SELECTION OF HAUL-OUT SUBSTRATE BY HARBOR SEALS (*PHOCA VITULINA*) ASSOCIATED WITH TIDEWATER GLACIERS IN KENAI FJORDS NATIONAL PARK, ALASKA.

by

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May 2011

Masters project submitted in partial fulfillment of the

requirements for the Master of Environmental Management degree in the

Nicholas School of the Environment

Duke University

2011

ABSTRACT

In Alaska, 10-15% of harbor seals use glacial ice as a haulout substrate on which to rest, molt, and care for young. Some glaciers in Kenai Fjords National Park are receding at a staggering rate which could reduce the habitat available to seals in the near future. Understanding the current usage of haulout substrate at both a local and region scale will be vital to effective and proactive management of the species in light of climate change predictions.

The primary goal of the present study was to evaluate the seasonal characteristics of ice availability and the associated patterns of usage by harbor seals in Northwestern Fjord—which terminates in a rapidly receding glacier. Patterns of seal attendance and ice conditions were evaluated across six sub-regions and across two summers. Data from Northwestern Fjord was also contrasted with observations conducted in a location, Aialik Bay, where the primary glacier is relatively stable.

Results of this analysis indicate seasonal patterns of ice availability and linkages between seasonal ice conditions and the numbers of seals present. Overall ice coverages did not have predictable seasonal trends but small and medium sized ice platforms had significant trends in their availability throughout the summer. In Northwestern Fjord attendance peaked in midsummer and was positively correlated with ice availability and the availability of large sized bergs. Seal attendance also exhibited seasonal trends in Aialik Bay but opposite those observed in Northwestern Fjord. This study provided a baseline understanding of habitat availability and usage for the study area. Further research examining the patterns of habitat use by sex, age class and the movement between fjords is needed to fully understand the dynamics of how harbor seals in Kenai Fjords National Park utilize habitat.

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INTRODUCTION

Life History

Pacific harbor seals (*Phoca vitulina richardsi*), (Gray, 1864) are found almost continuously along the Northwest Pacific coast, from Mexico to Japan, and as far north as the Bering Sea. Their range is extensive, but harbor seals favor coastal waters where they forage on a wide variety of species including sole, flounder, hake, cod, herring, octopus and squid (Pitcher 1981, Tollit et al. 1997; Hauser et al. 2008). As semi-aquatic pinnipeds, harbor seals haulout on rocks, beaches, ice floes and manmade structures. This behavior allows seals to rest, conserve energy, and avoid predators such as orcas (*Orcinus orca*). In addition, terrestrial habitats are essential to seals during the pupping and molting seasons. Observations have been made of harbor seals mating on land, but most reproductive activity occurs in the water (Allen, 1985). In contrast to other phocid seals which breed on land or ice, precopulatory behaviors, male defense of territories, and copulation occur in the water (Allen, 1985; Hays et al. 2004).

In Alaska, some harbor seals utilizes floating platforms of glacial ice, calved from tidewater glaciers, as haul-out substrate. Only 10-15% of harbor seals in Alaska use this habitat type (Bengston 2007) in regions spanning from LeConte Glacier in southern southeast Alaska through McCarty Fjord on the Kenai Peninsula. The present study examines ice-associated harbor seal found along the south-central coast of Alaska in the Kenai Fjords National Park.

Population Status

As currently defined by the Marine Mammal Protection Act (MMPA), three distinct stocks of harbor seals are currently recognized in Alaska: the Bering Sea stock, the Gulf of Alaska stock and the Southeast Alaska stock (Figure A1). As of 2009 harbor seals are not classified as 'depleted'

under the MMPA or as 'threatened' or 'endangered' under the Endangered Species Act (ESA). The seals examined in this study, those associated with tidewater glaciers, are located within the ranges of the NMFS designated Gulf of Alaska and Southeast Alaska stocks. Neither of these stocks is classified as strategic, but the actual status of these stocks is unknown (Allen and Angliss: NOAA stock assessment, 2009). For example, the National Marine Fisheries Service (NMFS) considers the Gulf of Alaska stock to be 'stable' (Allen and Angliss 2009) but other regions within this range have experienced a distinct and prolonged decline in abundance. In Prince William Sound and Kenai Fjords National Park, a decline occurred during the 1970s-1980s that resulted in a reduction of up to 80% of the historical abundance (Small et al 2003; Hoover-Miller et al 2011). Similar uncertainties regarding status exist in Southeast Alaska, with stark declines in Glacier Bay occurring at the same time that increases were observed in other areas such as Ketchikan (Calambokidis 1987; Allen and Angliss 2009; Womble et al 2010).

Due to these localized but severe population declines, harbor seals in Alaska have been a major focus for scientists and managers over the past 30 years. Many of these localized declines were observed in locations where seals utilize glacial ice such as the south Kenai Peninsula coast, and Glacier Bay (Small et al 2003; Womble et al 2010; Hoover-Miller et al 2011). Kenai Fjords and Glacier Bay are also both locations exposed to eco-tourism and experience extensive human visitation in the summer months. As a result, many long-term studies are seeking to assess the threats created by various modes of tourism on harbor seal populations (Lewis and Mathews 2000; Jansen et al. 2006, 2010; Jezierski 2009; Hoover-Miller et al 2010). In a few cases, researchers have begun to include covariates such as ice coverage and spatially explicit habitat descriptions in their behavioral studies of harbor seal responses to tourism (Jansen et al. 2006). For the most part, however, the focus of past research has been on quantifying if human activities have impacts on

populations and not the effects of glacial ice availability on seal attendance. As such the present study seeks to fill the informational gaps concerning the availability of glacial ice haulout substrate, particularly since many of the glaciers of interest are threatened by climate change.

Tidewater Glaciers

Approximately 20% of the Gulf of Alaska's watershed is comprised of glaciers (Royer, 1982). There are over 10,000 individual glaciers but only 51 are tidewater—or as defined by Russell (1893): "glaciers which enter the ocean and calve off to form bergs" (Figure A2 | Molina, 2008). In many cases, tidewater glaciers along the southwestern and southeastern coast of Alaska, have carved deep ocean-flooded valleys, or *fjords*. This type of coastline is a remnant of the past advance and retreat of glaciers throughout geological history.

Tidewater glaciers in this region advance and retreat asynchronously with each other and a variety of geophysical and climatic factors influence the dynamics of individual glaciers. Specifically fjord depth, sediment supply and fjord geomorphology have some of the greatest influences on glacial stability (Meier et al 1980; Wiles et al, 1995). Many studies support the hypothesis that it is actually these variables and not climate changes that contribute most to the retreat and advance cycles of tidewater glaciers (Wiles et al, 1995). As opposed to terrestrial terminating glaciers, tidewater glaciers directly interact with the marine environment and are affected greatly by this interaction. As salt water affects terminus melting rates, fjord depth the terminus and calving rates share a positive, linear relationship (Wiles et al, 1995; Meier and Post, 1987).

Just as the interface between ice and the marine environment is a defining characteristic of tidewater glaciers, this direct interaction that also makes glacial habitats important to marine

organisms. The waters at the terminus of tide-water glaciers have estuarine qualities; large, freshwater icebergs create salinity gradients as the glacial ice melts (Royer et al. 2001). Primary productivity in tidwater regions tends to be relatively high, supporting abundant secondary consumers and predators (Royer et al. 2001). Tidewater ecosystems can also support high levels of biodiversity and abundance. In addition to harbor seals, larval and juvenile stages of fish such as Pacific herring (*Clupea pallasi)* and pink salmon (*Oncorhynchus gorbuscha)* rely on the estuarine waters for the first years of their lives. At higher trophic levels, sea birds such as the Glaucous-winged gulls (*Larus glaucescens*) prey on these fish stocks (Hoover-Miller and Prewitt, 2009).

For harbor seals, tidewater glacier ecosystems provide haulout substrate necessary for the essential periods in their life history: pupping and molting. Unlike terrestrial haul-outs, availability of ice for haul out is not dependent on tidal fluctuations; thus seals have options for spending longer times hauled out, or can haulout at any time of day or night (Hoover-Miller, 1983). Ultimately there are a number of hypotheses that could explain why some harbor seals use glacial ice. Ice allows flexibility in haul-out patterns, may allow for haul out closer to prey sources, provides increased protection from orcas (*Orcinus orca*), or the preference may be a remnant behavior from a time when glaciers were dominant along the coastline.

Study Area: Northwestern and Aialik Glaciers

Within Kenai Fjords National Park, the present study focuses on the following two tidewater habitats: Northwestern Fjord and Aialik Bay (Figure A3). Northwestern Fjord is a narrow inlet that is separated from Harris Bay by a shallow and partially exposed moraine. It is home to three tide-water glaciers: Northwestern Glacier at the head of the fjord and Anchor and Ogive glaciers along the western shore (Figure A4). All three glaciers flow from the Harding Ice Field, the largest single

ice field located entirely within the United States (Molina 2008). Northwestern Glacier has experienced one of the most drastic recessions of any of the glaciers in the Kenai Fjords region with its terminus retreating close to 4.2km from 1950 to the mid-1990s (Molina 2008). Currently, Northwestern Glacier sits 8.04km north of its maximum extent (terminal moraine), and it has been noted that this predominant glacier is not only still rapidly receding, it is nearly terminating on shore (Molina 2008).

With its backward march, Northwestern glacier has exposed scoured granite walls and islands as well as a number of tributary glaciers. Two such glaciers, Anchor and Ogive reach the tidewater along the western shore of the fjord. Subsequent thinning of these glaciers has almost separated their terminus from the upper source area (Molina 2008), however they continue to calve ice into the marine environment. Many other glaciers are also present in the fjord but to not calve ice into the waters.

Limited monitoring in Northwestern Fjord indicates that numbers of seals have declined since 1979, (when a single count was conducted during pupping), but that at present numbers may be increasing (Hoover-Miller unpublished, NPS unpublished, and this study). During the 1979 survey, 909 seals were counted early in the pupping season (Hoover-Miller et al. 2010). This number was comparable to the number of seals observed in Aialik Bay that same year but the difference in the two areas has grown over time (Hoover-Miller et al. 2010). Due to its geography, Northwestern Fjord offered a prime location to examine how on the availability and characteristics of ice plays a role in harbor seal selection of haulout sites. It also provided an important glimpse into habitat use patterns near Northwestern Glacier prior to the glacier's full recession on shore.

Selecting Northwestern Fjord as the primary study area provided an optimal location for the assessment of ice availability, but it did not provide a complete picture of the habitat usage for the

whole Kenai Fjords region. General patterns of attendance such as presence during pupping and the molt are consistent across most glacial haulouts but fine-scale patterns of ice availability and seal attendance may differ between glacial haulouts. Most research on harbor seals in this region has focused on Aialik Bay, a glacially carved fjord to the east of Northwestern Fjord. Aialik Bay is wider, has a fully submerged (10m deep) terminal moraine and thus greater marine influence than Northwestern Fjord. Aialik Bay includes three tidewater glaciers: Aialik Glacier at the head of the bay, Holgate Glacier at the head of Holgate Arm, and Pederson Glacier along the western coast of the fjord (Figure A5).

The physical properties of the glaciers in Aialik Bay differ from those found in Northwestern Fjord. Aialik Glacier's terminus is wider than Northwestern Glacier's measuring 0.6km. The moraine east of Pederson Lake suggests that the glacier may have experienced significant regression prior to the first scientific investigation of this glacier in 1909. However, during the last century it has not experienced significant changes in the position of its terminus (Molina 2008).

Holgate Glacier, approximately 10 km southwest of Aialik Glacier, is a smaller tidewater glacier found at the head of the western branching Holgate Arm. Since 1909, this glacier has retreated over 1km (Molina 2008) but this location is rarely utilized by harbor seals as a haulout site.

Pederson Glacier is a formerly marine terminating tidewater glacier that has retreated over 1 km since its first mapping in 1909 (Molina 2008). Unlike Aialik, Holgate and the glaciers in Northwestern Fjord, Pederson Glacier's retreat left an exposed terminal moraine that limits the influence of seawater at the face of the glacier. Currently, the glacier terminates in a small estuarine

lake that is connected to Pederson Lagoon—a body of water with a small channel connecting it to the marine waters of Aialik Bay.

The harbor seal monitoring program in Aialik Bay was initiated from 1979-1981. Seals were periodically counted from 1983-1997 but routine monitoring was not continued until 2002 when the Alaska Sea Life Center reinstated observations of seals in Aialik Bay, (at Aialik Glacier and Pederson Glacier) using remotely controlled video cameras operated at the Alaska SeaLife Center (Hoover-Miller et al 2011). Seal counts have been made each year throughout the summer months, with more frequent surveys during pupping and molting—the periods when haulout attendance of specific age groups is greatest. Most seals observed in Aialik Bay are sighted on ice associated with Aialik Glacier, particularly with seasonal peaks in attendance during the pupping and molting season. Near Aialik Glacier numbers of pups and total numbers of seals have shown decline spanning three decades (Hoover-Miller et.al 2011). Near Pederson Glacier, harbor seals use the thick, pan ice and floating calved ice at the face of Pederson Glacier. Attendance at this glacial site does not usually peak until the molt, with few pups observed at this location (Hoover-Miller et al. 2011). This could be because the pan nature of the ice in early spring, similar to land-fast sea ice, potentially leaves young pups vulnerable to land predators (Burns 1970). Thus, it is not until the ice breaks up in late summer that it is a valuable site for hauling out.

Long-term monitoring has demonstrated that the numbers of seals hauling out in Aialik Bay fluctuate on multiple times scales but that the seals hauling out near Aialik Glacier continue to decline (Hoover-Miller 1983, Hoover-Miller et al, 2011). Seal populations throughout Kenai Fjords region have received considerable scientific attention, but few studies have focused on ice availability. One study looked at the habitat characteristics, specifically the patterns of ice availability, at Aialik Glacier. In the early 1980s, the ice in Aialik Bay was observed to be more

abundant and widely distributed in early June, when glacial activity was high and water temperatures were low, than it was in August, when glacial activity was low and water temperatures higher and that during the molt, haulout appeared limited by ice availability (Hoover-Miller 1983). Since Hoover-Miller's (1983) study, no studies in the Kenai Fjords region have looked into the role of ice availability on haulout dynamics.

In their paper on the persistent decline of the harbor seal population in Glacier Bay, Womble et al. (2010) called for additional research to examine the importance of glacial ice habitat for seals in light of the rapid change this habitat is experiencing. They suggest future studies should strive to better quantify the availability of glacial ice relative to harbor seal abundance and distributions. As such, the objective of the present study was to investigate: 1) how glacially calved haul-out substrate availability varies in Northwestern Fjord across various spatial and temporal scales, 2) how seal attendance patterns respond to habitat characteristics in Northwestern Fjord and 3) how seal attendance patterns differ at a regional scale.

METHODS

Northwestern Fjord: Shipboard Surveys

Vessel based surveys of Northwestern Fjord were conducted in 2009 and 2010. In 2009, surveys were conducted twice a week (Wednesday, Saturday) and in 2010 three times a week (Monday, Wednesday, Saturday) from June through August (n= 53). All trips set out from the Seward harbor, located at the northernmost part of Resurrection Bay. Routes varied due to weather conditions, distribution of wildlife sightings and other factors but generally followed a standard route (Figure A6).

Two observers were present on each trip and positioned themselves at the highest viewing platform. The surveys were opportunistic and passive, and did not interfere with vessel operations. At the beginning of a survey, a Garmin GPS track log was started and kept activated throughout the trip (datum reference: WGS 1984). Prior to departure observers recorded weather and sea conditions (percent cloud cover, precipitation, wind, and sea state on the Beaufort scale) as well as time of departure, and both captain and vessel name.

Opportunistic sightings of harbor seals were recorded throughout the trip but a formal survey of Northwestern Fjord began at the terminal moraine in Harris Bay (Figure A7). Surveys of Northwestern Fjord occurred close to solar noon, between 1200 and 1400 h. In each of seven predetermined 'subregions' (Figure A7), observers used 8x35 range finder binoculars and 8x40 Vortex binoculars to census harbor seals during approach and departure. Seals on ice were distinguished from seals in the water and on a few occasions, seals were observed hauled-out on rocks near the face of Northwestern Glacier. During the pupping season—June 5th through July 1st—observers further differentiated mother/pup pairs from single seals. At the onset of surveys in each subregion, weather conditions and sea state were recorded. If at any point in the survey,

distance to seals or weather conditions compromised the ability to distinguish seals or distinguish pups from older seals, observers noted counts or areas that were affected. Any observations with less than 'good' observer confidence or with weather conditions that impaired confidence (rain or fog) were removed from the analysis.

Ice Coverage Assessment

In each sub-region, observers qualitatively mapped ice floes and the general location of seals on the ice. Ice coverage and seal aggregations were sketched on maps of the area and the distance from the vessel to the closest seals was estimated and confirmed using the rangefinder binoculars. Field notes also indicated any glacial activity during the extent of the survey period including calving activity from both the main glacier and the hanging-glaciers along the perimeter of the fjord. To quantify habitat availability observers recorded ice-cover in as percent coverage of the total area and the relative contribution of large, medium and small ice bergs (e.g. 80/ 30-30-40). Ice-berg size characteristics were assessed following similar methods as those used by Hoover-Miller (1983) for ice in Aialik Bay: Large > 3 seal lengths, Medium= 1-3 seal lengths, and Small <1 seal length. Hoover-Miller (1983) originally defined large bergs as having generally high relief and inconsistent stability. Such bergs were rarely sighted in Northwestern Fjord. Thus, for the present study 'large bergs' were defined by size only and not relief. After each survey, the data for percentage coverage, and percent size of ice bergs were converted to area coverage using the areas of each subregion determined using ArcMap 10.

Aialik Glacier: Remote Video Monitoring

Regular vessel-based surveys of Aialik Glacier were not conducted, so census counts were gathered via remote-video monitoring. Remotely controlled video monitoring equipment developed and maintained by SeeMore Wildlife Inc. has been operated at the Alaska SeaLife Center in Seward, Alaska since 2002. The equipment includes visible light, block video cameras with 25X optical and up to 300X digital zoom. The cameras are mounted in weatherproof housings that include remote-controlled pan, tilt, zoom, and windshield wiper/washer assemblies. The cameras at Aialik Glacier are location at two different vantage points (Figure A8). The first is on Squab Island, approximately 2 km from the face of the glacier. This camera provides an oblique view of the area and was used most commonly in counts. The second camera location was on the cliff-face to the northeast of the glacier. Due to the greater elevation, the glacier camera was primarily used for overviews of ice circulation and to assess seal attendance near the face of the glacier. In 2009 and 2010, surveys of Aialik Glacier were conducted 3-5 times a day at 900, 1100, 1300, 1500 and 1700. Similar to the vessel-based methods, observers counted seals on ice and differentiated between single adult seals and mom/pup pairs. Based on the favorable haulout attributes described by Hoover-Miller et al (2011), the maximum count of seals and mother/pup pairs was recorded within two hours of solar noon (1400h) and used as the attendance value. To compare these counts with those at Northwestern Fjord, we selected counts on the same days that surveys were conducted at that location. Once again any observations with less than 'good' observer confidence, as well as observations compromised by distance, weather (rain/fog) or equipment malfunctions were excluded from our comparison analyses.

Ice Coverage Assessment

Due to the constraints of the cameras, ice coverage was calculated for the entire region of Aialik Bay North of Slate Island using photographs taken from the glacier-cliff camera. Microsoft—Image Composite Editor (ICE) was used to 'stitch' together photographs of 4 sections of the Bay to provide a composite picture of ice coverage (Figure A9). Due to camera restrictions, 2009 was the only year with data for the whole summer period (June 2-August 30). Percentage ice coverage of the total area was recorded, but size-composition was not possible due to low image resolution. Tidal influence was not considered for this study at either site. Previous studies have concluded that tidal fluctuations influence distribution of ice but not surface area available for haul-out (Hoover-Miller 1983). As the present study only used the metric of percent coverage, tides were disregarded.

Statistical Analysis

Discriminate Analysis

Preliminary observations in the field suggested that the ice calved from Northwestern Glacier (subregion 7; Figure A7) was of medium to large size while the ice found in subregion 5, typically calved from Anchor and Ogive glaciers, was brash or medium. To test this, a linear discriminate analysis (LDA) was performed to determine if the different subregions could be separated based on the size of their bergs.

Analysis of Ice Characteristics in Time Series

Northwestern Fjord. Ice coverage data was collected for all six subregions of Northwestern Fjord, but the two of greatest interest were subregion 5 and 7—the subregions with actively calving

tidewater glaciers. Generalized additive models (GAMs) were used to determine how 1) percentage ice coverage and 2) how large, medium and small bergs (both percent coverage and area coverage) changed over time for each of these sub-regions separately, as well as for the two regions combined. The method employed was similar to that described by Boveng *et al*. (2003). The GAM models are non-parametric which allows the data to suggest the pattern of ice characteristics over time instead of specifying the parametric form prior to modeling. In a departure from the methods of Boveng *et al.* (2003) it was assumed that the ice characteristics in each of the regions were normally distributed with mean determined by a link identity function. For some models, particularly those in subregion 5, the data were not normally distributed. In these cases a log-transformation of the data resulted in normal distribution, and the log-values were used for the GAMs. The additive predictors and model parameters were estimated using R 2.11.1 statistical software.

The modeled covariates were year and Julian Day (JD). JD was a continuous variable and was modeled as smooth non-parametric functions; year was modeled as a categorical factor. Similar to Boveng *et al.* (2003), the smooth terms were fit with the default degree of smoothing. This provided approximately 4 degrees of freedom for accommodation of moderate curvature or inflections—sufficient to discover any patterns while avoiding over-fitting the data. To determine if the covariates were significant in predicting ice characteristics, the first model contained all the covariates then each non-significant (p>0.05) term was dropped, one at a time. This resulted in final models for subregion 5, subregion 7 and subregion 5+7 combined.

Aialik Bay. Models for ice characteristics in time series were generated for Aialik Bay in a similar method; however, the only dependent variable tested was percent ice coverage as viewing capability from the cameras restricted size differentiation. Also, due to camera restrictions, 2009

was the only year with data for the whole summer period, thus year was not a covariate in this GAM.

Analysis of Factors Affecting Seal Haul-out Behavior

   Northwestern Fjord. The procedure for modeling the effects of habitat characteristics on the numbers of harbor seals hauled was similar to that performed for modeling trends in ice over time. GAMs were fitted to determine the relationship between the number of seals (Total seals = individual harbor seals + (2 x mom/pup pairs)) and the following covariates: percent ice coverage, percent large begs, percent medium bergs, percent small bergs, area large bergs, area medium bergs, area small bergs and Julian Day (JD). Again, assumed normal distributions were assumed and identity link models were fit for subregion 7 and subregion 5 + 7 combined. All covariates were continuous and fit with a smoothing factor. If the results of the previous analysis of ice trends suggested a relationship between two covariates (e.g. ice coverage ~ JD), that relationship was included as an interaction factor in the model. The final model was selected by step-wise removal of non-significant terms (p>0.05).

   Due to the zero-inflation of subregion 5 (only 11 of 53 days had seals present), the response of seal attendance to our covariates for this area was modeled in a slightly different fashion. All days with zero seal attendance were removed and the effects were modeled on days with seals present. This reduced the sample size (n=11) so it was only possible to model the effects of ice coverage and berg size (area and percent coverage) on seal attendance—independent of time or interactions between habitat and time. Also, the reduction in sample size prohibited utilizing a smooth term on the covariate for ice coverage, and required a tensor smooth for the covariate of size. Thus, the results of the GAMs for subregion 5 represent the non-smoothed relationship between habitat and

attendance, and the tensor smooth relationship between percent and area coverage for three sizes of bergs and attendance only on days that seals were present.

Finally, the analysis examined how variables in subregion 7 impact those in subregion 5. The first test determined whether seal attendance in subregion 7 could be used to predict attendance in subregion 5. To do this a GAM (link=identity, N) was fit to test if the number of seals in attendance in subregion 7 predicted seal attendance in subregion 5. Again, due to heavy zero inflation only days in which seals were present in subregion 5 were selected for this comparison. Secondly, the percent ice coverage in subregion 7 was used to predict seal attendance in subregion 5 and vice-versa using a GAM (link=identity, N) without a smoothing factor. This model helped to determine whether seals were selecting haul-out sites based solely on ice location or on other environmental variables present within a particular subregion.

Aialik Bay. Modeling procedures for seal attendance patterns in relation to habitat characteristics were conducted in the same fashion as those for Northwestern Fjord. Seal attendance was log transformed to meet the normality assumption of the GAM (link=identity); ice coverage percentage and JD were the two covariates tested and were modeled as smooth factors. Based on results of previous time series analysis of ice characteristics, no interaction factor between ice coverage and JD was included.

RESULTS

Northwestern Fjord

For Northwestern Fjord, a total of 53 surveys across 2009 and 2010 were considered of good quality. The mean numbers of seals and ice coverage are summarized by year, month and subregion and are presented in Table 1.

Table 1: Means and standard deviations of % ice coverage and seal attendance in Northwestern Fjord in each of 6 subregions; summer of 2009-2010.

% Ice Cover	2009			2010		
	June (SD)	July (SD)	August (SD)	June (SD)	July (SD)	August (SD)
Subregion 2	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Subregion 3	1.25% (3.5)	5% (5.4)	3.75% (5.2)	8.18% (9.8)	5.45% (5.2)	1.11% (3.3)
Subregion 4	1.25% (3.5)	1.66% (4.1)	0% (0)	2.72% (6.4)	0% (0)	0% (0)
Subregion 5	50% (36.6)	28.33% (18.3)	30% (20)	34.54% (31.1)	33.63% (30.1)	30% (23.9)
Subregion 6	7.5% (10.3)	5% (5.4)	8.75% (6.4)	3.63% (6.7)	7.27% (10.1)	1.11% (3.3)
Subregion 7	47.5% (31.5)	51.66% (9.8)	53.75% (23.2)	54.54% (24.6)	42.72% (28.6)	31.11% (23.1)

Seal Attendance	2009			2010		
	June (SD)	July (SD)	August (SD)	June (SD)	July (SD)	August (SD)
Subregion 2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Subregion 3	1 (2.8)	0 (0)	0 (0)	0.09 (.3)	0 (0)	0 (0)
Subregion 4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Subregion 5	62.1 (97.8)	21.5 (46.5)	5.6 (15.1)	12.2 (39.1)	35.5 (63.6)	0.1 (0.3)
Subregion 6	1 (2.8)	0 (0)	0 (0)	0 (0)	0.1 (0.3)	0 (0)
Subregion 7	173.5 (96.6)	372.2 (125.2)	342.875 (184.2)	306.8 (107.8)	279.6 (142.8)	164.4 (165.0)

Results of the ANOVA test indicated that there was no significant difference in ice coverage or seal attendance by year or month ($p > 0.05$) but that that ice coverage ($p < 0.0001$) and seal attendance ($p < 0.0001$) were both significantly different at the level of the subregion. A Tukey HSD test was used to determine which subregions were statistically different. For seal attendance, subregion 7 had significantly more seals than all other subregions ($p < 0.05$). For ice coverage, subregion 7 again had greater average ice concentrations compared to all other subregions ($p <$

0.05) Subregion 5 had the next greatest average ice coverage, and this difference was significantly

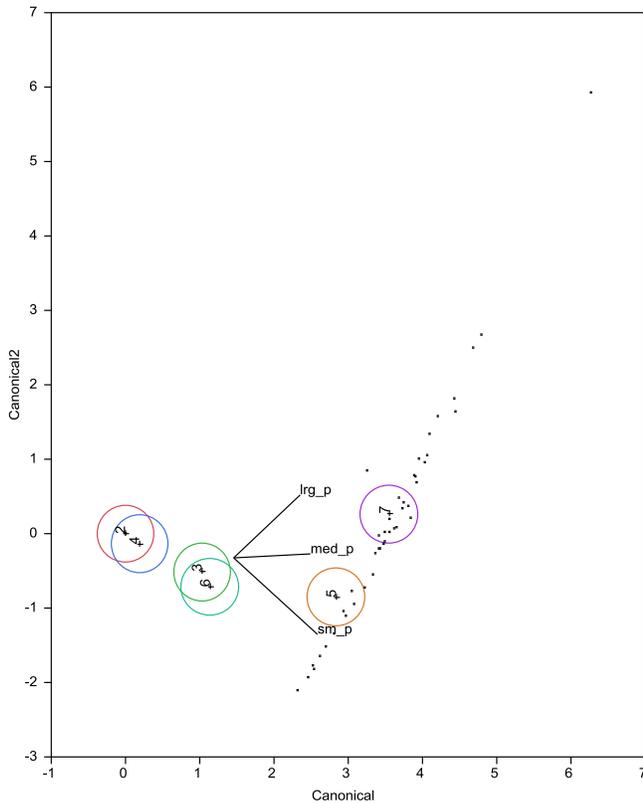greater than subregions 2, 3, 4 and 6 ($p < 0.05$).

Figure 1: LDA of subregions based on composition of berg size. The size of the circle corresponds to a 95% confidence limit for the mean. Groups that are significantly different tend to have non-intersecting circles.

To look at regional differences in size of ice in Northwestern Fjord, discriminate analysis was used to separate subregions. Subregions 2, 3, 4 and 6 were similar based on composition of berg size; they all had negligible amounts of all sizes of ice. The LDA did separate subregion 5 from 7 (Figure 1). Subregion 5 included small to medium sized ice bergs while subregion 7 exhibited medium to large sized bergs. Analysis of the trends of berg size across time and in relation to seal attendance was also modeled and the results are presented in the following sections.

Effects of Temporal Covariates on Ice Availability

A model was fit to determine how ice availability changes throughout the summer season and across subsequent years. Again, only subregion 5 and 7 were examined for trends in ice characteristics; from field observations and descriptive statistics (Table 1) these were the only two subregions with significantly different amounts of ice. Also, these were the two subregions in which glaciers were actively calving bergs. In neither 7 nor in subregion 5 did the GAMs indicate that

percentage ice coverage varied across Julian Day (p > 0.05). Subregion 5 and 7 were then combined to represent ice coverage for all of Northwestern Fjord. This model indicated that when combined, ice tended to decrease throughout the summer but the effect of JD was not significant effect on ice coverage (p = 0.0501;) (Figure 2).
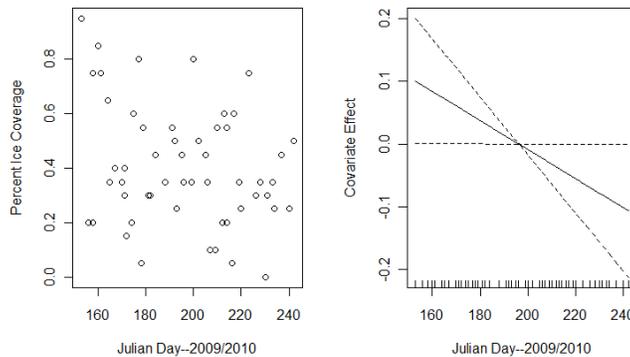
Figure 2: Effect of JD on Percent Ice coverage for the combined subregions 5 and 7. **Left)** Values of Ice Coverage across JD. **Right)** Smooth term component of GAM model. The solid line represents effect and the dashed-lines the 95% confidence interval. A significant effect is represented when both sides of the dashed line passing entirely above or below the 0.0 mark on the vertical axis. **R-sq.(adj) = 0.055   Deviance explained = 7.32%**

For individual subregions, the effects of JD on both the percent coverage and area coverage were examined. In subregion 7, the percent coverage of medium (p=2.67e-06) and small bergs (p=0.00809) were both significantly influenced by JD, but the effects were opposites. For medium bergs, there was a positive relationship between percent coverage and JD until mid summer (JD~198) at which point the relationship became negative (Figure 3). Conversely, the percentage of small ice increased throughout summer (Figure 3).

The effect of JD on percent coverage of large bergs appeared to indicate that early and later in the summer, large bergs were at low percentages with a peak coverage in mid-summer (Figure 3) but this trend was not significant (p= 0.0569).
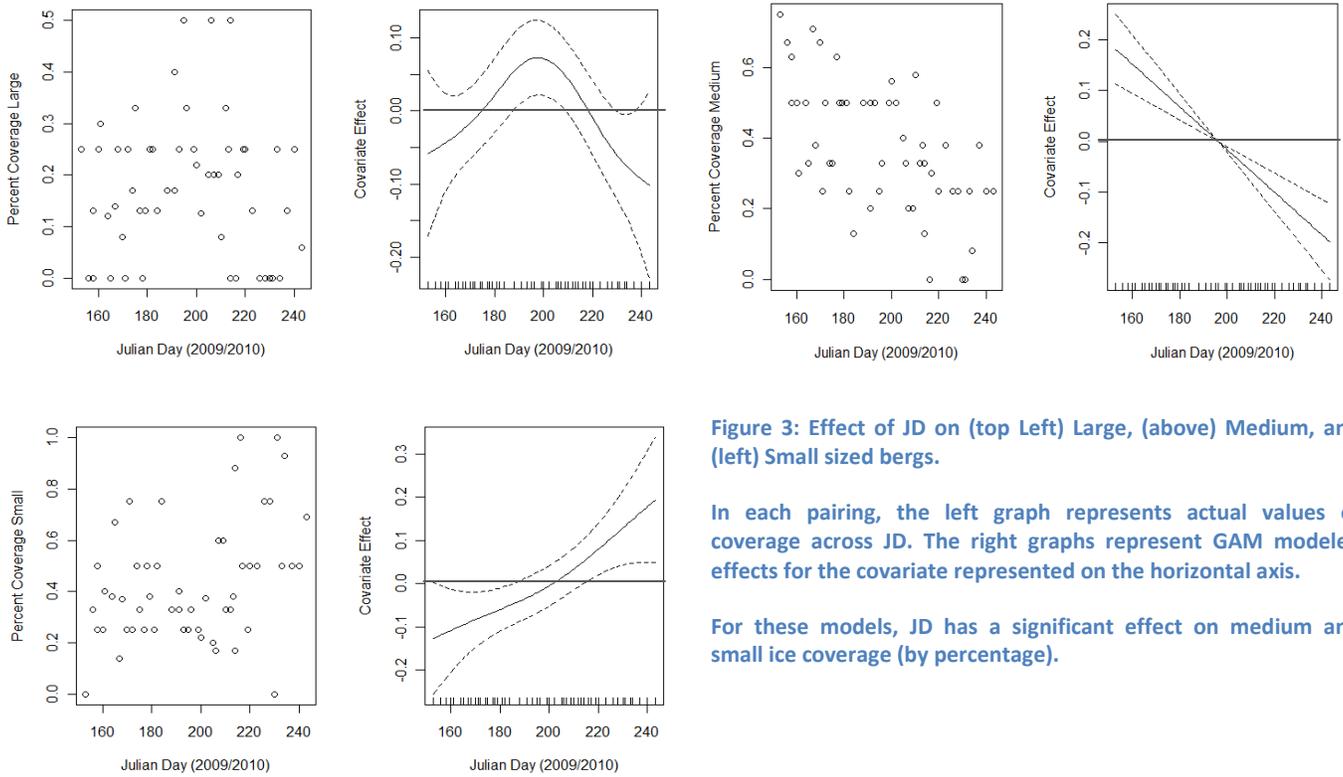
Figure 3: Effect of JD on (top Left) Large, (above) Medium, and (left) Small sized bergs.

In each pairing, the left graph represents actual values of coverage across JD. The right graphs represent GAM modeled effects for the covariate represented on the horizontal axis.

For these models, JD has a significant effect on medium and small ice coverage (by percentage).

Temporal changes in the area coverage of the three sizes of ice showed somewhat similar results to the GAM results for percent coverage. Again, medium bergs had a significant negative trend in area (p= 0.00548) throughout the summer with the inflection point around JD=198. JD did not appear to have an effect on the area of small (p= 0.366) or large bergs (p= 0.298).

For subregion 5, the effect of JD was not significant in predicting percent coverage or area of small, medium and large bergs sizes (p>0.05). Large and medium bergs had somewhat negative correlations between coverage by area and JD; however these trends were not statistically significant.

Effects of habitat and temporal covariates on seal attendance

Percent ice coverage across time

A GAM was used to determine the effect of JD and percent ice coverage on numbers of seals in subregion 5, subregion 7 and subregion 7 + 5 combined. In subregion 7, the location where Northwestern Glacier actively calves, there was no interaction term in the final model. Ice cover was the only covariate that had a significant effect on seal attendance (p=0.00153). The number of seals tended to increase over time, but effect of JD on seal attendance in subregion 7 was not significant (p=0.05793) (Figure 4).
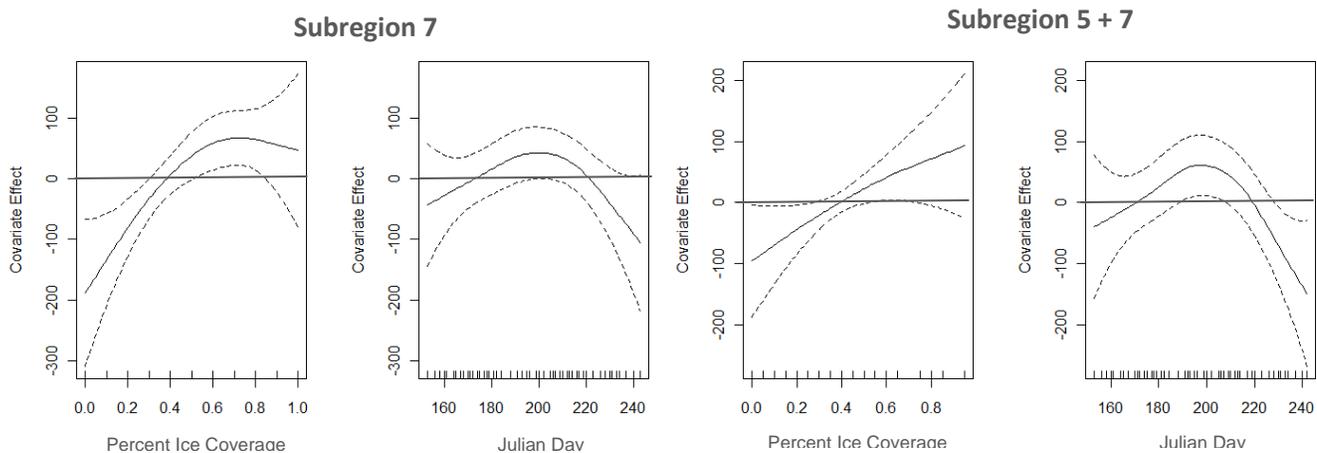
Figure 4: Effect of JD and percent ice coverage on seal attendance. **Left)** Smooth term components of GAM model subregion 7. R-sq.(adj) = 0.287; Deviance explained = 34.5% **Right)** Smooth term component of GAM model for subregion 5 and 7 combined. R-sq.(adj) = 0.219; Deviance explained = 27.7%. The solid line represents effect and the dashed-lines the 95% confidence interval.

In subregion 7, ice coverage less than 40% had a negative effect on seal attendance and ice coverage is between 50-80% exerted a positive effect on seal attendance with a peak around 70%. For subregion 5 and 7 combined, the initial model included JD, ice coverage and an interaction term. The final model dropped the interaction term due to insignificance, but indicated that both percent ice coverage (p=0.0346) and Julian Day (p=0.0357) affected seal attendance (Figure 4). For the combined subregion, seal attendance peaked in mid-summer. Also, ice coverage less than 40% exerted a negative effect and peak attendance was associated with 60-80% ice coverage.

In subregion 5, the model had to be adjusted to account for zero inflation (seals were only present for 11 of 53 days). The final model thus only looked at the effect of ice coverage for surveys in which seals were present and did not include a smoothing term. In this region, where Anchor and Ogive glaciers terminate, ice coverage had a significant effect on seal attendance (p=0.0315) although the intercept for the model was not significant (p= 0.0826) (Figure 5).
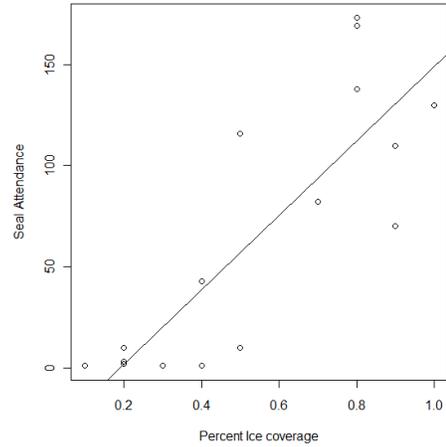

Figure 5: Subregion 5--Effect of Ice coverage on seal attendance on days in which seals were present. R-sq.(adj) = 0.354   Deviance explained = 41.8%

The effect of seal attendance in subregion 7 on seal attendance in subregion 5 was examined to determine if these regions co-vary. The additive model for this relationship indicated a tendency for an inverse relationship between attendance in subregion 7 and subregion 5 but the relationship was not significant (p=0.052) (Figure 6).
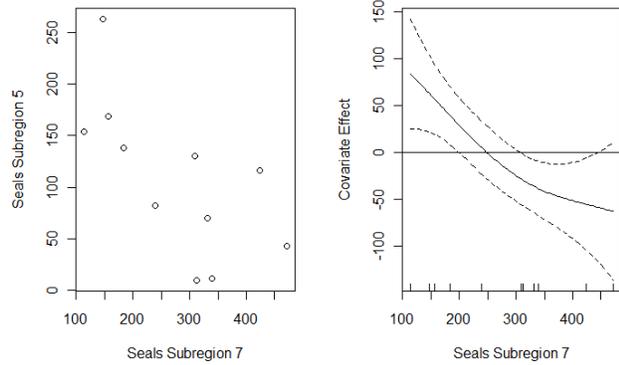
Figure 6: Effect of seal attendance in subregion 7 on seal attendance in subregion 5 on days when seals were present in both subregions. **Left)** Values of seal attendance in subregion 5 and 7 **Right)** Smooth term component of GAM model.

There was a significant negative relationship between the ice coverage in subregion 5 and attendance in subregion 7 (p=0.0263; Figure 7) but there was no
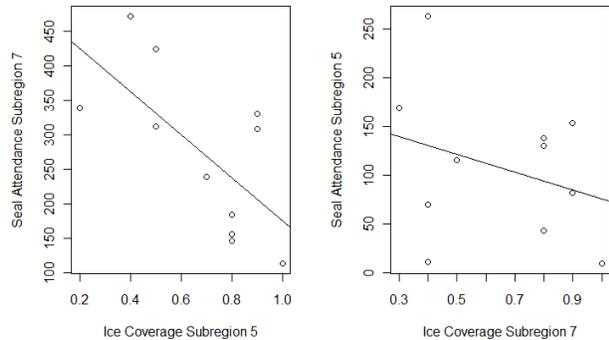
Figure 7: Relationship of seal attendance in subregion 7 to ice coverage in subregion 5 (left) and relationship between seal attendance in subregion 5 to subregion 7 ice coverage (right).

significant relationship between ice coverage in subregion 7 and the attendance in subregion 5 (Figure 7).

Unfortunately it was not possible to model the temporal relationship of seal attendance in subregion 5. However, as seals were present in only 11 of 53 surveys in subregion 5, it is likely the model for the combined subregions best describes the effects of JD on seal attendance in Northwestern Fjord.

Effect of size composition across time

In addition to looking at how general ice coverage across time impacts seal attendance, it was important to investigate the more detailed characteristics of the available habitat and how the size of available bergs impacted seal attendance in subregion 5 and subregion 7. Percent coverage
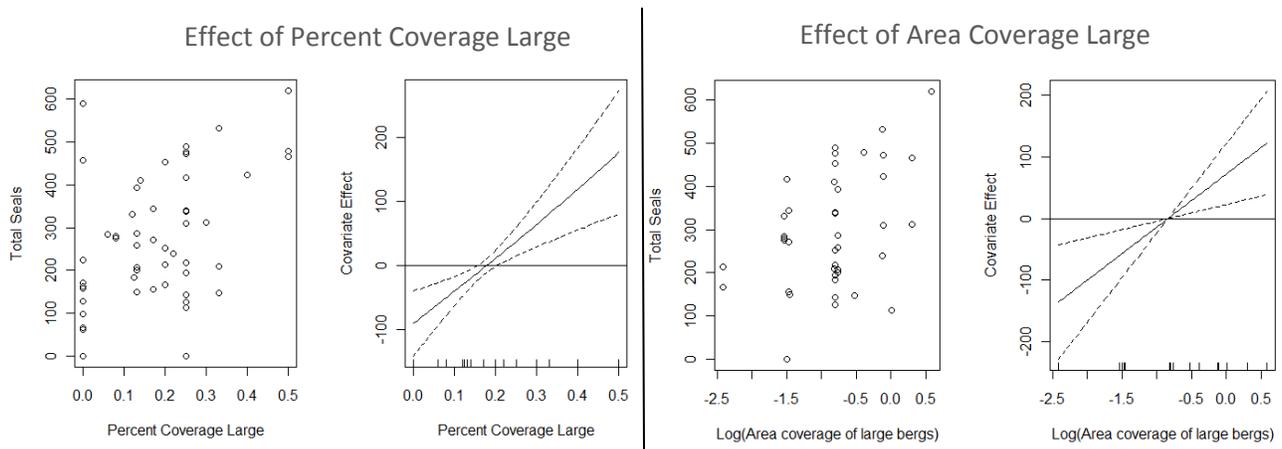
Figure 8: Effect of size covariates on Seal Attendance in Subregion 7. The percent coverage and area coverage of large bergs were significant in predicting seal attendance. In each pairing raw data (left panel) and GAM model of effects (right panel). For effect of Percent Coverage of Large Bergs: R-sq.(adj) = 0.203   Deviance explained = 22.1%. For effect of Area Coverage of Large Bergs: R-sq.(adj) = 0.158   Deviance explained = 17.9%

and area coverage of all three bergs, JD and the interaction between coverage and JD were modeled to test their effects on seal attendance. In subregion 7, both percent coverage and the Log(area) coverage of large bergs had a significant effect on seal attendance (p=0.00585 and p=0.00578

respectively; (Figure 8)). Percent coverage and area coverage of medium and small bergs showed no significant effect on seal attendance and are not shown here.

It appears that availability of large bergs up to 20% or $0.36m^2$ has a negative effect on seal attendance; and that percentages or area coverages greater than this inflection point exert a positive effect. Note that in subregion 7, percent coverage of large bergs never exceeded 50% of total ice coverage and the maximum area of large bergs was $1.79m^2$ (total for subregion = $4.48m^2$).

In subregion 5 the model was adjusted to look only at effects of percentage and area of different sizes of bergs on seal attendance on the surveys in which seals were present. The GAMs used for this analysis utilized a tensor smooth to account for small sample sizes and the original model did not include temporal covariates. The final model indicated that area coverage of large bergs was the only covariate with a significant effect on seal attendance in subregion 5
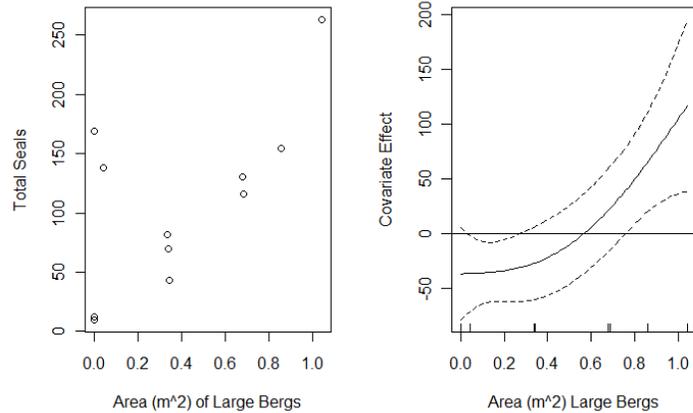
Figure 9: Effect of size covariates on Seal Attendance in Subregion 5. Large bergs were the only significant size covatiate in predicting seal attendance. Left) Values of seal attendance on days that seals were present in relation to area of large bergs; Right) GAM model of effects. R-sq.(adj) = 0.468   Deviance explained = 56%

(p=0.0438; Figure 9). Neither the covariates of small and medium sized bergs (both by percent and area coverage), nor the percent coverage of large bergs were predicting seal attendance.

The total area for subregion 5 was 3.42 m^2 and on days that seals were present, maximum coverage of large bergs was $1.04m^2$. From this model it appears that when large bergs are less than $0.2m^2$ the effect on seal attendance is negative; when large bergs are at coverages greater than $0.8m^2$ the effect on seal attendance is positive.

Aialik Glacier

Similar to the analysis of Northwestern Fjord, the relationship between ice availability and Julian Day was modeled. The GAM output indicated that JD has no effect on percent ice coverage (p= 0.74, n= 18). The second part of the analysis modeled the effects of JD and percent ice coverage on seal attendance (Figure 10). An interaction term was included in the model but was rejected for insignificance. The final model indicated that JD had a significant effect on seal attendance (p=0.0239) but the effect of percent ice coverage was positive but statistically insignificant (p=0.0652). Thus following a period of high seal attendance from late June through mid-July, seal attendance was reduced. Seal attendance then increased only to sharply drop off at the end of the summer.
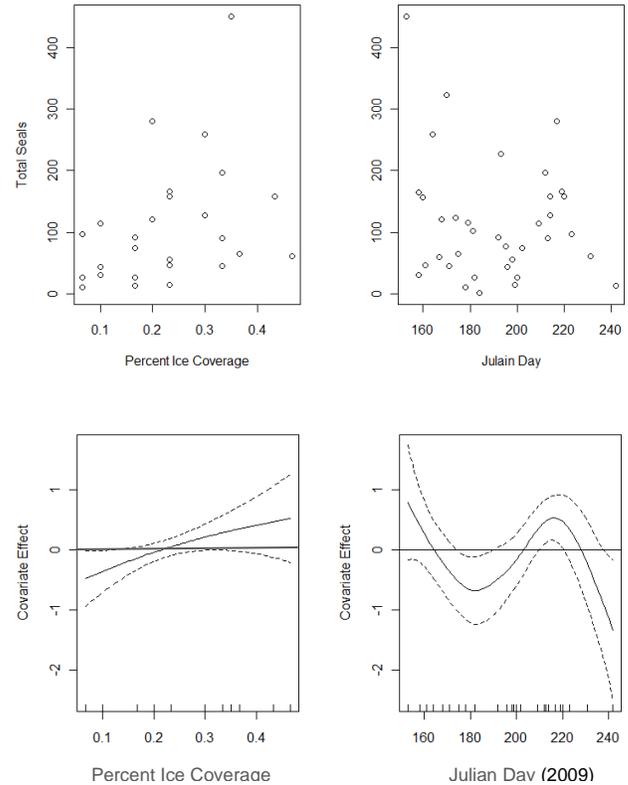
Figure 10: Effects of Ice Coverage (Left) and Julian Day (Right) on Seal Attendance at Aialik Glacier. Both had a significant effect on seal attendance and the GAM had an R-sq.(adj) = 0.219 with 27.7% of deviance explained.

DISCUSSION

The present study sought to investigate the relationship between ice associated harbor seals and their summer habitat in Kenai Fjords National Park, Alaska. The habitat was characterized by high levels of spatial and temporal variability in both the types of ice and the overall availability of ice. Furthermore, within Northwestern Fjord seals respond to ice conditions in a similar fashion at both regional and subregional scales. Patterns of attendance at Northwestern Fjord and Aialik Glacier exhibited opposite trends with respect to seasonality.

The selection of glacial ice as a haulout substrate, particularly for pupping and molting periods, is an adaptation that a small subset of harbor seals has retained over time. For pagophilic—or ice loving—seals, ice provides a protected and easily accessible habitat during an important period in their life histories (Johnston *et al.* 2005). Changes in the availability or composition of haulout substrates, especially in such key periods, can have implications for both individual fitness and population demographics. Fully understanding the patterns and relationships between ice and seal attendance prior to a large change—such as Northwestern Glacier fully grounding—will help to both conserve the population and ensure effective management in future years. Patterns of glacial ice availability across temporal and spatial scales, the effect of ice availability and composition on harbor seal haulout patterns, and the implications for effective management in Kenai Fjords National Park are further discussed below.

Spatial and Temporal Variations in Ice Conditions

Within Northwestern Fjord, three glaciers calve directly into the marine environment and provide floating ice platforms at various concentrations and sizes throughout the summer months. The general geography of the region, the distance between the terminus of Northwestern Glacier

and Anchor and Ogive glaciers, together with different calving rates and exposure to local currents create two aggregations of ice. This explains why the Linear Discriminate Analysis was able to separate subregion 5 and 7 from the other subregions based on the composition of different sized ice (Figure 1). Thus, the present study examined the two subregions separately to identify differences in ice availability or composition from June through August.

The results of the GAMs indicated that there was no seasonal trend in percent ice coverage or the availability of different sized bergs for subregion 5. Subregion 5 does has ice present throughout the summer, but it is less sheltered from tidal influence in comparison to subregion 7— which is partially blocked by Striation Island. Due to its exposure, it is likely that the ice that originated in subregion 5 region disperses into the surrounding subregions 3 and 4 (Table 1). This dispersion of ice into other regions could then be masking a seasonal trend in the ice originating from Anchor and Ogive.

In subregion 7 the overall ice coverage again did not change over time, but there was a seasonal change in availability of different sized bergs. As summer progressed, the percent and area coverage of medium bergs decreased, but the percent and area coverage of small bergs increased. Both patterns were likely the result of increases in water temperature, leading to increased rates of melting and a reduction in the longevity of larger sized bergs (Hoover-Miller and Prewitt 2009).

A pattern of decreasing ice coverage in late summer has previously been observed in Aialik Bay (Hoover-Miller 1983). In the present study, when subregions 5 and 7 were combined the observed pattern followed the trend described by Hoover-Miller (1983), but the relationship between ice coverage and Julian Day was not significant. It is possible that either the high variability associated with small sample sizes masked this trend, the seasonal extent of

measurement was too short or that that processes in Northwestern Fjord are not as predictable as those in Aialik.

Ice coverage and patterns of different sizes of icebergs were not different between 2009 and 2010. The sample sizes for each year were small, but the lack of variation across years was not entirely surprising. Glaciers undergo their cycles of advance and retreat on the scale of decades, centuries or even millennia. Annual differences are difficult to detect given these long-term cycles. Also, when considering such a relatively short timescale, other factors likely play a more important role. Data from the National Water and Climate Center were used to illustrate rainfall and average air temperatures for both 2009 and 2010 at a site just north of Seward on the Kenai Peninsula (Figure A10). There was high variability in air temperature and precipitation between years for the Kenai Peninsula. Factors such as rainfall, cloud coverage and wind likely attribute to the permanence and composition of ice within a fjord ecosystem. These variables could also impact seasonal patterns in ice coverage. It would be beneficial for future research to investigate relationships between weather and habitat availability, as well as to assess ice coverage patterns across longer time periods.

Comparisons between Aialik Glacier and Northwestern Fjord

In Aialik Bay, ice coverage also did not vary significantly over the time period examined, although previous studies have demonstrated a negative trend in percent ice coverage over time at this location (Hoover-Miller 1983). It is possible that the present sample size was too small to identify the seasonal patterns amidst the daily variability. Weather parameters might also play a role in the seasonal patterns of ice availability.

Overall, ice coverage did not exhibit seasonal patterns at either study site, but different sizes of icebergs followed predictable patterns during this study. The second component of this analysis investigated how patterns of habitat availability, in addition to temporal and spatial variables, affect harbor seal attendance and utilization of ice through the summer.

Effects of habitat on seal attendance

The process of habitat selection in pinnipeds is complex and numerous physical, biological and anthropogenic variables play a role. The importance of any single variable may differ depending on life stage, sex or season. In glacial ecosystems, annual fluctuations in harbor seal attendance have been correlated to the amount of ice discharged from glaciers as well as to the rate at which it is flushed from the system (Streveler 1979). This is not to say that prey availability, oceanographic conditions or other physical factors do not impact habitat selection, but for certain periods in the life history of harbor seals—such as pupping and the yearly molt—availability of suitable ice is likely a large determinant in attendance. Streveler (1979) further proposed that during these critical periods, seals are attracted to glacial fjords when the availability of ice exceeds some lower threshold and that if this limit is not met, individual seals will other suitable locations. The present study did not address the movements of individual seals, but it did demonstrate that seal attendance during the summer season is related to ice conditions, seasonality and the composition of the ice available.

Effect of ice coverage. In subregion 5, subregion 7 and in the combined subregions there was a significant positive relationship between ice coverage and seal attendance. The results of this analysis did not indicate the existence of any 'minimum' threshold, but numbers dropped off at ice

coverage of less than 40%. There also appeared to be a 'saturation' point, at around 70%, at which further increases in ice coverage did not result in increased seal attendance (Figure 4). These findings match those of Calambokidis (1989) and Hoover-Miller (1983) who both observed positive relationships between ice coverage and harbor seal haulout patterns in Glacier Bay National Park and Kenai Fjords National Park respectively. Calambokidis (1989) further noted that while increases in ice coverage corresponded to higher haulout numbers, reductions in ice coverage resulted in higher proportions of seals in the water and denser aggregations of seals on haulouts. The present study did not enumerate seals in the water or the density of seals on ice, but it seems reasonable to assume that if seals are not hauled out due to poor ice conditions, they will spend more time in the water. It is also possible that under these conditions, seals will simply switch to terrestrial haulout sites. The point at which seals become so concentrated that it is preferable to relocate to other types of habitat is unknown, but such knowledge would greatly improve the current understanding of the relationship between the habitat and seal behavior.

Effect of availability of different sized bergs. Determining habitat suitability requires looking at not just the amount of ice, but also its characteristics (Burns 1970). Thus, we examined how the availability of different sized bergs affected seal attendance. In both subregion 5 and subregion 7 seal attendance was positively correlated with the percent and area coverage of large bergs. The percent and area coverage of medium and small bergs did not impact seal attendance for either subregion. These results suggest that seals in subregion 5 and 7 have similar responses to availability of large bergs, but it is important to note that Northwestern Glacier had higher percent coverage and area coverage of large bergs than Anchor and Ogive combined. Should Northwestern

Glacier fully ground in the future, the availability of large bergs for the whole region would diminish, which could impact seal attendance.

Effect of JD. The final models indicated that seal attendance had a significant relationship with JD at the large regional scale but not at the subregion scale. In the subregion 5+7 model, a bell-shaped trend was observed with peak seal attendance occurring in midsummer and tapering off at the start and end of the season. The significant peak attendance in midsummer could relate to the attractiveness of large bergs and the general, though insignificant pattern, of large bergs being more prevalent in midsummer—tying both the habitat and temporal components of the system together.

Overall, the observed patterns of seal attendance suggest that the number of seals present in Northwestern Fjord is strongly related to seasonality as well as to the availability of ice. When examining the patterns at a smaller, subregion scale, attendance appears to be more strongly related to ice availability, the availability of different sized ice floes with a less important effect of seasonality. These finer-scale patterns are further supported by the analysis comparing the number of seals in subregion 7 to those in subregion 5 (Figure 6). The relationship between seal attendance in subregion 7 and ice coverage in subregion was significantly negative (Figure 7) suggesting that when ice is low in subregion 5, seals will select subregion 7. In contrast, there was no relationship to the attendance of seals in subregion 5 to ice coverage in subregion 7. These results indicate that as expected, seals use subregion 7 when ice coverage is low in subregion 5, but also that when ice coverage is high in subregion 5, attendance in subregion 7 declines. This confirms that as a whole, attendance in Northwestern Fjord has a seasonal pattern but attendance at the small scale is dominated by habitat and likely a number of other variables not explored in the present study.

Comparisons between Aialik Glacier and Northwestern Fjord

In the present study, attendance at Aialik Glacier is driven by seasonality, not ice coverage, and is opposite to the trend observed at Northwestern Glacier. At Aialik Glacier, seal attendance was high in early summer but declined into a minimum during midsummer. Attendance then increased at the end of summer and eventually petered off in mid-August. A possible explanation for this pattern is derived from the harbor seals' life history. Harbor seals, like many pinnipeds, exhibit strong site fidelity (Hoover-Miller et al 2011) for essential periods such as pupping, so it is likely that seals pupping at Aialik Bay are faithful to that location throughout the early summer. In addition, harbor seals breed shortly after the pupping period—early to mid July. It is possible that during the midsummer mating period, males are less likely to haul-out while they guard underwater territories. At this time juveniles might also be less represented at haulout sites due to avoidance of territorial males. Finally, while not significant, there was a trend of lower ice coverage at Aialik Glacier in midsummer. In this case, seals would be spending longer periods in the water or relocating to glaciers such as Northwestern or Pederson glacier with more favorable habitat conditions. All of these scenarios account for the decline in numbers in mid-summer at Aialik Glacier, but only the poor habitat explains the opposing peak in attendance seen in Northwestern Fjord in midsummer. Attendance in Northwestern Fjord is under the same life history constraints, but if the habitat at that location was more favorable than the habitat in Aialik Bay, according to Streveler (1979) seals would be likely to relocate. This would account for both the low attendance in Aialik as well as the high attendance in Northwestern during midsummer.

High counts in Northwestern Fjord corresponding to low counts in Aialik Bay may also suggest that factors such as differences in prey composition or availability, persistence of ice before dispersing, and frequency or intensity of disturbance could be playing a role in determining how

seals choose between the two locations. Telemetry studies of different age groups, sexes and site origins would be needed to sort out the roles of habitat, social interactions and general ecology on seasonal seal attendance seasonally. Tracking individuals would also provide insights into the amount of exchange that occurs between glaciers and if such movements are in response to habitat conditions, prey availability or other environmental variables.

Implications of Climate Change

Characterizing ice variability has become an increasingly important focus of marine research in the last 20 years. High latitude regions experience natural fluctuations in weather patterns and ice conditions at seasonal, yearly and decadal time scales (Hurrell and Deser 2010). Decreases in the extent of summer sea ice have been observed in the Arctic, and new summer minima were observed three times in the past 25 years (Chapman and Walsh 1993; Comiso *et al.* 2007). Such occurrences, along with anomalously high temperatures and wind patterns could have negative consequences for sea ice formation and retention in the near future which, in turn, will impact the organisms that rely on the ice during some portion of their life history (Comiso *et al.* 2007; Johnston *et al.* 2005).

Many species of pinnipeds rely on some form of marine ice as a haulout substrate. Hauling-out on ice benefits seals by providing a birthing and molting platform, protection from terrestrial predators, and for newly born pups still possessing their lanugo coats, it provides a camouflaged and dry location for their first weeks of life (Burns *et al* 1970; Johnston *et al* 2005). In the Bering and Chukchi Seas of Alaska, five species of pinniped are classified as "Pagophilic"—or ice-loving: the walrus (*Odobenus rosmarusi*), ringed seal (*Pusa hispida*), ribbon seal (*Histriophoca fasciatai*), bearded seal (*Erignathus barbatus*) and the close relative of the harbor seal—the spotted seal

(*Phoca larghai*) (Burns *et al.* 1970). Most of these species rely on the seasonal summer sea ice as a haulout substrate and as a substrate for breeding and pupping (Burns *et al* 1970; Simpkins *et al* 2003). The types and location of the ice utilized varies greatly amongst species and in most of these seals demonstrated a great deal of plasticity in their ability to follow seasonal and yearly variations in sea ice (Burns *et al.* 1970; Simpkins *et al* 2003).

Even with their demonstrated resilience to environmental fluctuations, the current projections for future sea ice suggest that pagophilic seals, as well as other marine mammal species, could be at risk (Johnston *et al* 2005; Ferguson *et al* 2005; Simmonds and Isaac 2007). Earlier break up of spring ice has been linked to decreases in recruitment of ringed seal pups (Ferguson *et al* 2005). In eastern Canada, light ice years and reductions in sea ice increase the risk of neonatal mortality, and epizootics due to crowding (Johnston *et al* 2005). In addition to these proximate risks, changes in ice coverage can have indirect effects on seal populations through loss of primary production and subsequent trophic interactions (Garrison et al 1987; Honer and Schrader 1982).

In light of these and other threats, the management and protection of ice seals in Alaska has been the concern of the National Marine Fisheries Service (NMFS) in the last decade. In 2008, the Center for Biological Diversity petitioned to list three ice seals as endangered under the ESA: the spotted, ringed and bearded seals (73 FR 51615). After extensive review, in 2010 NMFS concluded that the southern population of spotted seals should be listed as threatened (73 FR 65239). NMFS also proposed that the bearded and ringed seals both be listed as threatened under the ESA. These listings are still in the public hearing stage.

Harbor seals are not considered 'true' pagophilic seals because only a small proportion of individuals use ice and the these seals use ephemeral glacial ice—not sea ice. There are differences in life history and physiology but the general usage of floating ice platforms is similar to that of the

Pagophilic seals. Thus the risks harbor seals may face in regards to loss of ice may be similar to those experienced by ice seals. For example, Hoover-Miller (1983) noted that in Aialik Bay in 1979, ice was abnormally limited forcing pups and recently weaned young to spend extended periods in the water. Unlike ice seals, harbor seals are not born with a wooly lanugo coat, enabling them to enter the water from the moment of birth. This adaptation is advantageous in that it allows pups to relocate with the mother as ice shifts daily, but extended periods in the water may increase energy expenditures and lead to greater incidences of mother-pup separation (Hoover-Miller 1983, Jansen 2010).

No studies have quantified the threat of ice loss or of changes in the patterns of availability for harbor seal populations. Previous research in Glacier Bay attempted to assess the conditions of ice at locations represented by both rapidly receding glaciers as well as relatively stable glaciers (Calambokidis *et al.* 1987). Similarly to the findings of the present study, Calambokdidis and his colleagues found seal attendance was positively correlated with ice coverage and that ice cover and seal group size varied between two different inlets. Calambokidis (1987) noted that in Muir Inlet ice coverage and seal attendance were limited in an area with a receding glacier. He further suspected that when the glacier fully grounded the seals would have to relocate to other glaciers or transition to a terrestrial haulout site. In the present study harbor seals followed patterns of ice coverage and composition at the fine spatial scales and suggest potential larger scale shifts in distribution between Northwestern Fjord and Aialik Bay, but it is not possible to extrapolate from these findings to predict how the population will respond in the event of dramatic reductions in glacial ice.

There are anecdotal records of periods in which ice limitations appeared to influence the haulout behaviors of the seals in Northwestern Fjord. Throughout the 2010 summer season, the main face of Northwestern Glacier had demonstrated abnormally large calving events and the

westernmost side of the glacier began to push farther back, relative to the partially grounded right side. On August 4th, 18th, and 28th 2010—ice coverage ranging from 0-20% were observed in subregion 7 and no seals were observed hauled out on ice floes. Subregion 5 was also unusually devoid of ice at this time. On all three days observers noted approximately 50 seals hauled out on a rocky shoreline near the west face of the glacier. This behavior had not been observed at any other point in the summer, although the captain of the boat commented that in previous years he had seen seals haulout at that area on low ice days.

It is difficult to predict future trends, but it appears that as long as sufficient ice is available within one of the two subregions, seals will follow a predictable pattern both seasonally and in respects to localized ice coverage. Northwestern seals have already begun to regularly use rocky habitats and in Glacier Bay some have moved to new glacier sites or occupied terrestrial haulouts. It is not known, however, how these seals would respond to a lack of ice during the pupping months or for longer periods. Drawing from the examples of other ice seals, recruitment could be threatened as habitat diminishes. It might be that the seals follow Streveler's (1979) suggestion and relocate to other glaciers. Alternatively, more harbor seals could switch to terrestrial haulouts, presenting a new suite of challenges—including disease and predation—could become factors in population conservation.

This study has provided an initial look into the patterns of ice availability and the corresponding association patterns harbor seals exhibit in Kenai Fjords National Park. Further understanding of these intricate dynamics is still needed to establish baselines as well as to better quantify the impacts of climate change. As noted above, telemetry studies would be helpful in assessing if harbor seals move within and between fjords are in relation to ice conditions or other variables. Such studies have already been conducted in other ice associated regions such as Glacier

Bay, Endicott and Tracy Arms in southeast Alaska, but expanding that work to include comparative studies at geographically distinct locations where harbor seals also use glacial ice would give insights as to whether the same conditions and behaviors exist between similar ice-associated, but isolated populations.

In conclusion, the present study provided detailed information on the availability and selection of habitat by harbor seals across several temporal and spatial scales. It is hoped that the results presented here will be used to establish baseline information in light of future climate change and to inform proactive management of harbor seals in Kenai Fjords National Park.

ACKNOWLEDGEMENTS

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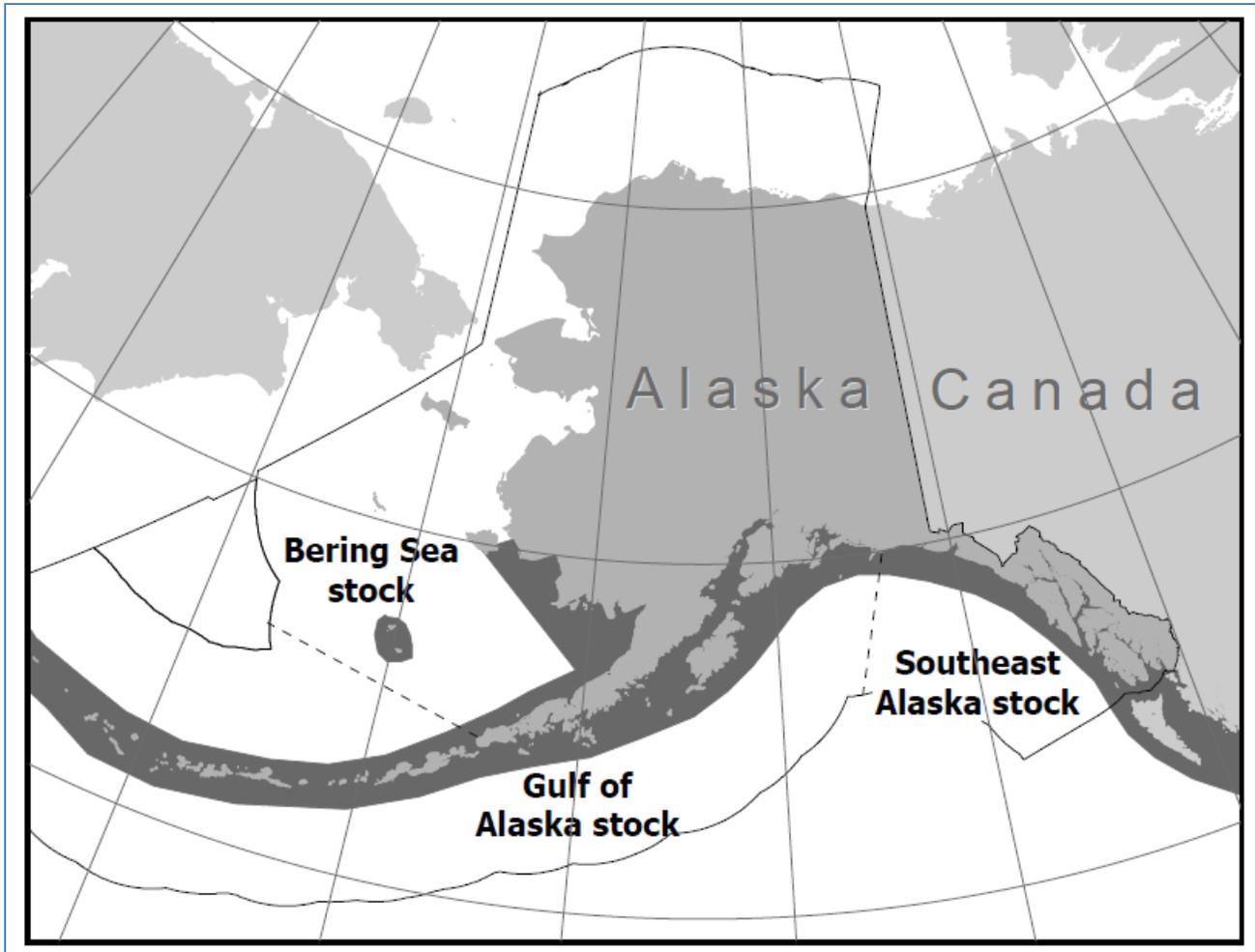
APPENDIX OF FIGURES

Figure A1: NOAA defined stocks and distribution of harbor seals in Alaska
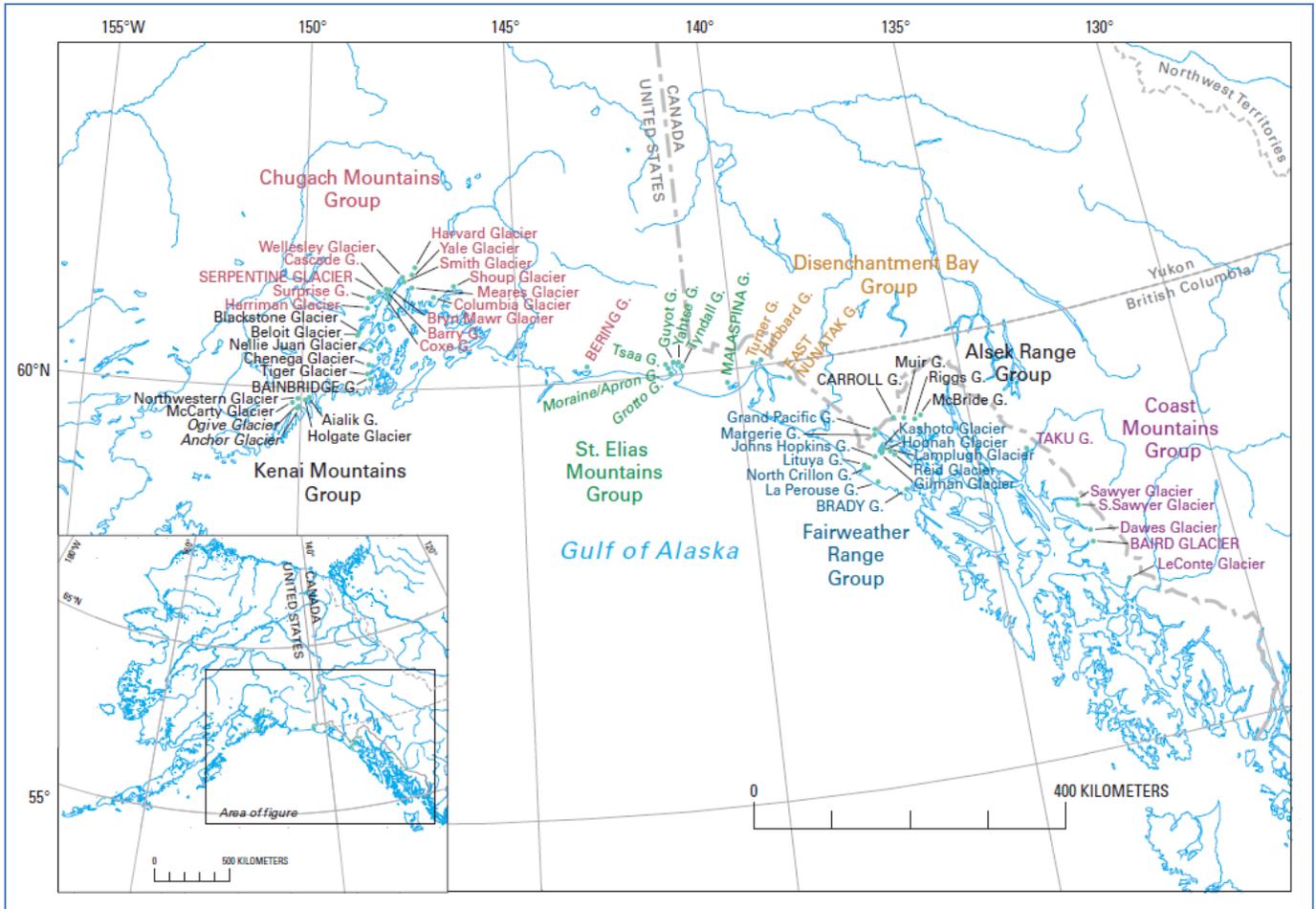
Figure A2: Map of active and former tidewater glaciers of Alaska compiled by the editors using glaciers selected by Viens (1995). G indicates glacier. Glacier names in italics have not been approved by the U.S. Board on Geographic Names. Glaciers shown in capital were previously classified as tidewater glaciers (MOLINA 2008, USGS).
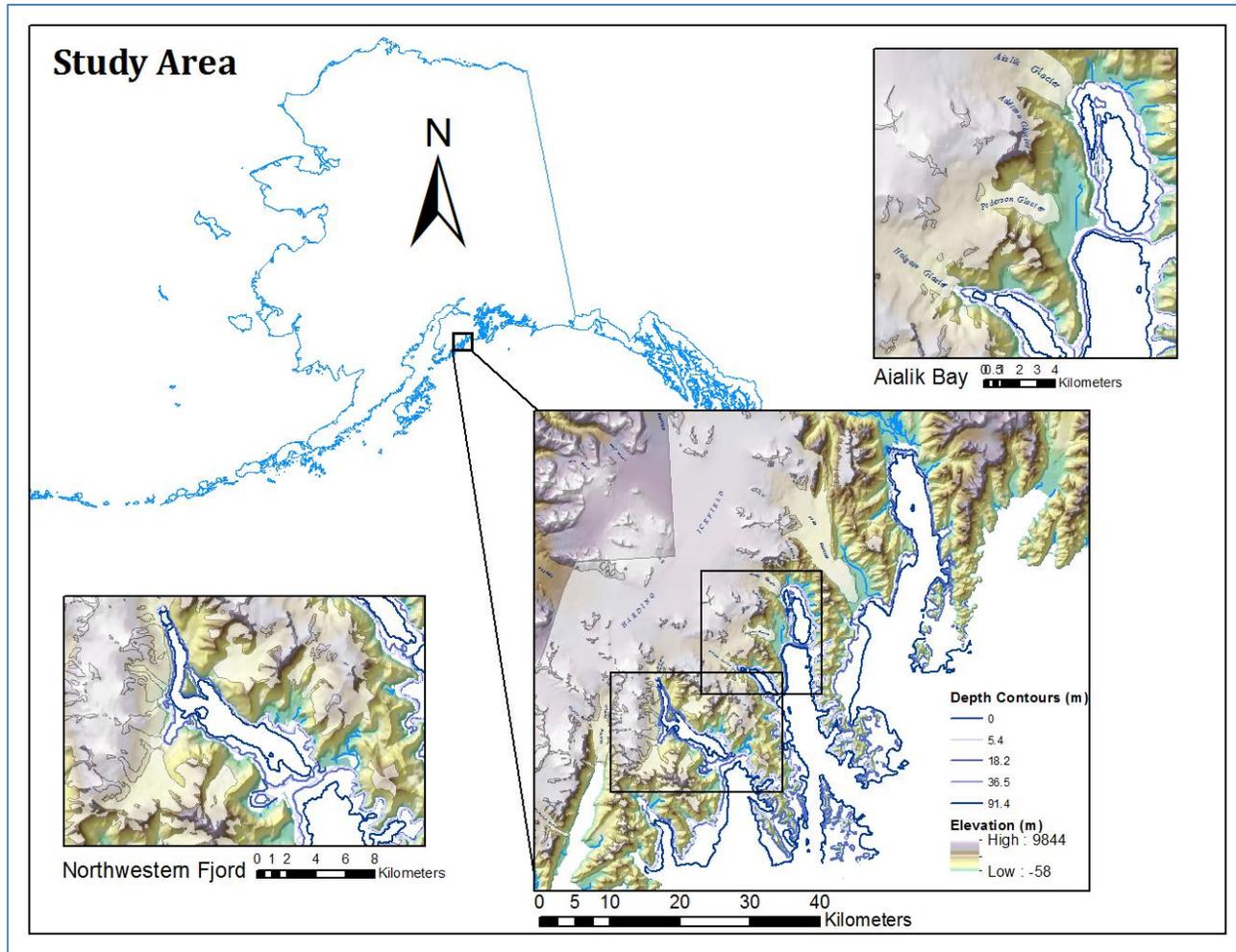
Figure A3: Study Area--Kenai Fjords Region. Subset maps indicate Northwestern Fjord (Left) and Aialik Bay (Right)

Figure A4: Top Left) Northwestern Glacier at its current extent with Striation Island in the foreground**. Top Right)** Anchor Glacier in 2009. **Left)** Ogive Glacier in 2000**.**

(Photos by B. Molina 2008 (Left and Center) and Amy Bishop (Right).
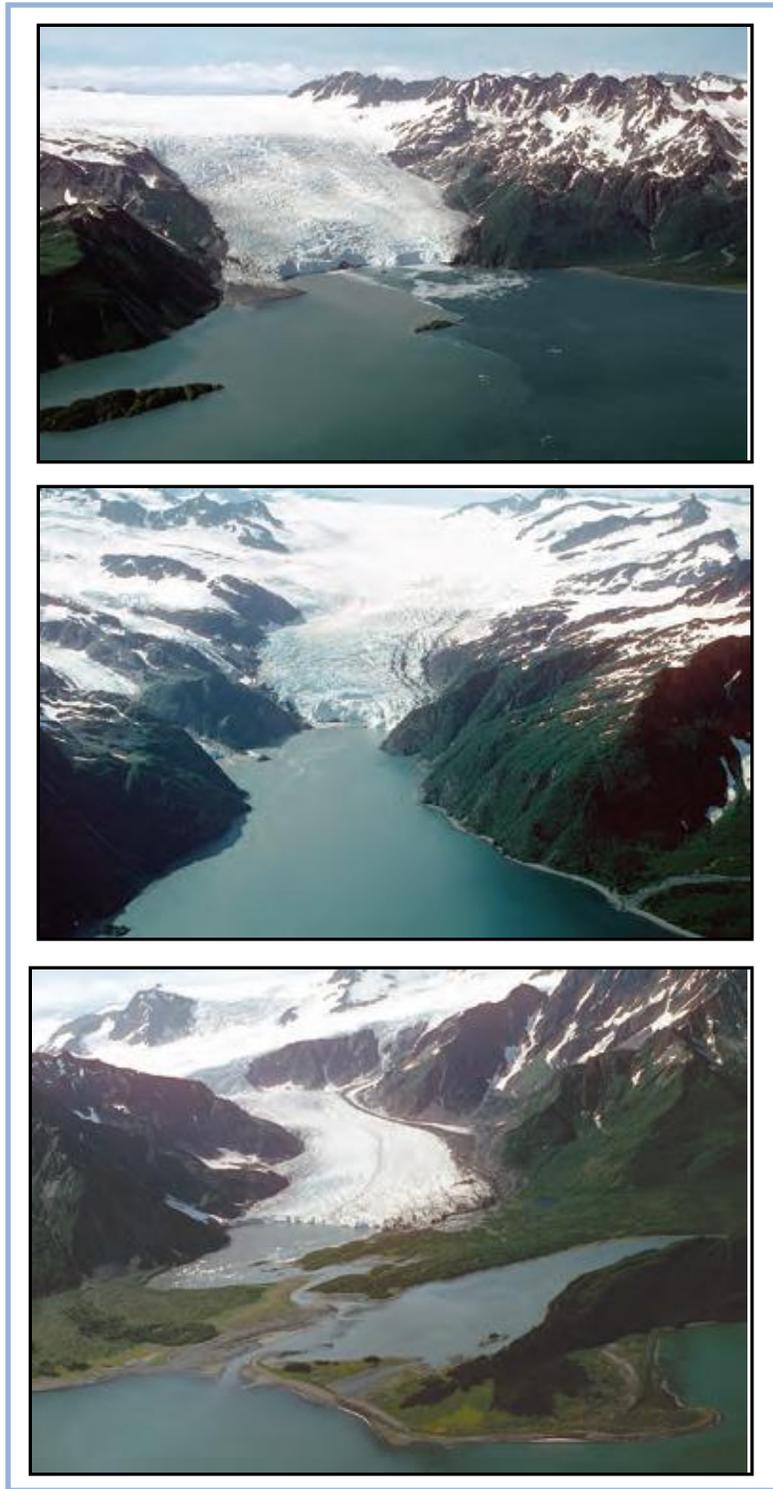
Figure A5: The Glaciers of Aialik Bay in 2000. Top) Aialik Glacier, Middle) Holgate Glacier and Bottom) Pederson Glacier (Photos: B. Molina 2008)
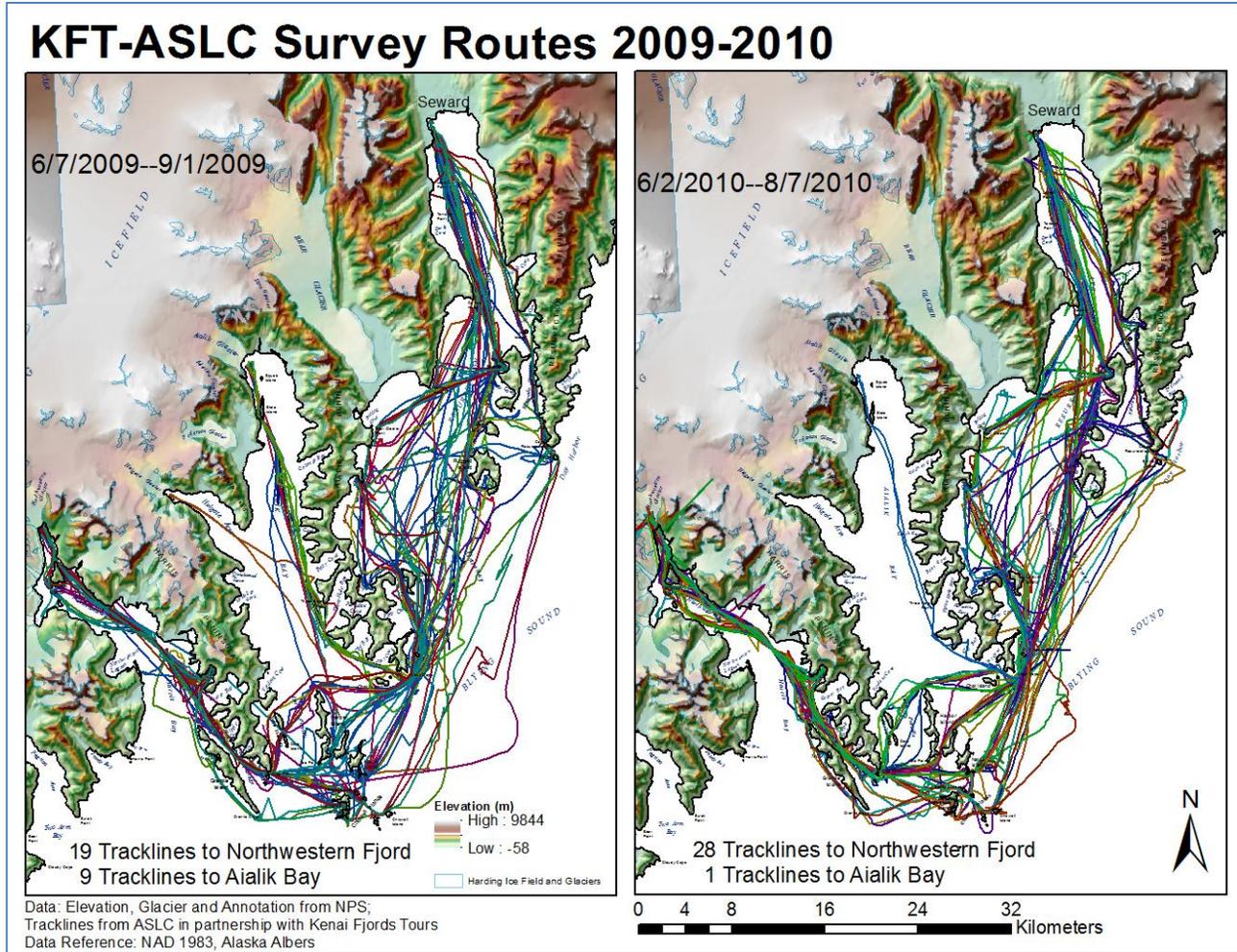
Figure A6: Harbor seal survey routes--summer of 2009 and 2010. Routes were determined by captains of Kenai Fjords Tours. Scheduled destinations were Northwestern or Aialik Galcier and all trips strarted and concluded from Seward harbor
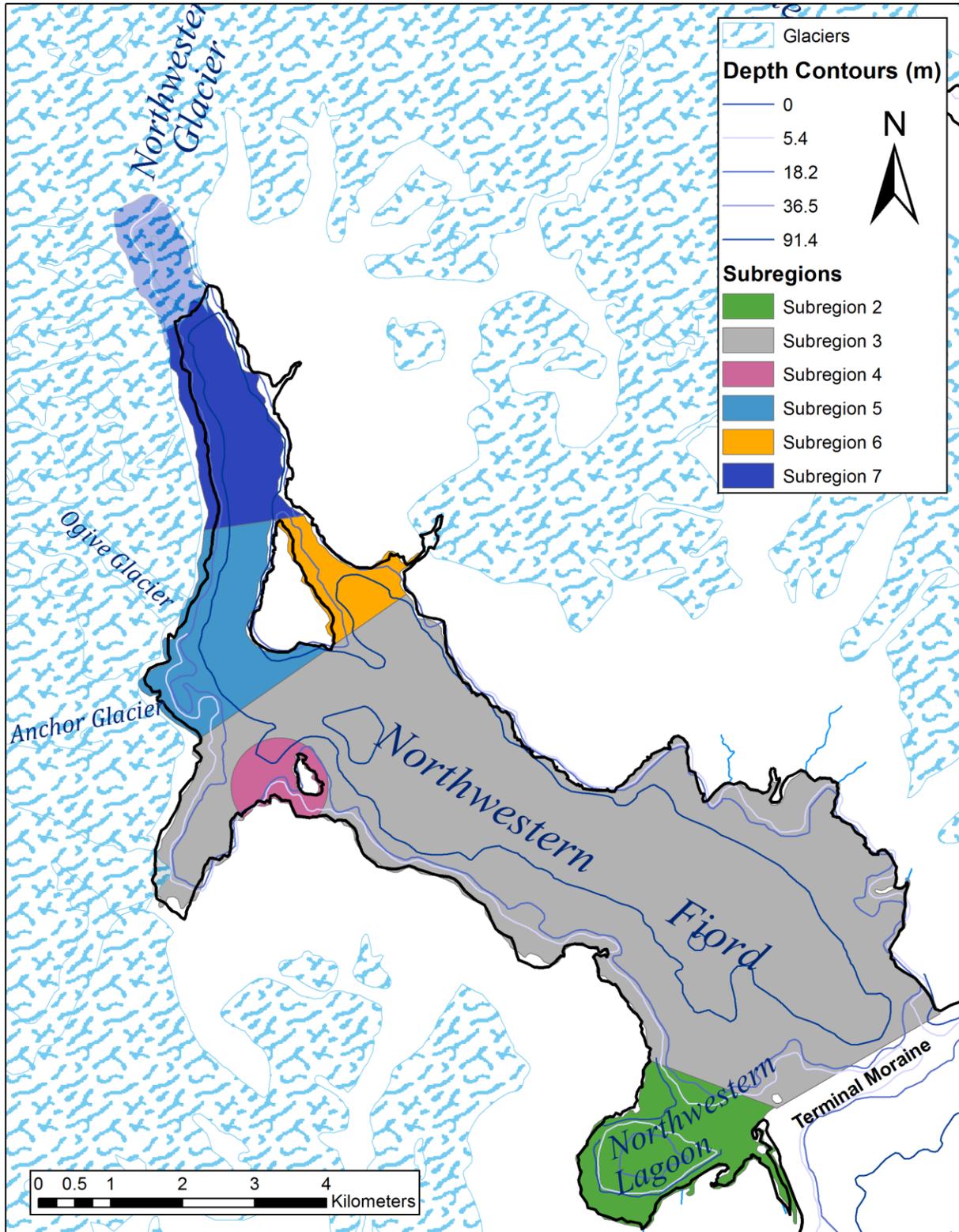
Figure A7: Survey Subregions and location of tidewater Glaciers in Northwestern Fjord. (Datum Reference: NAD83 | Albers; Glacial Extent, Elevation DEM and Bathymetry Contours courtesy of NPS).
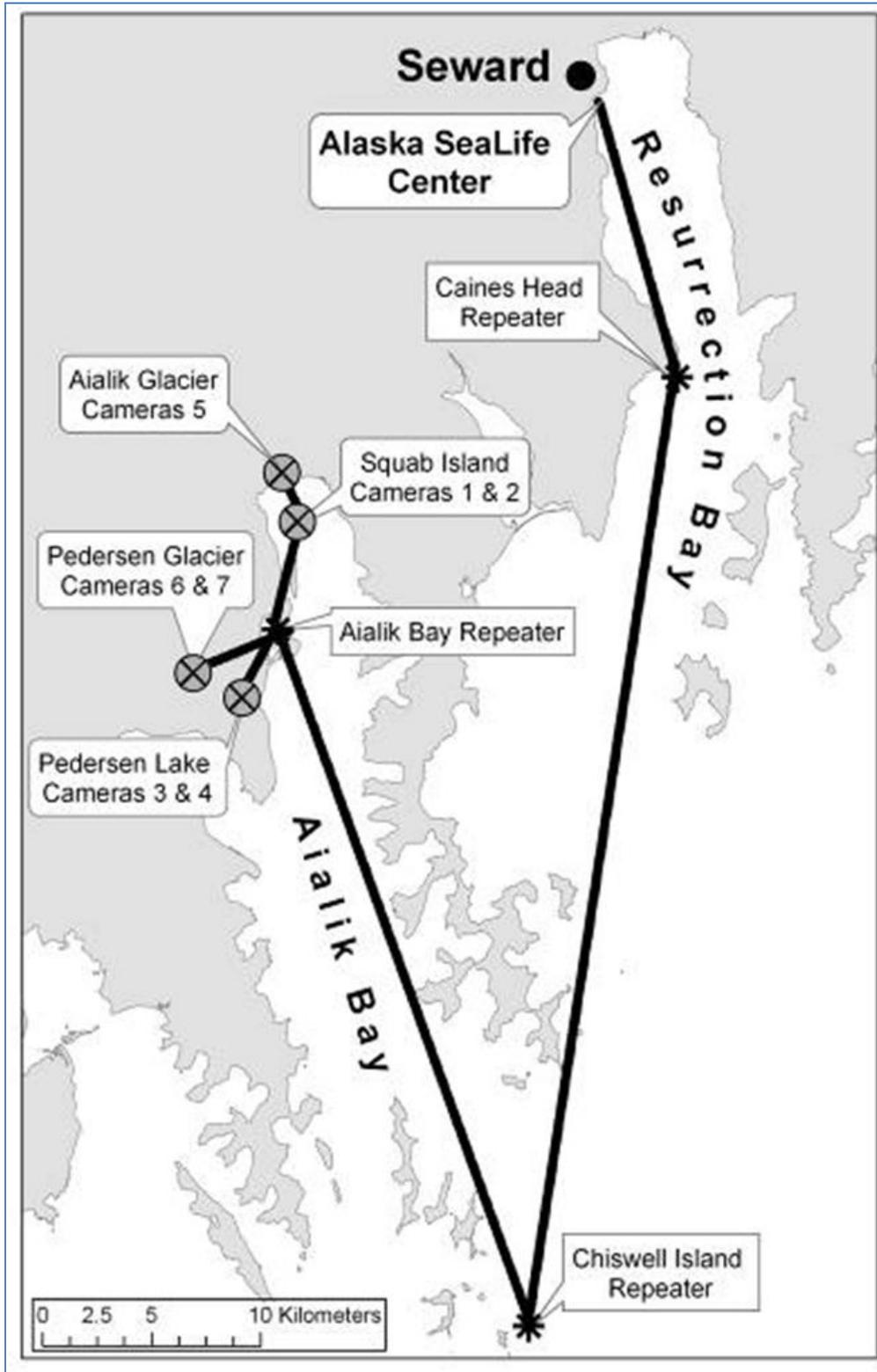
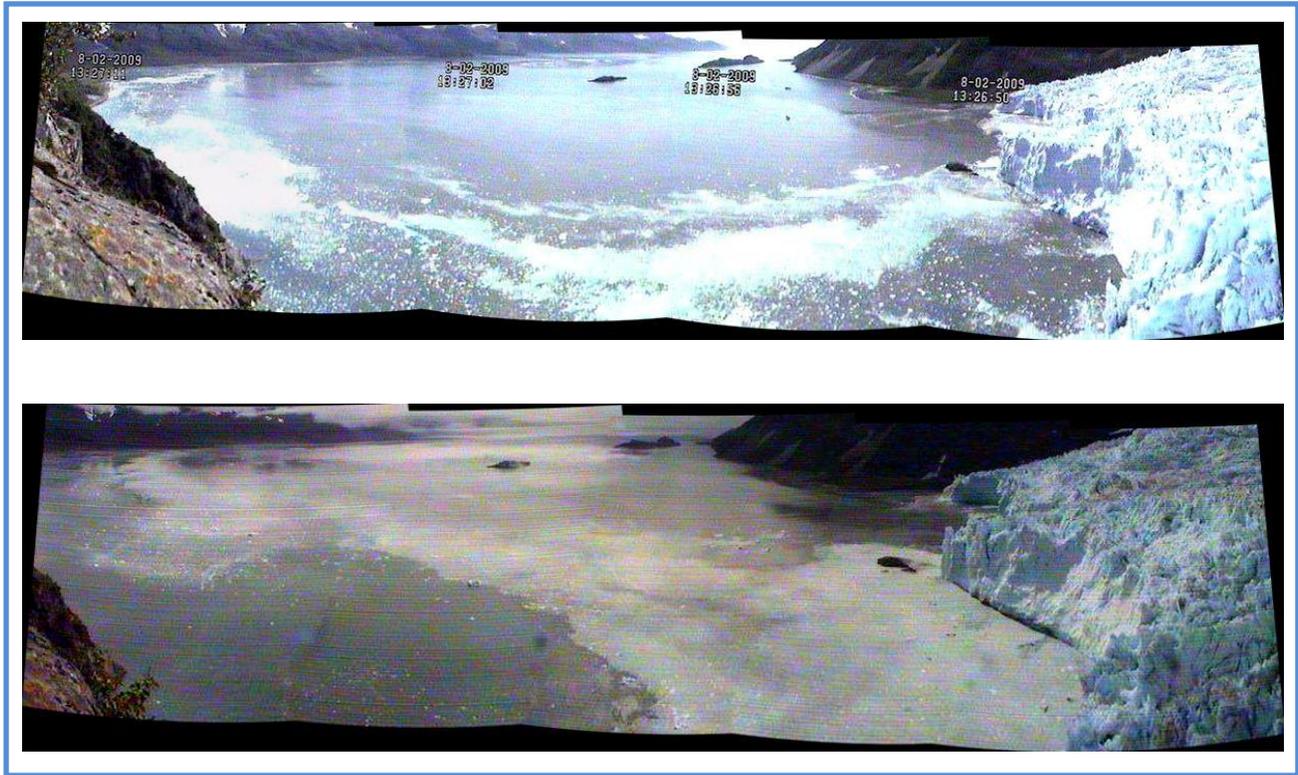**Figure A8: Location of Remote Viewing Cameras in Aialik Bay and Repeater System for VHF transmission.**

Figure A9: Ice distributions in Aialik Bay on Aug. 2 2009 (top) and 2010 (bottom) used to assess percentage ice coverage for the region. Photos were taken from the remote viewing camera placed along the cliff face and stitched together using Microsoft ICE®.
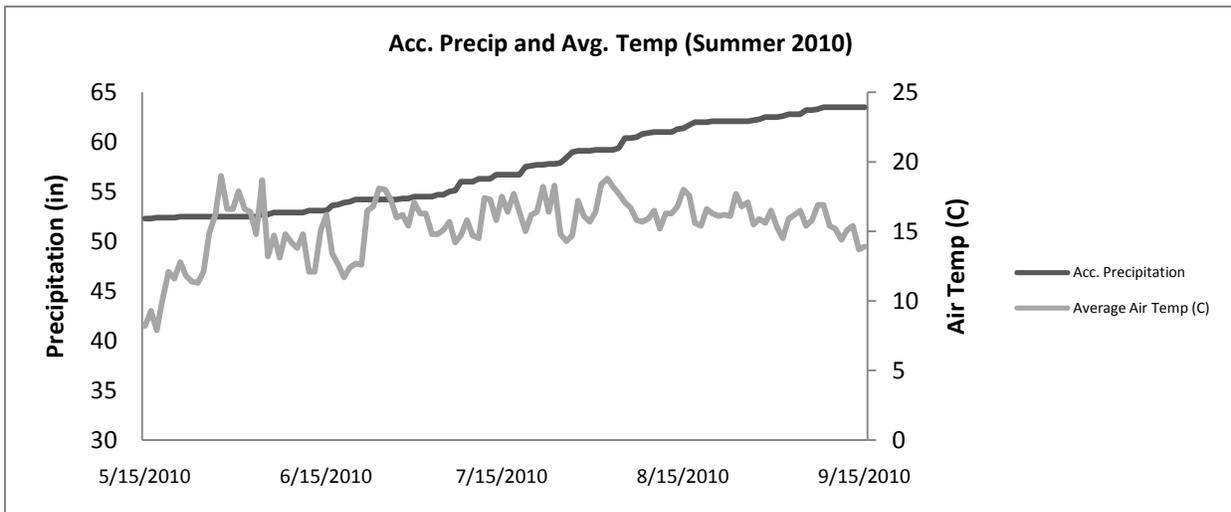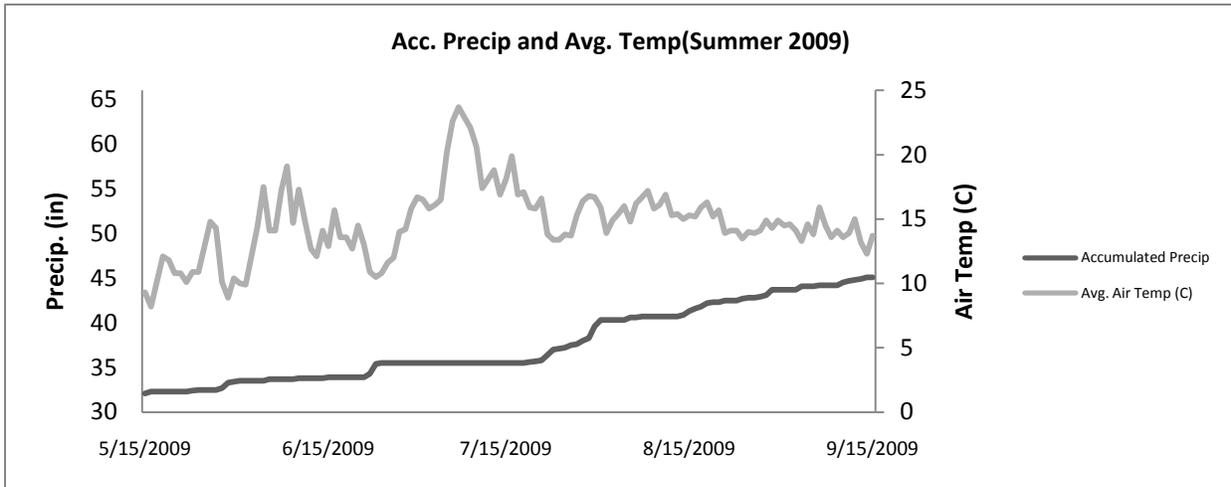
Figure A10: Data of accumulated precipitation and average air temperatures at Grouse Creek Divide, SNOTEL site # 964, Alaska (Lat: 60'16''N, Long: 149', 21" W; 700ft elevation). Data provided by US Department of Agriculture, NRCS, National Weather and Climate Center.