Chapter 5
Sea Ice Distribution and Ice Use by Indigenous Walrus Hunters on St. Lawrence Island, Alaska

Marie-Luise Kapsch, Hajo Eicken, and Martin Robards

Abstract The hunting success of St. Lawrence Island walrus hunters from Savoonga (*Sivungaq*) and Gambell (*Sivuqaq*) is studied in relation to weather and sea ice conditions for the period 1979–2008. Satellite remote-sensing data, including ice concentration fields from passive-microwave radiometer data, have been examined over the entire time series in conjunction with walrus harvest data from two community-level monitoring programs. Important information to aid with interpretation of these data sets was provided by the hunters themselves, in particular through a log of ice conditions and ice use by L. Apangalook, Sr., of Gambell. From these data, we determined which ice conditions (concentrations >0 and <30%) and which wind speeds (1–5 m s^{-1} at Savoonga and 5–9 m s^{-1} at Gambell), temperatures (–5 to +5°C), and visibility (>6 km) provide the most favorable conditions for the walrus hunt. The research demonstrated that at the local level, though not necessarily at the region-wide scale, the sea ice concentration anomaly is a very good predictor of the number of favorable hunting days. With the exception of 2007 (and to a lesser extent, 2008), negative anomalies (less ice or earlier onset of ice retreat) coincided with more favorable (Savoonga) or near-average (Gambell) hunting conditions, controlled mostly by access to ice-associated walrus. Ice access and temporal variability differ significantly between Savoonga and Gambell; in contrast with northern Alaska communities, St. Lawrence hunters were able to maintain typical levels of harvest success during the recent record – low ice years of 2007 and 2008. We discuss the potential value of data such as assembled here in assessing vulnerability and adaptation of Arctic communities depending on marine-mammal harvests to climate variability and change.

Keywords Sea ice · Subsistence hunt · Ice conditions · Pacific walrus · Climate change

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Introduction

The Alaska Native population in coastal Alaska has relied on the marine environment as a source of food and sustenance for centuries to millennia. In the Bering Sea, and to a lesser extent off the North Slope of Alaska, Inupiaq and Yupik Eskimo have specialized in hunting walrus from small boats among the ice. The success of the hunt is directly linked to sea ice conditions, weather, the life cycle and population dynamics of the walrus, and the social and technological settings of the hunt (Krupnik and Ray 2007; Metcalf and Robards 2008).

The distribution of sea ice in the northern Bering Sea is influenced by several factors. It is linked to atmospheric circulation patterns, such as the Pacific Decadal Oscillation (PDO) or the Arctic Oscillation (AO; Stabeno and Hunt 2002). These two patterns are associated with variations in sea surface temperature and atmospheric pressure and thus influence ice conditions. Currently, atmospheric variability and larger scale change have resulted in a decline in fall and summer ice extent and have impacted sea ice properties, with more open water present, an earlier breakup and later arrival of the fall pack ice in the Bering Strait (Huntington 2000; ACIA 2005; Grebmeier et al. 2006; Stabeno et al. 2007). Such sea ice changes can affect walrus indirectly through changes in the distribution and abundance of their prey (Benson and Trites 2002). Direct impacts are mostly in connection with walrus' use of sea ice as a platform for resting, giving birth, and nursing. Walrus seek out ice floes that are thick enough to support their weight, surrounded by natural openings (leads) or thin ice that allow for access to the water column (Fay 1982). They typically gather on unconsolidated pack ice in late winter and spring, within 100 km of the leading edge of the ice pack (Burns 1970; Gilbert 1999). Hence, a change in the distribution and concentration of sea ice can affect timing and pathways of Pacific walrus and in turn impact walrus hunters' success and safety.

The interactions between walrus and sea ice are well understood by biologists (Fay 1982; Ray and Hufford 1989) and native hunters (Krupnik and Ray 2007). What is less clear at this time is how recent changes in surface climatology and sea ice at the local (Noongwook 2000), regional (Stabeno et al. 2007), and pan-Arctic scale (Stroeve et al. 2008) affect the walrus subsistence hunt. Clearly, hunters are more aware of such changes than anybody, as expressed by Leonard Apangalook from Gambell who comments that the "walrus season is very short now" (Oozeva et al. 2004). At the same time, large-scale changes as expressed in multiple decades of harvest observation records have been examined (Metcalf and Robards 2008). What is less understood are the mechanisms by which ice conditions and weather impact the hunt and in particular hunter's access to walrus. Furthermore, in order to effectively manage walrus harvest in a changing Arctic and provide information to coastal communities as they adapt to change, the local conditions governing access and hunting success need to be linked to variables such as ice concentration or weather patterns that can be tracked and possibly predicted on longer timescales.

This chapter is seen as a small contribution to help close this gap. It examines sea ice and weather conditions and their potential impact on the walrus hunt for the two neighboring villages of Savoonga (*Sivungaq*) and Gambell (*Sivuqaq*, St. Lawrence Island; Fig. 5.1), two of the three primary walrus harvesting communities in Alaska over the past 60 years (Robards 2008). The study draws on a combination of ice observations by Siberian Yupik sea ice experts (gathered as part of a Sea Ice Knowledge and Use (SIKU) International Polar Year (IPY) project; Chapter 14 by Krupnik et al. this volume), weather records, and sea ice remote-sensing data obtained from different satellite sensors to provide both regional and local-scale perspectives on ice conditions. Information about the success and progression of the walrus hunt has been obtained from harvest records and local observations. The study focuses on three recent years (2006–2008), remarkable for their low summer minimum ice extent in the Pacific sector of the Arctic, and discusses the interplay between ice conditions, weather, and success of the walrus hunt in the context of long-term variability and change going back to 1979, the start of the systematic satellite record. The study is limited to the discussion of physical factors that control access to walrus and hence cannot provide insight into the role of variations in walrus distribution or population size nor the impact of sociological or technological change on the walrus hunt. Nevertheless, the study provides insight

Fig. 5.1 Map of the study region and the two villages on St. Lawrence Island, Alaska. The *black squares* identify the 75 × 75 km satellite subregions for Gambell and Savoonga and the *shaded areas* the ice edge for March, May, and July 2007

into what is regarded by many as the most important environmental constraints on the walrus hunt and their expression at the local level in relationship to large-scale, hemispheric climate change (Huntington et al. 2005); it is thus an important step in helping to downscale projections of future regional Arctic change to the community level at which the impact of such changes is manifested. At the same time, the detailed knowledge of local ice and walrus experts, also as expressed in hunting success, may help inform and guide future studies of the Arctic sea ice environment and walrus habitat.

Background – The Walrus Hunt on St. Lawrence Island

Walrus migration pathways are closely linked to the seasonal advance and retreat of the ice in the Bering and Chukchi Seas (Fay 1982; Krupnik and Ray 2007). Females and calves in particular remain within the margins of the ice pack as the ice edge moves north. Ice floes serve as platforms that allow walrus to feed over broad expanses of the shelf without having to retreat to land where access to food resources may be more limited and vulnerability to predation, disturbance, and trampling more exacerbated (Fay 1982). Bering Sea communities such as Gambell and Savoonga, that are located in the migration pathway of the walrus, thus have access to animals in close range to the village. Over the course of centuries, hunters from these communities have been able to develop and hone their hunting skills based on an intimate knowledge of the animal behavior and ice conditions.

Walrus hunting on St. Lawrence Island depends on several factors, including weather and ice conditions, the social and technological setting, and walrus ecology (Robards 2008). In Gambell and Savoonga the spring hunting season generally starts between the middle and end of April (Robards 2008, Benter and Robards 2009; Leonard Apangalook, personal communication 2009), when walrus begin to migrate northward with the thinning and retreat of the seasonal ice. Thus, hunters are strongly impacted by the rate of ice melt and retreat, which affects their ability to access and retrieve walrus. While walrus may migrate past the village it may be impossible for hunters under some conditions to pursue them because access to open leads is blocked by heavy near-shore ice conditions (Robards 2008). A further social constraint that may influence at least some hunters is the tradition or prioritization of postponing the focus on hunting walrus until the end of the subsistence whaling season in early May or until a whale has been harvested. While not all hunters may defer their hunt (Benter, personal communication 2009), the traditions of the whale hunt are one social factor that plays into the pursuit of walrus in early spring in some communities.

Irrespective of ice conditions, local weather conditions usually determine whether boats are able to safely hunt on a particular day. The hunters "rely on the mercy of the wind" (Leonard Apangalook, Gambell, personal communication 2009) and are also dependent on the visibility. If pack ice gets pushed against shore areas used to launch boats, there may be no other way to launch a boat without transporting boats to more distant locations across land. And if the visibility is poor, dangerous ice conditions are not readily apparent or predictable. Favorable weather is thus directly tied to safety on and in the ice and provides for better decision making by hunters. In recent years, hunters have also commented on how climate change has made it more difficult to apply traditional knowledge and anticipate changes in the weather or ice conditions (Krupnik and Jolly 2002). In prior years, "climate was more consistent, better predictable and people were able to plan their trips according to seasonal change. Now there is lots of wind, poor ice conditions and the polar pack has not been seen for the last 10–20 years. [. . .] Now there is just local grown ice around, which is less stable" (Leonard Apangalook, personal communication 2009).

In addition to the changes in weather and sea ice, the social and technological settings of the walrus hunt on the island have changed in many ways over past decades. Increases in the village populations, more numerous and faster boats (introduced in the 1970s), and better weapons (originally introduced in the 1800s; Robards 2008) have allowed Gambell and Savoonga to steadily increase their capacity to hunt walrus (Robards and Joly 2008). While many dramatic changes occurred prior to the start of the systematic remote-sensing record in 1979, social changes and technological advances continue and cannot be neglected in explaining the relationship between physical conditions and subsistence hunting.

Data and Methods

Sea Ice Data

To assess the potential for hunters to access ice-associated walrus and to link walrus harvest data to sea ice conditions, fields of daily sea ice concentration and total sea ice covered area have been obtained at the regional scale (75 × 75 km boxes and the whole Bering Sea area, Fig. 5.1), from satellite remote-sensing data for the time period 1979 to 2008. Specifically, data from the Scanning Multichannel Microwave Radiometer (SMMR) aboard the Nimbus-7 satellite from October 1978 to August 1987 and the Special Sensor Microwave/Imager (SSM/I) aboard the Defense Meteorological Satellite Program (DMSP) from July 1987 to present were used. Sea ice concentration at each grid cell is obtained from the corresponding brightness temperature and generated with the NASA Team algorithm (Eppler et al. 1992). For our calculations, final data released by the National Snow and Ice Center (NSICD) were used, including final NSIDC quality control (http://www.nsidc.org/data/nsidc-0051.html). The sea ice concentrations, averaged over a 75 × 75 km grid (Fig. 5.1), have an accuracy of ±15% during summer, when on ice melt ponds are present, and ±5% during winter (http://nsidc.org/data/docs/daac/nsicd0051_gsfc_seaice.gd.html). Multiple measurements are averaged to daily means and missing data are linearly interpolated.

The significance of sea ice concentration trends calculated in the results section has been tested with a single-sided *t*-test. This test is applicable to independent variables which holds for sea ice variables in the Bering Sea/St. Lawrence Island region, since the ice cover melts completely each summer with very little if any persistence of local anomalies into the spring of next year.

Weather Data

Hourly weather observations from the National Climatic Data Center (NCDC) have been examined (http://www.ncdc.noaa.gov/oa/land.html). The meteorological variables wind direction, wind speed, visibility, temperature, and cloud cover were chosen to assess whether hunting conditions were favorable. Many indigenous hunters report these variables as being of greatest importance when evaluating weather conditions for a hunt (Oozeva et al. 2004). The hourly measurements have been averaged to daily means (converted to and reported here in local time) in order to be able to compare them with daily sea ice concentration data.

Walrus Harvest Data

Daily walrus harvest data for the villages of Gambell and Savoonga have been analyzed between 1992 and 2008 for the spring hunting season, as well as for the years 1980–1984. Walrus harvest records for 1992–2008 were assembled by the U.S. Fish and Wildlife Service and the Alaska Eskimo Walrus Commission (AEWC). In the Walrus Harvest Monitoring Program (WHMP), during most of the spring the gender and age class for every walrus that had been retrieved were recorded by hunt monitors as hunters returned to the beach at their home village. The observation period for the years 1992–2004 and 1980–1984 amounted to 6–8 weeks each year between mid-April and mid-June and historically covered 90% of the total annual harvest numbers for Gambell and Savoonga (Benter, personal communication 2009). Only harvest data for which the date of harvest is known have been analyzed here. The same applies to the WHMP data between 2005 and 2008, when the observation period was reduced to 2 weeks, mostly in May. The monitors met most of the boats returning from walrus hunts, and hence the number of unrecorded walrus is thought to be relatively small (Garlich-Miller and Burn 1999). Since this study is not concerned with the age and gender distribution of walrus but focuses on the total number taken each day, all age and gender classes have been aggregated. The unpublished data from 1980 to 1984 were recorded during a similar harvest-monitoring program (Lourie 1982) and summarized by Robards (2008). To alleviate bias from the shortened season of direct observations used by the Walrus Harvest Monitoring Program since 2005, data from the Marking, Tagging, and Reporting Program (MTRP) for the years 2006–2008 have also been evaluated. The MTRP is a federally mandated program requiring all village hunters to report harvested walrus to the U.S. Fish and Wildlife Service within 30 days after the take, while the location of the hunt is unimportant. The numbers of walrus taken are aggregated into weekly values.

To examine the connection between these different data sets and observations by local hunters, favorable days for the walrus hunt were those days in the WHMP data on which at least one walrus had been taken. In contrast, days on which no walrus were taken were considered as unfavorable for the hunt, due to either limited access on account of ice conditions or hazardous weather or ice conditions. While we ignore any other factors that may have played into a decision for hunters not to go out, we only consider days between the onset of the spring hunting season (first walrus taken) and its end (last walrus taken, based on the harvest monitoring data). The time period between these two dates we consider as the length of the spring hunting season for a particular year, with some walrus taken outside of this time period in fall and winter. Since weather conditions may vary during a single day but we could only consider mean values for weather variables such as wind speed, this may have introduced small errors into assessments of suitable or unsuitable hunting conditions. At the same time, since hunters themselves rely on weather forecasts, erroneous forecasts may prevent hunting activity on suitable hunting days, potentially introducing small errors as well (Benter, personal communication 2009).

Local Observations of Ice Conditions and Hunting Activity

In order to help address the challenge of downscaling from satellite observations to local ice conditions and to aid in separating the different social, technological, and environmental factors impacting the walrus hunt, we rely on regular observations of ice conditions and sea ice use made by Leonard Apangalook from Gambell. Mr. Apangalook, a respected hunter with great knowledge of the local environment, has been keeping a daily log of weather and ice conditions, animal sightings, and activities associated with ice use (as part of the SIKU project under the leadership of Igor Krupnik; Chapter 14 by Krupnik et al. this volume); his records for the ice seasons in 2006–2008 have provided important insight into factors determining hunting success.

Results

Regional Ice Conditions, the Sea Ice Cycle, and Hunting Activities

Sea ice conditions around St. Lawrence Island are dominated by the seasonal cycle of temperature and associated weather and ice patterns. In recent years, the freeze-up of the ocean in front of Gambell (see Fig. 5.1) typically started in mid-December (Fig. 5.2). During the winter, ice concentration increases with an average (January

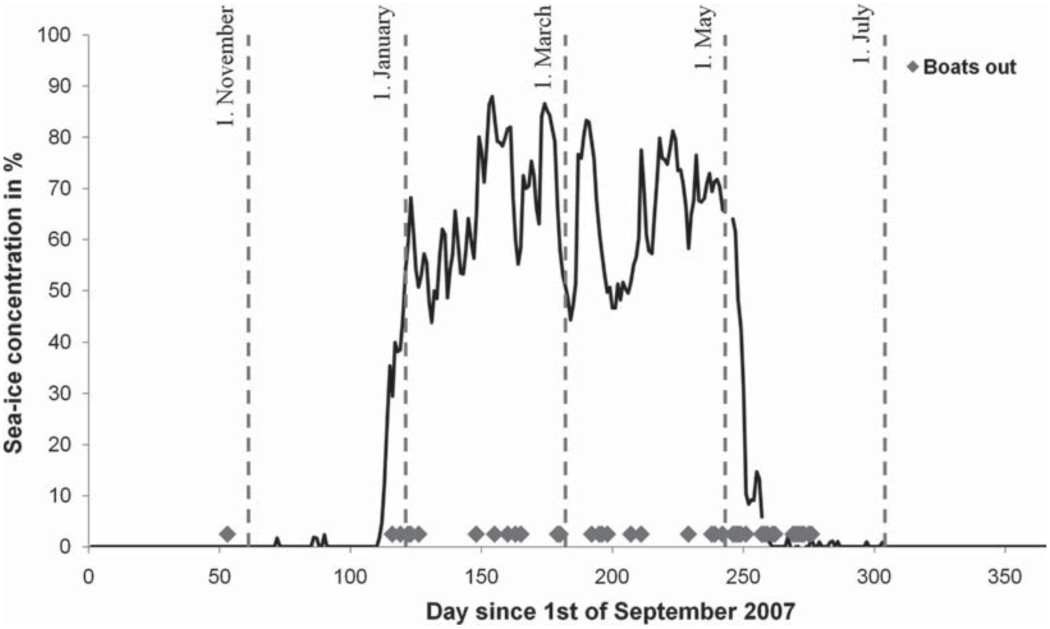

Fig. 5.2 Annual sea ice cycle in terms of ice concentrations derived from remote-sensing data (SSM/I) for Gambell, Bering Sea, from September 1, 2007 to August 31, 2008. The *diamonds* denote days on which one or several boats from Gambell were out hunting walrus and seals (based on observations by Leonard Apangalook)

through April) of 66% for the year 2007/2008. Ice concentrations remain high until the beginning of May, when they plummet with the start of breakup and melt, with ice completely absent starting in June. The start of freeze-up and breakup and the average winter sea ice concentration vary slightly between single years with about ±13 days for freeze-up and ±11 days for breakup in front of Gambell. A similar annual cycle is observed off Savoonga, though with higher wintertime ice concentrations (25% higher in 2007/2008) and an offset of the start of breakup of approximately 14 days due to a later ice melt.

Examining the dates on which hunters from Gambell were pursuing walrus or bearded seals by boat (L. Apangalook, unpublished observations 2008) indicates a close link between hunting activities and the ice cycle (Fig. 5.2). Thus, hunting by boat is mostly restricted to those times when sea ice – providing access to walrus that are migrating northward with the retreating ice – was present within a reasonable distance from the community while at the same time open leads allowed boats to pursue walrus. In 2007, Gambell hunters traveled on average between 13 and 146 km per harvested walrus, starting at the end of April with small distances, continuing through May with increasing travel distances between 32 and 80 km per captured walrus and finishing the season with larger distances in early June (Benter and Robards 2009). The most active time is during break-up, between the beginning of April and mid-May 2008 (Fig. 5.2). A similar conclusion is drawn from an analysis of the MTRP harvest records, which indicates that in the years 2006–2008 most walrus were taken between the end of April and early June (Fig. 5.3). In considering

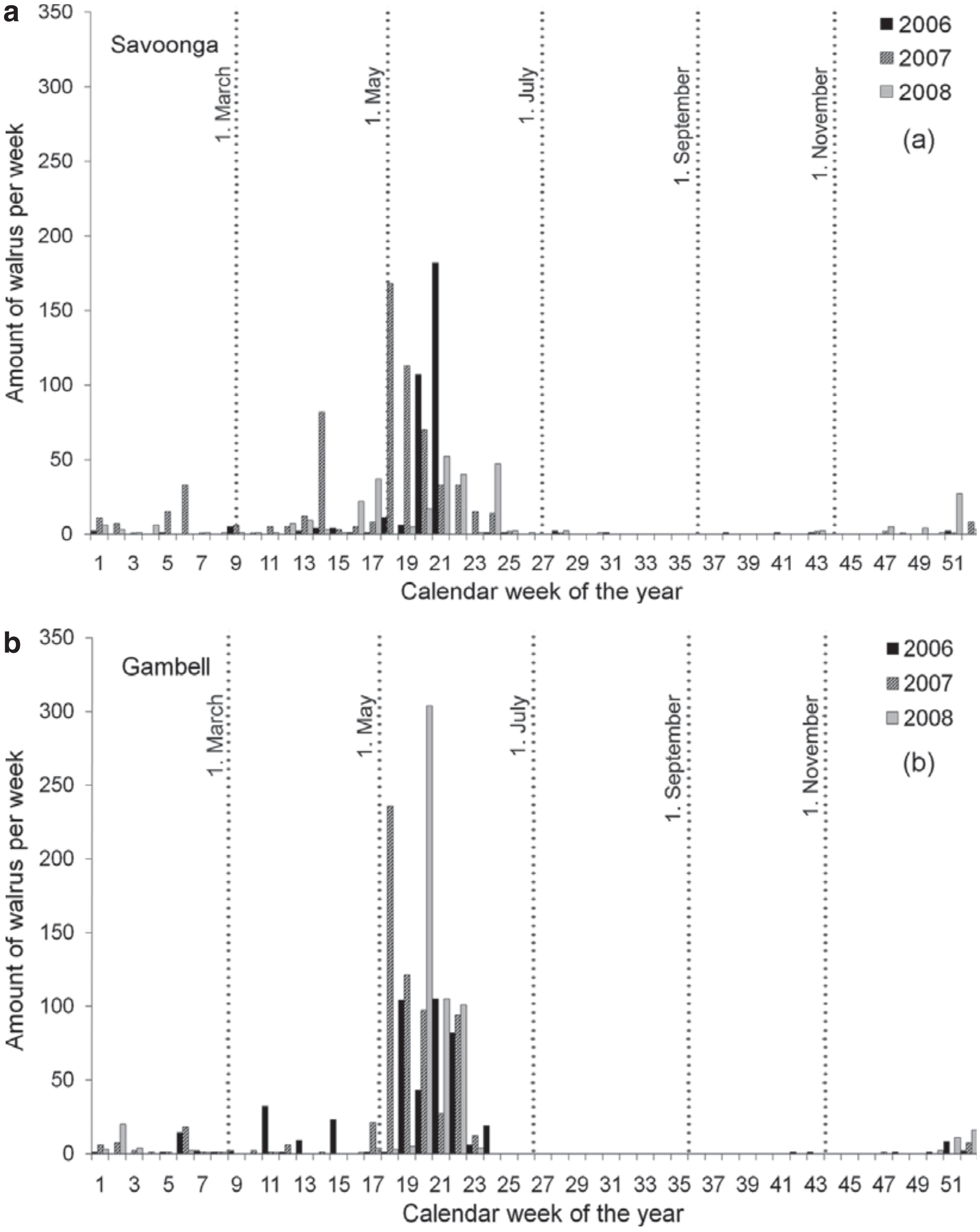

Fig. 5.3 Weekly takes of walrus harvested in (**a**) Savoonga and (**b**) Gambell based on MTRP data collected by the US Fish and Wildlife Service

MTRP data, it needs to be kept in mind that these data do not provide any insight into hunting effort, which is significantly larger based on observations by Leonard Apangalook (Fig. 5.2) or of an increased capacity to hunt (Robards 2008).

In addition to access afforded hunters by openings in the near-shore ice in early spring (Fig. 5.3a, 14th calendar week), in recent years they have also pursued walrus in the winter (November to January) in both Gambell and Savoonga, as evident from observations by Leonard Apangalook (Fig. 5.2) and MTRP data (Fig. 5.3). With wintertime ice concentrations mostly below 70–80% in Gambell (Fig. 5.2), the potential is high for a network of connected leads to provide access to walrus that overwinter close to the island – provided that near-shore ice conditions are favorable (see later). In Savoonga, the situation is somewhat different as ice concentrations are approximately 25% higher during winter, reducing the probability of finding leads and gaining access to walrus. However, Savoonga hunters use snowmobiles to hunt from landfast ice or haul boats over the island to gain access to open water in the polynya on the lee side of the island in the south.

Environmental Variables Controlling the Walrus Hunt

Weather Conditions and the Walrus Hunt

> North wind at 25 mph [11 m s^{-1}], 5 F [–15°C]. With large ice [floes] open leads extend to size of floes and good for boat hunting, but winds are high. Even walrus and seals don't like to haul on ice when it is windy (19th of March 2007).
>
> North wind at 21 mph [9 m s^{-1}], 4 F [–16°C]. Clear. Unable to get out by boat due to stronger winds and pack ice constantly moving down wind; with stronger wind the north current does not move ice north (20th of March 2007).
>
> Northeast wind at 20 mph [9 m s^{-1}]. 28 degrees [–2°C]. Heavy overcast with snow and fog. Everyone concerned about lack of favorable weather conditions and no hunting (10th of May 2008, 08:00 AKST).

These observations from the daily log of Leonard Apangalook from Gambell illustrate some of the weather conditions that impact the walrus hunt. Even if sea ice conditions would allow hunters to go out, weather may prevent that from occurring. To explore the extent to which weather impacts the hunt, National Weather Service observations from Gambell and Savoonga were compared to the walrus harvest records (WHMP data set, Tables 5.1 to 5.8). Based on statements by local

Table 5.1 Weather statistics for the spring season at Savoonga, 1993–2008

	Statistic	Wspd	Vis	SIC
Harvest days	Mean	4.0	12.4	25.0
	Number of days	210	195	215
	SD	2.1	3.6	26.8
	Max	20.2	16.1	97.6
	Min	0.4	0.8	0.0
Non-harvest days	Mean	5.2	11.0	37.5
	Number of days	329	195	334
	SD	3.1	4.1	34.7
	Max	20.2	16.1	97.6
	Min	0.0	0.1	0.0

Table 5.2 Weather statistics for the spring season at Gambell, 1992–2008

	Statistic	Wspd	Vis	SIC
Harvest days	Mean	5.0	13.0	17.2
	Number of days	239	219	238
	SD	2.2	3.3	19.6
	Max	11.7	16.1	92.3
	Min	0.0	0.8	0.0
Non-harvest days	Mean	7.9	11.6	22.3
	Number of days	343	219	342
	SD	3.2	3.9	22.8
	Max	16.5	16.1	92.3
	Min	0.0	1.3	0.0

Table 5.3 Walrus harvested in relation to wind direction in spring for Savoonga, 1993–2008

Wdir	Number of walrus	Fraction of harvest (%)	Wdir frequency (%)
NNE	52	1	3
NE	173	3	6
ENE	1503	28	21
ESE	615	12	14
SE	284	5	7
SSE	438	8	6
SSW	247	5	8
SW	461	9	8
WSW	803	15	14
WNW	477	9	5
NW	132	3	3
NNW	107	2	5

Table 5.4 Walrus harvested in relation to wind direction in spring for Gambell, 1992–2008

Wdir	Number of walrus	Fraction of harvest (%)	Wdir frequency (%)
NNE	2342	29	24
NE	802	10	15
ENE	956	12	9
ESE	446	6	6
SE	420	5	6
SSE	322	4	6
SSW	876	11	13
SW	661	8	8
WSW	556	7	6
WNW	125	21	1
NW	129	21	1
NNW	336	4	4

Table 5.5 Walrus harvested in relation to wind speed in spring for Savoonga, 1993–2008

Wspd (ms^{-1})	Number of walrus	Fraction of harvest (%)	Wspd frequency (%)
>1	395	8	5
1–5	3668	69	69
5–9	1142	22	25
>9	87	2	1

Table 5.6 Walrus harvested in relation to wind speed in spring for Gambell, 1992–2008

Wspd (ms^{-1})	Number of walrus	Fraction of harvest (%)	Wspd frequency (%)
>1	257	3	3
1–5	4660	58	47
5–9	3044	38	48
>9	33	0	3

Table 5.7 Walrus harvested in relation to visibility in spring for Savoonga, 1993–2008

Visibility (km)	Number of walrus	Fraction of harvest (%)	Visibility frequency (%)
0–3	76	2	2
3–6	72	1	3
6–9	96	19	14
9–12	1052	21	22
>12	2835	57	60

Table 5.8 Walrus harvested in relation to visibility in spring for Gambell, 1992–2008

Visibility (km)	Number of walrus	Fraction of harvest (%)	Visibility frequency (%)
0–3	29	0	1
3–6	352	5	4
6–9	500	7	8
9–12	917	12	18
>12	5758	76	69

experts wind direction, wind speed, visibility, cloud cover, and temperature were considered in the analysis. Ocean currents have not been considered because to our knowledge no systematically collected time series of currents (or other oceanographic data) is available for this region and this time period.

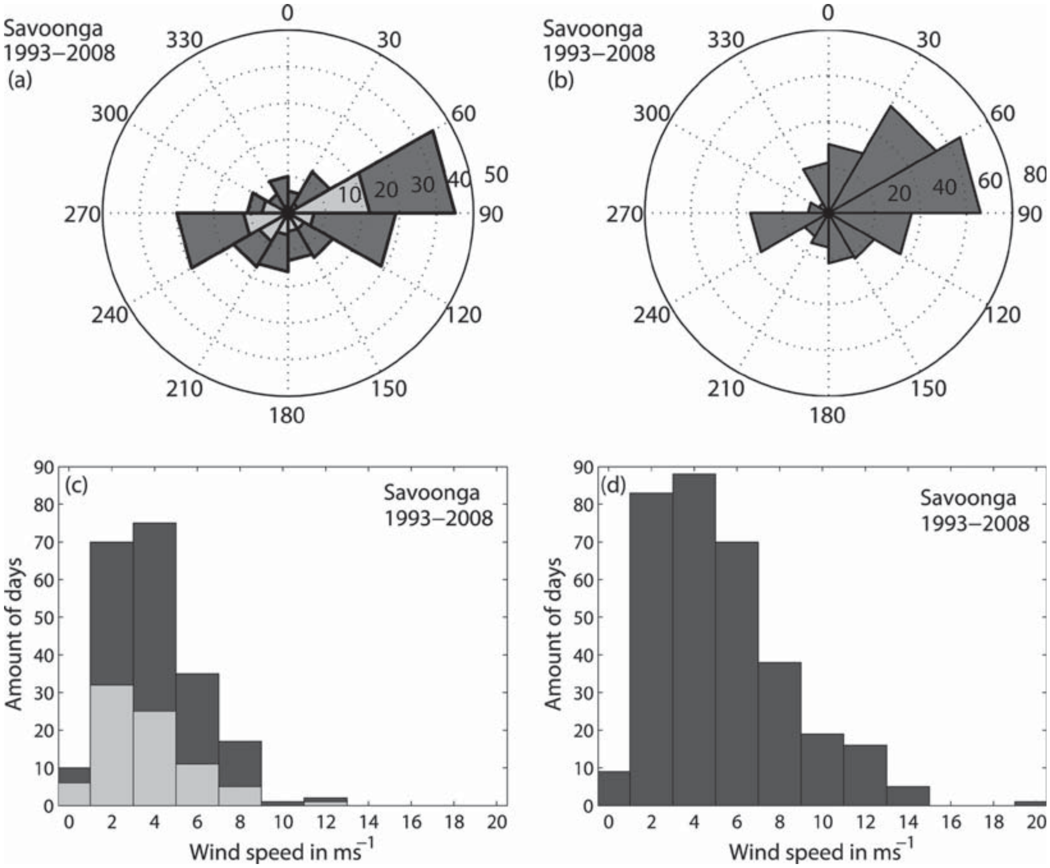

Fig. 5.4 Histogram of (**a**) wind direction and (**c**) wind speed for days on which walrus were taken, compared to (**b**) wind direction and (**d**) wind speed histograms for days (during the spring season) on which no walrus have been taken by Savoonga. The wind directions are summarized in 30° sections (0–30° = NNE, 30–60° = NE, 60–90° = ENE, etc.)

Wind Velocity

> Tunglu – When the wind blows and blows, it forms ice ridges in the northern side (in Gambell), and it also starts pushing ice south. Then the (wretched) ice covers the whole ocean with nowhere to go on boat (Oozeva et al. 2004, 49).

Wind direction and wind speed are very important factors determining whether crews go out to hunt. When the wind speed is low (less than about 2 m s^{-1}; George et al. 2003) open leads tend to freeze over in cold weather and are inaccessible; at very high wind speeds ice movement and deformation pose dangers, as indicated by Oozeva's description of the Yupik term *tunglu*. Since wind speed and direction also determine whether boats can be launched at village sites (ostensibly a north and west facing beach in Gambell and a north facing beach in Savoonga), weather station data have been analyzed for Savoonga and Gambell (Figs. 5.4 and 5.5).

Wind conditions on spring walrus harvest days between 1992 and 2008 differ between the villages, although the range of wind speeds during which walrus were taken is comparable for both (1–9 m s^{-1}; Tables 5.5 and 5.6; Figs. 5.4 and 5.5). In Savoonga, 69% of the walrus were taken when wind speed was between

1 and 5 m s^{-1}, corresponding to 69% of all harvesting days. In Gambell, more than half of the walrus (58%) were taken during the same wind speed interval, but these wind speeds only prevailed during 47% of all harvest days. On most hunting days, wind speed was between 5 and 9 m s^{-1} (48%). This is also evident when comparing mean wind speed on harvest dates. In Savoonga the mean overall wind speed was 4.0 ± 2.1 m s^{-1}, 1 m s^{-1} lower than in Gambell (5.0 ± 2.2 m s^{-1}; Tables 5.1 and 5.2). In Savoonga the mean wind speed for days when no walrus were taken was 5.2 ± 3.1 m s^{-1}, significantly higher (paired *t*-test with the null hypothesis that the means are equal can be rejected at the 5% level, $p = 0.05$) than during harvest days. The same holds for Gambell but the wind speeds on days without walrus takes are higher than in Savoonga (7.9 ± 3.2 m s^{-1}; Table 5.2; Fig. 5.5).

The wind directions favored by hunters from the two villages vary much more than the favored wind speeds, and both are correlated to some extent. In Savoonga, most walrus were harvested with winds from ENE, ESE, and WSW directions (Table 5.3). The prevailing wind direction in spring (month of March, April, May, and June) is from ENE, corresponding to 21% of harvest days (Table 5.5). In Gambell the preferred wind direction for the hunt is from NE (0–90°; 48% of all

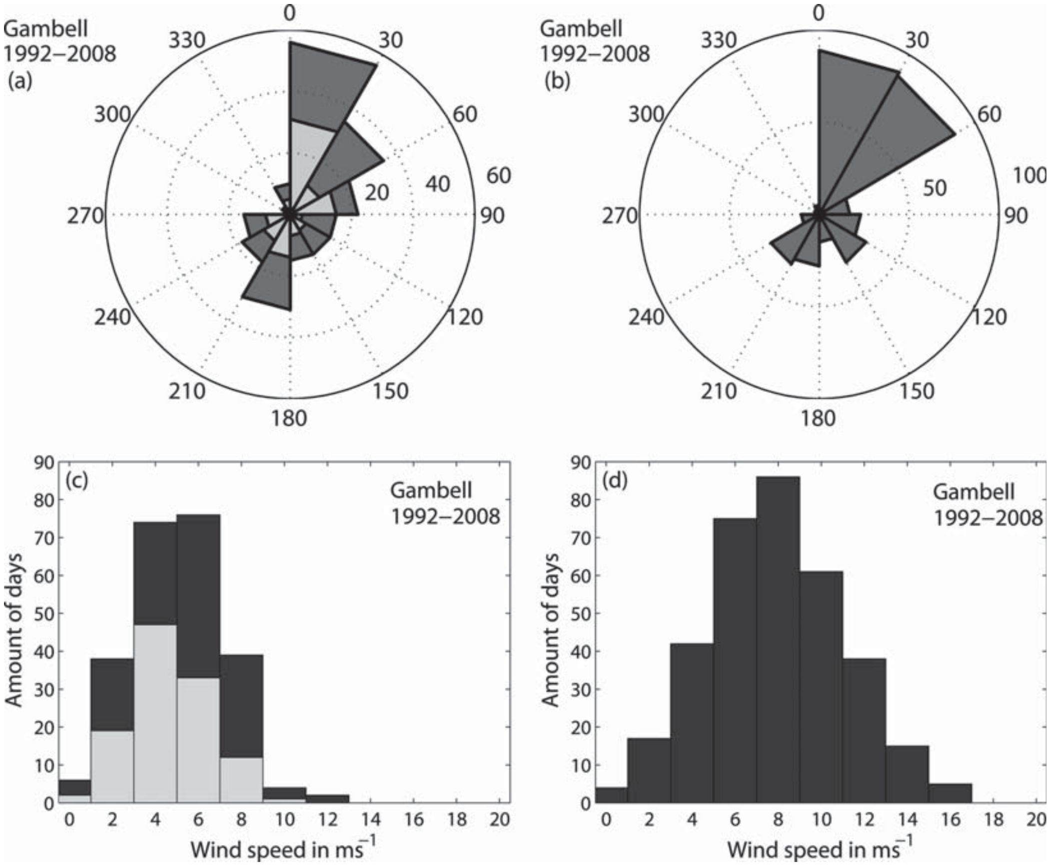

Fig. 5.5 Histogram of (**a**) wind direction and (**c**) wind speed for days on which walrus were taken, compared to (**b**) wind direction and (**d**) wind speed visibility histograms for days (during the spring season) on which no walrus have been taken by Gambell

hunting days) and from SSW. During NW winds (270–360°) hunters rarely went out (6%; Table 5.4).

Visibility

St. Lawrence Island hunters articulate that good visibility is key for being safe on the ice, to detect changes in ice conditions and to be able to spot walrus. Hence, hunters do not go out when they are unable to judge ice conditions or detect walrus due to poor visibility. This is reflected in the disproportionate number of harvests (and hunting days) for visibilities higher than 6 km (Tables 5.7 and 5.8). Harvest days with visibility below 6 km account for 5% or less of all successful harvest days in Gambell and Savoonga (Tables 5.7 and 5.8). In contrast, 60 and 69% of all days with walrus takes had visibility of more than 12 km in Savoonga and Gambell, respectively.

Cloud Cover and Temperature

Cloud cover and temperature play secondary roles for the walrus harvest during spring, other than through their indirect linkage to ice conditions and seasonal evolution of ice. At Savoonga, 57% of all walrus were harvested when the sky was overcast with 7–8 octas cloud cover, accounting for 69% of all harvesting days. At Gambell, the corresponding numbers account for 70% of the walrus harvested and 70% of all harvest days. This finding is explained by consistently cloudy conditions at both Savoonga and Gambell during the spring hunting season, with an average cloud cover of 7/8 ± 2/8.

The temperature ranged between –5 and +5°C for over 90% of the harvest days, and more than 95% of all walrus were harvested under these temperature conditions in both communities. On average the temperature was 1 K higher in Gambell and 2 K higher in Savoonga on days that walrus were taken compared to those days that no hunt took place.

Ice Conditions and the Walrus Hunt

The WHMP walrus harvest data indicate that based on ice concentration data for the 75 × 75 km grid monitored off both St. Lawrence Island communities, walrus were mostly taken when ice concentrations were above 0 and below 30% (Fig. 5.6). In both Savoonga and Gambell 88% of the harvests occurred for ice concentrations lower than 30% (Tables 5.9 and 5.10). These days account for 71 and 81% of all days on which walrus were harvested in Savoonga and Gambell, respectively.

While the spread of the data shown in Fig. 5.6 precludes major conclusions, the data do provide evidence that (1) in Savoonga disproportionately fewer walrus are caught at high (>60%) and very low (<10%) ice concentrations, with the opposite true for ice concentrations between 10 and 30%, and (2) in Gambell disproportionately fewer are harvested at ice concentrations <10 and >40%. For 36% of all days without a walrus take in Savoonga the sea ice concentration was below 10%. In Gambell the corresponding fraction was 47% of all days.

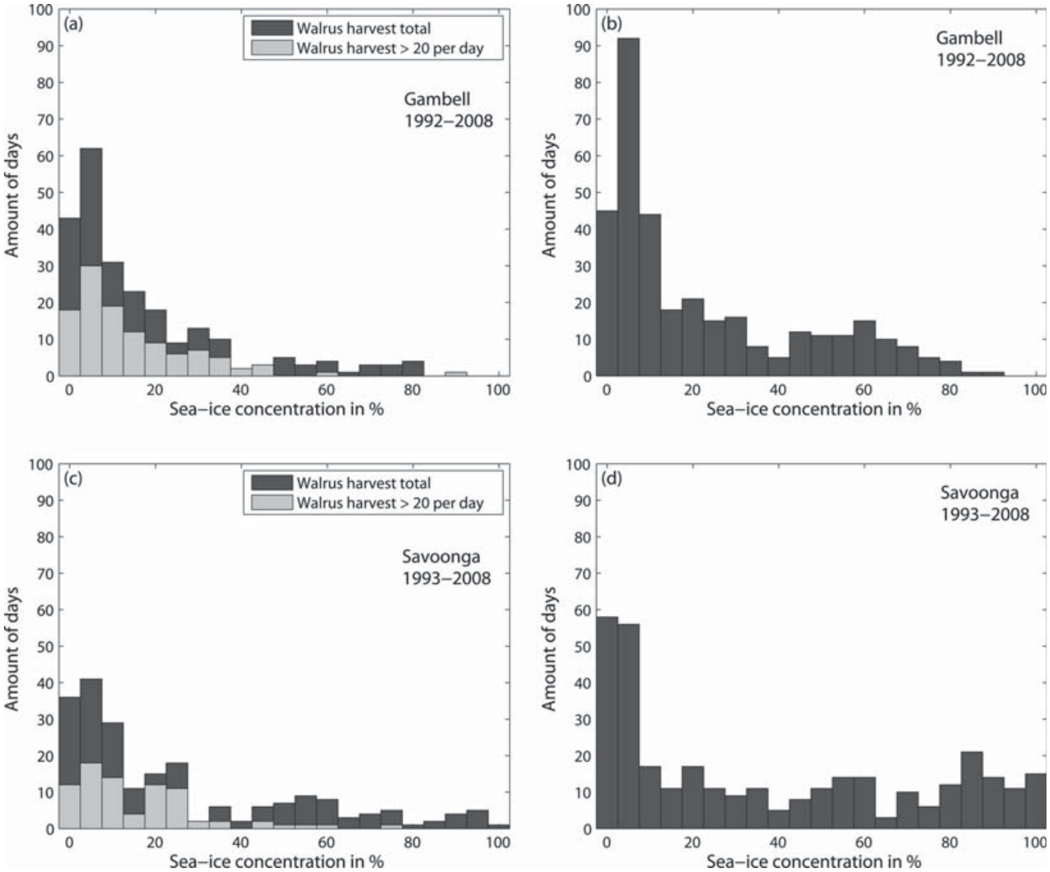

Fig. 5.6 Histogram of sea ice concentration days on which walrus were taken by (**a**) Savoonga and (**c**) Gambell, compared to ice concentration histograms for days (during the spring hunting season) on which no walrus were taken by (**b**) Savoonga and (**d**) Gambell

Table 5.9 Sea ice concentration and harvest data for Savoonga in spring of 1993–2008

SIC (%)	Number of walrus	Fraction of harvest (%)	SIC frequency (%)
0–10	2796	52	44
10–20	884	17	14
20–30	1019	19	13
30–40	182	3	3
40–50	98	2	5
50–60	162	3	7
60–70	70	1	5
70–80	83	2	3
80–90	4	0	1
90–100	36	1	4

Table 5.10 Sea ice concentration and harvest data for Gambell in spring of 1992–2008

SIC (%)	Number of walrus	Fraction of harvest (%)	SIC frequency (%)
0–10	3778	48	53
10–20	2165	28	18
20–30	944	12	11
30–40	626	8	8
40–50	166	2	2
50–60	18	0	3
60–70	55	1	2
70–80	23	0	4
80–90	2	0	0
90–100	22	0	0

Longer Term Change and Case Studies from the 1980s and 2000s

> The pattern [of walrus migration] is not the same today anymore like it used to be because of the climate change and the ice conditions have changed and the animals are affected by this global warming thing. That is sad to say. I think we are more adversely affected here because our walrus and whaling seasons are short, because of inclement weather . . . When I was growing up and later on as an adult hunting with my dad, we used to have good weather all the time (Leonard Apangalook, Sr., Gambell, St. Lawrence Island, in Metcalf 2003).

As expressed by Leonard Apangalook, Sr., and mentioned by George and Chester Noongwook (Noongwook 2000; Oozeva et al. 2004), hunters in Gambell have recognized changing sea ice, weather, and walrus migration patterns. These observations at the village scale coincide and as detailed by Huntington (2000) in many cases precede satellite observations of pan-Arctic sea ice retreat. This retreat has been most pronounced in the summer months, with the summer minimum ice extent declining by more than 10% per decade from 1979 to 2008, and record low extent in 2007 and 2008, almost 25% below the previous record minimum set in 2005 (Stroeve et al. 2008). Here, we examine how ice concentration has varied over those years in the ocean adjacent to Gambell and Savoonga (75×75 km as detailed in the methods section; Fig. 5.1), in areas important to walrus hunters.

Ice concentration anomalies based on annual averages for the ice year from September 1 through August 31 (Fig. 5.7a, c) and spring seasonal averages for March through June (Fig. 5.7b, d) for Savoonga and Gambell show substantially more inter-annual variation and a weaker trend than pan-Arctic data referenced above. Annual anomalies indicate a reduction in ice extent by 2%/decade for both Gambell and Savoonga, explaining 17 or 14% of the observed variance and are significant at the 95% level (t-test with the null hypothesis that the correlation coefficient is significant cannot be rejected, $p = 0.05$). Spring ice concentration anomalies are slightly higher, approaching 3%/decade. Since the mid-1990s, inter-annual variation in ice concentration appears to have increased significantly. The variance for spring concentration anomalies is generally higher than the annual anomalies.

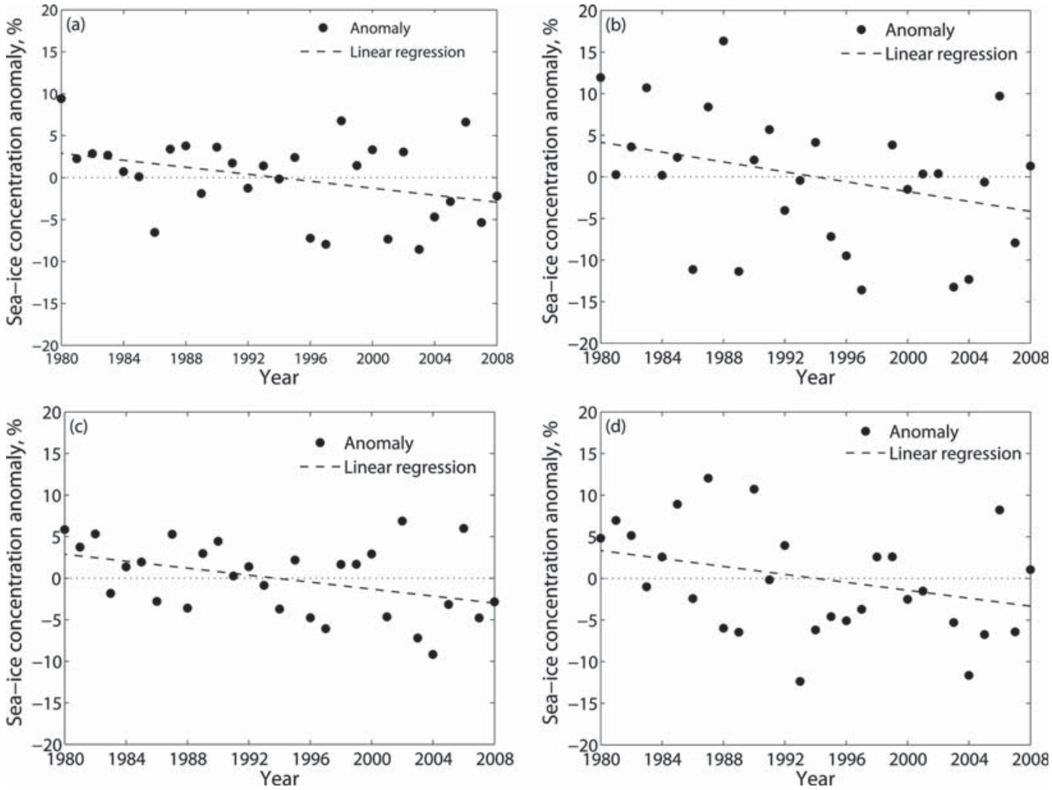

Fig. 5.7 Sea ice concentration anomalies (1980–2008) for each sea ice year and linear trends for entire time period in (**a**) Savoonga ($R^2 = 14\%$) and (**c**) Gambell ($R^2 = 17\%$). Sea ice concentration anomalies for the spring months (March through June) and linear trends are also shown for Savoonga ($R^2 = 9\%$) (**b**) and (**d**) Gambell ($R^2 = 9\%$). The anomalies are calculated by subtracting annual-averaged or spring-averaged values from the mean calculated for the entire time series. R^2 indicates the fraction of the variance explained by a linear regression

However, particularly noteworthy is the fact that none of the recent record minimum summer ice extent years register as record anomalies at the St. Lawrence Island locations.

As derived in previous sections of this contribution, hunters had the greatest success in taking walrus in the ice concentration range between above 0 and below 30% in Savoonga and Gambell. Taking these intervals as constraints for successful spring walrus hunts, we compared the years 1982–1984 as representative of the pre-decline Arctic ice extent with the years 2006–2008 as representative of reduced Arctic ice extent in recent years. In spring March–June of 1982–1984 ice concentrations were favorable for the hunt in Gambell (>0 to <30% ice concentration) on a total of 149 days. During the time period 2006–2008 (spring) there were only 92 days with such ice conditions, a reduction of 38% compared to the early 1980s. By contrast, in Savoonga no similar strong reduction was observed, with 100 favorable days in 1982–1984 and 94 favorable days in 2006–2008, a 6% reduction. In part, this is explained by the fact that in Savoonga disproportionately large numbers of walrus are taken on days with ice concentrations between 10 and 30%, which did not change significantly between the periods 1980s and 2000s. Gambell, on the other hand, experienced a reduction by 13% in the number of days amenable to a successful hunt (see also Fig. 5.6).

The hunting success during these observation periods in 1982–1984 was 116 walrus/week in Gambell and 60 walrus/week in Savoonga (weekly averages of the WHMP are calculated to reduce the error due to a decreased observation period). In the mid-2000s hunting success was slightly reduced by 3 walrus/week in Gambell, but had substantially increased by 36 walrus/week (38%) in Savoonga. Since the aggregated WHMP data (weekly totals) do not warrant a detailed analysis of hunting success on specific days (Benter, personal communication 2009), it is noteworthy that on highly successful days hunters brought in as many as 184 walrus in Gambell and 131 in Savoonga.

The time series of the number of days favorable to the walrus hunt determined for the satellite record (1979–2008) shows great inter-annual variability. While Gambell sees three fewer favorable hunting days (a reduction from 50 to 47 days) over the time period and Savoonga an increase of seven (37 days in 1980 and 44 days in 2008), these trends are not statistically significant (Fig. 5.8; t-test, $p = 0.05$). However, there is a clear link between the local ice conditions in spring (as determined for the study sites offshore from each village) and the number of favorable hunting days. Figure 5.9 illustrates how negative or positive sea ice anomalies in spring directly translate into more or fewer favorable hunting days. Spring ice concentration anomalies explain over 50% of the variance observed in the number of favorable hunting days (57% for Gambell and 63% for Savoonga, t-test, $p = 0.001$). Annual ice concentration anomalies account for 18 ($p = 0.05$) and 32% ($p = 0.001$) of the variance in Gambell and Savoonga.

Finally, we assessed whether the regional ice conditions in the Bering Sea might be a good predictor of the number of favorable days for the walrus hunt. While there is significant correlation between local ice conditions and ice concentration anomalies for the entire Bering Sea at the annual scale ($R^2 = 43\%$ for Gambell and

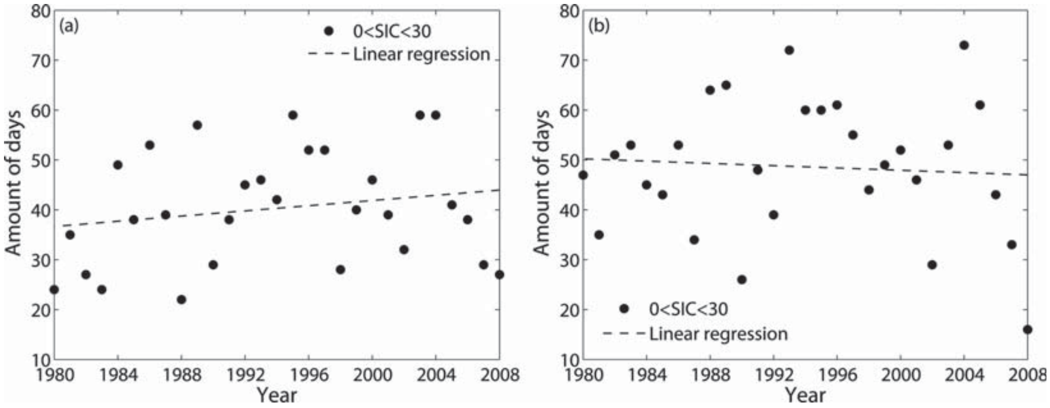

Fig. 5.8 Number of days when favorable sea ice conditions prevailed in (**a**) Savoonga and (**b**) Gambell

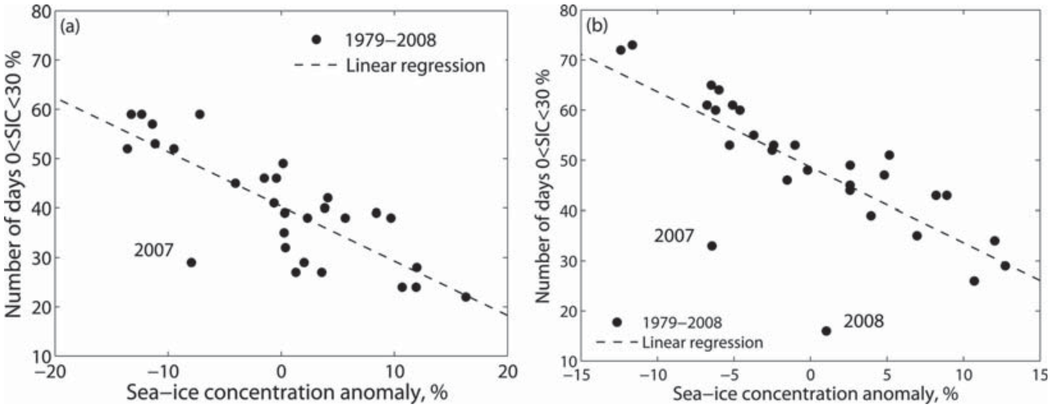

Fig. 5.9 Number of days on which the sea ice concentration exceeded 0% and was lower than 30% plotted relative to the sea ice concentration anomalies in spring for (**a**) Savoonga ($R^2 = 63\%$) and (**b**) Gambell ($R^2 = 57\%$)

$R^2 = 59\%$ for Savoonga; *t*-test, $p = 0.001$), this is less so for springtime anomalies ($R^2 = 12\%$ and $p = 0.05$ for Gambell; $R^2 = 27\%$ and $p = 0.01$ for Savoonga). However, most important is the finding that Bering Sea spring and annual ice concentration anomalies explain only 10% of the observed variance in the number of favorable hunting days.

Discussion

As evident from the results presented in the previous section, local, regional, and inter-annual variabilities and the shortcomings of coarse-resolution satellite data present a number of formidable challenges in reaching conclusions about the linkages between weather and ice conditions favorable to the walrus hunt on St. Lawrence Island. In part this is due to insufficient spatial and temporal resolutions, with respect to both harvest data (which are accurate to within a day, at least for the WHMP data) and weather records (which are daily averages of a limited set of observations). At the same time, the passive microwave satellite data analyzed here have significant limitations due to limited spatial resolution and errors in ice concentrations derived for the coastal zone (Massom 2009). To reduce the latter, we had to eliminate pixels that border on the coast from the analysis. While this does not affect overall trends, it may somewhat limit the perspective on hunting in close proximity to the village sites. We do note, however, that the study sites, 75 × 75 km in size, cover much of the region frequented by hunters, who on average travel between 13 and 146 km offshore during the season in Gambell (Benter and Robards 2009). Here, observations by Yupik sea ice experts, such as the detailed discussion of Gambell ice conditions provided by Leonard Apangalook, Sr., and Paul Apangalook (Chapter 14 by Krupnik et al. this volume), are invaluable in providing context and ensuring that satellite data are in fact representative of a specific site or ice-associated activity. We will discuss this aspect further below. However, despite such limitations, some tentative, broad conclusions with respect to the weather and ice conditions that favor spring walrus harvests can be drawn. Thus, Table 5.11 summarizes key findings and delineates the window of opportunity most favorable to hunting success in Savoonga and Gambell.

Table 5.11 reflects the fact that the most important role played by the weather is in controlling access to offshore sea ice that is bearing walrus while allowing for safe boating and hunting conditions among the ice pack or in open water. In particular the ice movement forced by winds and currents is of great interest to walrus hunters on St. Lawrence Island, evident in the description by George Noongwook (Savoonga) of a wind-driven ice phenomenon, referred to as *pequneq* in Yupik: "A coning of thin or freshly formed ice pushed by the storms before it crashes down [. . .] producing a small open lead for a very brief moment that closes almost instantly. If you get caught in one of these, you will not have time to escape! We have lost some of our people in these conditions all in the name of seeking food for survival" (Noongwook 2000). This description links the short-term variability of ice movement on a local scale with the ability of Savoonga hunters to interpret ice conditions. While the large-scale conditions prerequisite to *pequneq* can be extracted from satellite and

Table 5.11 Environmental factors relevant for local walrus hunting success off St. Lawrence Island, Alaska

Environmental factor or trend	Savoonga – favorable spring walrus harvest conditions	Gambell – favorable spring walrus harvest conditions
Sea ice concentration	Above 0% and below 30%; hunters need at least a few open leads that are wide enough to launch boats. Also, walrus prefer to rest on the ice, so a certain ice thickness (>60 cm; Fay, 1982) and floe size is necessary	
Wind speed	• 1–5 $m\ s^{-1}$ Higher wind speeds present boating safety hazards	• 5–9 $m\ s^{-1}$
Wind direction	ENE, ESE, WSW; these are the main directions when hunting takes place. Northerly winds push ice against the shore and close off access to sea	NNE, ENE, SSW; northerly winds in Gambell do not have as much influence on the hunt as in Savoonga because Gambell has a beach on the north and west side to launch boats from
Visibility	>6 km; good visibility is a key factor for safety on the ice and important to spot walrus	
Air temperature	–5 to +5 °C due mostly to the time of the year (spring break-up); at low wind speeds and low temperatures (<–20 ºC) leads tend to freeze (George et al. 2003)	
Cloud cover	Not important for the spring hunt; linked to temperature and indirectly to sea ice growth or melt and may hence on occasion correlate weakly with hunting success	
Sea ice concentration window favorable for spring hunt	1982–84: 100 days 2006–08: 94 days	1982–84: 149 days 2006–08: 92 days
Spring-hunt success	1982–84: 60 walrus/week 2006–08: 96 walrus/week	1982–84: 116 walrus/week 2006–08: 113 walrus/week

weather records, the temporal and spatial resolutions of such data are insufficient for deeper insight into such processes.

However, what this study does resolve quite well, as summarized in Table 5.11, are the differences in ice conditions (and to a lesser extent weather) between the villages of Savoonga and Gambell, as well as their impact on hunting success. Thus, small but significant differences in wind speed between villages on walrus harvest days with similar ice conditions and visibility suggest that hunting itself is not only dependent on the fact that sea ice is present. St. Lawrence hunters are very experienced and able to hunt and butcher walrus directly in the water (even if it is less efficient, inconvenient, and certainly the less preferred option from both, a hunter's or manager's perspective due to greater potential for loss) or to tow animals back toward shore for butchering (Benter, personal communication 2009). Hence, it is possibly also the behavior and distribution of walrus, as the animals are resting and nursing on the ice, that link ice conditions and hunting success. However, even if sea ice is present, sufficient open water is required for boat launching and navigation through leads or in loose pack ice. This circumstance is highlighted in the daily log of Leonard Apangalook on April 16, 2008: "No open water west side of Gambell where walrus, seals and whales pass by north on their northerly migration during this time of the season. Wide open water on the leeward side of the island, where Daniel Apassingok went out on boat from Kiyellek [Qayilleq] and got a bearded seal." With an ESE wind during that day ice was pushed against the coast east of Gambell while 5 km east from Gambell, at Qayilleq (a hunting camp, see Chapter 14 by Krupnik et al. this volume), ice got blown out and opened access to the sea. L. Apangalook's observation addresses three key points or prerequisites for access to ice and walrus:

1. There must be open water in form of large open areas or small open leads accessible, large enough to launch a boat
2. Wind stress can result in a wind-driven movement of sea ice that either packs ice against the coast or opens a coastal or flaw lead
3. The main advantage of Gambell compared to Savoonga is the position of the village, such that it has a north and a west beach and furthermore that the hunting spot Qayilleq is in close range around 6 km to the east, on the eastern side of the Gambell peninsula, allowing access to the lead system for different wind conditions. Savoonga hunters can compensate for more severe ice conditions and fewer options to launch boats by accessing other hunting spots on the south side of the island.

The first point is illustrated in the high-resolution Synthetic Aperture Radar (SAR) image of April 17, 2008 shown in Fig. 5.10, within less than one day of the ice conditions described by Mr. Apangalook and under comparable weather conditions. At this time, neither the west coast of the Gambell peninsula nor the north coast were ice free because of strong NNE winds on April 13 and strong SSW winds on April 16, 2008. Wind speeds of up to 9 m s^{-1}, possibly aided by currents, were able to move the ice up against the coast north and west of Gambell.

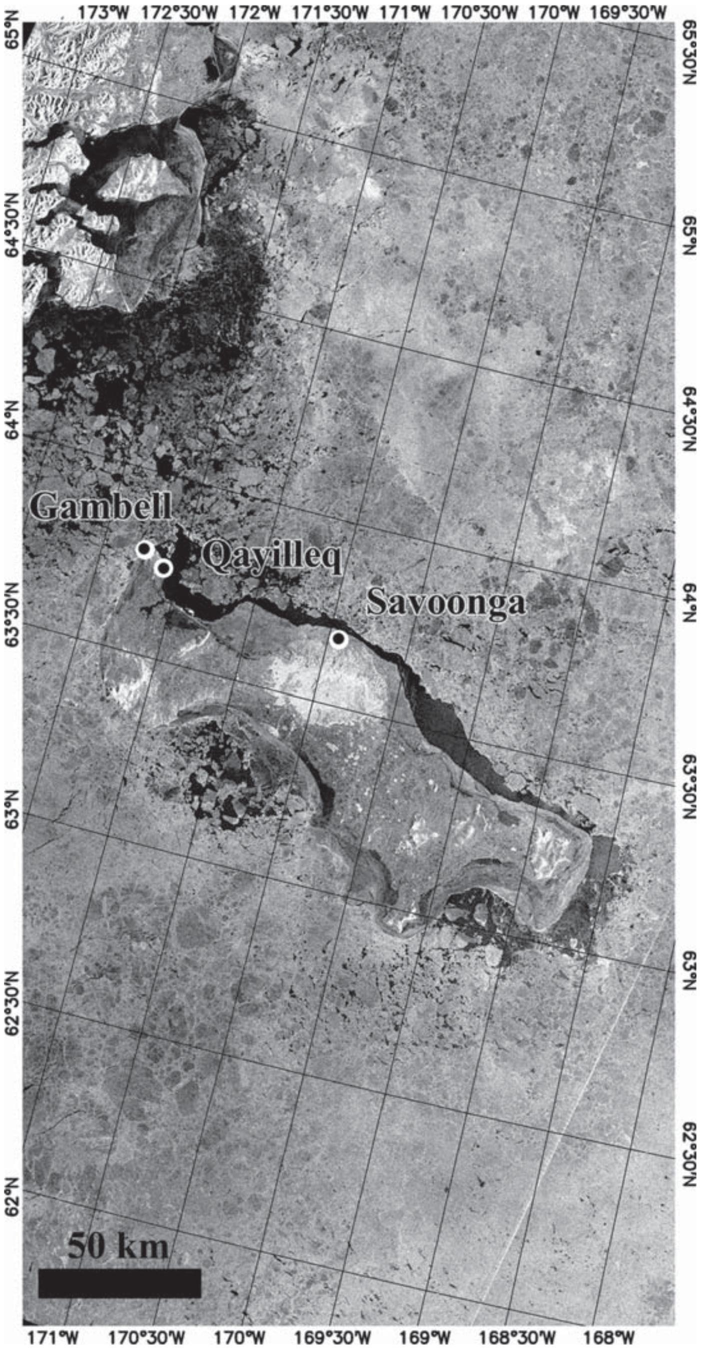

Fig. 5.10 Synthetic aperture radar (SAR) image for April 17, 2008, showing ice conditions around St. Lawrence Island, Alaska (image is 200 × 400 km in size, © Canadian Space Agency) and the locations Gambell, Qayilleq, and Savoonga

Therefore, hunters were not able to launch their boats from the beach at the community. However, the hunting camp Qayilleq had some open water extending well into the ice pack because of the southerly wind component on the 16th and 17th of April 2008 and wind speeds strong enough to move the ice. Hence, people were able to launch their boats at this site, in contrast with the main village of Gambell. Also at the coast of Savoonga a narrow lead opened due to the SSW winds, as seen in Fig. 5.10.

The second point emphasizes the importance of wind-driven sea ice motion, assuming that the under-ice currents are not strong enough to overwhelm the wind's forcing. The quote from G. Noongwook at the beginning of this chapter describes such a wind-driven sea ice phenomenon and its inherent danger. Winds control the opening and closing of leads under most conditions, but such processes are not directly observed at the relevant scale in passive microwave satellite imagery, precluding any analysis of linkages between wind speed and lead openings. However, since sea ice is much rougher than the open sea around the island and since ice impacts the larger scale surface wind patterns (Andreas 1998), sea ice performs an important service in support of harvest activities.

This is expressed by Leonard Apangalook, Sr.: "When there is no pack ice around Gambell anymore the winds are higher and people are not able to go out anymore [in spring]. [. . .] And as soon as the pack ice arrives [in fall] the wind calms down and makes weather conditions more reasonable" (personal communication 2009). This linkage between surface wind speed and ice concentration may also explain that Savoonga is slightly less windy (by 1 m s^{-1}) than Gambell in the spring with corresponding ice concentrations of 25 ± 27 and 17 ± 20%. While the difference in wind speed is small but significant, Leonard Apangalook (personal communication 2009) confirms that Savoonga, due to its somewhat more sheltered position, experiences less windy conditions. In general, it appears that high wind speeds do not influence the hunt as long as they do not exceed a certain threshold. This threshold amounts to 9 m s^{-1} in Gambell and 5 m s^{-1} in Savoonga. Above these thresholds, very few walrus were taken. Similar observations by Lourie (1982) for the years 1981 and 1982 indicate that hunters in Gambell were most successful on days with average wind speeds of 3–5 m s^{-1}. Of course, as pointed out earlier, any factors such as personal judgment as to whether a given weather situation is good for hunting or not as well as other socio-economic factors that come into play here are ignored in our simplistic analysis. Similarly, current speeds and their impact on ice openings and boating safety are not considered and may explain some of the variability observed in hunting activities.

The third point addresses the importance of the local topography relative to prevailing winds and ice conditions. Gambell lies on a peninsula and has coastal access to the west and north, as well as at another location 6 km away, offering several options for boat launching and explaining the somewhat broader range in favorable wind conditions compared to Savoonga (Figs. 5.4a and 5.5a). In Savoonga, hunting primarily took place when winds were ENE, ESE, and WSW. Walrus hunters went out rarely during northerly winds, since such winds block access to open water north of town. These differences and the satellite image shown in Fig. 5.10 demonstrate how strongly conditions can vary between the two locations. A key conclusion from examining the summary provided by Table 5.11 is that despite the limitations discussed earlier, there is some value in this type of analysis in order to arrive at a rough delineation of the weather and ice conditions that favor or reduce the probability for a successful walrus hunt. This is a first step toward assessing how changes in large-scale surface climate and ice conditions have the potential to impact the walrus hunt in two Bering Sea communities.

With respect to long-term variability and change, analysis of the satellite data record from 1979 to 2008 leaves us with a number of points to ponder. First, as to be expected and demonstrated in studies off northern Alaska (Eicken et al. 2009), inter-annual variability in ice conditions is larger for the confined hunting grounds of Gambell and Savoonga as compared to the pan-Arctic trend toward reduced summer ice cover. This is in part explained by the fact that the winter and early spring sea ice extent in the Bering Sea is currently above normal, most likely in conjunction with the atmospheric circulation patterns associated with the cool phase of the North Pacific Decadal Oscillation (NPDO, Overland et al. 1999). As a result, even the record-low ice summer of 2007 registers with above-normal ice extent in the Bering Sea through mid-May. It is only in late May that the rapid retreat started which led up to the record minimum in the pan-Arctic and the Pacific Arctic sector (Eicken et al. 2010). However, since ice concentration anomalies capture deviations from mean extent as well as deviations from the average timing of the seasonal cycle, both 2007 and 2008 (with the second-lowest ice extent in summer on record) register as modestly negative anomalies.

Second, changes in the ice cover do impact access to and availability of ice-associated mammals such as walrus. We found that sea ice concentration anomalies in spring are directly connected to the number of favorable hunting days (0 < SIC < 30%). This observation may seem trivial at first, i.e., if ice reduction were not shortening the ice season but simply decreasing the concentration on days with high ice cover. However, local ice experts' observations (see Krupnik et al. this volume) and our analysis indicate that in fact the picture is more complicated than that. Negative sea ice anomalies (reduced sea ice concentration) thus appear to increase the number of favorable opportunities for the hunt and hence provide the hunters with a longer time window during which they can successfully pursue walrus.

This can significantly reduce the risk associated with hunts on days where weather conditions or other environmental factors represent a hazard. Conversely, positive sea ice concentration anomalies, at least for the period studied, do impact the hunt in a negative fashion. The way in which the prevailing negative spring ice concentration anomalies in recent years have expressed themselves in the region is such that they resulted in improved conditions for the walrus hunt in spring. The spring ice conditions of 2007 and 2008 stand apart from this broad trend as evident in Fig. 5.9. In 2007, in particular, the number of favorable harvest days was anomalously small at Gambell. However, hunters in Gambell did not notice a decline in harvest numbers (Krupnik et al. this volume), in contrast with very poor harvests in communities further north, such as Wales in Bering Strait and communities on Alaska's North Slope (W. Weyapuk, Jr., personal communication 2007; J. Leavitt, personal communication 2007). The tight fit between favorable harvest days and local spring ice concentration anomalies evident from Fig. 5.9 suggests that this type of analysis can help in identifying extreme years – recognizing that hunters will find ways to address or adapt to such challenges. At the same time, the overall tight fit between favorable hunting days and local ice anomalies may provide an additional tool for walrus subsistence management that seeks to be responsive to environmental constraints on both animals and hunters (Robards 2008).

The comparison between the sea ice anomalies near the villages and for the whole Bering Sea has shown that even if the overall trend of sea ice on a scale of tens of kilometers to hundreds of kilometers in the Bering Sea is the same, the number of days with favorable ice conditions does not necessarily follow this trend at the regional level. This may be different for other subsistence communities, such as Barrow, where ice conditions are not as complex as in the vicinity of St. Lawrence Island. For example, an analysis of ice conditions in the eastern Chukchi and western Beaufort Sea suggests that local ice conditions track somewhat better with the regional ice anomaly patterns (Eicken et al. 2009) than observed here. Most important, however, this work illustrates a broader pattern of increasing decorrelation and decoupling between hemispheric scale processes that drive sea ice extent and concentration and those controlling the ice at the scale that matters to people hunting on and among sea ice (Gearheard et al. 2006).

Finally, in the past 4 years (2004–2008) a striking decline in the number of favorable harvest days is evident in Fig. 5.8. To assess to what an extent this trend mirrors potential changes in atmospheric forcing, we have examined data for the two most influential climate patterns in the region, the Arctic Oscillation (AO) and the North Pacific Decadal Oscillation (NPDO). By comparing surface ocean temperature and atmospheric pressure anomalies triggered by these patterns (annual averages of the sea surface temperature (SST) anomalies[1] triggered through NPDO and the leading mode of the 1,000 hPa height anomalies[2] for the AO, both poleward of 20°N, have been used) we found steadily decreasing SST anomalies starting in 2003 from +1 to –3 K in 2008. This significant correlation with the reduction in favorable ice conditions between 2004 and 2008 (Fig. 5.8) may be explained by the link between lower temperatures and above-normal ice concentrations, minimizing the number of days favorable to hunting from boats. The finding is also consistent with the fact that ice conditions were above normal during recent years in the Bering Sea during winter and early spring. By contrast, the AO anomalies did not show any significant correlation with any of the surface patterns and are hence deemed of lesser importance in explaining variations in hunting opportunities and success.

Hunters are well aware of changes in sea ice and climate and the associated evolution of the skill set inherited from past generations. This is echoed in George Noongwook's (Savoonga) comments: "The window of opportunity for conducting successful subsistence activities is going to become shorter because of warming climate. It is then up to [the hunters] to determine how, [they] can be more efficient and safety minded in terms of retrieving and stalking marine mammals" (Noongwook 2000). This comment reflects the fact that old hunting practices may have to change substantially in the future. It also speaks to the potential of younger hunters adapting their practices and improving hunting success, e.g., through the means of new technologies, more powerful boats, interpretation of satellite imagery, or the use of snowmobiles to access the south coast of the island.

Similarly, Leonard Apangalook, Sr., comments on less sea ice and higher winds at Gambell (personal communication 2009). Changes in sea ice conditions also have a direct influence on Pacific walrus (Robards 2008) and hence impact the subsistence hunt indirectly as well. These changes in turn bring about other impacts, such as shifts and potential conflicts with harvest times for other marine mammals, such as whales (Sease 1986; George et al. 2003).

Conclusions

This contribution explores the physical factors that are controlling the spring walrus hunt in Gambell and Savoonga. We were able to show that ice concentration, derived from satellite remote sensing at a scale of tens of kilometers, is significantly linked to the local walrus harvest success of the villages. At the same time, large-scale regional ice conditions in the Bering Sea scaled poorly with the number of favorable hunting days in each season, highlighting the need for downscaling approaches in linking sea ice use by coastal communities in this region to large-scale patterns of variability and change. The analysis of weather and ice data helped define the seasonal window of opportunity and the conditions under which hunters tend to be successful (summarized in Table 5.11). While this information is still limited in its scope and validity, it may be of value in developing scenarios or quantitative relationships between changes in weather and ice cover and potential hunting success that can be employed in model-based forecasts or studies of adaptation to climate variability and change.

Overall, the picture that emerges from this study for hunting success on St. Lawrence Island is complicated, as reflected by the nuanced and highly detailed statements hunters provide in this context. Overall, the research clearly demonstrated that for ice conditions at the local level off the village sites, the spring sea ice concentration anomalies are excellent predictors of favorable hunting conditions. Negative anomalies actually coincide with more favorable conditions, most likely because they correspond to a more accessible ice pack and potentially better access at the village site. The most recent years, however, with anomalously low arctic-wide summer ice extent clearly fall outside of this well-defined relationship since the rapid northward retreat of the ice edge in particular in 2007 greatly reduced the most favorable part of the spring shoulder season. Nevertheless, walrus hunters were able to cope and mostly by traveling longer distances (approaching 200 km away from the village for individual hunts, compared to studies by Lourie 1982, in the early 1980s when the maximum distance covered during the Gambell spring hunt was 113 km) the harvest season was deemed reasonably successful. Clearly, traveling longer distances increases vulnerability to storms and bad weather and greatly increases fuel costs, which already are at an all-time high. These potential challenges are exacerbated by the compression of the window of opportunity (Benter and Robards 2009).

As discussed in Chapter 4 by Krupnik et al. (this volume) and evident from the graphs and data shown here, comparatively low ice concentrations in the late winter and early spring do allow St. Lawrence Island hunters to venture out very early in the year. Here, the island is favored by its location that resides not too far within the maximum ice extent and hence results in loose ice pack conditions even in winter. At more northern coastal sites such winter hunts are not an option, also due to less favorable light and weather conditions. At the same time, at other villages the impact of more rapid ice retreat appears to be felt much more drastically (Eicken et al. 2010), requiring a more detailed region-wide analysis.

Another important conclusion to draw from this work is that there can be significant differences in weather and ice conditions between the two villages on St. Lawrence Island that impact access to walrus at any one time and also determine to what extent climate variability and change affect the villages. Hunters' insights in combination with high-resolution satellite imagery and weather records provide a very detailed picture of the conditions that favor access to walrus on sea ice (see also Table 5.11). Again, this information can help assess future developments and adaptation strategies if ice conditions were to continue to change. More important, as evident from the comparison between the window of opportunity in the early 1980s and spring of 2006–2008 (Table 5.11), the contrast between Savoonga and Gambell (the latter with a reduction in the number of favorable hunting days by 40%) can be substantial.

Given the importance of ice conditions and weather for a safe, successful hunt and recognizing that a shorter window of opportunity increases the risk to hunters (Noongwook 2000), it is noteworthy that currently forecasts for the region only cover the Alaska mainland and not conditions on St. Lawrence Island. Experienced hunters such as Leonard Apangalook report that these forecasts are significantly different from the conditions in Gambell (personal communication 2009). More analysis and further efforts are required to improve weather forecasts and potentially seasonal-scale forecasts of conditions that are applicable to the two villages' hunting grounds.

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Notes

1. http://jisao.washington.edu/pdo/PDO.latest
2. http://www.cpc.noaa.gov/products/precip/CWlink/daily_ao_index/ao_index.html

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