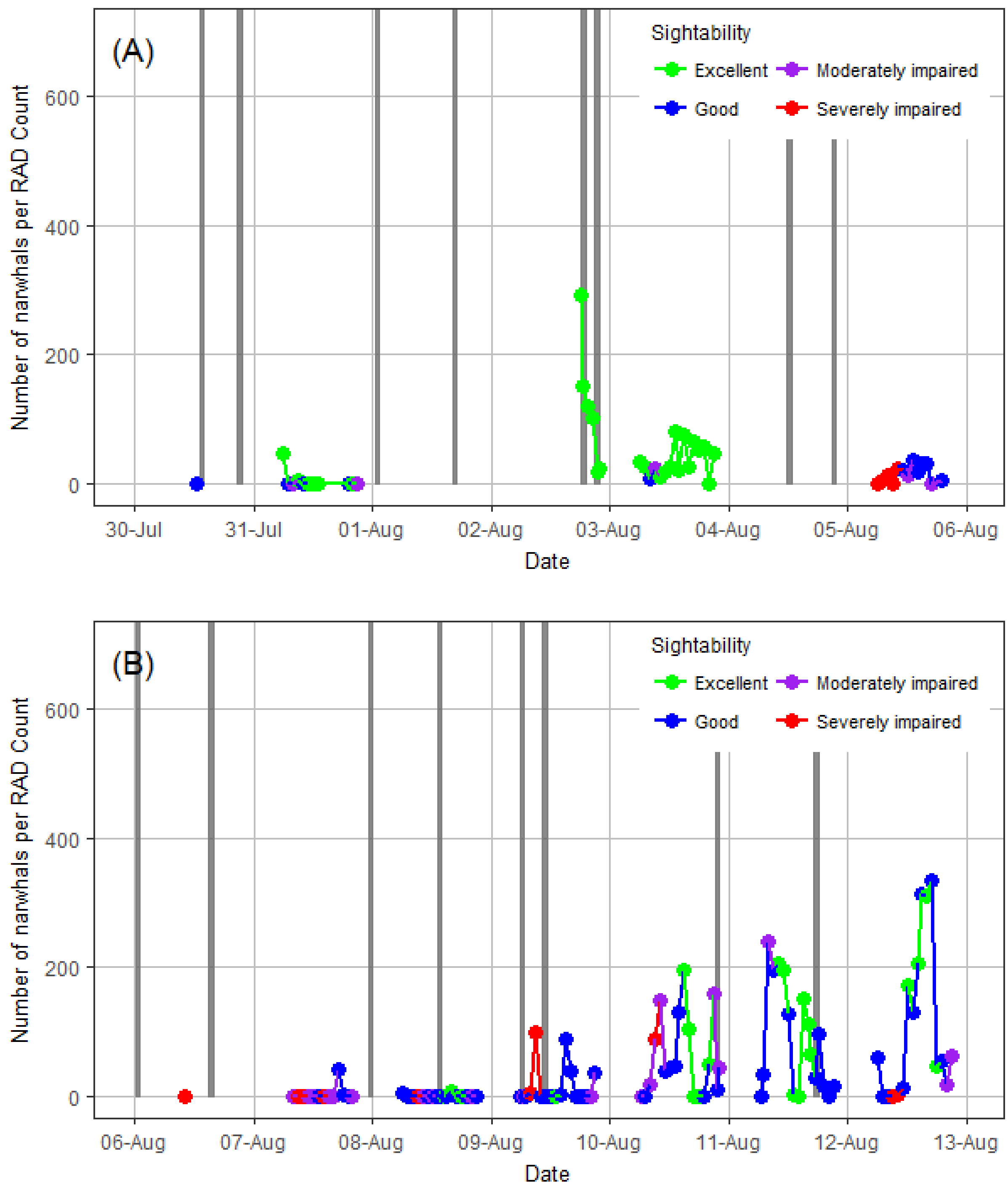


FIGURE 15. Numbers of narwhals observed during relative abundance and distribution (RAD) counts (n = 318) made under all sighting conditions during the shore-based study at Bruce Head, 2016. Partial counts with fewer than half of the strata counted are excluded. Colour-coding indicates sightability for substratum E1, which was used as a surrogate for mean sightability across the entire SSA. Vertical grid lines indicate time 00:00 EDT for each day, and the width of each grey shaded vertical stripe indicates the duration of large vessel presence in the study area.

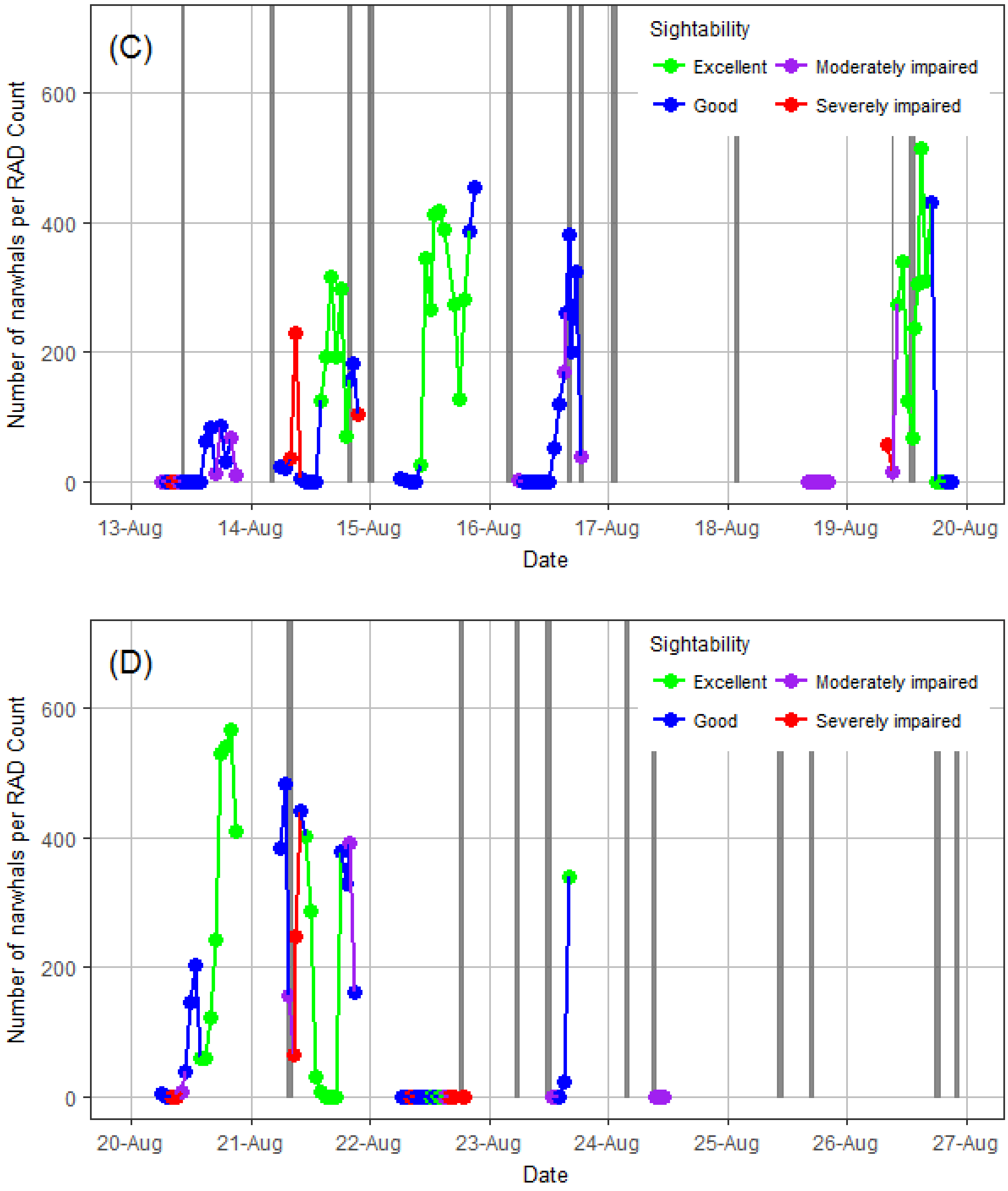


FIGURE 15 (continued).

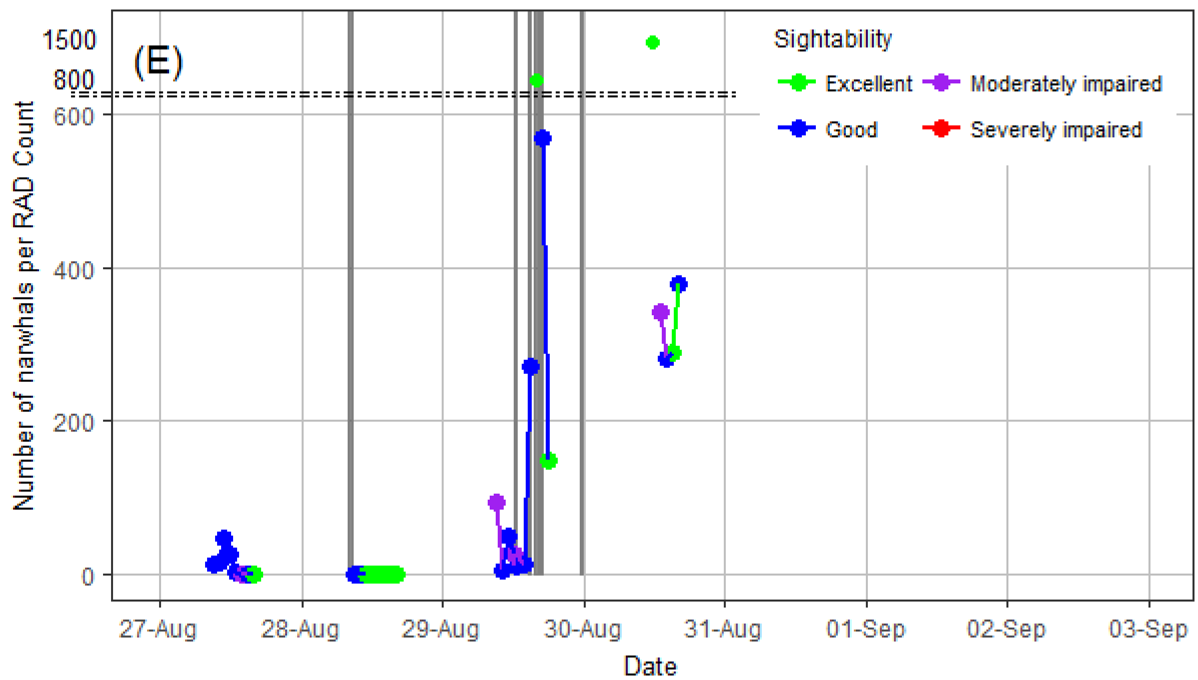


FIGURE 15 (concluded).

During the 2016 RAD counts, we recorded a total of 16,062 sightings (i.e., groups, where group size ≥ 1) of 27,888 narwhals over the 30 July – 30 August period, inclusive of all sighting conditions. Daily totals ranged from 0 to 3764 narwhals, and totals exceeded 1000 narwhals on 11 days. There were five days when no narwhals were observed. The maximum daily total of 3764 narwhals was recorded on 21 August, when 17 counts were made (Table 7).

The greatest numbers of narwhals were observed in the southernmost strata. Strata G, H, and I had total counts of 6249, 5712, and 5501, respectively; and stratum B had the lowest total count (609). Stratum totals generally increased from north to south, with lowest totals in strata A, B and C; intermediate in D, E, F; and highest in G, H, I (Figure 16).

Single narwhals were predominantly observed during RAD counts, though group sizes of two were also common (Figure 17). Sixty-six groups had 10 narwhals or more; the largest group size observed was 19.

3.3.1 Factors Related to Narwhal Numbers and Local Distribution

The GLMM analysis of the combined 2014–2016 RAD dataset was used to investigate factors related to numbers of narwhals counted in different parts of the stratified study area (SSA) during the three field seasons. A total of 814 RAD counts were made over the three field seasons: during 23 days from 3 August to 5 September 2014, 29 days from 29 July to 5 September 2015, and 27 days from 30 July to 30 August 2016. Overall, there was an average of 10 counts per day (range: 1–19 counts).

TABLE 7. Numbers of narwhals recorded during all RAD counts by stratum and day. These totals include counts attempted under all sighting conditions. Days highlighted in grey include at least some counts associated with the presence of large vessels.

Date (2016)	Number of narwhals										No. of counts[1]	Mean No. of narwhals/ count
	Stratum									All strata		
	A	B	C	D	E	F	G	H	I			
30-Jul	0	0	0	0	0	0	0	0	0	0	2	0
31-Jul	0	0	3	4	0	5	12	11	18	53	11	5
02-Aug	66	81	106	94	66	56	132	58	48	707	6	118
03-Aug	70	11	7	7	10	31	106	124	203	569	16	36
05-Aug	3	5	3	1	6	13	30	45	90	196	13	15
06-Aug	0	0	0	0	0	0	0	0	0	0	1	0
07-Aug	0	0	0	12	17	0	2	13	0	44	13	3
08-Aug	0	0	0	0	8	0	0	4	0	12	17	1
09-Aug	0	0	0	7	2	11	76	69	104	269	19	14
10-Aug	0	0	0	36	50	70	240	364	318	1078	18	60
11-Aug	34	4	8	31	55	204	336	412	406	1490	17	88
12-Aug	8	4	5	13	47	240	343	545	519	1724	16	108
13-Aug	0	0	0	12	26	13	75	80	149	355	17	21
14-Aug	0	0	2	12	136	262	556	488	503	1959	17	115
15-Aug	209	135	174	408	358	563	674	487	382	3390	15	226
16-Aug	3	25	26	73	166	304	493	326	134	1550	15	103
18-Aug	0	0	0	0	0	0	0	0	0	0	5	0
19-Aug	28	1	4	37	101	311	835	700	661	2678	15	179
20-Aug	12	38	53	229	439	616	600	440	504	2931	16	183
21-Aug	392	142	177	197	215	475	795	649	722	3764	17	221
22-Aug	0	0	0	0	0	0	0	0	0	0	14	0
23-Aug	0	0	0	0	5	29	81	129	120	364	5	73
24-Aug	0	0	0	0	0	0	0	0	0	0	3	0
27-Aug	0	0	0	1	1	2	12	13	75	104	8	13
28-Aug	0	0	0	0	0	0	0	1	0	1	8	0
29-Aug	3	5	32	117	131	292	510	512	329	1931	11	176
30-Aug	364	158	142	340	357	559	341	242	216	2719	5	544
Overall	1192	609	742	1631	2196	4056	6249	5712	5501	27888	320	87

[1] for some dates, some of the strata could not be counted when others were countable, i.e., counting effort was less than indicated here for some strata on some dates

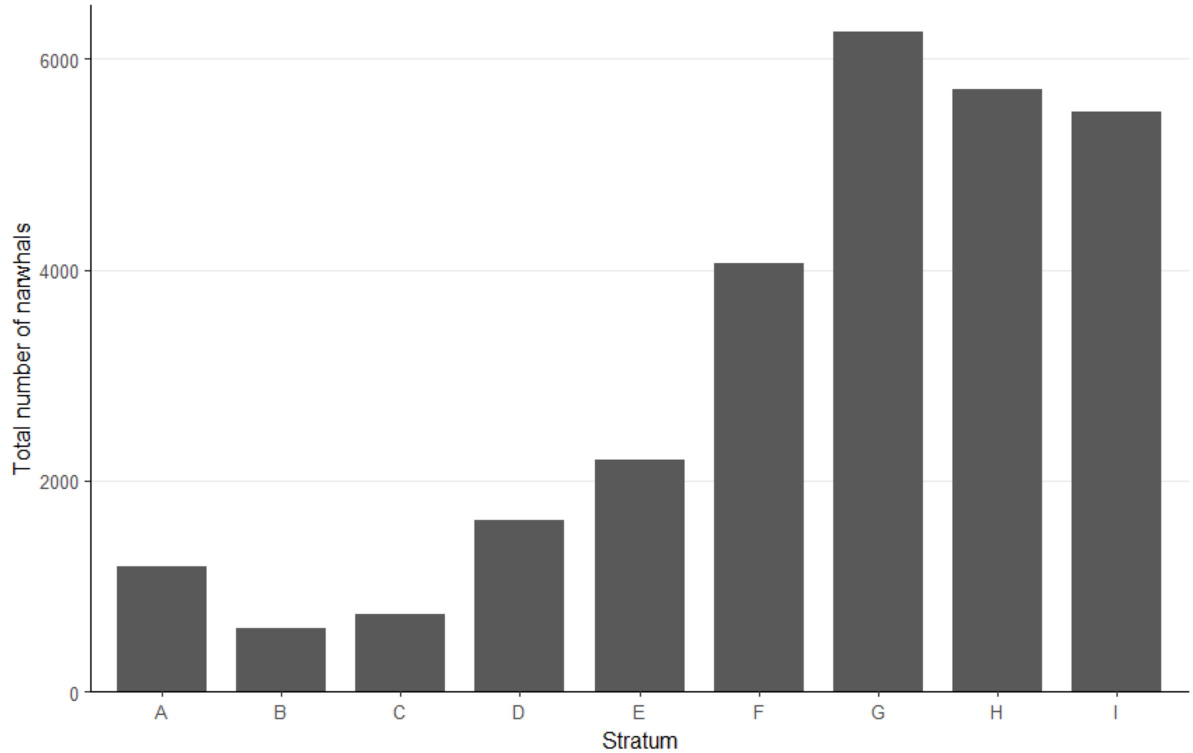


FIGURE 16. Total numbers of narwhals recorded in each geographic stratum during relative abundance and distribution (RAD) counts (*n* = 320) at Bruce Head, 2016.

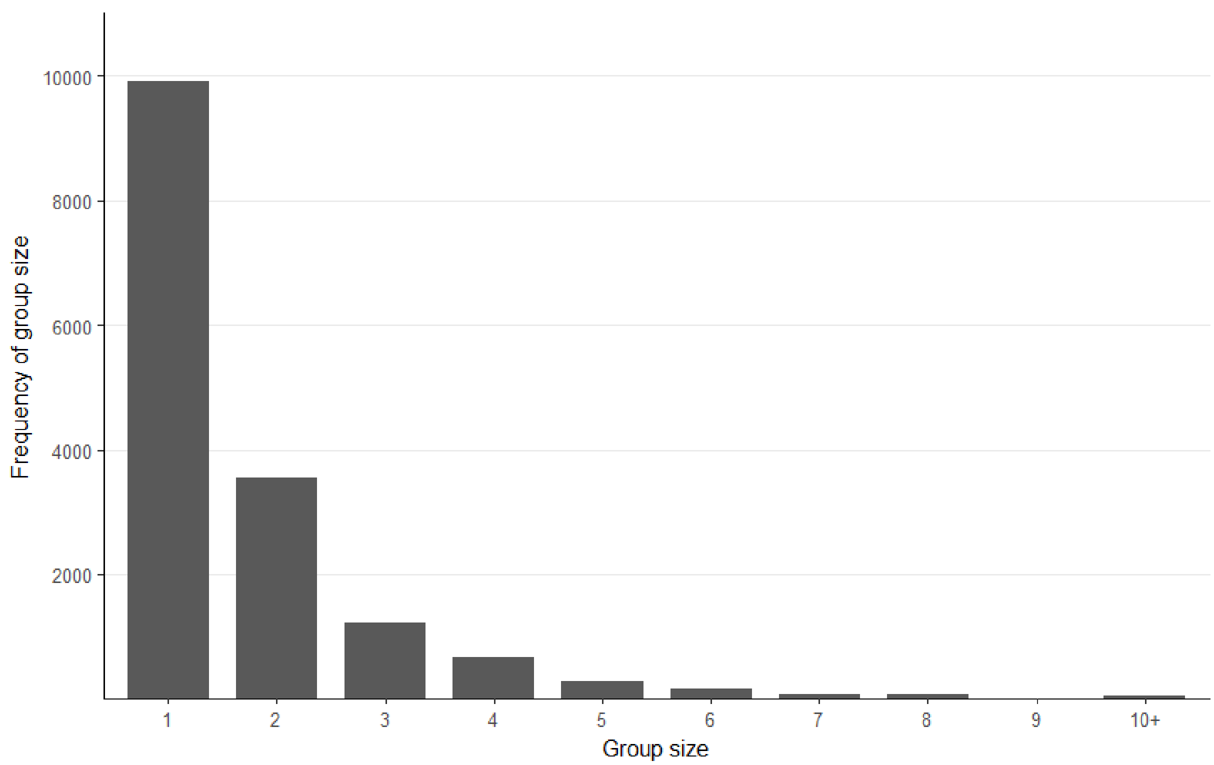


FIGURE 17. Narwhal group sizes during relative abundance and distribution (RAD) counts (*n* = 320) at Bruce Head, 2016.

The substratum counts in 2014–2016 were highly variable, and the data contained many zeros. After the data filters (see § 2.4.1.4) were applied, there were 19,444 substratum counts (i.e., n = 19,444 observational units), and 84% of these (16,370) were zeroes, i.e., no narwhals were observed. The number of narwhals observed in each substratum count ranged from 0 to 355. The residual plot for the GLMM fitted to the 2014–2016 counts indicated that the final model specification and link function were appropriate (Appendix H). The likelihood ratio test indicated the correlation parameter, ρ =0.48, was significant (Appendix H); thus, spatial autocorrelation was included in the model as a random effect.

3.3.1.1 Ore Carrier Scenario

The number of narwhals counted in a given substratum was significantly related to ore carrier scenario (Figure 18; Table 8). Highest numbers of narwhals were observed when an ore carrier was exiting the inlet (i.e., headed north through the SSA) and approaching the substratum in question; lowest numbers were observed when an ore carrier was exiting the inlet and departing the substratum. Counts for both of these scenarios were statistically different from the intermediate average counts when no ore carriers were present. The number of narwhals did not differ statistically during counts when ore carriers entered the inlet (i.e., headed south through the SSA) vs. counts when no ore carriers were present, regardless of whether the vessel was approaching or departing substrata. The interaction of ore carrier direction and stratum could not be tested due to limited degrees of freedom, but the arithmetic averages of observed counts indicated that narwhal distribution across the SSA differed substantially among ore carrier scenarios (Table 9).

3.3.1.2 Other Factors Related to Counts

Three additional categorical variables (of the four considered in the GLMM) were found to be significantly related to narwhal counts (Table 8). • *Stratum (i.e., north–south position)*: As shown earlier (Figure 16), narwhals were not evenly distributed throughout the SSA. In general, narwhal numbers increased from north (stratum A) to south (stratum I), and this trend was statistically significant according to the GLMM (Table 8). • Sightability: Substratum counts of narwhals decreased significantly as sightability conditions deteriorated (i.e., excellent > good > poor). • Tide: Counts of narwhals during ebb tides were significantly higher than during all other tidal categories, which did not differ from each other. • Year: The number of narwhals in a substratum did not differ statistically across years, although there was an apparent increase in numbers from 2014 to 2016 (Table 8).

All three continuous variables considered in the GLMM were significantly related to narwhal counts (Figure 19). • Hours Since Shots Fired (Hunting effect): Narwhal counts fluctuated in a statistically predictable manner as a function of time following shots fired (Type III p-value < 0.0001 for all 3 terms, Figure 19A). In the two to three hours immediately after a hunter fired a shot, narwhal numbers in the SSA were relatively low (Figure 19A). After three hours, narwhal numbers began increasing and peaked at 9–10 hours post-shooting, declining thereafter. • Julian Date (Seasonal effect: As expected, narwhal counts were zero or low early in the study seasons, increased to a peak, and then decreased again. In the GLMM, this is shown by the fact that substratum counts were significantly related to Julian date (Type III p-values for both terms $\leq$0.001). Narwhal numbers began increasing ~12 August (Julian date 224), peaked ~22 August (Julian date 234), and began decreasing 28 August (Julian date 240); Figure 19B). • *Hour of the day*: Narwhal counts were significantly related to hour, primarily through the quadratic term (Figure 19C; Type III p-values were 0.36 and <0.001 for the linear and quadratic terms, respectively). The highest counts of narwhals occurred around 14:00 EDT.

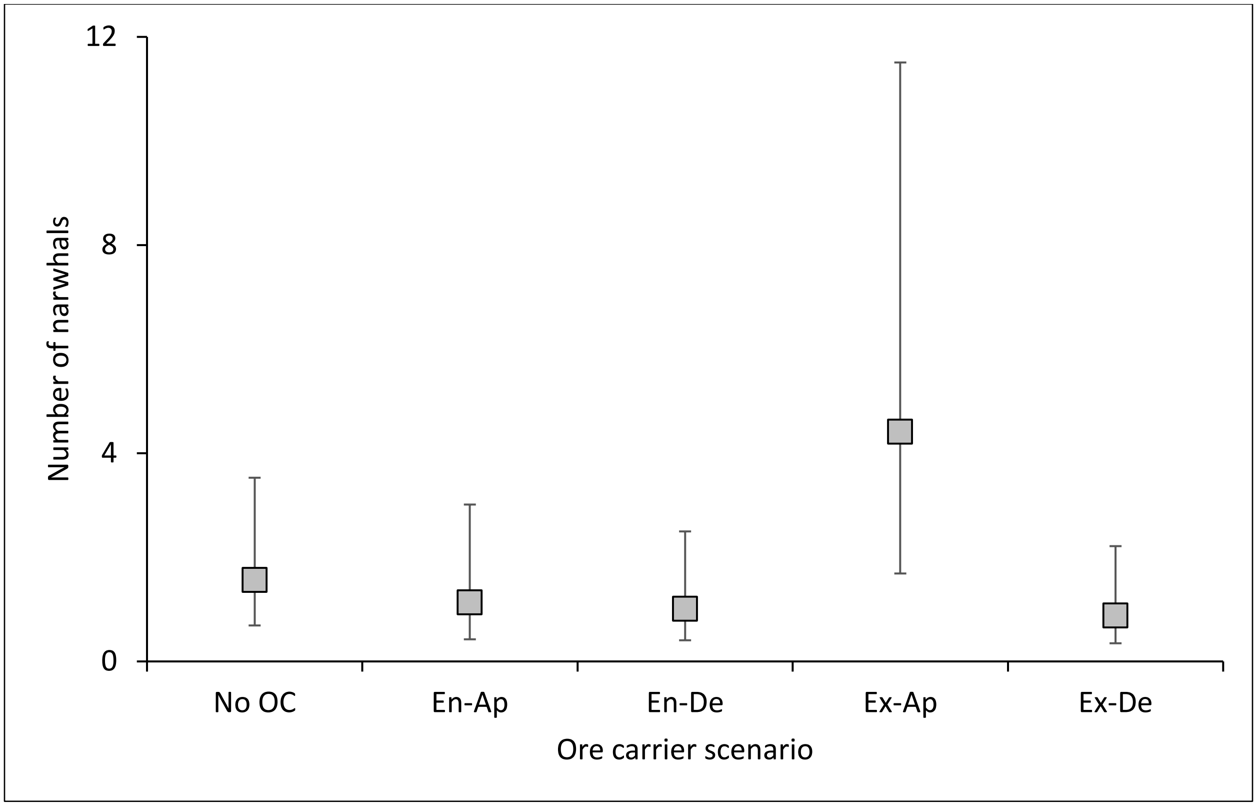


FIGURE 18. Predicted narwhal counts in a given substratum relative to ore carrier scenario, based on the generalized linear mixed model (GLMM) applied to 2014–2016 data. Plotted values are the predicted mean number of narwhals for the marginal distribution (i.e., all other effects not held constant) and their confidence intervals. Categories of ore carrier effect are defined as follows: No OC = no ore carrier present; En-Ap = ore carrier entering SSA and moving toward (approaching) a substratum; En-De = ore carrier entering and moving away from (departing) a substratum; Ex-Ap = ore carrier exiting and approaching substratum; Ex-De = ore carrier exiting and departing substratum. See Table 8 for *p*-values and ratios from pairwise comparisons.

Modelling these continuous covariates as polynomials seemed to provide an adequate fit to the observed trends (Figure 19). However, it should be noted that the observed means (plotted as gray dots) were influenced by all other effects not held consistent via the GLMM across the range of the covariate.

TABLE 8. Categorical variable effects on narwhal counts, based on the generalized linear mixed model (GLMM) fitted to substratum counts in 2014–2016. *Left of the vertical partition:* Overall Type III *p*-values are given for each effect, as well as the predicted mean number of narwhals for the marginal distribution (i.e., all other effects not held constant) and their confidence intervals. Shaded bars overlaying the predicted mean numbers represent those numbers scaled to the greatest mean value within that effect. *Right of the partition*: Pairwise comparisons among levels within each effect. For each comparison, the ratio of the greater mean to the lesser mean is provided above the diagonal line; below the diagonal are the corresponding pairwise *p*-values (Tukey adjusted for multiple comparisons). The ore carrier scenarios were named as follows: No OC = no ore carrier present; En-Ap = ore carrier entering Milne Inlet and moving toward (approaching) a substratum; En-De = ore carrier entering and moving away from (departing) a substratum; Ex-Ap = ore carrier exiting and approaching; Ex-De = ore carrier exiting and departing.

Effect (Type III *p*-value)	Predicted value	95% LCL	95% UCL	Levels for each effect								
Stratum (<0.0001)				A	B	C	D	E	F	G	H	I
A	0.23	0.09	0.58		1.6	1.0	4.0	7.7	14.5	31.1	42.4	49.9
B	0.14	0.06	0.36	0.2880		1.6	6.4	12.3	23.2	49.8	67.9	80.0
C	0.23	0.09	0.57	1.0000	0.2600		4.0	7.7	14.5	31.1	42.5	50.0
D	0.92	0.37	2.27	<0.0001	<0.0001	<0.0001		2.2	4.0	8.4	14.5	20.0
E	1.77	0.73	4.27	<0.0001	<0.0001	<0.0001	0.0031		1.9	4.0	5.5	6.5
F	3.32	1.38	7.97	<0.0001	<0.0001	<0.0001	<0.0001	0.0013		2.1	2.9	3.5
G	7.13	2.98	17.07	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		1.4	1.6
H	9.73	4.08	23.23	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.4550		1.2
I	11.46	4.80	27.38	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.1024	0.9480	
Ore carrier effect (<0.0001)				No Vess	En-Ap	En-De	Ex-Ap	Ex-De				
No OC	1.56	0.69	3.53		1.4	1.6	2.8	1.8				
En-Ap	1.13	0.43	3.01	0.7192		1.1	3.9	1.3				
En-De	1.01	0.41	2.50	0.3360	0.9999		4.4	1.1				
Ex-Ap	4.41	1.69	11.51	0.0005	0.0028	0.0002		5.0				
Ex-De	0.88	0.35	2.22	0.0129	0.9223	0.9266	<0.0001					
Tide (0.0015)				Ebb	Low slack	Flood	High slack					
Ebb	1.83	0.78	4.32		1.4	1.4	1.3					
Low slack	1.36	0.58	3.18	0.0184		1.0	1.0					
Flood	1.36	0.58	3.17	0.0020	0.9990		1.0					
High slack	1.39	0.58	3.30	0.0390	0.9943	0.9740						
Year (0.5189)				2014	2015	2016						
2014	1.09	0.34	3.46		1.3	1.9						
2015	1.39	0.49	3.91	0.8812		1.5						
2016	2.10	0.79	5.56	0.4592	0.7004							
Sightability (<0.0001)				Excellent	Good	Poor						
Excellent	2.18	0.93	5.12		1.5	3.3						
Good	1.47	0.63	3.42	<0.0001		2.2						
Poor	0.65	0.27	1.55	<0.0001	<0.0001							

TABLE 9. Observed mean number of narwhals by stratum and substratum ("Subsrt") during ore carrier transit scenarios in 2014–2016. Shading reflects magnitude scaled to the highest value in the table.

No ore carrier present			
Stratum	Subsrt 1	Subsrt 2	Subsrt 3
A	0.8	0.9	0.4
B	0.3	0.9	0.3
C	0.5	1.0	0.4
D	1.0	2.5	0.0
E	1.4	2.9	1.0
F	2.1	4.3	2.6
G	2.3	6.2	4.9
H	2.4	6.8	4.3
I	3.1	8.1	3.1

	Approaching substratum			Departing substratum		
Stratum	Subsrt 1	Subsrt 2	Subsrt 3	Subsrt 1	Subsrt 2	Subsrt 3
Ore carrier entering Milne Inlet						
A	0.0	0.1	0.0	0.0	0.0	0.0
B	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0	0.0	0.0	0.0	0.1	0.1
D	0.1	0.0	0.0	0.8	0.0	0.0
E	0.8	1.0	0.0	0.2	0.3	2.7
F	0.0	2.4	0.9	0.1	0.8	1.1
G	0.6	1.4	1.6	0.9	0.6	2.4
H	0.7	3.7	1.9	2.4	3.6	3.7
I	0.5	3.1	0.7	3.0	6.6	2.4
Ore carrier exiting Milne Inlet						
A	0.7	0.3	0.0	0.0	0.0	0.3
B	1.6	0.1	0.1	0.0	0.0	0.0
C	0.7	1.3	0.0	0.1	0.4	0.0
D	0.3	4.9	0.0	0.1	1.8	0.0
E	2.9	6.0	3.6	1.4	4.8	0.3
F	4.6	15.9	6.1	1.0	2.6	1.8
G	5.9	19.8	18.7	1.6	4.9	5.7
H	6.4	25.3	9.3	1.6	8.0	6.7
I	8.9	30.5	4.4	1.5	12.3	2.9

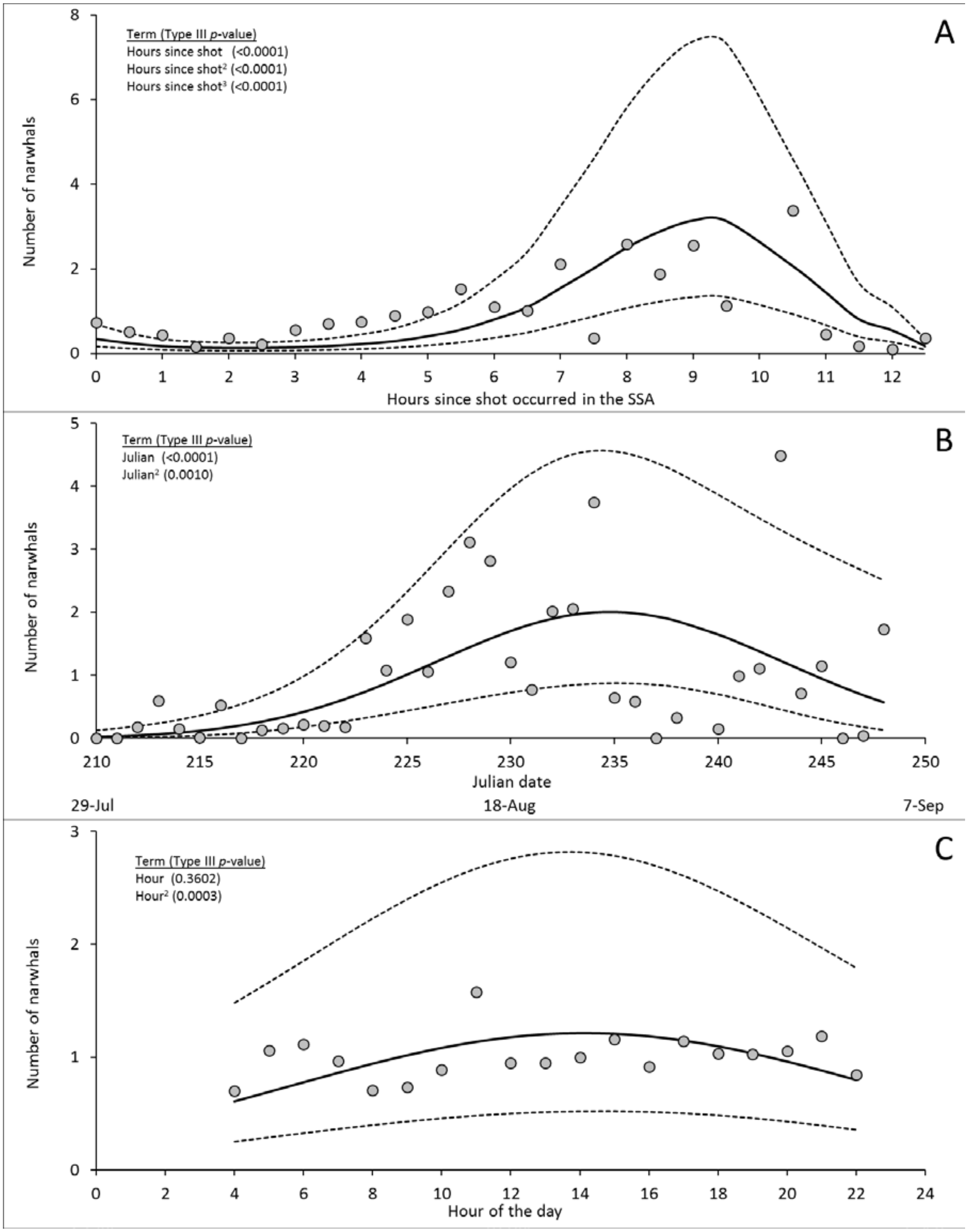


FIGURE 19. Hunting (A), seasonal (B), and time-of-day (C) effects on narwhal counts, based on the generalized linear mixed model (GLMM). Curves represent, for each effect, the predicted mean number of narwhals (solid line) and its 95% confidence intervals (dashed lines) when the effects of all other variables considered in the GLMM were held constant. Circles are the arithmetic means observed (i.e., with other variables not held constant). Both predicted and observed values were rescaled through division by their respective means to facilitate comparison. Time since shooting was modelled as a 3[rd] order polynomial; Julian date and Hour of the day were modelled as 2[nd] order polynomials.

3.4 Group Composition and Nearshore Travel Behaviour of Passing Narwhals

Data on group composition and nearshore travel behaviour were collected every day that observations were made in 2016, for a total of 282.5 hours of observation effort. Total daily observation effort ranged from 0.9 to 15.9 hours (Figure 20). As in 2014 and 2015, the number of narwhal groups observed in 2016 was variable over time from day to day and within a single observation period. For example, narwhals were not observed during several 8-hour observation shifts, in contrast to 96 narwhal groups observed during ~80 minutes of effort on 30 August. In 2016, narwhals were observed during most ~8-hour observation shifts, with the exceptions being five early shifts, one late shift, and one day (i.e., whole team) shift. There were four days during which narwhals were observed in the SSA but not in the BSA, therefore preventing the collection of group composition and behaviour data. (Both the group composition and the behaviour protocols require that narwhals be relatively close to the observation platform.) Narwhals were often observed moving north through the SSA along a trajectory that increased their distance from the nearshore side of the inlet as they passed Bruce Head. This trajectory was more apparent to observers in 2016 than in previous years.

Hunting activity was observed to affect narwhals passing Bruce Head, and therefore affected the amount of data collected on group composition and nearshore travel behaviour of passing narwhals on a number of occasions. Details are provided in Appendix I.

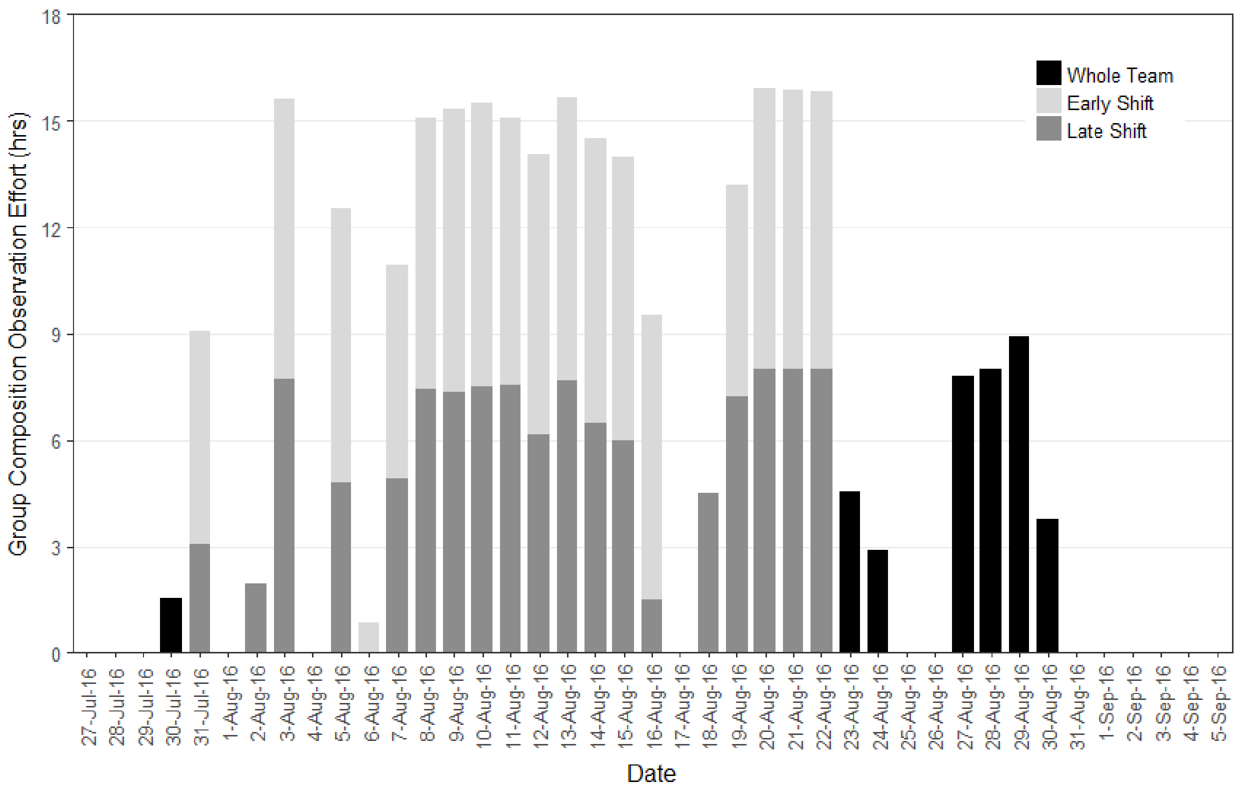


FIGURE 20. Number of hours of effort spent collecting data on group composition and nearshore travel behaviour of passing narwhals, by day and study team, during the shore-based study of narwhals at Bruce Head, 2016.

On only two occasions in 2016 was it noted that narwhals passed in front of Bruce Head so quickly that it was impossible to record group composition data for all passing groups. On neither of these occasions (16 August at 15:50, and 30 August at 12:10) was the quick passage of narwhals attributed to human activity.

3.4.1 All Groups Categorized by Type of Anthropogenic Activity

During 2014 to 2016, data were collected on a total of 1299 narwhal groups observed to pass in front of the observation platform (within ~1000 m of shore); most of this dataset (761 groups) was collected during the 2016 field season. The majority of groups were sighted in the absence of anthropogenic activity (i.e., no anthropogenic activity at the time of the sighting or 15 minutes prior to the sighting; Table 10).

3.4.1.1 Group Size

Overall, mean narwhal group size was 4.0 individuals (range: 1–45 narwhals, n = 1299; cf. § 3.6.1.1 —large aggregations of groups, spread across many substrata, were seen at times). Although mean group size was larger during periods with a large vessel (mean = 5.1), mean group size did not differ significantly among the four categories of anthropogenic activity (Table 11; p = 0.178).

TABLE 10. Occurrence of anthropogenic activity in the stratified study area (SSA) during data collection on group composition and nearshore travel behaviour of passing narwhals at Bruce Head, 2014–2016.

Type of anthropogenic activity	**Number of narwhal groups**[1]
None	1016
Large vessel only	77
Small vessel only	112
Large and small vessels present	0
Shooting occurred	54
Large vessel present and shooting occurred	3
Small vessel present and shooting occurred	7
Large and small vessels present, and shooting occurred	1
Totals	1270

[1] Anthropogenic activity was classified as occurring during a sighting if it occurred at the time of the sighting or during 15 minutes prior to the sighting.

TABLE 11. Mean narwhal group sizes observed during various types of anthropogenic activity during data collection on group composition and nearshore travel behaviour of passing narwhals at Bruce Head, 2014–2016.

Type of anthropogenic activity	Mean narwhal group size[1]
None	3.9
Large vessel only	5.1
Small vessel only	3.8
Shooting occurred	4.2
ANOVA[2] results	$F_{(3,84.29)} = 1.68$, $p = 0.178$

[1] Anthropogenic activity was classified as occurring during a sighting if it occurred at the time of the sighting or during 15 minutes prior to the sighting.

[2] One-way ANOVA on trimmed means with 2-sided *p*-value.

3.4.1.2 Group Spread

Both types of narwhal group spread (i.e., tight = narwhals ≤1 body width apart, vs. loose = narwhals >1 body width apart) were observed during all types of anthropogenic activity. Overall, narwhals were observed more frequently in tight groups than in loose groups (Table 12). The proportion of narwhal groups that were tightly vs. loosely spread differed significantly among types of anthropogenic activity ($p = 0.002$). The proportion of narwhals in tight groups was significantly lower in the presence of large vessels than in the presence of small vessels, shooting, or no anthropogenic activity (adjusted *p*-values <0.05 for all three pairwise comparisons; Appendix J). Though proportionately more narwhals were observed tightly grouped in the presence of shooting than in either the presence of small vessels or no anthropogenic activity, neither difference was significant; nor did group spread differ significantly in the presence of small vessels compared to no anthropogenic activity present (Appendix J).

TABLE 12. Narwhal group spread in relation to anthropogenic activity during collection of data on group composition and nearshore travel behaviour of passing narwhals at Bruce Head, 2014–2016.

Type of anthropogenic activity	Number and ratio (tight: loose) of narwhal group spread[1]		
	Tight	Loose[2]	Ratio
None	496	209	2.4
Large vessel only	32	29	1.1
Small vessel only	64	22	2.9
Shooting occurred	33	5	6.6
χ^2 results	$\chi^2 = 14.96$, *df* = 3, $p = 0.002$		

[1] Anthropogenic activity was classified as occurring during a sighting if it occurred at the time of the sighting or during 15 minutes prior to the sighting.

[2] Loose = narwhals >1 body width apart, tight = narwhals <1 body width apart.

3.4.1.3 Group Formation

Narwhals were most commonly observed in parallel formation during all types of anthropogenic activity (Table 13). Narwhals were less often observed in circular formation, and rarely observed in linear formation (Table 13). Figure 21 illustrates these formation types; Table 2 in § 2.3.5 provides more details about formation types. Sightings in linear formation were excluded from statistical testing because of small sample sizes. The proportion of narwhals in circular formation was arguably greater for sightings in the presence of large vessels than with small vessels or with no anthropogenic activity present; though the overall test result was significant (p = 0.032), both pairwise comparisons were not (both adjusted p-values ≤ 0.065; Appendix J). There were no other statistically significant pairwise comparisons.

TABLE 13. Narwhal group formation in relation to anthropogenic activity during collection of data on group composition and nearshore travel behaviour of passing narwhals at Bruce Head, 2014–2016.

Type of anthropogenic activity	**Number and ratio (parallel: circular) of narwhal groups according to group formation[1].**			
	Parallel	Circular	Linear[2]	Ratio
None	492	184	30	2.7
Large vessel only	34	26	1	1.3
Small vessel only	65	19	2	3.4
Shooting occurred	29	9	0	3.2
χ^2 results	χ^2 = 8.78, df = 3, p = 0.032			

[1] Anthropogenic activity was classified as occurring during a sighting if it occurred at the time of the sighting or during 15 minutes prior to the sighting.

[2] Sightings in linear formation were excluded from the analysis.

FIGURE 21. Narwhals swimming in parallel (A), circular (B), and linear (C) formations.

3.4.1.4 Travel Direction

Overall, narwhals were most commonly observed swimming south through the study area (Table 14). The proportion of narwhal groups swimming north vs. south differed significantly among types of anthropogenic activity (Table 14). Based on post-hoc pairwise comparisons, there were proportionately more groups of narwhals swimming south in the presence of large vessels than with small vessels and with no anthropogenic activity (both adjusted p-values = 0.0; Appendix J); and no difference for groups of narwhals in the presence of small vessels than with no anthropogenic activity. Though there were too

TABLE 14. Narwhal travel direction in relation to anthropogenic activity during collection of data on group composition and nearshore travel behaviour of passing narwhals at Bruce Head, 2014–2016.

Type of anthropogenic activity	**Number and ratio (south: north) of narwhal groups by travel direction[1].**		
	North[2]	South[2]	Ratio
None	316	678	2.1
Large vessel only	6	71	11.8
Small vessel only	39	73	1.9
Shooting occurred[3]	4	48	12
χ^2 results	$\chi^2 = 20.49$, *df* = 2, $p < 0.001$		

[1] Anthropogenic activity was classified as occurring during a sighting if it occurred at the time of the sighting or during 15 minutes prior to the sighting.

[2] Narwhals headed north to exit the inlet, and south to enter the inlet.

[3] Sightings during periods of shooting were excluded from this analysis.

few sightings of narwhals during periods of shooting to include in the analysis, the proportion of narwhals swimming south in the presence of shooting was almost equal that with large vessels (Table 14).

Results of the chi-square analysis for travel direction should be interpreted with caution. Chi-square analyses assume that observations are independent; it is very likely that the travel direction of narwhal groups is influenced by that of other nearby groups.

3.4.1.5 Travel Speed

With the exception of observations with large vessels, narwhals were most commonly recorded as swimming at medium speed (Table 15). However, proportionally more narwhal groups were classified as travelling at a fast speed in the presence of large vessels vs. all other types of anthropogenic activity. Overall, narwhal travel speed was significantly related to type of anthropogenic activity (p <0.001). Note that narwhal sightings classified as travelling slowly were excluded from this analysis because of the small sample sizes. The proportions of narwhals travelling at medium and fast speeds differed significantly for all pairwise comparisons with the exception of narwhals observed travelling during periods of no activity vs. shooting (all significant adjusted p-values < 0.03; Appendix J).

TABLE 15. Narwhal travel speed in relation to anthropogenic activity during collection of data on group composition and nearshore travel behaviour of passing narwhals at Bruce Head, 2014–2016.

Type of anthropogenic activity	**Number of narwhal groups and ratio (medium: fast) by travel speed[1].**			
	Slow[2]	Medium	Fast	Ratio
None	225	571	217	2.6
Large vessel only	4	13	60	0.2
Small vessel only	34	70	7	10
Shooting occurred	5	33	14	2.4
χ^2 results	$\chi^2 = 112.43$, *df* = 3, $p < 0.001$			

[1] Anthropogenic activity was classified as occurring during a sighting if it occurred at the time of the sighting or during 15 minutes prior to the sighting.

[2] Groups classified as travelling slowly were excluded from analysis.

3.4.1.6 Distance from Bruce Head Shore

The proportion of narwhal groups swimming inshore (<300 m) vs. offshore (>300 m) differed significantly among types of anthropogenic activity (p <0.001; Table 16). Proportionally more narwhal sightings were inshore in the presence of large vessels than in the presence of small vessels, shooting, or no anthropogenic activity (adjusted p-values <0.002 for all three pairwise comparisons; Appendix J). There were no other statistically significant pairwise comparisons.

TABLE 16. Distances of narwhal sightings from the shore of Bruce Head in relation to type of anthropogenic activity during collection of data on group composition and nearshore travel behaviour of passing narwhals at Bruce Head, 2014–2016.

Type of anthropogenic activity	**Number and ratio (inner: outer) of groups, according to distance from shore[1].**		
	Inner <300 m from shore	Outer >300 m from shore[2]	Ratio
None	743	271	2.7
Large vessel only	71	6	11.8
Small vessel only	71	41	1.7
Shooting occurred	35	17	2.1
χ^2 results	χ^2 = 20.64, df = 3, p < 0.001		

[1] Anthropogenic activity was classified as occurring during a sighting if it occurred at the time of the sighting or during 15 minutes prior to the sighting.

[2] Only sightings within the behavioural study area (BSA), whose outer edge was ~1 km offshore, were included in this analysis.

3.4.2 Groups of Known Composition

Group composition was determined for 1051 of the 1299 groups of narwhals observed in the inshore portion of the BSA during collection of group composition and nearshore travel behaviour data in 2014–2016. Group size averaged 3.4 and ranged from 1 to 26 (Table 17).

TABLE 17. Group size of all narwhal groups of known composition observed during the shore-based study at Bruce Head, 2014–2016 (n = 1051). Narwhal groups were classified into six broad categories of group composition

Group composition	**Group size**			**Number of groups**
	Mean	Minimum	Maximum	
No tusks, no calves or yearlings	2	1	17	361
No tusks, yes calves or yearlings	3.5	1	17	334
Mixed tusks, no calves or yearlings	4.7	2	15	116
Mixed tusks, yes calves or yearlings	8.9	3	26	75
Yes tusks, no calves or yearlings	2.7	1	16	157
Yes tusks, yes calves or yearlings	2.9	2	7	8
All groups	**3.4**	**1**	**26**	**1051**

More than half of the narwhal groups of known composition did not include narwhals with tusks (Table 17; Appendix K). Mixed groups accounted for the largest group sizes and the majority of group sizes >10, and calves and yearlings were rarely observed in groups that did not include adults or juveniles without tusks (Table 17; Appendix J).

Groups with calves or yearlings accounted for 417 (39.7 %) of the groups of known composition (Table 17). In addition to calves or yearlings, these groups were largely composed of adults without tusks and, to a lesser extent, juveniles without tusks (Appendix K). Groups with calves or yearlings were, on average, larger in size than groups without calves or yearlings (Table 17).

3.4.3 Groups of Known Composition in the Presence of Anthropogenic Activity

Note that analyses on group composition presented in this section classified anthropogenic activity as occurring if it occurred at the time of the sighting or during 15 minutes prior to the sighting.

3.4.3.1 Narwhal Groups With and Without Calves or Yearlings

The proportions of narwhal groups with and without calves/yearlings were similar during periods with large vessel, small vessel and shooting activity (Table 18). During periods with no anthropogenic activity, there were proportionally more narwhal groups without calves/yearlings. Overall, however, the proportions of groups with and without calves/yearlings were not sufficiently different among the four types of anthropogenic activity to be recognized as statistically significant (p = 0.070).

TABLE 18. Narwhal groups with calves or yearlings observed during various types of anthropogenic activity during collection of data on group composition and nearshore travel behaviour of passing narwhals at Bruce Head, 2014–2016.

Type of anthropogenic activity	**Number and ratio (no: yes) of narwhal groups with calves or yearlings[1].**		
	No	Yes	Ratio
None	496	309	1.6
Large vessel only	31	33	0.9
Small vessel only	55	48	1.1
Shooting occurred	24	21	1.1
χ^2 results	χ^2 = 7.05, df = 3, p = 0.070		

[1] Anthropogenic activity was classified as occurring during a sighting if it occurred at the time of the sighting or during 15 minutes prior to the sighting.

3.4.3.2 Narwhal Groups With and Without Tusks

Narwhal groups that included various combinations of tusked and no-tusk individuals were observed during all categories of anthropogenic activity (Table 19). However, these proportions differed significantly among types of anthropogenic activity (p <0.001). Proportions of groups that did and did not include tusked animals differed significantly between periods with large vessel activity vs. small vessel activity and between periods with small vessel activity vs. no anthropogenic activity (adjusted p-values = 0.0 and <0.001, respectively; Appendix J). The practical significance of these patterns is unclear at this time.

TABLE 19. Narwhal groups with tusked individuals (adults or juveniles) observed during various types of anthropogenic activity during collection of data on group composition and nearshore travel behaviour of passing narwhals at Bruce Head, 2014–2016.

Type of anthropogenic activity	**Number of narwhal groups, according to presence of tusked individuals[1].**		
	Yes[2]	Mixed	No
None	136	148	521
Large vessel only	15	16	33
Small vessel only	6	10	87
Shooting occurred	5	5	35
χ^2 results	χ^2 = 25.38, *df* = 6, *p* < 0.001		

[1] Anthropogenic activity was classified as occurring during a sighting if it occurred at the time of the sighting or during 15 minutes prior to the sighting.

[2] Yes = group consisted of one or more tusked adults or juveniles; Mixed = some with and some without tusks; No = none with tusks. Groups may or may not have included calves or yearlings.

3.5 Narwhal Focal Group Follows

A total of 50 focal groups (i.e., individuals or groups of narwhals) were followed on 12 days in 2016 (Figure 22). Overall, focal follow observation effort comprised 28.9 hours, and included a total 3.9 hours of focal follow data. The total number of focal follows ranged from 1 to 13 per day. In contrast to 2014 and 2015, narwhals were less frequently observed in the BSA in 2016, resulting in fewer opportunities to collect focal follow data.

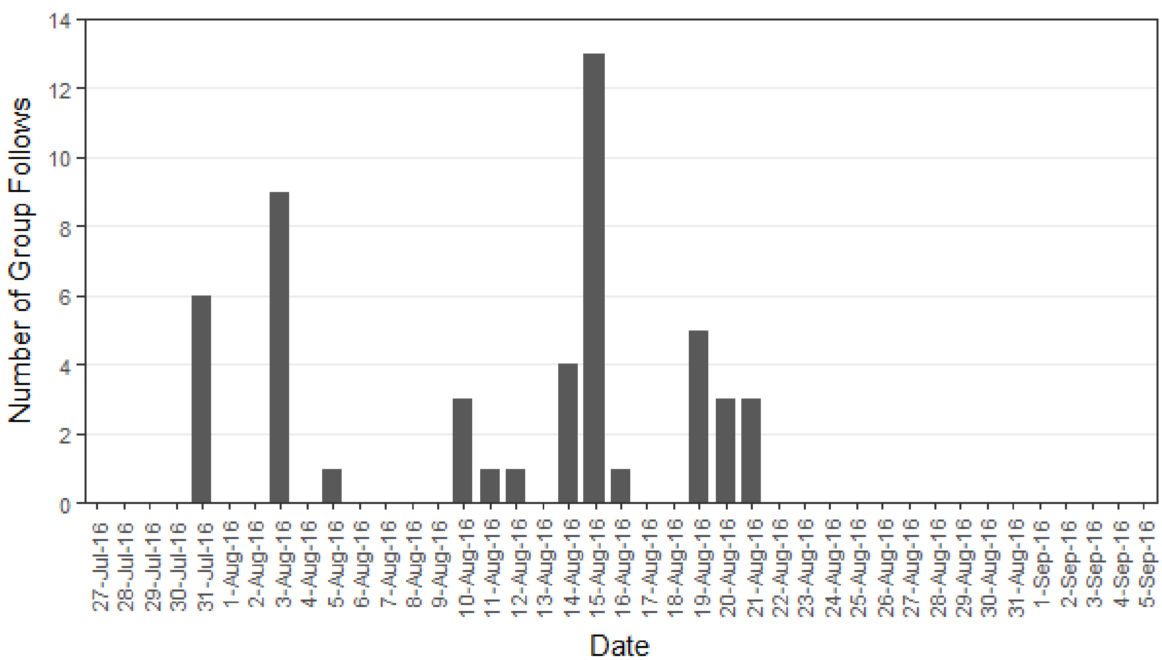


FIGURE 22. Number of focal group follows, by day, during the shore-based study of narwhals at Bruce Head, 2016.

During 2014 to 2016, there was a total of 218 focal follows. Focal follows predominantly ended when the focal group dove and did not resurface after five minutes (Table 20). Twenty of the focal group follows resulted in only a single fix, and were therefore excluded from further analysis.

The average duration of a focal group follow with two or more fixes was 4.3 minutes (range: 0.2 to 30.6 minutes) and had an average of five fixes (range: 2 to 40 fixes).

TABLE 20. Reason for termination of focal group follows during the shore-based narwhal study at Bruce Head, 2014 – 2016.

	Reason follow was terminated		
Year	**Group exited behavioural study area (BSA)**	**Group dove**	**Lost track of group**
2014	12	21	7
2015	26	68	34
2016	12	21	17[1]
Totals	50	110	58

[1] Includes one focal follow that was terminated when the group split into two smaller groups.

3.5.1 Behaviours Exhibited During Focal Group Follows

Focal groups primarily engaged in a single activity (i.e., primary behaviour; see § 2.3.5.2 for details) for the duration of the time that they were followed. During 2014 to 2016, 147 focal groups engaged exclusively in travelling (57.9% of the total focal follow time), 16 focal groups engaged exclusively in milling (9.1% of the total focal follow time), 3 groups rested with backs exposed, and 3 groups rested submerged (Appendix K). When multiple primary behaviours were observed during a group follow, travelling and milling were most often observed (22 of 25 follows with multiple primary behaviours). Four groups exhibited three primary behaviours during the course of a focal follow (Appendix K).

Narwhals were often, but not always, observed engaged in secondary behaviours (see § 2.3.5.2 for details) during focal group follows (Table 21). Diving was the most frequently observed secondary behaviour.

Nursing behaviour was observed during two focal follows. Both focal groups were single mother-calf pairs in tight, parallel formation; and both were observed on 22 August 2015 (see Smith et al. 2016 for more details).

In 2016, fish chasing was observed during seven focal follows (Table 21). Recall that some focal follows in 2016 involved "targeted" groups displaying particular behaviours of interest, including groups observed chasing fish. Thus, these 7 (of 50) focal follows in 2016 probably over-represent the frequency of chasing fish. These groups comprised 1 to 2 individuals, included either tusked or non-tusked adults, and in only one instance was a mother-yearling pair observed chasing fish. The tracks followed by narwhals chasing fish were typically very circuitous (Figure 23).

Side and back swimming, which narwhals engaged in while foraging on schooling fish during ad lib observations (§ 3.6.2.1), was observed during 23 focal follows, though only during one of these 23 follows was fish chasing also observed (Table 21). Focal group sizes ranged from 1 to 11, and of the 21 groups for which group composition was determined, 5 included calves.

TABLE 21. Secondary behaviours exhibited by narwhal focal groups during the shore-based study at Bruce Head, 2014–2016.

Secondary Behaviour(s)	Primary Behaviour			
	Travel	Mill	Rest with Back Exposed	Rest Sub-merged
Diving	131	10	1	2
Diving, Back swimming	9	1	0	0
Diving, Back swimming, Bubble rings, Rubbing	1	0	0	0
Diving, Back swimming, Bubble rings, Rubbing, Tusking	1	0	0	0
Diving, Side swimming	3	0	0	0
Diving, Bubble rings	1	0	0	0
Diving, Bubble rings, Rubbing	1	0	0	0
Diving, Bubble rings, Rubbing, Tusking	0	1	0	0
Diving, Rubbing	5	0	0	0
Diving, Nursing	1	0	0	0
Back swimming	3	1	0	0
Back swimming, Rubbing	0	1	0	0
Back swimming, Side swimming, Fish chase	1	0	0	0
Side swimming	3	2	0	0
Rolling	0	1	0	0
Rubbing	0	1	0	0
Rubbing, Tusking	0	1	0	0
Nursing	0	1	0	0
Fish chase	6	1	0	0
None	36	23	8	5

Surface activities (rubbing and tusking) were observed during nine focal follows (Table 21). Group sizes ranged from 2 to 6, and included both tusked and non-tusked narwhals. Four of these groups included calves.

3.5.2 Characteristics of Focal Group Tracklines

In 2016, the average “unbiased" (i.e., focal group was not targeted in order to characterize a particular behaviour) trackline with >2 fixes consisted of seven fixes and a track duration of 3.4 minutes (Table 22). Tracklines in 2016 were significantly shorter in both duration and total distance covered, and less linear, than in previous years (all overall *p*-values <0.0001; Tukey-Kramer *post-hoc* *p*-values <0.05); values for 2014 were not significantly different from 2015.

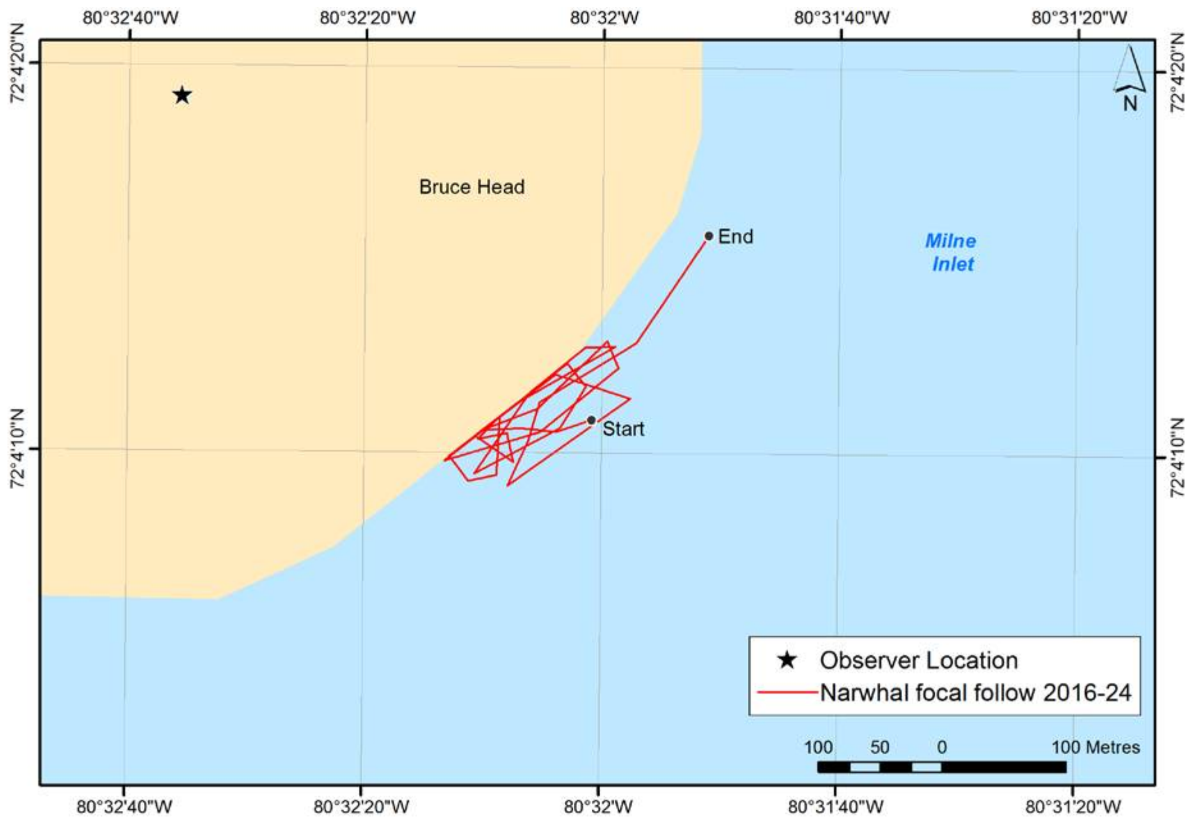


FIGURE 23. Trackline for a single adult narwhal (without a tusk) observed chasing fish at Bruce Head, 14 August 2016.

TABLE 22. Characteristics of tracklines with >2 fixes for all focal groups during the shore-based study at Bruce Head, 2014–2016.

Focal Group/Trackline Parameter	**Mean [min, max] by year**			
	2014 (*n* = 31)	2015 (*n* = 88)	2016 (*n* = 34), "unbiased"[1]	2016 (*n* = 4), "targeted"
Group size	5 [1, 34]	4 [1, 19]	2 [1, 6]	1 [1, 2]
Number of fixes	6 [3, 22]	6 [3, 25]	7 [3, 40]	18 [4, 37]
Track duration (min)	6.6 [0.4, 20.4]	5.1 [0.4, 30.6]	3.4 [0.4, 23.2]	12.9 [3.6, 23.5]
Total distance (m)	364.7 [26, 1193]	319.1 [37, 1401]	158.1 [14, 590]	614.0 [195, 1726]
Linearity[2]	0.9 [0.4, 1]	0.9 [0.2, 1]	0.8 [0.1, 1]	0.4 [0.1, 1]
Average trackline speed (kt)[3]	1.9 [0.4, 4]	2.2 [0.6, 4.4]	1.8 [0.5, 3.2]	1.9 [0.9, 3.3]
Minimum leg speed (kt)	0	0	0.1	0.1
Maximum leg speed (kt)	4.9	7.6	4.4	4.9

[1] "unbiased" = focal group was not targeted in order to characterize a particular behaviour.
[2] Linearity values close to 1 indicate a straight trackline.
[3] 1 kt = 0.51 m/s

Tracklines of focal groups that were targeted in order to characterize their behaviour while chasing fish were more circuitous (i.e., less linear) than for focal groups selected in an unbiased manner (Table 22).

Substantially fewer groups were followed in 2016 than in 2015 (Table 22), primarily because narwhals were observed to spend less time in the BSA in 2016 compared to previous years. Though narwhals were frequently present in the larger study area (SSA), they were often observed to move away from the nearshore area, and beyond the BSA, as they transited north (§ 3.6.1.1). Also, the tracklines documented in 2016 were more widely distributed in the BSA than in years past, reflecting effort by the observation team to record as many focal follow data as possible (Figure 24).

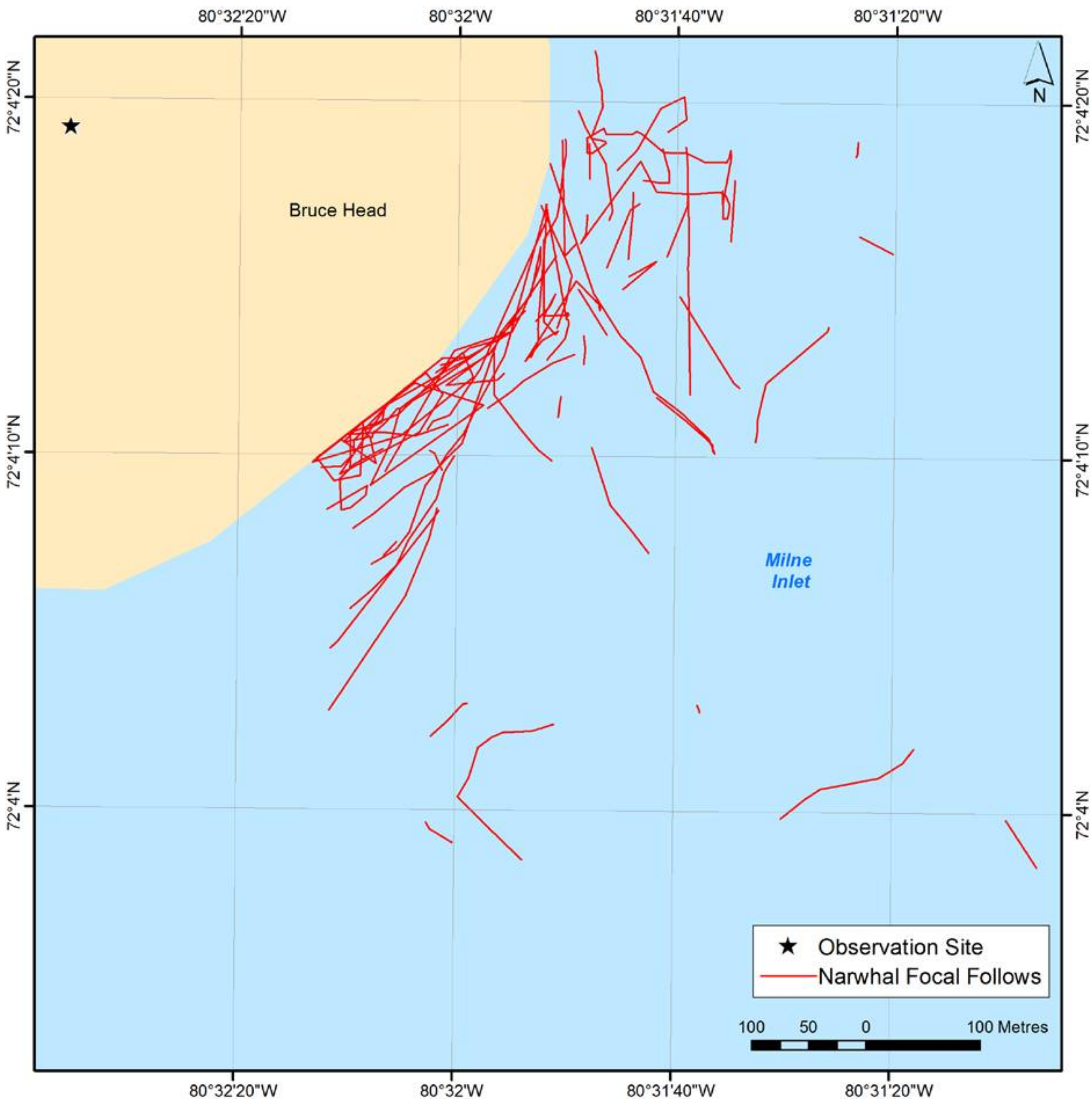


FIGURE 24. Tracklines for narwhal focal groups (*n* = 47) "followed" during the shore-based study at Bruce Head, 2016.

3.5.3 Narwhal Behaviour in the Presence of Large Vessels

Note that focal group trackline results presented in this section classified anthropogenic activity as occurring if it occurred at the time of the focal group follow or during 15 minutes prior to the follow.

The following comparisons are based on a very limited number of available focal-follow data: only four focal follows provided trackline data in the presence of large vessels (see § 2.4.2), so these results must be interpreted with caution. Linearity of trackline and average trackline speed did not appear to differ in the presence of large vessels relative to "no large vessel" conditions (Table 23). Maximum swim speed was lower in the presence of large vessels, but sample size with large vessels present was small (Table 23).

TABLE 23. Comparison of narwhal focal group and trackline characteristics in the presence vs. absence of large vessels, for all focal follows with >2 fixes during the shore-based study at Bruce Head, 2014–2016.

Focal Group/ Trackline Parameter	Focal group/trackline metric (mean [min, max]), according to presence or absence of large vessel[1].	
	None[2]	Large Vessel
Number of follows	133	4
Group size	4 [1, 34]	6 [2, 10]
Number of fixes	7 [3, 40]	7 [4, 9]
Track duration (min)	5.3 [0.4, 30.6]	5.7 [2.6, 10.3]
Total distance (m)	307 [14, 1726]	319 [105, 538]
Linearity[3]	0.9 [0.1, 1]	0.9 [0.9, 1]
Average trackline speed (kt)	2.1[0.4, 4.4]	2 [1.1, 2.9]
Minimum leg speed (kt)	0	0.2
Maximum leg speed (kt)	7.6	3.9

[1] Large vessels were defined as being present if they were observed in the SSA at the time of the follow or during the 15-minute period prior to the follow.

[2] None = no anthropogenic activity of any kind occurred.

[3] Linearity values close to 1 indicate a straight trackline.

3.6 Ad lib Observations

3.6.1 Narwhal Distribution and Movements in the Inlet

3.6.1.1 Distribution in the Inlet, and South of the Study Area

Narwhals were observed in the area south of the SSA on 23 days, and were commonly observed entering or exiting Koluktoo Bay and in the area generally directly south of the SSA. Narwhals were less frequently observed in the vicinity of Assomption Harbour. It was not uncommon for narwhals to be observed moving in and out of Koluktoo Bay more than once over the course of an 8-hour observation shift.

Narwhals were frequently observed travelling north into the study area, often having come out of Koluktoo Bay. When travelling north, narwhals were generally observed to move at a relatively slow pace, with some milling and resting at the surface. Narwhals typically moved north along the nearshore side and middle of the inlet. On several occasions, narwhals were observed to fan away from the nearshore side and into the middle of the inlet as they reached stratum G (e.g., on 9 and 10 August).

Though not always, northbound narwhals were frequently observed to reverse direction and head south again out of the study area for no apparent reason. This type of movement was observed twice on

10 August: in the morning, ~100 narwhals that had been heading north were observed to suddenly change direction when they reached stratum F2, swimming south and out of the SSA; in the afternoon, ~100 narwhals were again observed heading north, only to reverse direction and head south out of the SSA after reaching substrata F2/G2. A similar movement pattern was observed on 9 and 11 August, though the change in direction on those days was thought to be influenced by the presence of narwhal carcasses in the water at the point (§ 3.6.3.3).

On 15 August, 300+ narwhals were observed milling and travelling slowly north into the SSA, reaching stratum D by 14:00. By 15:00 narwhals were observed throughout the SSA from stratum A to south of the SSA. At 16:10, some narwhals were observed to have changed direction, and by 18:00, there were fewer narwhals (100+) present, and all were travelling south in the southern portion of the SSA (stratum D and south) and south towards Koluktoo Bay. By 19:00, a number of whales in the southern part of the SSA had again changed direction and were once again heading north. At this time narwhals were also observed swimming north out of Koluktoo Bay, and narwhal numbers had again increased to 200+. Narwhals were observed to swim north out of the SSA at ~21:00. There was no apparent reason for the observed changes in travel direction.

On 20 August, 100+ narwhals had been observed milling and slowly travelling north through the SSA, reaching stratum D at ~17:45. At 18:05, the narwhals, which were spread out from strata D to south of the SSA, were observed to change direction for no apparent reason, and then milled and slowly travelled south and towards Koluktoo Bay. At 18:35, the narwhals were observed to again change direction and head north. Approximately 200 narwhals were observed throughout the southern portion of the SSA, extending as far north as stratum C by 19:45.

On 21 August at ~16:20, ~200 narwhals were observed exiting Koluktoo Bay and heading north into the SSA, mostly into the middle and far-shore substrata. Narwhals were observed to travel slowly, reaching as far north as stratum E by 19:10; a few groups of narwhals in the BSA appeared to be lined up with the "tide line" visible on the water's surface. By 21:35, there were no narwhals visible south of the SSA, and all had exited the SSA to the north. The initial "wave" of narwhals was observed to exit out of substrata A1 and A2, and passed between Stephens Island and the nearshore. However, most narwhals were observed to have exited the SSA through Substrata A3 and A2, and passed between Stephens Island and the far-shore.

3.6.1.2 Herding Events

Fewer herding events were observed in 2016 than in previous years. In accordance with Marcoux et al. (2009), herds were generally defined as aggregations of groups of narwhals passing in front of the observation post, and a herding event was determined to have ended when time between successive observed groups was ≥ 30 minutes. These events were not well captured by the data collection protocols described in § 2.3.4–2.3.5. Herding narwhals were often very close to shore, and thus, were not in the field of view of the observers conducting RAD counts (see Figure 2). As well, herding narwhals often swam fast, reducing the likelihood that they would be immediately in front of the observation platform at the very same time that the observers conducting RAD counts were counting strata E and F. (Those were the two strata where narwhals very close to shore were visible.) Also, herding narwhals often travelled past the observation site in such large numbers and at such fast speeds that it was sometimes impossible for the team collecting data on group composition to record group sizes for all passing groups. Hunters on the point were often observed to shoot at narwhals during herding events. General notes on herding narwhals during the 2016 field season are summarized here.

<u>9 August</u> – More than 100 narwhals were observed streaming south past the observation point in large groups during ~21:07 to 21:30. Though the narwhals travelled too quickly for us to document all

individuals in the group composition dataset, groups were observed to contain both narwhals with and narwhals without tusks.

14 August – ~100 narwhals were observed herding south past the point beginning at 08:54. Severe glare hindered sightability, but the passing narwhals were observed to include many young animals, and many mother-calf pairs. Shots were fired at passing whales at 09:09 and 09:14, and whales were observed to dive and continue south, apparently moving away from the nearshore area towards the middle of the inlet as they went south.

30 August – Several thousand narwhals were estimated to have swam quickly past the point from ~11:20 to 13:20. The narwhals were observed to swim south through the study area, did not hug the nearshore as they swam past, and then fanned out to either side of the inlet after passing the point. Passing groups were observed to include animals with and without tusks, juveniles, and mother-calf pairs.

3.6.2 Observations of Narwhal Habitat Use

3.6.2.1 Foraging Activity

Narwhals were observed foraging on schools of arctic cod (*Boreogadus saida*) on numerous occasions during the 2016 field season. Fish species was confirmed when one of the Inuit study team members retrieved a fish specimen from the shoreline on a day when foraging behaviour was observed (Figure 25).

In 2016, schools of fish were first observed in the study area on 28 July; on this day seals were observed swimming rapidly through a "bait ball" and chasing fish. (Some fish schools were described as circular "bait balls"). Over the course of the field season, fish schools were observed on 13 days, and narwhals were observed foraging on the fish on nine of these days. The number of fish present decreased over the course of the field season, with notably fewer fish present by 6 August. Narwhals were last observed feeding on fish on 16 August. Fish schools were commonly observed as dark ribbons that stretched along the shoreline below the observation site. The ribbon was not static and often moved north/south and changed in thickness and shape, especially when narwhals were actively feeding (Figure 26).

Narwhals were observed to swim back and forth through the ribbon of fish, and this activity was captured in some of the focal follows (see Figure 23). Narwhals typically turned onto their side or back shortly before swimming alongside or into the fish (Figure 26). Fish were observed jumping, creating disturbance at the water surface, and swimming away from approaching narwhals. Both individual narwhals and small groups (up to five narwhals) were observed foraging on fish.

On 3 August, what appeared to be white foam was visible on the surface near the fish. No sample of the white foam was collected.

3.6.2.2 Narwhal Birth Event

On 11 August 2016, an adult narwhal without a tusk was sighted in substratum D1 at ~13:16 during the 13:00 RAD count. The narwhal was floating on the surface, appeared lifeless as it drifted in a slow circle, and was initially thought to be dead or dying. The narwhal was observed until 13:46. It appeared to be capable of turning (i.e., circling) in the water, but unable to propel itself forward. Only slow clockwise rotation was observed, but this was limited to two instances. It was observed flipper-slapping and attempting to dive, though it was only briefly below the surface of the water and always remained visible. The narwhal was often observed on its side and back, and at one point the whale appeared to contract its body creating a large splash before sinking slightly deeper in the water column. No blood trail or wounds were visible.

FIGURE 25. Arctic cod specimen collected from the shore below the observation platform following the observation of narwhals feeding on fish schooling nearshore at Bruce Head, 1 August 2016.

FIGURE 26. Narwhals feeding on arctic cod at Bruce Head, 2016.

A ringed seal (*Pusa hispida*) was observed to remain within ~10 m of the floating narwhal during this time. The seal was oriented towards the narwhal and maintained this distance and position as the narwhal drifted. The seal remained close to the narwhal until ~13:30 and then swam away toward the nearshore (westward). The seal was last observed (~13:35) in substratum D1, ~100 m from the narwhal.

The narwhal remained in about the same position in substratum D1 during the 14:00 RAD count. Though it generally appeared lifeless and moved little, it was observed to briefly disappear below the surface on occasion.

A mother-calf pair was observed in substratum C1 at 15:07 during the 15:00 RAD count. Focused observation on this pair of whales commenced at this time. The calf was initially observed on the mother's back and was wrinkled with fetal folds visible. Throughout the observation period, the calf was observed to swim awkwardly in the water, surfacing frequently and bobbing like a cork, before returning to rest on its mothers back. The mother moved north slowly and remained at or immediately below the water's surface.

Three attempted nursing bouts were observed. The mother was observed to turn her body slightly to allow the calf access to nurse. Though the calf appeared to be in the correct position to nurse, milk was not observed, nor were we able to visually confirm that the calf had successfully latched on. Attempted nursing bouts each lasted less than one minute.

On 12 August 2016, a mother-calf pair was observed swimming south past Bruce Head at ~06:15. Though the calf was very small, the observation team was not confident that this was the same pair involved in the birth event observed on 11 August. (Several mother-calf pairs were observed in the area during the days following the birth.) This mother-calf pair was observed slowly travelling nearshore in C1 during 12:30 – 12:45. The calf was observed to remain very close to the mother and frequently bobbed out of the water to breathe.

3.6.2.3 Nursing and Other Observations of Calves and Mother-calf Pairs

<u>3 August</u> – Nursing behaviour was observed by two mother-calf pairs in strata F and G. The adult whales were remained almost stationary at the surface with their tails submerged. The calves were observed surfacing to breath and then swimming below their mothers, presumably to nurse.

<u>5 August</u> – At least four mother-yearling pairs were observed in substrata G1 and H1. These pairs were travelling very slowly, swimming north and then cycling back to the south with the current.

The mother in a mother-calf pair observed swimming south past Bruce Head at 10:35 had a large shoulder wound that was bleeding. This individual was not observed to have been shot at by hunters at the point.

<u>7 August</u> – A lone calf was observed swimming (no obvious direction) through the outer BSA.

<u>9 August</u> – Two calves were observed milling and repeatedly making short dives in substratum F2. No adults were observed.

<u>11 August</u> – Mother-calf pairs were observed amidst the groups of narwhals exiting from Koluktoo Bay and then heading north towards the SSA ~3 hours after the passage of a large vessel (§ 3.6.3.1).

<u>12 August</u> – A mother with a very small calf was observed heading south in substrata E1/F1 at 06:15. A mother with a very small calf was later observed in substratum C1; the pair was slowly travelling away from the nearshore area, and the calf remained close to its mother and frequently bobbed out of the water to breath.

<u>14 August</u> – Many mother-calf pairs were observed amidst the groups of narwhals heading south during the morning herding event (§ 3.6.1.2).

<u>16 August</u> – Several mother-calf pairs were observed swimming south past the point shortly after the cargo vessel *Rosaire A. Desgagnés* entered the inlet (§ 3.6.3.1).

<u>20 August</u> – Nursing behaviour was observed in the BSA at 17:15. A female narwhal was observed resting at the surface while her calf nursed.

21 August – Approximately 15 minutes of nursing behaviour was observed by a single mother-calf pair in substratum H1, beginning at 09:30. This occurred ~1.5 hours after the passage of the *Golden Saguenay* (§ 3.6.3.1).

3.6.2.4 Surface Activity

11 August – At ~10:30, hundreds of narwhals were observed milling and resting in the area south of the SSA between Koluktoo Bay and Assomption Harbour. A pair of tusked narwhals was repeatedly observed to raise their tusks out of the water and cross them in the air. These interactions did not appear violent; the narwhals appeared to slowly struggle to force the tusk of the other narwhal below the water's surface, occasionally also raising their heads above the water's surface.

11 August – At ~17:30, 100+ narwhals were observed milling and frequently interacting with one another at the surface in the area south of the SSA. Both tusks and pectoral fins were observed above the water's surface.

12 August – At ~17:00, a group of four narwhals was observed engaged in surface activities in substratum G2. Narwhals were observed to flipper slap, rub against one another, and raise their tusks or tails above the water's surface.

14 August – Approximately 50 to 100 narwhals were observed logging at the surface in the area south of substratum I3 extending towards the centre of the inlet at ~11:37. Narwhals continued to mill and travel in various directions in the area south of the SSA until ~16:00, when northward movement towards the SSA was observed.

15 August – At 09:00, ~200 narwhals were observed south of the SSA, with the majority of groups south of substratum I2, and only a few groups south of substratum I3. Narwhals were observed to be milling, slowly traveling north, and logging at the surface. At 10:00, narwhals were generally observed south of strata I1 and I2, with a slow general movement northward. Some tusking was observed.

19 August – 200+ narwhals, including many single animals and group sizes up to five, were observed spread out across the southern portion of the inlet, south of the SSA from Koluktoo Bay towards the mouth of Assomption Harbour. Many narwhals were active at the surface, but were too far away to determine specific activities.

20 August – From 11:00 to 13:00, 200+ narwhals (group sizes 1 to 10) were observed south of the SSA and were distributed from the far shore to the mouth of Koluktoo Bay. Narwhals were observed milling, and splashing and tusking were observed. Tusking was again observed later in the day (18:30 to 20:30) in the southern portion of the SSA (strata E to I).

27 August – From 09:25 to 11:15, 50 to 100 narwhals were observed in the area south of the SSA, extending from the mouth of Koluktoo Bay towards substratum I2. Narwhals were generally observed milling and logging at the surface. Tusking was observed in several groups of narwhals.

29 August – Approximately six narwhals were observed engaged in a "flurry" of surface activity near the border between substrata G1 and H1 at ~12:00. Pectoral fins were observed carving through the water's surface, and it appeared that the narwhals were chasing one another. A tail slap was also observed.

30 August – A group of seven tusked adults were observed travelling through the BSA in tight, parallel formation at ~14:50. One of the narwhals was swimming on its back and side, and on one occasion was observed to roll completely, at which point its distended penis was visible.

30 August – A group of four narwhals were observed interacting with one another in substrata C1 and D1. The group comprised two tusked narwhals (one large and one small), and two narwhals without tusks. The non-tusked narwhals were observed rolling on top of one another, and appeared to be targeting the

large tusked male. Pectoral fins were frequently observed above the water's surface, and the large male was observed to occasionally thrust his tusk in the air.

3.6.3 Narwhal Behaviour in the Presence of Anthropogenic Activity

3.6.3.1 Narwhal Behaviour in the Presence of Large Vessels

11 August – At 17:25, 100+ narwhals were observed engaged in surface activity in the area south of the SSA (§ 3.6.2.4). During 17:45 to 17:50, narwhals in the western portion of the inlet appeared to be oriented or slowly travelling towards Koluktoo Bay as the ore carrier *Nordic Orion* entered the inlet and progressed south through the SSA (the *Nordic Orion* passed through the SSA from 17:08 to 18:00). During 17:55 to 18:05, several groups of narwhals (~50 narwhals total) closest to the vessel were observed either travelling parallel or orienting away from the vessel at moderate to fast speeds. Two small groups were observed travelling along a trajectory that would have crossed the bow, but dove before crossing and were not spotted again. Narwhals that had been oriented away from the vessel were observed to stop travelling within a few minutes of the vessel passing them, and began milling and logging at the surface. By 18:25, narwhals in the southernmost strata were headed north, and narwhals south of the SSA were milling or logging at the surface. By 18:45, narwhals in the SSA were observed heading in the general direction of Assomption Harbour, and narwhals that were already south of the SSA were oriented towards Koluktoo Bay. By 19:55, most narwhals had apparently moved into Koluktoo Bay; only ~20 narwhals remained in the area south of the SSA, and all but one group were near the mouth of Koluktoo Bay. From ~20:15 to 21:15, fewer than 50 narwhals, including several mother-calf pairs were observed heading south from the mouth of Koluktoo Bay, and then north into the portion of the inlet along the nearshore. Narwhals (<100) continued to move north into the SSA, and had reached stratum F by the time observations ended at 22:00.

14 August – By 16:00, ~50 narwhals had moved north into the SSA and were primarily distributed in the centre and far-shore parts of strata F to I, where they were milling. At 18:15, the majority of the narwhals (>100) in strata E though H were observed heading south. An increase in volume of breathing (i.e., louder exhalations) and vocalizations alerted observers to a change in behaviour (i.e., change in travel direction). The ore carrier *Golden Bull* had been visible in Milne Inlet to the north of the SSA since ~16:45, and eventually passed south through the SSA from 19:30 to 20:16. Prior to the passage of the *Golden Bull*, >100 narwhals in the southern portion of the SSA were observed to be oriented away from the vessel's trackline at approximate clock bearings 11:00 and 01:00 relative to the trackline. Once the vessel had passed, the narwhals then travelled northwards, parallel (and opposite) to the direction of vessel travel, at moderate and fast speeds. During 20:26 to 20:47, when the ship was south of the SSA, 200+ narwhals were observed travelling north through the SSA. The majority were observed in the far and middle substrata, extending as far north as stratum E. At this time some groups of narwhals were also observed exiting Koluktoo Bay.

16 August – Narwhals had been swimming mostly south past the point at a moderate swimming speed from ~15:20 to 15:50. At 15:50, travel speed increased such that group composition data could no longer be collected. The cargo vessel *Rosaire A. Desgagnés* exited the inlet at this time, passing north through the SSA from 15:51 to 16:20. During 16:20 to 16:30, several groups of mother-calf pairs were observed to travel south past the point; a group of mostly tusked narwhals surfaced in the outer portion of the BSA, where they proceeded to mill and drift slowly north; and a few narwhals were observed to feed close to shore. At 16:50, only two narwhals were observed south of the SSA.

16 August – As the ore carrier *Nordic Orion* approached the SSA from the south (i.e., it was exiting the inlet), a group of ~15 narwhals was observed heading south in the area south of the SSA. This group was primarily composed of tusked narwhals.

19 August – The ore carrier *Golden Pearl* exited the inlet and passed north through the SSA from 12:35 to 13:22. One group of six narwhals was initially observed to swim towards the approaching vessel, approaching it from the front, and then orienting towards it as it came closer. The group abruptly changed direction and swam quickly away from the vessel when the vessel was within <100 m. At 12:50, hundreds of narwhals were observed in strata H and I after the vessel had passed and was in substratum G2. Some narwhals were observed to surface in the wake of the vessel, ~six vessel lengths behind it, and many more were observed to the side of the wake, ~two vessel lengths away. (Vessel length was 225 m.) These narwhals were observed to rest at the surface and some slowly travelled north. At 13:10, when the ship was in the northern part of the SSA, hundreds of narwhals were observed heading north out of Koluktoo Bay, travelling towards the SSA at a moderate pace in the middle and nearshore portion of the inlet. No narwhals were observed in the vicinity of Assomption Harbour at this time.

21 August – The ore carrier *Golden Saguenay* exited the inlet and passed north through the SSA from 07:13 to 08:07. Prior to the passage of the vessel, 100+ narwhals were observed spread out and moving slowly south out of the SSA (at ~06:10). The narwhals were noticeably vocal as observers hiked down to the observation platform at ~06:00. As the vessel approached the SSA from Assomption Harbour at ~07:00, ~30 narwhals swam north along the nearshore side of the "shipping lane", with the majority of narwhals in strata G and H. When the vessel approached to within ~3 vessel lengths (i.e., 3 × 225 m), ~50 narwhals in substrata I2 and H2 were observed swimming towards the nearshore side of the inlet, with the majority of narwhals crossing in front of the bow (at distances >2 vessel lengths away). These narwhals were in many small groups. Two groups of slower-moving mother-calf pairs were observed within 1 vessel length of the vessel, and were not observed to increase swim speed as the vessel drew closer. After the *Golden Saguenay* had passed to the north, many singletons and groups of narwhals (~100 total) were observed travelling south and parallel to the vessel wake. Many narwhals were within one vessel length of the wake, and some were in the wake itself (~5 to 6 vessel lengths behind the vessel). By 07:40, some groups were oriented towards the wake and were observed slowly swimming or milling. A single mother-calf pair was observed to engage in nursing behaviour in substratum H1 from 09:30 to 09:45.

29 August –The cargo vessel *Anna Desgagnés* entered the inlet and passed south through the SSA from 14:26 to 14:58. Small groups of narwhals were observed to converge and form large groups on either side of the vessel's path (both inside and outside the wake). At 15:10, at least four groups of narwhals (group sizes 9, 10, 10+, and 19) were observed in substrata F1 and G1, behind the southbound vessel.

29 August – The ecotourism vessel *Silver Explorer* exited the inlet shortly after two previous large-vessel transits. (*Anna Desgagnés* travelled south through the SSA from 14:26 to 14:58 [see above], and *Nordic Oasis* exited through the SSA from 15:35 to 16:25.) *Silver Explorer* passed north through the SSA from 16:45 to 17:03. Hundreds of narwhals were observed in strata F through I, and were generally observed moving south after the northward passage of the *Silver Explorer*. Some milling and surface activity (i.e., splashing) were observed.

3.6.3.2 Narwhal Behaviour in the Presence of Small Vessels

3 August – A group of four narwhals near the shore dove when a small vessel approached. The same group of four narwhals was observed to re-surface ~15 minutes later in the same location.

9 August – Approximately 60 narwhals were observed streaming out of Koluktoo Bay and heading north through the middle of the inlet. At the same time a sailboat was known to be anchored on the south side of the mouth of Koluktoo Bay.

12 August – 100+ narwhals were observed heading north out of Koluktoo Bay at 10:40. A small vessel had been observed entering the bay at 10:25. At 12:05, narwhals were observed moving south back into Koluktoo Bay.

20 August – A small vessel was observed moving at a fast rate of speed south through the SSA and then on towards Assomption Harbour. Approximately 50 narwhals that had been observed milling south of and in the southern third of the SSA were then observed to move north into/through the SSA.

3.6.3.3 Narwhal Behaviour in the Presence Hunting Activity

31 July – Three narwhals actively foraging on fish were observed to depart the area when shot at once by hunters on the point.

7 August – Approximately 10 narwhals observed swimming near fish along the shore at 17:34 were observed to dive immediately after being shot at.

7 August – Five shots were fired between 17:25 and 17:52 and a narwhal was killed by one of the shots. A small vessel was launched to retrieve the dead narwhal; it returned to the point with the carcass at ~18:10. Narwhals were observed swimming in the area again at 18:20.

9 August – Hundreds of narwhals were observed moving north into the study area. They were observed to initially travel north along the nearshore side of the inlet, but gradually fanned out towards the middle of the inlet and away from the nearshore when they reached stratum G, effectively avoiding the point below the observation platform. At the time, there were three narwhal carcasses in the water at the point, and one of the Inuit study team members commented that the narwhals sometimes “know” there are hunters on the point. The narwhals unexpectedly changed direction and headed south shortly after reaching stratum G.

11 August – Hundreds of narwhals were observed generally moving north into the SSA, milling and swimming at a moderate pace. Narwhals that had been swimming north along the nearshore side of the inlet were observed to veer away towards the middle of the inlet, ~200 m south of the point. At the time, a narwhal that had been shot by the hunters at the point earlier in the morning was in the water being butchered, and blood was in the water spreading south into the study area. After reaching as far north as substratum E1, narwhals were observed to change direction and head south and out of the SSA. Narwhals were observed to spread out in the area between Koluktoo Bay and the entrance to Assomption Harbour, and were observed to mill, rest, and were noted as being very vocal.

11 August – Approximately 100 narwhals were observed milling and moving slowly in substrata D2 to G2/G3. These narwhals did not appear to react to a shot fired at a narwhal as it swam past the point in stratum F1.

13 August – Narwhals were observed feeding on schooling fish in front of the point at ~15:20. Feeding ended abruptly at 15:40 when a shot was fired from the point into substratum F1; narwhals were observed to dive and moved south out of the BSA.

19 August – 100+ narwhals had been observed in mostly small groups (1 to 6 narwhals), milling and logging in strata D to I when a shot was fired at 17:23. Narwhal group size was observed to increase as narwhals grouped together, and there was general movement south through the SSA towards Koluktoo Bay.

3.7 Other Marine Mammals

Twenty-nine sightings (88 individuals) of marine mammals other than narwhals were made opportunistically during the 2016 field season (Table 24). The majority of these sightings were made in the area immediately in front of the observation platform (Figure 27).

TABLE 24. Sightings of marine mammals, excluding narwhals, recorded opportunistically during the shore-based narwhal study at Bruce Head during 30 July – 30 August 2016. The numbers of sightings and individuals probably include some repeated observations of the same individuals.

Species	**Number of Sightings**	**Number of Individuals**
Bowhead whale	1	1
Polar bear	5	5
Ringed seal	18	21
Harp seal	4	57
Unidentified seal	1	4
Totals	29	88

There was a sighting of a single **bowhead whale** (*Balaena mysticetus*) on 11 August, travelling NE close to Bruce Head (Figure 28). The bowhead whale was observed between 07:57 and 08:20, when it dove and was not seen again.

A **polar bear** (*Ursus maritimus*) was observed swimming from the western to the eastern shore of the inlet on 10 August (Figure 27). It is likely that this same bear remained in the area for 10 days because there were an additional four sightings of a bear in roughly the same location. On 15 August, the bear was observed to flee inland and uphill in response to a small vessel that approached close to shore; the bear crested and disappeared over the hill on the opposite shore (i.e., near Agglerojaq Ridge; see Figure 27), an estimated 75 m above the height of our observation platform, in less than two hours. Over the course of the 10-day period, the bear was observed to rest and intermittently feed on a narwhal carcass on the shore. It was last observed in the water near the carcass on 20 August.

There were also many sightings of **seals**: numerous ringed, harp (*Pagophilus groenlandicus*) and unidentified seals were sighted in the study area throughout the field season. Many more seals were observed than were recorded because observation effort was focused on narwhals whenever they were present in the study area.

No **walruses** (*Odobenus rosmarus*) or **killer whales** were observed in 2016.

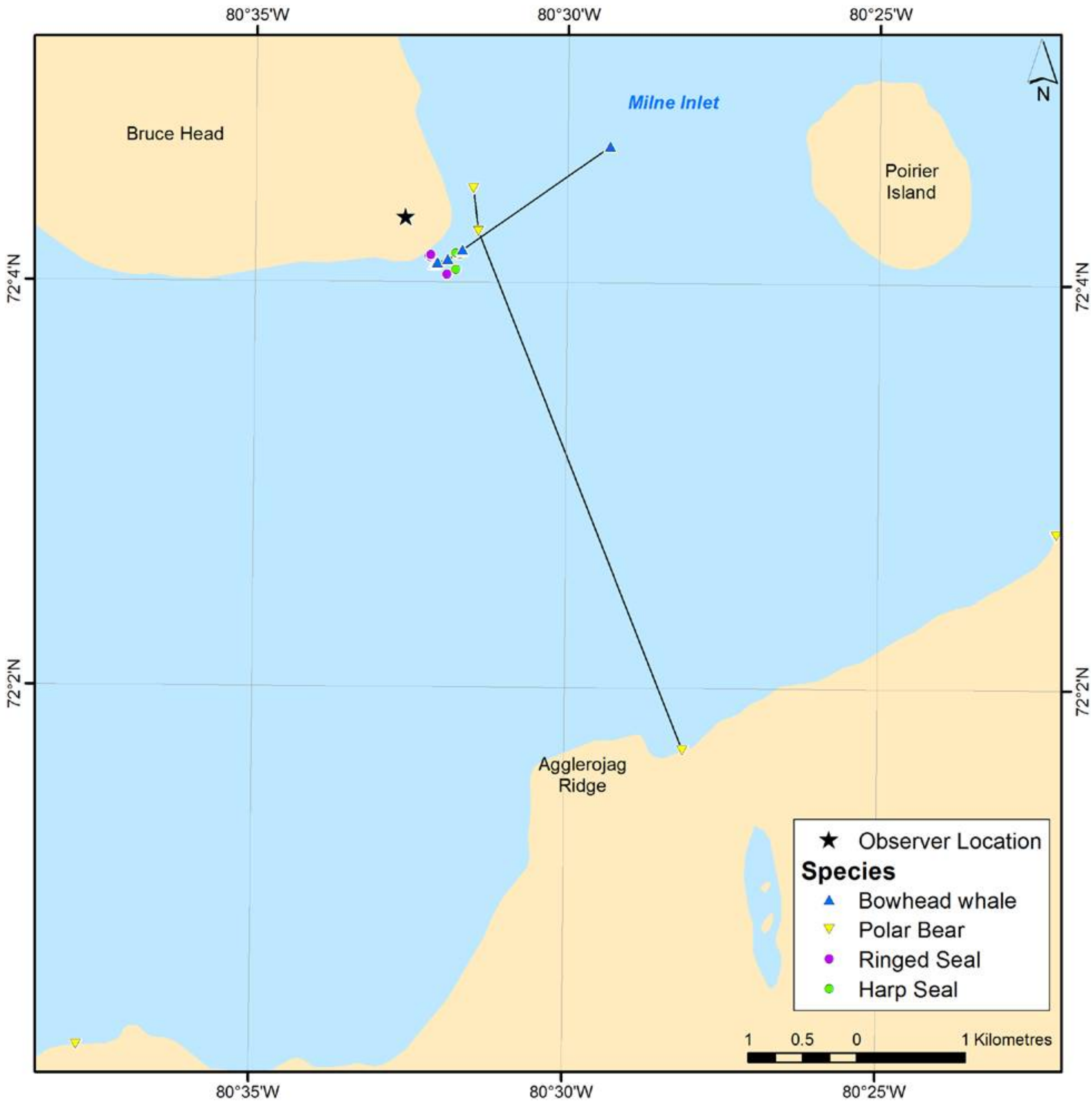


FIGURE 27. Sightings of marine mammals, excluding narwhals, recorded opportunistically during the shore-based narwhal study at Bruce Head, 2016. Also shown are the trackline of a polar bear and bowhead whale. Excludes sightings for which specific locations could not be determined.

FIGURE 28. Bowhead whale observed at Bruce Head on 11 August 2016.

4 DISCUSSION

In 2016, Baffinland's Mary River Project entered into the second year of the Early Revenue Phase. During the open-water season, there were 38 round-trip voyages of ore carriers chartered by Baffinland to ship ~2.7 million tonnes of ore from Milne Port to market in Europe. The shore-based monitoring study of narwhals undertaken each year from 2013 to 2016 is an important component of Baffinland's Marine EEM Plan for marine mammals. It is the first systematic investigation of the effects of shipping on narwhal relative abundance, distribution, and behaviour during the open-water season. The data collection protocols and analysis methods have evolved year after year, but for 2014–2016, the data collection protocols were sufficiently consistent to allow data from the three seasons to be combined for analysis. Consequently, the present results concerning shipping effects on narwhals are considered more robust than previously because of increased sample size from combining 2014, 2015, and 2016 data.

4.1 Observation Effort and Data Collected

In 2016, there was a total of 301.6 hours of observation effort over the course of 27 days at the observation site from 30 July to 30 August 2016. Despite spending fewer days at the observation site because of poor weather conditions, this is comparable to the level of effort achieved in 2015 (307 hours of observation effort over the course of 30 days; Smith et al. 2016) and almost double the effort achieved in 2014 when weather was quite severe (181.2 observation hours conducted over the course of 24 days; Smith et al. 2015). As in 2014 and 2015, weather conditions deteriorated towards the end of the 2016 field season.

An important change made to the study in 2016 was that the observation schedule was modified. Observation effort was scheduled to cover the same 16 consecutive hours (06:00 to 22:00 EDT) each day during the first four weeks of the field program, regardless of large vessel schedule. This time-span was selected to maximize the potential for successful data collection, based on a review of the timing of previous years' data collection efforts and sighting conditions. This change in observation schedule made for much improved camp logistics in 2016: a daily schedule could be established in camp, and the study team was no longer dependent on Baffinland personnel to relay changes in vessel sailing schedules in order to modify observation schedules.

A comparable number of RAD counts were made in 2016 (n = 320) and 2015 (n = 314; Smith et al. 2016), reflecting the similar number of hours of observation effort for those years. Fewer counts were made in 2014 (n = 180; Smith et al. 2015) when weather conditions often resulted in the cancellation or truncation of observation shifts. The quantity of group composition and focal follow data collected in 2016 was affected by reduced numbers of narwhals in the Behavioural Study Area (BSA) in 2016 as compared with previous years, thereby reducing opportunities to collect these data.

4.2 Vessel Traffic and Other Anthropogenic Activities

There has been a clear increase in vessel traffic in the study area over the 2013 to 2016 period, in terms of both number of large and small vessels and the geographic extent transited by these vessels (Appendix L).

The number of large vessels chartered by Baffinland that transited through the SSA during the 2016 field season more than doubled compared to 2015, which itself was more than double numbers for the 2013 and 2014 field seasons. From 30 July to 30 August 2016, there were 40 large vessel one-way transits chartered by Baffinland, of which 20 were observed by the study team. In 2013, 2014 and 2015, 6, 3 and 10 one-way transits of large vessels were observed, respectively (Thomas et al. 2014; Smith et al. 2015, 2016). The majority of Baffinland-chartered large vessel transits in 2016 and 2015 were ore carriers: 36 and 14 in 2016 and 2015, respectively.

There has been no appreciable change in large vessel ecotourism and medium-sized vessel traffic in the SSA during 2013 to 2016 (Appendix L; § 3.2.2 of this report; Thomas et al. 2014; Smith et al. 2016). Small motorized vessel traffic (i.e., aluminum skiffs and voyageur canoes) has seemingly increased in the study area during 2013 to 2016 (Appendices G and L; Thomas et al. 2014; Smith et al. 2015, 2016). The increase in small motorized vessel traffic is correlated with the increased level of hunting observed. The hunting camp at the base of the Bruce Head observation site is only accessible by boat, and was observed to be occupied on 22 days during the 2016 study period, compared with 16 days during the 2015 period (*cf.* Smith et al. 2016). In addition, boat-based narwhal hunting was observed more frequently in 2016 than 2015 (Smith et al. 2016), and the area with small-vessel tracklines was larger in 2016 (Appendix L, Figures L-3 and L-4).

Air traffic over the SSA included helicopters and small fixed-wing aircraft (including aircraft conducting aerial surveys), and did not change noticeably during 2013 to 2016 (Thomas et al. 2014; Smith et al. 2015, 2016).

4.3 Narwhal General Distribution, Movements, and Habitat Use

4.3.1 General Distribution

Many thousands of narwhals have been observed in the southern portion of Milne Inlet, roughly between Stephens Island and the mouth of Assomption Harbour (Figure 1), during 2013 to 2016. Daily counts in the SSA alone have ranged as high as 3761, and large numbers south of the SSA have often been crudely estimated as “hundreds” (Smith et al. 2016; this study — § 3.6.1.1). Narwhals have also been observed to be absent or nearly absent from the area on some days: during 2013 to 2016, no narwhals were observed in the SSA on 14 days, and fewer than ten were observed on five days (Thomas et al. 2014; Smith et al. 2015, 2016; this study — § 3.3). Narwhals were observed resting and milling, and swimming through the area. Herding events were sometimes observed to involve hundreds of narwhals, and sometimes relatively large group sizes (e.g., group sizes of 26, 28, and 30 were recorded during 2014 herding events; Smith et al. 2015). Herding events sometimes appeared to be correlated with anthropogenic activity (Smith et al. 2016).

In 2016, narwhals were generally observed to be unevenly distributed throughout the SSA and adjacent areas in the same manner as observed in previous years. During RAD counts, the majority of narwhals were consistently observed in the southwestern-most strata—i.e., near Koluktoo Bay and the entrance to Assomption Harbour, and were more often observed in substrata 2 and 3 (i.e., the approximately middle and eastern or southeastern portions of the SSA) than in substrata 1 (western portions). The northernmost strata were often observed to contain no narwhals (Tables 7 and 9 of this study; Thomas et al. 2014; Smith et al. 2015, 2016). During *Ad lib* observations, narwhals were frequently observed south of the SSA, including days when no narwhals were sighted during any RAD counts within the SSA. South of the SSA, narwhals were most frequently observed in the general vicinity of Koluktoo Bay. They were observed resting in the "mouth" of the bay, and exiting or entering the bay, sometimes moving in and out of Koluktoo Bay more than once over the course of an 8-hour observation shift. Narwhals were sometimes, though less frequently, observed in the vicinity of Assomption Harbour.

A similar distribution was observed during aerial surveys flown in southern Milne Inlet in the late 1980s and early 1990s: Kingsley et al. (1994) reported that narwhals were always observed in Koluktoo Bay, and they identified the northern part of eastern Koluktoo Bay as well as the southern shore of Bruce Head as a preferred centre of aggregation. Narwhals were also frequently observed along the western side of Milne Inlet from Bruce Head, and a "continuum" was observed stretching northwestward towards Athole Point (Kingsley et al. 1994). Kingsley et al. (1994) also observed that narwhals were absent from eastern and northern Milne Inlet when they were concentrated on the western side.

During aerial surveys conducted periodically (at ~two-week intervals) from 1 August to 22 October 2014, narwhals were present in large numbers in Koluktoo Bay and in the SSA, and were also present in smaller numbers near Milne Port in mid and late August (Thomas et al. 2015a). No narwhals were observed in these same areas during the mid and late September 2014 surveys whereas during aerial surveys conducted in mid-September 2013, narwhals were observed in high numbers at the entrance to Assomption Harbour, in Koluktoo Bay, and around Bruce Head. By late September 2013, no narwhals were observed in Koluktoo Bay and Milne Inlet (Elliott et al. 2015). Here and elsewhere we have not reported on findings of Baffinland's 2015 aerial survey monitoring program.

4.3.2 Movements

Narwhals were more often observed heading south through the SSA (i.e., entering the inlet) than heading north (i.e., exiting) during 2014 to 2016. In a comparable study at the same field location in 2007–2008, Marcoux et al. (2009) observed an area within ~450 m of Bruce Head, and sighted more narwhals entering than exiting Koluktoo Bay. Marcoux et al. (2009) hypothesized that this may have been because (a) narwhals swim farther offshore or spend more time underwater when travelling north and are therefore less often observed, or (b) narwhals "accumulate" in Koluktoo Bay over the course of the open-water period. Support for the former hypothesis was observed during 2014 to 2016, as a larger proportion of narwhals were observed swimming "offshore" (i.e., >300 m from shore) than onshore (i.e., <300 m from shore) when travelling north.

4.3.2.1 Herding Events

Narwhals are known to occasionally move in large herds (100s of animals) at rapid swim speeds near Bruce Head. Fewer herding events were observed in 2016 (n = 4) than in either 2014 or 2015 (16 and 5 events, respectively; Smith et al. 2015, 2016). In 2014 and 2016, the study team did not observe a cause to which any of the 2016 events could be attributed. This is in contrast to 2015, when four of the five herding events were observed in conjunction with some anthropogenic activity: on two occasions, herds of narwhals were observed just prior to, and in front of, the appearance of a large vessel; on one occasion a tusked animal in a group of herding narwhals was bleeding; and on a final occasion, an Inuit study team member communicated with hunters active north of Bruce Head who confirmed that herding narwhals were headed south (Smith et al. 2016). In 2016, collection of group composition data was interrupted by hunting activity on 13 occasions (Appendix I), resulting in narwhals diving and swimming quickly out of the area. It is possible that herding events observed at Bruce Head in 2016 were influenced by hunting activity at camps farther north in the inlet; Inuit study team members were regularly in contact with the hunters at the northern camps, though there were no instances in 2016 when information was relayed that would have led us to attribute an observed herding event to hunting activity farther north.

On several of the occasions when herding narwhals were observed in 2014, Inuit study team members remarked on possible causes for the herding behaviour, including killer whales and hunting activity. Narwhals were observed swimming rapidly and remaining close to the shoreline in Admiralty Inlet in 2013 while being pursued by killer whales (S. Ferguson, DFO, pers. comm., January 2015). On 12 August 2015, seven killer whales were observed immediately south of our study area by an Inuit team member departing Bruce Head by helicopter; though narwhals were observed in the SSA on 12 August, no herding events were observed that day (Smith et al. 2016). Killer whales have not been observed in the study area by the Bruce Head study team during 2013 to 2016 (Thomas et al. 2014; Smith et al. 2015, 2016; this study — § 3.7).

Examples of narwhal herding events have been described in the literature. Marcoux et al. (2009) also documented regular herding activity in front of Bruce Head. They reported that herding events lasted from 30 minutes to ~11 hours, lasted longer on exiting (i.e., travelling north) than on entering the inlet, were composed of 1–642 groups, and were highly aggregated in time.

4.3.2.2 Tide

Narwhal and beluga movements in and out of inlets have been correlated with tide (Vibe 1950; T.G. Smith et al. 1994; Smith et al. 2016). After accounting for the influences of other natural and anthropogenic factors, GLMM model results for the combined 2014–2016 data indicate that narwhal numbers in the SSA are higher during ebb tides compared to all other tidal states (Table 8; Smith et al. 2016). *Ad lib* observations made in 2015 and 2016 corroborate this finding. On a number of occasions in 2016, narwhals were observed to move north into the SSA, usually from Koluktoo Bay, and then reverse direction and head south again for no apparent reason (§ 3.6.1). Some of these movements and direction reversals appeared to coincide with the tidal changes:

- On 10 August 2016, ~100 narwhals that had been heading north changed direction when they reached substratum F2 at ~10:15 and then headed south and out of the SSA; the tide changed from ebb to low slack at ~09:50.
- On 15 August 2016, 300+ narwhals were observed travelling slowly north during ebb tide into the SSA, reaching stratum D by 14:00. Narwhals continued north after this, but by ~17:00 all narwhals still in the SSA were observed heading south; tide changed from ebb to low slack at ~15:15.
- On 20 August 2016, the northward movement of 100+ narwhals through the SSA during 17:45 to 19:45 coincides with a period of ebb tide (14:55 to 19:40); however, during this time narwhals were also observed to head south (briefly at 18:05) before again heading north (at 18:35).

- On 21 August 2016, ~200 narwhals were observed exiting Koluktoo Bay and heading north through the SSA during the ebb tide (15:35 to 20:25), and at 19:10, a few groups in the BSA were observed as being lined up with the "tide line".

Similar movements were observed in 2015 (Smith et al. 2016). On several occasions in 2015, narwhals were observed to gradually move out of Koluktoo Bay and then north into the SSA. Many of these narwhals appeared to be resting at the surface, and several at the northernmost edge of this distribution were oriented in a different direction than that in which they were moving. If narwhals in the area are using Koluktoo Bay as a refuge or resting area, it is reasonable to expect that resting narwhals may simply be "carried out" of Koluktoo Bay on a falling tide, and carried north into the SSA as the tide continues to fall.

Similar patterns of movement have been described for narwhals in Greenland, and for belugas in Cunningham Inlet (Somerset Island). Vibe (1950) observed narwhal herding activity on a regular basis in the fjord Inglefield Bredning (Greenland), and associated these events with tide flow and bouts of foraging. Hundreds of narwhals were observed passing into Inglefield Bredning on the rising tide over the course of an hour, and were then observed exiting the fjord some ten hours later after having finished foraging at the head of the fjord; these movements were observed throughout the summer (Vibe 1950; note that foraging behaviour was not specifically documented). T.G. Smith et al. (1994) found that the daily pattern of beluga distribution in Cunningham Inlet was influenced by tides — belugas moved farthest into the estuaries as tides rose, and then dispersed into deeper water or may have moved out completely when tides ebbed (whales were only able to reach upper channels of inlet on rising tide). These findings demonstrate the importance of accounting for the influences of natural variables when examining the effects of shipping on narwhals.

4.3.2.3 Time of Day

The GLMM model based on combined 2014–2016 RAD data indicated that narwhal counts in the SSA were significantly related to time of day with highest counts around 14:00 EDT. It is uncertain why narwhal numbers would be higher during the mid-day period. Marcoux et al. (2009) found no consistent pattern between narwhal movements and circadian cycle. It is possible that hour-to-hour differences in lighting conditions or other aspects of sightability might be involved in producing higher counts (on average) during the mid-day period.

4.3.2.4 Date

In 2016, narwhals were present in the SSA throughout the 30 July to 30 August period. However, the GLMM analysis of the combined 2014–2016 RAD data indicated that, within the study season, narwhal counts in the SSA were significantly related to Julian date. Narwhal numbers began increasing around 11 August, peaked at about 22 August, and began decreasing about a week later. This finding is in general agreement with observations made during systematic aerial surveys of the same area; narwhals were present in relatively high densities in Milne Inlet and Koluktoo Bay in late July/early August to mid-September in 2007, 2008, 2013, and 2014, with numbers peaking during mid to late August (Elliott et al. 2015; Thomas et al. 2015a,b).

4.3.3 Habitat Use

An understanding of narwhal habitat use of the SSA was gained through analysis of group composition, behaviour, and *ad lib* data. In 2016, narwhal calves were often observed in the SSA and adjacent areas, as observed in previous years (Mansfield et al. 1975; Hay and McClung 1976; Kingsley et al. 1994; Marcoux et al. 2009; Thomas et al. 2014; Smith et al. 2015, 2016), lending further support for the hypothesis that the area is important for calf rearing. During 2013 to 2016, groups with calves or yearlings accounted for 39.7 % of the groups of known composition. Marcoux et al. (2009) observed a higher percentage of groups with calves (52.5%), but acknowledged that their sample of groups of known composition was biased towards mother-calf pairs because they were easily identified. It is possible that our dataset is biased for the same reason but not to the same extent as for Marcoux et al. (2009). In the late 1980s and early 1990s, Kingsley et al. (1994) observed lower proportions of groups with calves in Milne Inlet and Koluktoo Bay (25.6% and 26.2%, respectively). Further support for the importance of Milne Inlet as an important area for calf-rearing comes from the numerous observations of mother-calf pairs and lone calves during 2014 to 2016 (Smith et al. 2015, 2016; this study — § 3.6.2.3). As well, nursing behaviour was observed on four occasions in 2016, and was also observed during two focal follows made in 2015 (Smith et al. 2016). It should be noted that on two occasions, mother-calf pairs were observed in the study area shortly after the passage of a large vessel; nursing behaviour was observed on one of these occasions (§ 3.6.2.3).

On 11 August 2016, we observed the birth of a narwhal calf off Bruce Head (§ 3.6.2.2.). To the best of our knowledge, this is the first time that such an event has been documented in the wild, and adds support to the suggestion by Remnant and Thomas (1992) that Milne Inlet is an area for calving in addition to calf-rearing. Prior evidence of calving in the area is provided by Mansfield et al. (1975), who in the course of sampling 62 narwhals in Koluktoo Bay during the summers of 1963–65, collected two newborn calves with the remains of umbilical cords attached (9 and 16 August 1963), and two foetuses measuring 18 and 28 cm on 19 August 1965. The timing of the 2016 birth event falls within the span of narwhal birth records (late June, July and August) compiled by Best and Fisher (1974).

During 2014 to 2016, the most common primary behaviour was travelling, and tracklines followed by focal groups (excluding those targeted in order to characterise fish chasing behaviour, see below) were relatively straight. Furthermore, tracklines followed in 2016 were observed to be slightly less linear compared to tracklines in 2014 and 2015. These observations are in agreement with the general impression of study team members in the field that narwhals were more often observed simply transiting through the BSA in 2015 compared to 2016. In 2016, narwhals transiting north past Bruce Head were often observed to follow a trajectory that increased their distance from shore (and therefore avoided the BSA) as they headed north. During 2014 to 2016, a wide variety of secondary behaviours were also observed, illustrating the many uses of the inlet by narwhals: back and side swimming, rubbing and tusking, nursing, and chasing fish.

In 2016, narwhals were observed on nine days foraging on arctic cod schooling close to shore during the first half of August. Fish chases were also observed during seven focal follows, during which groups comprised 1 to 2 individuals. Additional instances of side and back swimming, exhibited by narwhals foraging on arctic cod during *ad lib* data collection, were recorded during focal follows. Mother-calf pairs were observed to engage in these behaviours (fish chasing and side or back swimming) though the majority of these groups did not include calves or yearlings. Narwhals have been previously shown to consume arctic cod in the area. Of the 62 narwhal stomachs sampled by Mansfield et al. (1975) during 1963–65 in Koluktoo Bay in summer, ten were found to contain small amounts of squid beaks and arctic cod otoliths, and additional three contained unidentified fish remains. Finley and Gibb (1982) found arctic cod in the stomachs of narwhals harvested during the open-water season (primarily collected at Kounuk, on the western shore of Eclipse Sound) during late July to mid-September in 1978 and 1979. However, the amount of cod (and total amount of all prey types consumed) in these stomachs was less than from narwhals harvested earlier in the season at the ice edge and in ice cracks near Pond Inlet; empty stomachs were also only observed during the open-water season (Finley and Gibb 1982). Narwhals have also been observed participating in mixed species "feeding frenzies" on arctic cod near Pond Inlet and Grise Fjord in August and September (Finley and Gibb 1982; Finley et al. 1990b).

The presence of arctic cod did not appear to influence narwhals in the BSA to a large extent during 2016. Note that we can only comment on narwhal behaviour relative to arctic cod presence in the BSA as we were only able to see below the water's surface a short distance from the observation point. The number of narwhals observed foraging on arctic cod was generally small: foraging activity was observed by singletons or small groups of up to five narwhals (§ 3.6.2.1). As well, narwhals were not always observed foraging on arctic cod when it was present. This suggests that other, more influential factors determined the distribution and behaviour of narwhals in the study area. For example, on three occasions in 2016 (§ 3.6.3.3) narwhals were observed to abandon their foraging on arctic cod after being shot at by hunters on the point. As well, on 2 August 2016, narwhals were observed foraging on fish in the BSA approximately one hour prior to the northward passage of the *Nordic Orion*, but were observed to have left the BSA shortly (within ~30 minutes) after the passage. In contrast to this, on 16 August, narwhals were observed foraging on fish shortly after the northward passage of the *Rosaire A. Desgagnés*.

A variety of surface activities were observed in Milne Inlet during 2013 to 2016. In 2016, the majority of surface activity was recorded in the southern end of Milne Inlet, generally in the area between the entrances to Koluktoo Bay and Assomption Harbour. Milling, resting and logging at the surface, and interacting with one another (tusking, pectoral fin slapping, and splashing) were often observed. Tusking was also observed farther north in the inlet, but was much less common there (i.e., 3 instances of tusking recorded during focal follows in 2014 to 2016). Because most of these observations (except for tusking activity) were made at distances beyond ~4 km, it was rarely possible to determine the age and "sex" category of the individuals involved, thereby limiting our ability to further characterise these events. However, "unusual" behaviour, possibly (on rare occasions) including mating behaviour, was sometimes displayed in relative close proximity to the observation site.

Mating behaviour may have been observed by the study team on two occasions during this study. On 30 August 2016, two tusked narwhals (one large and one small), and two narwhals without tusks, were observed rolling on top of one another and pectoral fins were often observed in the air; the non-tusked narwhals appeared to have been targeting the larger tusked male. No copulation was observed during this interaction. However, at roughly the same time and location in the study area, a second group of seven tusked narwhals was observed travelling in a tight parallel formation, and when one individual rolled on its back, its penis was observed to be distended. On 13 August 2014, a pair of narwhals (one with a tusk and one without) were observed to engage in rubbing activity prior to orienting themselves belly-to-belly horizontally in the water. After only a short time in this position, the narwhals separated, at which point the male's penis was visibly extended (Smith et al. 2015). The only published record of mating behaviour is found in Vibe (1950), who described observations made by a Greenlandic Inuk as follows: "The whales copulated standing vertically in the water with their bellies turned towards each other". Unfortunately, there was no reference to time of year when this activity was observed. Based on the examination of reproductive tracts and foetuses, mating activity in narwhals is known to occur from March to May, with a peak in mid-April (Best and Fisher 1974; Hay 1984). It seems unlikely that the mating behaviour observed in August in Bruce Head results successful fertilization.

4.4 Narwhals in the Presence of Anthropogenic Activity

Narwhals are exposed to a variety of anthropogenic activities on a regular basis in southern Milne Inlet. All vessel traffic and other human activities observed in the study area during 2014–2016 were recorded, and vessel traffic and hunting were considered in analyses. However, it is recognized that narwhals may be influenced by undetected anthropogenic activities. Depending on the degree and duration of carry-over effects between a human activity and narwhal response, observations on narwhals in a "disturbed" state may be collected when there is no direct evidence of disturbance. This could occur, for example, if observers arrive at the observation site after an undetected vessel has passed through the study area. The ability (power) of the current analyses to detect and characterize anthropogenic effects may be reduced somewhat because not all sources of potential disturbance could be documented and taken into consideration.

4.4.1 Narwhals and Large Vessels

Narwhals in the Eclipse Sound complex are not naïve to the presence of large vessels (which we categorized as vessels ≥100 m in length)—narwhals have been regularly exposed to freight, fuel, tourism, Coast Guard, and naval vessels along the "northern shipping route" through Pond Inlet, Eclipse Sound, and Milne Inlet. In 2016, the second year of operations for Baffinland's Early Revenue Phase (ERP), narwhals were exposed to regular and frequent passages of large ore carriers, which were typically 225 m in length (38 round-trip voyages, of which 36 one-way transits occurred during 30 July to 30 August 2016). The shore-based study at Bruce Head sampled a small but important portion of narwhal summering habitat (~82.5 km^2 within the SSA) during the peak season of narwhal abundance, and allowed for detection of small-scale changes in narwhal relative abundance and behaviour related to shipping. The findings concerning effects of large vessels on narwhal relative abundance and distribution, behaviour and group composition are interpreted below based on combined data (systematic and *ad lib*) from 2014, 2015, and 2016.

4.4.1.1 Relative Abundance and Distribution

In 2016, despite increased shipping traffic, narwhals were regularly observed in the SSA and adjacent areas throughout the 30 July–30 August study period. Narwhals were regularly observed in the SSA during and after large vessel passages (see Figure 15). This was also the case in 2014 and 2015 (Smith et al. 2015, 2016).

As noted earlier, it is important to account for the influences of natural factors and other types of anthropogenic activity on narwhals when investigating the effects of large vessels. The generalized linear mixed model (GLMM) based on the combined 2014, 2015 and 2016 data examined the effects of ore carriers on narwhal numbers visible in defined areas (substrata) within the SSA, while accounting for the influences of natural variables (date, time of day, tide, sighting conditions, location within the SSA, year) and one additional type of anthropogenic activity (hunting) on narwhal numbers in those areas. The model based on the combined 2014–2016 data is improved relative to earlier versions because the larger sample size allowed for (1) better handling of the influences of hunting activity, (2) focus on the effects of only ore carriers (versus other large vessels not chartered by Baffinland), and (3) consideration of whether a large vessel was approaching or departing a given substratum.

For **ore carrier transits northward** through the SSA (i.e., exiting the inlet), results from the GLMM analysis of systematic counts were generally consistent with *ad lib* observations made by observers at Bruce Head in 2015 and 2016. Significantly higher numbers of narwhals (~2.8× higher, on average; Table 8) were observed when an ore carrier was headed north through the SSA and approaching a given substratum versus periods when no ore carriers were present. In this scenario, the model indicated that highest numbers of narwhals occurred in strata F–I of the SSA (southern portion, Table 9) as an ore carrier approached. These results are supported by *ad lib* observations of narwhals within the southern portion of the SSA (this study; Thomas et al. 2014; Smith et al. 2015, 2016). For example, on 21 August 2016, narwhals that had been previously observed south of the SSA were observed heading north into the SSA in advance of the *Golden Saguenay,* which had departed Milne Port. Higher number of narwhals in the SSA may also be explained by narwhals moving out of Assomption Harbour and the Milne Port area ahead of ore carriers transiting northward. Narwhals have been observed both in the Milne Port area by Baffinland personnel (ERM 2015) and in Assomption Harbour during aerial surveys (Thomas et al. 2015a).

The number of narwhals in a substratum was significantly lower (~1.8× lower, on average; Table 8) during periods when an ore carrier was headed north and departing a given substratum versus periods when no ore carriers were present. This indicates that once a vessel passed through an area, at least some narwhals had exhibited a localized avoidance response. *Ad lib* observations were variable and in some cases supported this model result. For example, immediately after the passage of the *Golden Saguenay* on 21 August, many narwhals were observed travelling south and out of the SSA. However, in some cases, *ad lib* observations did not seem to support the model finding; for example, hundreds of narwhals were observed resting and slowly travelling north in the southernmost strata shortly after the passage of the *Golden Pearl* on 19 August (see § 3.6.3.1).

For **ore carrier transits southward** through the SSA (i.e., entering the inlet), the GLMM analysis indicated that narwhal numbers in the observation areas tended to be lower, but not significantly so, than numbers when no ore carriers were present; this occurred regardless of whether the vessel was approaching or departing substrata. This finding differs from modelling results for large vessels (ore carriers plus others) in 2014 and 2015 (Smith et al. 2016). In 2016, *ad lib* observations were made during two southward ore carrier transits and these supplement the GLMM results. Narwhals were observed heading south toward Koluktoo Bay in advance of the *Nordic Orion* entering the inlet on 11 August 2016, and again heading south out of the SSA in advance of the *Golden Bull* entering the inlet on 14 August 2016. These responses appeared to be short-term as narwhals were observed to return to the SSA within several hours. Narwhals were also observed to swim south through the SSA towards Koluktoo Bay as the *Nordic Olympic* and *Nordic Oshima* transited south through the SSA in 31 August and 4 September 2015, respectively (Smith et al. 2016). Given the narrow shape of southern Milne Inlet, and nearby location of Koluktoo Bay away from the shipping route, it is not surprising that some narwhals would move into Koluktoo Bay in response to ore carriers.

Despite increased shipping traffic during the ERP and localized movements of narwhal groups in response to large vessels, there were no significant annual differences in narwhal numbers within the SSA in 2014, 2015, and 2016. Narwhals remained in their summering habitat near Bruce Head even though shipping traffic increased from 2014 to 2016.

4.4.1.2 Narwhal Behaviour and Group Composition

In this study, we were interested in characterising factors related to any differences in behavioural response to large vessel presence in Milne Inlet. Thus, some of the group composition variables (e.g., group size) and many of the metrics used to characterise focal group tracklines (e.g., speed) were considered because they were thought to be relevant to narwhal responses to large vessels during earlier studies (Cosens and Dueck 1988; Finley et al. 1990a). Other group composition variables (i.e., "sex" and age) were intended to allow us to investigate if behavioural responses are the same for all segments of the population. Unfortunately, the relatively small size of this dataset (partly a result of confounding by the frequent use of the hunting camp at the base of Bruce Head), precluded the rigorous analysis anticipated.

Available group composition and behavioural data were explored to provide insight into how narwhals respond to large vessel traffic. Some analyses were limited by small sample sizes, and caution must be exercised before generalizing based on these observations. Nonetheless, the results do provide useful information about narwhal responses to large vessels in Milne Inlet.

Based on analysis of combined 2014, 2015, and 2016 data, we had sufficient sample size to investigate the effects of large vessels (ore carriers plus other vessels >100 m in length, e.g., sealift and ecotourism vessels) on narwhal behaviour and group composition. During periods when a large vessel was present in the SSA, narwhals were more inclined to swim closer to shore (<300 m vs. >300 m), south rather than north, and at a faster speed. The presence of a large vessel was also related to narwhal group formation; with a large vessel underway nearby, proportionally more narwhals occurred in a loose (vs. tight) formation, and in circular (vs. parallel) formation. Narwhal group sizes were not found to differ significantly in the absence (average = 3.9) vs. presence (average = 5.1) of large vessels. Similarly, large vessels did not seem to affect narwhal group composition; there was no statistically significant difference in the proportions of narwhal groups with and without calves/yearlings during periods with and without large vessels in the SSA.

Narwhal group sizes observed at Bruce Head during 2014 to 2016 are comparable to those previously observed in Milne Inlet and elsewhere in the eastern Canadian Arctic during summer. Mean group size for this study was 4 individuals (range: 1–45). Group sizes were not found to differ significantly in the absence vs. presence of large vessels. Marcoux et al. (2009) observed groups that ranged in size from 1 to 25, with mean 3.5, and were larger when entering the inlet (i.e., travelling south) than when exiting. The proportions of groups with and without calves/yearlings were not sufficiently different among various types of anthropogenic activity to be recognized as statistically significant. As well, narwhals were regularly observed in the SSA throughout the 30 July to 30 August 2016 study period, and numbers of narwhals counted in the SSA were no lower (and in fact marginally higher) in 2016 than in 2014–2015.

4.4.2 Narwhals and Hunting Activity

The rocks at the base of the cliff at Bruce Head, immediately below the observation site, are often used by local Inuit for hunting narwhals and seals. This method of shore-based hunting (i.e., shooting from the shoreline at the base of Bruce Head vs. from a small vessel) is practiced during the open-water season at a number of locations in Eclipse Sound (Finley and Miller 1982). Most of the hunting (i.e., shooting) activity observed during the shore-based studies at Bruce Head was conducted from the shore, though shooting was also occasionally observed to occur from small vessels in 2015 and 2016 (Smith et al. 2016; § 3.2.4). The level of hunting at Bruce Head in 2016 was likely higher than that observed in 2015 despite a similar number of shooting events being recorded in each year (72+ events in 2015, Smith et al. 2016; 71 events in 2016). In 2016, the camp at the base of Bruce Head was occupied on 22 days (vs. 16 days in 2015; Smith et al. 2016). As well, in 2016 a number of narwhals were successfully harvested using a narwhal set net that was often deployed during 12 days in August (§ 3.2.4). In 2016, it was not uncommon for the study team to arrive at the observation site in the morning to find evidence of a successful narwhal hunt from the previous night.

Narwhals have been observed to respond to shooting by diving and increasing their swim speed (Thomas et al. 2014; Smith et al. 2015, 2016; this study). In 2016, collection of group composition data was interrupted 13 times when shots were fired at passing narwhals (Appendix I). Despite repeatedly being shot at from the same location, narwhals were always observed to return to the area at the base of Bruce Head, though the time until they returned was variable. Narwhals were observed to return to the area as soon as 30 minutes after shots were fired (§ 3.6.3.3), but were also observed not to return to the area during the remainder of an observation shift (5+ hr; Appendix I).

Given the frequency of hunting in the study area, observed narwhal response, and the potential for this to complicate interpretation of shipping effects, the importance of incorporating hunting into the multivariate analysis has been acknowledged (Smith et al. 2015, 2016). Our efforts to incorporate hunting in a meaningful way have improved as more data have become available. In 2015, hunting was included in the model as a categorical variable (i.e., shooting did/did not occur). This simplified depiction of hunting was all that the 2015 model could handle given the limited dataset then available to address all predictor variables of interest (Smith et al. 2016). In 2016, more data were available and that allowed us to include hunting as a continuous variable in the current analysis (i.e., hours since most recent shot; § 2.4.1). Modelling hunting as a continuous variable is clearly a better approach as it more accurately encompasses the nature of the response of narwhals to shooting (i.e., the response changes over time).

A strong "time since shooting" effect was found by the GLMM (Figure 19A). Following a shooting event, narwhal counts tended to be zero or low during the first 2–3 hr as narwhals left the area, but counts subsequently increased during hours 4 to ~9 as narwhals returned; thereafter numbers appeared to decrease (Fig. 19A). The initial portion of this response pattern to "time since shooting" is readily understandable. However, the apparent decrease in counts beyond ~10 hr was unexpected. We would expect that, in the absence of another disturbance or some natural cue (e.g., tide, foraging opportunity), narwhal numbers would increase and then eventually plateau. This model prediction beyond 10 hr may be spurious due to a limitation of the dataset: there were few counts for "time since shooting" >8.5 hours (n = 101 versus n = 5,415 counts for shorter intervals). This limited the model's ability to accurately characterise the response pattern at longer times since shooting.[1] Overall, allowance for hunting in the latest GLMM should improve the fit of the model and allow it to better characterise shipping and other effects, but the details of longer-duration hunting effects are probably not well represented in the model.

4.5 Other Marine Mammals

The species of marine mammals observed during 2016 had all been observed in the area during previous field seasons. Of note is the duration of time (~10 days) that a single polar bear remained in the area feeding on a narwhal carcass. Polar bears sighted in each of 2013 and 2014 were observed in the study area on a single day (Thomas et al. 2014; Smith et al. 2015).

Bowhead whales have been sighted by observers during each of the four study years, though fewer bowhead sightings were made in 2013 and 2016 than in 2014 and 2015. In all years, bowheads were sighted in August (from 9 to 26 August, across all years; Thomas et al. 2014; Smith et al. 2015, 2016; this study — § 3.7). The bowheads sighted during 2013 to 2015 were determined to be adults (previously reported as juveniles) based upon recent examination of available photos; the bowhead sighted in 2016 was determined to be either a small adult or large subadult (B. Koski, LGL, pers. comm., February 2017). During aerial surveys conducted on behalf of Baffinland, several bowhead whales were observed in the study area (and Koluktoo Bay) during the open-water seasons of 2007 and 2008 but not during 2013 and 2014 despite considerable survey effort (Elliott et al. 2015; Thomas et al. 2015a).

Over the course of their two-year study during the open-water periods of 2007 and 2008, Marcoux et al. (2009) made 33 bowhead sightings and nine beluga sightings; and reported that 70% of these whales

[1] As well, 13,908 count records included no value for time since shooting because no shot was observed in the period of continuous observation prior to that record. These missing values were coded as 12.5 hr, a value slightly larger than the longest time since shooting record (i.e., 11.9 hr). Making this substitution was deemed a reasonable approach (§ 2.4.1). However, our efforts to more accurately represent hunting in the model could be improved if a continuous record of hunting activity in the study area were available. This would increase the number of records with accurately-known time since shooting >8.5 hr, and reduce the number of missing values in the dataset.

were observed within a narwhal herd. Bowheads sighted during our study were not observed in narwhal herds.

Though not observed during the course of the Bruce Head field study, killer whales have been observed in Milne Inlet in the vicinity of Koluktoo Bay in August (Ford et al. 1986; Campbell et al. 1988; Marcoux et al. 2009; Smith et al. 2016).

4.6 Adequacy of 2016 Study Design and Analysis

4.6.1 Data Collection Protocols

In order to ensure comparability of data across years, we were cautious about making any changes to the data collection protocols that would preclude comparing or combining data across years.

We have not identified any changes to be made to the RAD data collection protocol for any future years of study. It is acknowledged that the relative abundance data likely suffer from detection bias; narwhals close to the far shore and in strata at the north and south ends of the study area are less likely to be detected than those close to the near shore and in strata immediately in front of the observation site. Despite this shortcoming, the study area was not truncated to include only the near shore area around Bruce Head because narwhals were frequently distributed unevenly within a larger portion of the study area (see Table 9) and it was important to record changes in narwhal distribution on this greater spatial scale. This non-uniform distribution of narwhals throughout Milne Inlet has previously been documented by Kingsley et al. (1994). The multivariate GLMM that was used in interpreting the systematic count data provided an ability to allow, at least in part, for differences in sightability within different parts of the study area.

In both 2016 and 2015, it was frequently not possible to collect data on group composition and narwhal behaviour because narwhals were simply not present in the BSA. On a number of occasions, narwhals appeared to fan out as they swam north through the SSA, thereby avoiding the area immediately in front of the observation platform. It is likely that this is attributed to the increased small vessel activity and presence of hunters at the campsite at the base of the cliff below the observation platform. Though moving the observation platform to an area farther away from the hunting camp might result in a better ability to collect group composition and behavioural data, we do not recommend this action owing to the logistical difficulties of such a move, the fact that the current observation location affords an excellent view of much of the southern portion of Milne Inlet, and the advantages of maintaining consistent observation procedures across years.

The *ad lib* observations made in 2016 provided a wealth of information on habitat use by narwhals in Milne Inlet, and helped to characterise narwhal response to various natural phenomena (e.g., tide) and anthropogenic activities. Though improved for 2016, the *ad lib* data collection protocol could be further improved to increase both the quantity and quality of these valuable observations.

4.6.2 Model Specification

Despite having additional data from the 2016 field season available for modelling, the model was still limited in the number of potential predictor variables that could be included. As such, only those variables of highest interest (i.e., ore carrier scenario, year) and most likely to have the greatest effect on narwhal numbers (e.g., sightability, hunting) were retained.

Hunting was included in the model as a covariate, an improvement over the 2015 model when hunting was included as a categorical variable. At this time, the lack of a continuous record of hunting activity is constraining our ability to accurately represent hunting in the model. A continuous record of hunting activity would be available if visual observation effort were extended to cover 24 hours a day (though this would also require that weather conditions not deteriorate to the point where observation shifts are cancelled). Alternately, a datalogger – potentially an underwater acoustic recorder – could be used to record hunting activity for the duration of the field season.

Only ore carrier vessel effects were examined once the 2016 data were combined with 2014 and 2015. Other large vessel types (i.e., sealift and ecotourism vessels) were necessarily included in the 2014 and 2015 RAD models (Smith et al. 2016, 2015) because, when those earlier models were developed, there were few data during ore carrier transits. Sealift and ecotourism vessels may elicit a different response by narwhals owing to the differing behaviour (speed and linearity of trackline) and different acoustic profiles of those vessels relative to ore carriers. Fortunately, the additional data collected in 2016 allowed the model to be refined to focus on ore carrier effects.

Observer bias was not incorporated into the model because the model cannot accommodate any more variables, and because we lack the necessary data to model bias (e.g., independent aerial survey counts made concurrently). We instead attempted to minimize observer bias in the field. All study team members collected data as a single team during a training session (in an effort to make sure all observers were "calibrated" the same); observers worked in pairs such that each pair always included an experienced observer; observers rotated through the different data collection roles; and less-experienced observers were given the option to not make particular counts when they felt their skill level was not adequate (i.e., less-experienced observers did not take on the role of counting narwhals with binoculars when there were many narwhals present in the SSA).

4.7 Summary

The 2016 shore-based study of narwhals at Bruce Head succeeded in meeting project objectives. Additional data required to investigate narwhal response during the open-water season were collected, and Inuit observers were trained and integrated into the study team. The additional data collected in 2016 allowed for the analysis of narwhal relative abundance to be expanded to incorporate more complete information on ore carrier presence and to more accurately represent hunting. Results of our analyses on narwhal relative abundance, distribution, and behaviour in southern Milne Inlet indicated narwhals responded to ore carrier transits by exhibiting temporary and localized displacement and related changes in behaviour. However, there was no overall decrease in the abundance of narwhals in the area.

5 ACKNOWLEDGEMENTS

We thank the following people and companies for their assistance in planning and implementing the Bruce Head observation program in 2016. Data were collected by Heather Smith, Patrick Abgrall, Colin Jones, Jeremy Gatten, Kathleen Leonard, Amber Stephens, and Sarah Penney-Belbin (all LGL); Jimmy Awa, Robert Aglak, James Quaraq, and Enooyaq Sudlovenick (Pond Inlet). Polar bear monitor duties were performed by Phanuel Enooagak, Enooyaq Sudlovenick, and James Pewatoalook (Pond Inlet). Max Bakken and Desmond Roessingh (Baffinland Camp Managers) improved and maintained our camp and kept us well-fed, warm, and safe. We thank Baffinland for setting up the campsite and dealing with logistics related to travel and life in camp: Allan Knight, Jim Millard, William Bowden, Andrew Vermeer, and Katherine Babin assisted with many aspects of camp setup and breakdown, and logistical support throughout the field season; Linda Chepyha and Shelley Potter co-ordinated travel to the field site and other logistical aspects; helicopter pilots flew us to and from camp and supplied us on a weekly basis; Milne Inlet Security and Environment staff kept us informed about large vessel transits and co-ordinated our daily check-in calls; Lea Willemse reviewed the HSE plan; Mary River and Milne Inlet medics assisted with health issues as they arose. George Iqalukjuak (Baffinland Community Liaison Officer) assisted with mobilization logistics in Pond Inlet. We thank the Mittimatalik HTO for supporting this project; Stephanie Besaw (LGL) for downloading AIS data throughout the field season; Anne Wright and Stephanie Besaw (LGL) for assistance with report formatting; Dilip Lal and Jeff Edelen (Topcon Sokkia) for assistance with the theodolite and data logger; Patrick Abgrall and Ted Elliott took care of provisioning the camp with all required scientific equipment; and Val Moulton was the LGL project manager. W. John Richardson of LGL provided senior advice and reviewed this report.

Bruce Head Study Team, 2016. Top row, left to right: Kathleen Leonard, James Quaraq, Phanuel Enooagak, Robert Aglak, Colin Jones; bottom row, left to right: Jeremy Gatten, Heather Smith, Enooyaq Sudlovenick, Patrick Abgrall, Amber Stephens, Jimmy Awa; absent: Sarah Penney-Belbin, James Pewatoalook.

6 LITERATURE CITED

Arab, A., M.L. Wildhaber, C.K. Wikle, and C.N. Gentry. 2008. Zero-inflated modeling of fish catch per unit area resulting from multiple gears: application to channel catfish and shovelnose sturgeon in the Missouri River. North American Journal of Fisheries Management 28:1044–1058.

Asselin, N.C., S.H. Ferguson, P.R. Richard, and D.G. Barber. 2012. Results of narwhal (*Monodon monoceros*) aerial surveys in northern Hudson Bay, August 2011. DFO Canadian Science Advisory Secretariat Research Document 2012/037. iii + 23 p.

Batschelet, E. 1981. Circular Statistics in Biology. London, Academic Press, 371 p.

Best, R.C., and H.D. Fisher. 1974. Seasonal breeding of the narwhal (*Monodon monoceros* L.). Can. J. Zool. 52:429–431.

Boveng, P.L., J.L. Bengtson, D.E. Withrow, J.C. Cesarone, M.A. Simpkins, K.J. Frost, and J.J. Burns. 2003. The abundance of harbor seals in the Gulf of Alaska. Marine Mammal Science 19:111–127.

Campbell, R.R., D.B. Yurick, and N.B. Snow. 1988. Predation on narwhals, *Monodon monoceros*, by killer whales, *Orcinus orca*, in the eastern Canadian arctic. Canadian Field-Naturalist 102(4):689–696.

Cosens, S.E., and L.P. Dueck. 1988. Responses of migrating narwhal and beluga to icebreaker traffic at the Admiralty Inlet ice-edge, N.W.T. in 1986. pp. 39–54 *In* W.M. Sackinger and M.O. Jeffries (eds.). Port and ocean engineering under Arctic conditions, Vol. 2. University of Alaska Fairbanks, Fairbanks, AK.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2004. COSEWIC assessment and update status report on the narwhal *Monodon monoceros* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. vii + 50 p.

DFO (Fisheries and Oceans Canada). 2015. Abundance estimates of narwhal stocks in the Canadian High Arctic in 2013. DFO Canadian Science Advisory Secretariat Scientific Advisory Report 2015/046. 10 p.

Dietz, R., M.P. Heide-Jørgensen, P.R. Richard, and M. Acquarone. 2001. Summer and fall movements of narwhals (*Monodon monoceros*) from northeastern Baffin Island towards northern Davis Strait. Arctic. 54:244–261.

Dietz R., A.D. Shapiro, M. Bakhtiari, J. Orr, P.L. Tyack, P. Richard, I. Grønborg Eskesen, and G. Marshall. 2007. Upside-down swimming behaviour of free-ranging narwhals. BMC Ecology 7:14 (19 November 2007).

Dolphin Communication Project. 2011. Catalog of surface and underwater behaviors of Atlantic spotted dolphins. Accessed 28 January 2016, http://www.dolphincommunicationproject.org/pdf/ethogram.pdf.

Doniol-Valcroze, T., J.F. Gosselin, D. Pike, J. Lawson, N. Asselin, K. Hedges, and S. Ferguson. 2015. Abundance estimates of narwhal stocks in the Canadian High Arctic in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/060. v + 36 p.

Dunn M.R. 2009. Review and stock assessment of black cardinal fish (*Epigonus telescopes*) on the east coast North Island, New Zealand. New Zealand Fisheries Assessment Report 2009/39, 55 p.

Elliott, R.E., S. Raborn, H.R. Smith, and V.D. Moulton. 2015. Marine mammal aerial surveys in Eclipse Sound, Milne Inlet, Navy Board Inlet, and Pond Inlet, 31 August – 18 October 2013. Final LGL Report No. TA8357-3. Prepared by LGL Limited, King City, ON for Baffinland Iron Mines Corporation, Oakville, ON. 61 p.

ERM. 2015. Milne Ore Dock Construction Environmental Management System: Environmental Monitoring Report. Prepared for PND Engineers by ERM Consultants Canada Ltd.: Vancouver, British Columbia.

Fife, D. 2014. fifer: A collection of miscellaneous functions. R package version 1.0. https://CRAN.R-project.org/package=fifer.

Finley, K.J. and E.J. Gibb. 1982. Summer diet of the narwhal (*Monodon monoceros*) in Pond Inlet, northern Baffin Island. Canadian Journal of Zoology 60:3353–3363.

Finley, K.J., and G.W. Miller. 1982. The 1979 hunt for narwhals (*Monodon monoceros*) and an examination of harpoon gun technology near Pond Inlet, northern Baffin Island. Report SC/33/SMIO to the International Whaling Commission. 12 p.

Finley, K.J., G.W. Miller, R.A. Davis, and C.R. Greene. 1990a. Reactions of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, to ice-breaking ships in the Canadian high arctic. Canadian Bulletin of Fisheries and Aquatic Sciences 224:97–117.

Finley, K.J., M.S.W. Bradstreet, and G.W. Miller. 1990b. Summer feeding ecology of harp seals (*Phoca groenlandica)* in relation to arctic cod (*Boreogadus saida*) in the Canadian High Arctic. Polar Biology 10:609–618.

Ford, J.K.B., L.M. Nichol, and D.M. Cavanagh. 1986. Preliminary assessment of the value of underwater vocalizations in population studies of narwhals in the Canadian Arctic. Prepared by West Coast Whale Research Foundation, Vancouver, BC for World Wildlife Fund Canada, Toronto, ON. vii + 44 p.

Funk, D.W., T.M. Markowitz, and R. Rodrigues. 2005. Baseline studies of beluga whale habitat use in Knik Arm, Upper Cook Inlet, Alaska, July 2004-July 2005. Rep. from LGL Alaska Research Associates, Inc., Anchorage, AK, in association with HDR Alaska, Inc., Anchorage, AK, for the Knik Arm Bridge and Toll Authority, Anchorage, AK, the Department of Transportation and Public Facilities, Anchorage, AK, and the Federal Highway Administration, Juneau, AK.

Gailey, G.A. and J.G Ortega-Ortiz. 2000. Pythagoras: Theodolite cetacean tracking. Texas A&M University, Galveston, TX, USA. 71 p. Available at: http://www.tamug.edu/mmbeg/_download/Pythagoras/Pythagoras_manual.pdf.

Gailey, G.A. and J.G Ortega-Ortiz. 2002. A note on a computer-based system for theodolite tracking of cetaceans. Journal of Cetacean Research Management 4(2):213–218.

Gailey, G.A., B. Würsig, and T.L. McDonald. 2007. Abundance, behavior, and movement patterns of western gray whales in relation to a 3-D seismic survey, Northeast Sakhalin Island, Russia. Environmental Monitoring and Assessment 134:75–91.

Hay, K.A. 1984. The life history of the narwhal (*Monodon monoceros* L.) in the eastern Canadian Arctic. Ph.D. thesis, McGill University, Montreal, QC. 255 p.

Hay, K.A. and A.W. Mansfield. 1989. Narwhal, *Monodon monoceros* Linnaeus, 1758. *In*: S.H. Ridgway and R.J. Richardson (eds). Handbook of marine mammals, vol. 4. River dolphins and the larger toothed whales. Academic Press, London, pp. 145–176.

Hay, K., and R. McClung. 1976. Observations on beluga and narwhal in the Canadian high arctic, summer 1974. Fisheries Research Board of Canada, Manuscript Report Series No. 1385. 55 p.

Heide-Jørgensen, M., R. Dietz, K. Laidre, K., and P. Richard. 2002. Autumn movements, home ranges, and winter density of narwhals (*Monodon monoceros*) tagged in Tremblay Sound, Baffin Island. Polar Biol. 25:331–341.

Heide-Jørgensen, M.P., R. Dietz, K.L. Laidre, P. Richard, J. Orr, and H.C. Schmidt. 2003. The migratory habits of narwhals. Canadian Journal of Zoology 81:1298–1305.

Heide-Jørgensen, M.P., P.R. Richard, R. Dietz, and K.L. Laidre. 2013. A metapopulation model for Canadian and West Greenland narwhals. Animal Conservation 16:331–343.

Heide-Jørgensen, M.P., N.H. Nielsen, R.G. Hansen, H.C. Schmidt, S.B. Blackwell, and O.A. Jørgensen. 2015. The predictable narwhal: satellite tracking shows behavioural similarities between isolated subpopulations. Journal of Zoology 297:54–65.

IMO (International Marine Organization). 2016. AIS transponders. Accessed 28 January 2016, http://www.imo.org/OurWork/Safety/Navigation/Pages/AIS.aspx.

Kingsley, M.C.S., H. Cleator, and M.A. Ramsey. 1994. Summer distribution and movements of narwhals (*Monodon monoceros*) in Eclipse Sound and adjacent waters, north Baffin Island, NWT. Meddelelser om Grønland, Bioscience 39:163–174.

Koski, W.R. and R.A. Davis. 1994. Distribution and numbers of narwhals (*Monodon monoceros*) in Baffin Bay and Davis Strait. Medd. om Grønl. Biosci. 39:15–40.

Laidre, K.L., M.P. Heide-Jørgensen, M.L. Logsdon, R.C. Hobbs, P.H. Heagerty, R. Dietz, M.T. Treble, and O.A. Jørgensen. 2004. Seasonal habitat associations of narwhals in the High Arctic. Marine Biology 145:821–831.

LGL and Greeneridge. 1986. Reactions of beluga whales and narwhals to ship traffic and ice-breaking along ice edges in the eastern Canadian High Arctic: 1982–1984. Environ. Stud. 37. Indian & Northern Affairs Canada, Ottawa, ON. 301 p.

Mair, P., F. Schoenbrodt, and R. Wilcox. 2016. WRS2: Wilcox robust estimation and testing. https://CRAN.R-project.org/package=WRS2.

Mann, J. 1999. Behavioural sampling methods for cetaceans: a review and critique. Marine Mammal Science 15(1):102–122.

Mann J. and B. Smuts. 1999. Behavioral development in wild bottlenose dolphin newborns (*Tursiops* sp.). Behaviour 136:529–566.

Mansfield, A.W., T.G. Smith, and B. Beck. 1975. The narwhal (*Monodon monoceros*) in eastern Canadian waters. J. Fish. Res. Board Can. 32:1041–1046.

Marcoux, M., M. Auger-Méthé, and M.M. Humphries. 2009. Encounter frequencies and grouping patterns of narwhals in Koluktoo Bay, Baffin Island. Polar Biology 32:1705–1716.

Minami, M., C.E. Lennert-Cody, W. Gao, and M. Roman-Verdesoto. 2007. Modeling shark bycatch: the zero-inflated negative binomial regression model with smoothing. Fisheries Research 84:210–221.

NAMMCO (North Atlantic Marine Mammal Commission). 2010. Report on the Joint NAMMCO/JCNB Scientific Working Group – narwhal. pp. 291-296 in NAMMCO Annual Report 2009. North Atlantic Marine Mammal Commission, Tromsø, Norway, 529 p.

Priest, H. and P.J. Usher. 2004. The Nunavut Wildlife Harvest Study. August 2004. Nunavut Wildlife Management Board, Iqaluit, NU. 822 p.

R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

RStudio Team. 2016. RStudio: Integrated Development for R. RStudio, Inc., Boston, MA http://www.rstudio.com/.

Remnant, R.A. and M.L. Thomas. 1992. Inuit Traditional Knowledge of the Distribution and Biology of High Arctic Narwhal and Beluga. Unpublished report by North/South Consultants Inc. Winnipeg, Manitoba. vii + 96 p.

Richard, P.R. 2010. Stock definition of belugas and narwhals in Nunavut. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/022. iv + 14 p.

Roberge M.M. and J.B. Dunn. 1990. Assessment of the subsistence harvest and biology of narwhal (*Monodon monoceros* L.) from Admiralty Inlet, Baffin Island, N.W.T. 1983 and 1986–89. Canadian Technical Report of Fisheries and Aquatic Sciences 1747:1–32.

Samuels, A. and P.L. Tyack. 2000. Flukeprints: A history of studying cetacean societies. Pages 9–44 In J. Mann, R.C. Connor, P.L. Tyack and H. Whitehead eds. Cetacean Societies: Field Studies of Dolphins and Whales. University of Chicago Press, Chicago, IL.

SAS Institute Inc. 2012. SAS Online Doc, Version 9.4. Cary, NC.

SEM and LGL. 2016. Mary River Project, Marine Environmental Effects Monitoring Plan (Draft, Vers. 1.1). Prepared by Sikumiut Environmental Management Ltd., St. John's, NL and LGL Limited, St. John's, NL for Baffinland Iron Mines Corporation, Oakville, ON. 81 p.

Shono, H. 2008. Application of the Tweedie distribution to zero-catch data in CPUE analysis. Fisheries Research 93:154–162.

Silverman H.B. 1979. Social organization and behaviour of the narwhal, *Monodon monoceros* L. in Lancaster Sound, Pond Inlet, and Tremblay Sound, N.W.T. M.Sc. thesis, McGill University, Montreal, QC. 144 p.

Smith, H.R., J.R. Brandon, P. Abgrall, M. Fitzgerald, R.E. Elliott, and V.D. Moulton. 2015. Shore-based monitoring of narwhals and vessels at Bruce Head, Milne Inlet, 30 July – 8 September 2014. Final LGL Report No. FA0013-2. Prepared by LGL Limited, King City, ON for Baffinland Iron Mines Corporation, Oakville, ON. 73 p. + appendices.

Smith, H.R., S. Raborn, M. Fitzgerald, and V.D. Moulton. 2016. Shore-based monitoring of narwhals and vessels at Bruce Head, Milne Inlet, 29 July – 5 September 2015. LGL Report No. FA0044-1. Prepared by LGL Limited, King City, ON for Baffinland Iron Mines Corporation, Oakville, ON. 73 p. + appendices.

Smith T.G., M.O. Hammill, and A.R. Martin. 1994. Herd composition and behaviour of white whales (*Delphinapterus leucas*) in two Canadian arctic estuaries. Meddelelser om Grønland, Bioscience 39:175–184.

Strong, J.T. 1988. Status of the narwhal, *Monodon monoceros*, in Canada. Canadian Field-Naturalist 102:391–398.

Stroup, W. W. 2013. Generalized Linear Mixed Models: Modern Concepts, Methods and Applications. Taylor & Francis Group, LLC. Boca Raton, FL.

Terceiro, M. 2003. The statistical properties of recreational catch rate data for some fish stocks of the northeast U.S. coast. Fishery Bulletin 101:653–672.

Thomas, T., P. Abgrall, S.W. Raborn, H. Smith, R.E. Elliott, and V.D. Moulton. 2014. Narwhals and shipping: shore-based study at Bruce Head, Milne Inlet, August 2013. Final LGL Report No. TA8286-2. Prepared by LGL Limited, King City, ON for Baffinland Iron Mines Corporation, Oakville, ON. 60 p. + appendices.

Thomas, T.A., S. Raborn, R.E. Elliott, and V.D. Moulton. 2015a. Marine mammal aerial surveys in Eclipse Sound, Milne Inlet, Navy Board Inlet, and Pond Inlet, 1 August – 22 October 2014. Final LGL Report No. FA0024-2. Prepared by LGL Limited, King City, ON for Baffinland Iron Mines Corporation, Oakville, ON. 70 p.

Thomas, T.A., R.E. Elliott, and V.D. Moulton. 2015b. Marine mammal aerial surveys in Eclipse Sound, Pond Inlet, and Milne Inlet, 1 August – 17 September 2015: Survey methods and effort. LGL Interim Report No. FA0059-1. Prepared by LGL Limited, King City, ON for Baffinland Iron Mines Corporation, Oakville, ON. 7 p.

Vibe C. 1950. The marine mammals and the marine fauna in the Thule District (Northwest Greenland) with observations on ice conditions in 1939–41. Meddelelser om Grønland, Bioscience 150:1–115.

Vincenty, T. 1975. Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations. Survey Review, 23(176):88–93.

Ver Hoef, J.M. and P.L. Boveng. 2007. Quasi-Poisson vs. negative binomial regression: How should we model overdispersed count data? Ecology 88:2766–2772.

Watt, C.A., J. Orr, B. LeBlanc, P. Richard, and S.H. Ferguson. 2012. Satellite tracking of narwhals (*Monodon monoceros*) from Admiralty Inlet (2009) and Eclipse Sound (2010-2011). DFO Can. Sci. Advis. Sec. Res. Doc. 2012/046. iii + 17 p.

Watt, C.A., J.R. Orr and S.H. Ferguson. 2017. Spatial distribution of narwhal (*Monodon monoceros*) diving for Canadian populations helps identify important seasonal foraging areas. Canadian Journal of Zoology 95:41–50.

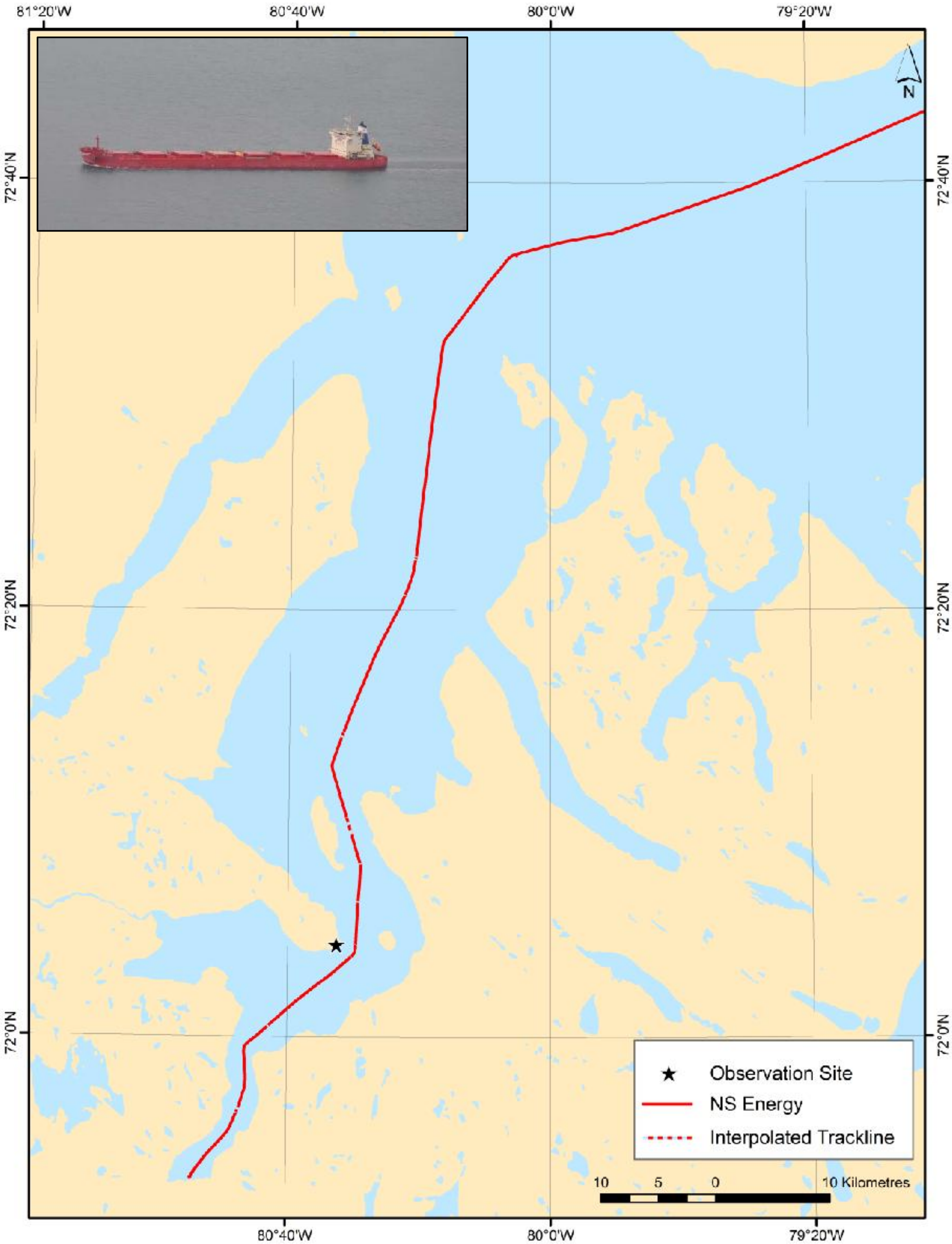
Williams, R., D.E. Bain, J.C. Smith, and D. Lusseau. 2009. Effects of vessels on behaviour patterns of individual southern resident killer whales *Orcinus orca*. Endangered Species Research 6:199–209.

This page left blank intentionally.

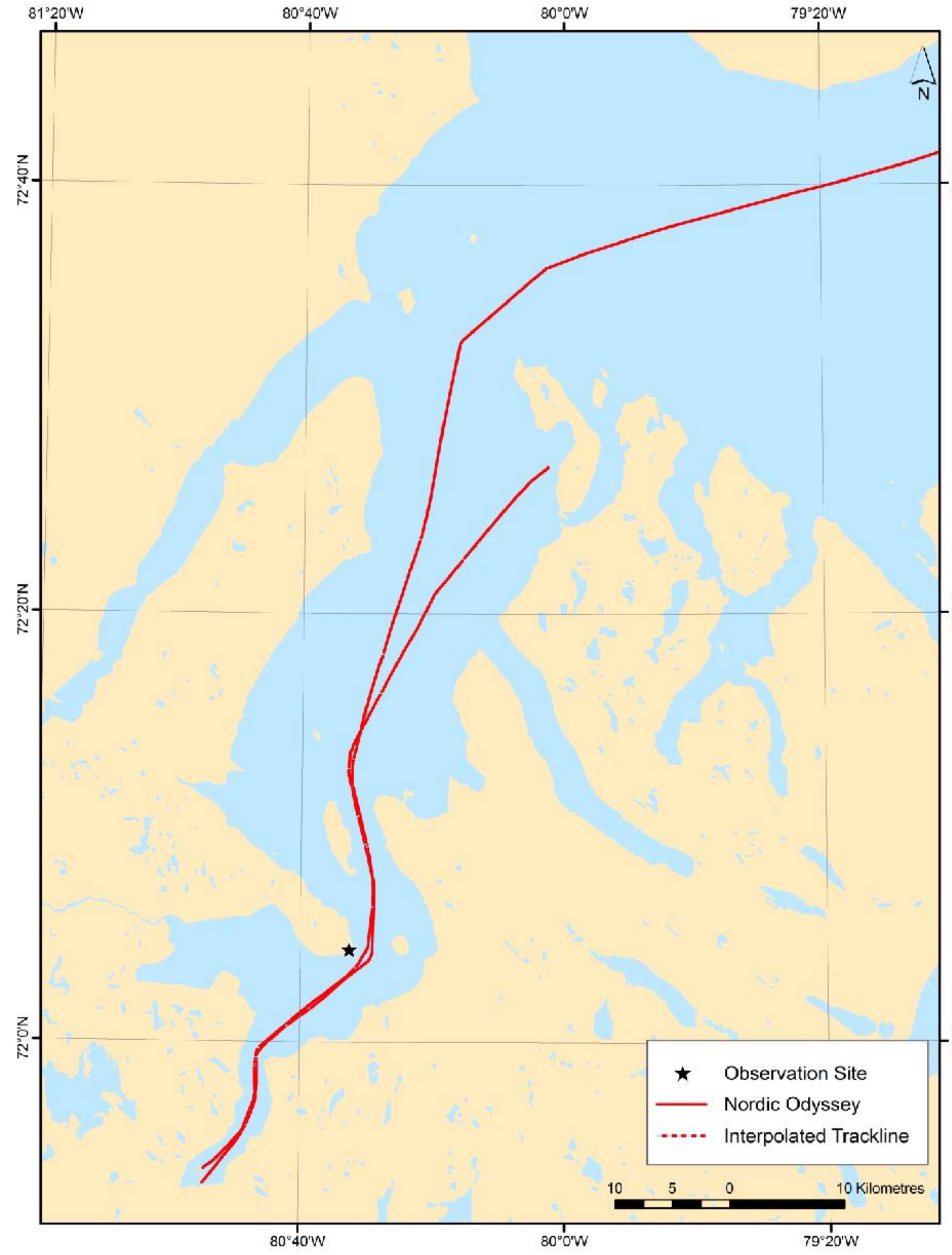
APPENDIX A: VESSEL TRACKS AND PHOTOS

Note: All tracklines in this appendix were created from a series of individual vessel positions (AIS data and total station fixes) and are considered approximations. Segments of trackline were interpolated when errors were present in the AIS dataset (see Appendix B). In segments of track where the interpolated trackline completely overlapped trackline generated directly from AIS positions, the AIS track was deleted from the figure for ease of view (i.e., if no solid trackline runs roughly parallel to the dashed trackline in the figure, then a solid trackline may be assumed to "exist" beneath the dashed segments). Maps show vessel presence in the vicinity of the study area during 30 July – 4 September 2016.

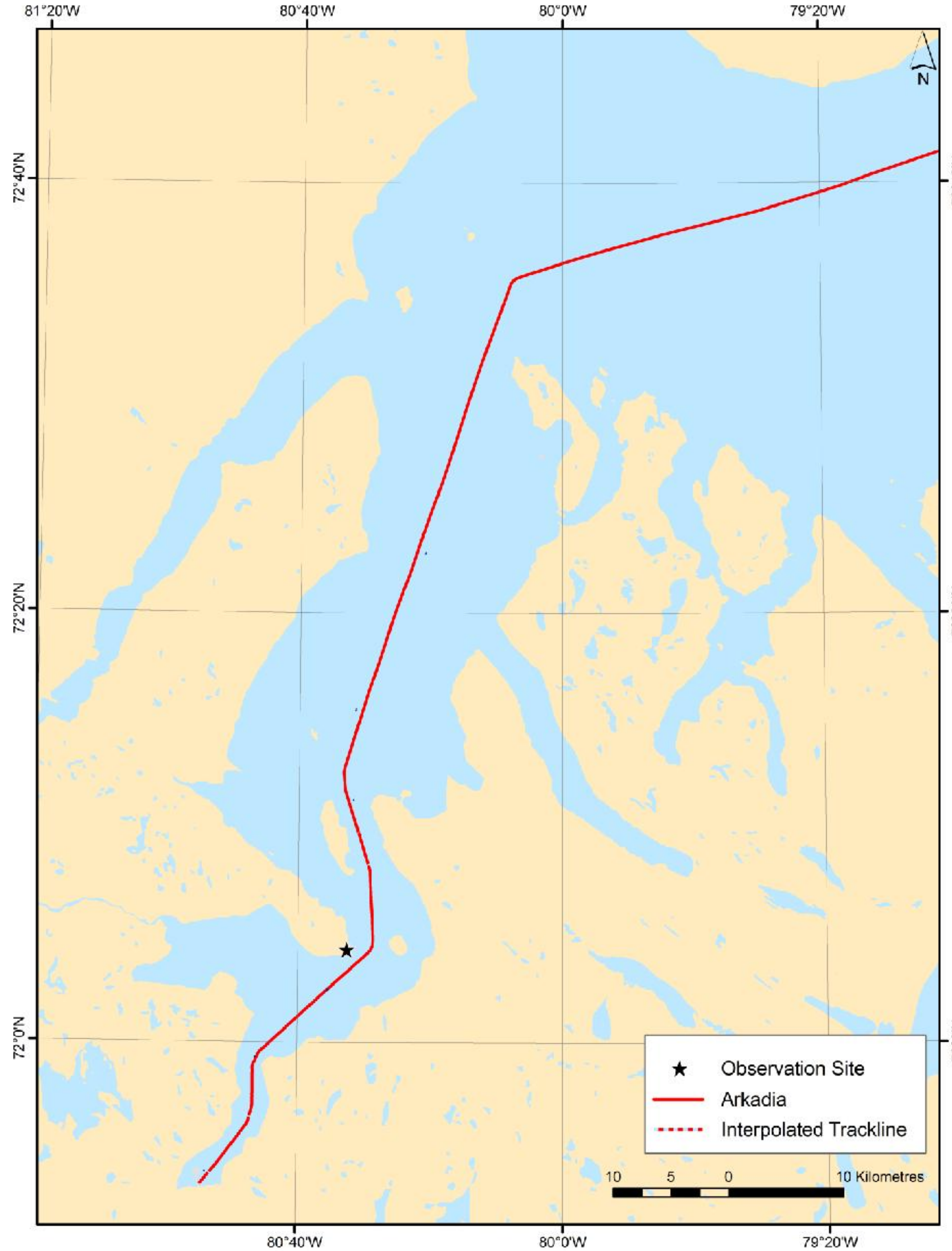
Large Baffinland Vessels (all > 100 m)



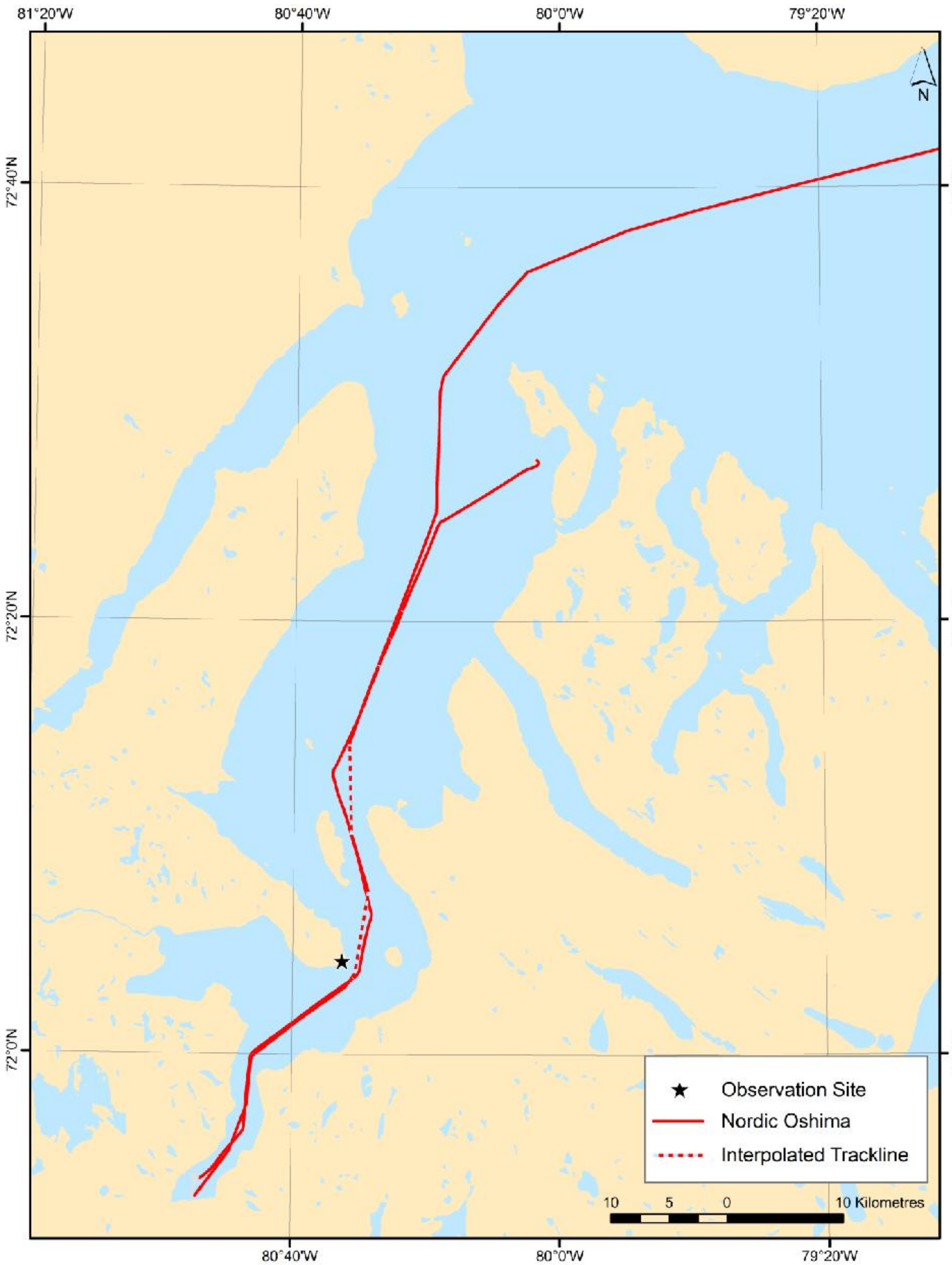
MV *NS Energy* (225 m) – 30 July 2016



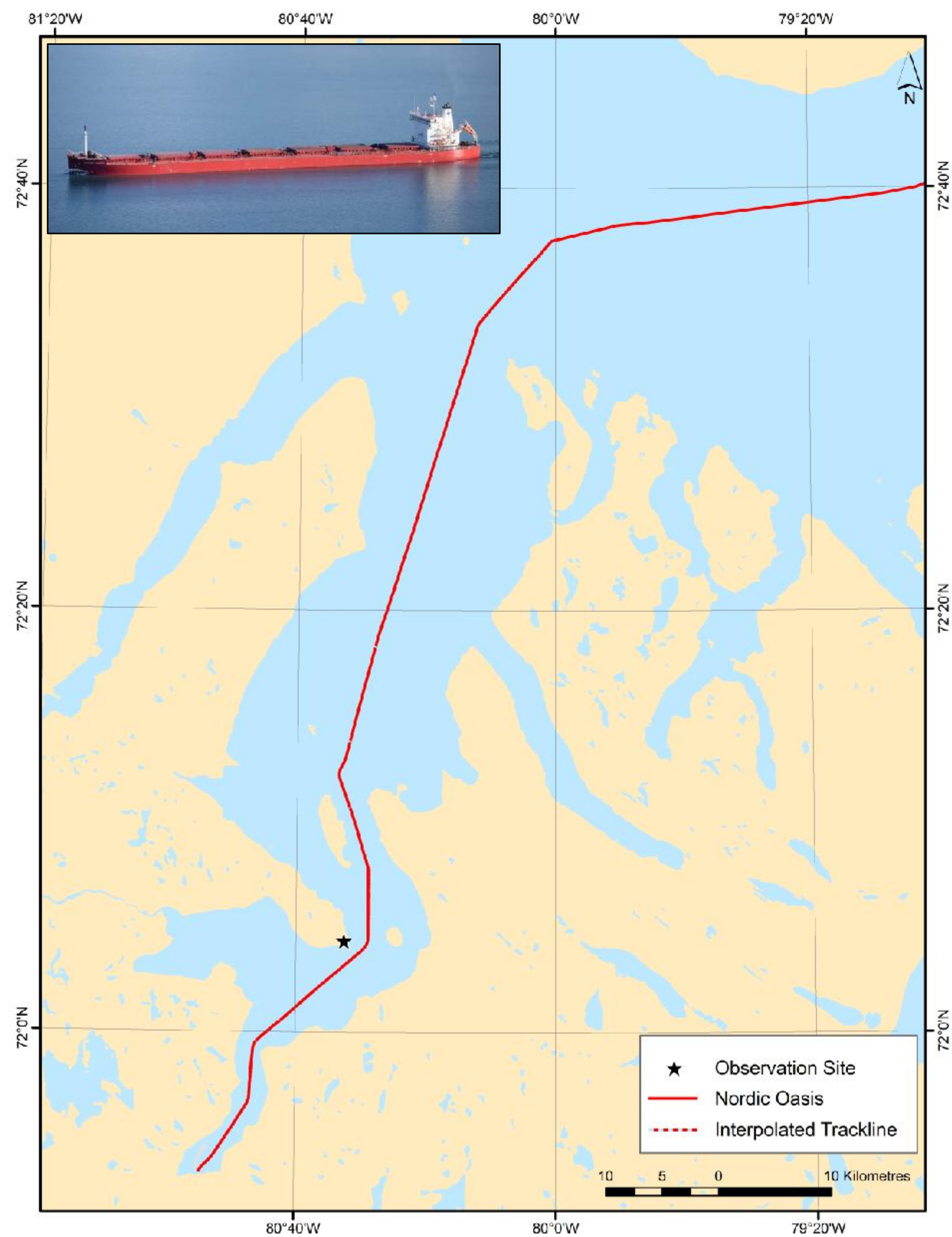
MV *Nordic Odyssey* (225 m) – 30 July and 4 August 2016



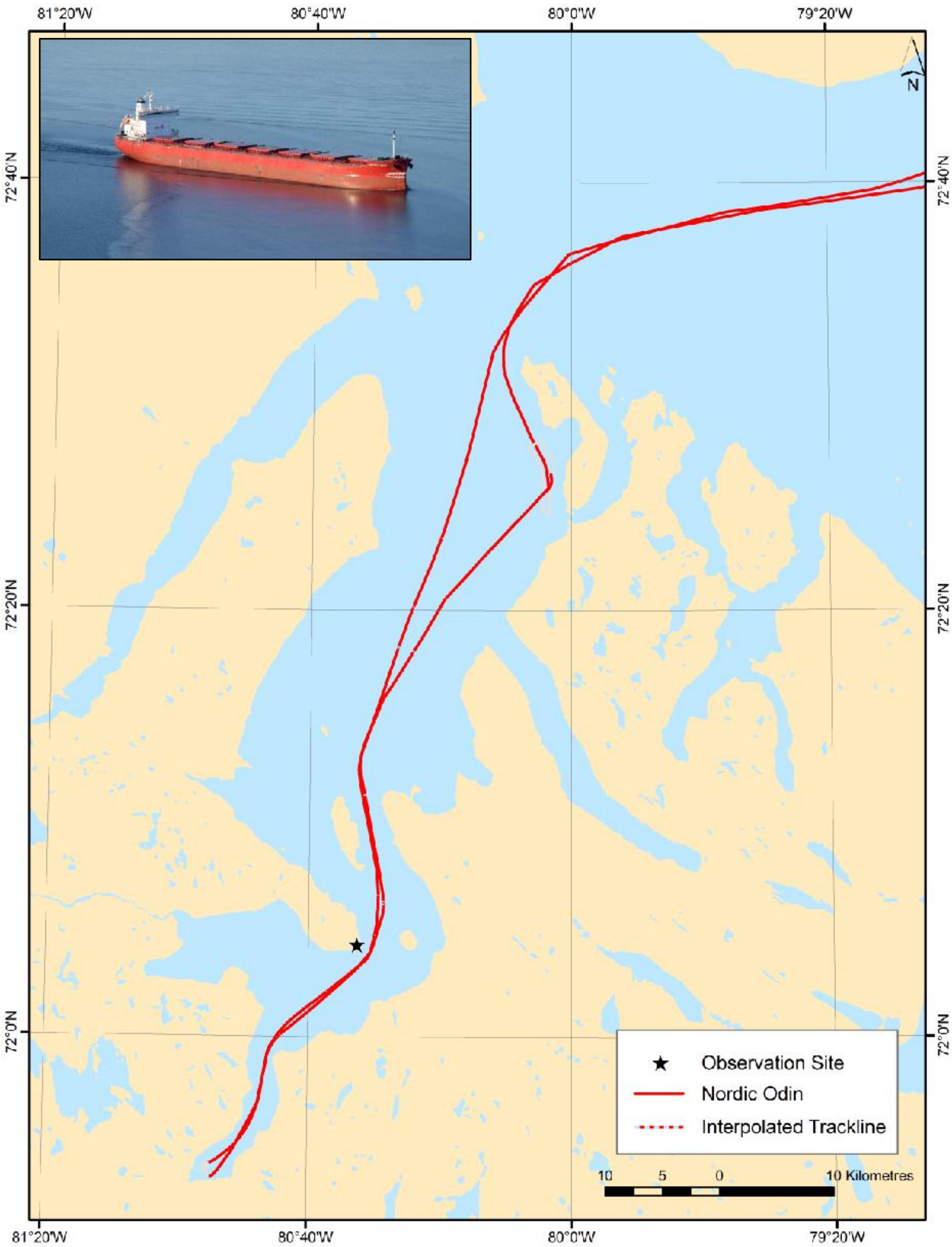
MV *Arkadia* (197 m) – 1 August 2016



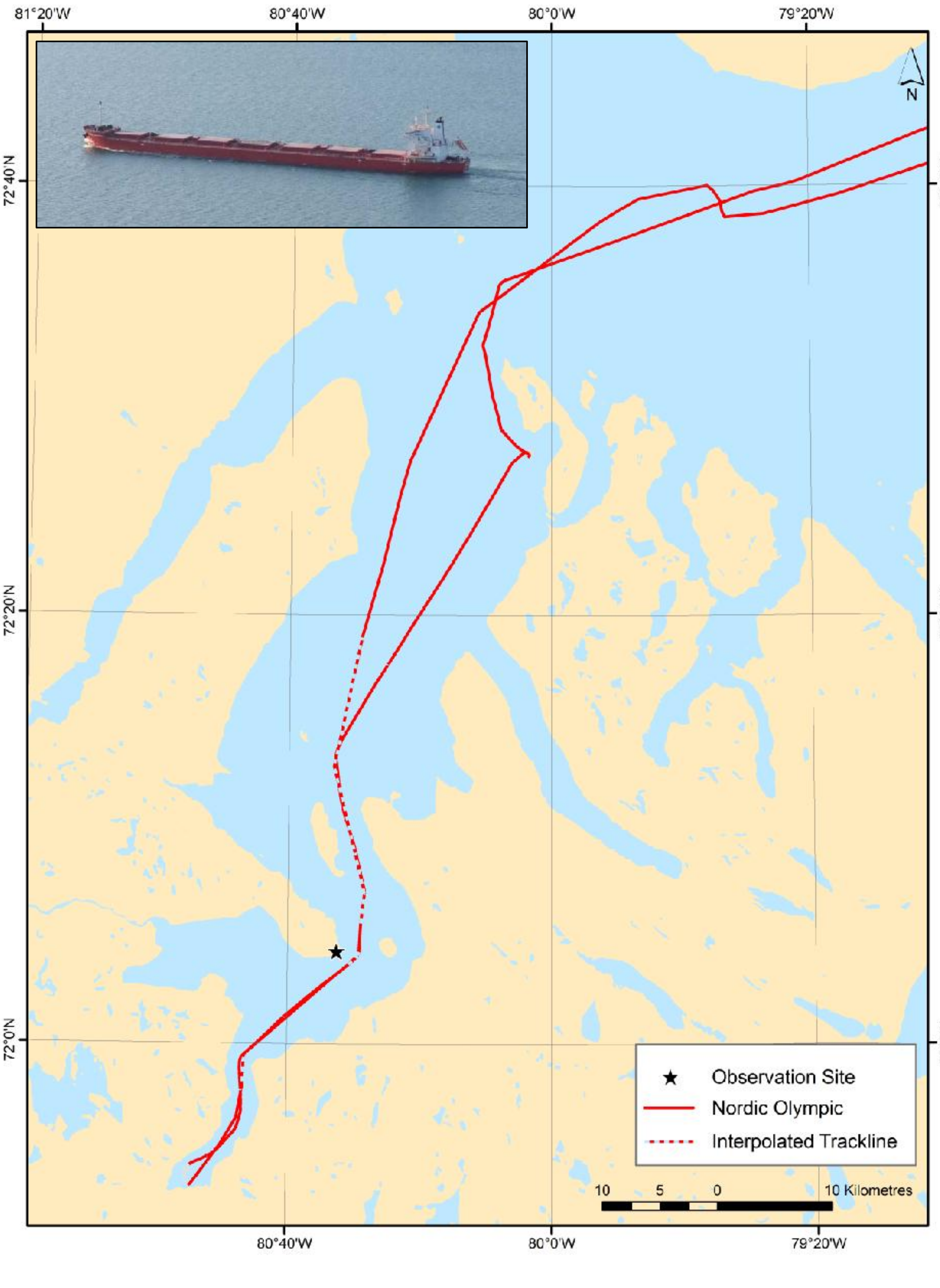
MV *Nordic Oshima* (225 m) – 1 and 6 August 2016



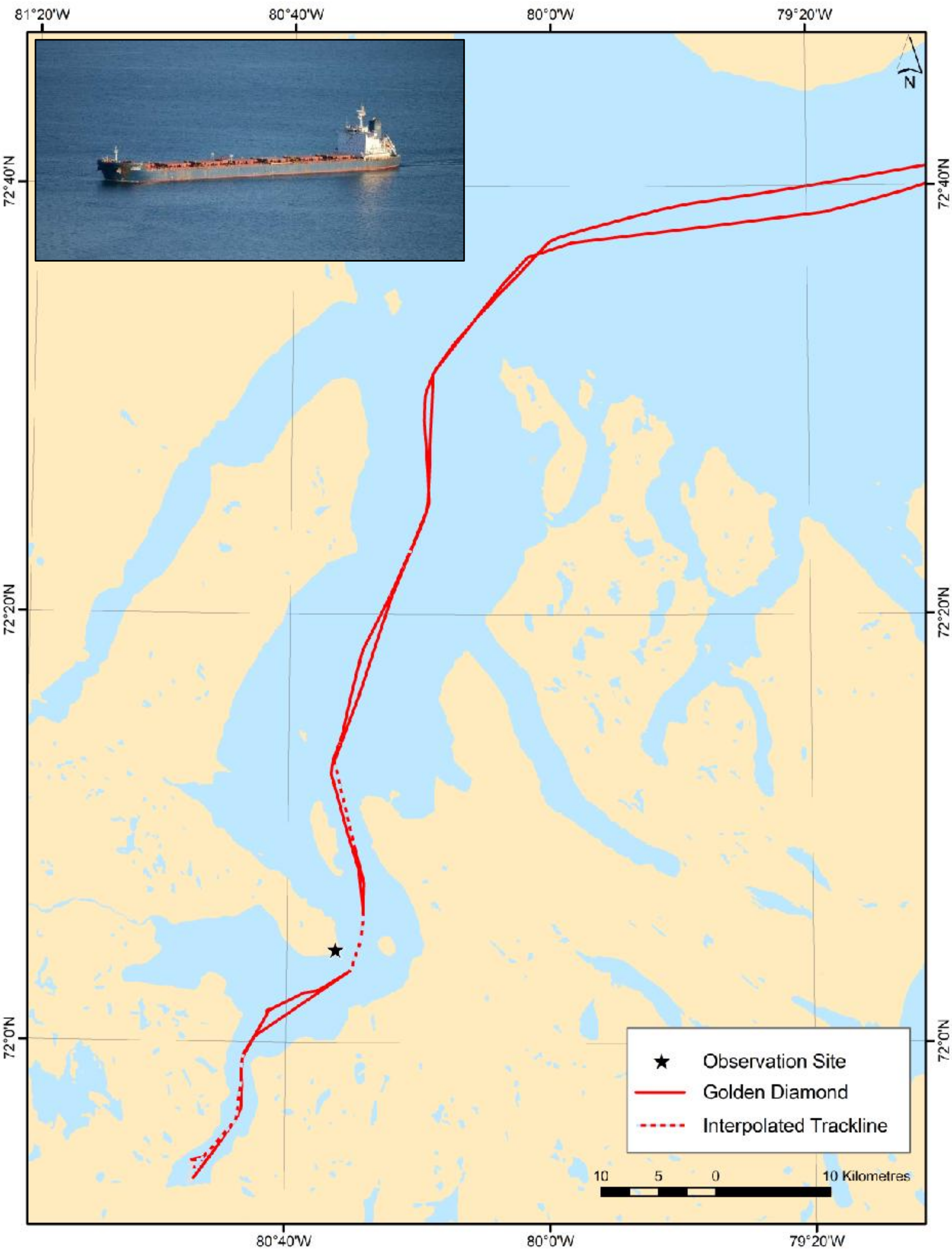
MV *Nordic Oasis* (225 m) – 2 August 2016



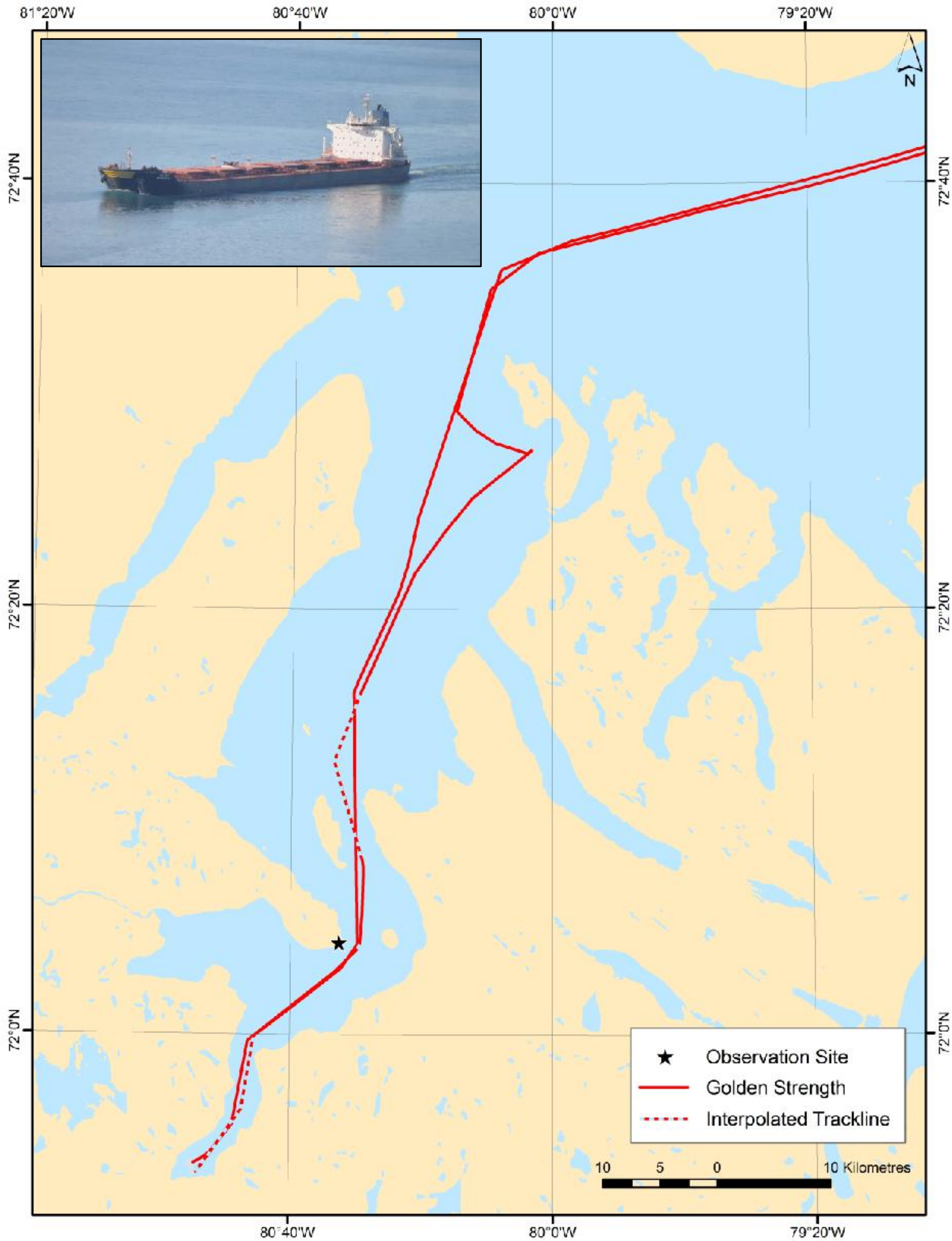
MV *Nordic Odin* (225 m) – 2 and 7 August 2016



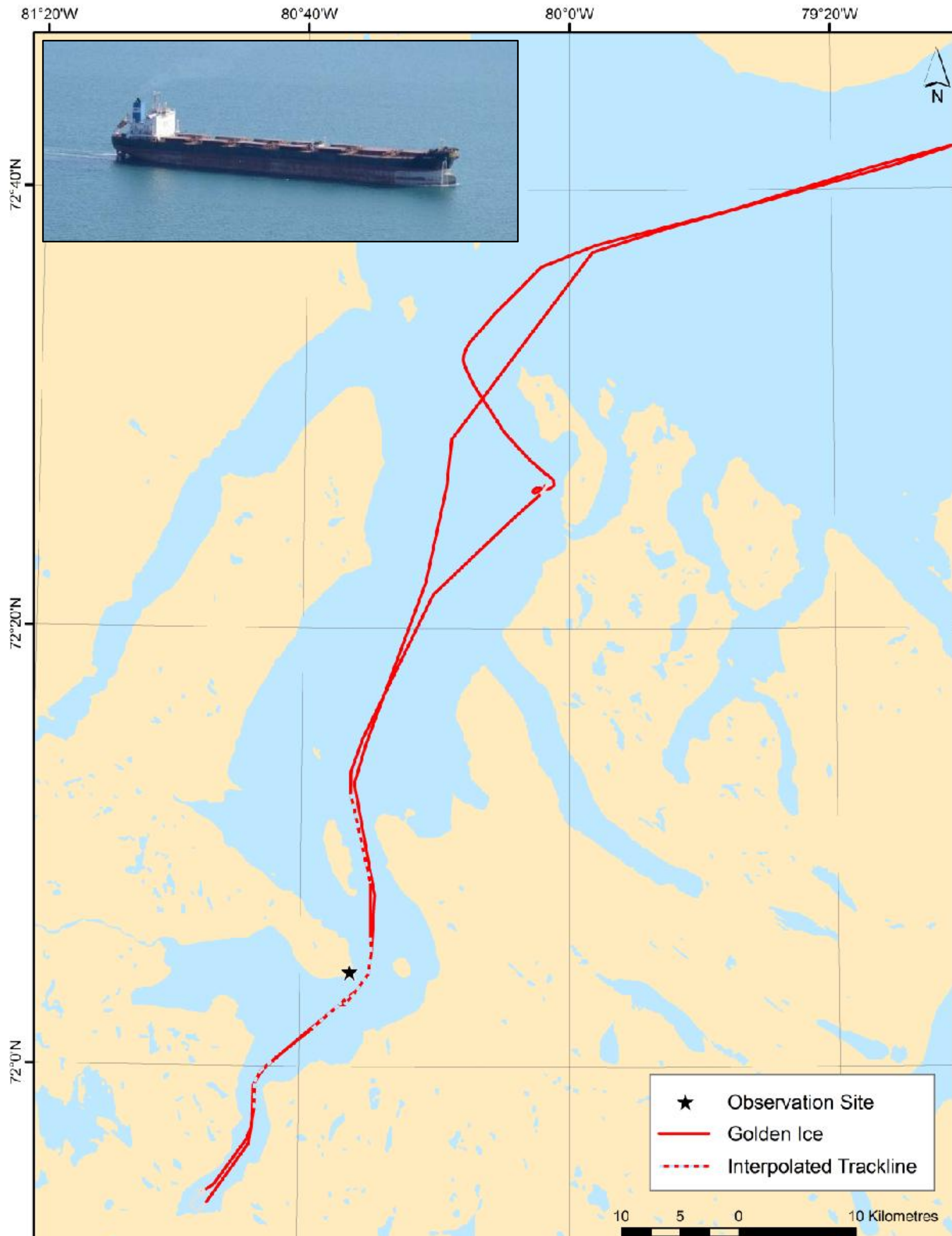
MV *Nordic Olympic* (225 m) – 4 and 9 August 2016



MV *Golden Diamond* (225 m) – 6 and 10 August 2016

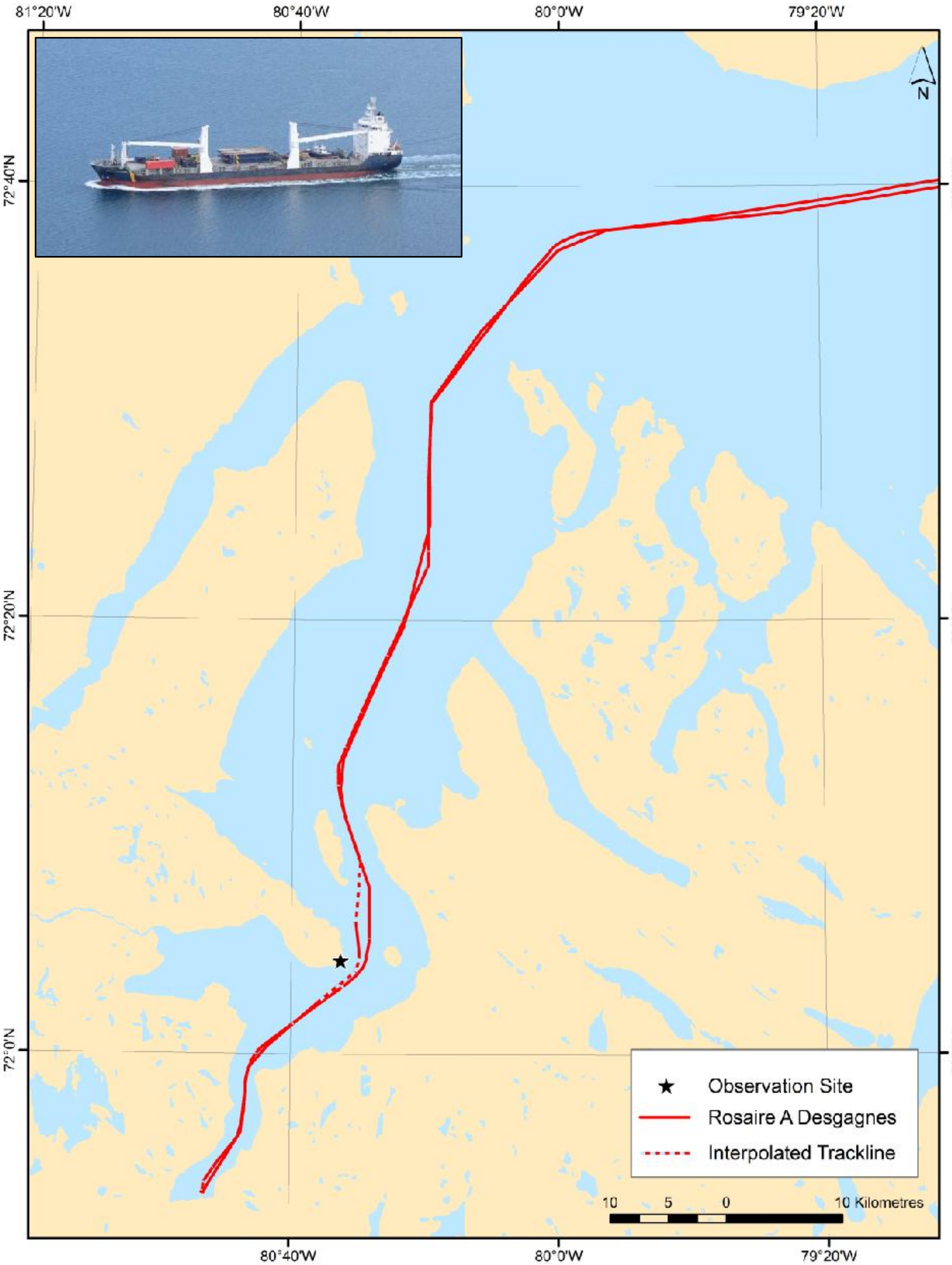


MV *Golden Strength* (225 m) – 8 and 13 August 2016

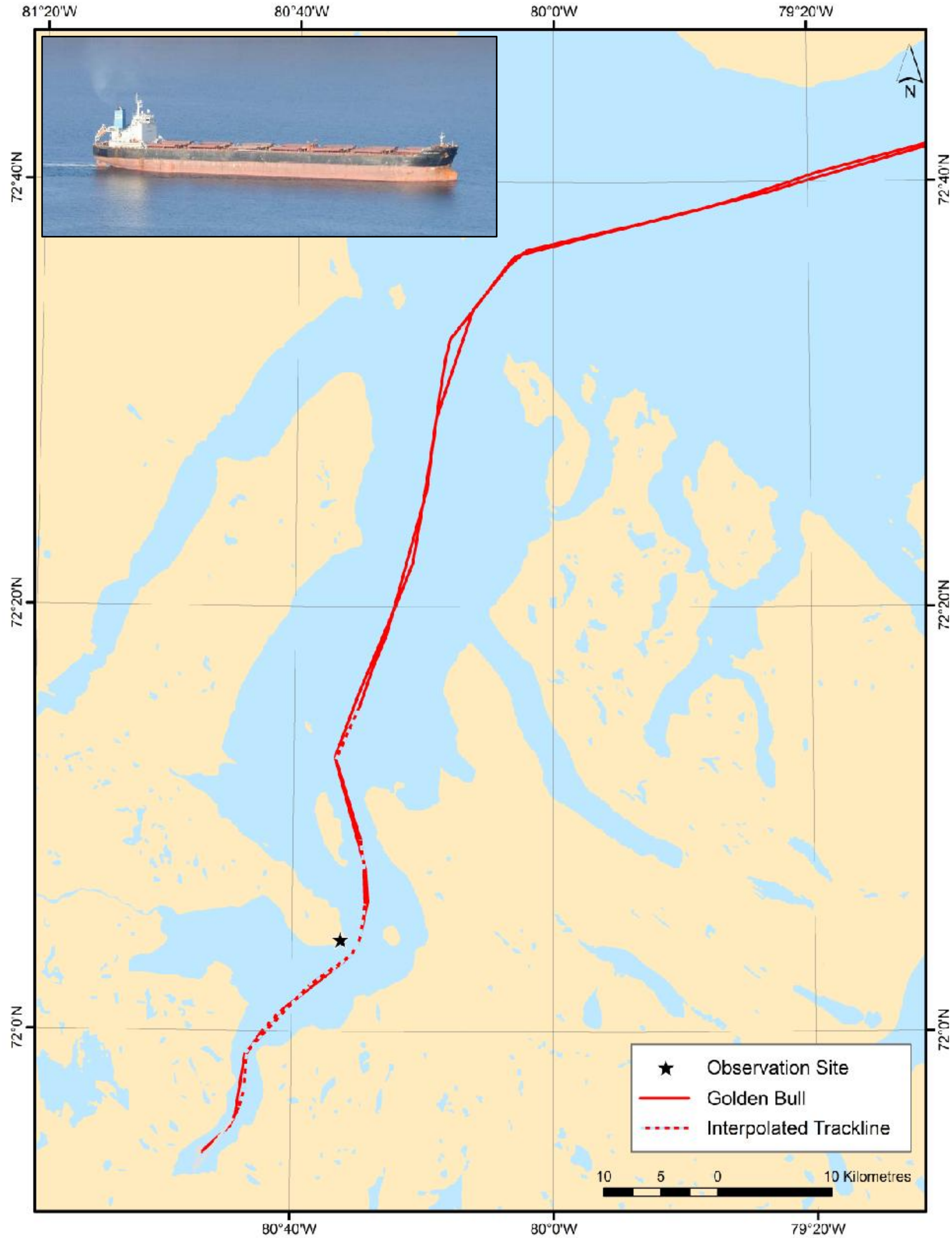


MV *Golden Ice* (225 m) – 9 and 14-15 August 2016

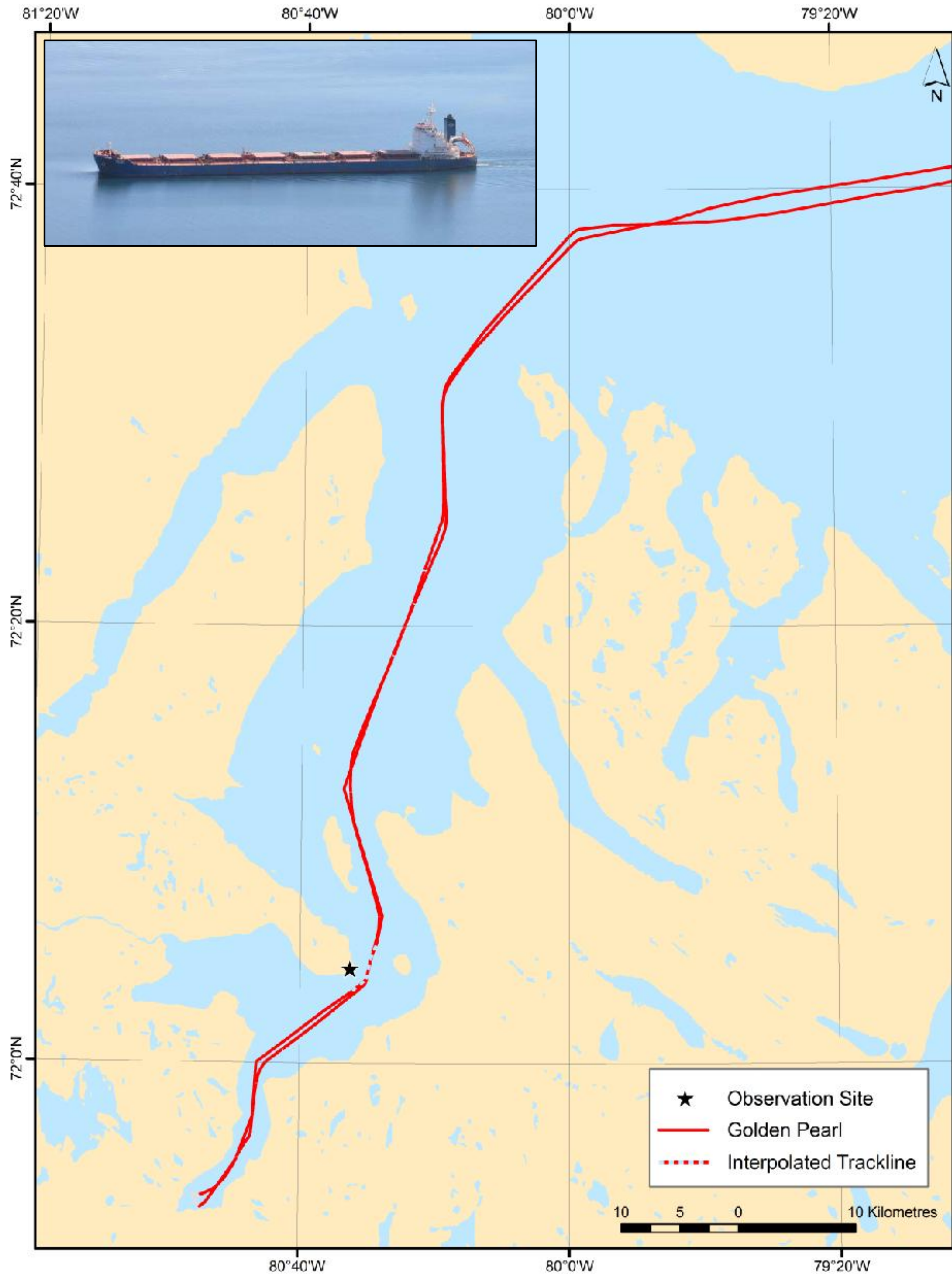
MV *Nordic Orion* (225 m) – 11 and 16 August 2016



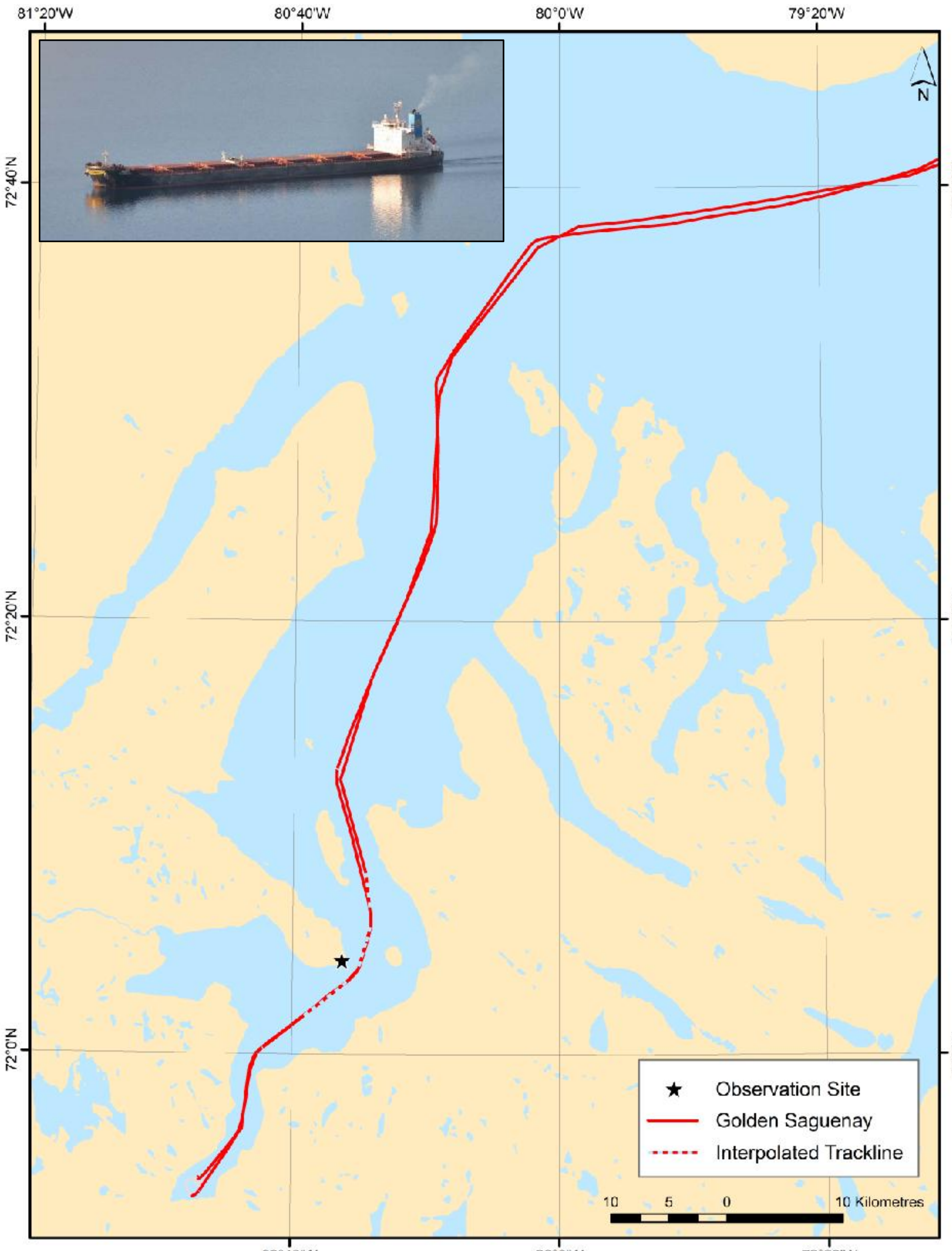
MV *Rosaire A. Desgagnés* (138 m) – 14 and 16 August 2016



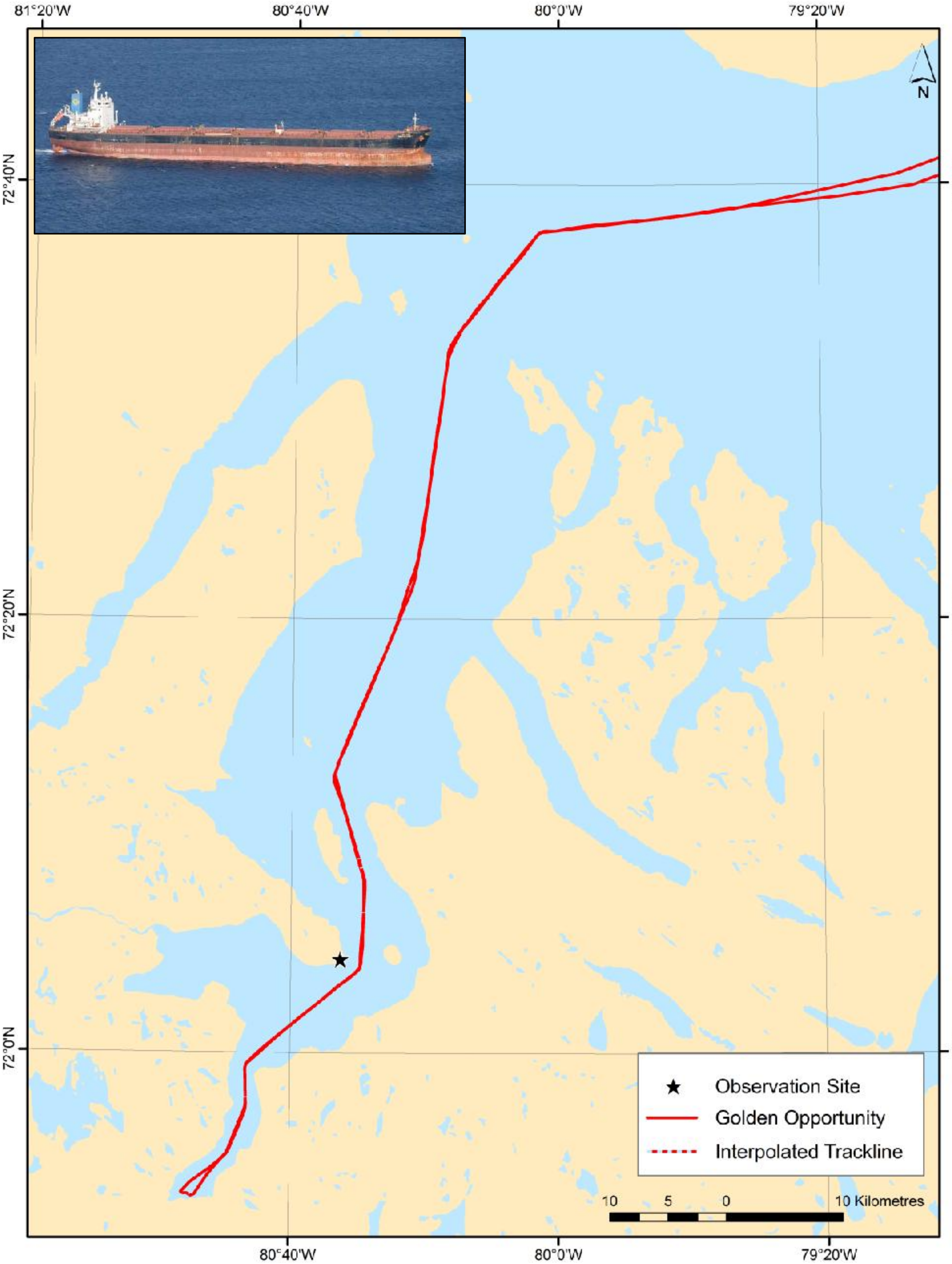
MV *Golden Bull* (225 m) – 14 and 18 August 2016



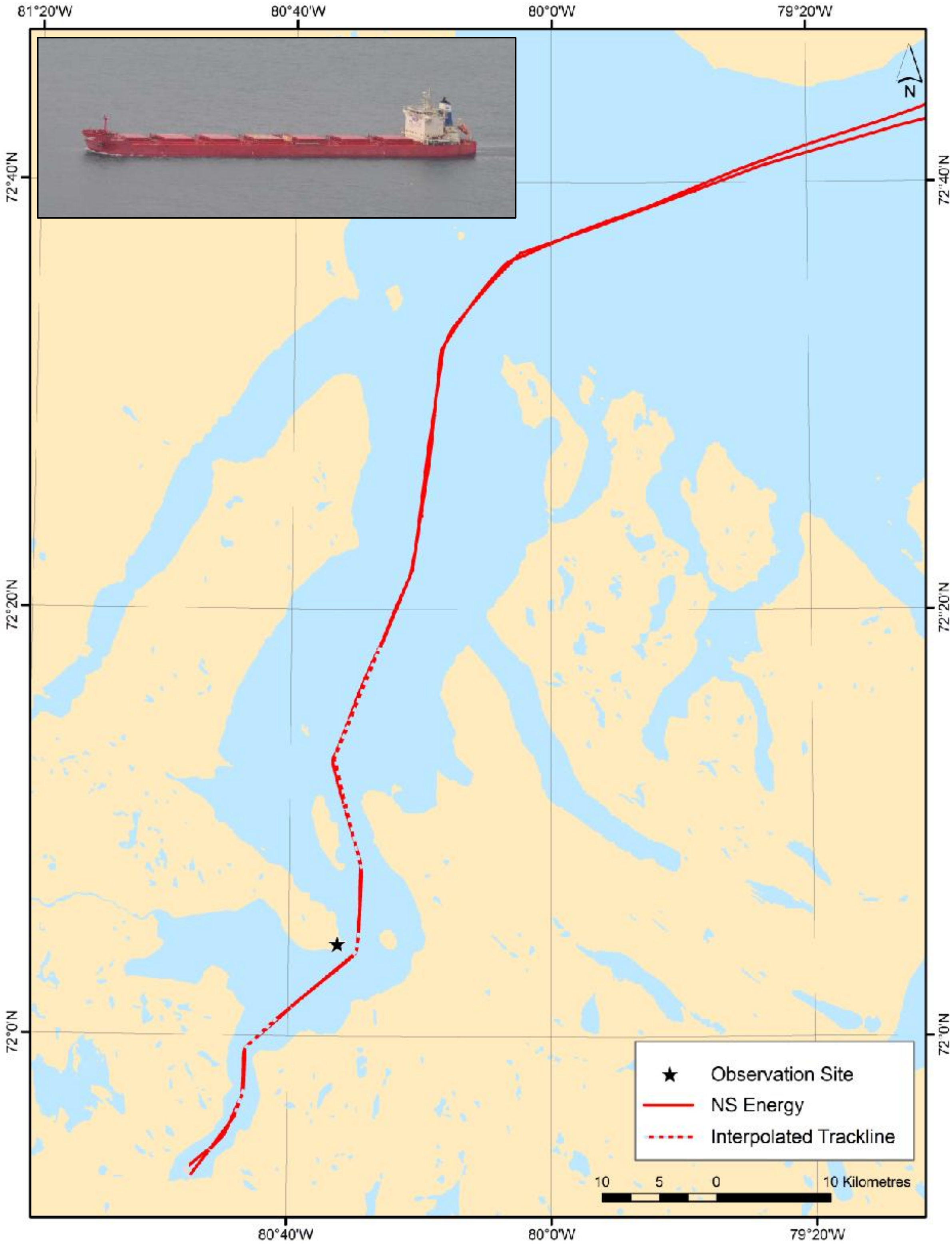
MV *Golden Pearl* (225 m) – 16 and 19 August 2016



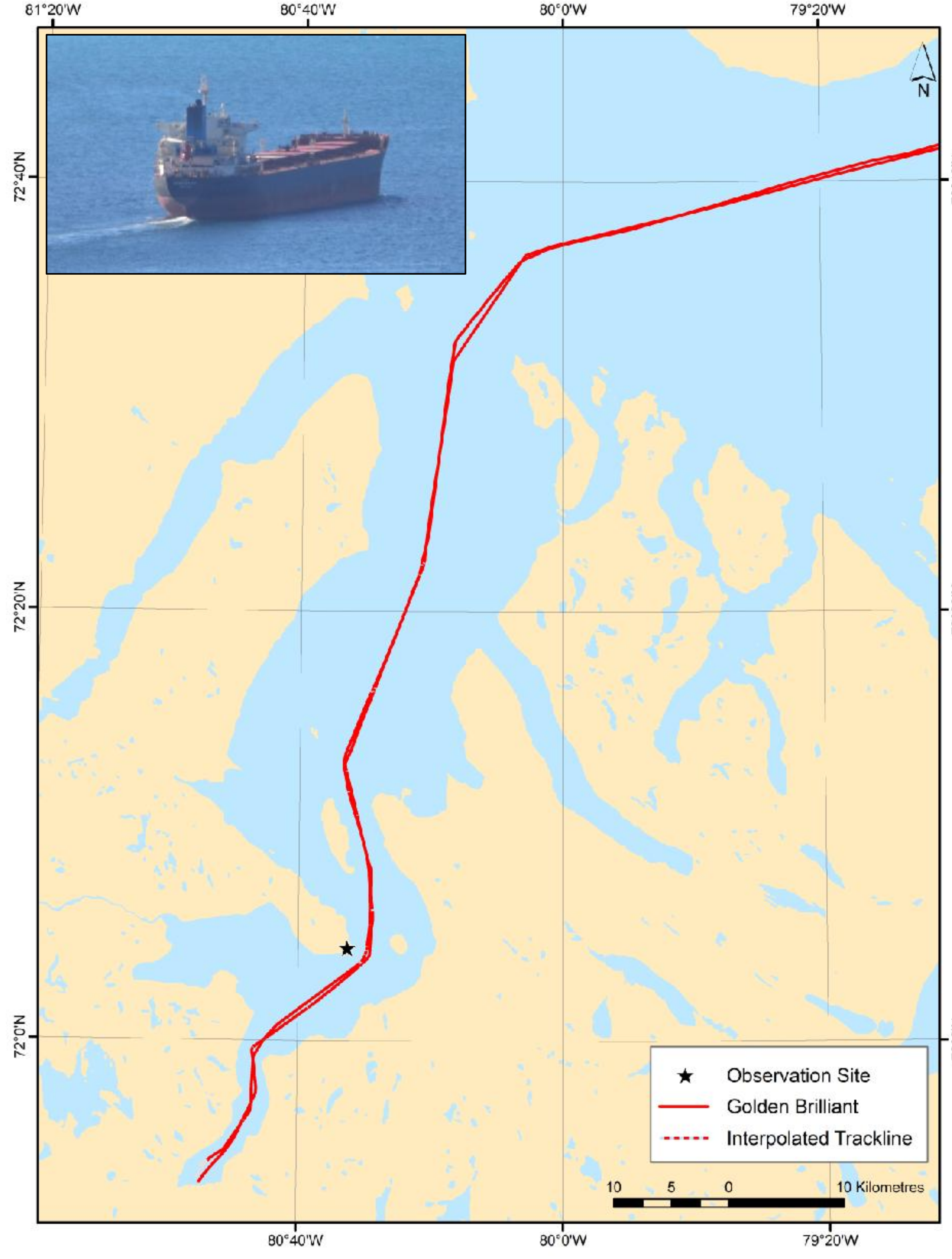
MV *Golden Saguenay* (225 m) – 17 and 21 August 2016



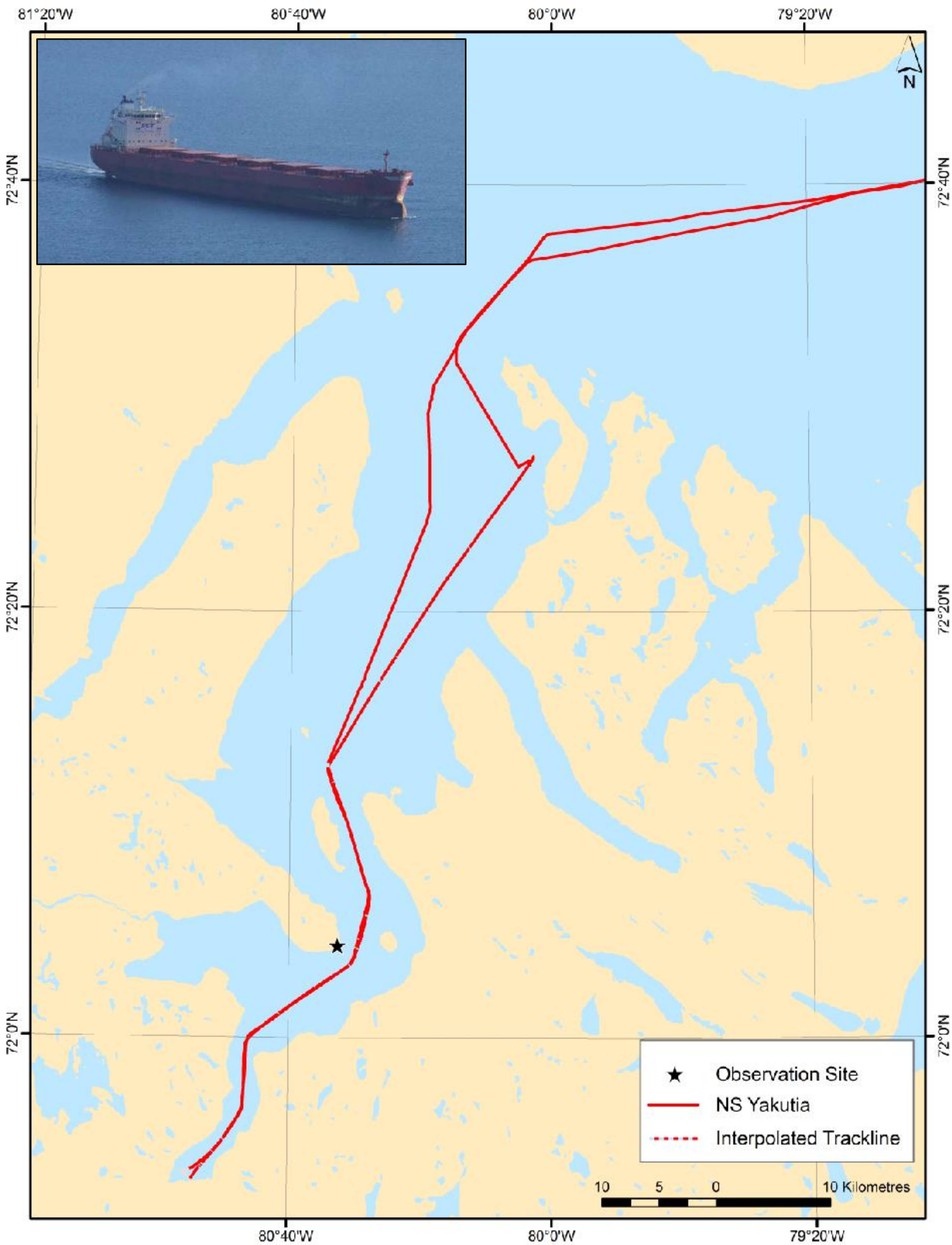
MV *Golden Opportunity* (225 m) – 22 and 24 August 2016



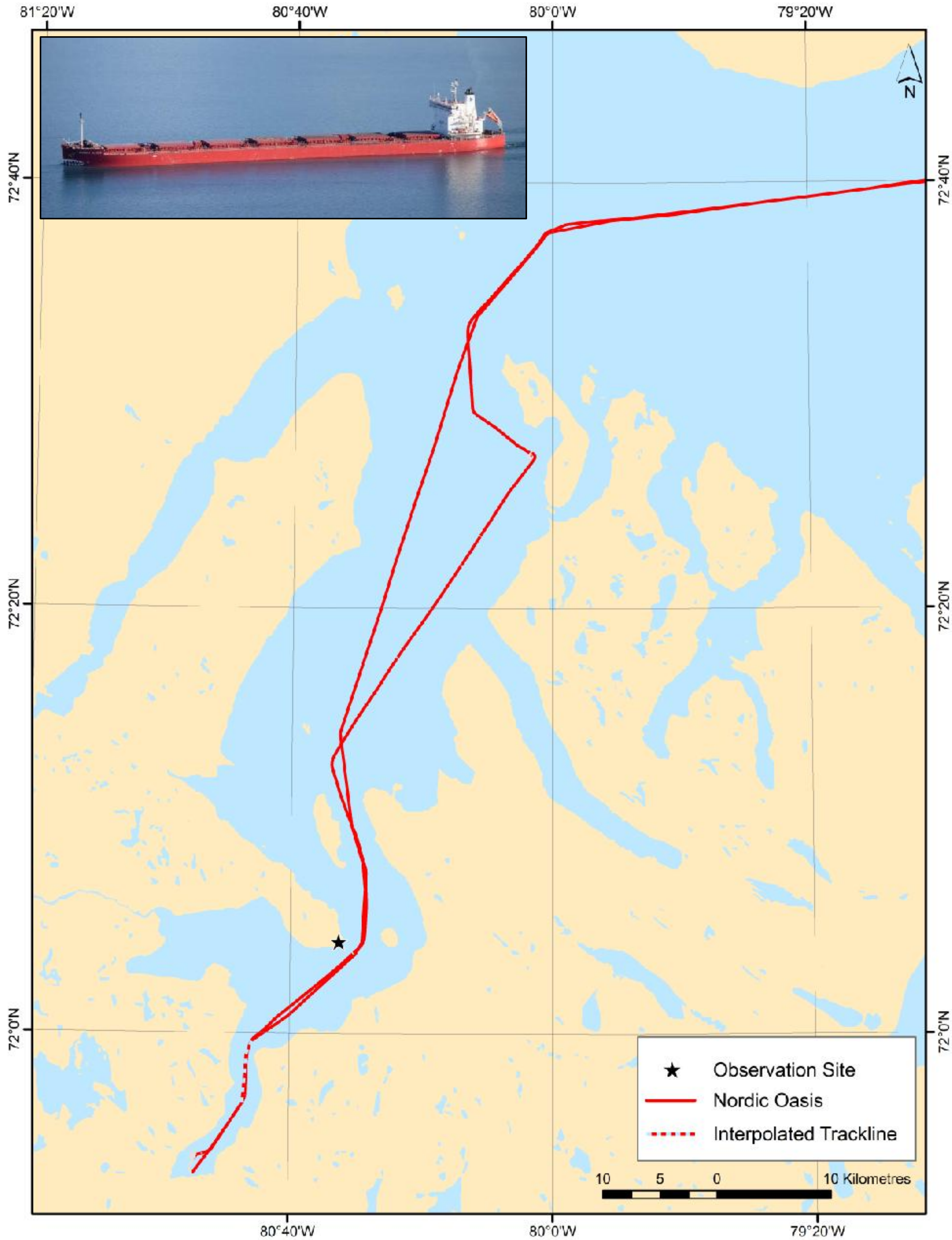
MV *NS Energy* (225 m) – 23 and 25 August 2016



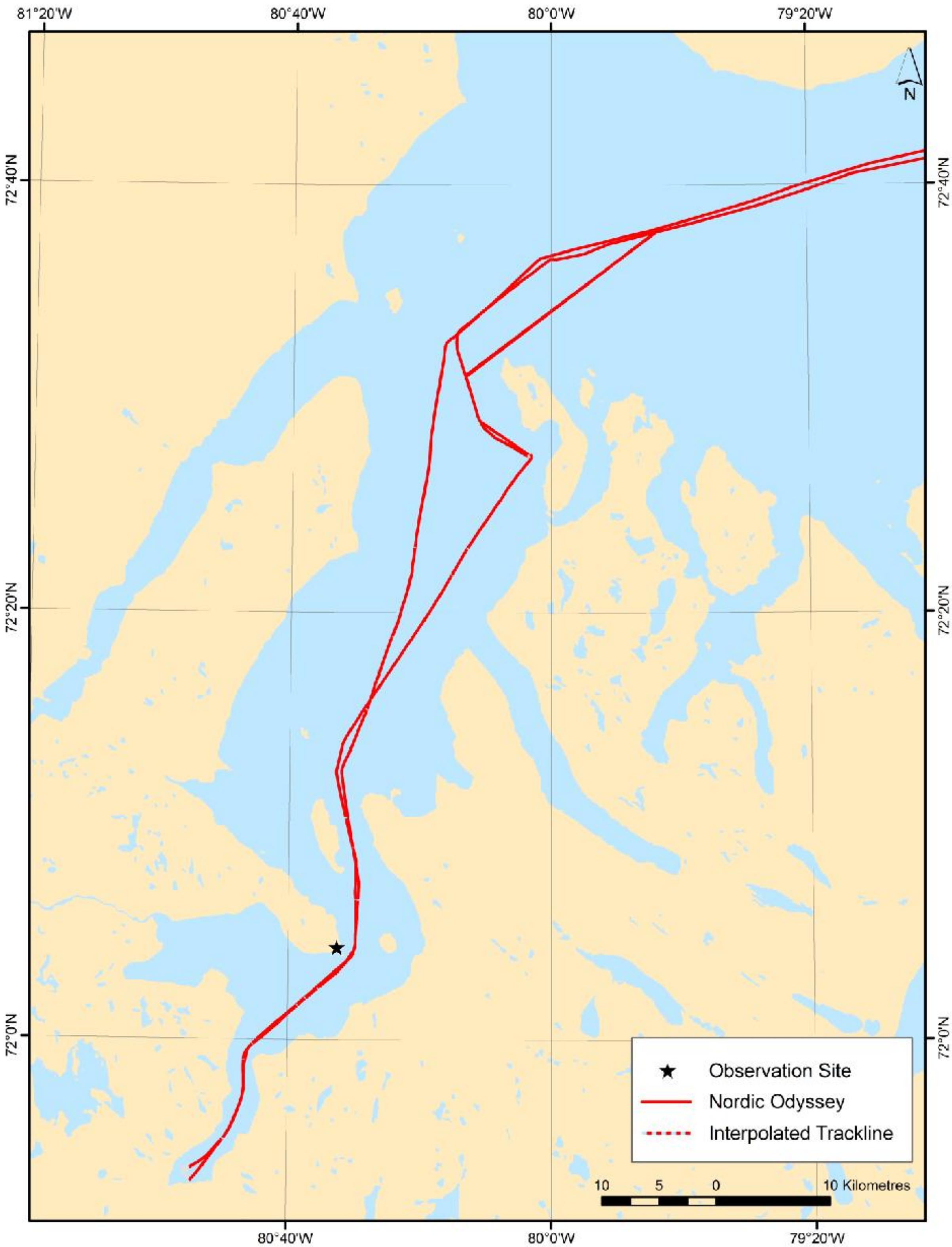
MV *Golden Brilliant* (225 m) – 23 and 26 August 2016



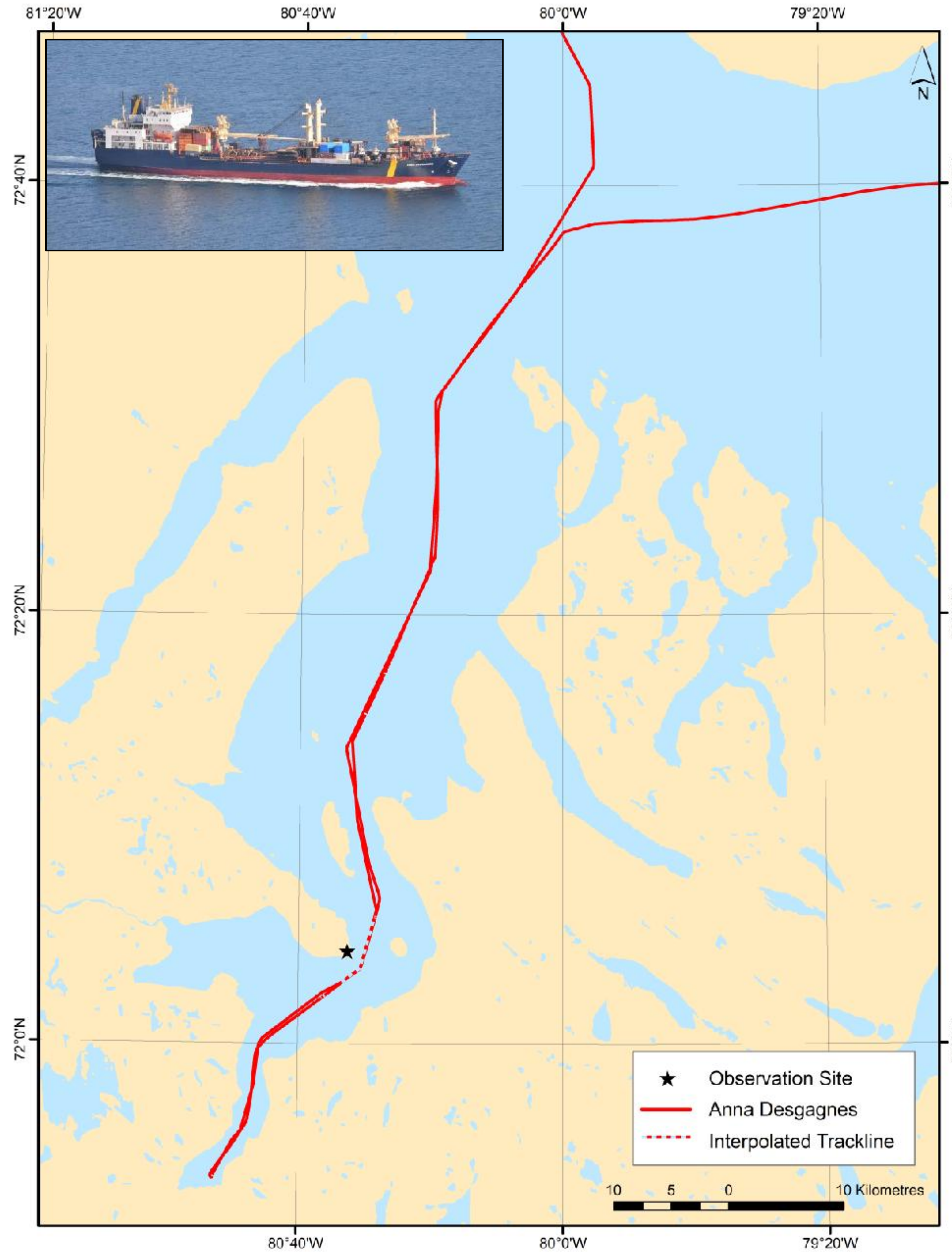
MV *NS Yakutia* (225 m) – 24 and 28 August 2016



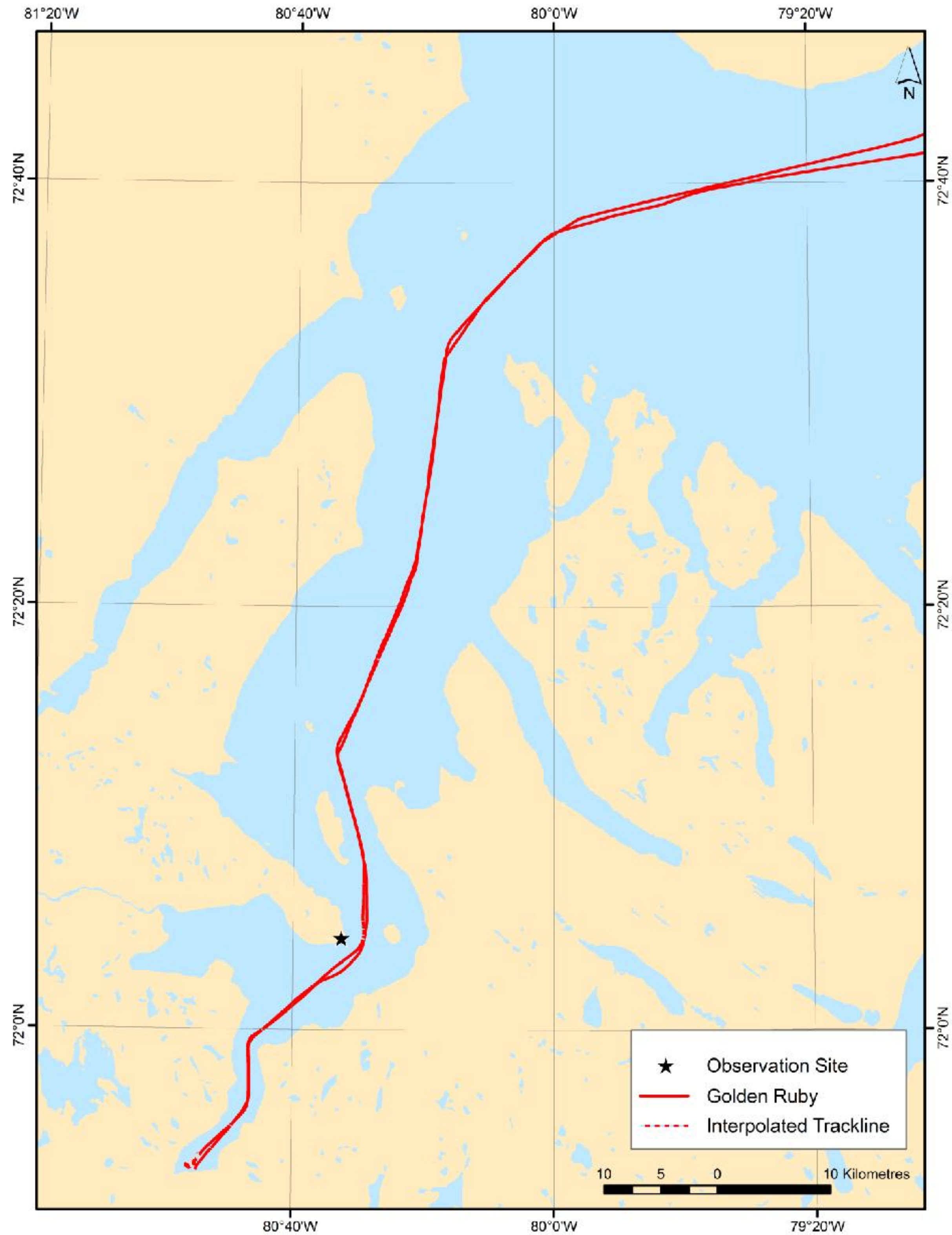
MV *Nordic Oasis* (225 m) – 25 and 29 August 2016



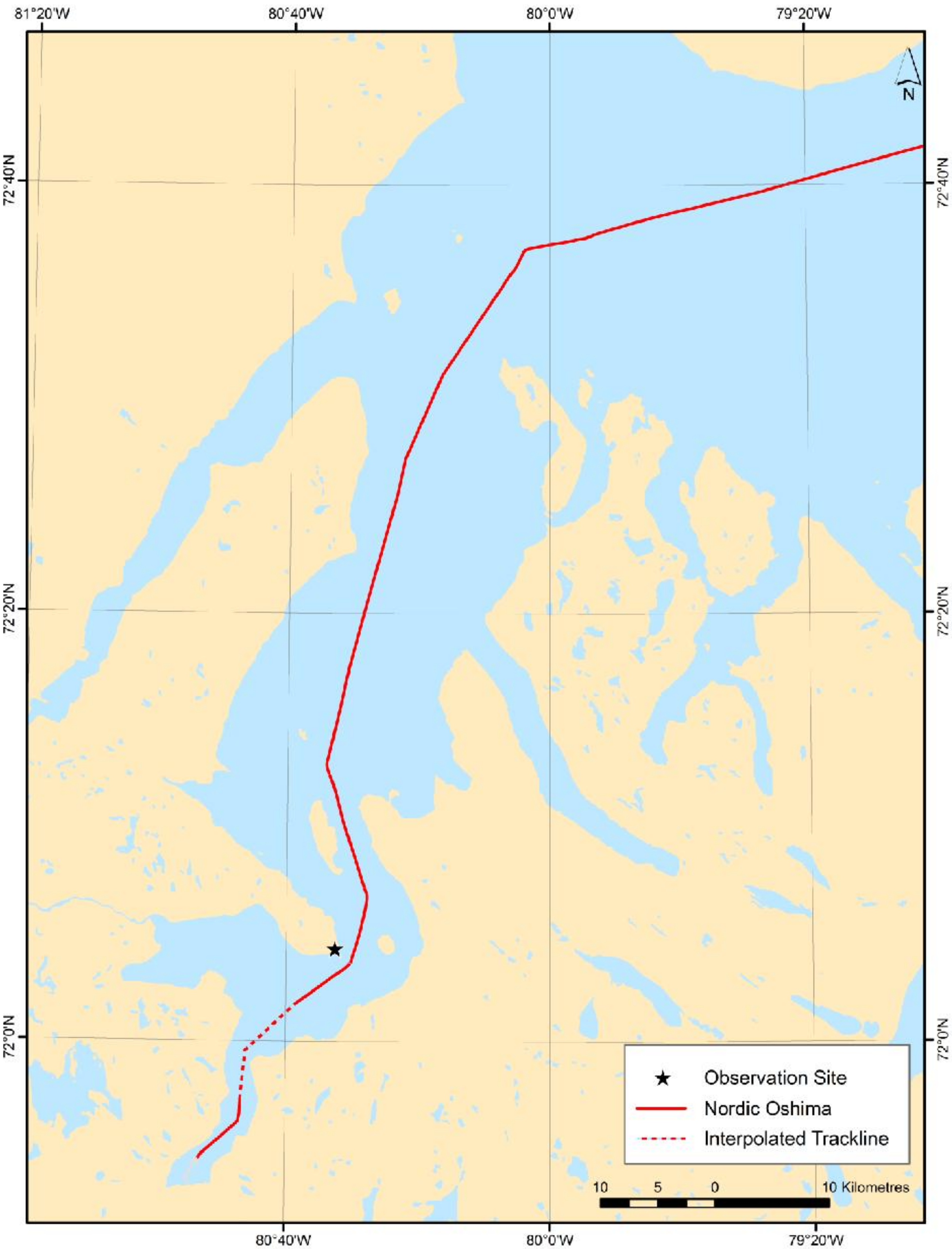
MV *Nordic Odyssey* (225 m) – 26 August and 1 September 2016



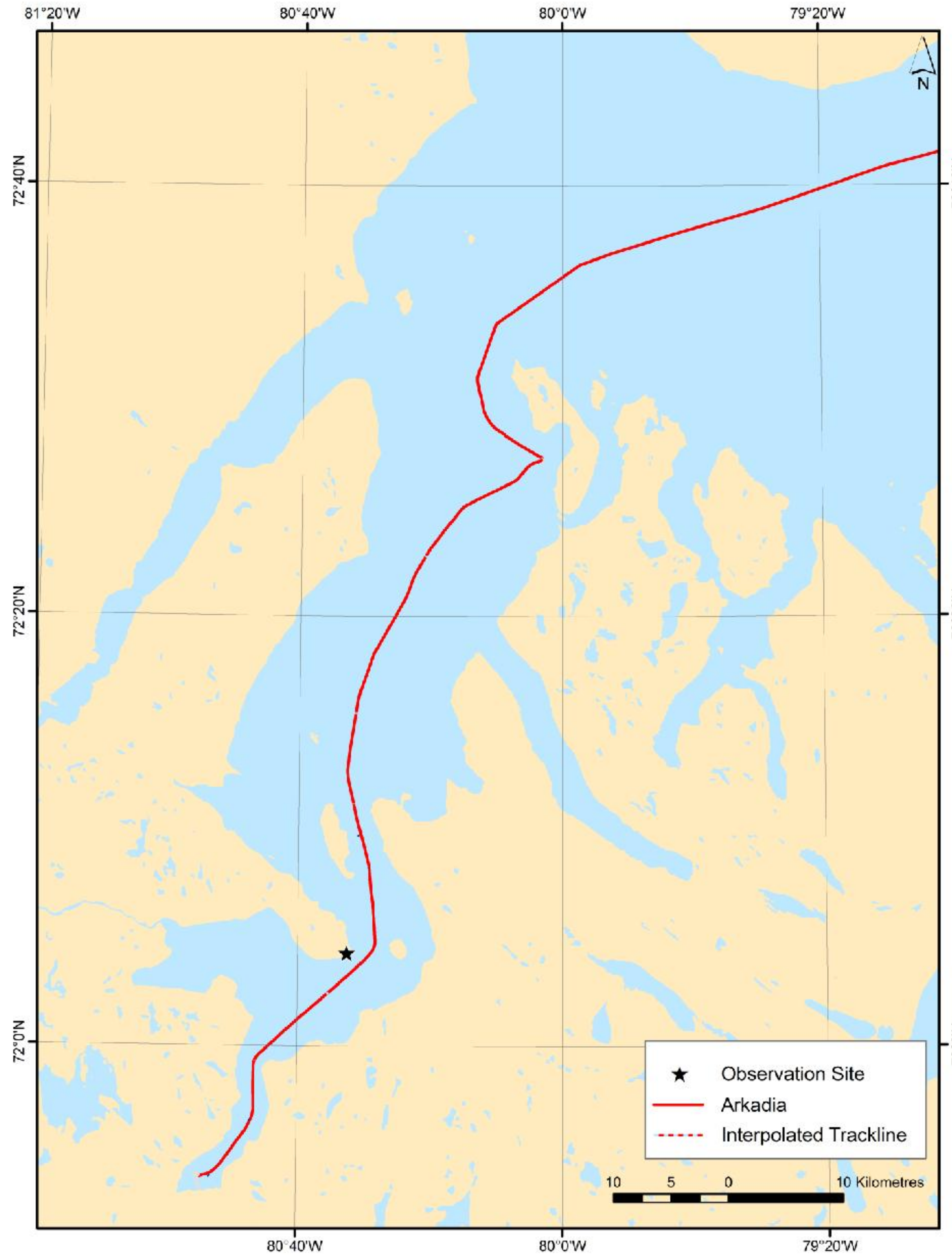
MV *Anna Desgagnés* (174 m) – 29 August 2016



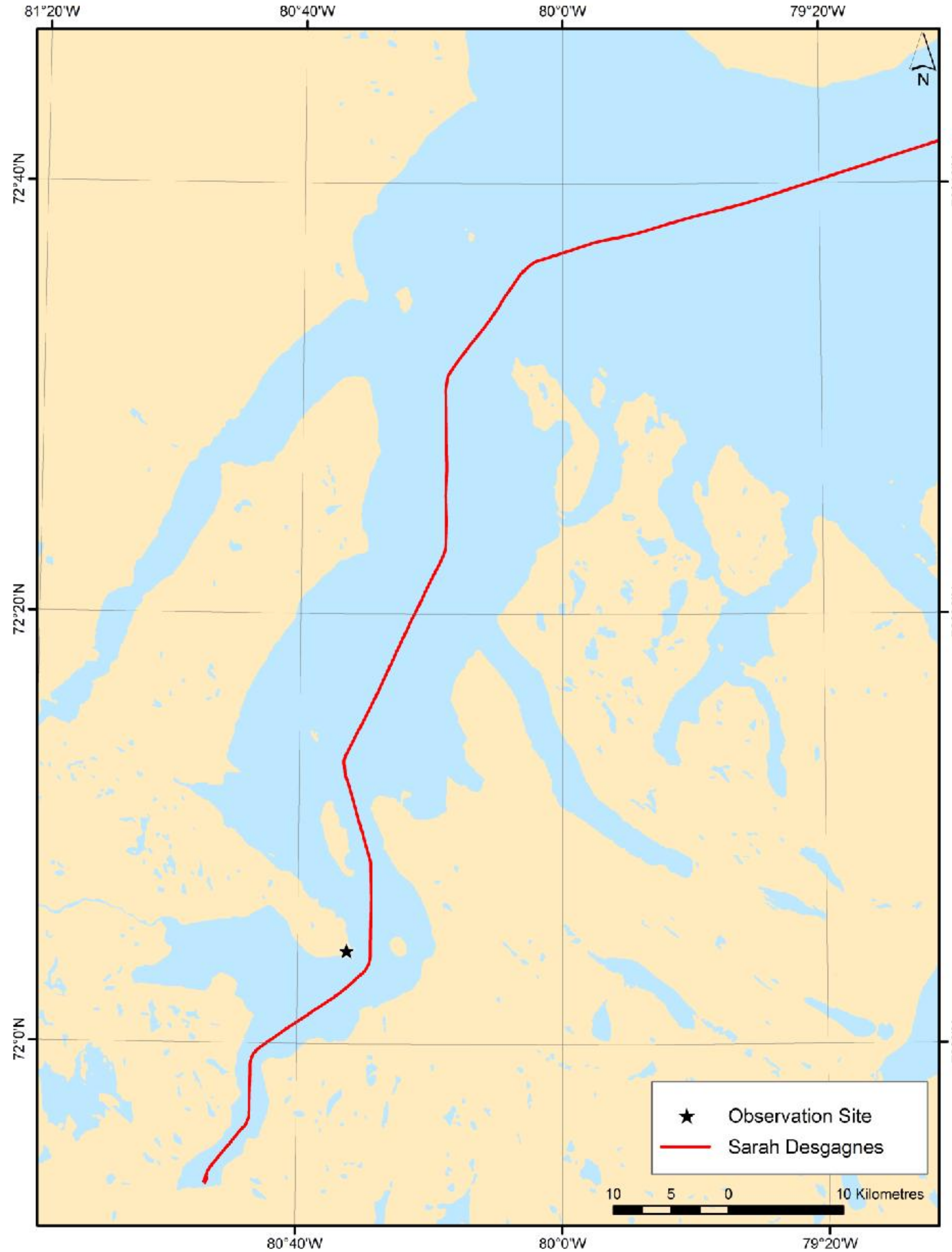
MV *Golden Ruby* (225 m) – 31 August and 3 September 2016



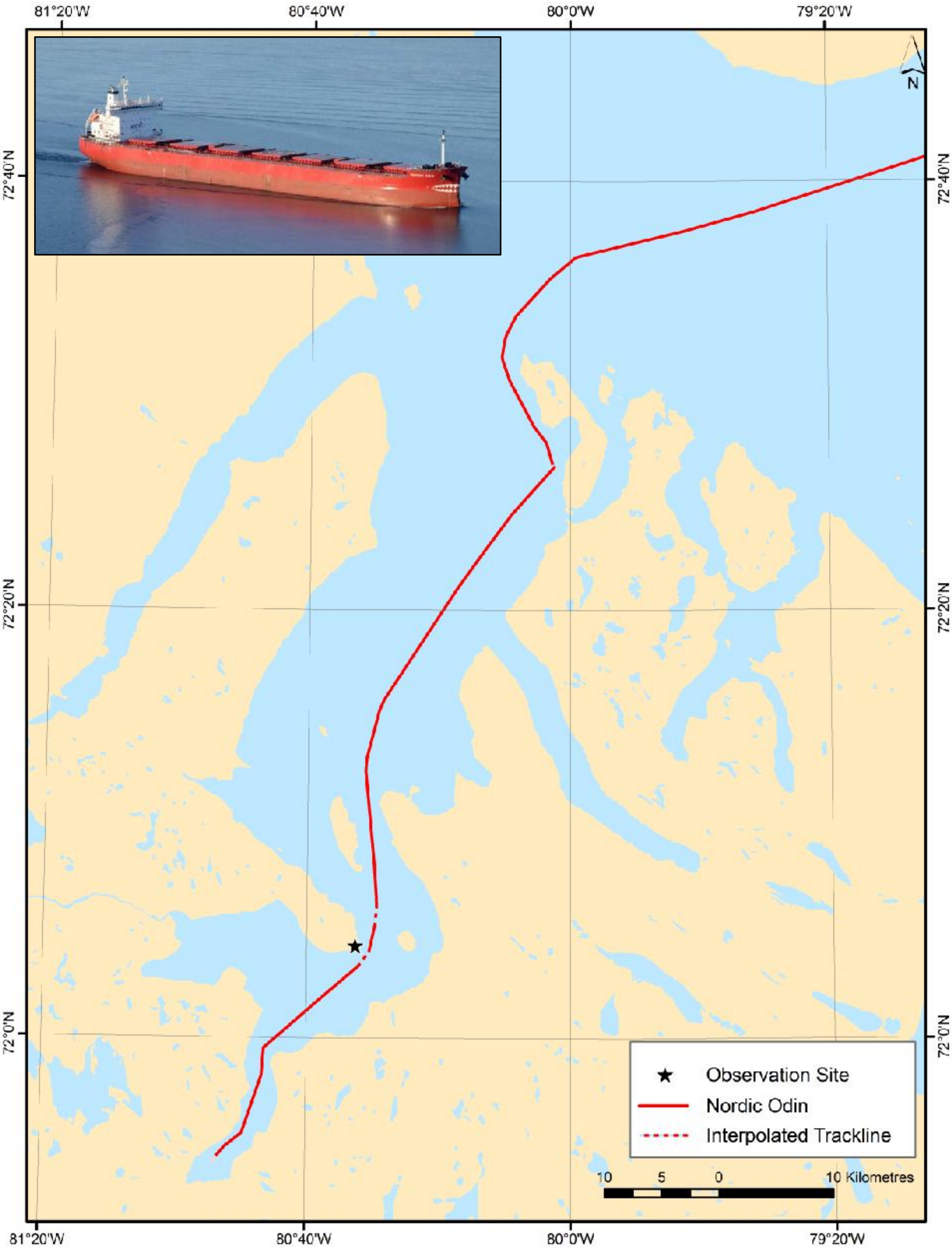
MV *Nordic Oshima* (225 m) – 1 September 2016



MV *Arkadia* (197 m) – 1 September 2016

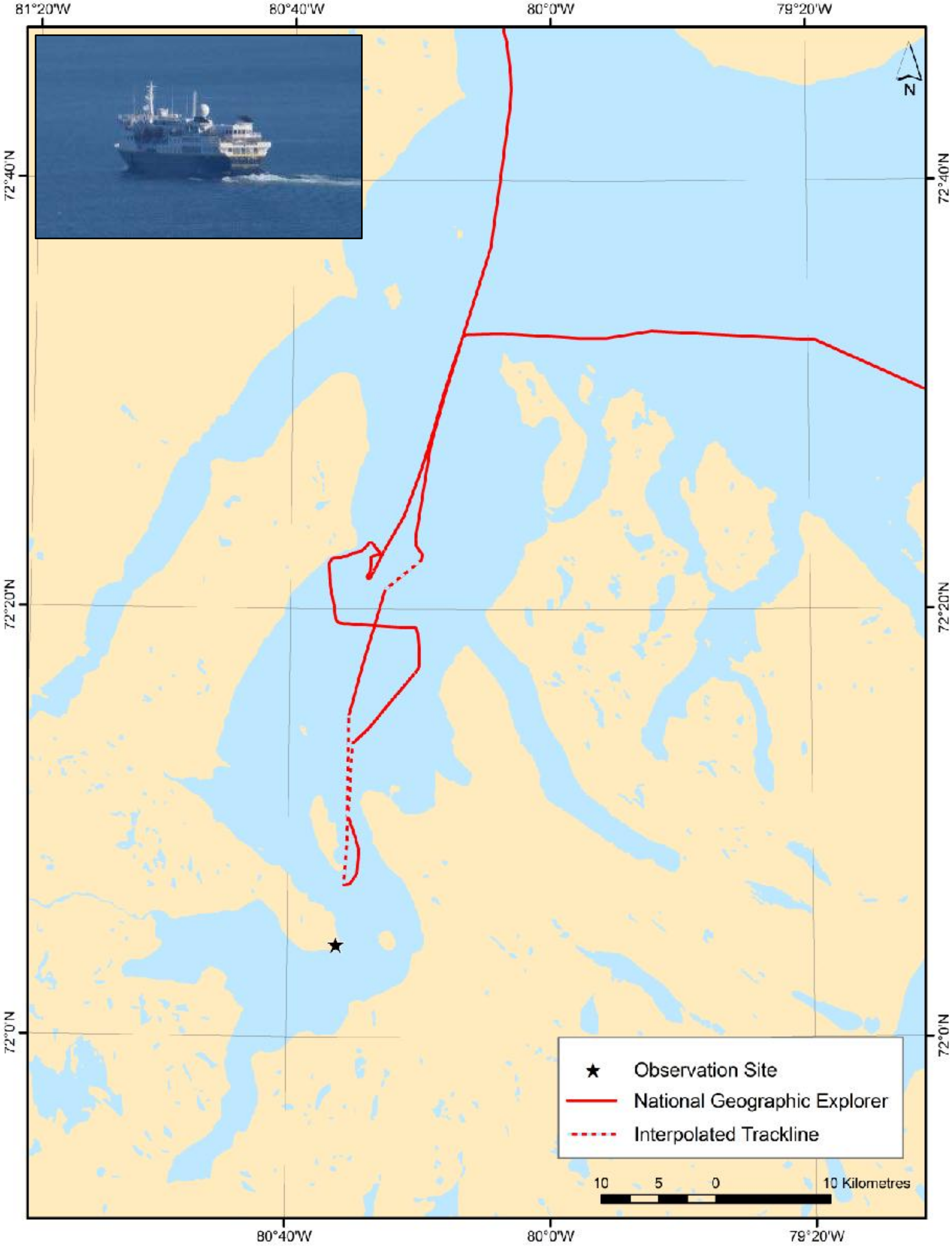


MV *Sarah Desgagnés* (148 m) – 2 September 2016

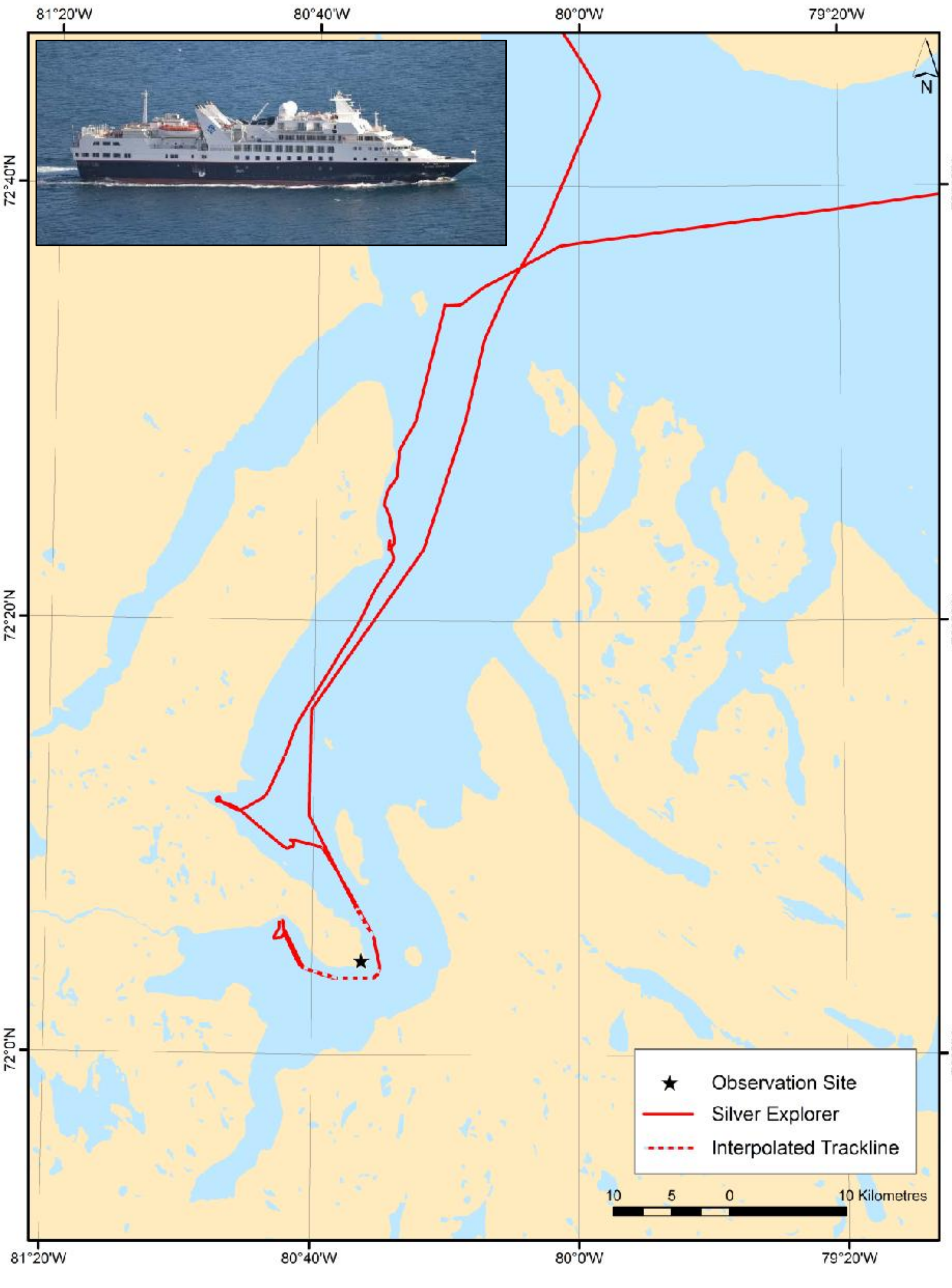


MV *Nordic Odin* (225 m) – 4 September 2016

Other Large Vessel (> 100 m)

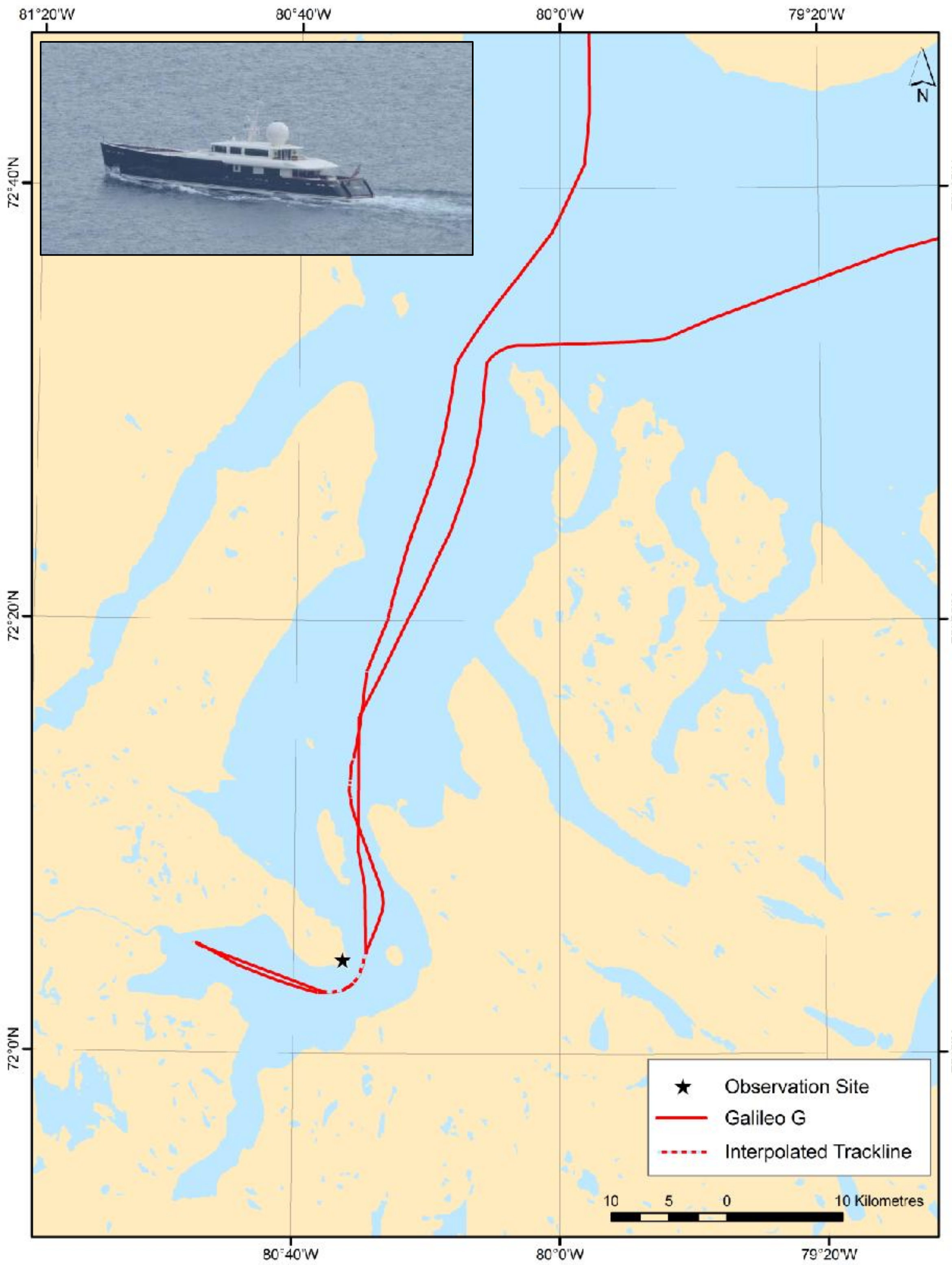


National Geographic Explorer (112 m) – 19 August 2016

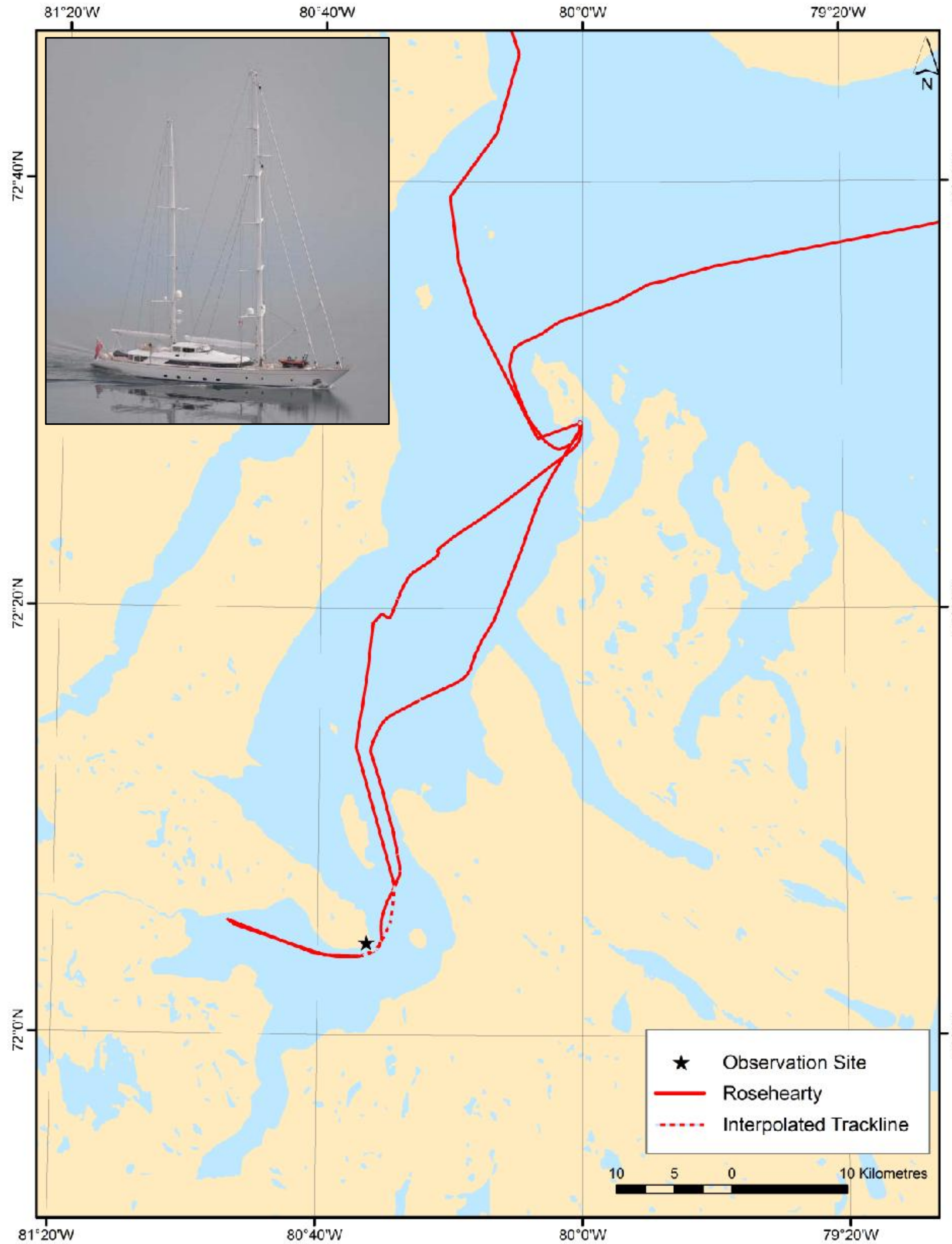


MV *Silver Explorer* (112 m) – 29 August 2016

Medium Vessels (50-100 m)



MV *Galileo G* (55 m) – 5 and 6 August 2016



MV *Rosehearty* (56 m) – 3 and 4 August 2016

Small Vessels (<50 m) - Examples

3 August

12 August

9 August

12 August

10 August

23 August

APPENDIX B: PROCEDURE FOR CORRECTING AIS DATA

AIS (Automatic Identification System) fixes consist of measurements of speed, heading, and location of vessels broadcast via onboard AIS transponders. For the shore-based study of narwhals at Bruce Head, AIS vessel data were collected using two independent methods: satellite-based AIS (s-AIS) signal reception, and field camp-based AIS signal reception. At present, the satellite based system does not provide 24/7 overhead coverage for AIS reception because the satellite constellation is not large enough. For this reason, the s-AIS data were supplemented with data collected via a field camp-based AIS receiver. In future, the s-AIS system will provide 24/7 coverage once the updated satellite system is fully operational (estimated 2018). At the end of the field season, the s-AIS and field camp AIS datasets were merged into a single dataset sorted by vessel and date-time to generate ship tracklines.

Three types of errors were encountered in the merged dataset:

1. Inadequate coverage (resulting in gaps in tracklines or "unbelievable" tracklines (i.e., vessels crossing land or transiting very close to shore).
2. Errors embedded in the date-time or location in the AIS data introduced discrepancies when vessel routes were defined by joining adjacent AIS fixes.
3. s-AIS data contained erroneous information such as very large errors in location information and missing or inconsistent ship identification data (MMSI number and name).

All errors in the merged AIS dataset were corrected prior to conducting analyses using the procedures detailed below.

A GIS was used to examine AIS data for vessels in the vicinity of Bruce Head. If a vessel's merged AIS data provided inadequate coverage within the study area during a particular transit, or if the vessel appeared to cross land or transit very close to shore, AIS data logged by that same vessel on other transits, and locations derived from theodolite fixes, were examined. Vessels commonly use previously followed tracklines to plot future courses in the study area. During the course of this study, it was observed that some vessels followed an outbound track that was virtually the same as the inbound track. Theodolite fixes (see § 2.3.1 of the report) were used to provide a time and bearing for a vessel, which were then used to determine the vessel location based on where that bearing crossed an expected track line based on previously or later collected AIS data. Theodolite fixes at distant locations usually have substantial distance errors because small errors in the vertical angle measured by theodolite translate to large horizontal distances. The azimuth (i.e., bearing) measured by the theodolite is not subject to much error regardless of the distance to the vessel. This information was used to add waypoints between known AIS fixes such that the replotted ship track through the study area was complete, did not cross land, and did not approach the shoreline too closely.

Anomalies introduced into the merged AIS dataset due to errors embedded in the location and/or date-time associated with the AIS fixes necessitated that adjustments be made to the merged dataset. Figures B-1 and B-2 illustrate the adjustments made to remedy these types of anomalies.

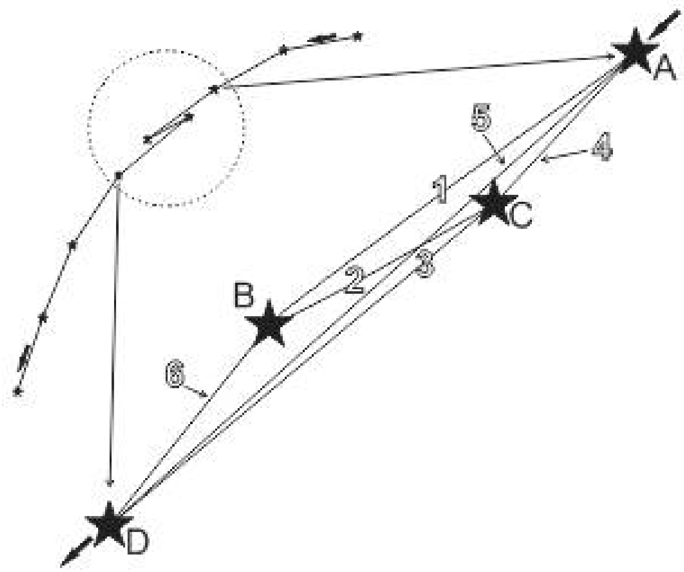


Figure B-1. Hypothetical vessel trackline illustrating an anomaly introduced due to errors embedded in the time recorded for AIS fixes — the locations of the fixes look approximately correct as they are along the same arc. However, when date-time adjacent fixes are joined by connecting segments there is an abrupt change in the heading of the vessel.

In Figure B-1, the time sequential AIS fixes (A, B, C, D) each have date-time, vessel speed, vessel heading and geographic location information; usually all four AIS fixes have very similar vessel speeds and headings. The date-time and geographic location of each adjacent AIS fix was used to calculate heading and speed, and these independent estimates were compared with those recorded in the AIS data. When segments had headings that deviated from adjacent segments or from the vessel AIS heading by ≥ 100° and especially ≥ 145°, they were flagged and examined in a GIS to visually confirm whether they looked erroneous. All headings were then calculated for all possible connections (1,2,3,4,5,6) for the two AIS fixes at either end of the flagged segment (B, C), as well as for those AIS fixes on either side (A, D) of the flagged segment. This was done to determine which AIS fix should be removed to minimize differences between remaining segment-based and AIS based headings. The flagging criteria were relaxed when vessels were turning because speed and heading change fairly quickly during turns.

In Figure B-2, the locations of the fixes look approximately correct, but there is a single fix that has deviated substantially from the arc of the vessel track. In this particular case the aberrant fix (C) would be deleted as long as the time difference between it and adjacent fixes (B, D) is not too large.

Large errors in location information in s-AIS data were identified when tracklines were displayed in a GIS. In addition, these errors were often flagged when the >100° criterion was applied to the data. For example, in Figure 2 above, segment CD would likely have a heading derived from the two AIS GPS fixes that was >100° different than the AIS data headings. Erroneous data points (e.g., C in Figure B-2) were deleted.

Missing or inconsistent ship identification in s-AIS data were corrected using a number of data sources. Theodolite location data and field notes on vessels collected by the study team at Bruce Head were examined; and missing ship ID information could be corrected when it was apparent it was contiguous with AIS data that did have vessel information (as determined via visual examination using a GIS).

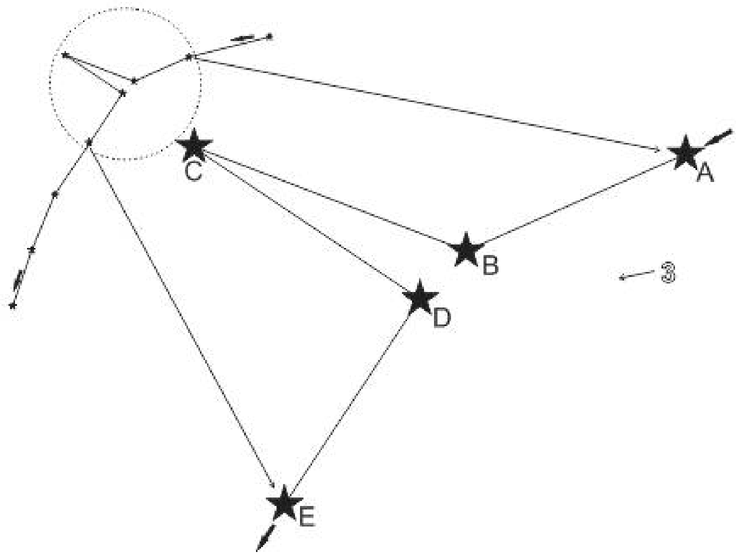
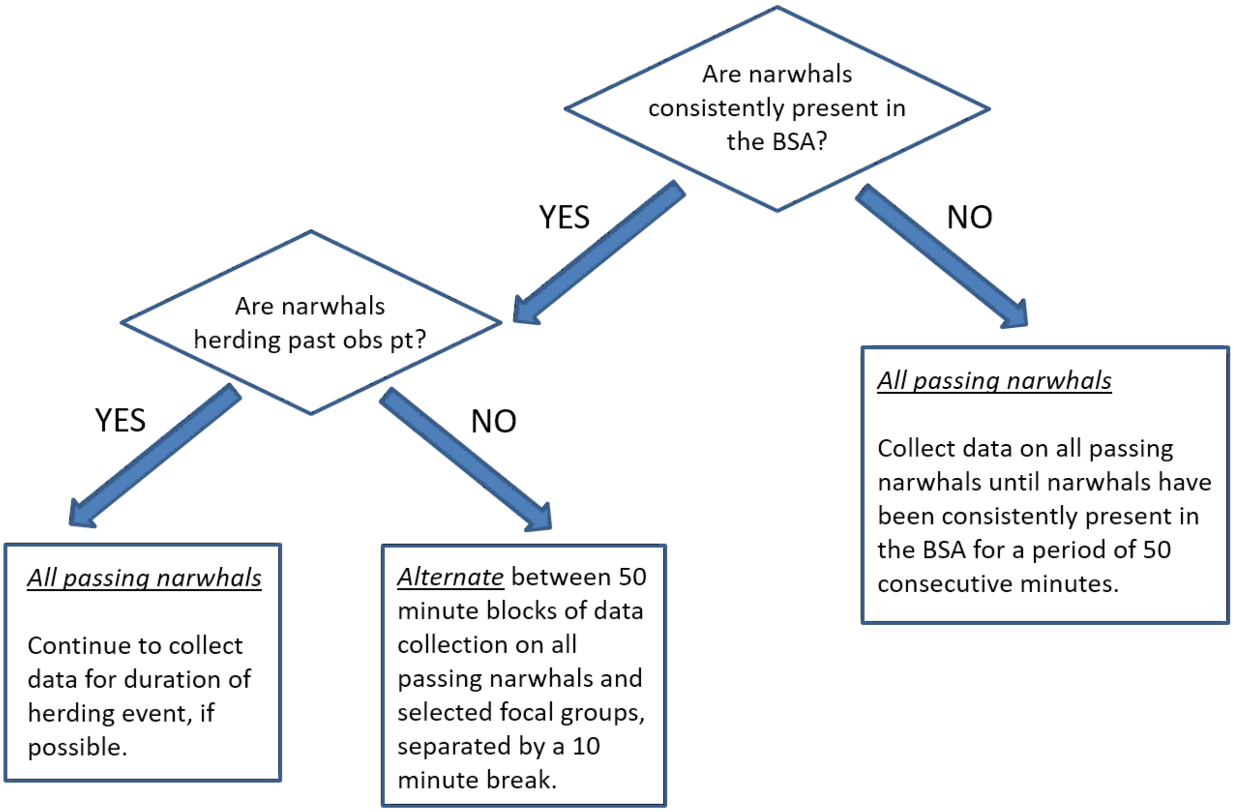


Figure B-2. Hypothetical vessel trackline illustrating an anomaly in the merged AIS ship track due to discrepancies in the latitude and longitude recorded for AIS fixes.

APPENDIX C: DECISION TREE USED TO DETERMINE DATA COLLECTION PROTOCOL FOLLOWED

Data was collected on either the nearshore behaviour of all passing narwhals or on groups selected for focal follows during blocks of time within each eight-hour observation shift. This decision tree was used to determine which protocol to follow during a given block of time. Note: BSA = behavioural study area.



APPENDIX D: CONVERSION OF THEODOLITE FIXES TO GEOGRAPHIC POSITIONS

Converting theodolite fixes to geographic locations required the following information:

- Location of the theodolite, determined using a handheld GPS unit.
- Location of a horizontal reference point (i.e., "False North") for theodolite azimuth measurements. This was determined using a handheld GPS unit.
- Location of a waypoint taken at a fixed location on the shoreline. This was determined using a handheld GPS, and was used to determine the elevation of the theodolite above water level.
- Tide elevation data (§ 2.3.2), which was used to correct the elevation of the theodolite above water level.
- Eye height of the theodolite eyepiece for each fix. This was measured and recorded each time the theodolite was set up or moved and was used to correct the altitude of the theodolite above water level.
- Azimuth and clinometer angle to the sighting from the observation location, measured using the theodolite.
- Correction for non-orthogonal local gravity field because the angle to the distant point (i.e. sighting) is measured as if the gravity field is exactly vertical to the ellipsoid, which it is not. This correction was determined using GPS-H 3.2.1 (Canadian Geodetic Survey 2013). The NS and EW deflection components were determined to be -4.1 and -7.0 arc-seconds, respectively, at the theodolite location (vertical deflection at the theodolite was assumed to equal its geodetic location on the geoid). Clinometer measurements were corrected using the formula:

  *(NS deflection component * cos α) + (EW deflection component * sin α)*

  where "α" is the azimuth to the sighting (Ceylan 2009). This vertical deflection in the direction of the azimuth was added to the clinometer angle measured by the theodolite to get the corrected angle.
- The geoid (i.e., water level) height at theodolite and the sighting. This was determined using GPS-H 3.2.1 (Canadian Geodetic Survey 2013).
- The radius of the earth along the azimuth between the theodolite and the sighting (Krakiwsky and Thomson 1974).

The <u>distance between two known geographic locations along the earth</u>'s oblate spheroid surface (i.e., the ellipsoid) was calculated using the inverse Vincenty formula (Vincenty 1975). Computer code for the Vincenty calculations was downloaded from the National Geodetic Survey (NGS 2016), and converted for use in Microsoft Excel. Fortran computer code for the forward and inverse Vincenty method was downloaded by following the "Inverse/Forward/Invers3D/Forwrd3D" link (NGS 2016). This code was recorded as Visual Basic for Applications (VBA) macros in Excel. VBA macros were tested to ensure results were consistent with online examples and other methods used to calculate distance and bearing between known geographic locations, and a new geographic location given a known location, distance, and bearing. The ellipsoid is 7.794 m above the geoid (i.e., water level).

The <u>absolute distance between the theodolite location and the sighting on the water</u> was calculated using the corrected clinometer angles. This distance was then adjusted by the ratio of the circumference of the radius of curvature (Krakiwsky and Thomson 1974) at the ellipsoid over the circumference of the radius of curvature at the geoid elevation to give the correct distance along the ellipsoid.

First, the height of the base of the theodolite above the water was calculated using the distance between the theodolite and the fixed shoreline location and the corrected clinometer angle as measured by the theodolite when a fix was made on the shoreline location. Geographic locations of sightings were then calculated using the theodolite eyepiece height (corrected for changes in observer/eyepiece height and tide elevation for each sighting), the corrected distance between the theodolite and the sighting on the ellipsoid, and the sighting azimuth.

Literature Cited

Canadian Geodetic Survey. 2013. GPS·H v3.2.1. desktop software. Downloaded and accessed on 15 December 2016 from https://webapp.geod.nrcan.gc.ca/geod/tools-outils/applications.php?locale=en#gpsh.

Ceylan, A. 2009. Determination of the deflection of vertical components via GPS and leveling measurement: A case study of a GPS test network in Konya, Turkey. Scientific Research and Essay Vol.4 (12), pp. 1438–1444.

Krakiwsky, E.J. and D.B. Thomson. 1974. Geodetic Position Computations. Geodesy and Geomatics Engineering, Lecture Notes, No. 39. 99 p.

NGS (National Geodetic Survey). 2016. NGS geodetic toolkit. Accessed 19 December 2016, http://www.ngs.noaa.gov/TOOLS/.

Vincenty, T. 1975. Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations. Survey Review, 23(176):88–93.

APPENDIX E: DAILY SUMMARY, 2016

20 July	- training in King City for LGL biologists - led by Heather Smith (HS) and Patrick Abgrall (PA) - attended by Jeremy Gatten (JG), Sarah Penney-Belbin (SPB), Kathleen Leonard (KL), Amber Stephens (AS)
21 July	04:45 – team arrives at airport for flights: Toronto-Ottawa-Iqaluit-Clyde River-Pond Inlet 08:20 – land in Ottawa 08:45 – flight to Iqaluit cancelled because of weather - overnight in Ottawa
22 July	07:00 – check in at airport for 8:30 flight from Ottawa to Iqaluit 11:00 – depart for Iqaluit (flight delayed due to weather) 13:53 – unable to land in Iqaluit because of fog, flight direct to Goose Bay to re-fuel 19:30 – land in Ottawa - overnight in Ottawa
23 July	- day in Ottawa because no flights available
24 July	07:00 – check in at airport for 8:30 flight from Ottawa to Iqaluit 14:35 – flight to Iqaluit cancelled because of weather - overnight in Ottawa
25 July	12:30 – charter bus to Montreal - grocery shopping for camp - overnight in Montreal
26 July	- biologist training in a.m. 11:45 – shuttle to Mirabel airport 14:30 – depart Mirabel on Nolinor flight to Mary River 19:45 – arrive Mary River
27 July	07:30 – biologist training (~2 hrs) 09:45 – Dornier from Pond Inlet arrives with Jimmy Awa (JA), Robert Aglak (RA), James Quaraq (JQ), Enooyak Sudlovenick (ES), Phanuel Enooagak (PE), James Pewatoalook (JP) 10:30 – Baffinland orientation & training 12:25 – depart Mary River on bus to Milne Port, arrive at 14:45 15:10 – first of four helicopter trips with personnel & gear to Bruce Head <u>Campsite weather</u>: sunny and bright - met by Max Bakken (MB; camp manager) & Desmond Roessingh (DR; ass't camp manager) - load of gear slung down to observation site via helicopter (e.g., Big Eyes, theodolites) 20:00 – brief camp orientation and safety meeting
28 July	<u>Campsite weather</u>: sunny and clear skies in a.m., rain throughout the afternoon 09:00–11:40 – full camp orientation and HSE plan review 12:45–13:15 – brief data collection overview 13:30 – depart for observation site with entire team @ obs site: platform supports straightened and strengthened, Big Eye pedestal installed, weather station up and running, holes in survival shack patched with sheathing tape 17:00 – team heads back to camp
29 July	<u>Campsite weather</u>: periods of rain throughout the day - rocks too slippery for hike – completed tasks in camp: AIS antennae up on kitchen tent, satellite phones programmed with emergency contact info, all emergency contact numbers verified, equipment prep for observation site, desks built in sleeping tents
30 July	<u>Campsite weather</u>: brief period of heavy rain and thunder overnight; a.m. overcast and damp but ground is relatively dry - AIS computer up and running 09:45 – entire team depart for obs site, arrive ~10:15 - review natural landmarks for RAD counts - gear organized in survival shack

	- Big Eyes bolted to pedestal - total station/data logger training - data collection begins - post-shift data backup procedures finalized - observation period: 12:42–14:14; shift ended early because of rain - weather: periods of rain; Sightability: mostly severely impaired; Beaufort Scale: 3 - no narwhals - RAD counts: 1 full, 1 partial (aborted because of rain) - focal follows: 0 - group comp effort: 1:33 hrs - vessels: large (1) - other: shooting (2) - marmam: 0 - campers on rocks below platform	
31 July	Early shift - observation period: 06:00–13:48; end shift early because of rain - weather: periods of rain; Sightability: mostly excellent; Beaufort Scale: 2 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 6 - group comp effort: 6:01 hrs - vessels: small (1) - other: shooting (3) - marmam: 0 - campers on rocks below platform	Late shift - observation period: 18:36–22:00; shift start delayed waiting for safe hiking conditions - weather: no precipitation; Sightability: good & moderately impaired; Beaufort Scale: 2,3 - no narwhals - RAD counts: 3 - focal follows: 0 - group comp effort: 3:03 hrs - vessels: small (1) - other: 0 - marmam: 0
1 Aug	Early shift - no observations: rain and wind	Late shift - no observations: rain and fog
2 Aug	Early shift - no observations: rain, wind, and fog	Late shift - observation period: 17:35–22:17; shift start delayed waiting for safe hiking conditions - weather: no precipitation; Sightability: mostly excellent; Beaufort Scale: 1 - narwhals in BSA & SSA - RAD counts: 6 - focal follows: 0 - group comp effort: 1:56 hrs - vessels: large (2) - other: airplane (1) - marmam: 0 - campers on rocks below platform
3 Aug	Early shift - observation period: 06:06–14:00 - weather: no precipitation; Sightability: good & excellent; Beaufort Scale: 1 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 9 - group comp effort: 7:54 hrs - vessels: small (1) - other: shooting (1) - marmam: ringed seal (2), harp seal (1) - campers on rocks below platform	Late shift - observation period: 14:00–22:00 - weather: no precipitation; Sightability: excellent; Beaufort Scale: 0,1 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 0 - group comp effort: 7:43 hrs - vessels: small (4) - other: shooting (1), airplane (1) - marmam: harp seal (1) - campers on rocks below platform

4 Aug	Early shift - no observations: rain and fog	Late shift - no observations: rain and fog
5 Aug	Early shift - observation period: 06:00–14:00 - weather: no precipitation; Sightability: mostly moderately impaired; Beaufort Scale: 3,4 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 1 - group comp effort: 7:45 hrs - vessels: 0 - other: 0 - marmam: 0 - campers on rocks below platform	Late shift - observation period: 14:00–19:38; shift ended early because of strong winds - weather: no precipitation; Sightability: good, moderate & severely impaired; Beaufort Scale: 3-5 - narwhals in BSA & SSA - RAD counts: 5 - focal follows: 0 - group comp effort: 4:47 hrs - vessels: 0 - other: shooting (1), helicopter (1) - marmam: 0 - campers on rocks below platform
6 Aug	Early shift - observation period: 09:52–10:43; shift start delayed because of fog, and ended early because of high winds - weather: no precipitation; Sightability: severely impaired; Beaufort Scale: 5,6 - no narwhals - RAD counts: 1 - focal follows: 0 - group comp effort: 0:51 hrs - vessels: medium (1) - other: 0 - marmam: 0 - campers on rocks below platform	Late shift - no observations: high winds
7 Aug	Early shift - observation period: 08:00–14:00 shift start delayed because of fog - weather: no precipitation; Sightability: moderate & severely impaired; Beaufort Scale: 4,5 - no narwhals - RAD counts: 6 - focal follows: 0 - group comp effort: 6:00 hrs - vessels: 0 - other: 0 - marmam: seal (1) - campers on rocks below platform	Late shift - observation period: 14:00–20:31; shift ended early because of strong winds - weather: no precipitation; Sightability: moderate & severely impaired; Beaufort Scale: 4-6 - narwhals in BSA & SSA - RAD counts: 7 - focal follows: 0 - group comp effort: 4:56 hrs - vessels: small (1) - other: shooting (5), helicopter (1) - marmam: 0 - campers on rocks below platform
8 Aug	Early shift - observation period: 06:15–14:00 - weather: no precipitation; Sightability: mostly good; Beaufort Scale: 3,4 - narwhals in BSA & SSA - RAD counts: 9 - focal follows: 0 - group comp effort: 7:37 hrs - vessels: large (1) - other: 0 - marmam: ringed seal (7)	Late shift - observation period: 14:00–22:00 - weather: no precipitation; Sightability: mostly moderately impaired; Beaufort Scale: 2,3 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 0 - group comp effort: 7:27 hrs - vessels: small (1), large (1) - other: shooting (2), helicopter (1) - marmam: 0

	- campers on rocks below platform	- campers on rocks below platform
9 Aug	19:45 – LGL biologist Colin Jones (CJ) arrives Mary River on Nolinor from Mirabel	
	<u>Early shift</u> - observation period: 06:00–14:00 - weather: no precipitation; Sightability: good; Beaufort Scale: 2,3 - narwhals in BSA & SSA - RAD counts: 10 full, 1 partial (aborted to start large vessel count) - focal follows: 0 - group comp effort: 8:00 hrs - vessels: small (1), medium (1), large (2) - other: 0 - marmam: ringed seal (3), harp seal (1) - campers on rocks below platform	<u>Late shift</u> - observation period: 14:00–22:00 - weather: no precipitation; Sightability: good; Beaufort Scale: 2,3 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 0 - group comp effort: 7:21 hrs - vessels: small (3) - other: shooting (8) - marmam: ringed seal (1) - campers on rocks below platform
10 Aug	08:05 – CJ arrives at Bruce Head via helicopter from Mary River (to join A-team 11 Aug)	
	<u>Early shift</u> - observation period: 06:08–14:00 - weather: no precipitation; Sightability: good; Beaufort Scale: 1-3 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 3 - group comp effort: 8:00 hrs - vessels: small (1) - other: shooting (1), helicopter (1), airplane (1) - marmam: ringed seal (2) - campers on rocks below platform	<u>Late shift</u> - observation period: 14:00–22:42 - weather: no precipitation; Sightability: good & moderately impaired; Beaufort Scale: 1-2 - narwhals in BSA & SSA - RAD counts: 10 - focal follows: 0 - group comp effort: 7:30 hrs - vessels: small (5), large (1) - other: shooting (7) - marmam: polar bear (1) - campers on rocks below platform
11 Aug	<u>Early shift</u> - observation period: 06:28–14:00 - weather: no precipitation; Sightability: mostly excellent; Beaufort Scale: 1 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 1 - group comp effort: 7:32 hrs - vessels: 0 - other: airplane (1) - marmam: bowhead (1), ringed seal (1) - campers on rocks below platform	<u>Late shift</u> - observation period: 14:00–22:00 - weather: no precipitation; Sightability: mostly good & excellent; Beaufort Scale: 0,1 - narwhals in BSA & SSA - RAD counts: 9 - focal follows: 0 - group comp effort: 7:33 hrs - vessels: small (3), large (1) - other: shooting (11) - marmam: 0 - campers on rocks below platform
12 Aug	<u>Early shift</u> - observation period: 06:08–14:00 - weather: no precipitation; Sightability: good; Beaufort Scale: 2,3 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 1 - group comp effort: 7:53 hrs - vessels: small (2) - other: 0 - marmam: ringed seal (1), harp seal (1)	<u>Late shift</u> - observation period: 14:00–21:32 - weather: no precipitation; Sightability: mostly good & moderately impaired; Beaufort Scale: 1,2 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 0 - group comp effort: 6:10 hrs - vessels: small (8) - other: shooting (1) - marmam: 0 - campers on rocks below platform

13 Aug	Early shift - observation period: 06:01–14:00 - weather: no precipitation; Sightability: good; Beaufort Scale: 2,3 - narwhals in BSA & SSA - RAD counts: 9 - focal follows: 0 - group comp effort: 8:00 hrs - vessels: small (3), large (1) - other: shooting (1) - marmam: 0	Late shift - observation period: 14:00–21:32 - weather: no precipitation; Sightability: good, moderate & severely impaired; Beaufort Scale: 3,4 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 0 - group comp effort: 7:40 hrs - vessels: small (7) - other: shooting (2), helicopter (1) - marmam: 0 - campers on rocks below platform
14 Aug	Early shift - observation period: 06:00–14:00 - weather: no precipitation; Sightability: good; Beaufort Scale: 2,3 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 4 - group comp effort: 8:00 hrs - vessels: small (2) - other: shooting (4) - marmam: 0 - campers on rocks below platform	Late shift - observation period: 14:00–21:32 - weather: no precipitation; Sightability: mostly good & excellent; Beaufort Scale: 1,2 - narwhals in BSA & SSA - RAD counts: 9 - focal follows: 0 - group comp effort: 6:30 hrs - vessels: small (2), large (1) - other: shooting (3), helicopter (2) - marmam: 0 - campers on rocks below platform
15 Aug	Early shift - observation period: 06:00–14:00 - weather: no precipitation; Sightability: good & excellent; Beaufort Scale: 1,2 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 12 - group comp effort: 8:00 hrs - vessels: small (5) - other: shooting (2), airplane (1) - marmam: polar bear (1) - campers on rocks below platform	Late shift - observation period: 14:00–21:32 - weather: no precipitation; Sightability: good & excellent; Beaufort Scale: 1,2 - narwhals in BSA & SSA - RAD counts: 7 - focal follows: 1 - group comp effort: 6:00 hrs - vessels: small (6) - other: helicopter (1) - marmam: 0 - campers on rocks below platform
16 Aug	Early shift - observation period: 06:10–14:00 - weather: brief period of rain; Sightability: good; Beaufort Scale: 2,3 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 1 - group comp effort: 8:00 hrs - vessels: small (3) - other: shooting (5), helicopter (1) - marmam: 0 - campers on rocks below platform	Late shift - observation period: 14:00–19:09; shift ended early because of rain - weather: rain at end of shift; Sightability: mostly moderately impaired; Beaufort Scale: 2,3 - narwhals in BSA & SSA - RAD counts: 6 full, 1 partial (aborted to start large vessel count) - focal follows: 0 - group comp effort: 1:31 hrs - vessels: small (2), large (2) - other: 0 - marmam: 0 - campers on rocks below platform
17 Aug	Early shift - no observations: rain and fog	Late shift - no observations: rain and fog

18 Aug	Early shift - no observations: fog	Late shift - observation period: 16:00–20:30; shift start delayed because of fog and ended early because of wind - weather: no precipitation; Sightability: moderate & severely impaired; Beaufort Scale: 3-5 - no narwhals - RAD counts: 5 - focal follows: 0 - group comp effort: 4:30 hrs - vessels: 0 - other: 0 - marmam: polar bear (1) - campers on rocks below platform
19 Aug	Early shift - observation period: 08:08–12:00; delayed shift start because of icing overnight - weather: no precipitation; Sightability: good; Beaufort Scale: 1,2 - narwhals in BSA & SSA - RAD counts: 7 - focal follows: 4 - group comp effort: 6:00 hrs - vessels: small (3), large (2) - other: 0 - marmam: 0 - campers on rocks below platform	Late shift - observation period: 14:00–22:00 - weather: no precipitation; Sightability: good & moderately impaired; Beaufort Scale: 1-3 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 1 - group comp effort: 7:13 hrs - vessels: small (1) - other: shooting (1) - marmam: ringed seal (1) - campers on rocks below platform
20 Aug	Early shift - observation period: 06:05–14:00 - weather: no precipitation; Sightability: good; Beaufort Scale: 3,4 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 3 - group comp effort: 7:55 hrs - vessels: 0 - other: shooting (1) - marmam: polar bear (1)	Late shift - observation period: 14:00–22:00 - weather: no precipitation; Sightability: good & excellent; Beaufort Scale: 0-3 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 0 - group comp effort: 8:00 hrs - vessels: small (4) - other: shooting (1) - marmam: polar bear (1) - campers on rocks below platform
21 Aug	Early shift - observation period: 06:08–14:00 - weather: no precipitation; Sightability: mostly good; Beaufort Scale: 0,1 - narwhals in BSA & SSA - RAD counts: 9 - focal follows: 3 - group comp effort: 7:52 hrs - vessels: small (2), large (1) - other: shooting (6), helicopter (2), airplane (1) - marmam: 0 - campers on rocks below platform	Late shift - observation period: 14:00–22:00 - weather: no precipitation; Sightability: good & excellent; Beaufort Scale: 0-2 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 0 - group comp effort: 8:00 hrs - vessels: small (6) - other: 0 - marmam: 0 - campers on rocks below platform
22 Aug	Early shift - observation period: 06:10–14:00	Late shift - observation period: 14:00–19:22; shift ended

	- weather: no precipitation; Sightability: good; Beaufort Scale: 1 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 0 - group comp effort: 7:50 hrs - vessels: small (5) - other: 0 - marmam: 0 - campers on rocks below platform	early because of high winds - weather: no precipitation; Sightability: moderate & severely impaired; Beaufort Scale: 1-6 - narwhals in BSA - RAD counts: 6 - focal follows: 0 - group comp effort: 8:00 hrs - vessels: small (4), large (1) - other: 0 - marmam: 0 - campers on rocks below platform
23 Aug	<u>Campsite weather</u>: high winds, high Beaufort Scale in early am; winds receded ~11:00 10:15 – HS, KL, AS depart camp (single shift from now on) for Mary River via helicopter 11:30 – RA, JQ, PE depart camp for Mary River via helicopter - HS, KL, AS fly to Mirabel on Nolinor, and continue home on 24 August - RA, JQ, PE will fly to Pond Inlet on charter flight on 25 August 12:00 – depart for observation site with single, combined team 17:15 – combined team heads back to camp - observation period: 12:26–17:00; delayed shift start because of wind and ended early because field crew transitioning to new schedule - weather: no precipitation; Sightability: moderately impaired; Beaufort Scale: 3-5 - narwhals in BSA & SSA - RAD counts: 5 - focal follows: 0 - group comp effort: 4:34 hrs - vessels: small (3), large (1) - other: 0 - marmam: 0 - campers on rocks below platform	
24 Aug	<u>Campsite weather</u>: skies mainly clear in early am, ominous clouds distant to the NE 10:05 – helicopter lands at observation site 10:20 – MB, DS and BIM personnel arrive at observation site; hiked from campsite 10:36 – helicopter departs observation site with BIM personnel - observation period: 09:05–12:00; shift ended early because of high winds - weather: no precipitation; Sightability: moderately impaired; Beaufort Scale: 2-5 - no narwhals - RAD counts: 3 - focal follows: 0 - group comp effort: 2:55 hrs - vessels: large (1) - other: helicopter (1) - marmam: 0 - campers on rocks below platform	
25 Aug	<u>Campsite weather</u>: heavy rain overnight; overcast with light rain/drizzle and periods of fog persisting throughout the day; soil wet and rocks slippery - no observations: rain, fog and unsafe hiking conditions - data entry in camp	
26 Aug	<u>Campsite weather</u>: heavy fog throughout the day; northerly winds moderate ; soil damp and rocks slippery - no observations: fog and unsafe hiking conditions	

	- data entry in camp
27 Aug	<u>Campsite weather</u>: overcast with high ceiling in am; skies clearing in the afternoon, winds light all day - observation period: 9:12–17:00 - weather: no precipitation; Sightability: good; Beaufort Scale: 2,3 - narwhals in BSA & SSA - RAD counts: 8 - focal follows: 0 - group comp effort: 7:48 hrs - vessels: small (8) - other: shooting (1) - marmam: 0 - campers on rocks below platform
28 Aug	<u>Campsite weather</u>: mainly sunny with light winds all day - observation period: 9:00–17:00 - weather: no precipitation; Sightability: good; Beaufort Scale: 1,2 - narwhals in SSA - RAD counts: 8 - focal follows: 0 - group comp effort: 8:00 hrs - vessels: small (3), large (1) - other: 0 - marmam: 0 - campers on rocks below platform
29 Aug	<u>Campsite weather</u>: mainly sunny with moderate to high winds all day - observation period: 9:01–18:30 - weather: no precipitation; Sightability: good & moderately impaired; Beaufort Scale: 2-4 - narwhals in BSA & SSA - RAD counts: 11 - focal follows: 0 - group comp effort: 8:54 hrs - vessels: large (4) - other: 0 - marmam: 0
30 Aug	<u>Campsite weather</u>: sunny and clear skies in am, clouding over and wind increasing in pm 10:30 – PA, DS, depart camp for Mary River via helicopter (5 people remaining at camp) - observation period: 11:15–16:45; delayed shift start due to winds and field team fatigue - weather: no precipitation; Sightability: good & moderately impaired; Beaufort Scale: 2-5 - narwhals in BSA & SSA - RAD counts: 5 - focal follows: 0 - group comp effort: 3:46 hrs - vessels: 0 - other: 0 - marmam: 0 - delayed shift start to account for crew fatigue from increased wind exposure and ship activity encountered during previous day's extended shift
31 Aug	<u>Campsite weather</u>: cold night (water line frozen); winds high with persistent gusts all day; occasional snowflakes in am - no observations: high gusting northerly winds

	- data entry in camp - organization of science gear to assist with demob
1 Sept	<u>Campsite weather</u>: high, gusty winds persistent overnight and throughout the day; scattered snow squalls in the am - no observations: gusting winds and snow squalls - data entry and verification in camp
2 Sept	<u>Campsite weather</u>: 5 cm of snow accumulation in the am; high, gusty winds persistent overnight and throughout the day; snow squalls and periodic hail conditions - no observations: high winds, snow squalls, ice on ground, rocks slippery - data entry and verification in camp - organization of science and camp gear to assist with demob
3 Sept	<u>Campsite weather:</u> extreme winds overnight; overcast with moderate winds in am, increasing throughout the day - no observations: high winds, cold conditions, Beaufort Scale: 6+ - data entry and verification in camp 13:45 – CJ, JG, ES, JA, MB to observation site for de-mob (BigEyes, weather station). 14:30 – weather station data downloaded and weather station disconnected 16:00 – CJ, JG, ES, JA, MB back at camp 18:30 – project data files organized 21:00 – VHF/AIS antenna taken down off kitchen tent
4 Sept	<u>Campsite weather:</u> sunny, clear skies in am; overcast in the afternoon with light wind - no observations: Camp demobilization. [weather forecast suggests large low pressure system, snow/rain and deteriorating flight conditions beginning afternoon of 5 Sept] 08:30 – project data files finalized and multiple digital back-ups prepared 09:45 – science gear from observation platform transported back to camp by helicopter (sling load) 10:00 – science gear sorted and re-packed in camp 11:00 – onward: camp de-mob continues through afternoon with helicopter slinging multiple cargo loads (science and camp gear) to Milne Port
5 Sept	<u>Campsite weather:</u> sunny, clear skies in am; overcast and snow flurries in the afternoon - no observations: Camp demobilization. AM: final camp de-mob 14:50 – JG, ES, JA depart for Mary River via helicopter 16:00 – MB and CJ close down Bruce Head camp for the season 16:15 – CJ and MB depart for Mary River via helicopter 18:00 – all personnel reunited at Mary River (Mine Site Complex)
6 Sept	All personnel at Mary River (Mine Site Complex) - LGL gear list (23 items) finalized and chain of custody handed over to Baffinland (Env Dept) - LGL gear to be transported from Milne Port to Mary River and readied for eventual cargo shipment south - CJ and JG fly south on Nolinor charter
7 Sept	- CJ and JG depart Montreal via commercial flights for home destinations - project data files (hard copy and electronic) transferred from JG to HS in Toronto - ES departs for Iqaluit - JA departs for Pond Inlet - MB travels south on Nolinor charter

APPENDIX F: TEMPERATURE AND WIND MEASUREMENTS AT OBSERVATION SITE, 2016

Table F-1. Observational shift and daily temperature and wind measurements recorded by the weather station at the observation site during the shore-based study of narwhals, Bruce Head, 2016.

Date	Temperature (°C) [Mean (Min, Max)]			Wind speed (m/s) [Mean (Min, Max)]			Daily Mean Wind Direction[2]
	Early Shift[1]	Late Shift	24-hr Day	Early Shift	Late Shift	24-hr Day	
29-Jul	10.9 (9.2, 12.1)	11.6 (8.7, 14.0)	11.3 (8.7, 14.0)	4.1 (0.0, 10.1)	3.3 (0.0, 11.2)	3.8 (0.0, 11.2)	189
30-Jul	9.7 (8.0, 11.5)	11.4 (10.1, 13.2)	10.6 (8.0, 13.2)	2.5 (0.0, 6.1)	2.6 (0.0, 7.3)	2.7 (0.0, 8.6)	188
31-Jul	9.7 (8.2, 11.1)	10.9 (8.6, 12.1)	10.2 (8.2, 12.1)	1.5 (0.0, 4.8)	6.3 (0.0, 15.0)	4.1 (0.0, 19.4)	159
01-Aug	10.4 (9.3, 11.7)	11.2 (9.9, 12.3)	10.6 (8.7, 12.3)	9.0 (1.8, 17.8)	8.4 (3.3, 14.1)	9.3 (1.1, 21.6)	62
02-Aug	10.0 (9.0, 10.8)	11.3 (9.1, 12.7)	10.8 (9.0, 12.7)	12.1 (4.1, 19.7)	6.7 (0.0, 15.4)	10.4 (0.0, 23.1)	51
03-Aug	10.2 (8.6, 12.9)	12.6 (11.3, 13.5)	11.0 (8.1, 13.5)	1.9 (0.0, 5.6)	1.2 (0.0, 3.6)	1.5 (0.0, 6.3)	178
04-Aug	11.0 (10.1, 12.2)	9.8 (6.2, 12.1)	10.3 (6.2, 13.4)	4.5 (0.0, 12.9)	7.6 (1.1, 16.0)	5.9 (0.0, 16.7)	124
05-Aug	4.6 (3.6, 6.6)	6.1 (4.7, 7.4)	5.1 (3.6, 7.4)	8.1 (0.9, 17.2)	8.8 (0.6, 15.8)	9.7 (0.6, 19.9)	163
06-Aug	4.0 (3.0, 5.4)	6.1 (4.7, 7.6)	4.8 (3.0, 7.6)	13.6 (8.2, 18.1)	12.7 (6.7, 19.1)	12.5 (4.3, 19.1)	167
07-Aug	5.6 (4.2, 7.8)	7.4 (5.7, 9.1)	6.1 (4.1, 9.1)	10.9 (5.8, 16.5)	10.6 (0.0, 16.5)	11.7 (0.0, 20.0)	151
08-Aug	6.4 (4.1, 7.9)	8.2 (7.5, 8.9)	6.8 (4.1, 8.9)	8.5 (5.1, 13.9)	9.3 (4.6, 13.7)	10.0 (4.6, 18.8)	154
09-Aug	7.7 (5.3, 10.1)	10.7 (9.1, 12.3)	8.8 (5.3, 12.3)	2.8 (0.0, 8.0)	1.2 (0.0, 5.5)	3.6 (0.0, 13.0)	188
10-Aug	8.5 (5.4, 11.9)	12.8 (10.7, 13.5)	10.3 (5.4, 13.5)	2.4 (0.0, 6.7)	2.6 (0.0, 6.4)	2.8 (0.0, 7.8)	209
11-Aug	11.2 (9.7, 13.5)	14.7 (13.0, 16.0)	12.2 (6.8, 16.0)	1.3 (0.0, 3.5)	1.9 (0.0, 4.6)	2.4 (0.0, 11.1)	190
12-Aug	12.2 (10.2, 15.0)	13.5 (11.0, 15.0)	12.1 (10.2, 15.0)	2.4 (0.0, 6.9)	4.8 (0.0, 10.3)	4.0 (0.0, 10.4)	141
13-Aug	8.7 (7.0, 10.9)	9.7 (8.0, 11.0)	8.9 (7.0, 11.1)	4.4 (0.0, 12.0)	6.5 (0.0, 12.3)	5.7 (0.0, 12.4)	159

Date	Temperature (°C) [Mean (Min, Max)]			Wind speed (m/s) [Mean (Min, Max)]			Daily Mean Wind
14-Aug	7.9 (5.8, 10.7)	11.2 (9.1, 14.5)	8.8 (5.2, 14.5)	3.3 (0.0, 8.4)	1.2 (0.0, 3.9)	3.8 (0.0, 14.3)	187
15-Aug	8.4 (5.4, 12.8)	12.2 (11.0, 13.5)	9.7 (5.4, 13.5)	1.3 (0.0, 4.5)	1.4 (0.0, 4.3)	1.3 (0.0, 4.5)	197
16-Aug	9.6 (8.6, 11.3)	12.1 (9.5, 13.6)	10.7 (8.6, 13.6)	7.2 (4.2, 10.3)	11.9 (6.0, 20.8)	7.9 (0.0, 20.8)	59
17-Aug	9.8 (9.1, 10.6)	10.5 (9.7, 11.0)	10.2 (9.1, 11.0)	10.2 (4.1, 14.7)	7.0 (0.0, 13.3)	7.7 (0.0, 14.7)	73
18-Aug	5.4 (4.7, 6.4)	4.9 (3.2, 7.2)	5.5 (3.2, 10.7)	4.3 (0.0, 10.5)	6.7 (0.0, 13.2)	4.7 (0.0, 13.2)	174
19-Aug	3.4 (1.5, 5.9)	6.5 (5.4, 7.2)	4.2 (1.2, 7.2)	4.5 (0.3, 10.0)	4.7 (1.0, 10.4)	6.4 (0.3, 14.4)	186
20-Aug	5.7 (3.6, 8.5)	9.6 (8.7, 11.0)	7.0 (3.5, 11.0)	5.4 (0.7, 9.1)	3.0 (0.0, 9.3)	4.6 (0.0, 10.0)	81
21-Aug	10.5 (8.0, 12.1)	12.2 (10.8, 13.4)	10.7 (6.9, 13.4)	1.4 (0.0, 3.7)	0.8 (0.0, 2.7)	1.3 (0.0, 4.0)	179
22-Aug	11.5 (9.3, 14.2)	10.0 (6.3, 14.1)	10.5 (6.3, 14.2)	1.3 (0.0, 4.7)	12.0 (0.0, 23.9)	6.3 (0.0, 24.6)	183
23-Aug	5.5 (3.7, 7.6)	8.1 (6.4, 9.5)	6.2 (3.7, 9.5)	9.9 (0.1, 21.0)	5.9 (0.0, 12.9)	10.0 (0.0, 25.3)	154
24-Aug	6.8 (5.6, 8.9)	7.3 (6.1, 9.0)	6.7 (4.8, 9.0)	6.6 (0.0, 16.5)	15.1 (8.5, 22.7)	10.2 (0.0, 22.7)	170
25-Aug	7.6 (5.5, 8.9)	8.7 (7.3, 10.3)	7.6 (5.3, 10.3)	7.2 (0.4, 15.2)	10.0 (0.3, 16.9)	9.8 (0.0, 21.4)	164
26-Aug	5.3 (3.9, 6.7)	6.9 (5.4, 7.7)	6.5 (3.9, 9.3)	9.2 (0.4, 16.9)	6.2 (0.0, 14.0)	7.5 (0.0, 16.9)	148
27-Aug	7.6 (6.9, 8.4)	8.8 (7.5, 9.6)	7.8 (5.4, 9.6)	4.5 (0.1, 9.0)	3.2 (0.0, 8.2)	4.0 (0.0, 9.9)	162
28-Aug	6.8 (4.5, 8.7)	9.8 (7.4, 10.7)	8.0 (4.5, 10.7)	1.4 (0.0, 5.5)	2.4 (0.0, 8.9)	2.2 (0.0, 8.9)	168
29-Aug	7.8 (6.9, 8.6)	9.0 (7.2, 9.8)	8.6 (6.9, 10.4)	8.3 (3.3, 11.6)	8.3 (4.1, 11.3)	7.3 (0.0, 11.7)	69
30-Aug	7.1 (5.8, 8.8)	6.0 (3.5, 9.9)	6.5 (3.5, 9.9)	4.8 (0.0, 10.8)	8.2 (0.0, 17.8)	6.3 (0.0, 17.8)	122
31-Aug	1.8 (0.8, 3.7)	3.4 (2.3, 4.8)	2.3 (0.7, 4.8)	3.7 (0.0, 10.8)	4.6 (0.0, 15.3)	5.0 (0.0, 15.3)	140
01-Sep	2.3 (1.6, 3.3)	3.8 (2.9, 5.3)	2.8 (1.6, 5.3)	6.2 (0.0, 17.4)	5.3 (0.0, 17.1)	6.7 (0.0, 17.4)	107
02-Sep	1.8 (1.3, 2.7)	1.8 (0.1, 2.6)	1.6 (0.1 2.9)	11.1 (0.6, 18.3)	6.0 (0.0, 13.6)	9.1 (0.0, 20.3)	77
03-Sep[3]	-0.3 (-1.1, 1.2)	0.3 (0.0, 0.5)	-0.4 (-1.8, 1.2)	10.3 (4.1, 15.6)	9.1 (3.4, 12.4)	8.4 (0.0, 15.6)	69

Date	Temperature (°C) [Mean (Min, Max)]			Wind speed (m/s) [Mean (Min, Max)]			Daily Mean Wind
Overall	7.5 (-1.1, 15.0)	9.1 (0.0, 16.0)	8 (-1.8, 16.0)	5.7 (0.0, 21.0)	6.1 (0.0, 24.6)	6.2 (0.0, 25.3)	145

[1] Early shift: 06:00 to 14:00; Late shift: 14:00 to 22:00.

[2] Based on 360 degrees with 0/360 indicating north. Any wind direction between 355 and 360 degrees for the entire duration of the 5-minute sample period was recorded as 0.

[3] Weather station was dismantled on 3 September; data recording ceased at 14:25.

APPENDIX G: VESSEL SUMMARY, 2016

Table G-1. Dates and hours during which vessels were present in the stratified study area (SSA) during observation periods for the shore-based study of narwhals at Bruce Head, 2016.

Date	Small Vessels	Medium Vessels	Large Vessels
30 July			13:00 – *NS Energy*
31 July	12:00 – 1 voyageur canoe with 1 outboard 20:00 – 1 voyageur canoe with 1 outboard		
1 Aug	No observations because of poor weather		
2 Aug			18:00 – *Nordic Oasis* 19:00 – *Nordic Oasis* 20:00 – *Nordic Odin* 21:00 – *Nordic Odin*
3 Aug	13:00 – 1 skiff with 1 outboard 14:00 – 1 skiff with 1 outboard 15:00 – 1 skiff with 1 outboard 16:00 – 2 skiffs, each with 1 outboard	14:00 – *Rosehearty* 15:00 – *Rosehearty*	
4 Aug	No observations because of poor weather		
5 Aug	No vessels		
6 Aug		09:00 – *Galileo G* 10:00 – *Galileo G*	
7 Aug	17:00 – 1 skiff with 1 outboard 18:00 – 1 skiff with 1 outboard 19:00 – 1 skiff with 1 outboard		
8 Aug	19:00 – 1 skiff with 1 outboard		13:00 – *Golden Strength*
9 Aug	13:00 – 1 skiff with 1 outboard 14:00 – 2 skiffs, each with 1 outboard 16:00 – 1 skiff with 1 outboard 17:00 – 1 skiff with 1 outboard 18:00 – 1 skiff with 1 outboard 19:00 – 1 skiff with 1 outboard 20:00 – 2 skiffs, each with 1 outboard		05:00 – *Nordic Olympic* 06:00 – *Nordic Olympic* 10:00 – *Golden Ice* 11:00 – *Golden Ice*
10 Aug	09:00 – 1 skiff with 2 outboards 13:00 – 1 voyageur canoe with 1 outboard 14:00 – 1 skiff with 1 outboard 15:00 – 1 skiff with 1 outboard 16:00 – 1 skiff with 1 outboard 17:00 – 1 skiff with 1 outboard 19:00 – 2 skiffs, each with 1 outboard 20:00 – 1 skiff with 1 outboard		21:00 – *Golden Diamond* 22:00 – *Golden Diamond*
11 Aug	15:00 – 1 skiff with 1 outboard 17:00 – 2 skiffs, each with 1 outboard 18:00 – 2 skiffs, each with 1 outboard 19:00 – 1 skiff with 1 outboard		17:00 – *Nordic Orion*
12 Aug	10:00 – 1 skiff with outboard 13:00 – 1 skiff with 1 outboard 14:00 – 2 skiffs, each with 1 outboard 15:00 – 2 skiffs, each with 1 outboard 16:00 – 2 skiffs, each with 1 outboard 18:00 – 3 skiffs, each with 1 outboard 19:00 – 2 skiffs, each with at least 1 outboard 20:00 – 1 skiff with 1 outboard		

Date	Small Vessels	Medium Vessels	Large Vessels
13 Aug	06:00 – 1 skiff with 1 outboard 08:00 – 1 skiff with 1 outboard 11:00 – 1 skiff with 2 outboards 12:00 – 1 skiff with 2 outboards 13:00 – 2 skiffs, both with 2 outboards 15:00 – 1 skiff with 1 outboard 16:00 – 1 skiff with 1 outboard 17:00 – 2 skiffs, each with 1 outboard 18:00 – 3 skiffs, each with 1 outboard 19:00 – 2 skiffs, each with 1 outboard		10:00 – *Golden Strength*
14 Aug	11:00 – 1 skiff with 1 outboard 12:00 – 1 skiff with 1 outboard 15:00 – 1 skiff with 1 outboard 20:00 – 1 skiff with 1 outboard		19:00 – *Golden Bull* 20:00 – *Golden Bull*
15 Aug	07:00 – 1 skiff with 2 outboards 11:00 – 2 skiffs, each with 1 outboard 12:00 – 1 skiff and 2 voyageur canoes, each with at least 1 outboard 14:00 – 1 skiff with at least 1 outboard 15:00 – 3 skiffs, 1 with 1 outboard, 2 with 2 outboards; and 1 voyageur canoe with 1 outboard 17:00 – 1 skiff with 2 outboards 18:00 – 1 skiff with 2 outboards 20:00 – 1 skiff with 1 outboard 21:00 – 1 skiff with 1 outboard		
16 Aug	11:00 – 1 skiff with 1 outboard 12:00 – 1 skiff with 1 outboard 13:00 – 2 skiffs, 1 with 1 outboard, 1 with 2 outboards 17:00 – 2 skiffs, 1 with 1 outboard, 1 with 2 outboards		15:00 – *Rosaire A. Desgagné* 16:00 – *Rosaire A. Desgagné* 18:00 – *Nordic Orion*
17 Aug	No observations because of poor weather		
18 Aug	No vessels		
19 Aug	08:00 – 1 skiff with 2 outboards 11:00 – 1 voyageur canoe with 1 outboard 12:00 – 1 voyageur canoe with 1 outboard 13:00 – 2 voyageur canoes, each with 1 outboard 18:00 – 1 voyageur canoe with 1 outboard 20:00 – 1 voyageur canoe with 1 outboard		12:00 – *Golden Pearl* 13:00 – *Golden Pearl*
20 Aug	14:00 – 1 skiff with outboard 15:00 – 2 skiffs, each with 1 outboard 16:00 – 3 skiffs, 2 with 1 outboard, 1 with 2 outboards 20:00 – 1 skiff with 2 outboards 21:00 – 1 skiff with 1 outboard		
21 Aug	12:00 – 1 skiff with 1 outboard 13:00 – 2 skiffs, 1 with 1 outboard, 1 with 2 outboards 14:00 – 1 skiff with 1 outboard 16:00 – 3 skiffs, 2 with 1 outboard, 1 with 2 outboards 17:00 – 1 skiff with 2 outboards 18:00 – 2 skiffs, each with 1 outboard		07:00 – *Golden Saguenay* 08:00 – *Golden Saguenay*

Date	Small Vessels	Medium Vessels	Large Vessels
	19:00 – 1 skiff with 1 outboard		
22 Aug	11:00 – 1 skiff with 1 outboard 12:00 – 3 skiffs, 2 with 1 outboard, 1 with 2 outboards; and 1 voyageur canoe with 1 outboard 13:00 – 1 skiff with 1 outboard 14:00 – 2 skiffs, 1 with 1 outboard, 1 with 2 outboards 15:00 – 1 skiff with 2 outboards, and 1 voyageur canoe with 1 outboard 17:00 – 1 skiff with 1 outboard 18:00 – 1 skiff with 1 outboard		17:00 – *Golden Opportunity* 18:00 – *Golden Opportunity*
23 Aug	16:00 – 2 skiffs and 1 voyageur canoe, each with 1 outboard		11:00 – *Golden Brilliant* 12:00 – *Golden Brilliant*
24 Aug			08:00 – *NS Yakutia* 09:00 – *NS Yakutia*
25 Aug	No observations because of poor weather		
26 Aug	No observations because of poor weather		
27 Aug	11:00 – 1 skiff with 1 outboard 12:00 – 2 skiffs, each with at least 1 outboard 14:00 – 2 skiffs, 1 with 1 outboard and 1 with 2 outboards; and 1 voyageur canoe with 1 outboard 15:00 – 1 skiff with 2 outboards; and 1 voyageur canoe with 1 outboard 16:00 – 2 skiffs, each with 2 outboards; and 1 voyageur canoe with 1 outboard		
28 Aug	09:00 – 1 voyageur canoe with 1 outboard 11:00 – 1 skiff with 1 outboard 16:00 – 1 skiff with 1 outboard 17:00 – 1 skiff with 1 outboard		07:00 – *NS Yakutia* 08:00 – *NS Yakutia*
29 Aug			12:00 – *Silver Explorer* 14:00 – *Anna Desgagné* 15:00 – *Nordic Oasis* 16:00 – *Nordic Oasis, Silver Explorer* 17:00 – *Silver Explorer*
30 Aug	No vessels		

APPENDIX H: ADDITIONAL STATISTICAL ANALYSIS RESULTS

Assessing the fit of the GLMM model to 2014–2016 narwhal count data

The residual plot for the GLMM fitted to the 2014–2016 counts indicated that the final model specification and link function were appropriate as residuals were spread evenly around the linear predictor for all but the greatest predicted values (Figure H-1).

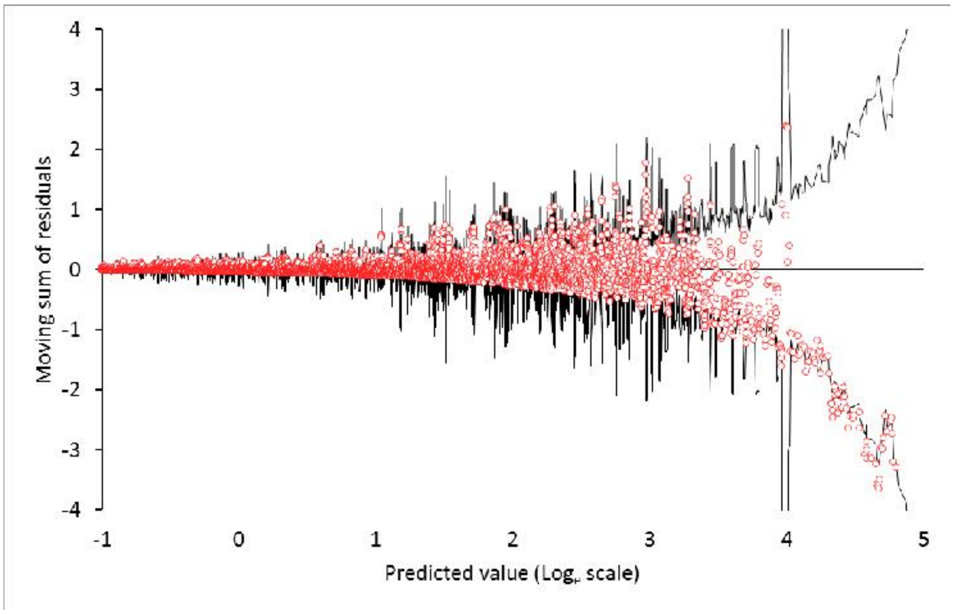


FIGURE H-1. Moving sum of raw residuals (red circles) plotted against the linear predictor for the number of narwhals (window size=10). Black lines represent two standard deviations at each window. Values were sorted by the linear predictor; the points plotted include only those beyond the first record when the observed number of narwhals was greater than zero to facilitate visualization of the remaining residuals.

RAD Model: Covariance

The likelihood ratio test for the RAD model indicated the correlation parameter, ρ =0.48, was significant, and the correlation among adjacent strata was substantial (Table H-1), justifying the need for the covariance structure as specified to account for spatial autocorrelation across strata. Not including this random effect would have produced confidence intervals and p-values for the RAD model that were biased low.

TABLE H-1. Average correlation coefficients (above diagonal line) and covariances (below diagonal line) among spatial strata. The overall correlation estimate ρ was 0.48 (SE=0.05), the average correlation between two strata on a given day separated in time by one hour (time differences between consecutive stratum counts were typically 3 min; e.g., the correlation between stratum A and B was $0.48^{0.05\ hrs}$=0.96). The overall covariance estimate σ^2 was 10.93 (SE=1.26) and represents the average within subject covariance. The covariance of two strata (found below the diagonal) is calculated by multiplying the respective correlation coefficient between the two (found above the diagonal) by σ^2. Likelihood ratio tests indicated that both ρ and σ2 were statistically significant (*p*-values<0.0001).

Stratum	A	B	C	D	E	F	G	H	I
A		0.96	0.93	0.90	0.86	0.81	0.76	0.71	0.68
B	10.54		0.96	0.93	0.90	0.84	0.79	0.74	0.70
C	10.16	10.54		0.96	0.93	0.87	0.82	0.76	0.73
D	9.80	10.16	10.54		0.96	0.91	0.85	0.79	0.75
E	9.44	9.80	10.16	10.54		0.94	0.88	0.82	0.78
F	8.88	9.21	9.55	9.91	10.28		0.94	0.87	0.83
G	8.36	8.67	8.99	9.33	9.67	10.29		0.93	0.88
H	7.77	8.06	8.36	8.67	8.99	9.56	10.16		0.95
I	7.39	7.67	7.96	8.25	8.56	9.10	9.67	10.41	

Group Composition and Nearshore Travels Patterns of Passing Narwhals – results of pairwise comparisons

Pairwise comparisons of group characteristics following a significant omnibus χ^2 result, repeated for each time window used to define level of anthropogenic activity. *Post-hoc* pairwise comparisons were made using a χ^2 with p-values adjusted using the Bonferroni method. Significant tests are highlighted in grey (α = 0.05).

Group spread (tight vs. loose), 15-minute window

```
χ2 = 14.955, df = 3, p-value = 0.001855
                     comparison raw.p adj.p
1          None vs. Large vessel 0.006 0.034
2          None vs. Small vessel 0.530 1.000
3              None vs. Shooting 0.028 0.166
4  Large vessel vs. Small vessel 0.008 0.049
5      Large vessel vs. Shooting 0.000 0.003
6      Small vessel vs. Shooting 0.159 0.952
```

Group formation (circular vs. parallel), 15-minute window

```
χ2 = 8.7808, df = 3, p-value = 0.03235
                     comparison raw.p adj.p
1          None vs. Large vessel 0.011 0.065
2          None vs. Small vessel 0.433 1.000
3              None vs. Shooting 0.711 1.000
4  Large vessel vs. Small vessel 0.011 0.064
5      Large vessel vs. Shooting 0.055 0.327
6      Small vessel vs. Shooting 1.000 1.000
```

Group travel direction (north vs. south), 15-minute window
(shooting excluded)

χ^2 = 20.493, df = 2, p-value = 3.549e-05

	comparison	*raw.p*	*adj.p*
1	None vs. Large vessel	0.000	0
2	None vs. Small vessel	0.523	1
3	Large vessel vs. Small vessel	0.000	0

Group travel speed (medium vs. fast), 15-minute window

χ^2 = 112.43, df = 3, p-value < 2.2e-16

	comparison	*raw.p*	*adj.p*
1	None vs. Large vessel	0.000	0.000
2	None vs. Small vessel	0.000	0.001
3	None vs. Shooting	0.738	1.000
4	Large vessel vs. Small vessel	0.000	0.000
5	Large vessel vs. Shooting	0.000	0.000
6	Small vessel vs. Shooting	0.006	0.033

Group distance from shore (inner vs. outer), 15-minute window

χ^2 = 20.64, df = 3, p-value = 0.000125

	comparison	*raw.p*	*adj.p*
1	None vs. Large vessel	0.000	0.001
2	None vs. Small vessel	0.034	0.204
3	None vs. Shooting	0.340	1.000
4	Large vessel vs. Small vessel	0.000	0.000
5	Large vessel vs. Shooting	0.000	0.002
6	Small vessel vs. Shooting	0.726	1.000

Group with calves (yes vs. no), 15-minute window

χ^2 = 7.0477, df = 3, p-value = 0.07039

Group with tusks (yes vs. mixed vs. no), 15-minute window

χ^2 = 25.381, df = 6, p-value = 0.0002902

	comparison	*raw.p*	*adj.p*
1	None vs. Large vessel	0.101	0.604
2	None vs. Small vessel	0.000	0.001
3	None vs. Shooting	0.236	1.000
4	Large vessel vs. Small vessel	0.000	0.000
5	Large vessel vs. Shooting	0.022	0.134
6	Small vessel vs. Shooting	0.439	1.000

Results of Statistical Tests Used to Compare Focal Follow Track Metrics Between Years

Differences among years with respect to the response average speed were tested with an ANOVA. All other responses required a generalized linear model to accommodate their respective distributions, which deviated from normal (Table H-2). *Post-hoc* testing was done via pairwise Tukey tests (Table H-3).

TABLE H-2. Statistical distributions and confidence intervals for trackline metrics compared among years.

Response	Distribution	Year	Mu	LCL	UCL
TotDistance	Lognormal	2014	263.07	190.07	364.104
TotDistance	Lognormal	2015	220.82	182.075	267.8
TotDistance	Lognormal	2016	110.98	81.369	151.367
AvgSpeed	Normal	2014	1.9419	1.622	2.262
AvgSpeed	Normal	2015	2.2375	2.047	2.428
AvgSpeed	Normal	2016	1.8294	1.523	2.135
TrackDurati	Lognormal	2014	4.9664	3.675	6.711
TrackDurati	Lognormal	2015	3.5487	2.968	4.243
TrackDurati	Lognormal	2016	2.1611	1.621	2.881
GroupSize	NegativeB	2014	4.8064	3.679	6.279
GroupSize	NegativeB	2015	4.0114	3.403	4.728
GroupSize	NegativeB	2016	2.0588	1.508	2.811
Linearity	Beta	2014	0.6678	0.555	0.764
Linearity	Beta	2015	0.7577	0.691	0.814
Linearity	Beta	2016	0.4553	0.354	0.561

TABLE H-3. Pairwise *p*-values for *post-hoc* tests of trackline metrics by year.

Response	Distribution	Overall_TypeIII_*p*	Year	_Year	Adjustment	*p*-values
TotDistance	Lognormal	<0.0001	2014	2015	Tukey-Kramer	0.63149
TotDistance	Lognormal	<0.0001	2014	2016	Tukey-Kramer	0.00062
TotDistance	Lognormal	<0.0001	2015	2016	Tukey-Kramer	0.00082
AvgSpeed	Normal	<0.0001	2014	2015	Tukey-Kramer	0.26291
AvgSpeed	Normal	<0.0001	2014	2016	Tukey-Kramer	0.8705
AvgSpeed	Normal	<0.0001	2015	2016	Tukey-Kramer	0.06806
TrackDurati	Lognormal	<0.0001	2014	2015	Tukey-Kramer	0.14308
TrackDurati	Lognormal	<0.0001	2014	2016	Tukey-Kramer	0.00035
TrackDurati	Lognormal	<0.0001	2015	2016	Tukey-Kramer	0.01206
GroupSize	NegativeB	<0.0001	2014	2015	Tukey-Kramer	0.49191
GroupSize	NegativeB	<0.0001	2014	2016	Tukey-Kramer	0.00021
GroupSize	NegativeB	<0.0001	2015	2016	Tukey-Kramer	0.00075
Linearity	Beta	<0.0001	2014	2015	Tukey-Kramer	0.28253
Linearity	Beta	<0.0001	2014	2016	Tukey-Kramer	0.02187
Linearity	Beta	<0.0001	2015	2016	Tukey-Kramer	0.00004

APPENDIX I: EFFECT OF HUNTING ON GROUP COMPOSITION DATA COLLECTION

Hunting activity was observed to affect narwhals passing Bruce Head, and therefore the amount of group composition data collected, on a number of occasions. Details are provided below for the occasions when group composition was either not conducted or cut short due to hunting activity.

<u>31 July, early shift</u> – No group composition data were collected after a group of two narwhals passing Bruce Head were shot at, and one was hit.

<u>5 August, early shift</u> – Eight groups of narwhals were observed between 10:09 and 10:35. A female narwhal in the group of two that passed at 10:35 was bleeding and was thought to have been recently shot by hunters camped north of Bruce Head. A single group of narwhals was observed to pass by after this.

<u>5 August, late shift</u> – 19 groups of narwhals were observed between 14:39 and 18:02. Narwhals were shot at as they swam through substratum D1 at 18:12, and no groups were observed after that.

<u>7 August, late shift</u> – 23 groups of narwhals were observed between 16:35 and 17:41. Five shots were taken at narwhals, and at least two were hit, as they passed through substrata D1 and E1 during 17:25 to 17:52. A final narwhal group was observed at 17:50 before group composition data effort was halted because of hunting. Group composition data effort was begun again at 19:00, and only one more narwhal group was observed to pass.

<u>8 August, late shift</u> – Five groups of narwhals were observed between 16:13 and 16:21. One narwhal in the final group was observed to be bleeding from a previous wound. This final group was shot at as it passed Bruce Head, and group composition data effort was briefly halted because narwhals swam too quickly to count. Although group composition data effort began again at 16:50, no narwhals were observed for the remainder of the shift.

<u>9 August, late shift</u> – 40 groups of narwhals were observed between 15:27 and 15:42. Five shots were fired (at a seal and a bird) between 16:00 and 16:43. Ten groups of narwhals were later observed between 21:07 and 21:20. Narwhals were shot at beginning at 21:20, and group composition data effort was stopped at this time.

<u>10 August, late shift</u> – 12 groups of narwhals were observed between 20:17 and 21:30. The last narwhal was shot at and hit, and group composition data effort was stopped as additional shots were fired at the wounded narwhal.

<u>13 August, early shift</u> – Narwhal group composition data were not collected despite a full eight-hour observation shift. During this shift, hunters at the point were observed retrieving and then towing out and sinking a narwhal carcass.

<u>14 August, early shift</u> – Shots were fired twice as narwhals swam south past Bruce Head. Both times narwhals were noted to dive below the surface and therefore were not included in group composition data.

<u>16 August, early shift</u> – The first narwhal observed during the early shift (at 06:14), swam into and was caught in the net set off the point. This narwhal was subsequently shot at five times. Only a single additional narwhal was observed during the remainder of the eight-hour shift.

<u>19 August, late shift</u> – Six groups of narwhals were observed between 14:34 and 17:23. A shot was fired at the last group of narwhals and group composition data collection was briefly halted. Though effort began again at 18:00, no more narwhals were observed.

<u>21 August, early shift</u> – 72 groups of narwhals were observed between 11:18 and 12:50. Four shots were fired between 12:00 and 12:49, and the last group of narwhals were observed swimming through a plume of blood. Two more groups of narwhals were observed at 13:10.

21 August, late shift – A small vessel was observed towing a narwhal carcass back to the point during 14:29 to 14:44. Thirty-nine groups of narwhals were later observed between 17:38 and 19:54.

APPENDIX J: NARWHAL GROUPS OF KNOWN COMPOSITION, 2016

Table J-1. Narwhal groups of known composition with respect to group size observed during the shore-based study at Bruce Head, 2014 to 2016 (*n* = 1051).

Group composition	**Group size**				**Number of groups**
	1	2 to 5	6 to 9	10+	
No tusks, No calves or yearlings					
No tusk adult	170	49	3	1	223
No tusk adult + No tusk juvenile	0	65	9	3	77
No tusk juvenile	46	13	1	1	61
No tusks, Yes calves or yearlings					
No tusk adult + Calf	3	167	12	1	183
No tusk adult + Yearling	0	61	4	0	65
No tusk adult + Calf + Yearling	0	10	2	0	12
No tusk adult + No tusk juvenile + Calf	0	31	18	6	55
No tusk adult + No tusk juvenile + Yearling	0	6	2	1	9
No tusk adult + No tusk juvenile + Calf + Yearling	0	0	0	1	1
No tusk juvenile + Calf	0	2	0	0	2
Calf	2	1	0	0	3
Yearling	4	0	0	0	4
Mixed tusks, No calves or yearlings					
Yes tusk adult + No tusk adult	0	27	6	0	33
Yes tusk adult + No tusk adult + No tusk juvenile	0	10	9	1	20
Yes tusk adult + No tusk adult + Yes tusk juvenile	0	2	4	0	6
Yes tusk adult + No tusk adult + No tusk juvenile + Yes tusk juvenile	0	0	2	3	5
Yes tusk adult + No tusk juvenile	0	4	1	1	6
Yes tusk adult + No tusk juvenile + Yes tusk juvenile	0	1	3	0	4
No tusk adult + Yes tusk juvenile	0	21	0	0	21
No tusk adult + Yes tusk juvenile + No tusk juvenile	0	9	4	1	14
Yes tusk juvenile + No tusk juvenile	0	6	1	0	7
Mixed tusks, Yes calves or yearlings					
Yes tusk adult + No tusk adult + Yearling	0	0	1	0	1
Yes tusk adult + No tusk adult + Calf + Yearling	0	1	0	0	1
Yes tusk adult + No tusk adult + Yes tusk juvenile + Calf	0	1	2	0	3
Yes tusk adult + No tusk adult + Yes tusk juvenile + Yearling	0	1	0	1	2
Yes tusk adult + No tusk adult + Yes tusk juvenile + Calf + Yearling	0	0	1	0	1
Yes tusk adult + No tusk adult + No tusk juvenile + Calf	0	0	4	7	11
Yes tusk adult + No tusk adult + No tusk juvenile +	0	1	1	0	2

Group composition	**Group size**				**Number**
Yearling					
Yes tusk adult + No tusk adult + No tusk juvenile + Calf + Yearling	0	0	1	0	1
Yes tusk adult + No tusk adult + Yes tusk juvenile + No tusk juvenile + Calf	0	0	0	9	9
Yes tusk adult + No tusk adult + Yes tusk juvenile + No tusk juvenile + Yearling	0	0	1	0	1
Yes tusk adult + No tusk adult + Yes tusk juvenile + No tusk juvenile + Calf + Yearling	0	0	0	1	1
Yes tusk adult + No tusk juvenile + Calf	0	1	0	0	1
Yes tusk adult + No tusk juvenile + Yes tusk juvenile + Calf	0	0	0	1	1
No tusk adult + Yes tusk juvenile + Calf	0	4	2	2	8
No tusk adult + Yes tusk juvenile + Yearling	0	4	0	0	4
No tusk adult + Yes tusk juvenile + Calf + Yearling	0	0	1	0	1
No tusk adult + Yes tusk juvenile + No tusk juvenile + Calf	0	0	7	3	10
No tusk adult + Yes tusk juvenile + No tusk juvenile + Yearling	0	1	1	0	2
No tusk adult + Yes tusk juvenile + No tusk juvenile + Calf + Yearling	0	0	2	1	3
Yes tusks, No calves or yearlings					
Yes tusk adult	47	47	11	1	106
Yes tusk adult + Yes tusk juvenile	0	19	6	0	25
Yes tusk juvenile	23	3	0	0	26
Yes tusks, Yes calves or yearlings					
Yes tusk adult + Calf	0	4	1	0	5
Yes tusk adult + Yearling	0	1	0	0	1
Yes tusk adult + Yes tusk juvenile + Calf	0	1	0	0	1
Yes tusk juvenile + Yearling	0	1	0	0	1
All groups	**295**	**581**	**126**	**49**	**1051**

APPENDIX K: NARWHAL FOCAL GROUP TIME BUDGETS, 2014–2016

Proportions of time narwhal focal groups engaged in four primary behaviours, observed during the shore-based study at Bruce Head, 2014–2016. Rows highlighted in green are follows that had three or more primary behaviours observed; rows highlighted in blue had two primary behaviours observed; and rows without highlighting had a single primary behaviour observed.

Year	Follow	Travel	Mill	Rest back exposed	Rest submerged	Total time (min)	No. of Fixes
2014	1	1.00	0.00	0.00	0.00	1.68	2
2014	2	1.00	0.00	0.00	0.00	4.28	3
2014	3	1.00	0.00	0.00	0.00	3.11	4
2014	4	1.00	0.00	0.00	0.00	0.57	2
2014	5	1.00	0.00	0.00	0.00	4.76	3
2014	6	1.00	0.00	0.00	0.00	4.74	7
2014	7	1.00	0.00	0.00	0.00	7.29	4
2014	8	1.00	0.00	0.00	0.00	3.50	2
2014	9	1.00	0.00	0.00	0.00	1.68	3
2014	10	1.00	0.00	0.00	0.00	1.45	2
2014	11	0.00	0.00	1.00	0.00	0.45	2
2014	12	n/a	n/a	n/a	n/a	0.00	1
2014	13	0.00	0.00	0.68	0.32	6.32	5
2014	14	0.22	0.13	0.66	0.00	6.14	6
2014	15	1.00	0.00	0.00	0.00	10.19	9
2014	16	0.08	0.92	0.00	0.00	20.43	22
2014	17	0.00	0.63	0.37	0.00	2.95	3
2014	18	0.00	0.00	0.00	1.00	0.62	2
2014	19	1.00	0.00	0.00	0.00	10.62	10
2014	20	1.00	0.00	0.00	0.00	17.30	13
2014	21	1.00	0.00	0.00	0.00	1.73	3
2014	22	1.00	0.00	0.00	0.00	4.88	3
2014	23	1.00	0.00	0.00	0.00	9.67	7
2014	24	1.00	0.00	0.00	0.00	9.80	8
2014	25	1.00	0.00	0.00	0.00	4.84	5
2014	26	0.39	0.00	0.61	0.00	6.42	3
2014	27	1.00	0.00	0.00	0.00	6.26	6
2014	28	1.00	0.00	0.00	0.00	7.69	4
2014	29	1.00	0.00	0.00	0.00	4.91	6
2014	30	1.00	0.00	0.00	0.00	3.34	4
2014	31	1.00	0.00	0.00	0.00	3.20	6
2014	32	0.00	0.00	1.00	0.00	1.87	4
2014	33	1.00	0.00	0.00	0.00	14.22	8

Year	Follow	Travel	Mill	Rest back exposed	Rest submerged	Total time (min)	No. of Fixes
2014	34	1.00	0.00	0.00	0.00	6.34	4
2014	35	1.00	0.00	0.00	0.00	5.19	8
2014	36	n/a	n/a	n/a	n/a	0.00	1
2014	37	1.00	0.00	0.00	0.00	0.55	3
2014	38	1.00	0.00	0.00	0.00	0.45	3
2014	39	1.00	0.00	0.00	0.00	0.57	2
2014	40	1.00	0.00	0.00	0.00	13.79	9
2015	1	1.00	0.00	0.00	0.00	1.01	3
2015	2	1.00	0.00	0.00	0.00	1.82	4
2015	3	0.00	1.00	0.00	0.00	0.33	2
2015	4	1.00	0.00	0.00	0.00	7.46	12
2015	5	1.00	0.00	0.00	0.00	3.55	5
2015	6	1.00	0.00	0.00	0.00	1.01	3
2015	7	1.00	0.00	0.00	0.00	1.75	4
2015	8	0.09	0.00	0.75	0.15	2.43	4
2015	9	n/a	n/a	n/a	n/a	0.00	1
2015	10	1.00	0.00	0.00	0.00	0.90	2
2015	11	1.00	0.00	0.00	0.00	2.86	5
2015	12	n/a	n/a	n/a	n/a	0.00	1
2015	13	n/a	n/a	n/a	n/a	0.00	1
2015	14	1.00	0.00	0.00	0.00	4.99	7
2015	15	1.00	0.00	0.00	0.00	0.99	3
2015	16	1.00	0.00	0.00	0.00	0.88	3
2015	17	1.00	0.00	0.00	0.00	0.22	2
2015	18	1.00	0.00	0.00	0.00	1.48	2
2015	19	1.00	0.00	0.00	0.00	7.25	4
2015	20	1.00	0.00	0.00	0.00	0.60	2
2015	21	1.00	0.00	0.00	0.00	0.45	3
2015	22	1.00	0.00	0.00	0.00	0.27	2
2015	23	1.00	0.00	0.00	0.00	0.28	2
2015	24	1.00	0.00	0.00	0.00	5.36	8
2015	25	n/a	n/a	n/a	n/a	0.00	1
2015	26	1.00	0.00	0.00	0.00	0.88	2
2015	27	0.39	0.61	0.00	0.00	8.43	5
2015	28	0.63	0.37	0.00	0.00	5.59	4
2015	29	1.00	0.00	0.00	0.00	3.82	4
2015	30	1.00	0.00	0.00	0.00	0.73	2
2015	31	n/a	n/a	n/a	n/a	0.00	1
2015	32	1.00	0.00	0.00	0.00	15.93	7

Year	Follow	Travel	Mill	Rest back exposed	Rest submerged	Total time (min)	No. of Fixes
2015	33	0.00	1.00	0.00	0.00	1.59	3
2015	34	1.00	0.00	0.00	0.00	1.37	4
2015	35	0.78	0.22	0.00	0.00	2.78	6
2015	36	0.90	0.10	0.00	0.00	9.35	9
2015	37	0.49	0.51	0.00	0.00	1.68	5
2015	38	1.00	0.00	0.00	0.00	1.78	4
2015	39	1.00	0.00	0.00	0.00	2.32	4
2015	40	1.00	0.00	0.00	0.00	1.58	4
2015	41	0.75	0.25	0.00	0.00	5.09	6
2015	42	1.00	0.00	0.00	0.00	1.43	3
2015	43	0.97	0.03	0.00	0.00	16.14	19
2015	44	1.00	0.00	0.00	0.00	1.66	3
2015	45	1.00	0.00	0.00	0.00	1.20	3
2015	46	0.00	1.00	0.00	0.00	2.56	4
2015	47	0.64	0.36	0.00	0.00	3.13	4
2015	48	n/a	n/a	n/a	n/a	0.00	1
2015	49	1.00	0.00	0.00	0.00	0.88	2
2015	50	1.00	0.00	0.00	0.00	12.40	7
2015	51	n/a	n/a	n/a	n/a	0.00	1
2015	52	1.00	0.00	0.00	0.00	9.38	12
2015	53	0.93	0.07	0.00	0.00	20.88	23
2015	54	1.00	0.00	0.00	0.00	10.35	10
2015	55	n/a	n/a	n/a	n/a	0.00	1
2015	56	1.00	0.00	0.00	0.00	5.15	5
2015	57	1.00	0.00	0.00	0.00	3.47	4
2015	58	1.00	0.00	0.00	0.00	0.60	2
2015	59	1.00	0.00	0.00	0.00	1.47	2
2015	60	1.00	0.00	0.00	0.00	4.31	6
2015	61	1.00	0.00	0.00	0.00	2.02	4
2015	62	0.92	0.08	0.00	0.00	30.63	25
2015	63	1.00	0.00	0.00	0.00	1.38	3
2015	64	1.00	0.00	0.00	0.00	0.23	2
2015	65	1.00	0.00	0.00	0.00	0.87	2
2015	66	1.00	0.00	0.00	0.00	1.55	3
2015	67	0.37	0.21	0.00	0.41	2.01	4
2015	68	n/a	n/a	n/a	n/a	0.00	1
2015	69	0.88	0.03	0.09	0.00	10.27	8
2015	70	1.00	0.00	0.00	0.00	2.57	4
2015	71	1.00	0.00	0.00	0.00	3.93	4

Year	Follow	Travel	Mill	Rest back exposed	Rest submerged	Total time (min)	No. of Fixes
2015	72	1.00	0.00	0.00	0.00	1.45	4
2015	73	0.83	0.17	0.00	0.00	8.37	6
2015	74	1.00	0.00	0.00	0.00	6.30	4
2015	75	1.00	0.00	0.00	0.00	3.58	3
2015	76	0.48	0.52	0.00	0.00	9.75	8
2015	77	1.00	0.00	0.00	0.00	8.34	6
2015	78	1.00	0.00	0.00	0.00	6.07	3
2015	79	0.87	0.13	0.00	0.00	10.29	10
2015	80	1.00	0.00	0.00	0.00	1.05	3
2015	81	1.00	0.00	0.00	0.00	6.09	9
2015	82	1.00	0.00	0.00	0.00	2.83	4
2015	83	1.00	0.00	0.00	0.00	3.90	4
2015	84	1.00	0.00	0.00	0.00	2.74	6
2015	85	1.00	0.00	0.00	0.00	3.13	7
2015	86	1.00	0.00	0.00	0.00	4.49	4
2015	87	1.00	0.00	0.00	0.00	4.03	4
2015	88	1.00	0.00	0.00	0.00	0.70	2
2015	89	1.00	0.00	0.00	0.00	3.55	5
2015	90	1.00	0.00	0.00	0.00	2.18	2
2015	91	1.00	0.00	0.00	0.00	3.48	4
2015	92	1.00	0.00	0.00	0.00	3.87	5
2015	93	1.00	0.00	0.00	0.00	3.73	3
2015	94	1.00	0.00	0.00	0.00	1.35	3
2015	95	1.00	0.00	0.00	0.00	2.10	5
2015	96	1.00	0.00	0.00	0.00	6.72	4
2015	97	1.00	0.00	0.00	0.00	0.50	2
2015	98	1.00	0.00	0.00	0.00	3.80	4
2015	99	0.00	1.00	0.00	0.00	3.67	6
2015	100	n/a	n/a	n/a	n/a	0.00	1
2015	101	n/a	n/a	n/a	n/a	0.00	1
2015	102	1.00	0.00	0.00	0.00	5.69	4
2015	103	1.00	0.00	0.00	0.00	2.88	5
2015	104	1.00	0.00	0.00	0.00	1.97	5
2015	105	1.00	0.00	0.00	0.00	0.42	2
2015	106	n/a	n/a	n/a	n/a	0.00	1
2015	107	1.00	0.00	0.00	0.00	5.14	7
2015	108	1.00	0.00	0.00	0.00	0.70	3
2015	109	1.00	0.00	0.00	0.00	7.89	5
2015	110	0.89	0.11	0.00	0.00	20.39	16

Year	Follow	Travel	Mill	Rest back exposed	Rest submerged	Total time (min)	No. of Fixes
2015	111	1.00	0.00	0.00	0.00	0.22	2
2015	112	1.00	0.00	0.00	0.00	2.11	3
2015	113	1.00	0.00	0.00	0.00	3.27	4
2015	114	0.81	0.19	0.00	0.00	13.39	8
2015	115	1.00	0.00	0.00	0.00	2.17	2
2015	116	0.00	0.00	1.00	0.00	0.92	2
2015	117	0.52	0.48	0.00	0.00	1.01	4
2015	118	n/a	n/a	n/a	n/a	0.00	1
2015	119	1.00	0.00	0.00	0.00	1.98	6
2015	120	1.00	0.00	0.00	0.00	4.19	6
2015	121	1.00	0.00	0.00	0.00	6.29	9
2015	122	1.00	0.00	0.00	0.00	0.70	2
2015	123	1.00	0.00	0.00	0.00	0.68	2
2015	124	1.00	0.00	0.00	0.00	1.13	2
2015	125	n/a	n/a	n/a	n/a	0.00	1
2015	126	1.00	0.00	0.00	0.00	3.46	3
2015	127	n/a	n/a	n/a	n/a	0.00	1
2015	128	1.00	0.00	0.00	0.00	0.45	2
2016	1	1.00	0.00	0.00	0.00	2.52	4
2016	2	1.00	0.00	0.00	0.00	2.20	7
2016	3	1.00	0.00	0.00	0.00	1.50	5
2016	4	1.00	0.00	0.00	0.00	1.25	6
2016	5	0.12	0.88	0.00	0.00	2.44	8
2016	6	0.00	1.00	0.00	0.00	7.86	18
2016	7	0.00	1.00	0.00	0.00	3.18	2
2016	8	0.00	1.00	0.00	0.00	3.10	9
2016	9	1.00	0.00	0.00	0.00	2.30	7
2016	10	1.00	0.00	0.00	0.00	1.05	2
2016	11	0.62	0.38	0.00	0.00	9.00	19
2016	12	0.00	1.00	0.00	0.00	23.17	40
2016	13	0.00	1.00	0.00	0.00	6.70	13
2016	14	0.00	1.00	0.00	0.00	1.12	3
2016	15	0.58	0.42	0.00	0.00	13.19	17
2016	16	0.00	0.00	0.00	1.00	1.94	4
2016	17	0.00	1.00	0.00	0.00	0.38	3
2016	18	0.00	1.00	0.00	0.00	3.02	9
2016	19	n/a	n/a	n/a	n/a	0.00	1
2016	20	1.00	0.00	0.00	0.00	3.47	7
2016	21	0.00	1.00	0.00	0.00	0.36	3

Year	Follow	Travel	Mill	Rest back exposed	Rest submerged	Total time (min)	No. of Fixes
2016	22	0.00	1.00	0.00	0.00	16.68	14
2016	23	1.00	0.00	0.00	0.00	3.64	4
2016	24	0.75	0.25	0.00	0.00	23.49	37
2016	25	n/a	n/a	n/a	n/a	0.00	1
2016	26	1.00	0.00	0.00	0.00	3.40	5
2016	27	0.00	1.00	0.00	0.00	3.16	5
2016	28	1.00	0.00	0.00	0.00	1.21	4
2016	29	n/a	n/a	n/a	n/a	0.00	1
2016	30	1.00	0.00	0.00	0.00	1.20	4
2016	31	1.00	0.00	0.00	0.00	1.19	3
2016	32	1.00	0.00	0.00	0.00	0.50	2
2016	33	1.00	0.00	0.00	0.00	2.41	6
2016	34	0.00	0.00	0.00	1.00	2.11	3
2016	35	0.00	1.00	0.00	0.00	0.88	2
2016	36	1.00	0.00	0.00	0.00	1.76	6
2016	37	1.00	0.00	0.00	0.00	0.50	2
2016	38	0.33	0.67	0.00	0.00	0.86	3
2016	39	1.00	0.00	0.00	0.00	2.88	4
2016	40	1.00	0.00	0.00	0.00	0.48	2
2016	41	1.00	0.00	0.00	0.00	1.27	3
2016	42	1.00	0.00	0.00	0.00	1.58	5
2016	43	1.00	0.00	0.00	0.00	0.52	2
2016	44	1.00	0.00	0.00	0.00	7.84	11
2016	45	1.00	0.00	0.00	0.00	1.62	5
2016	46	1.00	0.00	0.00	0.00	0.32	2
2016	47	1.00	0.00	0.00	0.00	1.88	6
2016	48	1.00	0.00	0.00	0.00	1.43	4
2016	49	1.00	0.00	0.00	0.00	0.65	2
2016	50	1.00	0.00	0.00	0.00	0.66	3

APPENDIX L: TRACKLINES OF VESSELS RECORDED AT BRUCE HEAD, 2013–2016

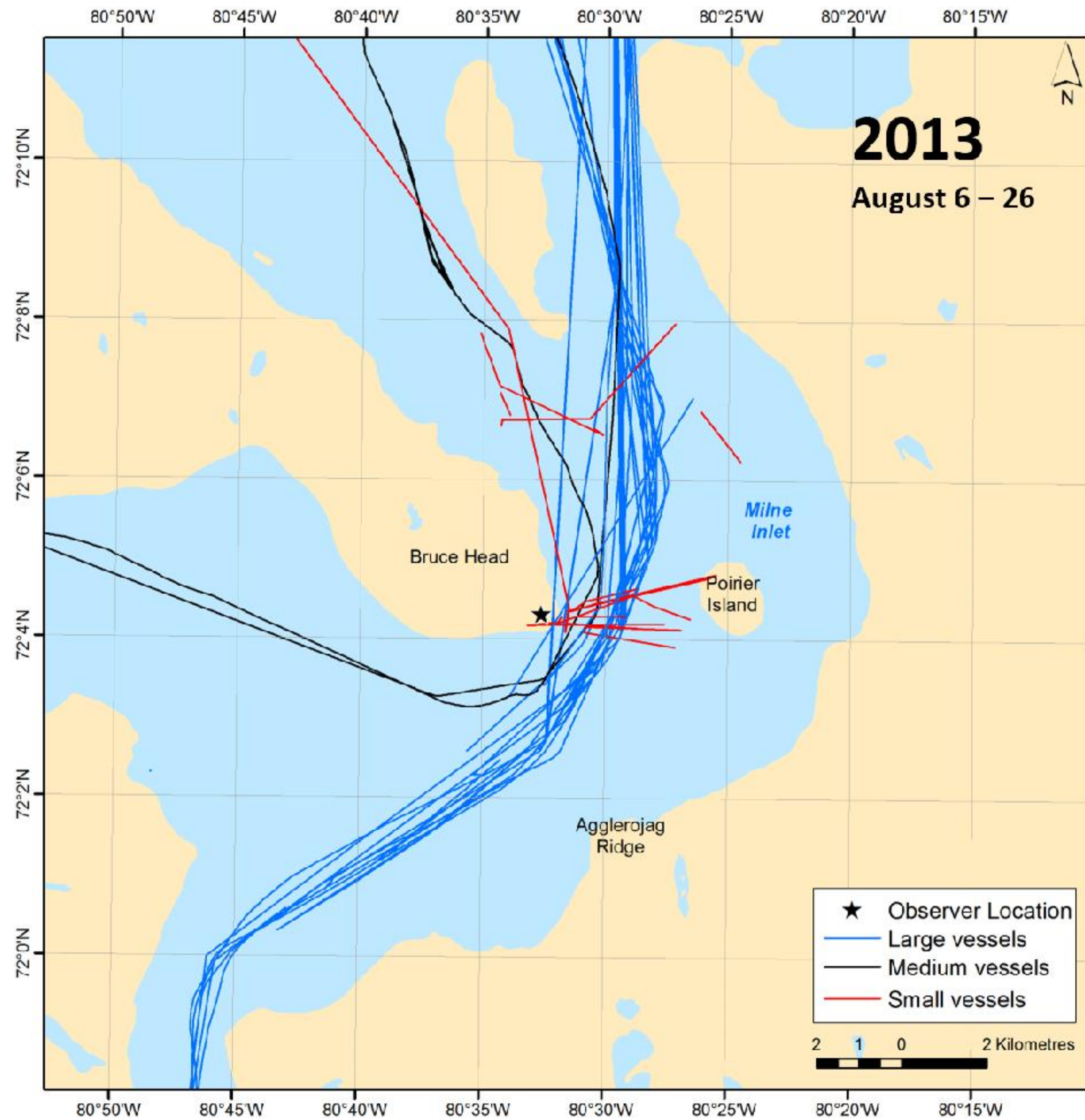


Figure L-1. Tracklines of large, medium, and small vessels derived from visual observations (i.e., theodolite fixes) and AIS data during the shore-based pilot study of narwhals in 2013. Large and medium vessel tracklines were largely derived from AIS data, which provided 24-hr coverage of the area. Small vessel tracklines were exclusively derived from visual observations, and are thus limited to times of observation effort by the study team.

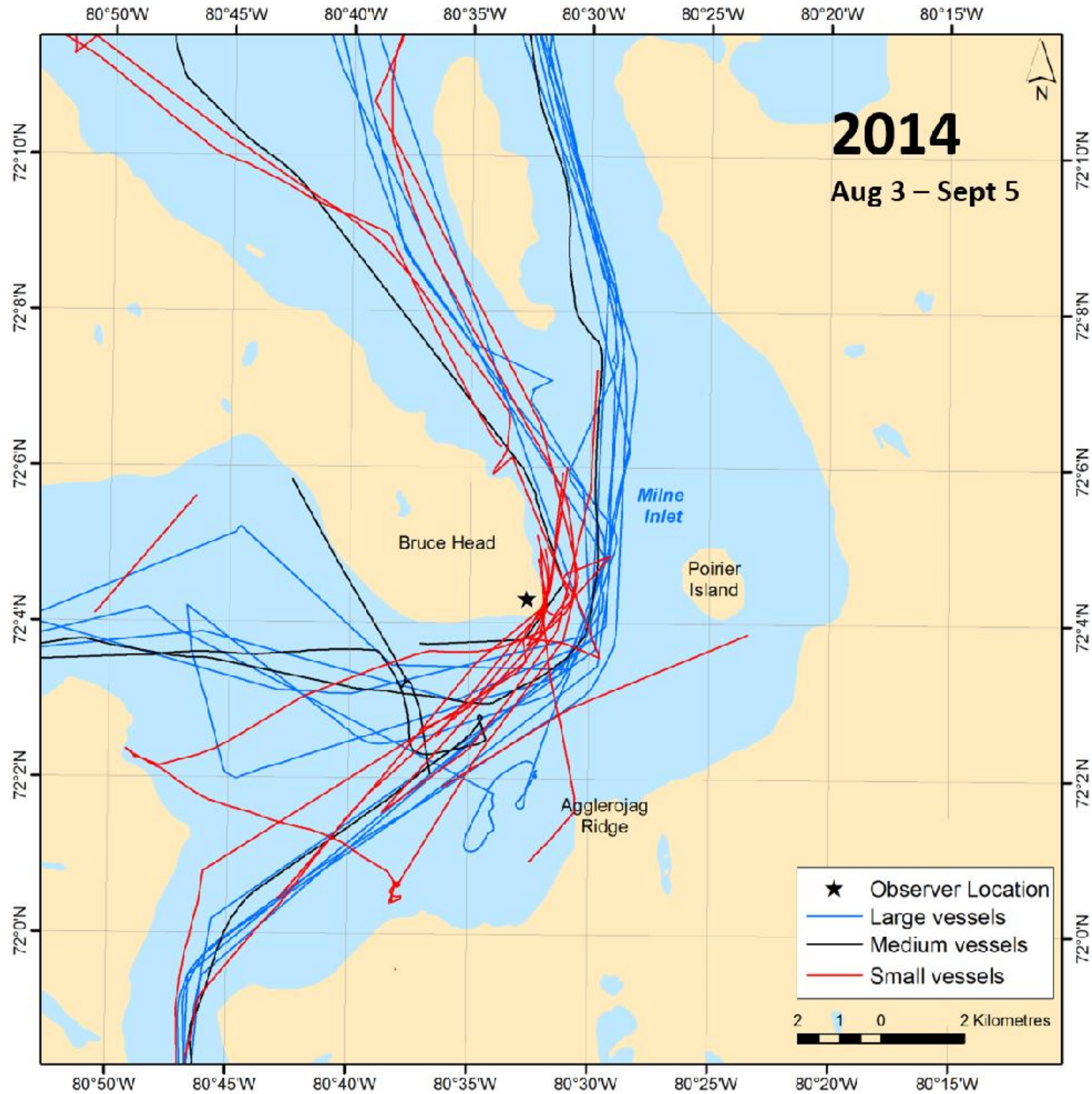


Figure L-2. Tracklines of large, medium, and small vessels derived from visual observations (i.e., theodolite fixes) and AIS data during the shore-based study of narwhals in 2014. Large and medium vessel tracklines were largely derived from AIS data, which provided 24-hr coverage of the area. Small vessel tracklines were almost exclusively derived from visual observations, and are thus primarily limited to times of observation effort by the study team.

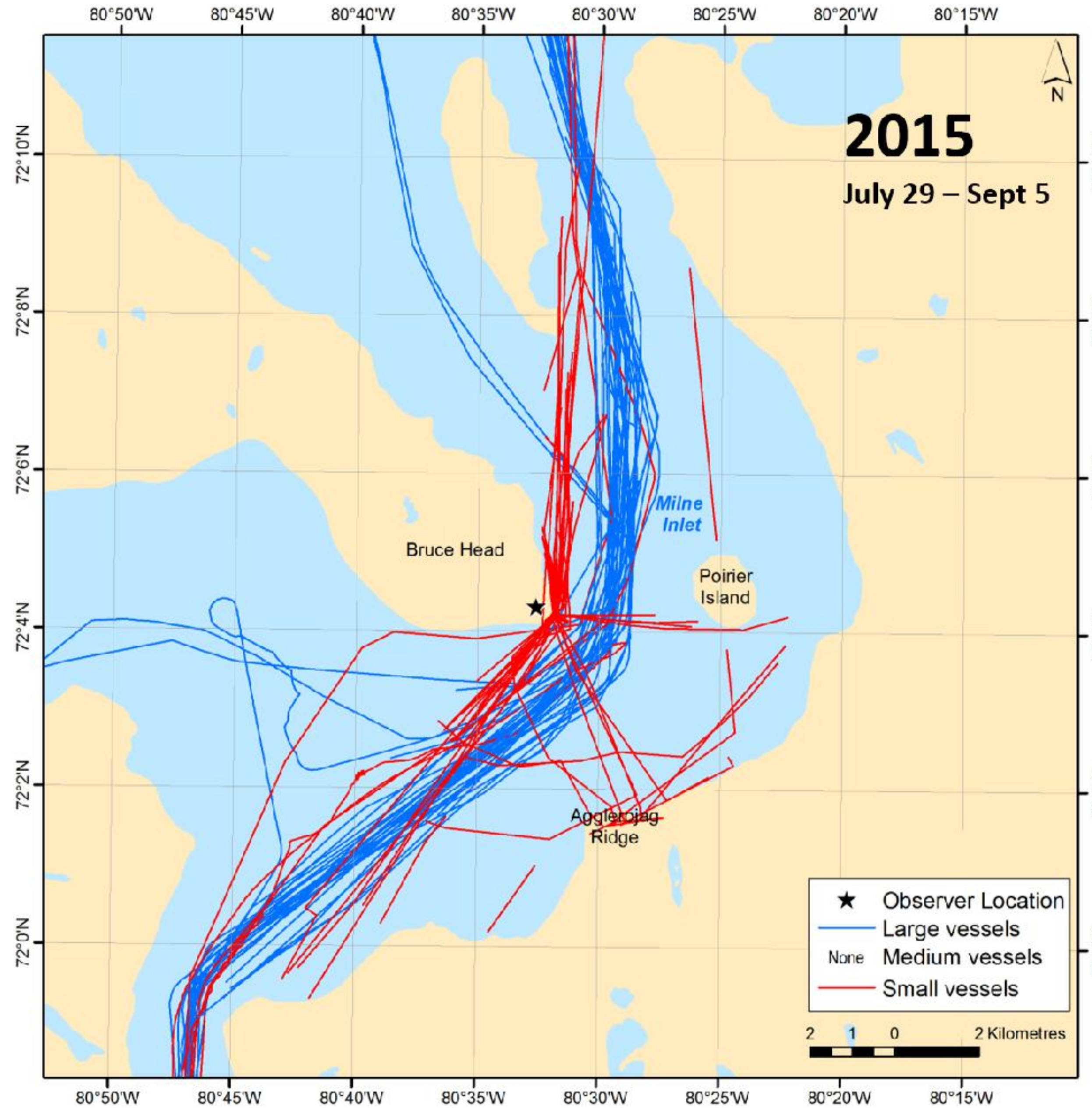


Figure L-3. Tracklines of large, medium, and small vessels derived from visual observations (i.e., theodolite fixes) and AIS data during the shore-based study of narwhals in 2015, the first year of Operational shipping for Baffinland's ERP. Large and medium vessel tracklines were largely derived from AIS data, which provided 24-hr coverage of the area. Small vessel tracklines were almost exclusively derived from visual observations, and are thus primarily limited to times of observation effort by the study team.

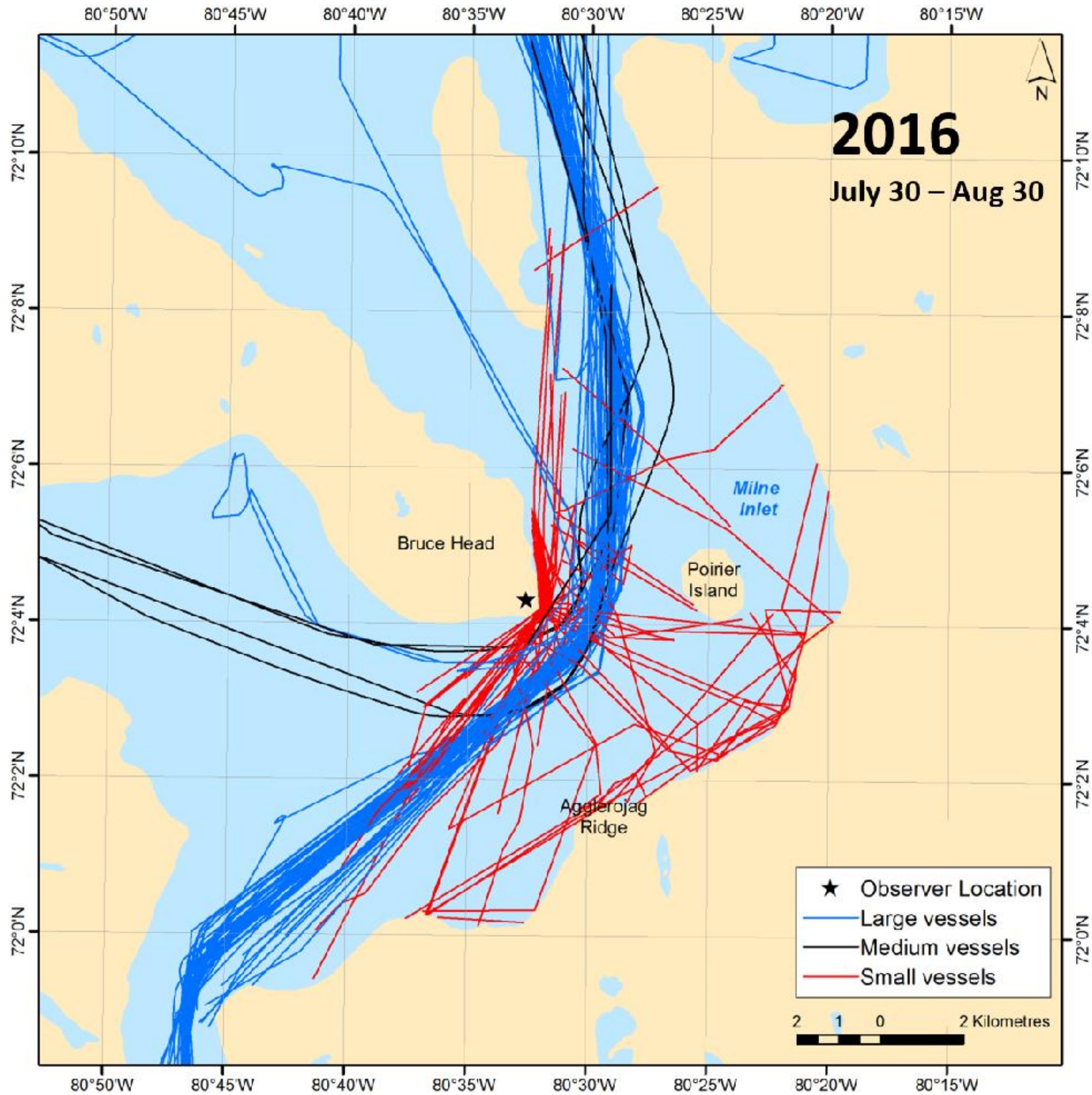


Figure L-4. Tracklines of large, medium, and small vessels derived from visual observations (i.e., theodolite fixes) and AIS data during the shore-based study of narwhals in 2016, the second year of Operational shipping for Baffinland's ERP. Large and medium vessel tracklines were largely derived from AIS data, which provided 24-hr coverage of the area. Small vessel tracklines were exclusively derived from visual observations, and are thus limited to times of observation effort by the study team.