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Changing Daily Wind Speeds on Alaska's North Slope: Implications for Rural Hunting Opportunities

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ABSTRACT. Because of their reliance on the harvest of fish and game, Alaskan rural communities have experienced a variety of impacts from climate change, the effects of which are amplified at high latitudes. We collaborated with hunters from the coastal community of Wainwright, Alaska, to document their observations of environmental change (e.g., sea ice, wind, temperature) and the implications of those changes for opportunities to hunt bowhead whale (*Balaena mysticetus*) during spring and caribou (*Rangifer tarandus*) during summer. We integrated hunter observations on wind with statistical analysis of daily wind speed data collected in the nearby community of Barrow, Alaska, between 1971 and 2010 to characterize changes in the number of days with suitable hunting conditions. Hunters in Wainwright currently observe fewer days than in previous decades with wind conditions suitable for safely hunting bowhead whales and caribou. The statistical analysis of wind speed data supported these conclusions and suggested that the annual windows of opportunity for hunting each species have decreased by up to seven days since 1971. This study demonstrates the potential power of collaboration between local communities and researchers to characterize the societal impacts of climate change. Continued collaborative research with residents of rural northern Alaskan communities could produce knowledge and develop tools to help rural Alaskans adapt to novel social-ecological conditions.

Key words: Alaska, bowhead whale, caribou, wind speed, North Slope, social-ecological system

RÉSUMÉ. Les collectivités rurales de l'Alaska dépendent de la récolte du poisson et du gibier et à ce titre, elles sont assujetties à une panoplie d'incidences découlant du changement climatique, dont les effets sont amplifiés en haute altitude. Grâce à l'aide des chasseurs de la collectivité côtière de Wainwright, en Alaska, nous avons consigné les observations de ces chasseurs relativement à l'évolution de l'environnement (en ce qui a trait, par exemple, à la glace de mer, au vent et aux températures) de même que les incidences de cette évolution sur les possibilités de chasse de la baleine boréale (*Balaena mysticetus*) au printemps, et du caribou (*Rangifer tarandus*) à l'été. Nous avons intégré les observations des chasseurs au sujet du vent à l'analyse statistique des données de la vitesse quotidienne du vent, données recueillies dans la localité avoisinante de Barrow, en Alaska, entre 1971 et 2010, afin de caractériser les changements quant au nombre de jours où les conditions de chasse sont convenables. Comparativement aux décennies précédentes, les chasseurs de Wainwright observent un moins grand nombre de jours, à l'heure actuelle, qu'au cours des décennies précédentes pendant lesquels le régime des vents se prête à la chasse sécuritaire de la baleine boréale et du caribou. L'analyse statistique des données de la vitesse du vent permet de soutenir ces conclusions et suggère qu'annuellement, la période pendant laquelle chacune de ces espèces peut faire l'objet de la chasse a diminué dans une mesure allant jusqu'à sept jours depuis 1971. Cette étude témoigne du pouvoir de collaboration qui pourrait exister entre les collectivités de la région et les chercheurs dans le but de caractériser les incidences du changement climatique sur la société. Les travaux de recherche en collaboration continue avec les habitants des collectivités rurales du nord de l'Alaska pourraient permettre de produire des connaissances et d'élaborer des outils qui aideraient les Alaskiens à s'adapter aux nouvelles conditions socioécologiques.

Mots clés : Alaska, baleine boréale, caribou, vitesse du vent, North Slope, système socioécologique

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INTRODUCTION

Ecosystems in northern Alaska are undergoing a variety of transitions resulting from climate change, the effects of which are amplified at high latitudes (Overpeck et al., 1997; Serreze et al., 2000). Rural communities in the region are isolated from urban centers and rely on harvesting ecosystem services, i.e., goods and services directly provided by their environment (Daily et al., 1997), as they have done for thousands of years. This dependence on ecosystem services (e.g., fish and game) makes many communities in rural Alaska key components of social-ecological systems (SESs)—integrated and dynamic systems in which people depend on resources drawn from their environment and influence ecological processes (Berkes and Folke, 1998). The harvest of fish and game to maintain local livelihoods also shapes and is shaped by cultural identities (Borré, 1991).

As a result of this connection, rural communities may be nutritionally and culturally sensitive to climatic transitions that alter their ability to access important fish and game resources (Chapin et al., 2006a; Laidler, 2006; Larsen et al., 2008). In this paper, we incorporate two different forms of knowledge to document some changes in climate and their implications for the availability of fish and game. Specifically, we focus on how changes over time in the number of days with suitable wind conditions during critical hunting seasons affect opportunities for the residents of Wainwright, a rural northern Alaskan community, to hunt caribou (*Rangifer tarandus*) and bowhead whale (*Balaena mysticetus*).

Much research has evaluated the environmental and societal consequences of climate change in Alaska (Kruse et al., 2004; Berner et al., 2005; Calef et al., 2005; Hinzman et al., 2005; Chapin et al., 2006b; Kofinas et al., 2010). Some documented impacts on rural Alaskans include decreasing sea ice extent and thickness, alteration of habitats important for the provision of fish and game, and thawing permafrost (Macdonald et al., 2005; Stroeve et al., 2008; Post et al., 2009). The majority of research has focused on the consequences of directional trends in climate that occur on monthly, annual, or decadal time scales. However, changes over time in the characteristics of day-to-day weather anomalies may also affect the availability of fish and game (Katz and Brown, 1992; Diffenbaugh et al., 2005; Gearheard et al., 2006; McNeeley and Shulski, 2011). For example, Berkes and Jolly (2001) described local observations of changes in the timing and intensity of weather events in the rural community of Sachs Harbour, Canada, that affect the community's ability to predict conditions and travel safely while engaged in the harvest of fish and game. Residents of Arctic Bay and Igoolik, Canada, noted dramatic changes in overall weather conditions, including the strength, direction, and predictability of wind and associated ice conditions, more sudden weather events, and the occurrence of unusual weather events such as rain in the winter (Ford et al., 2006a, 2008). Similar observations of changes in wind were recorded on St. Lawrence Island, Alaska (Noongwook, 2000).

While locally observed environmental change documented in qualitative research provides a rich and contextually valuable perspective that helps to identify important relationships, complementary quantitative analysis can further characterize critical details about the nature of changes (Berman and Kofinas, 2004). Few papers have attempted to pair local observations of changing day-to-day weather anomalies in Alaska with quantitative analysis. Walsh et al. (2005) evaluated statistical variance and persistence i.e., serial auto-correlation, in time series of daily maximum and minimum temperatures recorded at 54 northern meteorological stations between 1950 and 2000. The study attempted a quantitative explanation of statements made by rural indigenous Alaskans, who assert an increasing inability to predict daily weather with traditional methods. In the Alaskan subset of the data, results provided some evidence for increasing variance (i.e., unpredictability) in daily maximum temperature patterns during winter and spring, both critical seasons for the harvest of fish and game in northern Alaska. Another study addressing the increasing unpredictability of weather investigated statistical persistence in the values of hourly temperatures using 50 years of data from Baker Lake, Canada (Weatherhead et al., 2010). The authors found increasing variability in afternoon temperatures from one day to the next during spring.

The rich situational context provided in the results of qualitative research is frequently lost when researchers have attempted to further characterize the nature of local observations quantitatively. We propose that a holistic perspective, achieved by integrating the documentation of local knowledge with statistical analysis, may provide the most comprehensive understanding of the impacts and consequences of climate changes for rural Alaskan communities (Berman and Kofinas, 2004; Ashjian et al., 2010; McNeeley and Shulski, 2011). For example, Gearheard et al. (2010) integrated local knowledge from residents of Clyde River, Canada, with long-term meteorological observations to quantify changes in wind speed, wind direction, and variability of wind around the community. Comparisons of the two knowledge sources provided mixed results regarding the occurrence and nature of changes and identified where future research was needed to explain discrepancies.

The first objective of this paper was to collaborate with local hunters in the community of Wainwright, Alaska, to document their observations of changes in daily weather conditions over time and their perceptions of the resulting impacts on hunting opportunities. Although hunters described the dynamics of many daily weather variables (e.g., temperature, precipitation, sea ice conditions), we limited our evaluation to observed changes in the number of days with suitable wind conditions during critical hunting seasons because clear and distinct relationships were identified between wind conditions and the availability of multiple harvested species. Because long-term and frequently collected wind data were available from a weather station at Barrow, Alaska, the nearest coastal community to Wainwright, our second objective was to conduct a statistical analysis of that data set for comparison with the observations of hunters in Wainwright.

METHODS

Study Site

The village of Wainwright, Alaska, is located at 70˚38′ N, and 160˚0′ W, on the coast of the Chukchi Sea in northwest Alaska (Fig. 1). Wainwright is approximately 480 km north of the Arctic Circle and has a population of 556 people, of whom 90% are Iñupiat Eskimo (U.S. Census Bureau, 2010). Climatological conditions around Wainwright are harsh, characterized by cold, dark winters and moderate summers. The average temperature between 2001 and 2010 was −23˚C in January and 7˚C in July (Scenarios Network for Alaska Planning, 2011).

Located 145 km from Barrow, Wainwright is isolated from urban centers and accessible only by plane, boat, or snowmobile, depending on the season. Residents of the community take part in a mixed cash-subsistence economy, relying on locally harvested fish and game as well as store-bought foods. The cost of living is significantly higher in Wainwright and other rural communities in northern Alaska than in urban Alaska and the rest of the United States (Martin, 2012). Average annual per capita income between 2007 and 2011 was estimated at $20 653 (2011 U.S. real dollars) (ADLWD, 2013). Local plants and animals harvested from near the community play an important role in food security. On average, people in Arctic Alaska harvest approximately 200 kg of wild foods per person per year (Wolfe, 2004; Fall, 2012).

Interview Methods

With permission from the Wainwright Traditional Council, we conducted semi-structured interviews (Huntington, 1998) of resident hunters regarding changes in the number of days with suitable wind conditions for harvesting fish and game and the impacts of those changes on the availability of important species. During interviews, we discussed key topics and themes with participants instead of following a strict interview protocol (Huntington, 1998; Carter and Nielsen, 2011). This approach allowed for flexibility during discussions that might facilitate the emergence of novel concepts (Ford et al., 2006b).

With guidance from the Wainwright Traditional Council and Tribal Corporation (Olgoonik Corp.), we chose interview participants on the basis of their past hunting experience and current level of engagement in harvesting activities. As a result, all interview participants were considered to have an above-average familiarity with the local hunting system and weather patterns. We interviewed one to four hunters at a time, and we organized groups so that participants were familiar with one another (e.g., family relations, hunting partners) to provide a comfortable atmosphere that encouraged open discussion. We protected the anonymity of all participants.

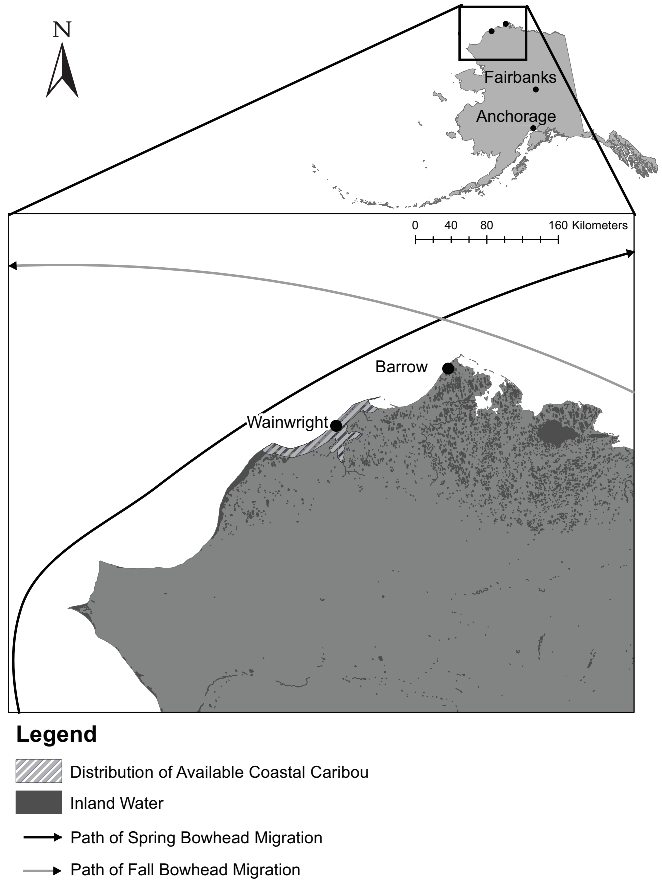

FIG. 1. Map of Wainwright, Alaska, and surrounding area. Also shown are the spring and fall bowhead migration paths and the distribution of coastal caribou during spring and summer.

Wind Speed Analysis

To further characterize the locally observed patterns of changes in wind conditions around Wainwright, we calculated changes from 1971 to 2010 in the number of days per hunting season with wind conditions considered safe for spring whaling and summer caribou hunting. We chose this time frame to best reflect our interview participants' frame of reference on the land. Interview participants were uncomfortable quantifying wind speed thresholds that corresponded to conditions considered safe for boating. Therefore, we relied on previous findings to define those thresholds. In an analysis of wind speeds on spring days when bowhead whales were harvested in Barrow, Alaska (Fig. 1), between 1990 and 1997, George et al. (2003) found that winds blowing less than 11 m/s were required for successful, safe spring whale harvests. However, fundamental differences exist between spring bowhead whaling in Barrow and in Wainwright. Wainwright interview participants described traveling many kilometers from the ice edge out into leads, sections of open ocean where wind has a relatively large effect on ocean roughness. Conversely, Barrow whalers travel short distances from the ice edge, often only 200 m, which reduces the impact of wind speed on ocean conditions and the consequent safety concerns (George et al., 2003).

Similarities in the distances traveled and levels of exposure to open water suggest that the conditions necessary for safe spring whaling and summer caribou hunting in Wainwright are more similar to those necessary for whaling in Barrow in the fall, when hunters travel farther from shore or shorefast ice (Moore and Clarke, 1992; George et al., 2003). An analysis of data from fall bowhead whale harvests in Barrow from 1984 to 2004 found that 85% of whales were harvested on days with a mean wind speed of less than 6 m/s (Ashjian et al., 2010). To provide a comprehensive statistical analysis of changes over time in the number of days with wind conditions suitable for hunting in Wainwright, we investigated both the 6 m/s and 11 m/s thresholds.

Wind speeds were recorded once every three hours at the Post Rogers Memorial Airport in Barrow, Alaska (71˚17′ N, 156˚47′ W), between 1971 and 2010 and were accessed through the Surface Hourly, Global (DS 3505) dataset of the National Climatic Data Center, National Oceanic and Atmospheric Administration (NCDC, 2013). Barrow is approximately 145 km northeast of Wainwright (Fig. 1). Both are located in similar settings on the Arctic coast and experience comparable wind conditions. During 2005, the only year with complete wind data for Wainwright, mean daily wind speeds for Barrow and Wainwright were positively correlated (Spearman's correlation coefficient = 0.82, $p < 0.01$).

Using Stata 10 (Stata Corp., 2007), we calculated average daily wind speeds during the spring whale (15 April – 15 June) and summer caribou (1 July – 31 August) hunting seasons. We then calculated the annual frequency of days per hunting season with an average wind speed equal to or below 6 m/s and 11 m/s. Data resulting from using the 6 m/s threshold met the model assumptions necessary to use ordinary least squares linear regression (OLS). We calculated variable coefficients and associated p-values to characterize changes over time in the number of days with suitable wind conditions per spring (whale) and summer (caribou) hunting season and evaluate their statistical significance.

The skewed distribution of days per hunting season between 1971 and 2010 with wind speeds below the 11 m/s threshold violated the assumption of normality of errors and precluded the use of OLS. To characterize changes over time using this threshold, we coded any season between 1971 and 2010 that had at least one day with average wind speed exceeding 11 m/s as one, and seasons during which winds did not exceed 11 m/s as zero. We then used logistic regression to calculate how the predicted probability that average daily wind speed would exceed the 11 m/s threshold at least once during any given season changed between 1971 and 2010. We evaluated the statistical significance of the relationship using the likelihood ratio test.

RESULTS

Wainwright Local Knowledge

We interviewed seven groups of hunters, totaling 17 individuals. During discussions, interview participants described relying on many species of fish and game to maintain food security. They also identified wind as a major determinant of access to two critical resources: bowhead whales and caribou. Bowhead whaling occurs in Wainwright in spring between mid-April and mid-June. Whaling crews journey by snowmobile from the coast over sea ice to leads. From there, crews launch boats to pursue whales and shoot them as they surface (Alaska Eskimo Whaling Commission, 2010). Harvested whales are towed back to shore for butchering, and the meat is shared with the entire community. The bowhead whale harvest plays a significant role in meeting nutritional requirements for most Wainwright residents (Wolfe, 2004; Kassam, 2009).

Interview participants explained that winds are the chief influence on characteristics of leads in the ice, which determine day-to-day hunting success. Hunters reported that strong winds from the south or east are required to open leads. Hunters felt that there were now a greater number of these leads opening than in the past and that they were larger. However, after leads open, calmer days are also necessary for the actual hunting of whales. If strong winds persist after a lead is open, rough seas increase the logistical challenges of whaling and endanger whaling crews. While some disagreement existed among interview participants, the majority of hunters believed that the number of days too windy to hunt whales had increased over approximately the last four decades. In fact, some hunters suggested that winds were now keeping them off the water an equivalent of an additional three to four days a week over the course of the season (i.e., ~50% decrease in access). Hunters felt that larger leads magnified the effects of consistently stronger winds by increasing wave sizes. Participants emphasized that the window for spring whaling is short and that consistently rough seas significantly reduce hunter success in harvesting whales. Some interview participants mentioned that they were not able to harvest as many whales as they used to because of the weather conditions.

Interview participants stated that although Wainwright hunters harvest caribou year-round, most are harvested by boat in July and August. During that time, hunters travel along the coast and rivers in search of caribou herds that gather near the water to escape warm inland temperatures and avoid summer insect harassment (Nelson, 1982). Interview participants confirmed that caribou harvests play an integral role in food security for the people of Wainwright (Nelson, 1969; Kassam and the Wainwright Traditional Council, 2001). By edible volume, the caribou harvest has been and continues to be similar to that of bowhead whale (Nelson, 1982; Bacon et al., 2009).

During the summer caribou hunting season, the coastal waters are clear of ice. Interview participants stated that in summer, windy conditions create rougher seas than in the spring because of receding sea ice. Pack ice often serves to dampen waves, thus ameliorating ocean conditions. Increased distances between the coast and the sea ice make it more likely that strong winds will produce larger waves, which amplify the effect on boating conditions. Further, participants mentioned that windy conditions reduce insect harassment, allowing caribou to stay inland, spread out, and become less accessible to hunters traveling by boat. Interview participants felt that the number of days with wind conditions suitable for safe travel to caribou hunting areas during the summer, like the number of days suitable for spring whale hunting, has decreased in recent decades.

While discussing the availability of both bowhead whales and caribou, hunters acknowledged that directional climatic trends on monthly, annual, and decadal scales also influenced hunting opportunities. However, they felt that the most critical changes occurred from day to day, citing changes in where, when, and whether leads open and the height of waves on a given day as a result of wind.

Wind Speed Data Results

Most results from the analysis of wind speed data recorded at the Barrow meteorological station between 1971 and 2010 provided support for the observations made by hunters in Wainwright, Alaska (Table 1). We found that the frequency of days with suitable wind conditions during both the spring whaling season and summer caribou hunting season decreased over time for three out of the four analyses conducted, concurring with qualitative conclusions. Using the 6 m/s threshold, the number of suitable spring days per season did not decrease significantly, with a coefficient of −0.18 (p = 0.11) (Fig. 2; Table 1). Logistic regression analysis showed that having a spring day on which average wind speeds exceeded 11 m/s was 33.4 times more likely in 2010 than in 1971 ($p < 0.05$) (Fig. 3; Table 1).

The number of summer days with suitable wind conditions per season using the 6 m/s threshold decreased with a coefficient of −0.19 ($p < 0.05$) (Fig. 4; Table 1). In other words, the average window of opportunity to hunt caribou decreased by 0.19 days per year from 1971 to 2010. The logistic regression analysis shows that having a summer day on which average wind speeds exceeded 11 m/s was 15.3 times more likely in 2010 than in 1971 ($p < 0.05$) (Fig. 5; Table 1). These findings indicate that hunters in Wainwright now have up to seven fewer days per year to hunt whales safely and seven fewer days per year to hunt caribou safely than they had in 1971.

TABLE 1. Final estimation results from ordinary least squares (OLS) regression and logistic regression quantifying changes in the number of days per season with average daily wind speeds below 6 m/s and the predicted probability that average daily wind speed exceeded 11 m/s at least once during any given season between 1971 and 2010. OLS and logistic coefficients are presented with standard errors in parentheses. Logistic odds ratios (OR) are also provided.

	Spring (15 April – 15 June)		Summer (1 July – 31 August)	
Variable	6 m/s (OLS)	11 m/s (Logistic)	6 m/s (OLS)	11 m/s (Logistic)
Year	-0.18	0.093**	−0.19**	0.074**
	(0.11)	(.038)	(0.08)	(0.036)
		OR: 1.10		OR: 1.08
Constant	396*	−186.18***	422.5***	−147.77***
	(217.1)	(75.55)	(155.8)	(71.66)
		OR: < 0.001		OR: < 0.001
Observations	40	40	40	40
R-Squared	0.07		0.14	
Pseudo R-squared		0.16		0.10
Log likelihood		−20.6		−21.1

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

DISCUSSION AND IMPLICATIONS

We collaborated with hunters in the northern rural community of Wainwright, Alaska, to document local observations of changes in the number of days with suitable wind conditions for hunting and the perceived impacts of those changes on opportunities for hunting bowhead whale in spring and caribou in summer. Additionally, we conducted a statistical analysis of daily wind data between 1971 and 2010 to further characterize the patterns observed by hunters. In concurrence with qualitative conclusions, the majority of results from the statistical analysis indicated a decreasing frequency of suitable days during the spring bowhead whaling season and summer caribou hunting season. The annual windows of opportunity for hunting have decreased by up to 11% during the spring and 12% during the summer since 1971. However, the consequences for rural livelihoods resulting from the effects of wind on hunting opportunities are highly complex because of the dynamic nature of the broader social-ecological context. Impacts may differ dramatically depending on the time of year and species being hunted.

Conflicting Effects of Wind on Spring Bowhead Whaling

The decreasing frequency of days with suitable wind conditions has conflicting and potentially non-linear effects on hunting opportunities and harvest levels during the spring bowhead whaling season. Interview participants stated repeatedly that strong winds create rough seas in open waters of the leads. Consistently rough conditions make whaling logistically more challenging and threaten the safety of crews themselves. As the window of opportunity decreases, whaling crews have fewer days with safe conditions on which to harvest whales each year.

There is also potential for negative additive effects as a result of interactions between changes in wind and other important social-ecological variables. For example, sea ice conditions play a critical role in successful whale harvests. Beginning in the winter before the hunt starts, whaling

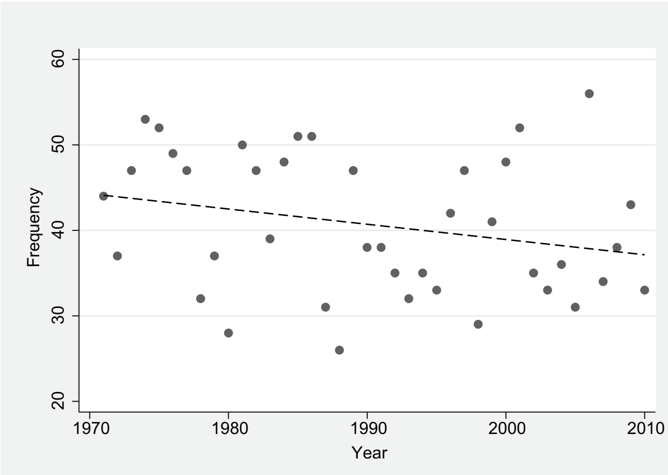

FIG. 2. Frequency of days with suitable wind conditions (< 6 m/s) during the spring bowhead whale season (15 April–15 June) of 1971–2010. Coefficient = −0.18 ($p = 0.11$). Figures on the y-axis represent the number of days between 15 April and 15 June with a mean wind speed equal to or below 6 m/s.

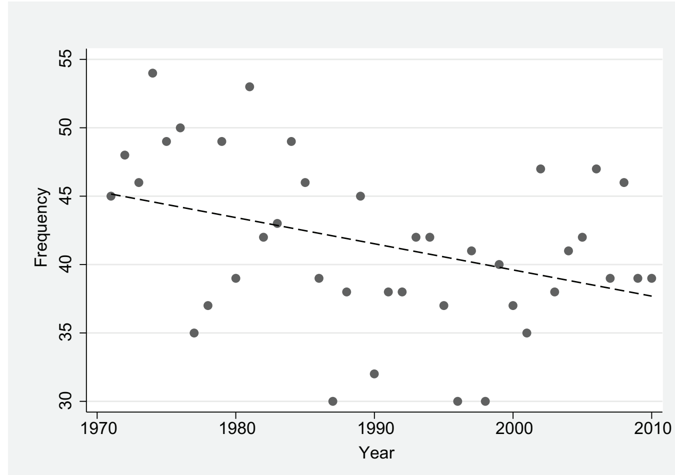

FIG. 4. Frequency of days with suitable wind conditions (< 6 m/s) during the summer caribou hunting season (1 July–31 August) of 1971–2010. Coefficient = −0.19 ($p < 0.05$). Figures on the y-axis represent the number of days between 1 July and 31 August with a mean wind speed equal to or below 6 m/s.

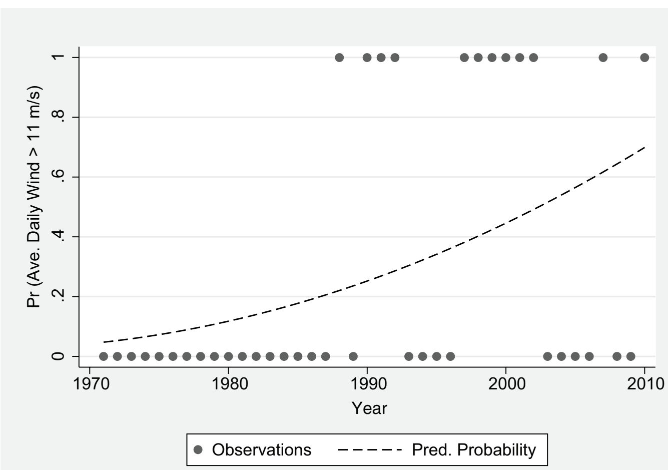

FIG. 3. Predicted probability that average daily wind speed exceeded 11 m/s at least once during the spring bowhead whale season (15 April–15 June) of 1971–2010. Odds ratio = 1.10 ($p < 0.05$).

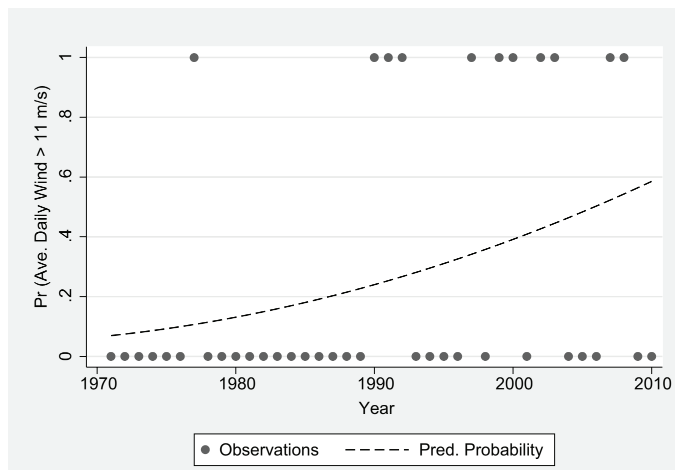

FIG. 5. Predicted probability that average daily wind speed exceeded 11 m/s at least once during the summer caribou hunting season (1 July–31 August) of 1971–2010. Odds ratio = 1.08 ($p < 0.05$).

crews in northwestern Alaska study ice characteristics and conditions to find strong ice on the edge of the lead where they can set up camp and land harvested whales the following spring (Druckenmiller et al., 2010). Hunters said that because of decreasing sea ice extent and thickness, they struggle increasingly to find ice conditions appropriate for whaling camps. The negative effects of decreases in the number of days with suitable wind conditions on bowhead harvests may be magnified by further losses in the window of hunting opportunity attributable to deteriorating sea ice.

Finally, there is constant pressure in rural communities across the Arctic to find employment in the cash economy as commercial goods and services increase in availability (Chabot, 2003). In fact, some people we interviewed were concerned that an increasing focus on finding formal employment has come at the expense of participation in traditional subsistence activities. Reducing the number of viable hunting days during whaling season by 11% as compared to 1971 requires considerable flexibility in whalers' schedules to capitalize on fair weather. Employment in the cash economy may reduce hunter flexibility and constrain successful whale harvests.

Conversely, a greater number of windy days may enhance hunting opportunities by improving hunter access to open leads, with more leads open at any one time, larger open leads, and greater frequency of opening. Increased access to leads reduces the logistical challenges of harvesting whales by shortening the distance traveled from the community to the ice edge and the time it takes to tow harvested whales through open water back to whaling camps. For example, in an analysis that evaluated wind speed and direction on days when spring bowhead whales were harvested in Barrow between 1990 and 1997, George et al. (2003) found that whales were more likely to be harvested on days with higher wind speeds up to 11 m/s because the winds held leads open. However, local observations in

Wainwright suggest that whaling crews from the community travel substantially farther on the water in the open leads compared to spring whalers in Barrow. Many people asserted that this change represents an important tipping point in the hunting system: as leads continue to grow in size and number, the benefits of easily accessible open water are outweighed by the amplified effects of wind speeds on boating conditions that result from the absence of sea ice.

Wind direction, in interaction with other factors such as sea ice, may also influence how changes in wind speed affect whaling opportunities. While wind direction data for our sampling period (1971 – 2010) are available at the Barrow weather station, data on other factors such as sea ice were insufficient to capture the complex effects of these interactions. However, it is important to note that under certain ice conditions, strong wind in the wrong direction (towards the south and west) may close existing leads, rather than opening new ones. Therefore, calmer days following strong winds blowing south and west are often of little value to whalers. Instead, these winds may interact with other factors, such as sea ice, to further reduce hunting opportunities. The only scenario in which south and west winds can be beneficial is if the wind picks up immediately after a whale is harvested, assisting hunters in towing the harvest through the water back to the coastal edge of the lead.

Managing the Effects of Wind on Bowhead Whaling

Many environmental changes, socio-economic transitions, and technological innovations since 1971 have either helped whalers cope with or enhanced the direct and additive effects of a decreasing number of suitable days. For example, several of the technologies used in whaling have improved. Hunters have replaced traditional skin boats with larger and more seaworthy metal skiffs (~5.5 m in length), which have made travel in rough waters less hazardous and reduced the effort needed to land harvested whales. Larger boats and technologies such as real-time monitoring of whale movements (e.g., satellite tracking and more radio tracking from airplanes) allowed hunters in Wainwright to harvest their first bowhead whale in community memory outside of the normal spring season during the fall of 2010 (Alaska Eskimo Whaling Commission, 2011). The snowmobiles used to tow boats over the ice to open leads are now more powerful and efficient than before, reducing travel time and fuel costs. Additionally, the weapons and methods used to harvest whales have evolved to reduce the number of whales that are struck and lost. As a result, whaling efficiency (number of whales successfully landed/number of whales struck) has increased from 50% historically to between 75% and 80% in recent years (Alaska Eskimo Whaling Commission, 2008). From a species population perspective, whaling opportunities have also increased. Bowhead whale populations have grown by an estimated 3.2% (± 1.8%) per year since precise estimates were possible (1978) (George et al., 2003), and in response, the International Whaling Commission has increased the subsistence quota for Alaskan communities (Ferrero et al., 2000).

Regardless of the social and ecological improvements that either buffer or enhance spring hunting opportunities, whaling crews in Wainwright now harvest significantly fewer whales as a proportion of the quota and the community's population compared to the numbers harvested in the 1980s and 1990s. Although the Alaskan subsistence bowhead whaling quota quadrupled between 1982 and 2010, the decadal average annual harvest of whales as a proportion of human population in Wainwright peaked in the 1990s, with a 15.4% increase from the previous decade, and in the 2000s, it has fallen slightly below harvest levels of the 1980s (Fig. 6) (Suydam and George, 2012; IWC, 2013). This pattern suggests that spring bowhead whaling in Wainwright is currently constrained by some component of the social-ecological system. Additionally, interview participants said that bowhead whales currently migrate past the community earlier in the spring than they used to, when the ice is still too thick to harvest them. If spring harvests continue to decline, even technological improvements and a larger population of whales will not be able to compensate for their reduced availability during the limited time they spend in the Wainwright area while migrating. It is uncertain whether whalers in Wainwright can make up for reduced hunting opportunities in the spring by increasing harvests during the fall. Bowhead migration routes in the fall are significantly farther out from the coast (Fig. 1). Further, conditions are rougher and more hazardous because of the lack of sea ice.

To help hunters improve whale harvests within the spring window, future research is needed to identify the relationships among variables (e.g., wind speed and direction, sea ice, employment responsibilities, social/cultural change) that may constrain whale harvests in Wainwright. For example, integration of our research with data on the relationship between wind direction, lead dynamics, and the actual successful harvest of whales on a daily scale (Ashjian et al., 2010; Druckenmiller et al., 2010) will provide useful insight into the cumulative effects of weather conditions that hinder hunting opportunities. Finally, understanding the complexity of social-ecological system dynamics will require improving data collection to reflect socio-economic conditions of Wainwright, considering the influence of factors such as employment and transfer payments, the cost of commercial goods and services, community population levels, and industrial development.

Effects of Wind on Summer Caribou Hunting

The decreasing number of days with suitable wind conditions has clearer effects on summer caribou hunting opportunities by boat than on bowhead whaling. Our results show as much as a 12% decrease in the annual window of hunting opportunity since 1971. The additive effects of strong winds

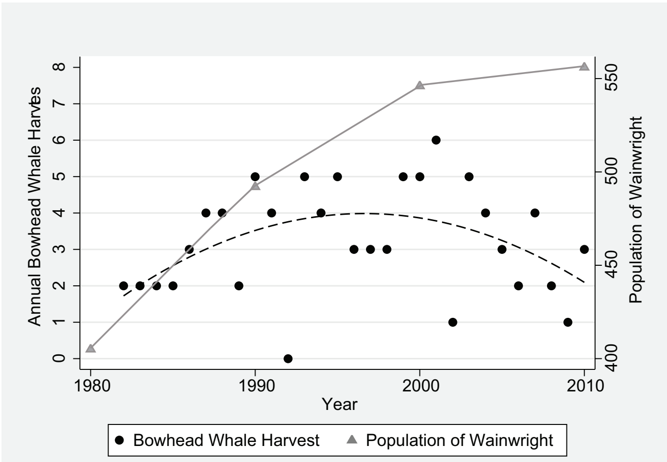

FIG. 6. Population of Wainwright and the annual bowhead whale harvest, 1982–2010.

and decreasing summer sea ice extent on boating conditions in July and August present increasingly substantial hazards for the safety of hunters. In addition to the hazardous effects of rougher seas, winds affect how caribou gather in accessible areas along the coast and rivers as a result of increased insect harassment on the interior tundra. Studies indicate that winds must blow less than 6 m/s for insects to harass caribou (Walsh et al., 1992; Russell et al., 1993). As the number of days with winds below the threshold decreases, caribou may increasingly remain dispersed across the interior tundra, dramatically reducing their availability by boat on windy days regardless of ocean conditions.

Managing the Effects of Wind on Summer Caribou Hunting

Caribou are distributed across the landscape around Wainwright throughout the year. Interview participants felt that they had many options to compensate for the reductions in summer hunting opportunities by boat. Examples included increasing efforts to harvest caribou from snowmobiles during the winter and using all-terrain vehicles (ATVs) to travel inland during the summer. Often, the insect harassment that drives caribou to the coast also deters local hunters from traveling inland. An increasing number of windy days could enhance inland hunting opportunities during the summer months. However, alternative hunting options need to be considered in the broader context of other climate-related factors that may influence caribou availability. For example, higher temperatures resulting from climate change could push caribou populations to cooler coastal areas regardless of wind conditions (Sharma et al., 2009). Under this scenario, hunters may need to stalk the shoreline using ATVs rather than boats because of rough water.

Additionally, decreases in the number of days with suitable wind conditions for hunting by boat may positively benefit caribou population dynamics. Research suggests that both the size of caribou herds and individual fitness could increase as a result of decreased insect harassment. Intense insect harassment has been linked to above-average calf mortality the following winter in the Western Arctic caribou herd (Klein, 1992). However, results from an analysis conducted by Haskell and Ballard (2004) found no relationship between summer insect harassment and following-year productivity of the Central Arctic caribou herd. They speculated that the negative effects of insects on productivity could become more prevalent as temperatures during shoulder seasons increase and the warm season lengthens.

The important role caribou play in meeting nutritional requirements of the community and their year-round presence illustrate the need for future research that evaluates options to compensate for the negative effects of increasingly windy conditions on summer caribou hunting. Important factors to consider while evaluating the viability of each option include the complex effects of increasing wind on the distribution and population dynamics of caribou herds in community hunting areas, the effects of other climatic changes on alternative harvest opportunities, and the possible influence on future hunting opportunities of interaction between transitioning socio-economic characteristics of the community and ecological variables.

CONCLUSIONS

A variety of environmental transitions due to climate change are occurring in northern Alaska, many with tangible effects on rural communities (Ford and Smit, 2004; Klein et al., 2005). The findings of this study demonstrate the potential power of combining multiple ways of knowing to characterize the effects of climate change on rural livelihoods. We show that, while directional trends in climatic variables occurring on monthly, annual, or decadal scales have large implications for the availability of ecosystem services, changes over time in day-to-day weather anomalies, such as the number of days with suitable wind conditions during critical hunting seasons, are also important drivers of social-ecological systems in northern Alaska. Finally, although changes in wind conditions will likely have largely negative effects on many current hunting opportunities, our findings demonstrate the potential for emergence of novel hunting opportunities with varying degrees of viability, such as fall whale hunting and winter caribou hunting. A number of potential adaptations might improve the viability of current hunting opportunities. These include using larger boats, improving real-time monitoring and capabilities of forecasting environmental conditions, and bolstering capabilities for rescuing hunters who become stranded. Continued collaborative research in northern Alaska is critical to empower residents with information and tools that document current climate and weather changes, identify emerging hunting opportunities, and inform adaption to novel conditions, while maintaining favorable social and ecological characteristics of the system.

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