Chapter 9
Assessing the Shorefast Ice: Iñupiat Whaling Trails off Barrow, Alaska

Matthew L. Druckenmiller, Hajo Eicken, John C. George, and Lewis Brower

Abstract At Barrow, Alaska, local Iñupiat whaling crews annually construct a network of seasonal trails through the shorefast ice during the traditional spring hunting season. These trails originate at locations along the coast and pass through diverse ice features, including ridged and rubbled ice, new and potentially flooded ice, and tidal cracks, before terminating at the shorefast ice edge where camps are established. The safety of this hunt relies on the careful observation of evolving ice characteristics from freeze-up onward and the understanding of how the interplay between ice dynamics, ice thermal evolution, and ocean and atmospheric processes leads to both stable and dangerous conditions. Partnering with Barrow whalers, a multi-year documentation of whaling trails, alongside a geophysical record of shorefast ice conditions, provides insight into how Iñupiat hunters monitor the development of the shorefast ice throughout winter and spring and how individual and community assessments of ice conditions and associated risks, traditions and knowledge, and personal preference determine trail placement. This contribution also discusses how the documentation of human use of the ice environment contributes to integrated observations of Arctic change and adaptation.

Keywords Barrow · Alaska · Iñupiat · Local knowledge · Shorefast sea ice · Whaling

Introduction

Along a 35-km stretch of coastline in northernmost Alaska, the Iñupiat Eskimos of Barrow have hunted the bowhead whale for centuries (Stoker and Krupnik 1993). As the whales migrate northward in spring toward summer feeding waters in the Beaufort Sea, the ocean is covered with sea ice that is continuously responding to

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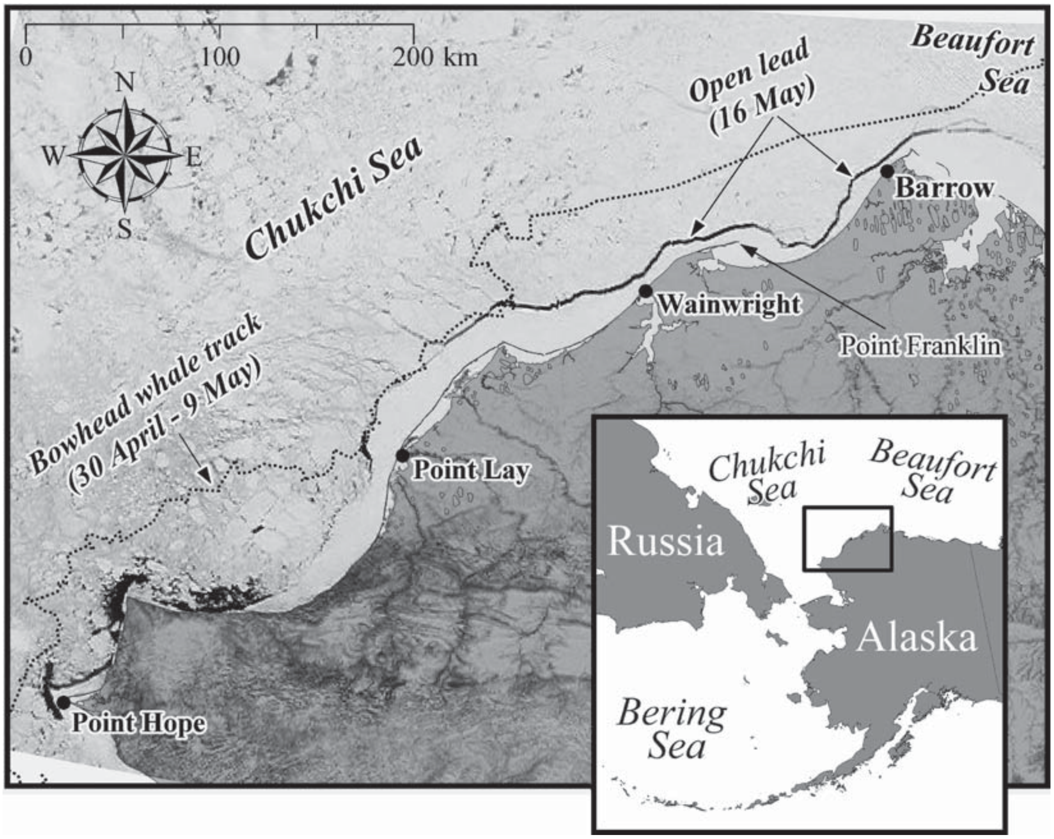

Fig. 9.1 Map of the western Arctic coastline of Alaska. Barrow, Wainwright, Point Lay, and Point Hope are whaling communities officially recognized by the Alaska Eskimo Whaling Commission and hunt in a similar fashion from the edge of the shorefast ice in spring. The *dotted line* shows the migration path of a satellite-tracked bowhead whale during the spring of 2009 (unpublished data provided by Alaska Department of Fish and Game). The whales typically migrate along this coastline between late March and early June and regularly surface in open water of the persistent coastal lead system. The background of this map, a Terra MODIS (Moderate Resolution Imaging Spectroradiometer) satellite image from May 16, 2009, shows a lead opening in a pattern that mirrors the shape of the coastline

the forces of winds and currents (see Fig. 9.1). A narrow shelf of coastal shorefast ice extends out from the land into potentially dangerous waters, shaping the environment that local hunters have come to understand. Whaling crews base their hunt from a network of trails that traverse the shorefast ice (*tuvaq*), often leading them as many as 16 km offshore. While hunters may not travel far, the ice conditions they experience are always changing and each year brings new challenges. Hunting efficiently, safely, and respectfully according to Iñupiat customs requires careful observation, years of experience, and the accumulated knowledge passed down from earlier generations.

In March the shorefast ice off Barrow has been shaped by several months' history of ice growth and dynamics – events that have anchored the ice to the sea floor and the coast. A short traverse of only a few kilometers from the village reveals a vast assortment of ice types, thicknesses, and morphological features (cracks, rafted ice, etc.). Interpreting the make-up of the ice in terms of safety and ease of travel partially determines where the hunters will establish their camps. Understanding whale behavior and recalling past ice conditions additionally informs the hunters' strategy. In late March whaling crews begin to move out onto the ice in great numbers. At this time, the shorefast ice is still evolving, and over the course of the whaling season (mid-April to late May) it deteriorates from its cold winter state. Hunters carefully assess the evolving conditions in relation to safety, on-ice travel, and successful hunting.

We observed the location of these trails and spoke with hunters about how ice conditions informed and shaped their hunting and travel decisions during three consecutive springs, 2007, 2008, and 2009. During this same time various components of a geophysical-based ice monitoring system were recording information on shorefast ice thickness, growth, decay, and deformation. Relating these observations to those of the hunters has stimulated conversations about the specific ice features and processes that the whalers consider important, led to interesting generalizations about shorefast ice variability, and provided important considerations for how to move forward in making scientific observations of sea ice useful to the community. It is our hope that this chapter sheds light on how hunters understand and interact with sea ice under current climate conditions. Our research also examined the relationships between physical environmental processes, such as those during freeze-up and break-up, and ice characteristics that can be monitored on scales relevant to the community's use of the ice (Druckenmiller, n.d.).

Throughout this chapter, Iñupiaq terms for sea ice are used to illustrate the diversity of the Barrow whalers' ice terminology and the complexity of their knowledge. Whenever brief definitions (explanations) are offered, they may not capture the full meaning of the term attributed by Iñupiat experts.

The Shorefast Ice Environment

Shorefast sea ice is present off Barrow for much of the year, typically between November and July. Recent research has shown that the ice is forming later in fall and breaking up earlier in late spring (Mahoney et al. 2007a) and that multi-year ice is becoming less abundant (Drobot and Maslanik 2003). Scientific predictions for a warmer Arctic and further reductions in summer minimum ice extent, and hence multi-year ice area, raise additional concerns for whether or not the "familiar" shorefast ice environment prior to the 1990s will persist. Community observations also indicate that sea ice is changing, but these observations are made against a different "baseline condition" than the one scientists often use. Hunters understand and observe ice conditions largely in relation to how they and their ancestors have used the local ice cover for travel and hunting. Each hunter comes to understand the local environment based on his personal experiences and those of the elders that taught him. While accounts expectedly vary between men, a basic understanding of the primary factors that shape the local shorefast ice environment is shared by

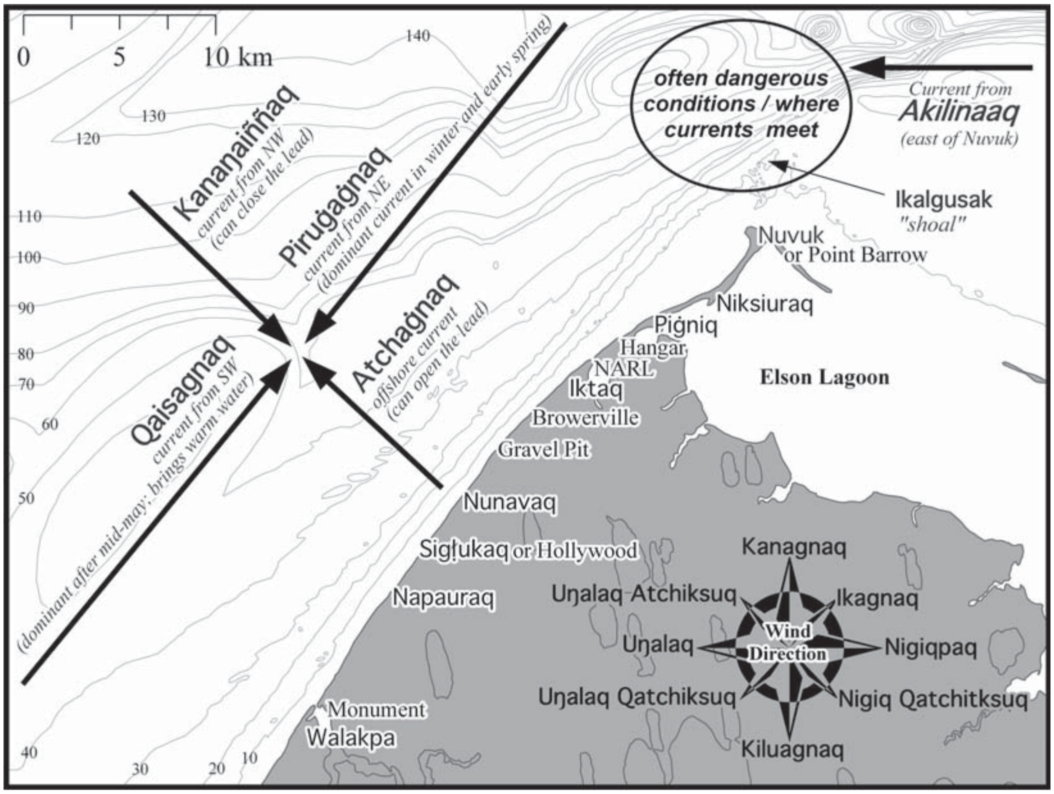

Fig. 9.2 Barrow's traditional knowledge of currents, winds, and ice drift directions. A subset of the many traditional place names and other commonly used terms unique to Barrow are shown at locations along the coast. "NARL" refers to the sight that was previously the Naval Arctic Research Laboratory. Bathymetry is shown as 10 m contours

the community. Figure 9.2 presents a map that shows a few of the key factors that various hunters have mentioned as important.

Point Barrow, located only several kilometers north of the present village, extends into the waters where the Chukchi Sea meets the Beaufort. While Barrow resides on the Chukchi Coast and the community bases their spring whale hunt on that side of the Point, it is not uncommon for hunters to also travel north of the Point. A regional perspective is important as hunters attribute ice dynamics to winds and currents and understand that stresses in ice are often transmitted over great distances, such as from the Beaufort side of the Point to the Chukchi side.

The dominant current is from the northeast (*piruġaġnaq*) during most of the year. However, in mid-to-late May, there is a shift in the major current direction to that from the southwest (*qaisagnaq*) and also an increase in current speed. *Qaisagnaq* is known to bring warm water that accelerates the melt and break-up of shorefast ice. In 2007, while discussing ice conditions near the Point, the late Arnold Brower, Sr., a Barrow elder and whaling crew captain, explained that there is more than one current that parallels Barrow's coastline. Often pieces of drifting ice of similar size can be seen side by side, yet traveling at different speeds. Somewhere near the Point these currents converge with each other and also with the current that comes from east of the Point. During drift ice conditions this meeting of currents can be observed by looking at ice floes turning in circles. As recalled throughout our interviews with hunters, old stories in the community tell of strong currents and ice conditions near the Point that are very dangerous for spring whaling in comparison to ice conditions to the southwest. Traveling north of the Point during an east wind is particularly dangerous. Today's whalers often describe past experiences north of the Point as defining moments for when they began to fully understand the risk of hunting on ice.

The dynamic conditions north of Point Barrow can lead to the formation of massive ridges, often through shear. These ridges are believed to ground in this area due to the presence of a shoal or *ikalgusak* (shown in Fig. 9.2). Here, large ridges serve as a point of deflection for drift ice coming from the east that could potentially impact and destabilize the shorefast ice off Barrow's Chukchi coast.

Winds play a major role in the drift of pack ice and in determining whether or not the lead along the shorefast ice is open. Onshore winds from the north to southwest may bring in pack ice to close the lead, while offshore winds from the northeast to south may open the lead. When an offshore wind is strong enough, it can locally depress sea level by developing an offshore current, which can cause certain areas of the shorefast ice to detach when cracks form around grounded ridges (George et al. unpublished; observations on landfast ice break-off events "Uisauniq" near Point Barrow, Alaska).

There are general patterns in how the shorefast ice develops along Barrow's coastline. On the regional scale, Barrow whaling captain Eugene Brower explained in 2009 that the shape of the coastline between Wainwright and Barrow can influence local ice conditions. With Point Franklin providing a deflection point (see Fig. 9.1), Barrow's coastline north of *Nunavaq* bears the brunt of the pack ice moving in from the southwest in comparison to that south of Nunavaq. For this same reason, and perhaps also due to the intricacies of coastal currents, the pack ice typically approaches the lead edge slower and with less force south of Nunavaq than it does further north. This leads to the ice south of *Nunavaq* and *Sigł ukaq* being flatter and less rough than the ice further north. Also in this region the shorefast ice typically extends out further than it does to the North. Once again, these are only general patterns and hunters clearly state that ice conditions are different each year.

Springtime Whaling: A Sequence of Observations

Barrow has been the location of continuous settlements for at least 1,300 years, with periodic settlements traced back as far as 5,000 years. In the mid-1800s Yankee whalers began regular contact with the settlement at Point Barrow, and by 1890 multiple commercial whaling operations were in full swing employing hundreds of Iñupiat whalers (Braund and Moorehead 1995). When 1908 brought the end to commercial whaling, subsistence whaling continued according to tradition, yet infused with technological advances, such as the bomb lance. Today, there are approximately 50 licensed whaling crew captains in Barrow that are responsible for supplying both the immediate community and their extended families across Alaska with food from the bowhead whale. Barrow whalers still use skin boats – *umiat* (wooden frames covered with bearded seal skins) – and thrive as expert hunters by applying knowledge and skills that have been transmitted across generations for centuries. The success of the hunt relies on assessing the shorefast ice – one of the more complex, ephemeral terrains on earth.

Evaluating the Ice in Preparation for the Hunt

Even though shorefast ice begins to appear off Barrow in November, January through March are the major ice-building months. This is the time when hunters count on heavy pack ice coming in to create ridges. Careful attention is given to how the different regions of the shorefast ice develop (see Fig. 9.3). First there is the flat ice zone (*igniġnaq*), which is typically either floating or bottom-fast, between the shore and ridges (*ivuniq*). Second, there is the zone where grounded pressure ridges (*kisitchat*) develop and provide the anchoring strength. These ridges typically form in shear. Multiple rows of ridges often exist between the *igniġnaq* and any extended floating shorefast ice (*iiguaq*), which is vulnerable to impact by drifting pack ice (George et al. 2004).

Whaling captain Crawford Patkotak explained that you have to observe the ice while thinking about what happened before. Hunters look for sediment entrained in ridges for clues that the ice scraped and grounded to the seabed as it formed. They

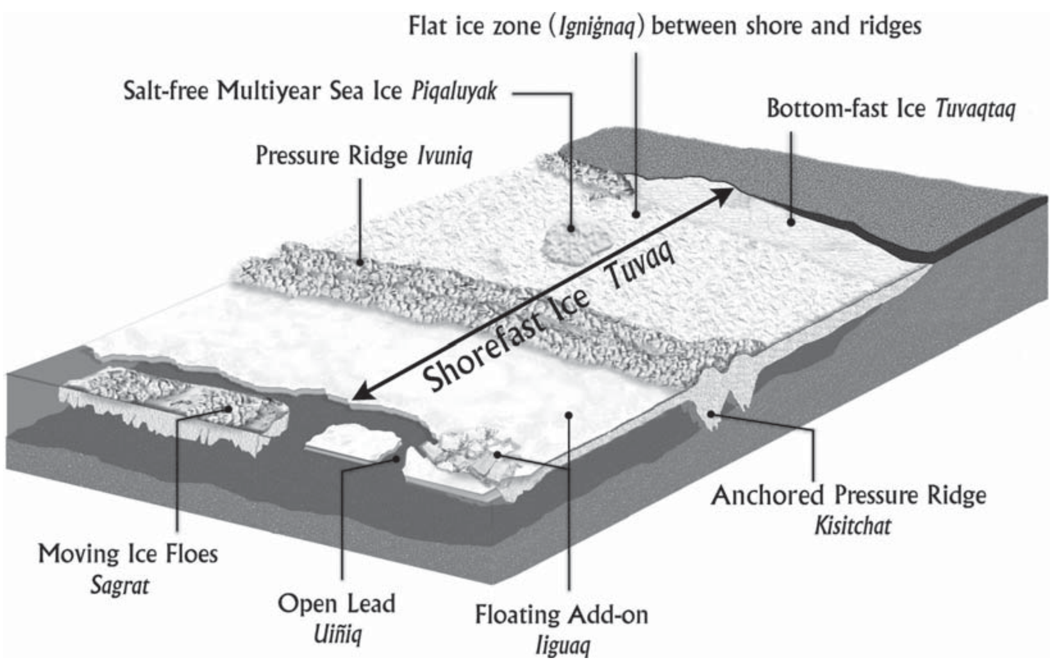

Fig. 9.3 Schematic representation of coastal sea ice in the Chukchi Sea off Barrow. Both English and Iñupiaq terms for ice structures are given (George et al., 2004). Modified with permission from an illustration by Deb Coccia

examine the ice makeup and question whether the ice near pressure ridges was there when the ridge formed or rather came in later. Every attachment represents a point of fusion where the ice may break out later in the season. Low winter temperatures are important for fusing the ice together. Winter is the time to watch the ice and decide where one needs to closely monitor throughout the whaling season. In addition to safety, hunters also examine the ice to determine the layout of snowmobile trails to be made from the beach to the open lead (*uiñiq*).

Building the Ice Trails

The physical process of building trails begins in late March. Both experienced and young members of the whaling crews use snowmobiles and ice picks to blaze and cut their trails across the shorefast ice according to a strategy that varies from crew to crew. A range of considerations exists for a whaling captain deciding where to place his crew's trail.

Safety and stability. The most important consideration for any whaling captain is the safety of his crew, which includes everyone from the hunters who will camp on the ice and pursue the whale to those who will come out to help with butchering and hauling meat. While every captain will agree that a successful hunt is not worth the loss of human life or of vital whaling equipment, different hunters have varying perceptions of risk. However, in general, a trail is chosen such that it traverses ice that is well grounded or securely attached to stable ice. Therefore, knowledge of the locations of cracks and points of attachment is important. It is quite common that winter seal hunters, who often travel on foot, provide detailed initial assessments of ice conditions.

Construction effort. Hunters must consider how much work it will take to build a trail. While a trail of several kilometers that connects many flat pans of ice may take only a few days work for a few men, a trail of similar length that traverses extremely rough ice and multiple rows of large ridges may take several weeks. Those crews taught to go where the ice is rough, thick, and well grounded inevitably accept that they will work harder for their trail. It is common for several crews to work together on the same trail near the shore. Once the trail nears the edge, however, the crews will split their efforts to build individual trails that will branch off from the main one.

Navigability and potential for evacuation. It is important to be able to drive a snowmobile quickly along a trail, especially when in need of swift evacuation off the ice. In consequence, trails are made as straight and as smooth as possible, utilizing large interconnected pans of flat ice, and are built wide enough to allow two snowmobiles to pass each other. When describing these strategies for Wainwright in the 1960s, Richard Nelson (Nelson 1969) discussed the use of refrozen cracks as a way to efficiently travel through areas of highly deformed sea ice. Trails nearly always approach the lead edge perpendicularly to the coast since this represents the shorter distance to land. Alternative evacuation routes are often considered, resulting in more than one trail leading to the beach or to safer ice. It is in this region of safe ice that a crew will often place their *naŋiaqtuġvik*, which is a place where they store their whaling equipment and camp when waiting for the lead to open or for other favorable conditions.

Ice edge conditions. Conditions at the edge are also critical for a successful hunt. Hunters prefer to find thick heavy ice (or rafted thinner ice) where they can place their camp, build a boat launch, and pull up a whale. Hunters indicate that ice thicker than 1.5 m is needed to haul up a large whale more than 16 m (53 ft) in length. Some prefer to find ridges near the lead that can be used as a perch to watch the water. Trail building when the lead is closed requires hunters to utilize observations made earlier in the season to make predictions for where the edge will be when the lead eventually opens. Even at times when the lead is open, ice conditions are not always ideal due to unstable or thin add ons (*iiguat*; plural form for *iiguaq*), leaving the crews in wait for more suitable ice edge conditions to develop.

Proximity to other crews and distance from town. Some crews prefer to hunt in places far removed from others as they prefer solitude and because they believe it promotes self-sufficient hunting practices. When a crew is on their own, they must focus on killing the whale with the first strike, as they cannot rely on help from other crews. Conversely, some crews prefer to remain close to assist each other when needed or to share favorable ice and trail conditions. The price of fuel and the time it takes to get to a hunting location also play a role in trail placement.

Forecast of late spring conditions. Hunters must consider both the conditions at the time they build their trail and those that will be encountered toward the end of the season. A trail that crosses large flat pans of thinner ice is at greater risk of having the ice wear dangerously thin once air temperatures warm, snow melts, and the warm current from the southwest arrives. Some may build trails on top of ridges and keep on higher elevation ice for as long as possible. The advantage is not only that they can see greater distances to landmarks and open water but also because it reduces the likelihood of the trail being eaten away by warm water or snowmobile traffic. In contrast, other crews may decide to place their trail in the lower elevation ice between and throughout ridges since the ridge walls serve as side ramps to the trail and prevent heavily loaded sleds from tipping.

Bowhead whale behavior. Understanding how the whales behave as they migrate along the ice edge also advises the hunter where to place his camp. When predicting where a whale will surface, hunters employ different strategies. Barrow elder Warren Matumeak explained that whales will swim beneath young thin ice, avoiding large ridge keels, and will surface in embayments along the edge (*kaŋikłuk*) (see Fig. 9.4). "Camping on the north side of these embayments and facing south" (*manilinaaq*) provides a good place to watch whales coming toward you and a good place to launch a skin boat. In turn, iluliaq refers to a location where you have only a view of whales traveling away. There are also hunters that prefer to place their camps at points along the ice edge (*nuvuġaq*) since these tend to provide good visibility and access to whales that swim from point to point and bypass embayments. Some hunters have also been taught that the whales are attracted to thick multi-year ice because it is shiny and may also provide feeding advantages. It is believed that ice with deep keels (thick multi-year ice or ridges) causes the water to churn and stir up krill.

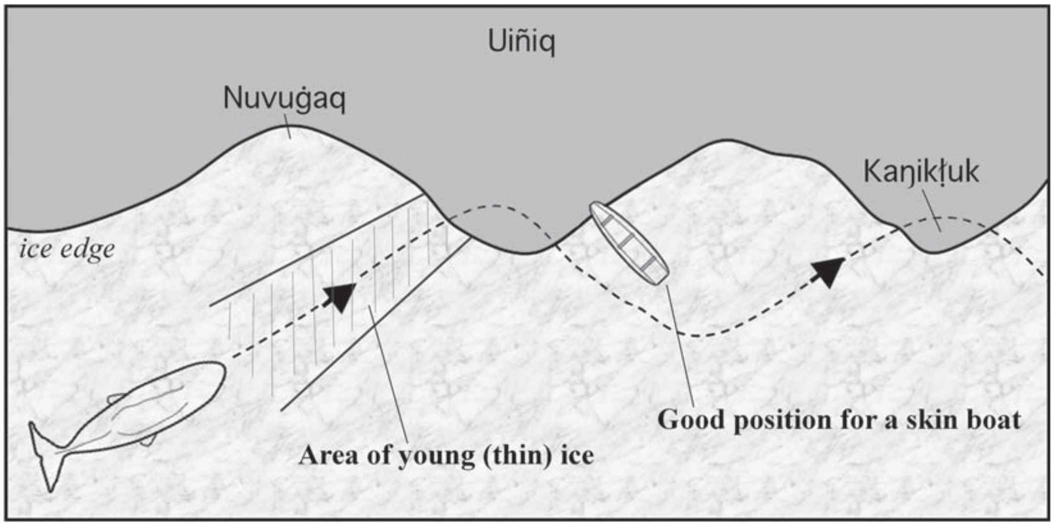

Fig. 9.4 Likely path of a bowhead whale as it swims along the ice edge. *Kaŋikḷuk* is an embayment along the ice edge. *Nuvuġaq* is a point of ice extending out from the lead edge. Adapted with permission from a sketch by Warren Matumeak

Elders' knowledge. In the end, the decision on where to place an ice trail for spring whaling may most strongly be influenced by tradition and what was taught by elders. Arnold Brower, Sr., noted that he learned from his elders to hunt in the north early in the season before the current from the southwest strengthened, thus minimizing the risk of losing a struck whale that is carried under the ice by the current. When the current intensified in mid-to-late May, he would move his crew to the south. Whaling Captain Nate Olemaun discussed how he was taught that the waters off *Sigłukaq* are rich feeding waters and are a good place to see whales. As noted earlier, many captains prefer to hunt south of the dangerous and unpredictable conditions north of the Point, despite acknowledging that this is a good place to see whales.

The trail network built by the Barrow whaling community evolves throughout the season as ice conditions continuously change and crews move locations. To assist in navigation most crews use distinct markers for their trails, such as painted wooden stakes or flags. Markers often note the crews' names. Trails are typically referred to by the name of the captain or crew or by the trail's point of origin, using the place-names and landmarks shown in Fig. 9.2.

Observations at the Ice Edge

When crews are "along the edge of the ice observing the environment and looking for whales" (*nipaaq*) they must continuously monitor the ice on which they are camped and the pack ice beyond, both of which are influenced by wind and current. To monitor the currents, hunters typically drop a sounding line into the water. Barrow whaler Joe Leavitt explained how an increase in a current's strength starts at the bottom and develops upward over the course of a few days, providing advanced notice of potentially precarious ice conditions. In particular, ice moving against the wind is an indication that the current is moving with considerable strength. Currents, especially when bringing in warmer water, can lead to the break-up of ungrounded ridge keels near the edge resulting in the "throwing-up of ice" into the lead (*muġaala*; see Fig. 9.5), presenting a danger to boats. When the lead is closed, these broken pieces can remain under the ice, only to emerge when the lead reopens.

A "water sky" (a dark band along the horizon that indicates open water; see Fig. 9.6) serves as a way to monitor for incoming pack ice that may present a threat to those at the ice edge. If the dark band begins to disappear, the pack ice is approaching. This is of particular concern when camped on *iiguaq*. In these conditions a whaling crew is forced to retreat to safer ice. When camped on multi-year ice at the lead, encroaching pack ice presents less of a hazard.

It is also important to monitor the current's strength to avoid striking a whale when conditions may prevent the crew from being able to haul it to the ice edge for butchering. A strong current, especially near the Point, has been known to defeat the efforts of several boats attempting to haul a single whale to stable shorefast ice. A decision "to launch a boat from the ice edge to go to the whale's path" (*pamiuqtak*) must be done only when conditions present an acceptable risk for the entirety of the hunt, which ends when the meat, *muktuk*, equipment, and people are on safe ice.

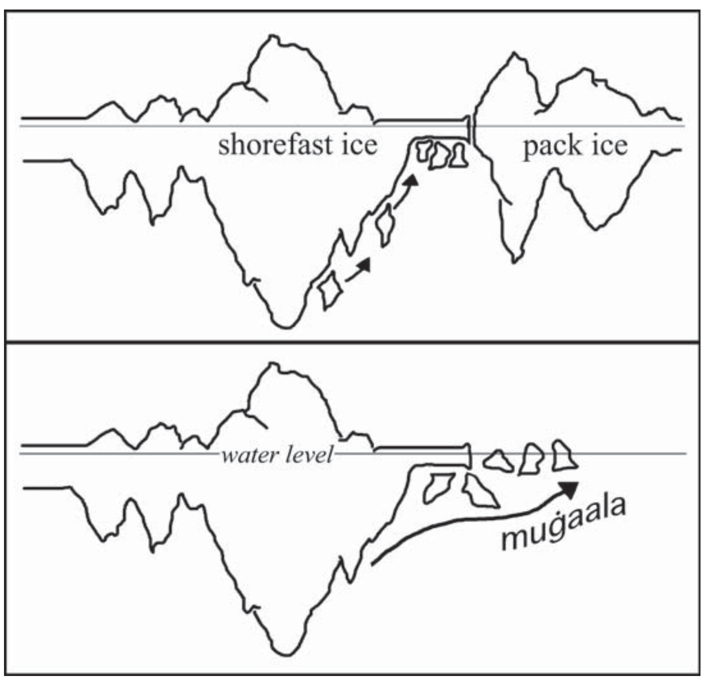

Fig. 9.5 *Muġaala* ("throwing-up of ice") at the ice edge. Following the opening of the lead as pack ice drifts away, loose pieces of ice detach from ridge keels (or from the bottom of rafted ice) and float up beneath the level ice or into the open water. When such pieces hit the level ice, they can produce a loud sound that is often misinterpreted by a hunter as a crack forming in the ice. Based on a description provided by Lewis Brower

Fig. 9.6 Dangerous open water on a whaling trail. Such "holes" may be attributed to heavy snowmobile traffic and warm water melting the ice from beneath. A "water sky" can be seen on the horizon, indicating an open lead. (Photo: M.L. Druckenmiller)

Monitoring the Shorefast Ice

Hunters carefully watch the shorefast ice along their trail throughout the season. There are several features that they pay particular attention to, such as previously identified cracks, newly formed cracks in the flat thin ice near grounded ridges, and areas where slush ice has been incorporated into the shorefast ice. Barrow whaler Lewis Brower told of how his father Arnold Brower, Sr., had taught him to build small handmade rows of compacted snow to perpendicularly extend across cracks so that fracturing or disturbances to the snow piles would serve to monitor the cracks' activity. Cracks or weak points where new ice has been added to the shorefast ice become particularly important in determining where the shorefast ice may break-out. *Katak*, which means "to fall," is the Iñupiaq term used to describe a sudden drop in sea level where the flat ice near grounded ridges cracks and may lead to a break-out (George et al. unpublished; Norton 2002).

Another feature that must be monitored is *muġaliq*, which is slush ice that forms through shear and the incorporation of snow. This ice can be found anywhere throughout the shorefast ice zone since it can freeze in place as the shorefast ice develops and evolves throughout the year. These areas are observed closely since they represent a particular danger as spring progresses. When frozen *muġaliq* warms it rapidly loses its integrity and acquires a quicksand-like consistency, breaking in a quiet manner. A quiet break-up process is particularly disconcerting to hunters since they often rely on sounds to warn of potentially threatening conditions, such as cracking and ridging.

By mid-to-late May, warmer air temperatures and the arrival of the warm current from the southwest escalate the transition of shorefast ice toward increasingly unsafe conditions. The "glue" that is holding the weak areas together begins to release. Old cracks melt out, and newly formed "cracks open up, never to refreeze" (*nutaqqutaq*). After the snow melts, trails develop dark areas of water or extremely thin ice, where snowmobiles can easily fall through (see Fig. 9.6). Also by this time, the majority of passing whales become increasingly large and difficult to pull up onto thin ice at the edge. *Kasruq* ("when one is done with whaling and pulls their gear off the ice") takes place either when Barrow has reached its quota of strikes or when ice conditions are no longer suitable for whaling.

Looking for Old Ice

The retreat and thinning of the Arctic's perennial ice, observed each September as the ice extent is at its annual minimum, is a clear indication that conditions in the Arctic have changed over the last 40 years. Since 1979 when satellites first began monitoring Arctic ice, the extent has declined as much as 10.2% per decade (Comiso et al. 2008). After the mid-1970s, hunters along Alaska's Chukchi coast also began observing that ice conditions, in particular shorefast ice morphology and stability, began to deviate from what was considered normal for prior decades, as reflected in direct observations and elders' teachings (Norton 2002). In large part, these observations note that multi-year ice, which here refers to ice that has survived at least one summer's melt season, is becoming less abundant over the long term. Figure 9.7 shows multi-year ice near Point Barrow.

Both hunters and scientists view the presence or absence of multi-year ice as an indicator of change and as proxy for a range of processes related to stability and decay of coastal and offshore ice. Scientists view multi-year ice as important for regulating the amount of solar energy that enters the ocean over the course of the summer and early fall, thus partially controlling the growth conditions for new ice in late fall. In the coastal environment, multi-year ice assists in the formation of shorefast ice by providing anchoring points. When winter approaches and the prevailing clockwise circulation pattern in the Beaufort Sea brings multi-year ice south- and westward, multi-year floes enter the coastal region during a time when ice dynamics and the growth of new ice build shorefast ice. The degree to which these processes coincide determines the amount of multi-year ice entrained into the shorefast ice zone.

With perennial ice retreating further to the north and less multi-year ice present during fall freeze-up (Maslanik et al. 2007; Nghiem et al. 2007), the period of stable shorefast ice has grown shorter as well. A widespread concern of the Barrow community is that with the loss of multi-year ice, ice conditions will become increasingly unfamiliar and the hunting season will shorten. In the past, the whaling

Fig. 9.7 Multi-year ice near Barrow. Whaler Roy Ahmaogak is shown standing in front of *piqaluyuk* that grounded near the shoal north of Point Barrow in 2009. Roy stated that "Ten years ago, the reduction in multi-year ice was not so noticeable. But in recent years we have seen a large disappearance of multi-year ice. I was surprised to see two-story *piqaluyuk* north of Nuvuk this year." The *lower panel* of images presents three QuikSCAT satellite scenes from December 1 of 2006, 2007, and 2008 – prior to the whaling seasons discussed later in this chapter. The regions of ice appearing bright – corresponding to higher radar backscatter – north of Alaska can be interpreted as multi-year ice. In general, the amount of multi-year ice drifting near Barrow at this time of year is related to the amount of multi-year ice incorporated into the shorefast ice environment, which forms around this time. (Photo: M.L. Druckenmiller)

season often extended into the month of June, while in recent years the hunt has concluded around the third week of May. Crawford Patkotak, for instance, recalled that in 1987, a year with a lot of heavy multi-year ice off Barrow, his father Simeon Patkotak, Sr., landed a 16 m (52 ft) whale on June 15.

Whalers consider the advantages and disadvantages of multi-year ice. Hunters, similar to Arctic engineers, appreciate the physical properties of multi-year ice and understand that it possesses greater strength than more saline first-year sea ice, but that it is also much more brittle and can shatter upon impact or as a result of a build-up of internal stresses due to surface cooling or heating. When hunters discuss multi-year ice, it is often noted that it is dangerous to camp on for this reason. However, it is also often referred to as a stable platform to base a hunt from at the lead edge. This apparent discrepancy comes from the fact that whalers do not group all multi-year ice into one class. Ice is not simply first-year ice or multi-year ice. In fact, "multi-year" ice is not a term commonly used by Barrow hunters. *Piqaluyuk* is the term used to refer to multi-year ice that is salt-free and serves as a preferred source of drinking water. Large pans of this type of salt-free ice may shatter upon impact. *Tuvaġruaq* is a large region of old ice (perhaps often "old" first-year ice or second-year ice, and younger than *piqaluyuk*) that is stable and will not shatter. Some hunters describe *tuvaġruaq* as not only a single type of ice but rather as a stable conglomerate of different types, potentially even of *piqaluyuk* and younger thin ice. This type of ice, when found along the edge, is resistant to break-out and is suitable for pulling up a heavy whale. However, because of its thickness and associated freeboard, a ramp (*amuaq*) must be cut at the edge in order to pull the whale from the water.

Monitoring and Mapping the Ice Trails

The research presented in this contribution is part of a broader effort to put in place a coastal sea ice observatory at Barrow that addresses both scientific research questions and the information needs of the community and other stakeholders that conduct activities on sea ice (Druckenmiller et al. 2009; Eicken et al. 2009). A key aspect of the observatory is to examine how geophysically derived ice thickness measurements and the monitoring of near-shore ice movement and deformation are relevant to the whaling community's springtime assessments of ice stability and safety. A coastal radar mounted on a building that overlooks the shorefast ice where many of these trails are located monitors the movement and stabilization of ice throughout the year. Collaboration with hunters and the community has enabled data collection during a time when they are most active on the ice.

Between 2001 and 2006, the North Slope Borough Department of Wildlife Management maintained periodic records of where and over what types of ice (e.g., grounded ridges, rubble, flat pans of ice) the community placed ice trails during spring whaling. After a suggestion that a more thorough and complete mapping of the trails take place each spring, we began this effort by mapping the ice trails during 2007, 2008, and 2009. The trails were traveled by snowmobile with a handheld Garmin GPS (geographic information system) device. Using ArcGIS, a collection of GIS software products, the tracks were plotted and placed on recent SAR (synthetic aperture radar) satellite images to produce maps for the community. With input from the community and iterative improvements, these maps have evolved into a product that is useful for on-ice navigation, general ice-type discrimination (flat ice versus rough ice), and as a reference for Barrow's Search and Rescue operations.

With permission from the individual whaling crews, continuous ice thickness measurements were made along most trails using an electromagnetic induction device (Geonics EM31 conductivity meter), which estimates ice thickness by detecting the distance between the surface of the ice and the sea water below. This device was placed on a large wooden sled and hauled along the trails to provide quick indirect measurements (see Fig. 9.8). Measurements are most accurate (to within a few percent of total thickness) over un-deformed ice less than 3 m thick as compared to thicker, rough ice, such as ridges, but still provide detailed information about ice

Fig. 9.8 Snowmobile hauling a sled with the ice survey instruments. Shown here is the EM31 conductivity meter that measures ice thickness, a highly accurate differential GPS, and a radar-reflector mast, which allows the measurements to be located in the imagery collected by the coastal radar in downtown Barrow (see Fig. 9.9). The skyline of Barrow can be seen in the distant background. (Photo: M.L. Druckenmiller)

thickness variations across the entire extent of shorefast ice (Haas et al. 1997). While this chapter presents an overview of the data, a specific discussion of how these measurements relate to changing ice conditions and the responses of the hunting community will be discussed in a later contribution.

This is not the first such project to map sea ice travel by high Arctic communities. Other studies have done so (Aporta 2004; Tremblay et al. 2006) and likewise describe trail breaking and navigation of these temporary landscapes as requiring an experienced ability to discern reoccurring environmental patterns.

A Brief Survey of Weather and Ice Conditions During 3 Years of Whaling

Each year brings new and unique ice conditions to Barrow, and with each year a story can be told about how the community interpreted these conditions and responded during the spring whale hunt. From 2007 to 2009, we visited Barrow each spring to investigate ice conditions, map the ice trails, and speak with hunters. While these years may be characterized as "typical low multi-year ice years," the information presented here places many of the observations made by the community into a framework for year-to-year comparison.

2007: Successful Whaling on Thin Ice Following a Break-Out

The 2007 whaling season was very successful with Barrow landing 13 whales, including a record number of small juvenile whales, known as *ingutuks*. The locations where many of the crews chose to hunt demonstrated two important points. First, hunters tolerate ice conditions that may first appear unsafe if other conditions – the wind, currents, and tides – are favorable. The risk associated with specific ice conditions clearly relates to the length of time a hunter may decide to stay on the ice in that area. Second, hunters choose their camp locations based on not only ice conditions but also whale behavior.

On March 31, 1 week before crews began constructing their trails, a break-out event occurred in the shorefast ice off Barrow (see Fig. 9.9). Immediately following this event, adjacent first-year ice from south of the location piled up and replaced

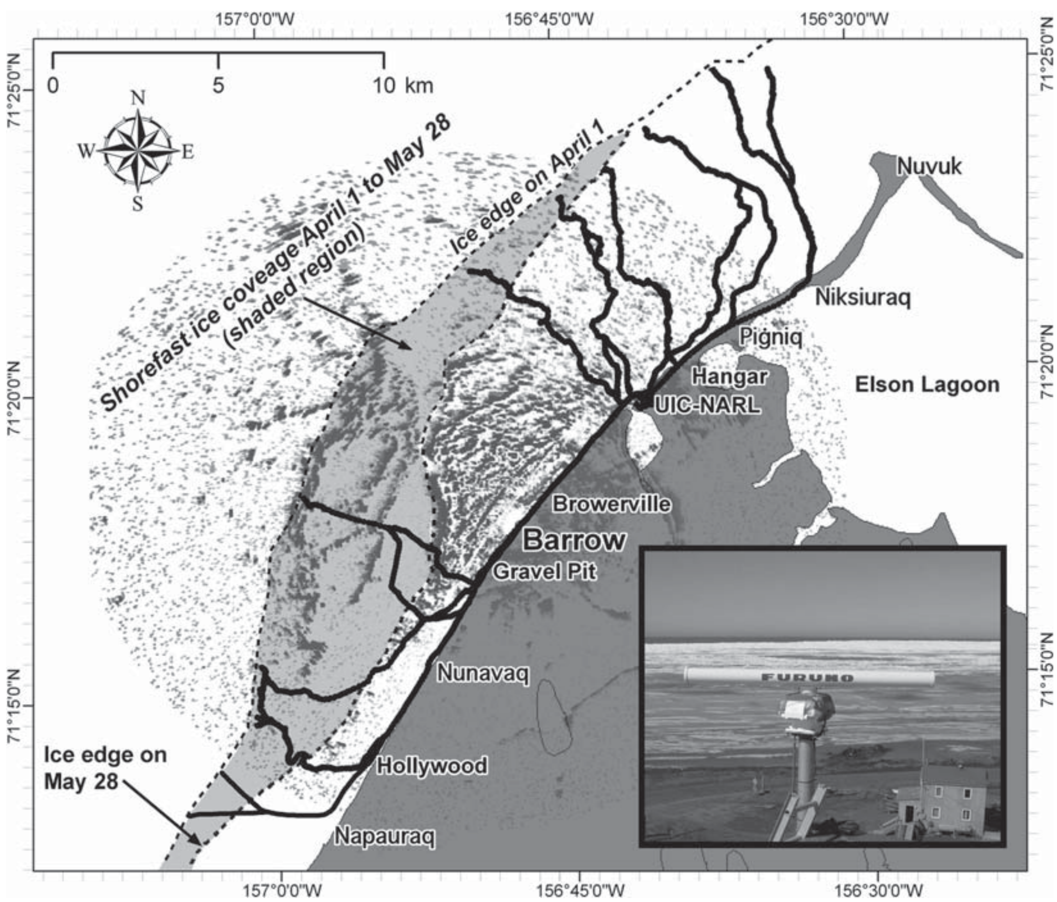

Fig. 9.9 Map of the 2007 whaling trails. Many of the trails shown here traversed the region that existed in the shorefast ice between break-out events on March 31 and May 28. The background in this image shows a sample radar backscatter image (*dark speckles* represent ice features) as recorded during the break-out on May 28. The location of the main trail off Napauraq was hand-drawn after the whaling season ended based on the input from members of the community. The 10 kW X-band Furuno marine radar in downtown Barrow is shown in the *lower right* photo. (See also Color Plate 5 on page 474)

the ice that broke out. This ice, despite being quite thin relative to the shorefast ice to the north and possessing few grounded ridges, remained in place throughout the entire whaling season and provided the location where most of Barrow's whales were landed (Druckenmiller et al. 2009). This circumstance may be in part due to the observation of one hunter that the whales were following the edge of the southern lead and overshooting the crews camped at the lead edge further north. Barrow reached its quota on May 25 and the ice broke out again on May 28 at approximately the same location as on March 31. Figure 9.9 shows the area of shorefast ice present between these break-out events. Also shown in this figure are the trails that traversed this region and a radar image from the March 31 break-out as recorded by the Observatory's coastal radar.

Barrow whaler Joe Leavitt, along with elders Arnold Brower, Sr., and Wesley Aiken, observed that this first-year ice was held in place by only a few "key" ridges and that favorable conditions allowed the community to successfully whale in this area. Except for between May 7 and 13, the wind throughout the season (see Fig. 9.10) allowed the lead to remain open and prevented pack ice from colliding with the shorefast ice. Prior to the May 28 break-out, however, the trails in

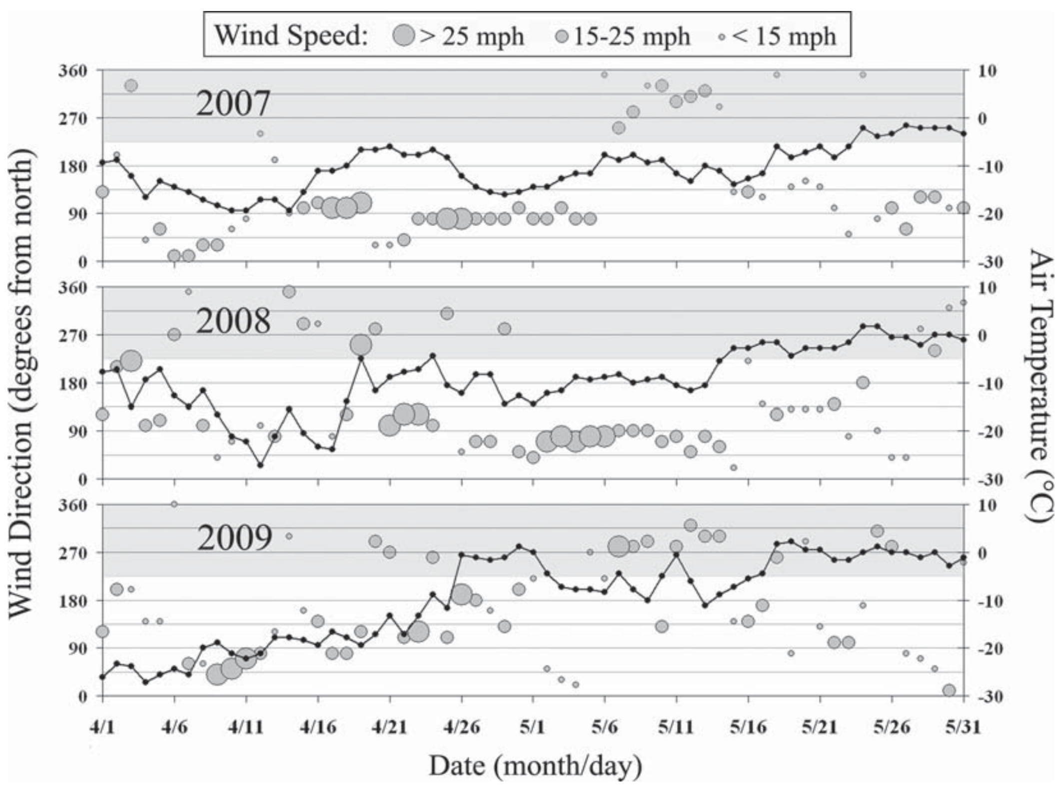

Fig. 9.10 Winds and air temperature during the 2007, 2008, and 2009 whaling seasons. Wind direction and speed (maximum 2-min readings) and air temperature (daily averages) are denoted by the *gray circles* and *solid lines*, respectively. The *shaded* regions span the wind directions (southwest to north) that tend to close the lead. Data were recorded at the Post-Rogers Memorial Airport and accessed from the National Climate Data Center

the south were worn dangerously thin by large amounts of snowmobile traffic and previously refrozen cracks began to open, which may have significantly contributed to the second break-out (Druckenmiller et al. 2009). After the trails in the south deteriorated some crews moved to the trails in the north to take advantage of safe ice conditions persisting later into May.

2008: Whaling in the North Long After Southern Trails Deteriorate

During the 2007–2008 ice year, stormy conditions during the period when ice moved in and stabilized along the coast contributed to a rough shorefast ice cover composed of highly deformed thin first-year ice. In some areas, ridges were exceptionally close to the beach due to the high winds driving these ridges near shore. This was particularly evident off Nunavaq, where some ice had even blown up onto the beach. Whaling captain Harry Brower, Jr., explained that there was a repeated sequence of ridge building followed by ice coming in to add on that contributed to a rough but stable ice cover. Brower decided to place his trail off Nunavaq (see Fig. 9.11) because the ice off NARL was too rough.

Cold conditions in early April helped to provide stable shorefast ice at the start of whaling. Similar to 2007, but in stark contrast to 2009, 2008 experienced a dominating east wind that kept the lead open (see Fig. 9.10). Most crews encountered good conditions in late April and early May allowing Barrow to catch a lot of whales during this period. The first whale was landed by Eugene Brower's Aalaak Crew on April 26. However, while the east wind tended to keep the lead open, it also presented a hazard – crews pulled off the ice when winds approached 25 mph believing that such an offshore wind can drop the water level and lead to a break-out as floating ice cracks away from grounded ridges.

Whaling captain Tom Brower III reported that in the first week of April a late-season snowfall, which contrasts with a more firmly packed winter snowfall, led to hazardous conditions. First, the fresh snow served as an insulating layer allowing the warm currents to more efficiently melt the thin ice from below. Later in May, when air temperatures increased, the snow quickly melted, which then in turn accelerated surface ablation through enhanced solar heating. Crews that were unable to land whales earlier in the season concentrated at the trails north of Browerville as those to the south became dangerous with areas worn thin from snowmobile traffic and warm water. Brower reported having to abandon their trail off Napauraq in early May only after a few days of heavy use.

Figure 9.11 shows the 2008 trails and where ice thickness measurements were made during the season. While these data are useful from the standpoint of tracking long-term trends in the thickness distribution of shorefast ice, it also assists in understanding how different types of ice are used by the community. For example, Fig. 9.12 shows the cross-sectional thickness profiles from two trails. The thin ice at the end of Jacob Adams Crew's trail was chosen for a camp since it was identified as flat ice where whales would be swimming beneath (see Fig. 9.4 and related discussion) and surfacing at the edge. Their crew, among many others, decided this

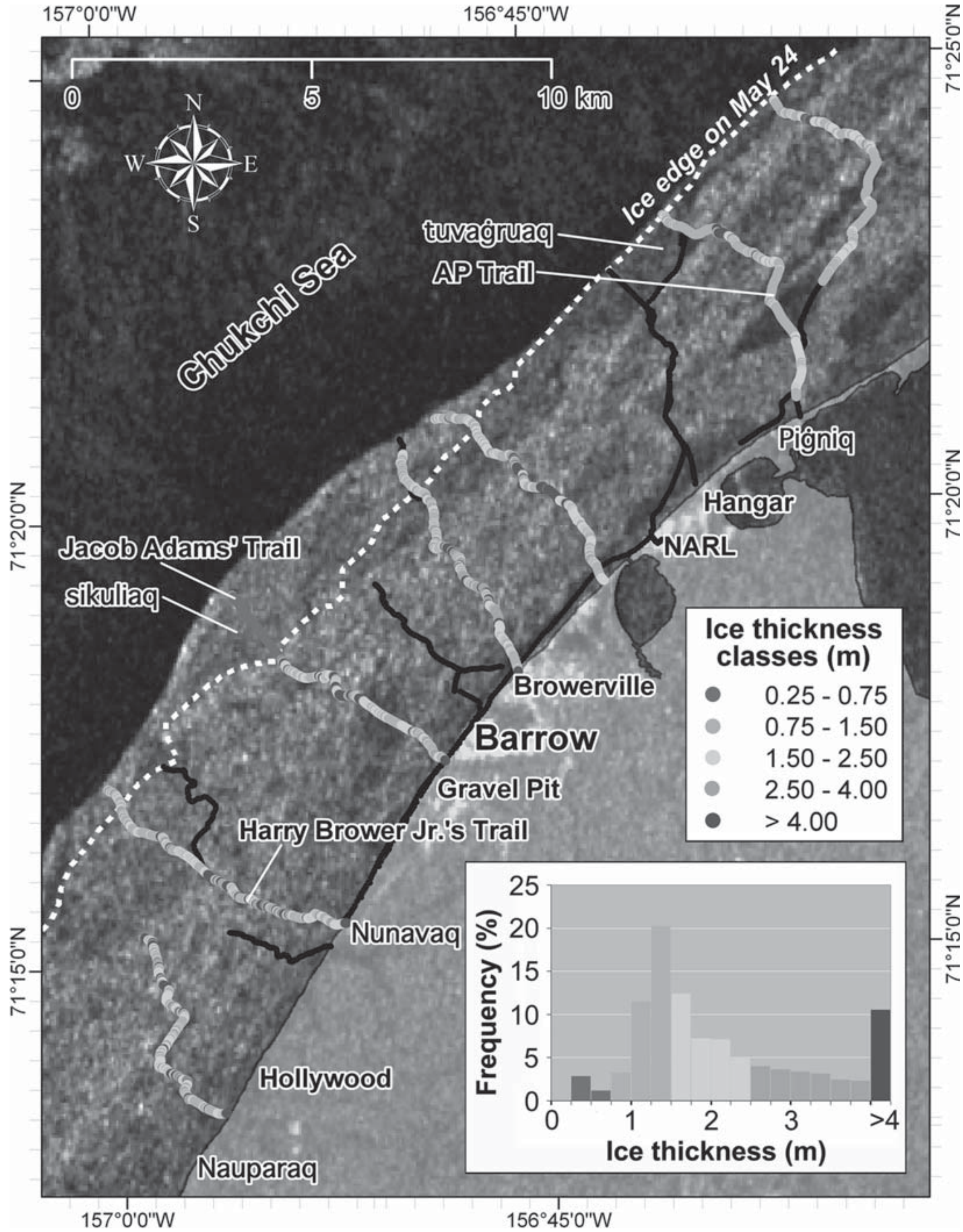

Fig. 9.11 Map of the 2008 whaling trails. Trails are shown here with ice thickness data overlaid on select trails where measurements were made. The two trails south of Nunavaq were not fully mapped since they were incomplete at the time of mapping in early to mid-April. The trail off Barrow was abandoned before making it to the ice edge. The SAR image, acquired by the RADARSAT-1 satellite and provided by the Canadian Space Agency and C.E. Tweedie and A.G. Gaylord, is from April 5, 2008. (See also Color Plate 6 on page 475)

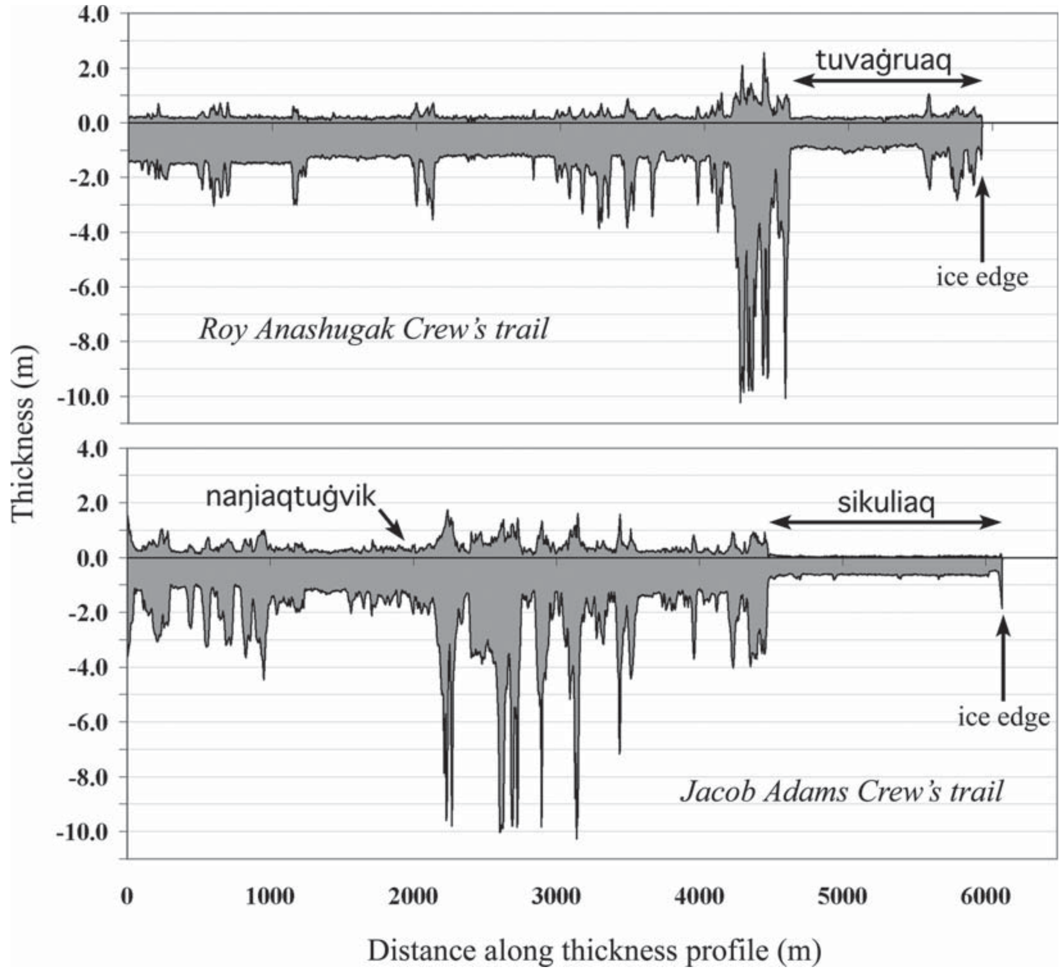

Fig. 9.12 Cross-sectional ice thickness profiles along two different whaling trails. The 2008 trails of Roy Anashugak Crew and Jacob Adams Crew were measured on April 5 and 7, respectively (see Fig. 9.11). Labeled features are based on interviews with Jacob Adams, Herman Ahsoak, and Gordon Brower. The level ice in the zones labeled "*tuvaġruaq*" and "*sikuliaq*" had average thicknesses of 1.0 and 0.5 m, respectively. The location of the *naŋiaqtuġvik*, or "safe camp," is shown for Adams' trail but was not documented for Anashugak's trail. Differential GPS was used to survey the surface elevation and an EM-31 conductivity meter was used to measure ice thickness. True thickness is the total thickness of ice above and below the water line, which is at zero. The proportionality between the *x* and *y* axes is such that the thickness is emphasized. Ridge thicknesses over 4 m are underestimated by up to 30% due to instrument limitations (Haas 2003)

sikuliaq (young ice formed along the edge of solid ice) was a good place for a camp. However, they reported having to retreat to their *naŋiaqtuġvik* (safe camp; labeled in Fig. 9.12) multiple times when the west wind brought in the pack ice and when the strong east wind threatened to drop sea level and break the extended floating ice from the grounded ice. Significant portions of this *sikuliaq* broke off following impact with pack ice brought in with the west wind on April 25. However, the ice remained safe and allowed several crews to stay camped there. Adams landed a 9 m (30 ft) whale on May 7, just before the remainder of the *sikuliaq* broke out. Adams noted that such ice is suitable for pulling up a whale approaching 12 m (40 ft) in length, but would not be sufficient for a whale of 15 m (50 ft).

By mid-May, crews abandoned Adams' trail since newly deformed rough ice at the edge prevented easy access to open water. As previously mentioned, many crews moved to the trails north of Browerville. Older, thicker, and more stable flat ice (*tuvaġrauq*) near the edge allowed crews to easily connect these trails together near the lead (beyond the last row of ridges) with secondary trails (not shown in Fig. 9.11). This enabled hunters to travel between camps without the need to come a long way back toward shore in order to get on another trail. Also, connected trails always provide more numerous escape options in the case of dangerous conditions. Unlike the *sikuliaq* further to the South this *tuvaġrauq* remained in place into late May, beyond the end of the whaling season.

2009: West Wind Leads to Unsuitable Ice Edge Conditions

The shorefast ice of 2009 was representative of typical ice conditions in recent years with a few noteworthy differences, which are discussed later in this section. Off NARL and Browerville the shorefast ice was heavily ridged and deformed with few areas of level ice. Despite the near-absence of larger pieces of old ice, it was very stable all the way to the last major row of ridges at about 3 km offshore. The few scattered pieces of *piqaluyuk* were landward of already well-grounded ice, providing little service to the crews, other than as a source of drinking water. The last row of grounded ridges was separated by a system of cracks from the outermost floating ice. The ice off Gravel Pit had formed in place and was very flat and thin yet with no noticeable cracks. Due to the lack of anchored ice, except for a few ridges close to shore, the crews in this area were extremely cautious of any drift ice that approached. The conditions off Hollywood were similar to those off Gravel Pit – flat ice that had mostly formed in place – although many hunters indicated that it was more firmly grounded. In this area, notable cracks developed later in the season. The ice off Monument formed a large promontory of shorefast ice (*nuvuġaqpuk*) that extended approximately 11 km offshore (see Fig. 9.13). The distance required to reach the edge was one reason crews may have decided against hunting in this area, but perhaps the more important reason is that most believed this promontory of ice would eventually collide with pack ice and break away. However, surprisingly, the *nuvuġaqpuk* remained throughout the entire whaling season.

Despite stable conditions along the general extent of the shorefast ice, the pack ice, winds, and currents never cooperated to make the ice edge suitable for whaling. Tuuq is when the pack ice collides with the shorefast ice edge and acts as a chisel (George et al. 2004). While such events surely present danger to crews camped at the edge, they are also relied on by hunters to "fix-up" the ice – to thicken thin ice through deformation and to rid the edge of dangerous attachments (*iiguat*). An ideal sequence of events would involve heavy pack ice coming in to "fix-up" the ice, driven by the wind and/or current in such a manner that hunters are able to foresee

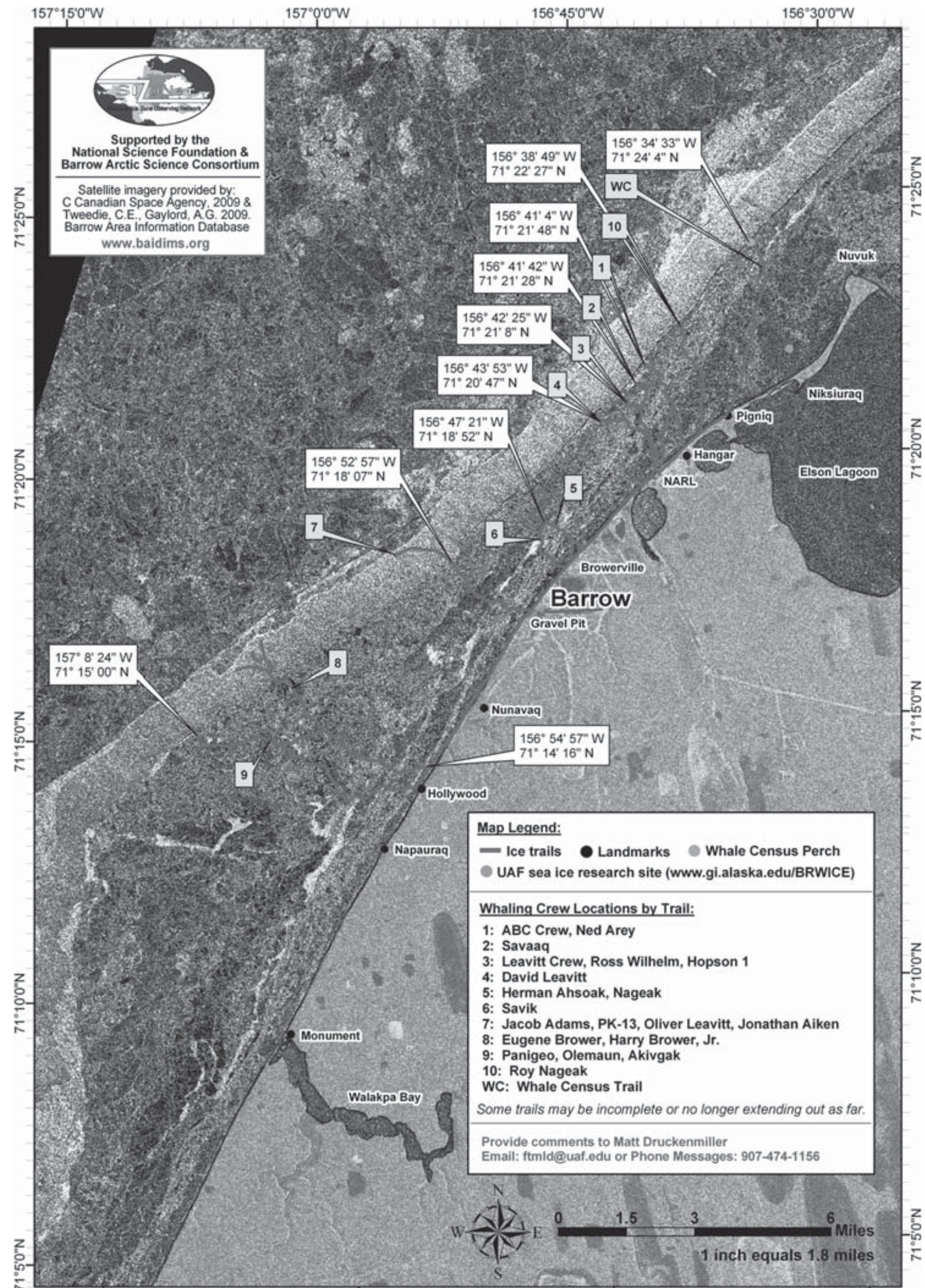

Fig. 9.13 Map of the 2009 whaling trails. This exact map was provided to the community during the whaling season. The SAR image, acquired by the European Remote Sensing satellite ERS-2 and provided by the Canadian Space Agency and C.E. Tweedie and A.G. Gaylord, is from May 16, 2009, just prior to the opening of the lead shown in Fig. 9.1. Various GPS locations are labeled to assist with navigation. Locations are also shown for the camp of the 2009 bowhead whale census orchestrated by the North Slope Borough's Department of Wildlife Management and of our sea ice mass balance site that measured level ice growth and other variables of interest. (See also Color Plate 7 on page 476)

the event and pull off the ice. Next, the lead would open to reveal ice edge conditions suitable for safely hauling up a whale.

Beginning on April 20, just as most crews were finishing their trails, the west wind arrived and dominated throughout the remainder of the whaling season (see Fig. 9.10). The wind-driven pack ice either formed *iiguat* or on occasion built up a moving one-story high wall of slush ice (*muġaliq*) along the edge. Especially for the crews off NARL, *iiguat* persisted and when one broke off another formed. Gordon Brower recalled that in late April his crew was fortunate to be camped on *tuvaġruaq* for a few days but that the area was still considered unsafe since it was only connected to the grounded ice by thin young ice. Many hunters described 2009 as a "waiting game" – waiting for the lead to open or for edge conditions to improve. Most were only camped at the edge for 1 or 2 days and were prepared to run at a moment's notice. Some hunters never even brought their boats onto the ice.

The year 2009 was also difficult since the *muġaliq* incorporated within the shorefast ice never froze solid. Potentially thawing temperatures arrived on April 26, followed by a refreeze and then another thaw later on May 18. Warm weather and the arrival of warm water (as suggested from interviews with the hunters) led to a quick deterioration of trails and cracks, and in particular to those south of *Nunavaq*. This sequence of events made the conditions in the South very unsafe. Some crews pulled off the ice as early as May 12 due to these unsafe conditions, but also because the larger whales were beginning to move through. Similar to 2007 and 2008, the trails off NARL and northward remained intact longer than those to the south.

On May 16 a southeast wind opened the lead for a short time (see Figs. 9.1 and 9.10) and in the early hours of May 17, ABC Crew (Arnold Brower, Sr., Crew) landed an 8 m *ingutuk* from trail number one (see Fig. 9.13) and was able to find a pan of *tuvaġruaq* to successfully haul up the whale. Three other crews caught whales before May 23 but experienced great difficulty in finding a suitable place to butcher because of *muġaliq* at the edge. One whale was struck and butchered at trail one and two were struck from the trails off Hollywood. Of these latter two, one was hauled to trail seven and the other to trail four in hopes of finding ice that would support the weight of the whales and also because the trails off Hollywood were not safe enough to permit safe passage for the large number of people required to butcher a whale. Each attempt failed and as the whales were pulled onto the ice, they would immediately break through. In all three cases they had to cut off the heads of the whales (1/3 of the whale's body) in the water and anchor it to the ice edge. These poor butchering conditions unfortunately did not allow the crews to retrieve the entirety of the whale meat, and in one case they were only able to collect the skin and blubber (*muktuk*). Joe Leavitt stated that if heavier ice conditions had existed in 2009 butchering all four whales would not have been a problem.

To some members of the community the success of the whale hunt is more than just about climate and ice conditions; it is connected to the well-being of the people. Roy Ahmaogak, for instance, said, "One of the most heartbreaking things about this year was that we weren't given the opportunity to practice traditional whaling because of the ice. Barrow and its people have been feuding and bickering at each other all this last winter. This is the reason we think the ice didn't go out this year and it stayed closed. This will make us think this coming year that we have to watch our tongue and to watch what we say to people. We are lucky to have two blanket tosses this year. It will teach Barrow and people like us." In the end, Barrow joyously celebrated the four caught whales during two *Nalukatak*. Barrow then set their sights on the non-traditional fall bowhead hunt, which is done in open water with outboard engines and aluminum boats.

Discussion

The initial placement of ice trails is largely in response to ice conditions, traditional practices, and crew preference; however, there seems to be a pattern of the trails to the south having to be abandoned earlier in the season due to the ice deteriorating, causing the crews to concentrate at the trails north of town. This is in contrast to that which Arnold Brower, Sr., explained regarding how crews in the past typically moved south later in the season as currents intensified and conditions in the north became dangerous. This raises the question of whether climate and environmental change are impacting how the community uses the ice cover. The seasonal summaries presented here span a 3-year period and accordingly can only present a brief look at how present climate and ice conditions impact spring whaling.

Changes in shorefast ice characteristics are much more complicated than the obvious reduction in the presence of multi-year ice. During our conversations, Arnold Brower, Sr., and Tom Brower III both noted that shorefast ice prior to the 1980s extended much further out, was flatter, and was composed of thicker level ice than today. While detailed analysis of how shorefast ice characteristics have changed over time is beyond the scope of this chapter, it is clear that changes are taking place that present a new assortment of challenges for the whaling community. If hunters continue struggling to find sufficiently grounded and stable ice, such as the *tuvaġruaq* experienced in 2008, they may increasingly have to deal with the problems encountered in 2007 and 2009 – early spring break-out events close to shore and ice edge conditions that are not suitable for pulling up a whale.

The presence of *muġaliq* dominated the observations of hunters in 2009. This slush ice, which forms through shear at any time throughout winter or spring, represents a type of ice that lacks the drainage of salt water that typical thermodynamic ice production promotes, thus rendering it potentially unstable and responsive to slight changes in temperature. Hunters acknowledged that this ice is common but that 2009 was remarkable because it was so widespread and air temperatures did not allow for this ice to retain its integrity late into the season. Coupling this phenomenon with an understanding that advection of warm water can lead to the destabilization of shorefast ice by melting grounded ridge keels (Mahoney et al. 2007b) and refrozen cracks reveals that shorefast ice as a stable platform for hunting and travel is closely linked not only to climate change but also to weather and oceanographic variability.

Lastly, the summary of how the crews responded to ice conditions during these 3 years begs the important question of whether there is a clear and distinguishable local zonation of ice conditions along Barrow's coastline. This topic, worthy of further investigation, may underscore the fact that Barrow's ice environment allows for understanding not only how ice conditions respond to climate but also to subtleties in local and regional conditions, such as bathymetry and coastal currents. This may present an opportunity for scientists to further discover the local expert sea ice knowledge found in Barrow, which likely possesses an intricate understanding of the processes that may govern a local zonation of conditions and further lead to improved scientific monitoring that is relevant to the community's activities on ice.

Conclusions

The Barrow community continues to practice successful traditional spring whaling from shorefast ice while making observations that lend a new perspective to understanding processes that dominate the present-day coastal sea ice environment. Hunters assess shorefast ice in a highly specialized manner as they consider safety, navigation, hunting strategies, and traditional knowledge and practices. Detailed characteristics of year-to-year ice conditions, which are unobservable by standard scientific monitoring programs, manifest in impacts to the whaling community. Utilizing the collaborative and experiential (as opposed to experimental) approach presented here – a type of ethnoglaciology – we are working toward an improved understanding of how to observe the local environment in a manner to track changes important to both climate study and the community. This research may ideally begin to illustrate how strategic adaptations in the way the community uses the shorefast ice are indicative of and responsive to environmental change.

Mapping Barrow's ice trails allows us to piece together how ice characteristics spatially and temporally relate to the community's use of the ice. These maps are providing a valuable product to the community while also serving as a useful reference tool for scientists and hunters to communicate across barriers of culture and experience. It is our hope that this project continues as a long-term monitoring effort to unite advanced scientific instrumentation and expertise, traditional knowledge, and ice use by a modern arctic whaling community.

Acknowledgments This research was made possible with the assistance of several experienced Iñupiat whalers: Billy Adams, Jacob Adams, Roy Ahmaogak, Herman Ahsoak, Arnold Brower, Sr., Eugene Brower, Gordon Brower, Harry Brower, Jr., Lewis Brower, Tom Brower III, Jeffrey Leavitt, Joe Leavitt, Warren Matumeak, Ben Nageak, Nate Olemaun, and Crawford Patkotak. Thanks to Ronald Brower Sr., for reveiewing the use of Iñupiaq terminology. We would like to also thank the North Slope Borough Department of Wildlife Management, Barrow Arctic Science Consortium, Barrow Whaling Captains Association, and Allison Gaylord and the Barrow Area Information Database. This publication is the result in part of research conducted as part of the Seasonal Ice Zone Observing Network with financial support from the National Science Foundation (OPP-0632398), the Oil Spill Recovery Institute, and the Cooperative Institute for Arctic Research (Project CIPY-34) with funds from the National Oceanic and Atmospheric Administration (cooperative agreement NA17RJ1224 with the University of Alaska).

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