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Evaluating the Effects of Climate Change on Indigenous Marine Mammal Hunting in Northern and Western Alaska Using Traditional Knowledge

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Iñupiaq, Yup'ik, and Cup'ik hunters in 14 Alaska Native communities described a rapidly changing marine environment in qualitative traditional knowledge interviews conducted over the course of a decade with 110 individuals. Based on their observations, sea ice conditions are the most notable change, with later freeze-up, thinner and less reliable ice, and earlier and more rapid break-up. Marine mammal populations in northern and western Alaska have been affected by changes in the physical environment, with alterations to migratory timing and routes, distribution, abundance, health, and behavior. Despite these changes, marine mammal populations in the region remain generally healthy and abundant. For hunters, access is the biggest challenge posed by changing conditions. Sea ice is less safe for travel, particularly for more southerly communities, making hunting more dangerous or impossible. Rapid break-up has reduced the time available for hunting amid broken ice in spring, formerly a dependable and preferred season. Social change also affects the ways in which hunting patterns change. Increased industrial development, for example, can also alter marine mammal distribution and reduce hunting opportunity. Reduced use of animal skins for clothing and other purposes has reduced demand. More powerful and reliable engines make day trips easier, reducing the time spent camping. An essential component of adjustment and adaptation to changing conditions is the retention of traditional values and the acquisition of new information to supplement traditional knowledge. Our findings are consistent with, and add detail to, what is known from previous traditional knowledge and scientific studies. The ways in which hunters gather new information and incorporate it into their existing understanding of the marine environment deserves further attention, both as a means of monitoring change and as a key aspect of adaptation. While the changes to date have been largely manageable, future prospects are unclear, as the effects of climate change are expected to continue in the region, and ecological change may accelerate. Social and regulatory change will continue to play a role in fostering or constraining the ability of hunters to adapt to the effects of climate change.

Keywords: climate change, sea ice, marine mammals, alaska natives, traditional knowledge, arctic, subsistence

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INTRODUCTION

Arctic sea ice is changing rapidly (Perovich et al., 2016), with far reaching effects on Arctic indigenous hunters. The summer retreat of sea ice is one of the most visible signs of climate change on Earth. The effects are far-reaching. Within the Arctic, loss of sea ice is changing patterns of water temperature, stratification, primary productivity, and distribution and abundance of fishes, seabirds, and marine mammals (Huntington et al., 2015). Changes in sea ice are not limited to summer. Sea ice is forming later in fall, more open water can be found in winter, thickness has decreased and there is less multi-year ice, spring melt occurs earlier, and broken ice disappears more quickly than in the past (e.g., Kwok et al., 2009; Walsh, 2013; Perovich et al., 2016). These and related observations have been made by satellites, field studies, and indigenous peoples of the Arctic coasts (e.g., Gearheard et al., 2013; Johnson et al., 2015; Perovich et al., 2016).

For Arctic marine mammals, changes in sea ice may have extensive effects. Ice-adapted seals rely on ice for nursing pups; seals and walruses (*Odobenus rosmarus*) use ice as a platform for resting (Burns, 1970). Bowhead (*Balaena mysticetus*) and beluga whales (*Delphinapterus leucas*) live in ice-covered waters, which may provide refuge from predators and competitors (Nerini et al., 1984). Polar bears (*Ursus maritimus*) spend most of their lives on sea ice, hunting their primary prey of ringed seals (*Pusa hispida*) (Smith, 1980). With less ice, these species must adjust or their populations may decline (Laidre et al., 2015). At the same time, less ice opens the Arctic to greater use by species that are less ice adapted, such as humpback (*Megaptera novaeangliae*), fin (*Balaenoptera physalus*), and killer whales (*Orcinus orca*) (Moore and Huntington, 2008). The impacts of climate change on Arctic marine mammals have not caused documented population declines to date, and highly ice adapted species, such as bowhead whales and ringed seals have responded positively (Crawford et al., 2015; George et al., 2015).

For indigenous hunters of marine mammals in Arctic Alaska, changes in sea ice affect the ability to travel to hunting areas, the safety of traveling and hunting, and the duration of the hunting period (e.g., Noongwook et al., 2007; Kapsch et al., 2010; Fienup-Riordan et al., 2013). The effects on marine mammals may further compromise hunting success, if animals are less abundant or less available, if body condition worsens, or if novel diseases and parasites begin to affect the hunted species (Hovelsrud et al., 2008; Gadamus, 2013; Huntington et al., 2016). Not all changes are negative, however. As one example, later fall freeze-up has allowed whalers on St. Lawrence Island in the northern Bering Sea to develop a fall bowhead hunt to compensate for poor spring hunting conditions during their traditional spring hunt (Noongwook et al., 2007).

There is reason for concern about the future well-being of Arctic marine mammals (e.g., Laidre et al., 2015) and their continued availability to indigenous hunters (e.g., Huntington et al., 2016). Projections of sea ice extent show a continued rapid decline of summer sea ice, leading to warmer waters in summer and fall, later freeze-up in fall, and thinner ice in winter (Jefferies et al., 2013; Wood et al., 2015). While many Arctic marine mammals and many hunters display adaptability and resilience to change (Cochran et al., 2013), it is likely that ecological changes will continue in the wake of physical changes, with long-term consequences that are unlikely to be beneficial to species and hunting practices adapted to cold and ice.

With this background, our research has focused on the traditional knowledge held by marine mammal hunters on the western and northern coasts of Alaska. That knowledge is the product of long-term observations by individual hunters and lessons passed down through generations, resulting in a deep understanding of the local environment, the connections that characterize the ecosystem, and the relationship between hunters and animals (e.g., Kawagley, 1995; Berkes, 1999). The information provided by traditional knowledge holders is a valuable complement to what is learned by standard scientific studies, such as satellite telemetry, biomonitoring, abundance surveys, and the like (e.g., Huntington et al., 2004). Furthermore, hunters can describe the climate-related changes they see, how those changes affect the animals they hunt and their own ability to hunt, and if and how the hunters have been able to respond to changing conditions thus far.

In this paper, we present the results of a decade of interviews with Iñupiaq, Yup'ik, and Cup'ik hunters from Kaktovik to Mekoryuk, Alaska. An earlier paper (Huntington et al., 2016) presented briefly our results concerning the effects of sea ice loss on marine mammals. Here, we expand on those findings to set the biophysical context and then explore in greater detail than previously the impacts to hunters and hunting. This paper draws on the same material as the previous paper with additional interviews from three more villages. This information is geographically extensive and has been compiled over many years, offering a rare case of temporally deep and spatially broad coverage of hunting activity in relation to environmental conditions in Alaska.

METHODS AND MATERIALS

Semi-Directive Interviews

We conducted interviews with 110 residents of 14 communities, starting in 2007 and with the most recent in January 2017 (see **Table 1**, **Figure 1**). In two communities (Wainwright and Utqiaġvik, formerly known as Barrow), we conducted interviews on two occasions, focusing on different species. In neither case was anyone interviewed on both occasions. We interviewed hunters from the adjacent villages of Stebbins and St. Michael together. The interviews have been part of three different projects, focusing on bowhead whales, walrus, and ice seals, but in all cases, hunters often spoke about species and phenomena other than the target species of the interview.

The number of participants from a given village ranged from 5 to 13. We found, consistent with others (e.g., Voorhees et al., 2014), that little new, additional information arose after five or six interviews, and thus that five or six interviews were sufficient. Villages in which we interviewed more individuals were those in which we conducted group interviews in addition to or instead of individual interviews (see below). The participants ranged in age from mid-20s to over 80 years old, with most

TABLE 1 | Summary of community research effort.

Community	Year	Species focus	No. of Participants
Kaktovik	2007	Bowhead whales	6
Utqiaġvik	2007	Bowhead whales	6
Wainwright	2008	Bowhead whales	7
Point lay	2011	Walrus	5
Wainwright	2011	Walrus	13
Point hope	2013	Walrus	8
Utqiaġvik	2015	Walrus and ice seals	10
Elim	2015	Ice seals and walrus	8
St. Michael and stebbins	2015	Ice seals and walrus	8
Kivalina	2016	Ice seals, walrus, bowhead whales	5
Kotzebue	2016	Ice seals	6
Shishmaref	2016	Ice seals and walrus	5
Hooper bay	2017	Ice seals, walrus, beluga whales	11
Scammon bay	2017	Ice seals, walrus, beluga whales	5
Mekoryuk	2017	Ice seals, walrus	7
Total: 14 villages, 15 research visits	Work in 7 years in 11-year period	Focus on 7 species	110 participants overall

being active, middle-aged individuals. We found that local leaders and residents tended to suggest elders when asked for suggestions for interviewees for a "traditional knowledge project." If instead we asked about active hunters, we received suggestions for individuals from their 20s to their 60s. When we asked individuals if they would be willing to be interviewed, many younger hunters were reluctant to speak to "traditional knowledge" in deference to elders, but were willing to talk if we emphasized our interest in their own experiences.

The interviews followed the semi-directive method (Huntington, 1998, 2000), in which the interviewers have a list of topics to be covered (**Table 2**), but the person being interviewed can pursue his or her own lines of thought and connections among topics. The interview is thus more of a conversation, rather than a questionnaire or otherwise structured process. One advantage of this approach is that is leaves open the possibility of topics and connections that the interviewer did not anticipate, allowing the person being interviewed to describe the ecosystem, the species, and the activities in ways that make sense to him or her and not according to a predetermined notion of how the components of the system interact.

The interviews were conducted with individuals and with groups ranging from 2 to 13 persons. Individual interviews allow more time and interaction with the individual, whereas group interviews allow those being interviewed to spur each other's memories or otherwise stimulate more extensive discussion than might occur with only the visiting researchers. In group interviews, however, it is also possible that younger hunters defer to older ones rather than contradict or appear to know more than their elders. Personal conflicts may also arise, stifling discussion or sharing of information, so social dynamics must be managed in group interviews.

During the interviews, the researchers took notes by hand, many of which were on maps of the region, from which they drafted reports detailing the cumulative observations made by those being interviewed. In rare instances where individuals reported contradictory observations, we noted the discrepancy in the draft report and specifically requested clarification from the individuals when they reviewed the draft. The draft reports were sent by mail to the participants, with a postage-paid return envelope, to provide the opportunity to correct, expand upon, or otherwise comment upon the reports. We received some corrections and changes in this way. If any discrepancies or disagreements remained at this stage, we included both observations or comments in the final report, noting the disagreement among individuals. After the comments and corrections had been addressed, we issued a final report, which are all available on the Alaska Department of Fish and Game website (http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.traditionalknowledgereports).

Ethical Considerations

The Alaska Department of Fish and Game, under whose auspices the research was conducted, does not have a human subjects research review committee nor a requirement for such review. Nonetheless, we sought to follow the spirit of the ethical requirements appropriate to research of this kind. Prior to the fieldwork, the research project was presented to and approved by the Alaska Eskimo Whaling Commission and the Eskimo Walrus Commission, two Alaska Native led organizations that co-manage marine mammals. We wanted to be sure that the research was indeed worth doing and would add to the available information concerning marine mammals in Alaska, as justification for asking for the time and expertise of the individuals we interviewed. Both commissions agreed that the project was worthwhile, to complement information being generated by other means, such as aerial surveys and satellite telemetry, which have their own limitations.

We did not expect the commissions to be expert in the specific topic of research ethics, so did not limit our efforts to obtaining their support. The lead author has had training in the ethical conduct of human subjects research and has been involved in university-led projects that have included review by human subjects research boards, so he applied his experiences to our research, too. In recognition of the intellectual property rights of the interview participants, free, prior, and informed consent (United Nations, 2007) was obtained from all individuals who were interviewed. The project was explained to each individual, their questions were answered to the best of our ability, and the interview proceeded only when the individual was satisfied. There is a conflict between respecting an individual's privacy and giving him or her credit for his or her work and knowledge. We let each interviewee choose whether to be mentioned by name in the reports. In no cases were any individuals associated with any specific observations, comments, or interpretations in the reports, and no direct quotes were used. We also avoided asking questions that concerned personal information (e.g., the

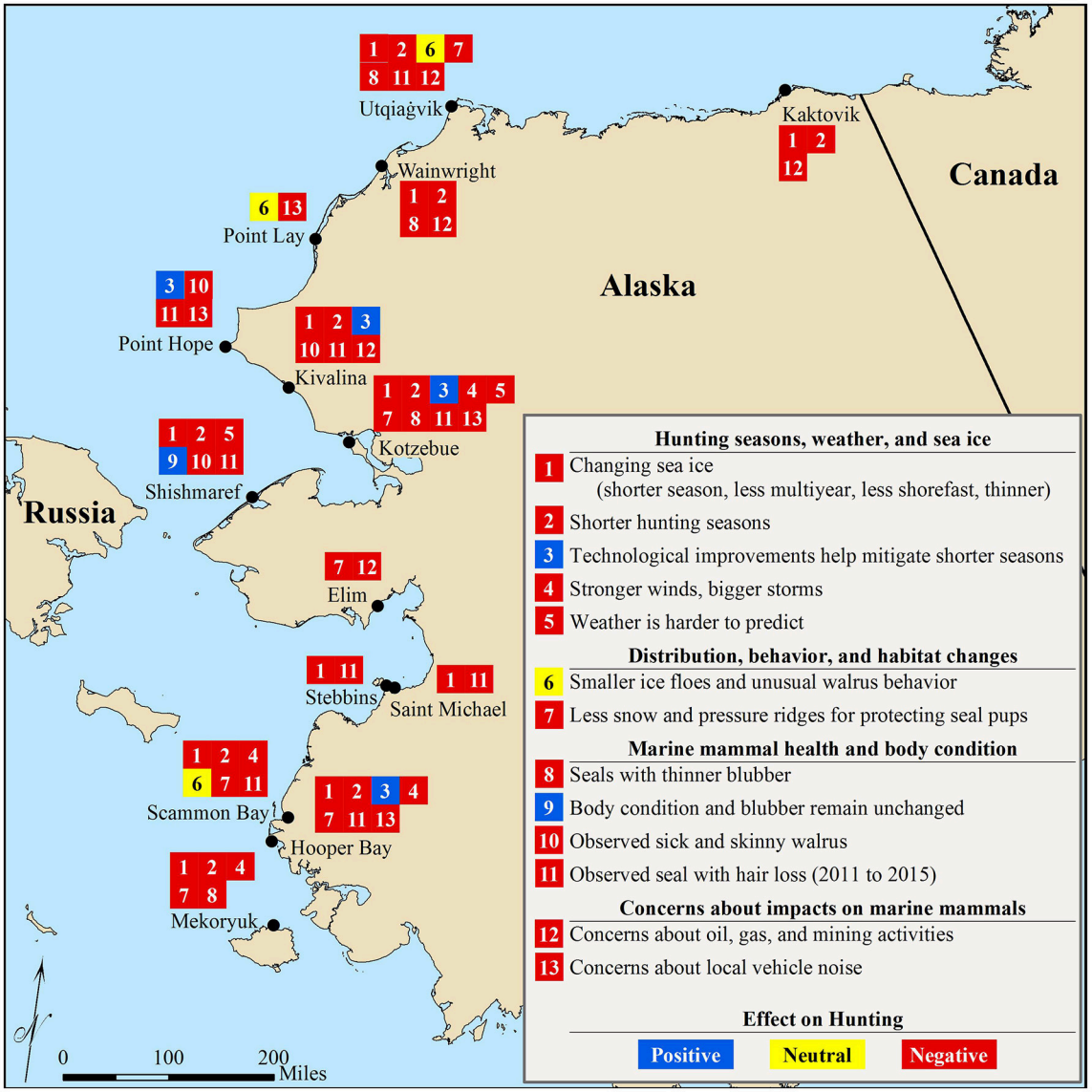

FIGURE 1 | Common observations from traditional knowledge interviews in 14 communities across Alaska from 2007 to 2017.

TABLE 2 | Example of the list of topics the researchers sought to address in the interviews. This list is from the interviews in Hooper Bay in January 2017.

Seasonal patterns of distribution of ice seals, walruses, and beluga whales
Haulouts on land (seals and walrus)
Use of rivers by seals
Feeding patterns and prey for all marine mammal species
Impacts from climate change and hunter responses to those changes
Parts of marine mammals that people eat
Information about other marine mammals
Information about other aspects of the environment and people

The lists for other communities were similar, with variations depending on the species of interest and local conditions and geography.

number of animals a hunter had taken, or the specifics of preferred hunting methods), and avoided writing down any such information that interviewees provided of their own accord.

As has become the standard practice for this kind of research in Alaska, the persons being interviewed were paid $150 for their time participating in the initial interview, and another $100 for reviewing the draft report and replying with corrections or with approval for the report as drafted. The payment was a lump sum, not contingent upon the amount of time spent in the interview nor on any judgment by the researchers about the quality of the interview or the cooperation of the interviewee. If an individual appeared reluctant to be interviewed, we attempted to address his or her concerns first, and were willing to take no for an answer

in preference to using the offer of payment as an inducement to agree to participate. Naturally, in small communities the information that we were paying people to be interviewed was not a secret, but no one volunteered to be interviewed or approached us before we approached them. We believe therefore that the payments were an appropriate recognition of an individual's contribution to the study, rather than an ulterior motive for participants.

Acquiring and Transmitting Traditional Knowledge

A description of methods would be incomplete without addressing the ways in which traditional knowledge is originally acquired and transmitted. This process has been described, for example, by Noongwook et al. (2007), who note that traditional knowledge is gained by experience, transmitted to others by stories and example, and continually tested and refined against new observations. While traditional knowledge contains extensive and detailed information about the habits, behaviors, and patterns of animals as well as conditions of water, ice, and weather, it places great emphasis on the safety of those traveling and hunting. Partly for this reason, traditional stories often emphasize the unusual, so that hunters will recognize the anomalous situation and be ready to respond appropriately. Noongwook et al. noted the persistence of traditional knowledge and the commitment to accuracy by recounting the resumption of whaling at the traditional site of Pugughileq by residents of Savoonga, Alaska, after a hiatus of several decades. The knowledge that had been passed down, now out of living memory, remained the basis for the safe and successful resumption of this activity in that site.

RESULTS

The interviews were conducted as part of three separate projects, with the common theme of marine mammals, but different foci at different times and in different communities. The results thus do not consistently cover the same topic in every community or for every species. There is, however, sufficient overlap for a regional picture to emerge from the community-specific observations (**Figure 1**). **Figures 2–5** are provided as examples of the detailed information collected at selected communities (Utqiaġvik, Shishmaref, Elim, and Scammon Bay) from different regions of the study area. Where relevant, we note which observations came from which community.

The years in which the interviews were conducted is shown in **Table 1**. The span of a decade means that many changes reported in more recent interviews have occurred since the earliest interviews were done. Given the pace of change in the region, it is likely that some of the earlier information is now out of date. We do not have repeat visits to the same communities on the same topics to allow for direct comparisons over time. Nonetheless, even the earliest interviews described changes to the physical and biological environment and consequently to hunting practices, providing insight into the impacts of climate change on marine mammal hunters in northern and western Alaska.

Physical Changes

The dominant physical change reported by hunters has been related to sea ice. Sea ice forms later in fall, is thinner and less reliable during the winter, breaks up earlier in spring, and is scarce or absent throughout the summer. Most of those interviewed said that the greatest impacts to hunting have come from changes to sea ice, as described further in the section Changes in Hunting. Here, we present the changes to the physical environment observed by hunters, beginning with sea ice.

Sea Ice

The timing and patterns of freeze-up has changed in several ways. In Utqiaġvik, multi-year ice (i.e., ice that formed one or more winter previously and did not melt in the subsequent summer) used to arrive in October, when the sea started to freeze. Now, multi-year ice is rarely seen and freeze-up happens later, with little or no shorefast ice into November. Wainwright hunters report a similar pattern, with ice now forming as late as December or even after Christmas, further noting that the absence of multi-year ice leaves no anchors to hold the young ice in place, with the result that the thinner ice is carried away whenever the water rises. The lack of stability means the ice does not grow thick over the winter. In January 2016, there was still open water along the beach at Kotzebue, when the ice should have been solid. Shishmaref hunters said that the ocean usually freezes by November, but in the fall of 2015, there was open water until Christmas. In Stebbins in the winter of 2014–15, the ice did not freeze until December, and went out soon after that when it was only a few inches thick. In Mekoryuk, those interviewed noted that the Cup'ik names for the months of the year, which describe what is happening in the environment, no longer reflect the actual timing of events. November was known as the time that sea ice covers the ocean, but freeze-up occurs later now.

Once the ice has formed, Kotzebue hunters say that it is thinner and that this trend appears to be continuing. In 2015, the ice did not stay for good until March. Shorefast ice used to form in fall and stay until June, but this is no longer the case. The ice used to remain in place inside Kotzebue Sound, with large pressure ridges in the center making good denning habitat for seals. Today, the ice is thinner and flatter. Pressure ridges still form closer to shore, so seals can still make dens, but the thinner ice is more dangerous for traveling, and there are more cracks and open water. In Shishmaref, the ice is thin and dangerous much of the time, not solid and reliable as it once was. There are no large pressure ridges to hold the shorefast ice in place. Near Stebbins and St. Michael in the 1970s and 1980s, shorefast ice extended to Egg Island and hunters could travel there and to Golosovia over the ice. Today, the shorefast ice extends only a few miles from shore and it is not possible to travel nearly as far on the ice. The ice is thinner and breaks off more easily, making traveling conditions more dangerous. The ice used to form large pans, but now is more crumbled up. Scammon Bay hunters said there is little shorefast ice now, and the ice that remains is thin and floats away easily. There are few big ice floes any more. People used to be able to travel over solid ice to Cape Romanzof to gather

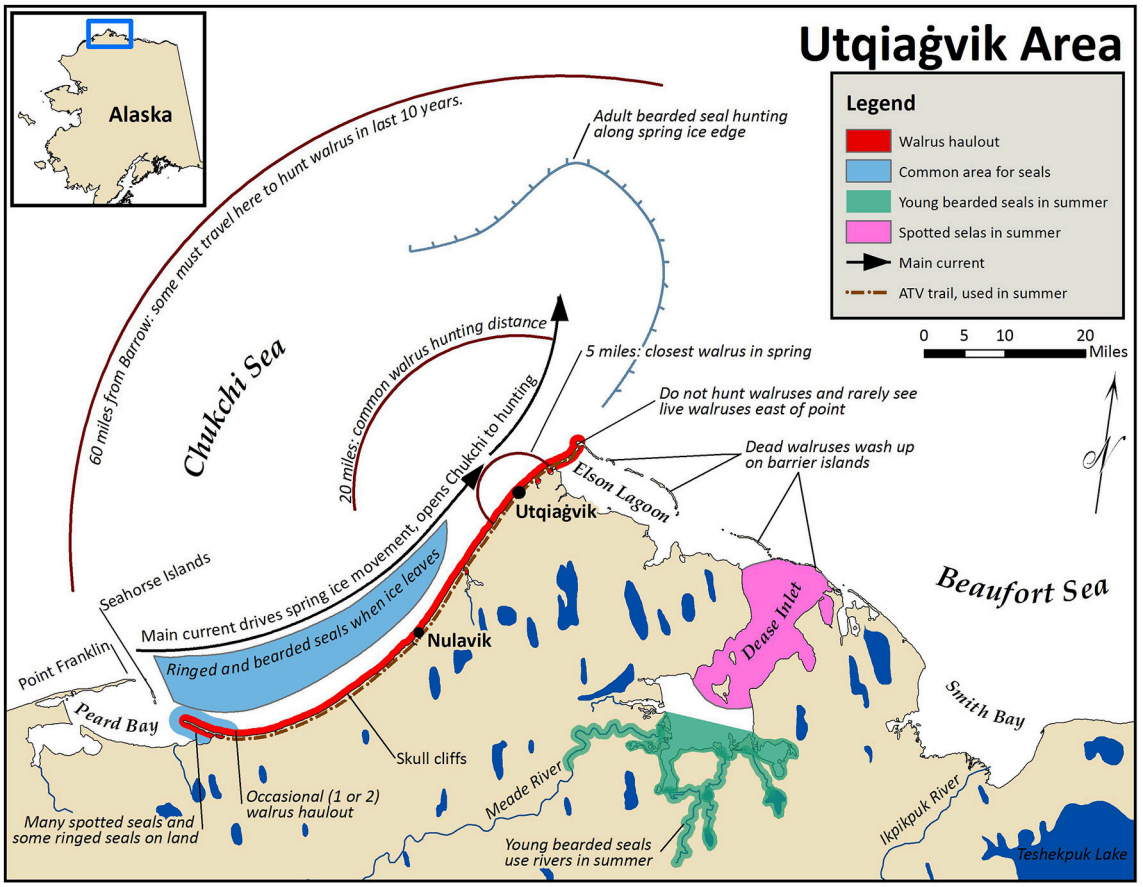

FIGURE 2 | Traditional knowledge about the movements and behavior of marine mammals near Utqiaġvik (formerly Barrow), Alaska as described during interviews in January 2015.

driftwood, but this is no longer possible. Hooper Bay hunters report a similar pattern. The ice used to be solid during the middle months of winter, but now there is often thin ice and open water. There is now little or no shorefast ice, whereas there used to be extensive shorefast ice that hunters could use. Mekoryuk also used to have stable ice on the north side of Nunivak Island, near the village, in December, January, and February. Now, the ice can go away in mid-winter, even in the bay by the village. In late 2016, people had been able to gather mussels (*Mytilus edulis*) from the beach because there was no ice in the way, which had never been possible in winter before.

Spring break-up has also changed dramatically. In Utqiaġvik, shorefast ice has become thinner and more susceptible to breaking off in spring. Breakup happens earlier. Wainwright similarly says that the breakup of shorefast ice used to happen in late June or July, but now may start in May, making travel dangerous and limiting the time whalers can spend whaling. In Kivalina, the shorefast ice does not stay as long as it used to. In some years, it starts to melt as early as March. In Shishmaref, the hunters point out that there are no longer any large pressure ridges to hold the ice in place, so in spring the ice breaks up quickly and is dangerous to travel on. Hooper Bay, Scammon Bay, and Mekoryuk all report a similar pattern, of early and faster breakup. Scammon hunters said that by April it is now too warm and the ice goes away.

After breakup, hunters all along the coast report that the broken ice disappears very quickly, whereas it used to persist in the area for several weeks or, in the more northerly locales, come and go all summer with the winds and currents. Now, once the ice has gone, the water stays open until fall. As discussed in section Changes in Hunting, this has had a major impact on hunting opportunities for seals and walrus.

Weather and Snow

Sea ice has not changed in isolation. Kotzebue hunters said that an east wind will open the ice west of a line between Cape Espenberg and Cape Krusenstern. In the old days, hunters would travel to the ice edge to hunt seals after the wind calmed down and the risk of being blown out to sea had diminished. Today, east winds may open the ice well into Kotzebue Sound. The open water still freezes again, but now it remains thin. Some hunters believe the east winds are stronger than they used to be. In addition, there are fewer strong west winds to push the ice into Kotzebue Sound and form large pressure ridges that can hold the ice in place. Scammon Bay hunters say that the weather has been more violent in recent years. Fall storms come early, winds are

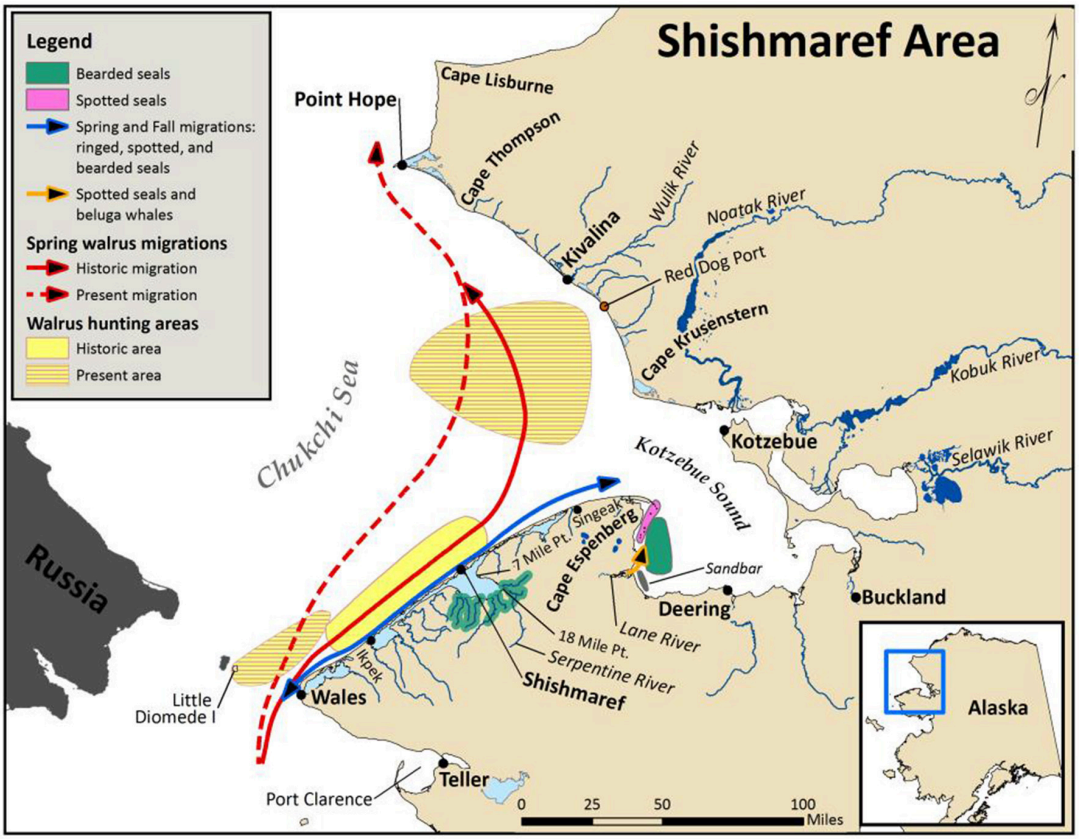

FIGURE 3 | Traditional knowledge about the movements and behavior of marine mammals near Shishmaref, Alaska as described during interviews in January 2016.

stronger, and the air is warmer. In Hooper Bay, the weather has changed, making hunting harder and more dangerous. Storms are more persistent than they used to be, and there are more windy days and fewer calm days. There are fewer northwest winds that bring big, thick ice floes and marine mammals into the area, and more east winds that push the ice away. Mekroyuk has also seen a rise in windiness, with calm periods lasting only a day or so instead of a week or more. Residents have seen old photos of people kayaking in completely flat water, which is not common today.

Snowfall and accumulation have decreased in many communities. Kotzebue, Scammon Bay, Hooper Bay, and Mekoryuk all commented on this trend. Mekoryuk has seen rain in mid-winter, which was unknown in the past. Snowmelt is coming earlier and happening more quickly, making it difficult to travel on the land or cross rivers.

In Kotzebue and Shishmaref, some of those interviewed said that the weather has become harder to predict. Winds and bad weather can come up more quickly, making it too hazardous to travel a long way over the ice, such as across Kotzebue Sound.

Ecological Changes

Changes in sea ice and other parts of the climate system have affected marine mammals and the ecosystem of which they are part. Some of these changes affect hunting and the condition of the animals that are hunted. While the details of changes vary to some degree from community to community, nearly all communities reported extensive ecological change in many forms.

Presence and Migration of Marine Mammals

Whalers in Kaktovik have seen no changes to the timing of the fall migration of bowheads, nor to behaviors such as feeding near the shore. Kaktovik and Utqiaġvik whalers have seen an increase in the number of bowhead whales over the past several decades. In Utqiaġvik, the whales are coming earlier than they used to. Wainwright whalers have seen the spring bowhead migration begin earlier, perhaps due to the lack of multi-year ice as an obstacle. Formerly, the first group of bowhead whales, primarily small, young whales, could occur in late April, but now happens earlier in the month and even in March. Near Kivalina, bowhead and beluga whales migrate north in spring through leads in the ice. The whales continue this basic pattern, but more open water amid the ice means they can take a more direct route from Wales to Point Hope, farther from Kivalina. When the ice is thick offshore, the whales are more likely to follow the shoreline closer to Kivalina, typically about 30 km (20 miles) offshore.

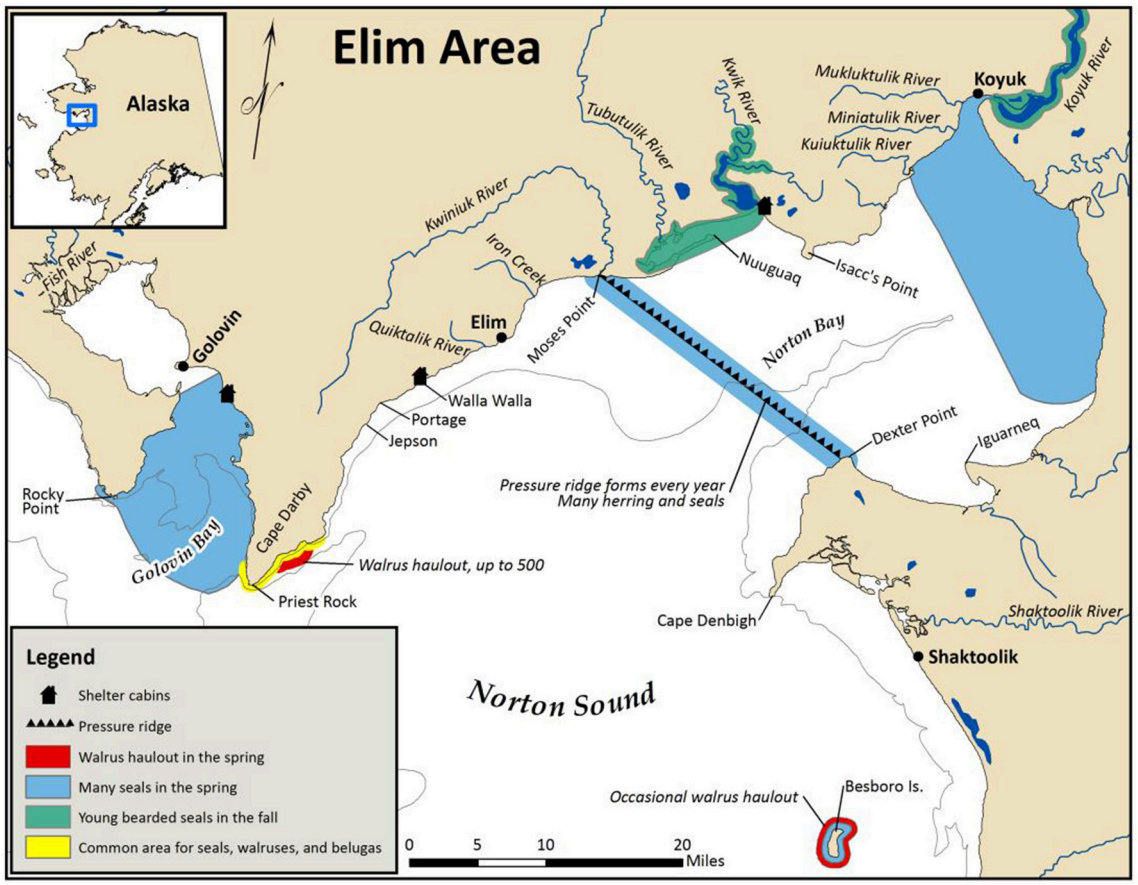

FIGURE 4 | Traditional knowledge about the movements and behavior of marine mammals near Elim, Alaska as described during interviews in February 2015.

Beluga whales have been seen at unusual times of the year, for example in January 2015 near Elim. These whales were being pursued by killer whales, but it is very rare to see belugas in January near Elim. In Hooper Bay, belugas were seen in January 2016, also an unprecedented sight.

In Hooper Bay, spotted seals (*Phoca largha*) used to arrive in abundance in April on their way north, but now some spotted seals can be found in the area all winter. St. Michael hunters report fewer spotted seals since the ice began changing in the 1990s and 2000s. In Kotzebue, hunters said that spotted seals may be arriving a little later than they used to in spring, and are staying much longer in fall. In Kivalina, the timing of the arrival of spotted seals does not seem to be affected by changes in sea ice, as the spotted seals follow the fish rather than responding to ice conditions.

In Shishmaref, the changes in ice conditions mean that bearded seals migrate closer to the shore and the village than they used to, but the walrus migration is now farther offshore because the pack ice is less dense and more broken up than in the past. Kivalina hunters have seen the path of the walrus migration shift to a more direct route from Shishmaref to Cape Thompson or Point Hope, which means the animals are 80 km (50 miles) away from Kivalina, which is too far to travel by boat in broken ice. Point Hope hunters, in turn, say that the walrus are not coming as close to the point as they used to, but travel farther offshore. Fewer males are seen in spring now and fewer walrus overall, hundreds instead of thousands. The shift in location coincides with the changes in sea ice, especially the loss of thick ice in winter. In Wainwright, south winds used to bring ice floes laden with walrus close to land in spring. The walrus were abundant enough that the ice floes appeared brown. This has not happened since the mid-1960s. Today, fewer walrus are seen hauled out on top of the ice.

The timing of the migrations of different species has begun to blend together. In Shishmaref, bearded seals (*Erignathus barbatus*) and walrus may now arrive at the same time in spring, and both are arriving earlier than before. Mekoryuk hunters see fewer bearded seals now than in the past. Formerly, bearded seals were found off the north shore of the island in springtime, but this is less common now. In Hooper Bay and Scammon Bay, bearded seals have been arriving as early as February in recent years, whereas they typically used to come in late March and stay into May.

Hooper Bay sees fewer ringed seals now than formerly, perhaps because changes in ice conditions draw the seals to

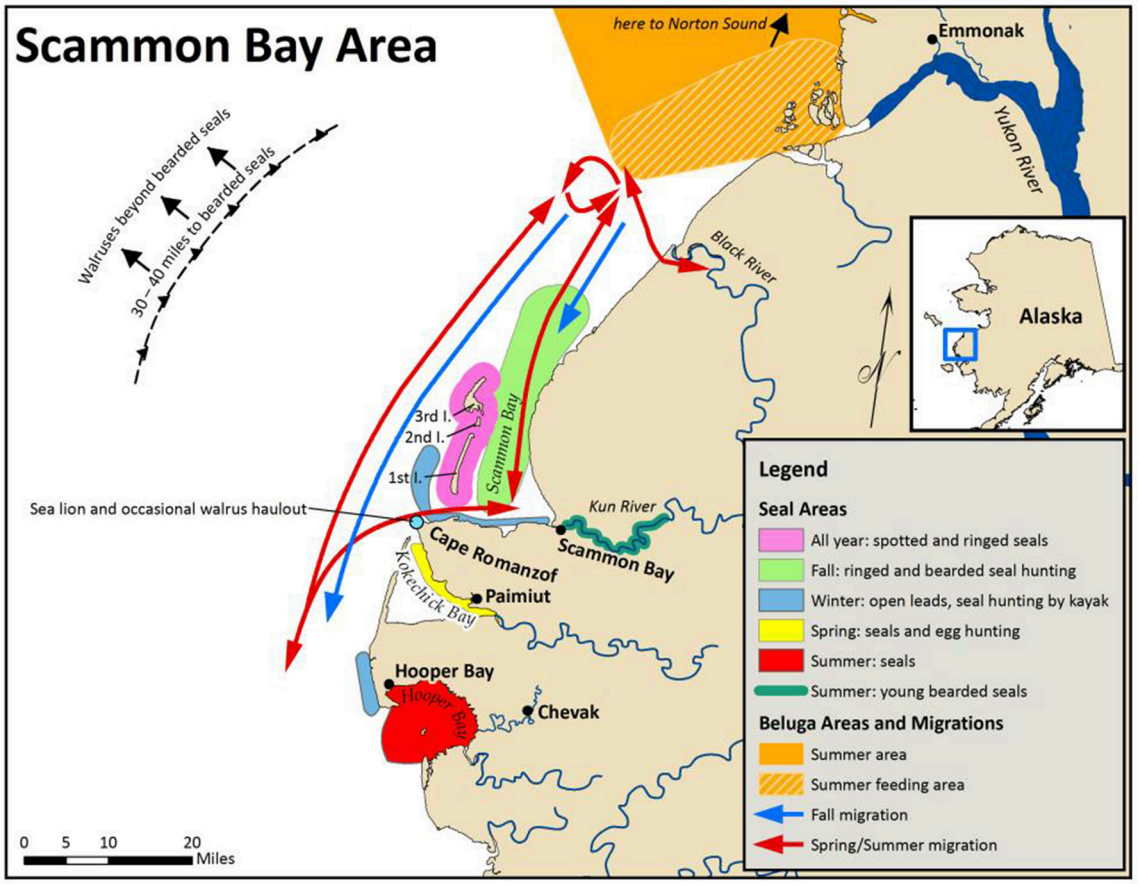

FIGURE 5 | Traditional knowledge about the movements and behavior of marine mammals near Scammon Bay, Alaska as described during interviews in January 2017.

more distant ice habitat. Nonetheless, seals of all kinds remain abundant, because the coast is their highway. In Scammon Bay, hunters said ringed seals are the most abundant seal in cold winters, but in warmer winters the spotted seals can be more plentiful. There are fewer ribbon seals in Kotzebue Sound than there used to be. Hunters used to see them now and then, but hardly see them at all now.

Steller sea lions (*Eumetopias jubatus*) are not as common around Mekoryuk as they used to be. Sea lions were common in the Hooper Bay area in the 1970s and 1980s, and the village corporation is named for them. From the 1980s until recently, sea lions were only seen infrequently, usually at Cape Romanzof, where six or eight might haul out high on the rocks. In the past few years, sea lion numbers seem to be increasing in the area, though they remain less common than in the 1970s and 1980s.

There are more killer whales near Scammon Bay and in Kotzebue Sound than there used to be. In Point Hope, by contrast, hunters report seeing fewer killer whales in recent years. While fishing for Pacific halibut (*Hippoglossus stenolepsis*) near Scammon Bay, large whales have been seen in summer in the past decade, which is new. It is unknown which species of whales they see.

Distribution, Behavior, and Habitat

Changes in sea ice distribution and thickness have been the main cause of changes in walrus distribution and behavior near Utqiaġvik in recent years. Formerly, walrus were found on large ice floes in herds of as many as 3,000 animals. Today, ice floes are smaller and thinner, and walrus are seen in small groups of 10–15 animals or medium sized groups of 50–100. Near Scammon Bay, in the spring of 2016, the ice left early and while local residents were halibut fishing, they saw small groups of bull walrus swimming north in open water, about 30 km (20 miles) offshore. People were unsure where the walrus could rest without ice floes nearby.

In Kotzebue in the spring of 2015, there were many seal pups despite conditions that did not appear to be good for raising pups. Less thick ice and fewer pressure ridges provides less denning habitat for ringed and bearded seals. Ringed seals pup in snow lairs, so when the snow melts early, the pups have no protection from predators, such as jaegers, ravens, and foxes. Bearded seals pup on top of the ice but pressure ridges protect pups from the wind. Bearded seals are found farther from shore near Utqiaġvik than they used to be. In Norton Bay, there is a persistent pressure ridge that forms between Moses and Dexter Points during winter and spring. It makes good denning habitat for ringed and bearded

seals, though the snow is not as deep now as it used to be. There are fewer seal dens on the ice as a result, but still many breathing holes in the ice in spring between Elim and Cape Darby. Scammon Bay hunters say that the lack of snow means fewer snowdrifts on the ice, thus less habitat for seal lairs.

Beluga whales were once abundant in Kotzebue Sound each summer, but local hunters say that since the 1980s it is not even clear if there is a Kotzebue Sound population to speak of. Hunters say that an ice entrapment in Russia killed thousands of belugas and is the most likely culprit, though they acknowledge there was a lot of harvesting of belugas in the years before that event, too. In some years since the mid-1980s, belugas have come into Kotzebue Sound, but this is not common. A few animals are seen in the region from time to time, but no consistent migrations.

Utqiaġvik residents occasionally see polar bears that swim to shore in summer. Having come a long way from the ice, they are typically exhausted. People let them rest, as the elders say they should be left alone. One bear slept for a day or two after collapsing on the shore before recovering.

Seals and Walrus on Land

Utqiaġvik hunters see ringed seals on land occasionally, typically south of Utqiaġvik, perhaps because of the noise of all-terrain vehicles on the beach near the community. Utqiaġvik hunters have not seen much change in the number of walrus hauling out on land in that area, though it is possible it has become more common in the last decade or so.

Near Point Lay, on the other hand, there has been a great change, as tens of thousands of walrus now haul out on the barrier islands a short distance north of the village. In 2009, the walrus hauled out farther north, near Icy Cape, but since then the haulout has been close to the village. Villagers had seen large haulouts before, but they were infrequent and typically closer to Icy Cape. Most of the walrus hauling out were females and juveniles, with few large bulls. Other than the haulout, Point Lay hunters have seen few changes to the distribution and behavior of walrus in their area.

Point Lay hunters report that walrus on land are sensitive to smells, noises, and the movements of other animals. The sound of outboard motors or gunshots will cause the walrus to flee. People boating past a haulout have to be especially careful, as many walrus are in the water and may attack a boat if provoked. Walrus are wary of the approach of people or bears, but hunters who approach carefully can get within a few meters of the animals without provoking a reaction. In response to the haulout, Point Lay residents have adjusted their own activities, avoiding boating in the area of the haulout and requesting airplanes to stay well above and away from the site. The villagers have also turned down most requests to visit the site, from media and others. As a result, few walrus have been killed in the haulouts, in contrast to 2009 when disturbance from brown and polar bears likely caused stampedes that killed many young walrus.

Body Condition

Utqiaġvik hunters say that bearded seals have had thinner blubber in recent years. Hunters need to get to a seal quickly before it sinks, and the quality of the seal oil (rendered from blubber) has changed, too. The same trend has been seen in Wainwright for both ringed and bearded seals, noting that the blubber is yellower than it used to be. The taste of the meat has changed, too, which is true for other species of marine mammals and waterfowl. Kotzebue hunters have seen the same pattern in bearded seal blubber, which now is typically only 2–4 cm (1–1.5 inches) instead of the usual 7–10 cm (3–4 inches). In Shishmaref, by contrast, people report that the quality of seal meat, oil, and hides have not changed, though spotted seals in recent years have been larger than they used to be. Mekoryuk, farther south, also sees thinner blubber in bearded seals.

Wainwright and Point Lay residents say that walrus body condition remains good, with no change over time. Point Hope hunters are seeing more skinny and sick walrus in spring in recent years. Kivalina hunters took a female walrus in July in both 2014 and 2015, but the blubber was thin and the meat was dark red and smelled bad. They were unable to eat the walrus as a result. In Shishmaref, people report that walrus are skinny, perhaps because they have to swim farther from the retreating sea ice to the places where they can feed. Otherwise, the walrus appear healthy.

Disease

In Utqiaġvik, ringed seals with bald spots and sores were seen starting in the summer of 2011. These seals hauled out on the beach more frequently than ringed seals usually do. The diseased seals are thin and do not flee when a person approaches. Hunters avoid animals with signs of disease, including these ringed seals. In subsequent years, seals with these signs of disease have been seen less often. The same phenomenon has been seen in Point Hope, also starting in 2011. Some sick seals are seen from time to time, but the number of sick animals in 2011 was much higher than normal. The sores were around the eyes and mouths of the seals and on their tails. One hunter said they looked like scratches on the face and hind flippers. Kivalina hunters have seen a few sick bearded seals in recent years, with large hairless areas. It used to be very rare to encounter a sick seal, and most seals remain healthy, but sick seals are more common now. A few sick ringed seals have been seen on the beach in the past few years. As was seen in Utqiaġvik and Point Hope, the sick seals do not move away when people approach.

In Kotzebue, the people interviewed said that hair loss is normal in seals, and can be seen on ringed, bearded, and spotted seals. When seals were taken, hunters' wives would pull the hair to see if it came out, if the seal was molting. Molting or hairless seal skins make for good leather for ropes, boot soles, and other purposes. If the hairless seals seemed otherwise healthy, they would be eaten. If not, they would be fed to dogs. The increase in hairless seals lately may be due to incomplete molt, perhaps because there is less sea ice for the seals to spend time resting on, affecting the molting process. The disease, in which hair loss is accompanied by sores and other signs of poor health, is new, and was first seen in 2011. Hunters do not want to handle or eat such seals. Some hunters believe the disease may be nature's way of dealing with overpopulation of seals.

Since 2011, Shishmaref hunters have seen many diseased animals, with sores around their flippers and back end, white

livers, and bald spots or complete hairlessness. The sick seals of all species are typically thin, with little blubber. The hair feels like sandpaper instead of being smooth, and it falls out easily. In 2015, there were more sick seals than in 2014. Hunters avoid diseased animals, not wanting to touch them if they seem severely ill. Sick bearded seals do not dive right away when approached by boat, nor do they stay down long once they have dived.

Some sick seals were seen near St. Michael and Stebbins in 2011, but not many. One diseased ringed seal was seen on the beach in the summer of 2014 and did not flee when approached by an all-terrain vehicle. Scammon Bay residents saw ringed seals with boils on their necks and bellies in 2015. These seals were acting fearless, unlike normal seals, a behavior also seen starting in 2011. Hunters chose to go for spotted seals instead, as the spotted seals appeared healthy. Hunters have seen sick seals and hairless seals in the past, but they were rare. In Hooper Bay, sick seals have been seen occasionally, but most seals are healthy. The sick seals have boils on their skin and black fur. This is a new phenomenon, seen among ringed and spotted seals. One diseased seal, which has pustules on its lungs and heart, was cut open and left on the beach, but even the gulls and ravens avoided it.

Prey and Ecosystems

In the fall of 2006, Kaktovik whalers saw unusually abundant jellyfish in the waters off the village. This had been seen in other years, too. Dolly varden char (*Salvelinus malma*) and cisco (*Coregonus* spp.) were the most common fishes in the area, but now there are more salmon than there used to be.

Between Wainwright and Utqiaġvik in 2010, there was a bloom of red algae. This was the first, or at least one of the first, times such an event was seen. That year, the jellyfish were larger than usual. The hunters are concerned that the algae could affect mollusks, shrimp and krill, and the rest of the foodweb.

In the summer of 2014, the jellyfish near Elim were so abundant that they clogged fishing nets. The jellyfish were also larger than usual. Starfish taken in crab pots appeared to be eating jellyfish.

Scammon Bay halibut are declining but walleye pollock (*Gadus chalcogrammus*) and Pacific cod (*Gadus macrocephalus*) have appeared in recent years. Fishermen have caught skates and salmon sharks (*Lamna ditropis*), both regarded as unusual. The Pacific herring (*Clupea pallasii*) run is happening earlier, in mid-May now; it used to come in late May and early June. The herring run continues to coincide with the ice going out. People have seen new birds in the area, too, which hunters do not recognize. In Hooper Bay, the salmon (*Oncorhyncus* spp.) are coming earlier but remain abundant, halibut are more abundant, but salmon sharks are also caught, which they did not see before. Mekoryuk now catches many skates while longlining for halibut. This is new, and skates are considered a nuisance. Halibut longlining, however, is a relatively recent practice in Mekoryuk.

Other Impacts to Marine Mammals

In addition to changes in the natural world, hunters see or are concerned about impacts from human activities. Kaktovik whalers fear offshore oil and gas activity will deflect bowhead whales farther away from shore. Utqiaġvik whalers have seen such deflections during offshore operations, but note the whales return to their usual migration route after the activity stops. Utqiaġvik whalers also note the impact of increased snowmachine traffic on the ice, which has contributed to changes in local migratory patterns, such as fewer whales swimming close to the ice edge. Wainwright whalers are also concerned about the impacts of offshore oil and gas activities and shipping in their area. If animals are pushed away from shore, they will be harder to hunt. If they are pushed closer to shore, they may be farther from their preferred feeding areas.

In Point Hope, some hunters attributed changes in the distributions of marine mammals to the greater use of outboard engines by local residents, as well as to increased ship traffic in the region. They note that the smell of fumes and exhaust affect walrus, not just the noise. Kivalina residents have seen a considerable decrease in marine mammal abundance in their area following construction of the Red Dog Mine Port Site, to the southeast of the village, in the late 1980s. The noise from that facility deflects marine mammals migrating up the coast, pushing them offshore and out of reach of hunters. Instead, Kivalina hunters now often travel northwest to Cape Thompson, which is expensive because it requires a lot of fuel. Kotzebue hunters also see impacts to marine mammal distributions from boat traffic and associated noise. Jet planes landing and taking off from the Kotzebue airport are loud and can be heard from far away. If ship traffic increases during marine mammal migrations, it could have a major impact. Elim residents, too, are concerned about the impacts of coastal activity such as dredging and port construction in Nome, and would like to learn what they can about the impacts of development that has already taken place. In Hooper Bay, hunters saw belugas avoid the bay in the fall of 2016 when re-supply barges were present and there was other noise associated with runway construction near the shore.

Changes in Hunting

The most notable impacts to hunting have been from changes in the physical environment, specifically changes in sea ice. The rapid break-up of ice in spring results in a much shorter period of good hunting, and the instability of shorefast ice makes travel and hunting more hazardous in winter and spring. In some locations, hunters report decreases in abundance of the animals, resulting in lower hunting success. Changes to equipment and other social factors have also affected marine mammal hunting.

A Shorter Broken Ice Period

Utqiaġvik hunters said that formerly the pack ice would come and go during the summer, as winds shifted, bringing the ice-associated animals within range of hunters at various times during the summer. In recent years, however, the ice has gone out quickly and rarely returns resulting in hunters traveling further to hunt. There is still a great deal of variation from year to year. In Wainwright, hunters have to go far offshore in search of walrus after the ice breaks up. The ice used to leave the shore in July but now it leaves in June and does not return, leaving a very short hunting season for walrus and seals. In some years, hunters see no walrus at all, even if they travel up to 65 km (40 miles) offshore.

In Kivalina, this pattern is even more pronounced. While marine mammals remain abundant in the area, sea ice is no longer a reliable platform for hunting. Instead, it is a dangerous place to be, preventing hunters from reaching marine mammals and limiting the length of the hunting season. This change began in the late 1990s, when pack ice disappeared from the area after only 1 week, instead of the usual several weeks. Hunters had to make sure to take advantage of the brief opportunity rather than taking their time to go hunting. In 2015, offshore winds carried the ice out and the ice did not return after the wind died, as had been the usual pattern. Hunters fear this could be the new pattern.

Kotzebue hunters saw the same rapid retreat in 2015, citing thin ice during winter and east winds at the time of break-up, pushing the weak ice away. Instead of 2 or 3 weeks of good hunting conditions for bearded seals, there was only 1 week or less. The lack of ice also meant that waves could build within Kotzebue Sound, making boating more hazardous for hunters. Some ice remained near Goodhope Bay, in the southwestern part of the sound, but it was dangerous to travel that far. One advantage of less ice is that the bearded seals congregate around the remaining ice floes, so hunting can be good if hunters can find ice. Hunters further noted that the ice is no longer stable enough for spring camping. The ice-related loss of hunting opportunity is the only big change they see.

Scammon Bay hunters say they need to be ready to take advantage of hunting opportunities when they arise, especially in times of change like the present. This means going hunting at times that are not customary, but when seals and other animals are nonetheless available and accessible. In spring, the good hunting season used to last 2–3 weeks, when it was possible to go boating but the ice was still nearby. Now, hunters may have less than a week of good conditions before the ice is too far away. Some hunters have started avoiding spring hunting and its new risks, focusing instead on fall hunting. For these hunters, the new strategy seems to be working so far.

Hooper Bay residents also report a shorter spring hunting period. Larger boats and more powerful motors allow hunters to go farther offshore, as much as 100 km (60 miles) from land, but this is expensive and risky, and very disappointing when no marine mammals are found. The problem is not a shortage of animals, as seals and other marine mammals are plentiful and healthy, but simply a matter of getting to the animals. They are far away or ice conditions are not favorable. Thin ice, for example, does not allow people to travel over it to the ice edge as they once did and it is not a good platform for cutting up larger seals. Without shorefast ice, launching, and landing boats directly from shore can be hazardous because of breaking waves. In deeper water at the ice edge, the waves do not present such a challenge.

In Mekoryuk, changing ice in the past decade or two has reduced the broken-ice spring hunting season from a few weeks to a week or less. If the hunters miss the opportunity, they may have to go without seal oil.

Timing and Conditions

Kaktovik hunters used to be able to use ice floes as lookouts during whaling. Now, there is less ice during the fall whaling season. The spring bowhead migration pattern in Utqiaġvik has changed, with fewer whales traveling along the edge of the shorefast ice and fewer whales seen southwest of the community. Whalers who used to set up camp 20 km (12 miles) southwest of Utqiaġvik have had to move farther northeast along the shorefast ice. This shift may be a result of thinner ice and less multi-year ice, which is associated with feeding opportunities for bowhead whales, thus reducing the attraction of the area southwest of Utqiaġvik.

In Utqiaġvik and Wainwright, it is harder in spring now to find flat areas of ice that are thick enough to support a bowhead whale for butchering. Formerly, any flat area would be thick enough, but this is no longer the case. Smaller ice floes also limit the areas where walrus are able to haul out. Utqiaġvik hunters say they can hunt walrus in open water, but it is much harder than getting them on ice floes. The walrus must be towed to ice or land for butchering, and are known to be aggressive when in the water, even to the point of attacking boats and teaming up to do so. This can happen after one of the walrus has been killed.

In Kivalina, hunters can no longer hunt ringed seals in December or January, because the ice is too thin. Instead, they must wait until February or March. Kotzebue hunters find that bearded seals arrive earlier in spring, but stay on thin ice where hunters cannot reach them. While bearded seals can be hunted in open water, hunters prefer to get them on the ice since hauling them in and out of the boat is difficult. In Scammon Bay, by contrast, the spring hunt for ringed seals has expanded to include December through February, because there is thinner ice and more open water in winter. Bearded seal hunting is harder due to fewer seals in both spring and fall, in addition to poor conditions in spring.

Other Factors

Point Hope hunters are struggling to get the marine mammals they need. They cite too much traffic in the air and on the sea, with ships coming too close to the point, in the path of the marine mammals and the places that people hunt. When animals are deflected away from the point, hunters have to travel farther, using more gas and thus facing higher costs, and incurring more risk with longer travel distances.

In Kivalina, the availability of powerful outboard engines and high-powered rifles has helped hunters adjust in ways that would not have been possible in the old days. Hunters can make day trips instead of having to camp on land or ice. Hunters need to incorporate new knowledge to adjust to a rapidly changing environment.

In Kotzebue, there is not as much hunting as there was in the past, largely because there are fewer dogs to feed. Hunters also used seals to make sealskin pokes for storing oil and meat, but today people use other containers and do not need to take seals for this purpose.

Continuity in Knowledge, Principles

Amid the changes happening to climate and marine mammals, reliable knowledge remains essential to safe and successful hunting. Hunters continually compare what they know about the sea and the animals against new observations, adjust what they know, and share new observations with one another.

Furthermore, the basic principles that have served hunters and their communities through the generations (i.e., preparing for the hunt, cooperation, patience, and sharing the harvest) remain relevant today. These were not topics about which we sought information, but several of those we interviewed brought them up.

Acquiring and Updating Knowledge

Younger hunters who were interviewed distinguished traditional knowledge (i.e., learned from elders and others with extensive experience) from modern knowledge held by those who have only hunted from motorboat and snowmachine, not from skin boats and dog teams. Thus, younger hunters have different skills and knowledge than their fathers and grandfathers. Their skills are nonetheless applicable to hunting in today's conditions. The younger hunters are aware that conditions are changing fast, and that elders who no longer hunt may not know all the details of what ice and marine mammals are doing now.

In Wainwright, whalers will have been on the ice throughout the winter, watching where the ice breaks off and assessing where it is likely to do so in spring. This helps them plan the locations of whaling camps. Elders used to tell young boys at whaling camps to keep quiet even when there was no open water, so that whales would not be disturbed as they migrated. The first whales set the path for those that follow, so it is especially important not to disturb those whales. In spring, the whalers also hear news from their fellow whalers on St. Lawrence Island and in Point Hope, which provides them advance notice that the bowhead migration is coming. They expect whales to arrive in Wainwright about a week after they reach Point Hope, depending on the intervening ice conditions.

Hunters in Kotzebue observed the same practice of letting the first animals pass by, but today hunters no longer coordinate their hunting efforts, and some hunters may pursue the first animals they see.

Values, Principles for Interacting with the Environment

Sharing of seals and other animals is very important for Kivalina hunters. Hunters provide for their own families, for their relatives, for elders, and for others in the community. The first animal of the season is typically shared, so many people are excited when the first one is taken, knowing it will be distributed widely. People say that if you give first, more will come, so they do not like to keep their first catch. This practice applies to caribou (*Rangifer tarandus*) as well as to marine mammals.

In Scammon Bay, hunters said it is important to take what you can, when you can, so long as it is done respectfully and without waste. Sharing with elders and others who cannot hunt is also important. In the old days, if Scammon Bay had a successful season, they would load kayaks with meat and other foods and take them to Hooper Bay and other communities to share.

One Hooper Bay hunter emphasized that the lessons of the elders are vital, reflecting the skills and the values that have allowed people to survive and thrive in the region for countless generations. Successful hunters share with those in need, especially elders who can no longer hunt. While reliance on the store and things from elsewhere is weakening the connection to the land, it remains essential to pass on the values of respect and sharing to the younger generation. Hunters used to prepare extensively before going hunting, to be ready for any situation. Ammunition was scarce and expensive, so hunters were patient to wait for a good shot. They stayed calm and relaxed, placing safety first. Today, many hunters go without emergency gear and without making the necessary physical and mental preparation for the hunt. This is a loss that can have fatal consequences.

DISCUSSION

Physical Changes

Hunters from all communities described extensive changes to sea ice, snow, and weather. The results from the different communities are consistent with regard to later fall freeze-up, thinner ice throughout the winter, and earlier and more rapid break-up in spring. Less snow and less predictable weather, though noted in fewer communities, were still consistently reported by those who commented on these topics. The local details vary, as would be expected across a large north-south gradient and from interviews conducted over a decade, but the overall picture of a changing physical environment shows dramatic change over the past two decades throughout northern and western Alaska.

These patterns are consistent with what has been found in other studies of traditional knowledge (e.g., Krupnik and Ray, 2007; Fall et al., 2013; Huntington et al., 2013a) and are well-documented in the scientific literature, including measured decreases in multiyear ice (e.g., Maslanik et al., 2007; Kwok et al., 2009; Perovich et al., 2016) and snow levels (e.g., ACIA, 2005), and projected trends of less, thinner, and a shorter duration of ice in the future (e.g., Overland and Wang, 2007; Overland et al., 2014). The level of local detail available through traditional knowledge and the ways in which physical changes affect ecology and human activity are important contributions to the available literature, though further exploration of this topic would require dedicated studies (e.g., Gearheard et al., 2006, 2013; Johnson et al., 2015).

Ecological Changes

In all communities, hunters described changes in the migrations, distribution, abundance, health, and behavior of marine mammals and to the ecosystem as a whole. At the same time, the ecosystem in most areas was described as productive, with marine mammal populations generally perceived as abundant and healthy.

Descriptions of rapid changes in the biological environment are consistent with the results of other traditional knowledge studies (e.g., Noongwook et al., 2007; Gadamus et al., 2015), including the persistence in most locations of abundant and healthy marine mammals (e.g., Huntington et al., 2013a,b; Voorhees et al., 2014), and the influence of social factors in shaping the outcomes of physical and biological changes (e.g., Fienup-Riordan et al., 2013).

Ecological change has been reported widely in the scientific literature, including the influence of changing sea ice on biota.

Recent status reviews of ice associated seals highlighted the concerns associated with changing seasonal sea ice (Boveng et al., 2009, 2013; Cameron et al., 2010; Kelly et al., 2010). Following the status reviews, bearded and ringed seals were listed as threatened under the endangered species act based on predictions that Arctic sea ice habitat would degrade in the foreseeable future (Federal Register, 2012a,b). Since the ruling, the U.S. District Court for District of Alaska (2014, 2016) reversed both actions, but the reversal of bearded seals was overruled by the U.S. Court of Appeals for the Ninth Circuit (2016). Currently only bearded seals are listed in Alaska. The lack of summer ice in the Chukchi Sea is also concerning for Pacific walrus according to a status review was completed in 2011 (Garlich-Miller et al., 2011) and based on those concerns a final decision on listing under the ESA is due in 2017. It is important to note that most of these concerns are based on expectations about how marine mammals will respond to future conditions and effects, rather than on current observations of decreasing abundance or health.

The apparent disagreement between hunters' observations of abundant and healthy animals and the potential for designating the same species as endangered is thus more a matter of timeframe than conflicting data. Traditional knowledge can contribute further through additional and on-going monitoring of marine mammals and other parts of the environment, to help detect changes in behavior, diet, migration patterns, health, and other parameters important to understanding the well-being of a particular population.

Changes in Hunting

To date, hunters consistently report that the greatest impacts to hunting have come from changes in the physical environment, primarily sea ice. Changing sea ice conditions affect access to and availability of marine mammals, predominantly for the worse (e.g., Fidel et al., 2014). Thinner ice is less reliable as a surface for travel in winter and spring, so hunters cannot go out or go as far. The rapid break-up of ice in spring has greatly reduced the time that seals and walrus are readily available for hunting. Lack of ice at other times of the year and increases in wind have made boating more dangerous at a time when hunters often have to travel farther to find marine mammals. Hunters are able to adjust to some degree, by changing the timing or methods of the hunt, by being ready to take advantage of favorable conditions while they last, or by using bigger boats with more powerful engines and better navigational technology to reduce risks when traveling farther. Many of these responses come at a cost, for example the expense of a new boat and motor or the use of more fuel to go farther. Some of the responses also come at the cost of higher risk, if hunters have to travel in times and to places when conditions are marginal for safety.

Changes in marine mammals and other aspects of the ecosystem, by contrast, appear to have had much less of an impact, at least so far. While there are some reports of reduced abundance or lowered body condition of marine mammals, overall the hunters described relatively robust populations of animals in generally good physical health, suitable for hunting and human consumption. Some species, such as bowhead whales and perhaps spotted seals, appear to be thriving under the current conditions. Others, such as bearded seals and walrus, show signs of at least regional decreases in abundance (i.e., distribution), which may reduce hunting opportunities in those areas. Not surprisingly for bearded seals, these changes appear most prominent at the southern end of their range, where sea ice is no longer a reliable feature of the winter ocean.

The impacts of a changing physical and ecological environment on marine mammal hunting in the Arctic have been reported in other studies of traditional knowledge; for example shorter hunting seasons (Krupnik and Ray, 2007), unstable sea ice as a hunting platform (Fall et al., 2013), and increased concern over shipping, and oil and gas exploration (Hovelsrud et al., 2008), and reduced hunting opportunities due to changing weather patterns and ice conditions (Ashjian et al., 2010; Kapsch et al., 2010; Hansen et al., 2013; Huntington et al., 2013b). The ability of hunters to adjust, with varying degrees of success, to changes that have occurred thus far is, of course, no guarantee that they will continue to be able to do so. Nor is the hunters' ability to adapt an excuse for others to ignore the underlying causes of climate and environmental change in the Arctic and beyond (Loring, 2013).

Continuity in Knowledge, Principles

Hunters in our study noted the continued utility of traditional knowledge and the principles for safe and successful hunting while recognizing the need to add new information concerning modern hunting methods and the changing environment. Not all traditional practices continue to be strictly followed, such as letting the first animals pass by to establish the pattern of the migration in that season. Some hunters no longer prepare themselves as thoroughly as used to be the common practice, which can reduce safety and diminish respect for the animals. But important cultural practices such as sharing remain highly valued, both to hold communities together and to show respect for the animals that are taken.

Some holders of traditional knowledge have distinguished knowledge, the acquisition and sharing of information, from wisdom, the judgment to use that knowledge appropriately and ethically (e.g., Kawagley, 1995; Mercullieff, 2016). This distinction is a useful way of separating the skills and expertise that need to be updated as conditions change from the skills and expertise that remain relevant regardless of those conditions. Hunting with new equipment or at a different time of year requires learning how to use the new gear or what to look for in one season vs. another. Approaching the hunt with patience and humility, however, is necessary no matter how or when the hunt is undertaken. Sharing and cooperation remain essential in any season, for the long-term well-being of the community and the environment.

The idea that traditional knowledge is losing its relevance ignores the efforts that hunters make to acquire and share new information. As younger hunters in Utqiaġvik said, the knowledge of those who no longer hunt may be static, but those who continue to be active are constantly checking what they know against new observations. Traditional knowledge in this sense is traditional because of the system of observation and interpretation that has long been used, not because the knowledge itself is rooted in the past. The inclusion

of younger hunters in studies of traditional knowledge can help make sure that the knowledge that is documented is up to date, and can also demonstrate that younger members of the community can be holders of valuable information, in addition to the knowledge and wisdom of the elders.

Relying on basic principles but also adding new knowledge demonstrates adaptability in the face of climate change (e.g., Hallwass et al., 2013; Pearce et al., 2015). Much has been made of using traditional and scientific knowledge together to develop a better understanding of the changing environment and the impacts that changes have and will continue to have on humans (e.g., Gearheard et al., 2013; Ambrose et al., 2014; Baztan et al., 2017). In such efforts, the ways in which hunters and other holders of traditional knowledge continue to add to their understanding are often overlooked. Community-based monitoring efforts provide one form of recognition (e.g., Gadamus et al., 2015; Alessa et al., 2016), but are often focused primarily on the observations themselves rather than analysis and interpretation within a traditional knowledge context. The ways that hunters evaluate and assimilate new observations deserve greater recognition as a means of adaptation (e.g., Huntington et al., 2017), for it is in this setting that hunters can apply their new knowledge directly to the tasks they undertake.

Future Prospects

Physical change is the most prominent Arctic manifestation of global climate change, with summer sea ice extent a global indicator of the extent of that change. Models indicate continued warming and continued declines in sea ice, so it appears unlikely that current conditions will remain constant. The apparent lag between physical change and ecological impacts makes it difficult to determine how extensive the effects on Arctic marine mammals will be and over what timeframe they will occur. To date, marine mammal hunters in northern and western Alaska have been affected more by physical change than by ecological change. As the ecosystem responds to physical change, however, it seems likely that extensive changes will occur to the distribution, abundance, and body condition of Arctic marine mammals. These changes may play a larger role in future impacts to marine mammal hunters.

How subsistence societies will change and how quickly is a question of great interest and importance. Some decisions and actions have a short time horizon, such as whether and where to go hunting on a given day. Others, such as the purchase of a new boat and motor, will have repercussions for years to come. The degree to which climate change expectations feature into such decisions is not yet clear. Hunters are also concerned about potential impacts from industrial development, commercial shipping, and other human activities, over which they have relatively little influence. How those activities will affect marine mammal hunting remains to be seen, as does the ability of regulatory actions to reduce negative impacts. Changes in distributions of marine mammals raise the potential for new hunting opportunities, if those opportunities are legal. For example, decreases in the walrus harvest could be offset by harvesting the increased population of gray whales in summer when the ice is gone, but the International Whaling Commission would need to set hunting quotas for large whales other than bowhead whales so that hunters can take advantage of range shifts that bring other whales within reach of Alaska Native communities.

The research reported here and similar research done elsewhere has shown both the extent of climate-related impacts on Arctic marine mammal hunting to date and the ability of hunters to adjust and respond to the changes that have been seen. Hunters cannot adjust to every change, and nor should they be expected to (Loring, 2013), but their flexibility with regard to interannual variability appears to be serving them well so far with regard to climate change. It is less clear how long this ability will be able to serve them. Further research is needed to better understand how marine mammal hunters and their communities adjust to change, what conditions foster successful responses vs. unsuccessful ones, and what policies, regulations, and other outside assistance can support successful responses that retain the essential cultural elements of marine mammal hunting in northern and western Alaska in light of continued warming.

AUTHOR CONTRIBUTIONS

LQ conceived the studies and HH helped design them. HH, LQ, and MN conducted the interviews and prepared the summaries. HH drafted the manuscript and LQ and MN revised it. All authors participated in the final revisions and addressing reviewer comments and all gave final approval for publication. All are responsible for the contents of the article.

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