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SUSTAINING A HEALTHY HUMAN–WALRUS RELATIONSHIP IN A DYNAMIC ENVIRONMENT: CHALLENGES FOR COMANAGEMENT

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Abstract. Native communities in the Bering and Chukchi seas have long relied on walrus for a multitude of nutritional, social, and cultural needs. Impacts to walrus in the past have resulted in profound consequences to these communities. For example, on St. Lawrence Island during the 1878–1880 "Great Famine" as many as 2000 people (>90% of the island's population) starved after the walrus herds were decimated by Yankee whalers. Loss of walrus was further confounded by a wave of fatal contagion and difficult hunting conditions attributable to short-term climatic changes. Today, the ability of coastal hunters to access, harvest, transport, store, and utilize walrus is still affected by a dynamic suite of endogenous and exogenous factors, including ecological, social, economic, and political conditions. Impacts specifically as a result of changing climate will affect Native Alaskan hunters within the context of these diverse and sometimes global factors. The Eskimo Walrus Commission (EWC) works within a comanagement agreement with the U.S. Fish and Wildlife Service (USFWS) to address these challenges. However, the EWC's goals may differ from the USFWS within the current comanagement and policy context. Whereas the USFWS is primarily interested in walrus population health (assessed through estimates of population size and native harvest), EWC is primarily interested in a broader scope, encompassing the health of the human–walrus relationship. New scientific tools associated with the study and management of linked human–ecological systems may provide a framework within which to address these goals. Here we present an overview of the challenges, needs, and research relating to climate change that are of interest to the EWC and in particular, the sustained health of the human–walrus relationship.

Key words: comanagement; ecology; health; Odobenus rosmarus divergens; *social-ecological system; walrus.*

Introduction

Over recent decades, there has been an increasing interest in the value of local knowledge, particularly indigenous knowledge, by ecologists and natural resources managers for understanding environmental changes such as those that result from a changing climate (Feit 1998, Berkes 1999, Pitcher 2001, Oozeva et al. 2004). Local indigenous knowledge is frequently termed "traditional ecological knowledge" (TEK), and among other attributes, it reflects careful observations of the local environment, combined with interpretation according to local practices and perceptions in various forms (Krupnik and Jolly 2002, Huntington and Fox 2005). Concurrently, local knowledge systems such as TEK and participation by indigenous communities in research have also taken an increasingly important role in the globally emerging field of community natural resource management. This includes arrangements such as comanagement (Kellert et al. 2000). We present comanagement of Pacific walrus (*Odobenus rosmarus divergens*) as a case study, reflecting on community observations, questions, and needs and how these relate to climate change. We frame this analysis within the context of the dynamic human–walrus relationship, a relationship in which "hunting is more than just gathering food" (EWC 2003:85).

Prominent comanagement institutions have developed between federal agencies and indigenous groups to help address local needs for a continued relationship with their local resources; for examples, the Alaska Eskimo Whaling Commission (AEWC) and the Eskimo Walrus Commission (EWC) in the United States and the Fisheries Joint Management Committee (FJMC) and Nunavut Wildlife Management Board (NWMB) in Canada. Although there is healthy skepticism regarding how well comanagement addresses local needs as opposed to perpetuating top-down policies (Nadasdy 1999, Castro and Nielsen 2001, Hunn et al. 2003), there have been notable successes when local knowledge, science, and management come together, particularly when focusing on a single resource (Kellert et al. 2000). For example, Alaska North Slope Iñupiaq whalers presented their local observations and knowledge about the bowhead whale (*Balaena mysticetus*) migration in a

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manner that challenged Western scientific assumptions. This lead to a more grounded inquiry of the migration, improvement to scientific understanding, and ultimately to policy and comanagement that was both better grounded in solid science and oriented toward local needs (Albert 1988, Huntington 1989, 2000).

Clearly, local knowledge of a particular environment is important context for any scientific study or management plan in that region (as it proved to be for bowhead whales in Alaska). Scientists frequently spend only brief amounts of time, and sometimes no time at all, in their chosen environment of study (Rose 1997). Certainly in the Arctic, few scientists have multigenerational temporal knowledge and understanding of a specific site, or spend as much year-round time at remote Arctic locations, as local community residents and their ancestors have done. Scientists are therefore generally limited in their ability to establish the relevant context for their locality of research interest without local endorsement (for example, finding links between local weather patterns and broader climate changes). However, although TEK can contribute to the field of ecology by providing insights into the challenges presented by temporal and spatial scales (Schneider 2001), local support through use of TEK alone to supplement science does not represent an effective sharing of information (Wenzel 1999, Kofinas 2005).

Scientists frequently devalue TEK, which is much more than simple observations; it is dynamic and drives local questions and inquiry based on nuanced local understanding of specific observations and knowledge (Huntington 1998, Berkes 1999, Krupnik and Jolly 2002). True integration of any local knowledge systems would require as full an understanding of the epistemology (foundations) of those local systems of knowledge as a scientist requires of the epistemology of their own field(s). Nevertheless, we, as have others (e.g., Hunn et al. 2003, Nadasdy 2003, Huntington et al. 2004, Oozeva et al. 2004, Gearheard et al. 2006, Stevenson 2006), expect that with care, sharing of expertise, and openness to institutional changes, answers might be found that can satisfy local-scale questions and needs, as well as help explain the relationship between local short-term and larger scale phenomena. Unfortunately, from a comanagement perspective, the application of locally derived questions to scientific inquiry is dependent upon the power and resources available to translate those questions into research priorities (Pomeroy and Berkes 1997, Nadasdy 1999, Berkes et al. 2005).

Communities, the Eskimo Walrus Commission, and Comanagement

Native communities in the northern Bering and Chukchi seas have long relied upon walrus for a multitude of social, nutritional, and cultural needs. The close connection within the human–walrus relationship was clearly demonstrated on St. Lawrence Island during the 1878–1880 "Great Famine" when from 1000 to 2000 people (possibly >90% of the island's population) died after walrus herds were decimated by Yankee whalers (Mudar and Speaker 2003, Crowell and Oozevaseuk 2006). The loss of this primary resource was further exacerbated by a wave of fatal contagion and climatic conditions that hampered hunting in subsequent years (possibly an El Niño-La Niña event; Mudar and Speaker 2003). Today, the ability of coastal hunters to access, harvest, transport, store, and utilize walrus is likewise still affected by a dynamic suite of endogenous and exogenous factors, including ecological, social, economic, and political conditions. Impacts specifically as a result of climate change on walrus populations will affect Native Alaskan hunters within the context of these diverse and sometimes global factors.

The Marine Mammal Protection Act (MMPA) was passed in 1972 with an exemption allowing Native Alaskans to harvest marine mammals provided it is done for subsistence purposes, for the purpose of creating and selling authentic native articles of handicraft and clothing, and not accomplished in a wasteful manner. The Eskimo Walrus Commission (EWC) was established in 1978 to represent the needs and interests of Native Alaskan hunting communities with both federal and State of Alaska management agencies (Langdon [1989] and Chambers [1999] provide detailed descriptions of the origins and development of the Eskimo Walrus Commission). This relationship developed into a formal Memorandum of Agreement between the EWC, the U.S. Fish and Wildlife Service (USFWS), and the Alaska Department of Fish and Game, which was signed in 1987. It wasn't until 1994 that the MMPA was reauthorized with the Section 119 amendment authorizing cooperative agreements between U.S. government agencies and Alaska Native organizations (ANOs) to conserve marine mammals and comanage subsistence use by Alaska Natives. Consequently, for the first time, the USFWS could, by regulation, formally consult with ANOs, such as the EWC, on marine mammal management. The first official cooperative agreement between the USFWS and the EWC was signed in 1997, when the formal process of comanagement began to develop. The EWC now works with the increased capacity provided by a formal cooperative agreement to address the challenges faced by its 19 represented Yup'ik, St. Lawrence Island Yupik, and Iñupiaq communities. The stated purposes of the agreement are to (1) conserve Pacific walrus in Alaska; (2) comanage subsistence uses of Pacific walrus by the involvement of subsistence users through the EWC; (3) provide the EWC with information on walrus population, status, and trends for the development of sound management practices integral to fulfilling their mission of representing the interests of subsistence users and walrus hunters; and (4) provide the USFWS with information for the monitoring of walrus population, status, and trends to fulfill its species oversight responsibilities.

The overall research interests by parties within this kind of comanagement arrangement may be fundamentally different from those applicable to current federal policy (Pomeroy and Berkes 1997, Stevenson 2006). Within the walrus comanagement agreement, the federal agency (USFWS) is currently most interested in walrus population health and monitors it through population and harvest estimates, which is essential for its management mandate. The local comanagement body (EWC) provides significant contributions to these efforts by helping to collect biological samples, supporting harvest reporting, and recognizing local knowledge. Conversely, the EWC must balance its position as (1) an advocate for local community hunters; (2) a steward of the environment; and (3) a legitimate advisor of agencies. In the first role, there may be a healthy tension between local and governmental needs, although this type of situation is often particularly demanding for the community representatives (Gray and Sinclair 2005, Kofinas 2005). The EWC position is to act on behalf of walrus-hunting communities, with their consent, and not as an agent or extension of USFWS. This distinction is important and necessary to maintain a productive, cooperative relationship. In the second role, commissioners of the EWC have identified the need to take a more holistic, ecosystem-level approach to studying the human–walrus relationship, rather than focusing on a single component of the ecosystem (i.e., just the walrus or harvest of walrus). The EWC's long-standing focus on environmental health and its implications to human health (human health residing outside the mandate of USFWS) includes all factors affecting walrus and hunters, such as pollution, climate change, disturbance, and outside social pressures against Native Alaskan harvests of marine mammals. In the third role, EWC may develop its own research needs to aid in answering its own priorities. Based on these roles, it should be expected that complete comanagement (Pinkerton 2003) and conservation plans will include scientific inquiry that covers the full spectrum of the human–walrus relationship. This is concordant with current developments in research of linked social-ecological systems. These systems are complex and evolving (Folke et al. 2002), in which all things are both connected and related, two of the central tenets of TEK (Pierotti and Wildcat 2000).

Further developments in Pacific walrus comanagement are likely to involve a more concerted effort to encompass the full human–walrus relationship. To do so, it is likely that issues relating to power sharing will need to be addressed in order to continue improving collaboration between indigenous peoples, scientists, and policy makers concerned with the sustained use of living resources in a changing environment (Caulfield 2000). As an example, the USFWS not only monitors walrus but unilaterally enforces the laws and policies framing walrus management. In this manner government holds the final authority in management and policy and frames research to fulfill their management mandate. Accordingly, walrus-hunting communities often perceive the USFWS walrus management and law enforcement activities as the same. For example, voluntary participation in a harvest data collection program, compliance with the MMPA's Marking, Tagging, and Reporting Program (MTRP) requirements, and enforcement of walrus harvest guidelines are blended together into one interaction. This differential power within the cross-scale arrangement between the USFWS and the EWC alone (emphasized through the USFWS's law enforcement) may undermine trust in resource management (Adger et al. 2006). Developing a long-term successful comanagement system that is built on mutual trust may involve restructuring national laws and policies, as well as governmental agencies. New partnerships and agreements may also be needed to resolve specific questions. These issues can be addressed through a more responsive and effective inclusion of local questions, insights, and needs by science and policy. Furthermore, once research is completed, the EWC can provide significant input toward interpretation and communication of that research information to the communities it represents. In this manner, questions that are derived from the EWC with the representation of local community interests and knowledge and manifested in research could significantly contribute to the goals and needs of comanagement: of building trust and a collective identity, and ensuring the responsible comanagement of the Pacific walrus population in a changing environment (Langdon 1984, Pomeroy and Berkes 1997, Natcher et al. 2005).

The Eskimo Walrus Commission and Climate Change

Currently, some of the most compelling questions and challenges faced by communities that reside in the Arctic are those that reflect the contemporary experiences and predicted effects of a changing climate. According to climatologists, over recent decades, climate change has had a profound impact on the thickness and areal extent of seasonal sea ice and is predicted to continue to do so with the addition of positive feedbacks from the melting ice cover (ACIA 2005). Biologists expect both direct and indirect consequences of these changes to be especially important to pinnipeds such as walrus, which rely on sea ice and are influenced by its variability (Kelly 2001, Cooper et al. 2006). However, in addition to direct effects of a changing climate, social scientists and anthropologists expect impacts will act in concert with other ecological, social, economic, and political changes, with profound implications for the people who rely on walrus for nutritional, social, and cultural needs (Nuttall 2005). Therefore, consideration of the health of the human–walrus relationship requires consideration of numerous interacting components (see other marine mammal examples in Marsh et al. [2003]).

Concerns about "health" are frequently cited by the EWC commissioners (see Burek et al. [2008] for a further discussion of health). Health is seen holistically, with little differentiation between people and walrus, as the two are directly linked in multiple ways, via the environment through a unique relationship that has persisted for thousands of years. We expect that with close attention to the ecology of walrus and the human–walrus relationship, scientists can help improve our collective understanding of the mechanisms by which climate change is positively or negatively affecting the health of walrus and the people who rely on them. Here we present some experiences and efforts by the Eskimo Walrus Commission to establish what is changing in the human–walrus relationship and what questions those changes raise. The EWC recently hosted two bio-monitoring workshops (in 2003 and 2005) and a bilateral summit with Chukotkan research and subsistence interests in 2004. These workshops included a wide variety of participants connected to the Pacific walrus and its habitat through occupation, scientific study, and culture. In all cases, they provided a forum to develop research plans collectively and a venue to compile information and issues related to hunter observations of their local environment.

Focal Research Topics Relating to Climate Change

We have divided our discussion into research topics that the EWC has identified specifically about the health of walrus, the walrus environment, and of the human–walrus relationship.

Walrus health

Baseline data of the Pacific walrus population and health are particularly sparse. Although the Pacific walrus population is thought to be roughly 200 000 animals, there has never been a population survey in which there has been confidence in the reliability of estimates. Most recent biological information on walrus population health has been derived from age and gender composition of harvested animals (Garlich-Miller et al. 2006).

Despite little confidence in absolute population estimates, observations by hunters provide useful insights into the effects of climate change on walrus. Walrus are limited in their range by constraints on diving depth: less than 90–100 m for their benthic invertebrate prey to be effectively accessed (Fay 1982, Fay and Burns 1988). Prey is also distributed heterogeneously in the environment. Accordingly, hunters reported that the physical condition of walrus was generally poor in 1996–1998 (e.g., emaciation) when reduced sea ice forced walrus to swim much further between feeding areas, leading to reduced fat reserves (Pungowiyi 2000). Additionally in 1998, during the extreme retreat of sea ice (Maslanik et al. 1999), walrus using the ice for substrate were taken beyond the continental shelf and over water too deep to feed on benthic prey. Confounding the depth constraints on feeding, loss of ice in shallow water precludes an ice resting platform for female walrus and their calves. More recently, the continuing extreme summer recessions of sea ice have been associated with female walrus arriving at Wrangell Island in poor condition after the long swim between the ice and land in the fall (A. Kochnev, *personal communication*). In the summers of 2002, 2004, and 2007 there were also unusual sightings of emaciated female walrus, or abandoned calves along the Beaufort Sea coast where walrus are rarely seen ashore (C. George, *personal communication*; B. Streaver, *personal communication*). Abandoned calves were also found swimming in water >3000 m deep to the north of Barrow during the summer of 2004 (Cooper et al. 2006).

In addition to observations of walrus health and condition, unfamiliar migration patterns are being reported by hunters (e.g., A. Ahkinga in EWC [2003]), including those in which the normally segregated herds of males are migrating with females and calves in mixed groups as the ice recedes faster in the spring (C. Menadelook and J. Madsen in EWC [2003]). Similarly, there have been changes in the demographic structure of walrus at terrestrial haul-outs in the Gulf of Anadyr, where predominantly male attendance in the 1960s has been replaced with a more mixed or even female-dominated attendance in recent years (Smirnov et al. 2004).

Although data collected in the Walrus Harvest Monitoring Program (e.g., the demographic structure of the walrus population) can help assess the effects of climate change on specific components of the walrus population, walrus hunters have also raised concerns and questions about how climatically related changes in walrus ecology will affect the prevalence of contaminants, biotoxins, disease, and parasites (e.g., A. Ahkinga and C. Menadelook in EWC [2003]). However, without good baseline information, little is known about how these factors affect the individual- or population-level health of walrus. Consequently, the impacts that a changing climate and sea ice environment will have on walrus health are also unknown. To address these needs, biologists can aid in assessing the nutritional and epidemiological health status of the Pacific walrus population and how climate change may affect these biological processes.

Walrus habitat and environmental health

As with the walrus themselves, the manner in which the entire suite of mechanisms set in motion by climate change will impact the walrus environment is largely unknown. However, of these mechanisms, ice and perhaps weather are the most studied. Direct impacts on the quality, distribution, and seasonal patterns of sea ice have been widely observed by walrus hunters, for example, in Barrow (C. Brower in Krupnik [2000]), Shishmaref (H. Pootookooluk and J. Sinnok in EWC [2003]), on St. Lawrence Island (E. Apassingok in

Krupnik [2000]; P. Omiak, Sr., L. Apangalook, and C. H. Petuwaq Koonooka in EWC [2003]; Oozeva et al. 2004), and in the Bering Strait generally (Pungowiyi 2000). These changes in sea ice are coupled with general changes in weather that have been more extreme over the last 10–20 years at St. Lawrence Island (Noongwook 2000), with fewer calm days in the Bering Strait (Pungowiyi 2000) and with less predictable patterns (C. Pungowiyi in Krupnik [2000]).

Changes in climate and its impact on sea ice, weather, and ocean productivity are likely to lead to changes in the health, distribution, and abundance of walrus prey and thus walrus feeding ecology (Grebmeier et al. 2006). These changes may also feed back to ocean productivity through the role of walrus in bioturbation of sediments. In this manner walrus are thought to integrate climate-controlled sea ice dynamics with benthic production at hierarchical scales of interaction (Ray et al. 2006). Coupled with the changes in sea ice, walrus may also be forced to redistribute to land, rather than using ice during summers (ice being preferred as substrate). However, by doing so, walrus are no longer on a mobile platform passing over a stationary benthic feeding habitat (in effect, becoming central place foragers). This risks walrus overexploiting benthic fauna within their foraging range from terrestrial haul-outs.

Walrus attendance at traditional haul-outs has changed in some regions (e.g., Smirnov et al. 2004); they have been hauling out in different places than normal in northern Alaska (C. Brower, *personal communication*; C. George, *personal communication*) and, in 2007, in much greater numbers on the Chukchi Sea coast. Changes in the terrestrial haul-out habits of walrus may place them in areas in which they are more vulnerable to disturbance (including as a result of shipping, offshore oil and gas development, or new fishing areas) and contamination. Greater use of coastal haul-outs may also lead to increased predation by polar bears (*Ursus maritimus*), and deaths as a result of stampeding (Kelly 2001). Ecologists can help address these processes through integrated assessments of factors determining such things as productivity, feeding behavior, sea ice dynamics, patchiness of food supply, and cascading trophic dynamics (Tynan and DeMaster 1997, Ray et al. 2006). Ecologists can also develop spatially explicit models that explore the potential scenarios that result from altered sea ice distributions (as a result of climate change) on the walrus population based on known ecological needs.

The health of the human–walrus relationship

Whereas walrus and ecosystem health might be limited to a biological or ecological investigation at multiple spatial and temporal scales, the health of the human–walrus relationship adds a complex suite of socioeconomic factors. Interactions and feedbacks within and between biological, ecological, and social systems at multiple scales provide significant complexity to an assessment of the health of the human–walrus relationship.

At perhaps the most fundamental level, the ability of hunters to safely and successfully access walrus and transport their catches back to communities has always been dependent upon favorable wind, ice, currents, and other weather conditions (Ellanna 1983). Research on subsistence hunting in Chukotka that integrated data on sea ice and weather conditions and villagers' observations confirmed profound decadal-scale shifts in their local success at walrus hunting. For example, the varying spring position and later northern retreat of seasonal pack ice led to differing walrus migration patterns and hunting success in different regions. During the previous warming phase of the 1930s and 1940s, communities in northern Chukotka seemed to have greater success at walrus hunting in the years when southern areas were doing poorly and vice versa (Krupnik and Bogoslovskaya 1999).

Changes in weather, ice, and oceanographic conditions have not only affected the migration timing and patterns for walrus (W. Takak in Craver [2001]) but also contributed to profound interannual and interdecadal variation in hunting season (Fig. 1). More rapid recession of sea ice (H. Toolie in Craver [2001]; P. Omiak, Sr., L. Apangalook, and D. Sockpick in EWC [2003]) can restrict the window of time available for hunters to provision themselves with walrus. Earlier recession of ice also leads to an earlier walrus-hunting season that can impinge on the preceding whaling season (that requires quieter tactics to be successful, using skin boats and sails that are less suited to a combined walrus hunt). The types of walrus traditionally harvested in the hunt by various communities may also be less available as a result of environmental change that differentially alters male and female migratory patterns. For example, the community of Gambell traditionally prefers to harvest females during the spring hunt, whereas the community of Diomede prefers to harvest males.

Changes in sea ice, weather, and walrus prey distribution collectively affect local walrus abundance and seasonal patterns. These factors can therefore indirectly force hunters to spend greater time in open water to effectively access and transport walrus back to communities. The generally greater extent of open water coupled with more severe weather such as greater winds and more storms then combine to make marine mammal hunting a much more dangerous venture (L. Apangalook in EWC [2003]). These changes further conspire with economic factors such as gas prices that can restrict a hunter's ability to spend enough time hunting to successfully maintain a healthy human–walrus relationship.

With these challenging and sometimes dangerous conditions come substantial threats to communities dependent on walrus hunting. The devastating famine on St. Lawrence Island in the 1880s highlighted the dependence of the region's communities on walrus. This dependence still exists today for several communities (Little and Robbins 1984), perhaps to a lesser extent than in the 19th century, but certainly to a significant degree. The economic viability of these communities relies on a successful traditional subsistence model that includes utilizing a natural resource in a sound ecological manner for food, materials, and handicrafts. For these communities, walrus are also a cultural resource and are an integral part of community life, a routine part of their world. Because of this familiarity and dependence, walrus represent both a foundation for a way of life and a challenge to preserve in an often-antagonistic world in which legal, political, and environmental viewpoints frequently collide.

In addition to challenges associated with hunting walrus, changes in the environment that impact walrus health and ecology can alter the health of the human–walrus relationship. Consequently, there are continued (and unanswered) questions from walrus hunters and their communities about walrus health and the risks and benefits of consuming walrus products. These questions can, in part, be measured through assessing the exposure to contaminants, biotoxins, and disease; the health of walrus; the nutritional quality of walrus products; and the manner in which these factors collectively impact communities. Contaminants and their relationship to both walrus health and the safety of walrus products for human consumers has been a prominent issue for the EWC for many years. Lentfer (1988:34) indicated the need to "determine the nature, level, and sources of contaminants, the effects of those contaminants on the health and reproduction of walruses, and the potential dangers (if any) for people of the Bering-Chukchi region who consume walrus meat." However, two decades later, apart from rudimentary reporting of "levels" for some contaminants, fundamental questions about the health of walrus and particularly the safety and nutritional value of walrus products for human consumption are still unaddressed and remain a primary concern for walrus hunters.

An altering climate is likely to affect contaminant pathways and therefore contaminant exposure for walrus. For example, if walrus begin to disperse further west along the Siberian coast, they may be subjected to more contaminated regions of the Arctic. Increasing water temperature may also increase methylation of mercury (Booth and Zeller 2005) and release contaminants from the melting ice pack (Macdonald et al. 2003). All these processes will work in conjunction with additional inputs of contaminants into the environment. There is general recognition that methyl mercury will continue to be of global concern, with increases in disposal from the United States and emissions from China (Booth and Zeller 2005). Based on hunter observations of unusual epidemiology and sparse information on contaminants, communities are concerned with assessing what is safe and dangerous in particular tissues and types of prepared foods.

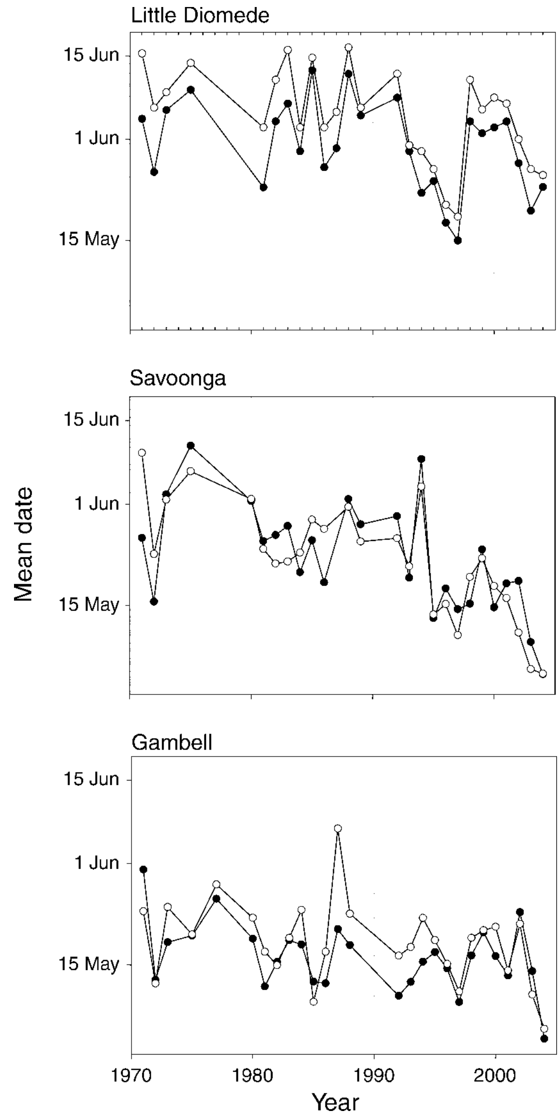

FIG. 1. Mean hunting date for adult male and female walrus recorded as harvested since 1970 during the spring hunt at the Bering Sea villages of Diomede (Little Diomede Island), Savoonga (St. Lawrence Island), and Gambell. Solid circles are females, and open circles are males. Data are not adjusted for season length of the spring hunt. Data were compiled from Alaska Department of Fish and Game and U.S. Fish and Wildlife Service unpublished annual harvest reports.

Finally, any discussion of health relating to the human–walrus relationship needs to incorporate social, economic, and political conditions. In Chukotka, the collapse of the Soviet era led to severe shortages in food, consumer goods, and employment. By 1998, supplies from outside Chukotka were exceeded by supplies (including walrus) from local hunters (Ainana 2000). The return to a greater reliance on a subsistence economy in Chukotka may provide an interesting model to consider for those that will become more reliant on local subsistence resources if Alaska is faced with economic recession in the future (that will act in conjunction with climate change impacts). Integrated scientific research can help address these diverse factors through identifying and characterizing the links between walrus, hunting communities, environmental health, economics, globalization, and climate change.

Discussion

Scientific research has largely focused on understanding the effects of climate change on the environment, ecosystem processes, and wildlife (Nuttall 2005). However, the challenges faced by communities that use walrus for subsistence are both increasingly dynamic and complex, including not only environmental changes (such as climate), but also economic, social, cultural, and political factors. Local repercussions from climate change for walrus and the communities that depend on them will be a complex mix of multiple negative and positive factors (Kelly 2001). We expect that these repercussions might be mitigated by the ability of local communities to learn about and understand the changes taking place in a timely manner.

It is likely that with a changing environment (including climate) altering walrus distribution, seasonal migration patterns, and health, local communities will also need to change. In order to sustain their relationship with walrus, a community's ability to adapt will depend on its traditional ecological knowledge system with support and complimentary research by science. Traditional ecological knowledge involves the human experience, and is, consequently, local in nature and a function of society. It is based in the traditions of learning the skills and knowledge necessary to live successfully where one is fundamentally reliant on local natural resources. It is because it is experiential and personal that all hunters and others living a subsistence lifestyle are "engaged in a life long personal search for ecological understanding…" (Battiste and Henderson 2000:45). Significant to understanding why this is a continual process of study is the concept that things inevitably change "in both predicable and unpredictable ways," and therefore adaptability is critical (Sahlins 1999, Battiste and Henderson 2000:46). Similarly, TEK should be considered an essential tool for true comanagement, since it is crucial to the maintenance of a community's involvement and partnership. Traditional ecological knowledge can support comanagement because it is traditional and community-based. It is traditional not because it is ancient and passed down for many generations; rather what makes this knowledge traditional is how it is acquired, how it is used, and that it can continue to develop (Pierotti and Wildcat 2000). The social nature of this knowledge is in the way it is shared and learned, which is in the unique cultural context of each indigenous group. This is the critical aspect for comanagement purposes: how it is learned, how it is evolving, and possibly where it is going.

We expect that research and policies governing the human–walrus relationship and management will also need to continually adapt to these new circumstances. Policy constraints that have been recognized by the EWC, the State of Alaska, the USFWS, and Chukotkan walrus managers to inhibit sound biological management of walrus throughout their range (Fay et al. 1989, Langdon 1989) are clearly barriers to moving forward.

All our questions are complex in their scientific scope, but not beyond the scope of current scientific inquiry. They require interdisciplinary approaches and novel methods to deal with multiple stressors (McCarthy and Martello 2005). Effective solutions to climate change impacts will likely require policy that is formulated from the integration of local perspectives with scientific expertise from biology, ecology, economics, law, political science, human behavior, adaptive management, statistical uncertainty, sociology, philosophy, ethics, and property rights (Meffe et al. 1999, Marsh et al. 2003). To address the uncertainty and scope of these needs, new management paradigms such as adaptive comanagement using interdisciplinary approaches that include humans within the environment (frequently termed social-ecological systems) may be of great use (Olsson et al. 2004). To develop trust within the comanagement arrangement, adaptive comanagement can offer opportunities for mutual learning, scenario building, and experimental policies that reflect local and national needs for a more holistic understanding and management of the human–walrus ecosystem (Olsson et al. 2004). Communities that believe and strongly hold that their well-being and future depend on walrus hunting will be the best partners in comanagement. Finally, there is a need to better understand and discuss the social changes that frequently occur when specific resources are restricted in resource-dependent communities (either through ecological, economic, social, or political limits to availability).

Despite the challenges, the research areas presented in this paper related to health of walrus, the walrus environment, and the human–walrus relationship could aid our understanding of climate change in a manner that includes those people who will feel the impacts first and most intensely. However, answering questions brought forward by the EWC will only be fulfilled if local needs manifest as priorities to community hunters, agencies, and scientists who wish to build effective partnerships and to funding institutions that will support these locally driven ventures.

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Literature Cited

ACIA [Arctic Climate Impact Assessment]. 2005. Scientific report. Cambridge University Press, Cambridge, UK.

Adger, W. N., K. Brown, and E. L. Tompkins. 2006. The political economy of cross-scale networks in resource co-management. Ecology and Society 10:9. ⟨http://www.ecologyandsociety.org/vol10/iss2/art9/⟩

Ainana, L. 2000. Preservation and development of the subsistence lifestyle and traditional use of natural resources by native people (Eskimo and Chukchi) in selected coastal communities (Inchoun, Uelen, Lorino, Lavrentiya, Novoye Chaplino, Sireniki, Nunligran, Enmelen) of Chukotka in the Russian Far East during 1998. National Park Service, Anchorage, Alaska, USA.

Albert, T. F. 1988. The role of the North Slope Borough in Arctic environmental research. Arctic Research of the United States 2:17–23.

Battiste, M., and J. Y. Henderson. 2000. Protecting indigenous knowledge and heritage: a global challenge. Purich, Saskatoon, Saskatchewan, Canada.

Berkes, F. 1999. Sacred ecology: traditional ecological knowledge and resource management. Taylor and Francis, Philadelphia, Pennsylvania, USA.

Berkes, F., N. Bankes, M. Marschke, D. Armitage, and D. Clark. 2005. Cross-scale institutions and building resilience in the Canadian North. Pages 225–247 *in* F. Berkes, R. Huebert, H. Fast, M. Manseau, and A. Diduck, editors. Breaking ice: renewable resource and ocean management in the Canadian North. University of Calgary Press, Calgary, Alberta, Canada.

Booth, S., and D. Zeller. 2005. Mercury, food webs, and marine mammals: implications of diet and climate change for human health. Environmental Health Perspectives 113:521–526.

Burek, K. A., F. M. D. Gulland, and T. M. O'Hara. 2008. Effects of climate change on Arctic marine mammal health. Ecological Applications 18(Supplement):S126–S134.

Castro, A. P., and E. Nielsen. 2001. Indigenous people and co-management: implications for conflict management. Environmental Science and Resource Policy 4:229–239.

Caulfield, R. A. 2000. Political economy of renewable resource harvesting in the Arctic. Pages 485–513 *in* M. Nuttall and T. V. Callaghan, editors. The Arctic: environment, people, policy. Harwood Academic, Amsterdam, The Netherlands.

Chambers, J. J. 1999. Co-management of walrus in Alaska: The Eskimo Walrus Commission and the U.S. Fish and Wildlife Service. Thesis. University of Alaska, Fairbanks, Alaska, USA.

Cooper, L.W., C. J. Ashijian, S. L. Smith, L. A. Codispoti, J. M. Grebmeier, R. G. Campbell, and E. B. Sherr. 2006. Rapid seasonal sea-ice retreat in the Arctic could be affecting Pacific walrus (*Odobenus rosmarus divergens*) recruitment. Aquatic Mammals 32:98–102.

Craver, A. 2001. Alaska subsistence lifestyles face changing climate. Northwest Public Health. Fall/Winter 2001:8–9.

Crowell, A. L., and E. Oozevaseuk. 2006. The St. Lawrence Island famine and epidemic, 1878–80: a Yupik narrative in cultural and historical context. Arctic Anthropology 43:1–19.

Ellanna, L. J. 1983. Bering Strait Insular Eskimo: a diachronic study of economy and population structure. Division of Subsistence Technical Paper Number 77. Alaska Department of Fish and Game, Anchorage, Alaska, USA.

EWC [Eskimo Walrus Commission]. 2003. Conserving our culture through traditional management. Kawerak, Nome, Alaska, USA.

Fay, F. H. 1982. Ecology and biology of the Pacific walrus, *Odobenus rosmarus divergens*, Illiger. North American Fauna 74. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., USA.

Fay, F. H., and J. J. Burns. 1988. Maximal feeding depth of Pacific walruses. Arctic 41:239–240.

Fay, F. H., B. P. Kelly, and J. L. Sease. 1989. Managing the exploitation of Pacific walruses: a tragedy of delayed response and poor communication. Marine Mammal Science 5:1–16.

Feit, H. A. 1998. Self-management and government management of wildlife: prospects for coordination in James Bay and Canada. Pages 95–111 *in* R. J. Hoage and K. Moran, editors. Culture: the missing element in conservation and development. Kendall/Hunt, Dubuque, Iowa, USA.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. S. Holling, and B. Walker. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. Ambio 31:437–440.

Garlich-Miller, J. L., L. T. Quakenbush, and J. F. Bromaghin. 2006. Trends in age structure and productivity of Pacific walruses harvested in the Bering Strait region of Alaska, 1952–2002. Marine Mammal Science 22:880–896.

Gearheard, S., W. Matumeak, I. Angutikjuaq, J. Maslanik, H. P. Huntington, J. Leavitt, D. Matumeak Kagak, G. Tigullaraq, and R. G. Barry. 2006. "It's not that simple": a collaborative comparison of sea ice environments, their uses, observed changes, and adaptations in Barrow, Alaska, USA, and Clyde River, Nunavut, Canada. Ambio 35:203–211.

Gray, I., and P. Sinclair. 2005. Local leaders in a global setting: dependency and resistance in regional New South Wales and Newfoundland. Sociologia Ruralis 45:37–52.

Grebmeier, J. M., J. E. Overland, S. E. Moore, E. V. Farley, E. C. Carmack, L. W. Cooper, K. E. Frey, J. H. Helle, F. A. McLaughlin, and S. L. McNutt. 2006. A major ecosystem shift in the northern Bering Sea. Science 311:1461–1464.

Hunn, E. S., D. R. Johnson, P. N. Russel, and T. F. Thornton. 2003. Huna Tlingit traditional environmental knowledge, conservation, and the management of a "wilderness" park. Current Anthropology 44(Supplement):S79–S103.

Huntington, H. P. 1989. The Alaska Eskimo Whaling Commission: effective local management of a subsistence resource. Dissertation. Scott Polar Research Institute, University of Cambridge, Cambridge, UK.

Huntington, H. P. 1998. Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge. Arctic 51:237–242.

Huntington, H. P. 2000. Using traditional ecological knowledge in science: methods and applications. Ecological Applications 10:1270–1274.

Huntington, H., T. Callaghan, S. Fox, and I. Krupnik. 2004. Matching traditional and scientific observations to detect environmental change: a discussion on Arctic terrestrial systems. Ambio 13:18–23.

Huntington, H. P., and S. Fox. 2005. The changing Arctic: indigenous perspectives. Pages 61–98 *in* Arctic Climate Impact Assessment: Scientific report. Cambridge University Press, Cambridge, UK.

Kellert, S. R., J. N. Mehta, S. A. Ebbin, and L. L. Lichtenfeld. 2000. Community natural resource management: promise, rhetoric, and reality. Society and Natural Resources 13:705–715.

Kelly, B. P. 2001. Climate change and ice breeding pinnipeds. Pages 43–55 *in* G.-R. Walther, C. A. Burga, and P. J. Edwards, editors. "Fingerprints" of climate change. Kluwer Academic/Plenum, New York, New York, USA.

Kofinas, G. 2005. Hunters and researchers at the co-management interface: emergent dilemmas and the problem of legitimacy. Anthropologica 47:179–196.

Krupnik, I. 2000. Native perspectives on climate and sea-ice changes. Pages 25–39 *in* H. P. Huntington, editor. Impacts of changes in sea ice and other environmental parameters in the Arctic. Report of the Marine Mammal Commission Workshop, Girdwood, Alaska, 15–17 February 2000. Marine Mammal Commission, Bethesda, Maryland, USA.

Krupnik, I. I., and L. S. Bogoslovskaya. 1999. Old records, new stories: ecosystem variability and subsistence hunting in the Bering Strait area. Arctic Research of the United States 13: 15–24.

Krupnik, I. I., and D. Jolly, editors. 2002. The earth is faster now: indigenous observations of Arctic environmental change. Arctic Research Consortium of the United States, Fairbanks, Alaska, USA.

Langdon, S. 1984. Alaska native subsistence: current regulatory regimes and issues. Alaska Native Review Commission XIX. Alaska Native Review Commission, Anchorage, Alaska, USA.

Langdon, S. 1989. Prospects for co-management of marine mammals in Alaska. Pages 154–169 *in* E. Pinkerton, editor. Co-operative management of local fisheries: new directions for improved management and community development. University of British Columbia Press, Vancouver, British Columbia, USA.

Lentfer, J. W. 1988. Selected marine mammals of Alaska: species accounts with research and management recommendations. Marine Mammal Commission, Washington, D.C., USA.

Little, R. L., and L. A. Robbins. 1984. Effects of renewable resource harvest disruptions on socioeconomic and sociocultural systems: St. Lawrence Island. Alaska Outer Continental Shelf Office, U.S. Minerals Management Service, Anchorage, Alaska, USA.

Macdonald, R. W., D. Mackay, Y.-F. Li, and B. Hickie. 2003. How will global climate change affect risks from long-range transport of persistent organic pollutants? Human and Ecological Risk Assessment 9:643–660.

Marsh, H., P. Arnold, M. Freeman, D. Haynes, D. Laist, A. J. Read, J. Reynolds, and T. Kasuya. 2003. Strategies for conserving marine mammals. Pages 1–19 *in* N. Gales and M. Hindell, editors. Marine mammals: fisheries, tourism and management issues. CSIRO Publishing, Collingwood, Victoria, Australia.

Maslanik, J. A., M. C. Serreze, and T. Agnew. 1999. On the record reduction in western Arctic sea ice cover in 1998. Geophysical Research Letters 26:1905–1908.

McCarthy, J. J., and M. L. Martello. 2005. Climate change in the context of multiple stressors and resilience. Pages 945–988 *in* Arctic Climate Impact Assessment: Scientific report. Cambridge University Press, Cambridge, UK.

Meffe, G. K., W. F. Perrin, and P. K. Dayton. 1999. Marine mammal conservation: guiding principles and their implementation. Pages 437–454 *in* J. R. Twiss, Jr. and R. R. Reeves, editors. Conservation and management of marine mammals. Smithsonian Institution Press, Washington, D.C., USA.

Mudar, K., and S. Speaker. 2003. Natural catastrophes in Arctic populations: the 1878–1880 famine on St. Lawrence Island, Alaska. Journal of Anthropological Archaeology 22: 75–104.

Nadasdy, P. 1999. The politics of TEK: power and the "integration" of knowledge. Arctic Anthropology 36:1–18.

Nadasdy, P. 2003. Reevaluating the co-management success story. Arctic 56:367–380.

Natcher, D. C., S. Davis, and C. G. Hickey. 2005. Co-management: managing relationships, not resources. Human Organization 64:240–250.

Noongwook, G. 2000. Native observations of local climate changes around St. Lawrence Island. Pages 30–34 *in* H. P. Huntington, editor. Impacts of changes in sea ice and other environmental parameters in the Arctic. Marine Mammal Commission, Bethesda, Maryland, USA.

Nuttall, M. 2005. Hunting, herding, fishing, and gathering: indigenous peoples and renewable resource use in the Arctic. Pages 649–690 *in* Arctic Climate Impact Assessment: Scientific report. Cambridge University Press, Cambridge, UK.

Olsson, P., C. Folke, and F. Berkes. 2004. Adaptive co-management for building resilience in social-ecological systems. Environmental Management 34:75–90.

Oozeva, C., C. Noongwook, G. Noongwook, C. Alowa, and I. Krupnik. 2004. Watching ice and weather our way/Akulki, Tapghaghmii, Mangtaaquli, Sunqaanga, Igor Krupnik. Sikumengllu Eslamengllu Esghapalleghput. Arctic Studies Center, Smithsonian Institution, Washington, D.C., USA.

Pierotti, R., and D. Wildcat. 2000. Traditional ecological knowledge: the third alternative. Ecological Applications 10: 1333–1340.

Pinkerton, E. 2003. Toward specificity in complexity: understanding co-management from a social science perspective. Pages 61–77 *in* D. C. Wilson, J. R. Nielsen, and P. Degnbol, editors. The fisheries co-management experience: accomplishments, challenges, and prospects. Kluwer, Dordrecht, The Netherlands.

Pitcher, T. J. 2001. Fisheries managed to rebuild ecosystems? Reconstructing the past to salvage the future. Ecological Applications 11:601–617.

Pomeroy, R. S., and F. Berkes. 1997. Two to tango: the role of government in fisheries co-management. Marine Policy 21: 465–480.

Pungowiyi, C. 2000. Native observations of change in the marine environment of the Bering Strait region. Pages 26–29 *in* H. P. Huntington, editor. Impacts of changes in sea ice and other environmental parameters in the Arctic. Report of the Marine Mammal Commission workshop, Girdwood, Alaska, 15–17 February 2000. Marine Mammal Commission, Bethesda, Maryland, USA.

Ray, G. C., J. McCormick-Ray, P. Berg, and H. E. Epstein. 2006. Pacific walrus: benthic bioturbator of Beringia. Journal of Experimental Marine Biology and Ecology 330:403–419.

Rose, G. A. 1997. The trouble with fisheries science. Reviews in Fisheries Biology and Fisheries 7:365–370.

Sahlins, M. 1999. What is anthropological enlightenment? Some lessons of the twentieth century. Annual Review of Anthropology 28:i–xxiii.

Schneider, D. C. 2001. The rise of the concept of scale in ecology. BioScience 51:545–553.

Smirnov, G., M. Litovka, A. Pereverzev, V. Tneskin, Y. Klimenko, and N. Rultyntegreu. 2004. Conservation and environmental monitoring of coastal walrus haul-outs in the Gulf of Anadyr in 2003. Technical Report. National Fish and Wildlife Foundation, Washington, D.C., USA.

Stevenson, M. G. 2006. The possibility of difference: rethinking co-management. Human Organization 65:167–180.

Tynan, C. T., and D. P. DeMaster. 1997. Observations and predictions of Arctic climate change: potential effects on marine mammals. Arctic 50:308–322.

Wenzel, G. W. 1999. Traditional ecological knowledge and Inuit: reflections on TEK research and ethics. Arctic 52:113–124.