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Pacific walruses, indigenous hunters, and climate change: Bridging scientific and indigenous knowledge

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Abstract

This paper presents and evaluates two perspectives on changing climate–walrus–human relationships in the Beringian region, from the viewpoints of marine biology and ecology, and from that of indigenous hunters. Bridging these types of knowledge is vital in order to grasp the complexity of the processes involved and for advancing understanding of subarctic marine ecosystems that are currently experiencing rapid ecological and social change. We argue that despite substantial gaps and distinctions, information generated by scientists and indigenous hunters have many similarities. Differences in interpretation are primarily due to scaling and temporal rates of change of knowledge, which could be rectified through more active sharing of expertise and records, enhanced documentation of indigenous observations, more collaborative research, and increased insight from the social sciences.

Keywords: Bering Sea; Climate change; Indigenous knowledge; *Odobenus rosmarus*; Walrus

1. Introduction

The Pacific walrus, *Odobenus rosmarus divergens*, is a critical Beringian species due to its key role in the Beringian ecosystem (Ray et al., 2006) and the extensive dependency on walruses by many indigenous communities of the Northern Bering and Chukchi Sea shores of Alaska and Siberia (Krupnik, 1993). Hence, changes in walrus distribution, abundance, and life cycle may be crucial indicators of ecosystem change, and would certainly act as drivers of social change. Understanding the nature of these changes is made urgent by growing evidence of recent shifts in climate, ocean and atmospheric circulation, sea-ice distribution, and other physical-ecological parameters that seem to be triggering dramatic restructuring of the marine ecosystems of Beringia (Grebmeier et al., 2006). Concerns also have been expressed about negative impacts of these changes on northern indigenous communities and their biological resources (Huntington, 2000; Krupnik and Jolly, 2002; Ray and McCormick-Ray, 2004).

Indigenous people have been exploiting Beringian marine ecosystems for at least 6000 years; walrus

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hunting became the staple of local economies as early as 2000 years ago (Krupnik, 2000). Prior to the modern economic era (about the early-1900s), walrus hunting supplied 60–80% of all subsistence food consumed in many communities in the Bering Strait region (Krupnik, 1993). Almost every part of the walrus was used. The people and their dogs ate the flesh; tools and weapons were made from ivory and bone; and skins provided covers for boats and dwellings. People spoke of walruses in tales and myths, honored them in ceremonies and prayers, and called children and geographical places by names used to describe them. Thus, indigenous knowledge of walruses springs from millennia of use.

In contrast, biologists became aware of the basics of Pacific walrus life history only since the mid-19th century, during the era of commercial whaling. Following the decline of whaling, whalers turned their attention to walruses for oil (blubber), hides, and tusks. The Pacific walrus population was soon reduced from possibly as many as 300,000 animals, estimated to be the carrying capacity, to about 50,000 (Fay, 1957, 1982; Fay et al., 1989). Whaling-ship logbooks and statistical models indicate that about 200,000 walruses were killed from 1867 to 1883, with 35,700 killed in 1876 alone (Bockstoce, 1986; Bockstoce and Botkin, 1982; Fay et al., 1989). A byproduct of that slaughter was the acquisition of substantial knowledge of walrus life cycle and behavior (cf. Allen, 1880; Elliott, 1881). During recent decades, major gaps in knowledge have been closed through field observations, tagging, aerial counts, and work with indigenous hunters. We do know that sea ice is a key factor in walrus distribution and population dynamics, due to the walrus' dependency on it as a habitat for reproduction and feeding (Fay, 1982; Fay et al., 1984; Ray and Hufford, 1989). Sea ice is also the feature of polar ecosystems most subject to rapid climate change (Sarmiento et al., 2004; Smetacek and Nicol, 2005). This creates a critical need to link processes and information about sea ice, walruses, and indigenous people who depend on walrus for their economic and social wellbeing.

2. Current scientific understanding of walrus biology and ecology

Scientific understanding of the life cycle of Pacific walruses is largely based on Fay's (1982) classic monograph, which summarized what was then known of this species's biology and ecology (Fig. 1). Contrary to the general belief that walruses mate in the spring, Fay (1982) showed that ovulation and spermatogenesis occur in mid-winter. Behavioral observations demonstrated that mating is accompanied by a male "song" and occurs within open-water arenas surrounded by sea ice (Fay et al., 1984). Mating occurs in winter, but implantation of the fertilized egg in the uterus does not occur until June–July of the same year, a phenomenon known as "delayed implantation"; thus, fetal development is about 10 months. Consequently, walruses are among the slowest reproducing of all marine mammals, females being capable of bearing calves only every second year, at most.

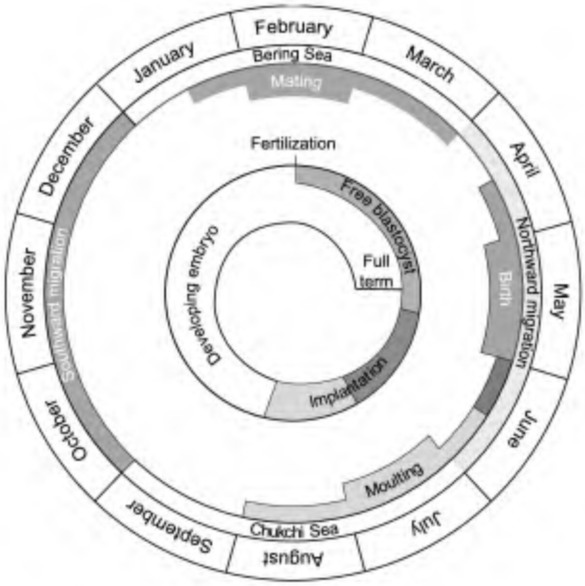

Fig. 1. Generalized depiction of the Pacific walrus' life cycle: mating occurs in the broken pack in mid-winter; calves are born mainly in May during the northward migration; and the southward migration occurs in fall. The circle in the center shows the timing of implantation. Adapted from Fay (1981).

What remains less clear is the spatial aspect of walrus life history. Research conducted during the past half-century, particularly through aircraft surveys and from ice-breakers, has shown that Pacific walruses congregate in highly patchy patterns of groups of hundreds to thousands of animals during the winter breeding season in two principal areas: the west-central Bering Sea southwest of St. Lawrence into the Gulf of Anadyr, and in northern Bristol Bay (Fig. 2; Fay et al., 1984; NOAA, 1988; Ray et al., 2006). Both areas are in shallow seas over the Beringian continental shelf,

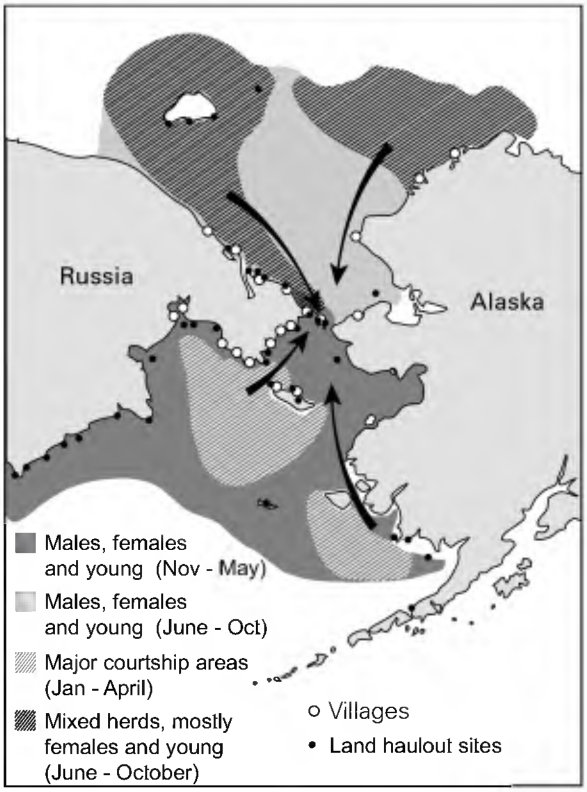

Fig. 2. Generalized seasonal distribution patterns and annual migration routes of Pacific walruses in Beringia, showing summer and winter concentrations. Black dots indicate male walrus summer haulout sites; open circles indicate hunting and monitoring villages. From Fay (1982), NOAA (1988), Ray et al. (2006), Garlich-Miller and Burn (1999); G.L. Hunt, personal communication.

rich in clams and other benthic invertebrates that constitute food for walruses. The major habitat southwest of St. Lawrence is dominated by an ice type called "broken pack", thick ice that is generously interspersed by leads and polynyas, allowing access from ice to water and back again at all conditions of wind and weather (Ray and Hufford, 1989; Ray et al., 2006). Bristol Bay is not a major area of broken pack, but does contain sea ice, thick and extensive enough to support groups of walruses. Separating these two areas is a broad, north-south band of "rounded pack" extending from the Bering Strait to Nunivak Island that, due to opposing currents and winds, is densely concentrated and lends only very limited access to open water. This rounded pack divides walrus sea-ice habitat and the two major winter concentrations, strongly suggesting a "metapopulation" structure, with the possibility of limited genetic interchange among individuals in winter during the breeding season. However, direct proof of subpopulations of Pacific walruses awaits further research.

Keys to resolving uncertainties of population structure concern sea-ice dynamics and migration patterns. After the breeding season, adult males and adult females with subadults and newborns, begin to move to separate destinations (Fig. 2). By calving time, adult females, younger animals, and a few adult males move northward with the retreating pack ice from the vicinity of St. Lawrence Island to the Bering Strait; by late June–July, they are distributed mainly in the eastern and western Chukchi Sea. The great majority of adult males, on the other hand, head for land haulout sites in Bristol Bay, the Gulf of Anadyr, and north and south on the Chukchi Peninsula, where they remain until September or October (Jay and Hills, 2005; Mymrin et al., 1990). Thus, females mostly inhabit sea ice all year long, whereas for males it is only during fall through spring.

In early fall, annual sea ice again begins to form, first in the northern Chukchi Sea, then extending rapidly southward, soon making the Chukchi Sea and the Bering Strait region inhospitable for wintering walruses. Contrary to the northward migration in spring, walruses probably swim southward ahead of the freezing pack or with young ice too thin to bear their weight. These annual movements make good sense. The separation of the sexes during summer affords maximal access to food throughout Beringia; the spring migration with the ice gives walruses a platform for birthing and rest; and the fall migration ahead of the freezing pack reduces the risk that individuals may become trapped. But how groups of a thousand or more walruses become associated with extensive, thick winter ice sufficient to bear their weight remains unknown. We do know from aerial surveys and natives' observations that from September to December, depending on variations in weather and sea-ice formation, the herds assemble in the vicinity of St. Lawrence Island, especially around the Punuk Islands southeast of the Island. However, even if some sea ice were present at that time, it would be generally too thin to support them. Thus, the walrus' only recourse is to haul out on land to rest. There, from November through December or January, walruses await the formation of thick broken pack near their land haulouts. Thus, we may reasonably assume that when thick ice forms in their vicinity, walruses occupy it in groups, and then move with the "conveyor belt" (Pease and Overland, 1984) of sea ice to the central Bering Sea. As for the Bristol Bay group, no direct information is yet available. It is likely that these walruses take advantage of sea ice as it moves in the direction of Bristol Bay.

From an ecological perspective, the Pacific walrus appears to be a key species within Beringia. Walruses are major consumers of benthic fauna, annually consuming an estimated 2–3 million metric tons of benthic biomass, or as much as the entire Bering Sea fishery (Fay, 1982; Ray et al., 2006). Another major effect of walrus feeding is 'bioturbation' (disturbance of the benthic environment), which occurs over thousands of $km^2 yr^{-1}$ (Nelson and Johnson, 1987). This annual to multi-year walrus bioturbation has the potential to result in significant, large-scale ecological changes, such as alterations of both sediment and biological-community structure (Born et al., 2003; Oliver et al., 1983). Additionally, the release of nutrients from sediment pore water by bioturbation is locally about two-orders of magnitude greater than background release, with possible effects on local to regional production processes (Ray et al., 2006).

The above effects strongly suggest that if the habitats and movements of walruses were to be fundamentally altered by climate change or other factors, so would the ecological functions that walruses perform in Beringia. That is, should arctic–subarctic sea ice continue to diminish, as most of current climate models predict (ACIA, 2004), walrus's sea-ice habitat would be reduced such that their access to feeding habitat would also be greatly reduced. It follows that the walrus' key ecological roles would be redistributed, diminished, or lost, with the strong probability that Beringian ecosystem processes could be significantly altered. Already, Grebmeier et al. (2006) have observed a northward shift in Beringian communities and productivity that could have profound effects on commercial and subsistence use.

3. Indigenous hunters' knowledge

Arctic and subarctic subsistence communities were always strategically positioned to take advantage of local resources. Gambell at the northwestern tip of St. Lawrence Island, Alaska, about 200 km south of the Bering Strait (Fig. 3), offers a good example of a location assured of dependability of abundant migrating marine mammals and birds. Proof of this is found on Gambell's gravel spit

Fig. 3. Aerial view of Cape Sivuqaq, with the Sivugaq (Gambell) Mountain and the village of Gambell. Photograph by G.C. Ray 1999, from the panel photo at Sivuqam Inc., Gambell, Alaska.

where lie the remains of two millennia of human history and remains of innumerable walruses, whales, and seals taken by local hunters. Through the narrow body of water at the junction of Alaska and Siberia, where Gambell sits, passes one of the world's greatest mammal migrations. The timing and sequences of migrating species is critical. Bowhead whales (*Balaena mysticetus*) are normally first to pass from mid-April to early May when heavy sea ice is moving northward under influences of winds and ocean currents. Herds of walruses with their calves, as well as bearded seals (*Erignathus barbatus*), soon follow, from late April to early June. Finally, with late spring ice in May–June come the other seals—ringed (*Phoca hispida*), spotted (*Phoca largha*), and ribbon (*Phoca fasciata*)—together with one of the world's greatest concentrations of seabirds. Gambell hunters claim that with this last wave of marine wildlife comes a second group of migrating walruses.

Subsistence hunters talk about walruses in many ways. First, hunters use many more terms for specific age–sex categories and groupings of walruses associated with sea ice than biologists usually recognize. For example, Yupik hunters of St. Lawrence Island use almost a hundred terms for various types of walruses, walrus products, and related phenomena.[1] Often one term condenses a comprehensive package of information about age,

[1]W. Walunga, C. Noongwook, C. Koonooka, Ayveghem Yupigestun Aatqusluga. St. Lawrence Island Yupik Walrus Dictionary. I. Krupnik (Ed). Illustrated manuscript produced under the project 'Sea-Ice Associations of Pacific Walruses' (2004). All Yupik terms and definitions for the various types of walruses used in this paper are taken from the entries in the 'dictionary.'

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sex, and size of the walrus grouping, its association with ice, and its direction of movement. Because of this, hunters may identify a particular walrus or a certain group of animals with very high precision, as seen from the following:

> *Ayughaayak*—in the springtime, when there is no solid pack ice anymore, the walrus mostly consisting of bulls would head towards land from out of Qayilleq to sometimes around Kangii [on the northern side of St. Lawrence Island]. They would get on the shore-fast ice, or former shore-fast ice in great numbers. Their stomachs are usually filled with clams.... Those are usually big bulls that we can see north to northeast from Savoonga in the springtime, usually in late May and early June. They are normally on ice but may be also on open water with some ice floes (Chester Noongwook, 2004).

In spite of a sophisticated nomenclature, subsistence hunters do not view the walrus as going through a well-defined annual life cycle. Nor do they have a comprehensive view of the regularly changing seasonal age–sex groupings, akin to the scientists' perspective. To them, walruses are always around somewhere; that is, if walruses are not seen nearby they will reappear again in due time. What really matters to indigenous experts is *when* each of the many specific groupings arrives in a given year, so that the walruses may be hunted. The hunters may be curious about *where* walruses go, but their direct experience is local. So, as walruses move northward to the Chukchi Sea in June or southward to the southern Bering Sea in December, hunters in the Bering Strait communities have only rather vague perceptions of their seasonal distribution.

Since walruses appear near St. Lawrence Island in great numbers in spring and fall, their arrival marks key dates in the hunters' annual calendar. Hunters usually claim that the "walrus calendar" begins in mid-fall, when walruses arrive on their southbound migration after a long summer's absence:

> Usually it starts upon here in November.... That's what we call *anleghaq* [fall walrus migrating south]. That's when the pack comes down and the herd, the big herd passes through the island. When the ice pack gets close to the island. They are coming from the deep North, from somewhere above the Arctic Circle. They just come straight from north along the ice pack, fresh new ice coming again. This is how it looks to us. That ice would be about a foot thick. These are mostly females and young bulls; females have their yearlings. No big bulls yet, maybe one or two in between. The big bulls come after that. So, it's mostly females and yearlings, *unkuvalget* [females with young walruses, *unkuvak*]. That's the kind of walrus that's coming here in November (Aaron Iworrigan—February 2004, Gambell).[2]

Thus, to the hunters, walruses come and go in particular groups, each specific to a certain location or season. St. Lawrence Island hunters are well aware that most fall walruses (*anleghaq*) usually move to the Punuk Islands, where they come ashore (*uugta*, walrus on land). Some fall walruses, however, stay for the whole winter along the northern side of St. Lawrence Island and may be pursued by hunters in sea-ice leads, polynyas, or through breathing holes. In winter, more walruses seem to the hunters to be concentrated along the southern and western shore of the island, where they may be encountered either as small groups resting on ice (*nunaavak*, pl. *nunaavaget*) or as mixed group of females and young bulls on drifting ice (*iwaagutaq*). These observations support the hunters' view that walruses do not disappear from the St. Lawrence vicinity in winter, for some broken ice and occasional walruses are always present in the area.

With the spring migration, starting in late April, the big herds reappear *en masse* once again. According to hunters, groups on ice usually arrive in waves, known under specific terms, *qaakneq* (pl. *qaakneghet*, groups of walruses traveling on top of drifting ice floes) or *unegyuuq*: (big concentrations of primarily female walruses west of Gambell) in ice-free water. Traveling spring walruses (*qaakneq*) may come in several forms, such as *qaakneghlak* (big herd on ice), or *qaakneghpaghqu* (many groups on ice floes). The largest concentration that occurs very rarely is called *qiighqaghsiiq*—literally like an island. Finally, a late spring wave of primarily young females arrives. Those female walruses (*qavreq*) travel in small groups, usually with some calves and yearlings. They are the last to move northward in early or mid-June, after most sea ice has gone. In hunters' words, they usually do not see walruses off St. Lawrence Island after this last wave moves north, or until the arrival of the mixed herd

[2] All quotations from subsistence hunters cited in this paper were recorded from taped interviews in Gambell and Savoonga, St. Lawrence Island, Alaska, between 1999 and 2004.

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(*anleghaq*) in fall. Hunters do not know where walruses go when they pass beyond the Bering Strait; unlike biologists, they are not usually concerned with questions that are beyond their observation range.

Similarly, hunters are usually specific about the particular age–sex composition of each group of walruses, but their explanations for why these groups are formed or for the factors that influence walrus migration are different from those of biologists. Hunters may simply say that "there are more bulls on the Siberian side than we have here" or that there is always "a concentration of adult bull walruses off Savoonga (*ayughaayak*) in springtime," when females with calves are passing by Gambell. Whereas walrus biologists interpret walrus groups in terms of population dynamics (e.g., Fay et al., 1989), to hunters the groups they see are outcomes of specific winds, currents, and ice conditions that occur in specific combinations each season or each year. Additionally, a typical hunter's account is always year- and site-specific, with little relevance to variability of the whole population. In the hunters' view, if the hunting is bad in one place it might be good elsewhere, although experienced hunters may calibrate their accounts to include reference to changing conditions:

> Walrus hunting was different [in Gambell] this past spring. It was very short and we got less walrus this past year, because they were all gone very quickly following the ice up North. Because the ice melted too fast, the walruses moved faster and in shorter time than usual. When I was young, we used to start hunting for migrating walruses in June, and this was mostly for migrating bulls that stayed on the eastern side of the Gambell Mountain. This spring, the walrus hunting started much earlier and it ended up in the last part of May, because the walruses were already too far away up North, for our hunters to go after them (Conrad Oozeva, in Oozeva et al., 2004).

As a result of long association with walruses, the depth of natural-history knowledge, coupled with environmental observation that many hunters have attained, is remarkable:

> The current we have here moves almost around St. Lawrence Island; it is a clockwise current. Most of the animals we have here follow this clockwise movement around St. Lawrence Island. The bowhead whales do this in spring, when they move from the Southeast Cape to *Pugughileq* at the Southwest Cape to Gambell, and then through the strait between the island and Siberia. The walruses also follow this clockwise movement; this is why we have walruses always after they have them in Gambell. Even the birds travel this way from west to east, but only in the morning. I have seen them so many times flying from the side of Gambell and further northeast. In the evening they come back and they travel counterclockwise, from here back to Gambell area....

> We also have two kinds of walruses here, around our island. The scientists call it 'Pacific walrus'; but we know that there are two of them, and we have two different names in our language. One is called *aiwam ayveq*—the 'northern walrus.' It always follows the ice when it moves north. It is bigger, wider, and its skin is lighter, like when the walruses spend several days in water, they come out like pale. There is also *ughqa ayveq*—southerly walrus; it is shorter, smaller, and it has darker color. This walrus stays here, around the island. These are different types—both bulls and cows. The northern walrus always goes north with the ice, when it moves north. So, these days we are getting more and more southerly walrus; we are seeing more of these walruses all the time.

> We were told that this southerly walrus used to stay in wintertime on some island—we do not know where it is and do not have the name for this island in our language. It may be somewhere in the Aleutians Islands, we do not know...So, now this southerly walrus is coming closer to our island, because of the changing weather conditions. But we rarely see the northern walrus anymore (Chester Noongwook, in Oozeva et al., 2004).

Finally, environmental concerns are very much on hunters' minds. There is much nostalgia about the 'good old days', but explanations of change can be very modern:

> The pattern [of walrus migration] is not the same today anymore like it used to be because of the climate change and the ice conditions have changed and the animals are affected by this global warming thing. That is sad to say. I think we are more adversely affected here because our walrus and whaling seasons are short, because of

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inclement weather…. When I was growing up and later on as an adult hunting with my dad, we used to have good weather all the time" (Leonard Apangalook, Sr., Gambell, St. Lawrence Island, in Metcalf, 2003).

To summarize, indigenous hunters' knowledge is usually drawn from local observations; it always includes references to weather, wind, currents, and sea-ice conditions. The hunters' breadth of sea-ice knowledge is not less remarkable than that for walruses, and hunters' sea-ice terminologies also exceed the lexicon used by scientists (George et al., 2004; Nelson, 1969; Nichols et al., 2004; Oozeva et al., 2004). This attention to detail and hunters' localized perspective contrast strongly with the scientists' usual focus on larger-scale phenomena. In contrast, scientists' reliance on statistically derived weather and climate information, annual sea-ice patterns and charts drawn from satellite imagery has no parallels in the Native toolkit.

4. Walrus and *ayveq*

Overall, walrus biologists and St. Lawrence Island hunters agree on many basic points of walrus biology and ecology, including: seasonal differences in distribution and abundance; separation into different groupings; and two seasonal peaks of abundance around St. Lawrence Island. The hunters' observation of the timing of two spring waves of walruses (Metcalf, 2003) is also similar to the scientific possibility that the Pacific walrus is structured as a "metapopulation," as both views are supported by sea-ice dynamics. It is little wonder that these sets of knowledge are similar, as they derive from similar long-term data-collection processes, and, often, in the same natural setting.

Despite these similarities, differences in interpretations remain profound. There is no 'silver bullet' in bridging these two very different types of knowledge, as the accounts on what biologists name 'Pacific walrus' and hunters call *ayveq* often have little correspondence with each other. This offers room for a third perspective that may usefully come from anthropologists who have explicit interests in explaining how hunters' knowledge ('traditional ecological knowledge' or TEK) is generated. Anthropologists are also concerned with 'bottlenecks' in the indigenous knowledge transmission process, how hunters' environmental knowledge is currently changing, and why. These and other similar issues may be critical when trying to bridge biologists' and hunters' knowledge.

4.1. Scaling: how "local" is local?

Most arctic biological and ecological data collection depends on highly sophisticated technology, such as satellite imagery, computer mapping, aerial counts, icebreakers, helicopters, and radio-telemetry used to track migrations across broad regional scales. The data collected are used to build long-term, large-spatial-scale scenarios of species' distributions and models of population dynamics. Subsistence hunters have little of this (Berkes, 1999; Callaway, 2004), but they compensate with a depth of local observation. The potential scientific power of an arctic subsistence hunters' monitoring system is substantial. More than a thousand Native subsistence hunters from 18 Alaskan communities hunt walruses every year, and several hundred more live on the Siberian side (Fig. 2); this does not include several hundred elders, who maintain their expertise and who actively participate in observation and knowledge sharing. During hunting, each walrus must be spotted, chased, killed, and butchered—usually several hours of hard work (Nelson, 1969). At least 5000–6000 walruses are now killed each year by Native hunters in Alaska and Chukotka (MMC, 2003). Many more are observed but not chased, killed but not retrieved, or not reported as catch. Each walrus hunt thus contributes several hours of observations to hunters' knowledge of walrus biology, behavior, population health, and ice and weather conditions. Every walrus butchered also can be a study of body status, condition, stomach contents, and other factors, such as disease and parasite load (Fig. 4). If anything unusual is found, the information is shared with other hunters and elders, and any case out of the ordinary is often extensively discussed. Also, hunters' records are temporally continuous from year to year and their observations usually cover the same sites (areas) and often the same animal groupings over many years, even generations.

Therefore, one would expect to find differences between scientific and indigenous knowledge in *scaling*, that is, in ways of interpreting natural phenomena at different spatial and temporal levels. For example, hunters' views of two types of walrus off St. Lawrence Island, named 'northern' and 'southern' walruses offer evidence to support the concept of a possible metapopulation structure of

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Fig. 4. St. Lawrence Island hunters butcher a male walrus killed in floating spring ice off Gambell, Alaska. Each walrus carcass is carefully examined for body status, signs of parasites and/or internal sickness. Photograph by G.C. Ray, Circa 1963.

the Pacific walrus population. Hunters' geographical knowledge, however, is too limited to corroborate this assumption across the entire species' range. Even though biologists are attentive to local variations in walrus behavior and distribution, their broader framework and reliance on large-scale modeling and statistics may leave them uncertain about the value of hundreds of local details that come with subsistence hunters' perspectives.

The integration of different scales of observations in those and many similar cases will obviously require a long-term accommodation of two different levels of data 'resolution.' It may most naturally come from cooperation over specific matters of high mutual concerns—for example, the ongoing shifts in walrus habitats due to sea ice and climate change, or the increased safety risks due to earlier ice break-ups and unstable winter ice cover. Such collaboration of two types of knowledge, from hunters and scientists, has already been sought in the studies of shore-fast ice dynamics, ice formation, sea-ice and weather observations (George et al., 2004; Nichols et al., 2004; Krupnik, 2002; Norton, 2002). In matching hunters' knowledge and scientists' perspectives, both sides will have to integrate the different temporal and spatial resolutions of their respective records.

4.2. Knowledge change

Scientific information is highly dynamic and is advancing rapidly. In contrast, the body of data typical for indigenous knowledge is based on long-term personal observations and elders' memories, and thus changes very slowly (Callaway, 2004; Nadasdy, 1999). The speed of 'modernization' and change has been central to many discussions of indigenous knowledge among social scientists for more than a decade (Berkes, 1999; Krupnik and Vakhtin, 1997; Nadasdy, 1999; Ohmagari and Berkes, 1997; Wenzel, 1999).

Although the body of scientific information on the Pacific walrus changed increasingly from the late 1800s to the mid-1900s (see above), the dynamics of hunters' knowledge has been totally different. If one were to ask hunters of the 1800s about walruses, the observational side of their knowledge would probably be similar to that of today. But the explanatory framework would have had little correspondence to what we normally hear from modern hunters. There would have been no references to thinning of sea ice, walrus population health, over-hunting, and bad weather, to say nothing of global climate change. Rather, walrus behavior would have been explained in terms of breaking traditional taboo regulations, of bad human treatment of walruses, and of disrespect (or low respect) for their spirits. Old interpretations would feature stories about people who did not "clean walrus bones on the beach" or some reckless youth who "skinned a baby walrus alive and let it go" and thus offended the animal's spirit. These were all stories recorded by early visitors and preserved in some legends of today (cf. Crowell and Oozevaseuk, 2006; Krupnik and Vakhtin, 1997).

Actually, today the knowledge of subsistence hunters is, perhaps, changing faster than scientists' knowledge. The generation of elders that once held traditional worldviews and beliefs is mostly gone. Present-day elders are typically devout Christians who attended government schools. Many are highly literate and skilled in using modern equipment, including satellite phones, radios, and computers. Alaskan subsistence hunters have been working closely with wildlife biologists for over a half-century and they are now quite familiar with the biologists' views and studies. Many hunters go to scientific meetings; they interact with wildlife specialists at various policy conferences and joint co-management committees; and they watch scientific visual materials, PowerPoint presentations, videos, and computer animations.

As the elderly generation of today's subsistence hunters is being replaced by younger cohorts, the new generations of primarily bilingual, better-educated and travel-seasoned northern residents

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will, probably, add even more information and perspectives borrowed from scientists into the hunters' knowledge system. Ten or 20 years from now, those two knowledge systems may be much closer than they are today—at the expense of more traditional, local portions of hunters' knowledge. The discourse between scientists and hunters then may be about ecosystems, global warming, game management, metapopulations, and similar issues taken fully from the scientists' list, but hopefully augmented by the indigenous hunter's knowledge base.

5. Conclusions

It appears obvious that climate warming will promote cascades of change, which in combination have the potential to alter patterns and processes of Beringian production and utilization by indigenous peoples. A foremost question is: What is to be gained by integration of scientific and indigenous knowledge? The response seems obvious: better understanding of local to regional biological and ecological conditions, and a transition into more powerful decision-making on the part of indigenous peoples. In fact, both processes are well underway, particularly in Canada, where the use of indigenous people's knowledge in resource management decisions is already a mandatory practice under Canada's 'Ocean Strategy' of 2002 (Myers et al., 2005). This strongly suggests a substantial potential for knowledge sharing and monitoring, which may expand beyond the required reporting of walrus take (and losses) and hunter compliance that so far has been the main pattern of information 'sharing' in Beringian walrus management system in both the US and Russia (Burn, 1998; Garlich-Miller and Burn, 1999).

The benefits of knowledge sharing are by no means trivial, for they relate directly to the major scientific issue of Beringia—climate change. Assumptions about Beringian resiliency have recently been brought into question by abundant evidence that climate warming is occurring and is affecting the entire Beringian ecosystem, including walruses (Grebmeier et al., 2006; Sarmiento et al., 2004; Smetacek and Nicol, 2005; Ray et al., 2006). A major regime shift and a cascade of consequent effects appear inevitable. Specifically with respect to walruses, the combined effects of their feeding and population health must be placed in the context of long-term regional climate changes and responses. This is particularly important, since sea ice works as a control mechanism on walrus distribution (Ray et al., 2006). As atmospheric and ocean circulation shift and climate warms, winter ice gets thinner and less concentrated and does not advance as far south as usual. As a consequence, the distribution of broken pack ice is fundamentally changed in both extent and position. In spring and summer, the ice breaks up earlier and retreats more rapidly. Additionally, a climate feedback occurs, in which shrinking summer ice cover exacerbates polar warming. The Arctic is now moving rapidly towards an ice-free summer regime, which has been the "normal" condition only for the subarctic (e.g., Bering Sea). In rough agreement with observations, many—but not all—climate simulation models predict that a transition to seasonal sea ice will occur, with very little or almost no summer ice over the Arctic Ocean by the end of this century (ACIA, 2004; Lindsay and Zhang, 2005; Overpeck et al., 2005).

The subsistence hunter is an important element in this cascade of events. If projections are correct, there may be little ice and too few walruses to hunt in the near future, and even if there are some walruses, they will pass by more rapidly and farther from Native communities. Local hunters and elders have expressed their grave concerns about shrinking ice and their endangered subsistence economies and cultures. Those concerns are widely shared across the polar regions (cf. Noongwook, 2000; Pungowiyi, 2000; Fenge, 2001; Krupnik and Jolly, 2002; Metcalf, 2003). Of all participants in current climate change debates, indigenous hunters are the parties that have most to lose. As many northern subsistence cultures are already going through painful transitions in their annual cycle, hunters' anxieties must be addressed and their concerns duly documented.

This brings us back to our major point, namely, that the present pool of 'operational' knowledge of the Pacific walrus remains unbalanced as to the level of representation of the views of scientists and indigenous hunters. In today's discussions of climate change, of its impacts and indicators, the voices of indigenous experts are greatly under represented. Fully incorporating those voices into research regimes and policy debates would be a major step toward a more equal dialog and a partnership built on data-sharing and mutual respect (Berkes, 2002; Fenge, 2001). Therefore, intensified efforts are needed to bridge the scientific

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and indigenous records of sea ice, walruses, and changes in human–animal relationships—very much as had been done earlier regarding local knowledge of small-scale fishermen (Berkes, 1999; Maurstad, 2004; Neis and Felt, 2000) and/or indigenous medicinal and edible plant-users (DeValt, 1994; Kuhlein and Turner, 1991).

In fact, the most insightful example of how this bridge may be built may come from current collaboration and data sharing between marine biologists studying the Western Arctic Bowhead whale (*B. mysticetus*) and indigenous subsistence whalers in Alaska and Siberia, who hunt whales under quotas set by the International Whaling Commission. From the late 1970s, subsistence hunters increasingly have been brought into the whale-monitoring and census-taking system created by marine scientists, and their knowledge has been included in scholarly publications on an ever-growing scale. This has significantly increased our understanding of bowhead whale biology and behavior. For example, hunters' observations have confirmed the existence of a separate Bowhead whale stock, or 'sub-population' that migrates to the western Chukchi Sea in summer time (Bogoslovskaya, 2003), a fact long contested by many biologists. Hunters' knowledge also helped to establish the critical role of wind strength and direction as the key factors that determine the timing and pace of whale migration (George et al., 2003). Again, biologists commonly focus on sea ice, food webs, and age–sex structure as the key parameters of whale ecology, while *wind direction* during the time of migration is commonly omitted.

As we have pointed out in this paper, subsistence hunters have many similar ideas regarding Pacific walrus ecology, such as the existence of 'northern' and 'southern' walruses off St. Lawrence Island, or the combined role of sea ice, winds, and currents as factors in determining walrus distribution. Hunters' knowledge, however, has yet to be tested. An even more critical issue concerns the readiness of management agencies to invest adequate resources into the documentation of hunters' knowledge. In the case of the Bowhead whale, it took almost two decades to forge the lasting partnership between the National Oceanic and Atmospheric Administration (NOAA) and the Alaska Eskimo Whaling Commission (AEWC) in support of documentation of whalers' knowledge. With the Pacific walrus, the process is still in its initial stage, in Alaska and Russia alike.

General recognition is also lacking that indigenous knowledge follows many of the same intellectual and analytical steps as modern science, though in its own specific way. Much like scholarly research, many hunters make observations and process their data into information. However, true experts, such as Conrad Oozeva, who knows 100 terms for various types of sea ice, or Chester Noongwook, who can explain the routes of marine mammal migrations around St. Lawrence Island, are exceptional. It is these experts and their unique and multifaceted knowledge of Beringian ecology that is our shared treasure. As such, efforts by many interested parties are needed, so that this treasure is fully accounted, respected, and put to use by Native communities, scholars, and management agencies alike.

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