Not to be Cited Without Prior Reference to Author(s) ES CM 2008/B:13

Monitoring Climate Related Changes in the Availability of Ringed Seal Pupping Habitat in Coastal Labrador

by

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Abstract:

Relatively little is known about the adaptive capacity of ringed seals (*Phoca hispida)* to climate change in many parts of their range. However, because the species requires certain sea ice and snow conditions to successfully overwinter and rear a pup, ringed seals are thought to be sensitive to climatic variability that alters these required habitat characteristics. The pups are born in a protective snow cave (lair) constructed by the female near a well-drifted pressure ridge or ice hummock on landfast ice or relatively stable pack-ice. Adequate snow cover and/or appropriate ice roughness have been correlated with increased survival of ringed seal pups in the High Arctic and in Hudson Bay. The objective of this study was to map and quantify the available habitat for breeding ringed seals using RADARSAT imagery of ice conditions during February and March and data collected by on-ice teams of hunters from the communities of Nain, Hopedale and Rigolet, Labrador. Ice and snow condition data from 2001-2006 at the Nain study area illustrated how expansive intrusions of highly deformed rough ice (2004), extensive sheets of smooth ice (2006), inadequate snow cover (2001 and 2002), an abrupt and early spring melt (2003), and spring storm events (2005, 2006) impacted the availability of suitable pupping habitat. Although, the occurrence and degree of ice deformation was the key determinant of quality habitat, persistent snow accumulation on the ice and the maintenance of a stable ice platform despite severe, unseasonable spring storms (i.e. high seas and rain) appeared to be critical.

Key Words: Ringed seal, pupping habitat, landfast ice, climate change

Introduction

Ringed seals are ecologically important species in seasonally ice-covered marine systems because they are high level aquatic predators and they are also important prey for polar bears and other species dependant on sea ice as a foraging platform (Ainley *et al.* 2003; ACIA 2005) The distribution, abundance and productivity of ringed seals are influenced by appropriate sea ice deformation (roughness) and snow conditions (e.g. Furgal *et al.* 1996, Hammill and Smith 1988, Hammill and Smith 1991, Smith and Stirling 1975). The pups are born in a snow cave (lair) constructed by the female near a well-drifted pressure ridge, ice hummock in landfast ice or relatively stable pack ice. The lair protects the pup from predation by polar bears as well as provides much needed shelter from the wind and cold temperatures. Given that ringed seals require certain sea ice conditions to successfully overwinter and rear a pup, the species may be vulnerable to climate related-changes in these conditions (Tynan and Demaster 1997; ACIA 2005; Learmonth *et al.* 2006)

Although the species is well studied in some areas of its range, there are major data gaps in other geographic regions. Despite this problem there is growing evidence that climate change and/or variability can negatively impact the species. In the Beaufort Sea during the winter of 1973-74, heavier than normal pack ice conditions coincided with subsequent declines of ringed seals and polar bears the following year (Stirling et al. 1977; Stirling and Lunn 1997). It was thought that a reduction in the availability of leads and open water areas along the landfast/pack ice interface contributed to the declines. This heavy ice scenario occurred again in the Beaufort Sea from 1982-1985 with similar results except that seals present in the area were also in poor condition (Harwood and Stirling 1992). The authors speculated that a regional reduction in marine productivity and lack of prey availability contributed to the decline in condition. Conversely, an early spring break-up of Beaufort ice in 1998 enhanced general marine productivity and prey availability, but the event still had a significant negative affect on the growth, condition and survival of the pups that were not fully weaned at the time. These animals were forced into the water too early and experienced a truncated nursing period, resulting in slower growth and higher mortality (Smith and Harwood 2001). There is also mounting evidence that early collapse of lairs from rain or warm temperatures can expose pups to high levels of predation by polar bears and foxes (e.g. Stirling and Derocher 1993).

A more recent study examining the impacts of climate change on ringed seals in western Hudson Bay showed that pup recruitment into the population varied from lower than average in the 1970s and 1990s to higher than average in the 1980s. Prior to 1990, this pattern of recruitment generally reflected snowfall but was most strongly correlated with spring break-up times. However, during the 1990s, snowfall, snow depth and April/May air temperatures were more important factors. (Ferguson et al. 2005). Snow depths below 32 cm corresponded with a significant decrease in seal recruitment. The current trends of earlier spring break-up of sea ice and declining snowfall and snow depth suggests continued low pup survival in the future for western Hudson Bay (Ferguson et al. 2005).

With the development of new remote sensing technology and analysis techniques, the use of satellite imagery to map and quantify ringed seal habitat is feasible. Studies in the central Arctic (e.g. Nichols 1999; Barber and Iacozza 2004) have developed the use of habitat suitability indices to identify overwintering habitat based on synthetic aperture radar (SAR) imagery. Nichols (1999) was able to reliably separate ice types (first year landfast ice, second year and multi-year ice) in the Barrow Strait region based on the different dielectrical properties. Incorporating some of this information, Barber and Iacozza (2004) developed a ringed seal habitat suitability index for the region using visual inspection of ice deformation on RADARSAT imagery from 1997-2001. Primary habitat was considered to be first year ice with visible linear features (i.e. pressure ridges), secondary habitat was smooth first year ice and tertiary habitat included all other ice types (i.e. first year rubble and multi-year ice). There was little evidence of any trends in the availability of each type of habitat over the temporal and spatial scale examined; inter-annual variability was high for most areas of the study block. Neither study was able to incorporate the importance of snow conditions and used imagery with a resolution of 100-200m.

Objectives for this study were to: 1) map and quantify the available sea ice habitat for breeding ringed seals using RADARSAT imagery (resolution 25-30m) and snow/ice data collected by on-ice teams of hunters from the communities of Nain, Labrador (2001-2006); 2) document what habitat was being used by breeding seals (2001-2003), and 3) comment on the link between sea ice condition and the availability/accessibility of ringed seal pups during the spring based on interviews with experienced hunters from Nain and Hopedale area. The development of remote sensing technology as a research tool in combination with biological studies and traditional knowledge would allow researchers to quantitatively link the reproductive ecology of seals to their habitat and examine the adaptive capacity of the species to climate change.

Methods

The study areas were situated near the communities of Nain, Hopedale and Rigolet, Labrador (Fig.1a). The Nain study site was located in landfast ice approximately 25km southeast of the community and covered a 40 x 25km block of habitat (Fig. 1b). This presentation will focus on a sub-set of data collected from a smaller block (30 x 25km) at this site (2001-2006). However, a similar time series of on-ice habitat monitoring and satellite imagery was collected at the study area near Rigolet located at the east end of Lake Melville (2001-2006). A less extensive data-set is also available for the Hopedale site (2003-2006). During the first phase of this project (2001-2003) an emphasis was placed on interpreting March satellite imagery, collecting snow and ice habitat data and locating habitat used by pupping seals. In later years (2003-2006), some key March habitat work continued, but a greater emphasis was placed on trying to monitor the availability (relative abundance) and conditions of pups in the early spring and following fall (only some aspects of these data will be presented here).

To characterize potential pupping habitat during mid-March, an on-ice team of hunters and DFO personnel collected data on ice thickness (1.0cm), snow accumulation (0.5cm), maximum/minimum snow drift development (0.5cm), and pressure ridge heights (1.0cm) at 20 stations from 2001-2006 at the Nain site. Measurement protocols generally followed Furgal *et al.* (1996) and Hammill and Smith (1988) and were taken over a 2 or 3 day period at approximately the time that satellite images were acquired. At each station snow depths (n=9 or 13) were taken at 5m intervals in a cross pattern centered on the hole drilled for ice measurements. Maximum/minimum drift measurements (n=at least 6 when drifts were present) and the height of any pressure ridges or rough ice were taken within 50m of the station location. Data collected from 2001-2006 at 15 of stations is reported here. Additional ice and snow measurements were taken on route from one station to another if there was a significant change in the habitat. These locations were marked using a hand held GPS to aid in satellite interpretation.

During March at least one standard (30m resolution) or extended high (25m resolution) RADARSAT I image was obtained for the study site. The images were georeferenced, underwent only minimal processing and then were used to identify and quantify different sea ice types in the study area following the general approach of Barber and Iacozza (2004). Data collected by the on-ice team were used to ground-truth the image and provide a more detailed interpretation of the image. Sea ice in the study area was then classified as unsuitable (US), marginal (M), secondary (S) or primary (P) pupping habitat based on general knowledge of ringed seal habitat requirements in other areas of the Arctic and on knowledge of productive areas within the study site. The criteria used for classification included maximum and mean snow depths, maximum snow drift height, presence and size of rough ice and evidence of a stable ice platform (Table 1; Appendix 1a-f). MapInfo was used to calculate the area of each type of sea ice habitat available in the study block. In cases where a well defined pressure ridge was isolated in an area of unsuitable or marginal habitat, the ridge was marked with a line buffered by 20m on either side.

During early May in 2002 and 2003 when the spring melt had progressed to the stage when the majority of birth lairs had collapsed, a three person team (two hunters from Nain and one person from DFO) conducted searches for the structures at each of the station sites, the vicinity around each site and the travel corridor on route to other stations. A structure was identified as a probable birth lair using the following criteria: 1) complex construction characterized by one or more chambers; 2) the presence of moulted lanugo frozen into the walls or floor of the structure; and/or 3) evidence of old blood stains consistent with birthing in one of the chambers. Search time was documented and all lairs were marked with a GPS position. In 2001, the window of opportunity to conduct on-ice work in May was missed due to an accelerated spring melt. Therefore, a series of strip transects were flown in a fixed wing air craft at approximately 92m to obtain a general indication of the habitat used; coverage of the detailed study block was near complete. Structures were marked using the aircraft GPS and were either classified as breathing holes or a complex structure based on the relative size of the hole and evidence of a collapsed chamber(s); in some cases the presence of a female with a young pup assisted in the identification of the structure. Although these data are not directly comparable to those collected 2002-03, they are informative from the perspective of habitat use and therefore included here. During the course of the study all hunters involved in the project were asked to comment on whether there had been any long-term changes in the relative abundance of seals (both adults and pups during the spring), seasonal distribution, or body condition. An emphasis was placed on comparing the 1990s and the study period.

Results

The satellite imagery and on-ice data documented an area of 609km^2 of landfast ice in the vicinity of Nain. Ice and/or snow conditions appeared to be harsh from a ringed seal pupping perspective in all years except 2003 and 2005 (Table 2; Appendix 1a-f; Figures 2-7). In 2001 and 2002 all unmarked areas on the images of the study block were classified as unsuitable habitat while in 2003 unmarked areas were classified as marginal. From 2004-2006, the area west of Stations 3 and 15 (large channels with smooth, windswept ice and transitory drift) appeared to be unsuitable pupping habitat and represented approximately 21.7% (132km^2) of the entire study block. Pack ice was also considered to be unsuitable for pupping habitat when present.

Comments on Snow and Ice Conditions:

2001 and 2002 (Figure 2 and 3): These two years where characterized by the lowest snow accumulation documented during the study as well as large expanses of smooth, undrifted ice. In most areas, the mean snow depth and maximum drift height were less than 20.0cm and 35.0cm, respectively resulting in approximately 95% of the habitat being identified as unsuitable for pupping. This was particularly the case in 2001. There was evidence of wolf and fox tracks throughout the study block in 2001; two probable birth lairs were excavated by wolves and wolves were seen traveling on the ice during the field work. Evidence of predation in 2002 was not as pervasive. Spring melt was unusually quick in 2001 and prolonged by approximately three weeks in 2002 compared to recent years.

2003 (Figure 4): There were extensive areas of well defined linear and braided pressure ridges as well as areas of distinct hummocks throughout the study block; snow drift development and snow accumulation were also excellent. These conditions were the most optimal combination of conditions documented during the study period with approximately 48% of the area being identified as primary or secondary habitat. Less than 6% of the available habitat was identified as unsuitable. The ice was soft and thickness was generally reduced throughout the study area; both factors contributed to a quick spring melt.

2004 (Figure 5): The study area was characterized by a significant intrusion of 92km^2 of first year pack ice near Humby and Sandy Island as well as large consolidated rubble fields of landfast ice that pushed towards the inner coastal islands. Therefore, of the remaining suitable habitat, only 2.3%(15km^2) was considered to be primary or secondary pupping habitat. A large portion of the study area was designated marginal habitat given evidence of an extremely active ice platform late into the freeze-up period.

2005 (Figure 6): The edge of the pack ice was to the east of the study site and there was also a marked reduction in the area covered by rubble fields compared to 2004. A total of 13% (80km^2) of suitable habitat was considered to be primary or secondary pupping habitat. High snow fall accumulation along with good drift size and some defined pressure ridge development contributed to the increased availability of quality habitat. However, storm surges during April are thought to have dispersed/loosened the protective band of pack-ice causing the land-fast ice in some areas along the coast to break-up before the end of the lactation period.

2006 (Figure 7): Pack-ice (178km^2) unsuitable for pupping pushed well into the study site. Compounding the situation, the landfast ice formed in an almost continuous, relatively thin sheet extending right out to the pack ice. There did not appear to be any primary or secondary pupping habitat in the area; the entire area appeared unsuitable for pupping. Marginal habitat may have existed along the landfast/pack ice edge, and along the shorelines of some islands. The snow and ice conditions also deteriorated due to rainfall during March.

Habitat Used by Pupping Seals:

In 2002, of the 25 of the probable birth lairs found in the study block, 20 were located in habitat designated as primary or secondary on the imagery. Three lairs were located in habitat designated as unsuitable; however, two of those were situated along an identifiable shoreline ridge which usually has adequate snow accumulation but is in a shallow water area affected by tidal activity. In 2003, all of the 23 birth lairs were located in primary or secondary habitat. Although data on the location of complex structures collected in 2001 are not directly comparable to 2002 and 2003, they do provide some insight into the areas used for overwintering activities and pupping. Approximately 61% of (23/38) structures were located in habitat designated as primary, secondary or marginal. Of those located in unsuitable habitat, 10 were in the vicinity of a recognizable sea ice feature while 5 appeared to be located in areas with no ice features that would allow adequate drift development.

Linking Sea Ice Conditions and Ringed Seal Productivity:

Interviews with the Nain and Hopedale hunters (n=7) involved in the study regarding any longer-term changes in relative abundance and availability of pups in the spring provided the following interpretation. From 1980-1996 there was little noticeable change in the relative abundance of ringed seals, they remained in generally good condition, they were observed in almost all months of the year and there were no comments on any consistent changes in the relative availability of pups taken in the spring hunt. There may have been an increase in seal numbers after the ban on harp seal pelts in the early 1980s, but changes were thought to be relatively local and not related to climate or ice variability. Information on overwintering areas, the importance of the flow-edge habitat and key pupping areas during this time period was consistent with observations from the 1960s and 1970s (Brice-Bennett 1977). However, since the late 1990s there have been declines in the abundance/availability of pups as well as decreased access to pups during the spring hunt due to poor ice conditions. None of the hunters could recall such an extended period of poor spring ice conditions accompanied by such unpredictable and unusual weather patterns. Nor could they recall a period when travel for spring seal hunting had been so restricted and difficult. There are also fewer observations of older seals in coastal waters at other times of the year. Hunters from the Lake Melville area have also experienced increased difficulty hunting pups due to poor ice conditions; however, unlike Nain and Hopedale, there have been no reports of declining seal numbers in recent years. Table 3 summarizes the ecological factors that have affected the availability of primary and secondary pupping habitat and the hunter's interpretation of pup availability and accessibility during the spring.

Discussion

The availability of good quality ringed seal pupping habitat in the landfast ice environment of coastal Labrador in the vicinity of Nain was determined by the following ecological factors: 1) lack of snow accumulation and adequate drift development on the ice, 2) unsuitable ice roughness (both the lack of rough ice and intrusions of continuous rubble fields), 3) thin, soft ice contributing to an early spring break up, 5) unseasonably warm temperatures in late March and April causing lairs to collapse, 6) spring rain events, and 7) intense spring storm surges that loosen and disperse the pack ice allowing an early break-up of the land fast ice. The combined use of RADARSAT imagery, near concurrent snow/ice data and traditional knowledge, to identify and quantify the availability of pupping habitat has proven to be a useful approach. The higher resolution of imagery used for the study (approximately 30m vs. 100m as commonly used) was both effective and efficient for identifying the ice features thought to be important in determining the quality of pupping habitat. Additional information on the dynamics of freeze-up, the spring melt progression and timing of extreme spring weather events will further improve the image-based assessment of pupping habitat (compilation of these data are ongoing). Satellite technology is continually developing and will provide improved imagery over the next few years facilitating better habitat assessment (e.g. the RADARSAT II satellite is now operational and offers new polarization options that will enhance the identification of sea ice features). From this perspective, results of this study are important from a comparative basis and will provide direction for future research. Once data from each of the three study sites are fully analyzed and these findings are then 'stepped-up' to the regional geographic scale, this approach could significantly improve our understanding of the adaptive capacity of ringed seals to changing ice conditions.

During the course of the study, marginal, secondary and primary habitat was compressed to varying degrees between smooth ice with minimal or transitory drifts in the inner channels and bays along the western portion of the Nain study block and pack-ice to the east. In 2004 and 2006 there appeared to be little or no band of ice with appropriate deformation for ringed seal pupping however, in the other years, variable amounts of suitable ice was present. In both scenarios, interpretation of the available radar imagery was able to track these annual changes. However, satellite interpretation without appropriate snow data would not have provided as accurate of an assessment of the availability and the quality of the habitat. Snowfall information for northern Labrador is limited and often does not reflect conditions on the sea ice. Therefore, the on-ice monitoring component of the study was important and the results emphasize the need for better snow accumulation data for sea ice in the region. Conditions in 2005, (i.e. storm surges in April) and 2006 (i.e. significant rain in March) illustrate how important monitoring extreme storm events in the spring may be. Ice and snow conditions as well as ice thickness were adequate for successful pupping in 2005, but in many coastal areas the nursing period may have been truncated due to an early partial break-up of the landfast ice. The already unsuitable ice conditions in 2006 were exacerbated by the rain event.

There were relatively few problems interpreting the satellite imagery using the on-ice data. On the 2005 imagery, ice characterized by small, jumbled pieces of rough ice indicative of an active freeze-up zone sometimes resembled areas of heavily wind sculpted snow drifts on smooth ice. In addition, some of the areas identified as marginal habitat on the image had very good snow accumulation and drift development but little evidence of rough ice to ensure drift stability. Presently it is not clear whether these areas should be identified as secondary rather than marginal habitat; additional image analyses are ongoing. Identifying relatively isolated hummocks of rough ice that may provide adequate habitat when surrounded by ice with small, but sculpted drifts was also difficult. However, given that the images used have been subjected to only minimal processing that could improve clarity, sharpen any linear patterns and control the effects of speckle (an artifact of SAR imagery), some of these identification problems could be solved once more technical work is completed on the image. The large expanse of extremely smooth landfast ice extending to the edge of the pack-ice in 2006 is remarkable and was noted by the hunters as being unusual. The on-ice data collected supports this interpretation, but the scenario is somewhat exaggerated on the image due to a heavy glaze on the snow for almost the entire study block. On-ice data indicated that there were areas of small sized rough ice buried under the snow in some areas. This observation does not change the designation of habitat quality but does indicate that obtaining imagery early in the winter season before major snow accumulation may improve image interpretation.

The location of birth lairs in 2002 and 2003 provided support that on-ice data collection and image interpretation cued in on ice features that were relevant for seals pupping in coastal Labrador. In 2001, 39% of the complex structures were located in habitat classified as unsuitable while the remaining were found in marginal, secondary or primary habitat. However, of those located in unsuitable habitat, 26% were in the vicinity of a visible ice feature that could have accumulated some snow given the conditions that year. It must also be kept in mind that not all the structures located were birth lairs (some were likely adult seal haul-out lairs or enlarged breathing holes) and that the GPS locations were not as accurate as the on-ice locations given the aerial survey techniques used. It is also possible that given the very poor ice and snow conditions in 2001, suitable habitat was so limited that seals were trying to use any rough ice with some snow accumulation that could be found. None the less, these data illustrate how the imagery can be interpreted at different levels of detail, that there is a need to establish which level is most appropriate for classifying habitat, and that snow conditions are important. Although the birth lair detection component of the study was not designed to quantify structure density, it does provide the basis for a comprehensive study in the future; especially from the perspective of a comparison between the Lake Melville site and the coastal sites. In Lake Melville, the relative density of birth lairs was higher, the lairs were generally larger, and the structures were more complex (Sjare unpublished data). These differences were likely related to greater snow accumulation and more consistent/stable ice conditions during the course of the study.

There was good consensus among hunters from the Nain and Hopedale areas that the relative abundance of ringed seals in general, the availability of pups during the spring hunt and the access to pups in the spring has changed notably since the late 1990s. However, hunters did not have strong opinions on whether these observations represented a decline in total abundance or a large scale distributional shift. During the course of the study there was no evidence of seals moving into the inner bays to pup. Any significant shift into these areas would have been noted by hunters in the area. There were also no reports of pups sighted in the pack-ice along the land-fast ice edge. However, because of the mobile and unstable nature of the pack in most years, hunters do not travel off the floe edge any distance. During the study, some lairs were found near the shoreline of islands, but hunters indicated this has always been the case. The water depth around the island and the amount of tidal activity are thought to determine which islands are used (excessive ice movement is known to be unsuitable). Determining the suitability and use of pack-ice for pupping is a key question that needs to be addressed in order to provide a comprehensive assessment of the availability of pupping habitat in coastal areas. In years when ice and snow conditions are poor, monitoring some of the inner bays for pupping activity would also be useful for detecting any shifts in habitat use. A comparison of growth and condition of pups taken along the coast with those taken from Lake Melville (a habitat characterized by less variable ice and snow conditions) may also support some of hunter’s observations (Sjare unpublished data). Also, an examination of the age structure of the fall catches could provide evidence of decreased seal productivity during this period of the study when compared to the available time series going back to the mid-1980s. However, these data have not been analyzed (Sjare, unpublished data).

In summary, several of the ecological factors affecting the quality and availability of ringed seal pupping habitat are consistent with what is known for the species in other areas of its range. However, the annual changes over the duration of the study period appeared to be extreme and the interactions of the factors (particularly those related to the pack-ice) somewhat surprising. Thus the rate and scale of change in the landfast ice habitat and the subsequent response by ringed seals in Labrador may provide an important 'snapshot' for future conditions in other parts of the Arctic.

Acknowledgements:

We would like to thank all the hunters and community members in Nain, Hopedale and Rigolet who have either supported or participated in the project. The expertise of D. Wakeham, D. Mckinnon and W. Penney both in the field and lab was greatly appreciated. Funding for the project was provided by Environment Canada's Northern Ecosystem Initiative Program, the Canadian Space Agency (GRIP and the Earth Observation Program) and the Department of Fisheries and Oceans. Support from the Nunatsiavut Government was greatly appreciated.

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Figure 1. General study area and location of detailed study block near the community of Nain, Labrador. The community of Rigolet is located on the eastern end of Lake Melville. Hopedale is located on the coast approximately halfway between Nain and Rigolet.

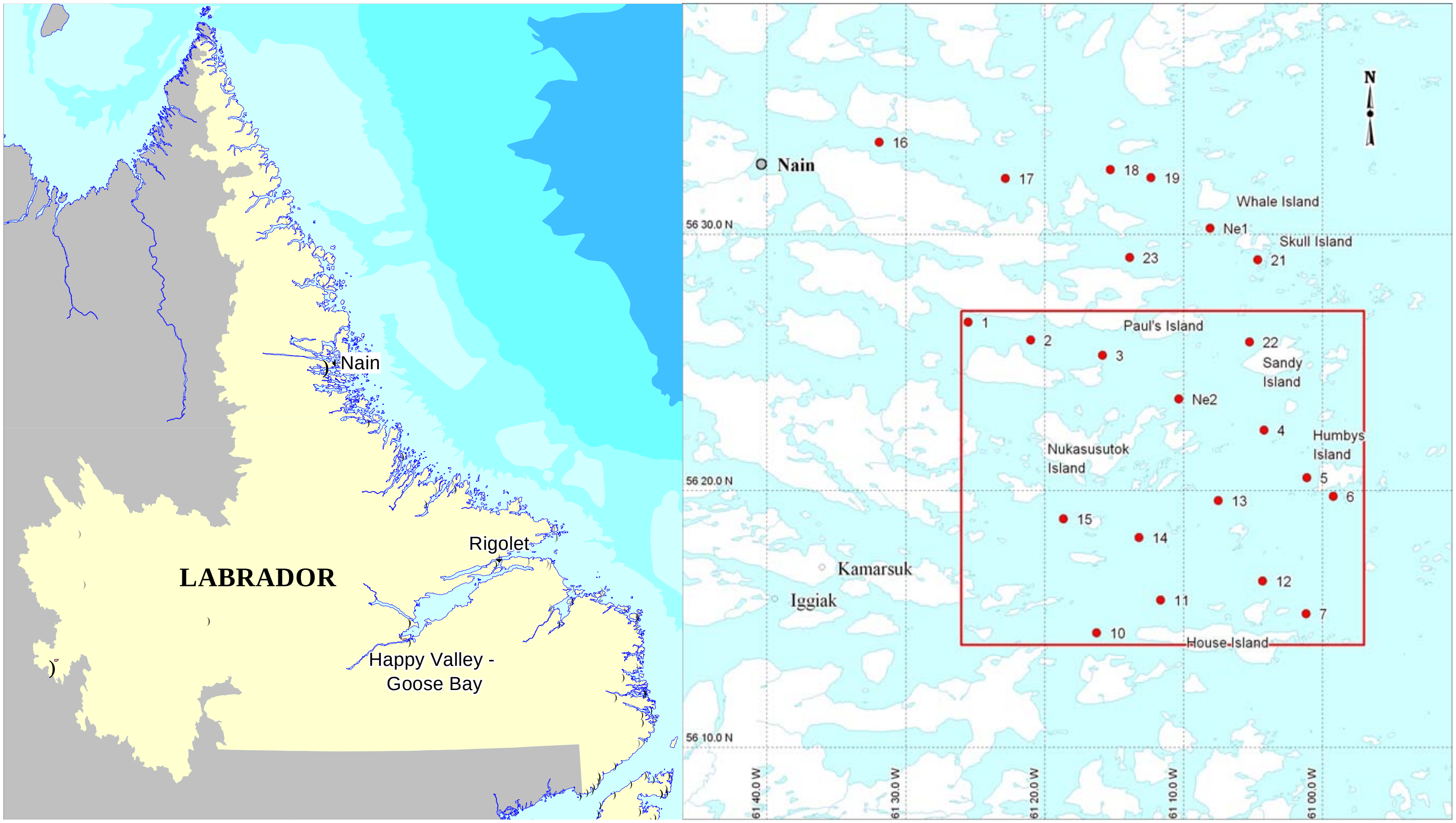
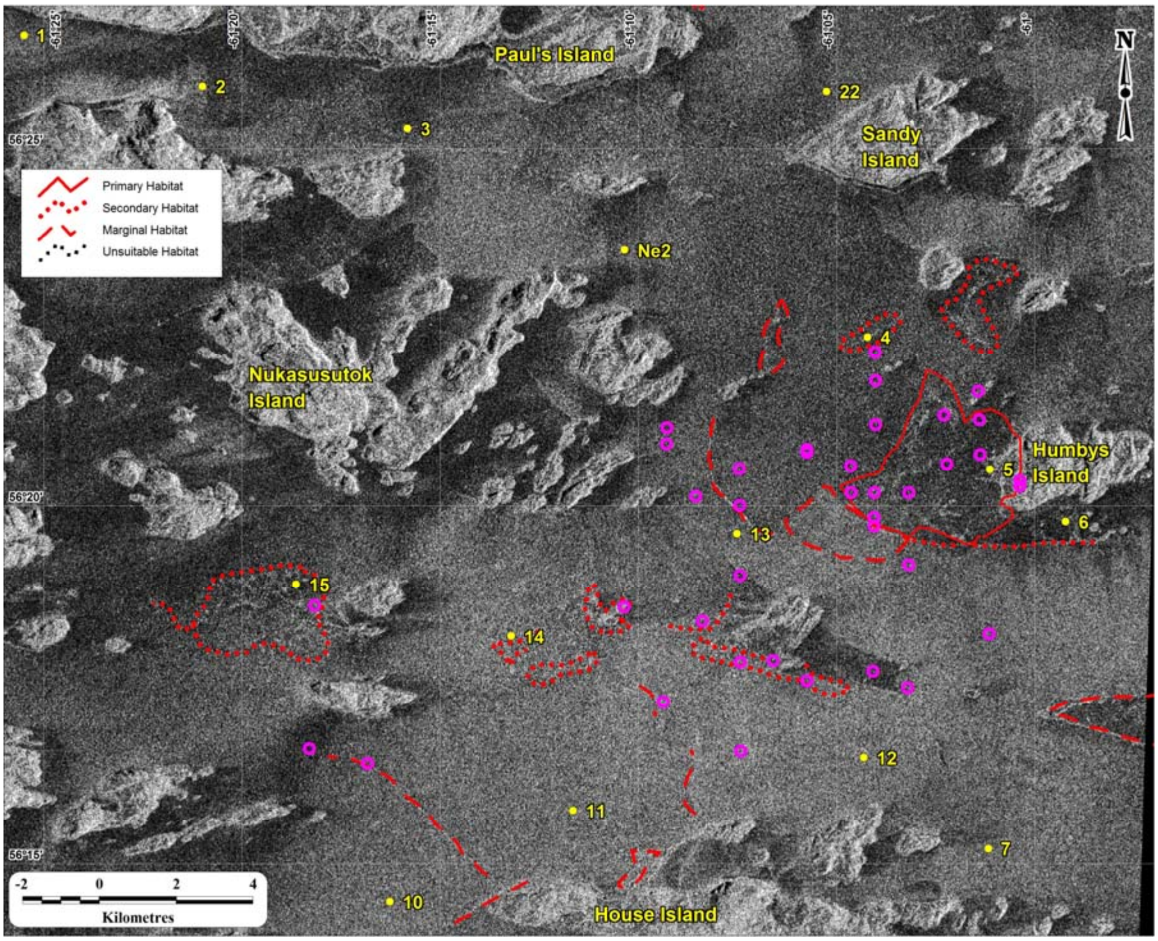


Figure 2. RADARSAT I image* of the ice conditions in the detailed study block near the community of Nain, Labrador in 2001. In this image any unmarked areas were identified as unsuitable habitat. The location of complex ringed seal structures are identified by a pink circle. Station locations are numbered.



*Note on image interpretation: Generally ice roughness is depicted by increased reflection of the radar signal. Within a particular image, pack-ice and rubble show as white or bright grey areas respectively, while smooth ice with little drifting show as black or light grey. Most of the beam modes for the images presented here are Standard 5 or 6 or Extended high 3 or 6.

Figure 3. RADARSAT I image of the ice conditions in the detailed study block near the community of Nain, Labrador in 2002. In this image any unmarked areas were identified as unsuitable habitat. The location of ringed seal birth lairs are identified by a pink circle.

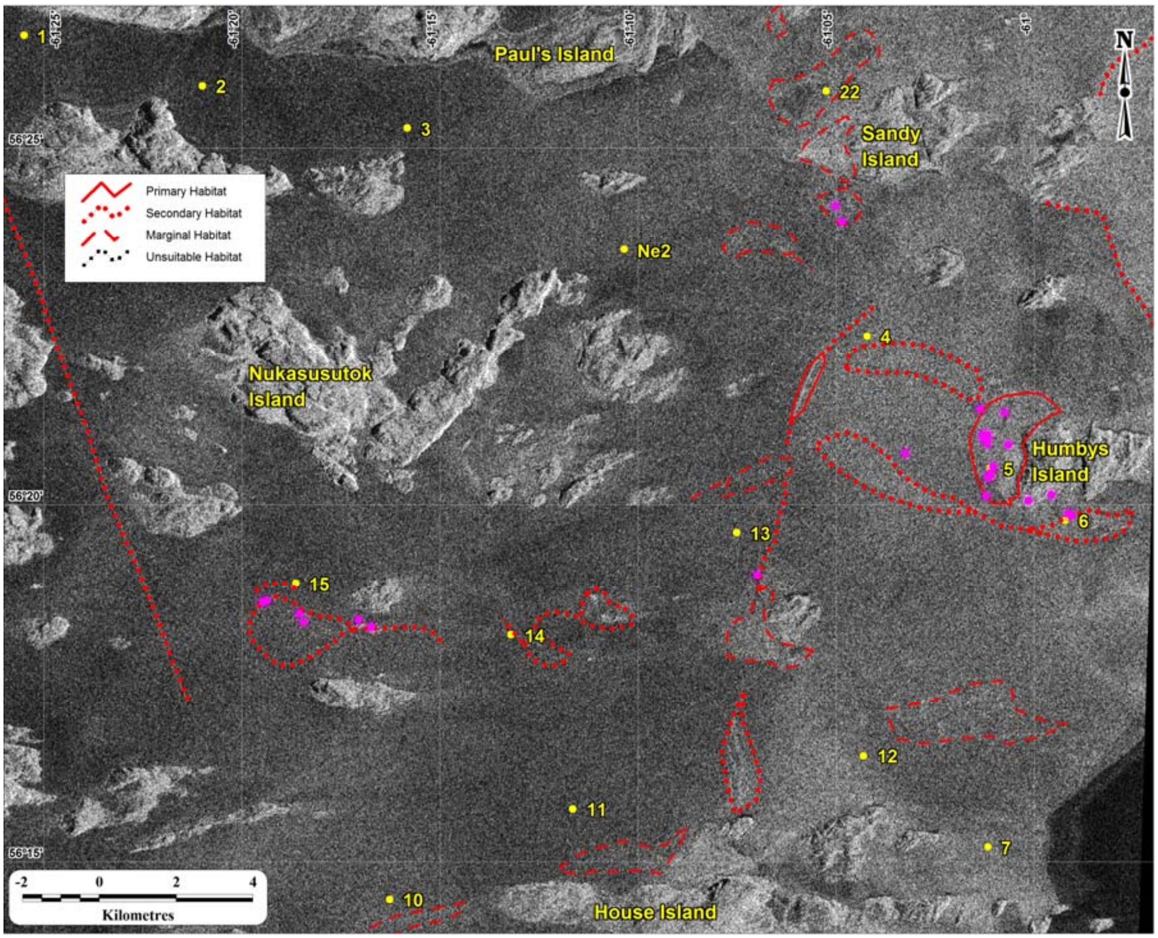


Figure 4. RADARSAT I image of the ice conditions in the detailed study block near the community of Nain, Labrador in 2003. In this image any unmarked areas were identified as marginal. The location of ringed seal birth lairs are identified by a pink circle.

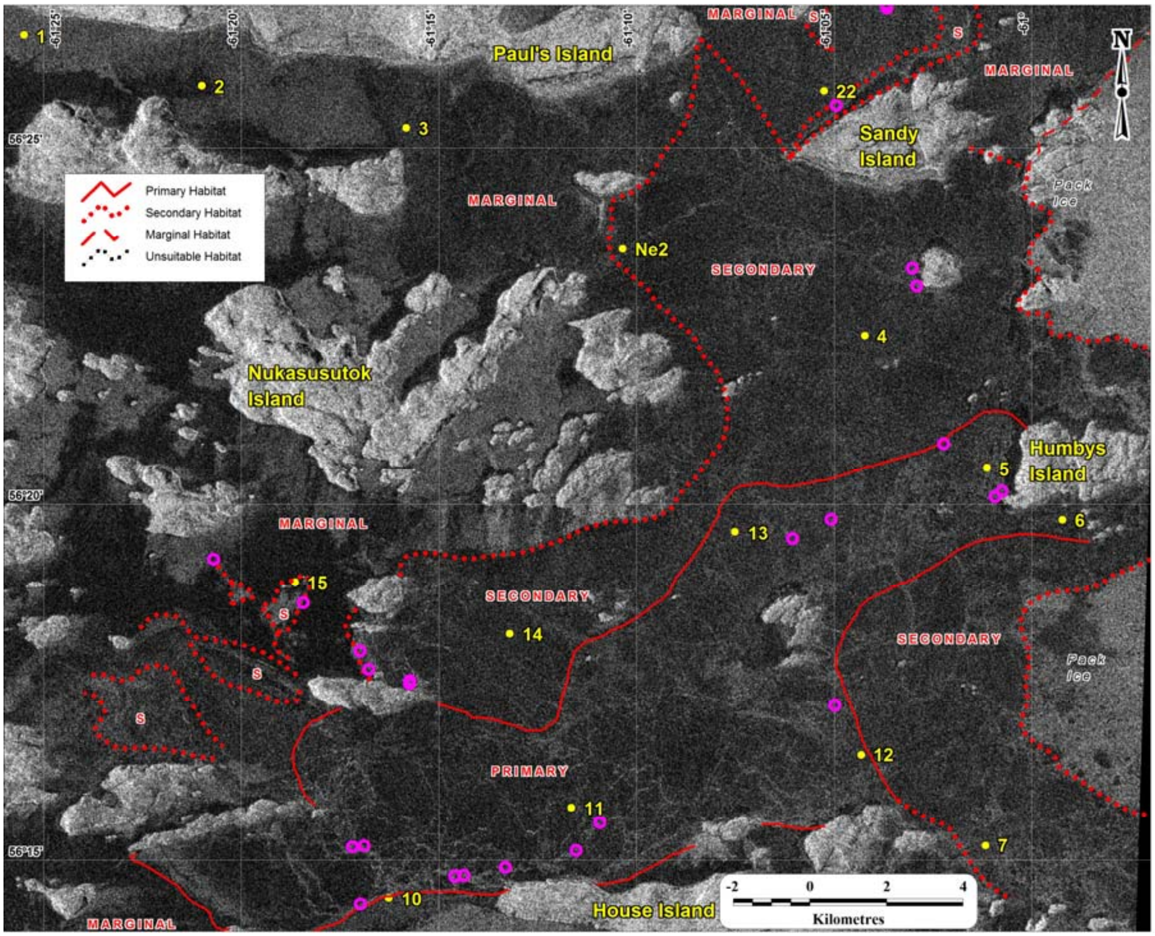


Figure 5. RADARSAT I image of the ice conditions in the detailed study block near the community of Nain, Labrador in 2004. The channels/bays along the western edge of the study area and the pack-region to the east were identified as unsuitable habitat; other unmarked areas were identified as marginal. From 2004-2006 there was no on-ice work to detect birth lairs.

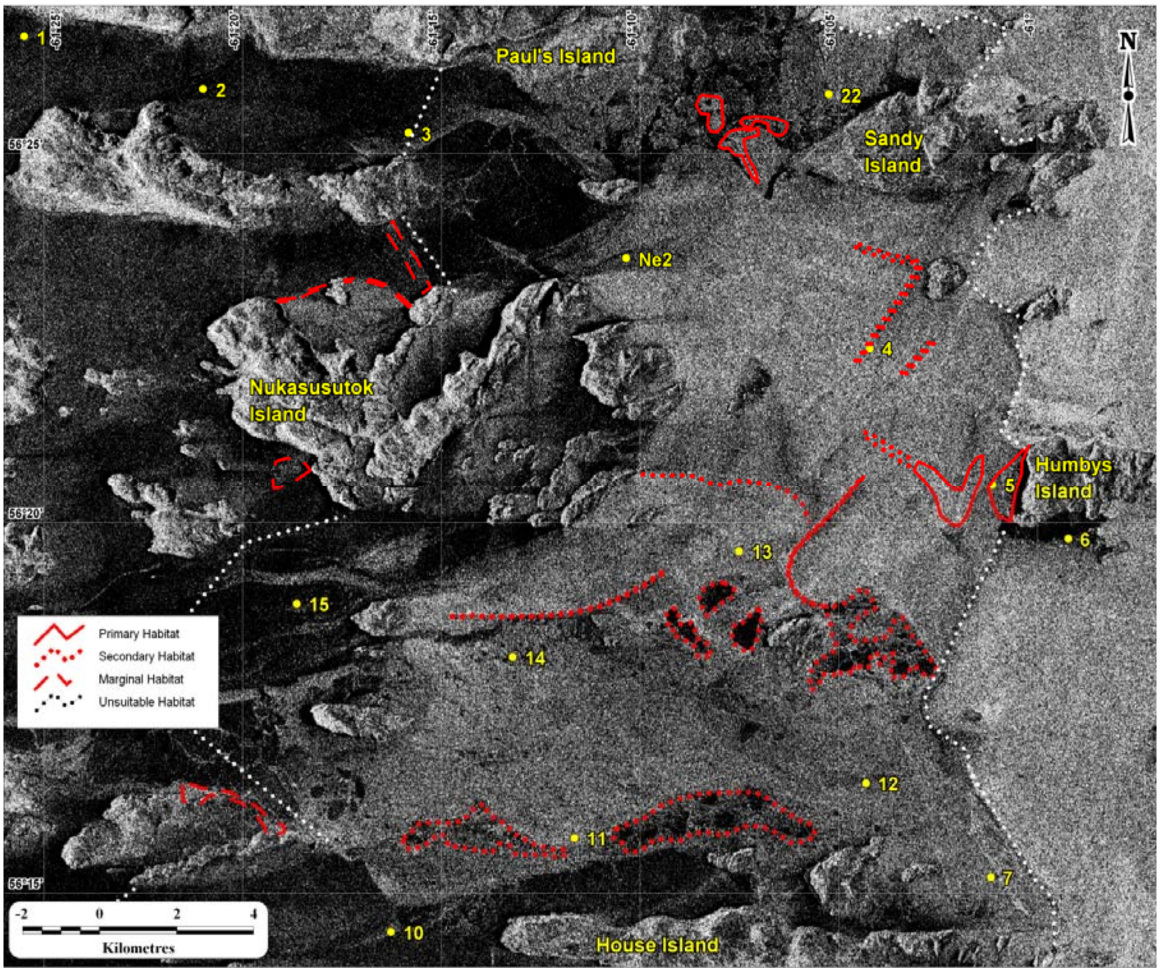


Figure 6. RADARSAT I image of the ice conditions in the detailed study block near the community of Nain, Labrador in 2005. The channels/bays along the western edge of the study area were identified as unsuitable habitat; other unmarked areas were identified as marginal.

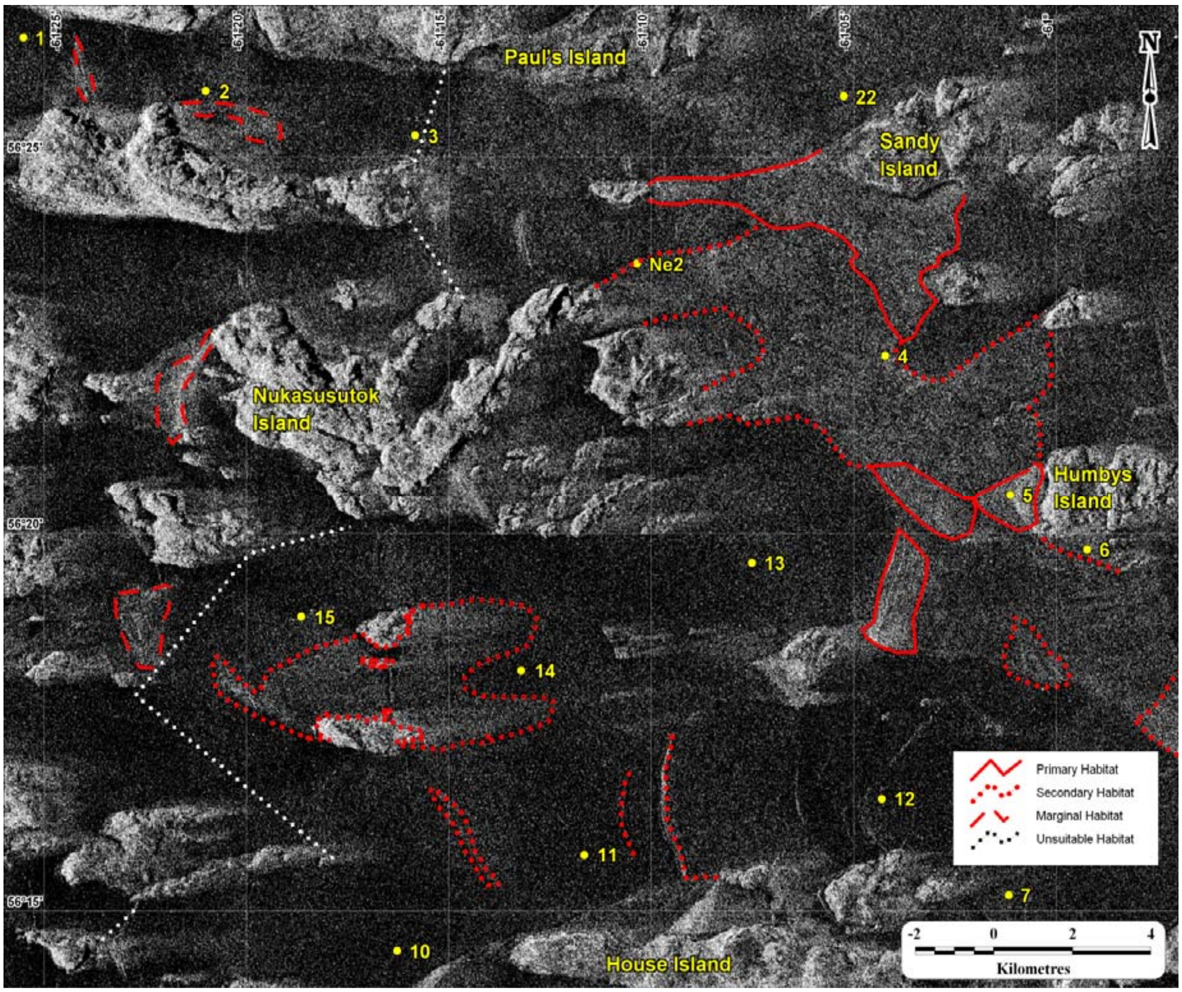


Figure 7. RADARSAT I image of the ice conditions in the detailed study block near the community of Nain, Labrador in 2006. The entire study block was characterized by unsuitable pack-ice to the east and unsuitable smooth, minimally drifted landfast ice in the remainder of the block.

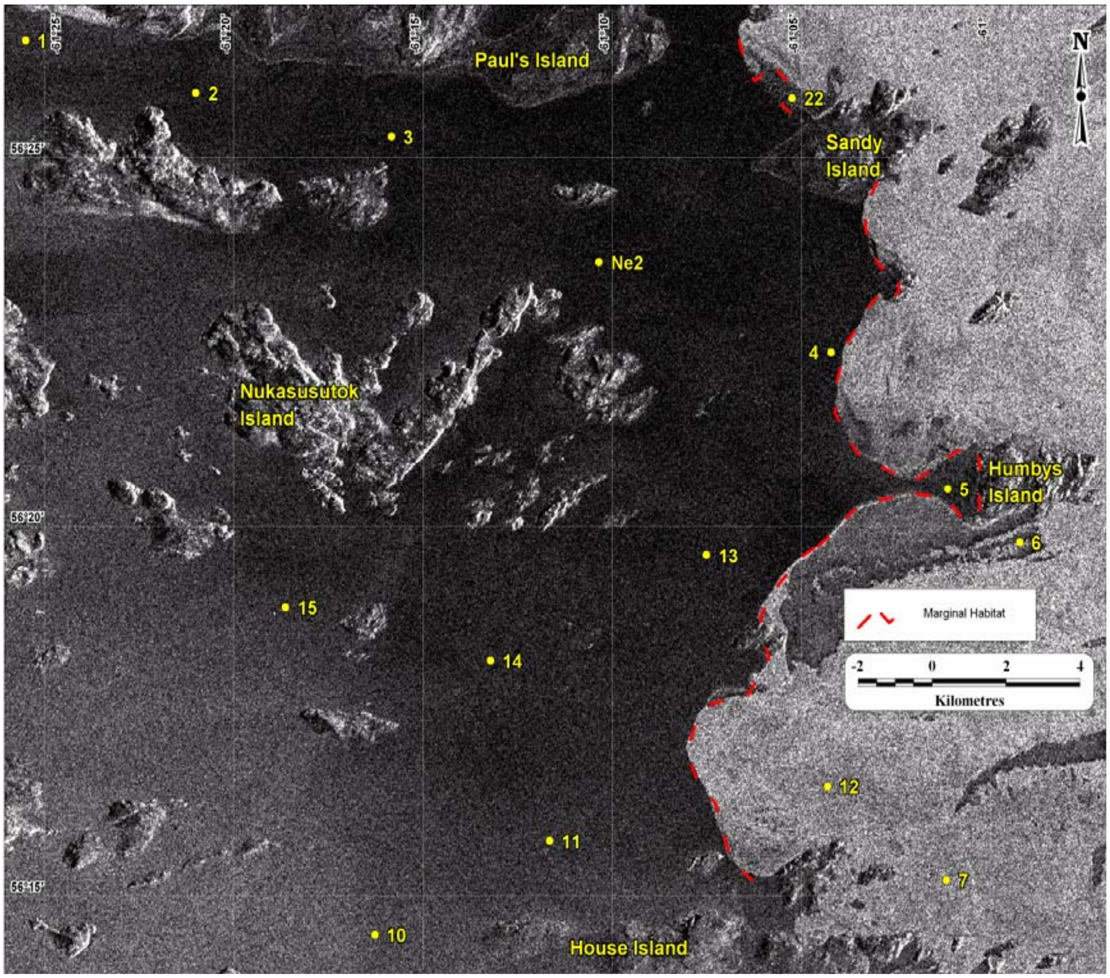


Table 1. Summary of the criteria used to assess the quality of ringed seal pupping habitat based on data collected at each station in the Nain study area from 2001-2006.

Habitat Feature	Primary (P)	Secondary (S)	Marginal (M)	Unsuitable (UN)
Mean Snow Depth	>45cm	35-44cm	20-34cm	<20cm
Drift Development	>55cm	45-54cm	35-44cm	<35cm
Presence of Rough Ice	well defined features	some definition	scattered hummocks or rubble	none or rubble
Size of Rough Ice	>80cm	50-79cm	>50cm	

Table 2. The availability (km^2) of ringed seal pupping habitat in the Nain study area from 2001-2006.

Habitat Type	2001 (km^2)	2002 (km^2)	2003 (km^2)	2004 (km^2)	2005 (km^2)	2006 (km^2)
Primary	8 (1.3%)	5 (0.8%)	119 (19.5%)	3 (0.5%)	20 (3.3%)	
Secondary	17 (2.8%)	12 (2.0%)	174 (28.6%)	11 (1.8%)	60 (9.9%)	
Marginal	5 (0.8%)	18 (3.0%)	282 (46.3%)	367 (60.3%)	397 (65.2%)	
Unsuitable	579 (95.1%)	574 (94.2%)				301 (49.4%)
Eastern Channels				136 (22.3%)	132 (21.7%)	130 (21.3%)
Pack Ice			34(5.5%)	92 (15.2%)		178 (29.3%)
Total Area	609 (km^2)	609 (km^2)	609 (km^2)	609 (km^2)	609 (km^2)	609 (km^2)

Table 3. Summary of ecological factors affecting the suitability of landfast ice conditions for pupping from 2001-2006. A preliminary evaluation of the relative abundance (i.e. availability) of pups and whether they were accessible to hunters due to ice conditions during the spring hunt is also provided.

Year	Key Ecological Factor(s) Affecting Ice Suitability	Evaluation of Availability and Access of Pups to Hunters	Comments
2001	inadequate snow cover and lack of deformed ice with fast spring melt	limited availability and limited access	numerous reports of dead pups on the ice; evidence of predation; quick spring melt limited spring hunting period
2002	inadequate snow cover; lack of deformed ice; prolonged spring melt	limited availability but good access	reports of dead pups on the ice – though not a prevalent as in 2001
2003	excellent ice roughness and snow conditions; however, ice thin, soft ice; unseasonably warm spring; early melt	unknown availability and limited access	higher than average snow fall so pups not visible until later in May – too late for travel in warm temps; limited availability after spring break-up
2004	excessive amount of pack ice as well as rough, rafted ice	limited availability and access difficult	no evidence that seals pupped deeper in bays;
2005	early break-up due to intense spring storms along coast	limited availability and limited access in areas affected by storm	ice conditions were suitable for pupping and winter temperatures seasonal but lack of protective band of pack ice during high seas appeared to be important in spring
2006	inadequate amount of rough ice; early spring break-up linked with warm winter temp., thin ice and rain in March	limited availability and limited access	evidence of collapsed lairs and high pup mortality along coast; evidence of lair collapses in March on Lake Melville; pups born on the ice; evidence of high predation in all study sites

Appendix a: Summary of snow and ice conditions in the Nain study area in 2001.

	Habitat Feature					
Ice Stations	**Snow Depth (cm; mean ± SD; n)**	**Snow Depth (Max/Min)**	**Drift Height (cm; range; n)**	**Ice Thickness (cm)**	**Pressure Ridge or Rough Ice Height (cm; mean ± SD; n)**	**Habitat Suitability**
1	5.2±0.83 (9)	7.0-4.5	none	94.0	none	NS
2	5.8± 5.08 (9)	16.5-2.0	10.0-12.0 (3)	100	none	NS
3	7.1±4.94 (9)	14.0-2.0	10.5-16.0 (3)	103.0	none	NS
NE2	ND*					
4	7.4±3.02 (9)	12.5-4.0	10.0-31.0(6)	90.0	50±18.1(6)	M
22	ND					
5	8.6±3.82(9)	15.0-6.0	17.0-51.0 (9)	95	48±17.6(6)	S/P
6	4.3±3.94(9)	12.0-1.0	18.0-49.0	95	55±18.6(6)	S/P
7	5.4±3.62 (9)	10.0-2.0	9.0-14.0	85	none	NS
10	10.1±5.16	20.0-2.0	11.0-19.5	99	none	NS
11	8.6±4.77(9)	14.0-1.0	12.0-19.0	105	none	NS
12	5.56±3.09	11.0-2.0	none	88	none	NS
13	ND				none	
14	5.5±3.26 (9)	12.0-2.0	7.0-15.0 (3)	102	none	NS
15	4.0±3.81	11.0-1.0	7.0-13.0	103	41±17.6 (3)	S

*ND=no data for site

Appendix b: Summary of snow and ice conditions in the Nain study area in 2002.

	Habitat Feature					
Ice Stations	**Snow Depth (cm; mean ± SD; n)**	**Snow Depth (Max/Min)**	**Drift Height (cm; range; n)**	**Ice Thickness (cm)**	**Pressure Ridge or Rough Ice Height (cm; mean ± SD; n)**	**Habitat Suitability**
1	3.1±2.47(9)	9.5-1.5	17.0-34.5(5)	118	None	NS
2	3.6±1.01(9)	5.5-2.0	25.0-36.5 (5)	110	none	NS
3	9.17±4.79(9)	4.5-20.5	31.0-55.0(6)	110	none	NS/M
NE2	8.1±4.57(9)	16.0-2.0	8.5-35.0(6)	109	none	NS
4	6.1±2.6 (9)	12.0-4.0	20.0-34.5(6)	94	none	NS/M
22	9.3±7.15(9)	14.5-1.0	15.5-30.0 (6)	116	none	NS/M
5	26.1±7.39 (9)	34.0-9.0	25.0-52.5 (6)	118	72±10.9(6)	S/P
6	6.6±3.75	14.5-1.5	8.5-22.0(6)	91	69±17.6(5)	NS/M
7	7.5±3.79 (9)	17.0-4.5	21.5-38.0(6)	74	none	M
10	20.5±8.83 (9)	28.5-11.5	26.0-41.0 (6)	117	none	NS/M
11	11.1±4.20 (9)	21.5-8.0	13.0-22.0 (6)	123	none	NS
12	8.2±2.03 (9)	11.0-5.0	13.0-21.0 (6)	76	none	NS
13	9.8±5.89(9)	15.0-2.0	15.0-40.5(6)	121	none	NS/M
14	15.3±6.10 (9)	26.0-6.5	18.0-29.5 (6)	121	none	NS
15	19.3±5.92 (9)	26.0-10.0	34.0-47.5 (6)	114	none	S

Appendix c: Summary of snow and ice conditions in the Nain study area in 2003.

	Habitat Feature					
Ice Stations	**Snow Depth (cm; mean ± SD; n)**	**Snow Depth (Max/ Min)**	**Drift Height (cm; range; n)**	**Ice Thickness (cm)**	**Pressure Ridge or Rough Ice Height (cm; mean ± SD; n)**	**Habitat Suitability**
1	22.7±7.96	31.5-11.5	24.0-36.0(6)	88	none*	M
2	24.8±10.3	37.5-8.0	22.0-50.5(6)	89	none	M
3	34.0±4.15	41.0-28.5	40.0-59.0(6)	86	none	M/S
NE2	24.2±12.72	45.0-11.0	17.5-53.5(6)	88	none	S
4	42.2±8.6	61.0-34.5	43.0-68.5(6)	92	none	S/P
22	34.7±14.20	42.0-33.0	39.0-62.5(6)	87	none	S
5	47.7±6.22	57.5-36.5	41.5-73.0 (6)	92	none	P
6	19.1±6.27	24.5-10.5	23.0-51.5 (6)	79	None	S
7	26.8±5.69	40.0-21.5	31.3-48.0(6)	86	none	S
10	36.2±7.59	26.5-48.5	44.0-68.5(6)	94	none	P
11	38.0±8.97	47.5-27.5	42.5-67.5 (4)	65	none	P
12	30.1±5.01	37.5-25.0	34.5-52.0 (6)	80	none	S
13	37.2±4.37	47.0-31.5	36.5-68.0(6)	90	none	S/P
14	35.9± 4.01	44.0-30.0	38.5-55.5 (6)	87	none	S
15	14.0±6.1 (9)	22.5-8.0	18.0-36.0 (6)	92	none	M

* Some ice features may have been covered by snow in 2003. Well defined ice features in vicinity of stations and along travel route.

Appendix d: Summary of snow and ice conditions in the Nain study area in 2004.

Ice Stations	Habitat Feature					
	Snow Depth (cm; mean ± SD; n)	**Snow Depth (Max/ Min)**	**Drift Height (cm; range; n)**	**Ice Thickness (cm)**	**Pressure Ridge or Rough Ice Height (cm; mean ± SD; n)**	**Habitat Suitability**
1	21.0±7.5(13)	35.0-10.0	19.5-35.0(7)	86	none	NS
2	24.5±6.0(13)	41.0-14.5	28.0-41.0(9)	68	none	NS
3	18.5±9.0(13)	29.0-7.5	20.0-35.0(8)	78	none	NS
NE2	31.0±9.5(13)	44.0-14.5	30.0-44.0(8)	84	none (drifts sculpted)	M
4	32.0±7.0(13)	47.0-21.0	41.0-56.0(8)	62	58.0±16 (hummocks)	S
22	31.0±3.5(13)	37.5-26.0	25.0-36.5(8)	62	62±7(8) (hummocks)	M
5	44.5±7.5(13)	56.5-30.5	41.0-75.5(8)	99 (rafting)	0.85±10(8)	P
6	27.0±16.0(8)	30.0-7.5	0-51.0(7)	68	99.5±37.5(9) (ridge)	NS/M
7	ND					
10	28.0±8.5(13)	43.5-13.5	22.0-48.5(8)	120 (rafting)	45±9(8)	M/S
11	48.5±10.5(13)	63.5-30.0	41.5-77.0(8)	108 (rafting)	92±17(8) (large rubble)	S/P
12	28.0±9.5(13)	45.5-14.0	23.0±57.0(8)	127 (rafting)	62±14(8) (rubble)	M
13	35.0±6.0(12)	52.0-30.0	19.0-42.0(8)	92	51±11(8)	M
14	27.0±8.1(10)	40.0-17.0	22.0-41.5(8)	122 (rafting)	52±6(8)	M
15	22.0±12.6(13)	45.0-5.0	27.0-45.5(7)	68	none	M

Appendix e: Summary of snow and ice conditions in the Nain study area in 2005.

Ice Stations	Habitat Feature					
	Snow Depth (cm; mean ± SD; n)	**Snow Depth (Max/Min)**	**Drift Height (cm; range; n)**	**Ice Thickness (cm)**	**Pressure Ridge or Rough Ice Height (cm; mean ± SD; n)**	**Habitat Suitability**
1	26.0±10.0 (13)	45.0-12.5	31.0-64.0 (5)	100	none	NS
2	32.0±12.0 (13)	44.5-7.5	33.0-58.0 (6)	122	none	NS
3	45.5±7.5 (13)	57.0-31.5	45.0-65.09(6)	94	83 (1)	NS/M
NE2	38.0±14.0 (13)	59.0-23.5	34.0-83.5 (4)	102	84±8 (7)	S/P
4	47.0±14.0 (13)	65.5-26.0	47.5-65.0 (4)	147	88 (1)	P
22	51.5±77.0 (6)	63.5-31.0	51.5-77.0 (6)	92	none	S/P
5	61.0±11.5 (13)	82.0-51.0	54.0-90.9 (9)	130	110±20 (4)	P
6	49.0±8.0 (13)	64.5-34.0	48.5-64.5 (5)	136	none	S/P
7	37.5±6.0 (13)	64.5-34.0	48.5-64.5(5)	136	none	M/S
10	39.0±9.0(13)	49.0-24.5	41.5-62.0(6)	86	none	M/S
11	40.5±9.0(13)	60.0-26.0	44.0-60.0(6)	91	none	M/S
12	41.0±10.0(13)	60.0-26.5	58.0-69.0(6)	55	none	M/S
13	41.0±6.5(13)	53.5-31.0	51.0-63.0(9)	89	none	M/S
14	43.0±8.5(13)	57.0-32.5	42.0-65.0(6)	86	none	M/S
15	35.5±9.0(13)	49.5-22.0	36.5-55.0(6)	93	none	M/S

Appendix f: Summary of snow and ice conditions in the Nain study area in 2006.

	Habitat Feature					
Ice Stations	**Snow Depth (cm; mean ± SD; n)**	**Snow Depth (Max /Min)**	**Drift Height (cm; range; n)**	**Ice Thickness (cm)**	**Pressure Ridge or Rough Ice Height (cm; mean ± SD; n)**	**Habitat Suitability**
1	21.0±6.5(13)	33.0-13.0	27.0-42.5(5)	88	none	NS
2	34.0±4.5(13)	36.5-28.5	34.5-43.5(4)	81	none	NS
3	26.0±3.5(13)	33.0-20.5	26.0-33.0(4)	80	none	NS
NE2	28.5±8.5(13)	42.0-20.0	37.0-60.5(4)	72	none	S
4	inaccessible					
22	inaccessible					
5	inaccessible					
6	inaccessible					
7	inaccessible					
10	35.0±7.5(13)	48.0-22.5	36.5-48.0(3)	82	none	M/S
11	30.0±7.0(13)	43.0-23.0	37.5-41.0(4)	65	none	M
12	inaccessible					
13	28.4±6.5(13)	42.5-18.5	25.5-40.5(4)	64	none	M
14	19.5±5.0(13)	28.0-10.5	21.0-28.0(3)	65	none	NS
15	39.0±8.5(13)	51.5-27.5	31.5-58.0(5)	94	none	M/S