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Disturbance of Harbor Seals by Cruise Ships in Disenchantment Bay, Alaska: An Investigation at Three Spatial and Temporal Scales

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Disturbance of Harbor Seals by Cruise Ships in Disenchantment Bay, Alaska: An Investigation at Three Spatial and Temporal Scales

Final Report with Results on:

1) Behavioral response of seals to approaching vessels (*fine scale*);
2) Variation in local seal abundance and distribution in relation to environmental factors including vessel traffic (*medium scale*); and
3) Comparing variation in seal abundance between nearby bays with and without cruise ship traffic (*large scale*)

by
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Executive Summary

Cruise tourism in Alaska has been growing rapidly since the early 1970s. Over the last decade there has been increasing concern about possible impacts on sensitive coastal ecosystems. Attention has focused most recently on the possible effects of tour vessels, particularly cruise ships, on subsistence resources that have been critically important to Alaska Natives for many generations. Harbor seals that haul out year-round on floating ice near tidewater glaciers are one such resource of concern because their habitat is a popular destination for tourism. This study examined the potential effects of cruise ships on the behavior, abundance, and distribution of harbor seals in Disenchantment Bay, Alaska, from early May 2002, at the onset of seal pupping, to mid-August 2002, during the molting season.

Analyses presented here of the behavioral observations – conducted from cruise ships – indicate that the likelihood of harbor seals vacating ice floes rose steeply when ships approached to less than 500 m; seals approached by a ship at 100 m were 25 times more likely to enter the water than seals approached at 500 m. Seals were also four times more prone to enter the water when ships approached them directly rather than passing abeam. The proportion of seals that entered the water when ships passed within 200 m was nearly 75% compared to less than 10% entering the water at distances where seals showed no apparent overt response to vessels (i.e., > 600 m).

Analysis of aerial strip-transect sampling (by video playback) showed pronounced shifts in seal abundance, with a decline of 75% in mid-May during early pup-rearing. Abundance rebounded to peak levels in late June, as cruise ship traffic reached maximum levels. Sightings of mother-pup pairs also peaked in late June. Seal abundance then stabilized at near-peak levels from late June until the end of the study in early August. The decline in seal abundance in mid-May was already underway at the first cruise ship entry. Seal abundance then steadily increased in concert with increasing ship traffic, suggesting that changes in overall abundance were influenced by factors other than ship presence, such as constraints related to pupping and breeding, or other environmental variables.

Space-time statistical models of the effect of environmental and cruise ship covariates on seal abundance and distribution were conducted in two stages: one model to assess effects on the distribution of seals (i.e., absence-presence in a grid); the other to assess effects on seal abundance in grid cells where seals occurred. The two models showed that ice cover was a dominant factor with seals tending to occur at the highest frequency and in higher numbers in intermediate ice cover (i.e., 50-70% coverage by area). Mother-pup pairs showed similar patterns with regard to the type of ice cover. Other natural variables, such as precipitation, wind speed, and the area of ice habitat available to seals, did not have a measurable effect on the abundance or distribution of the pooled seals or mother-pup pairs.

Measures of ship traffic, including time spent at closest approach and number of ship visits occurring on the 3 days prior to a survey, did not have a statistically measurable effect on the abundance of all seals or mother-pup pairs. A negative relationship between ships' closest approach distance and both seal abundance and distribution (i.e., more seals at shorter distances) is likely the result of close spatial overlap between ships and seals in conjunction with no obvious avoidance by seals of areas used by ships. However, increased time that ships spent at their closest approach coincided with tighter distributions of harbor seals with no detectable change in abundance. This suggests that seals aggregated more closely with increasing ship presence. Such findings are consistent with other studies of marine mammals that show denser aggregations during periods of disturbance. Coupled with no apparent negative effect of ship distance on seal abundance (e.g., no short-term avoidance of areas used by ships), these findings suggest the seals' aggregation response is independent of proximity to ship areas and thus appears to occur at distances greater than the 500 m threshold suggested by the shipboard observations.

The seasonal comparison of seal abundance between Disenchantment Bay and nearby Icy Bay, where cruise ships are reportedly rare, showed some pronounced differences. The maximum total count at Icy Bay was reached in August (5435) during molting, with numbers having steadily increased from lower counts in May (1011) and June (2543) during early to mid-pupping. In contrast, the peak count at Disenchantment Bay (2149) occurred in June at mid-pupping with numbers falling slightly through July (1786) and August (1778). The different seasonal patterns suggest that comparable numbers of seals use the two sites during pupping but that only a third to half the number of seals use Disenchantment Bay during the molting period. Information about the actual movement of seals, possibly between the two sites, in relation to natural and anthropogenic factors would aid in interpreting these patterns.

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1.0 Introduction

Alaska is a major destination in cruise tourism, with the third highest share (8%) of the total world capacity ranking only behind the Caribbean (41%) and the Mediterranean (13%; CLIA 2005). The cruise ship capacity allotted to Alaska has nearly quadrupled since 1987, surpassing the Bahamas (6%), and current annual growth is 8% compared to a slight decline averaged across the industry (CLIA 2005). The North American fleet in 2004 comprised 192 ships, an 18% increase from 163 ships in 2000; an additional 17 are projected by 2008 (ICCL 2005). At least half of the summer visitors to Alaska, which is approaching a million annually (ADEC 2004), embark on a cruise (ADCED 2004). These statistics, combined with a growing interest globally in nature-based and cultural tourism, eco-tourism, and adventure travel (Reynolds and Braithwaite 2001; WTO 2001), point to Alaska's growing popularity among cruise tourists. This growth has prompted concern about the potential environmental impacts of cruise tourism in Alaska and whether it is environmentally sustainable. In particular, marine living resources and the local people who rely on them may be sensitive to the changes brought about by the presence of cruise ships. Marine mammals are some of the most conspicuous examples of potentially vulnerable species because they historically congregate in coastal habitats, such as tidewater glacial fjords, that are now popular destinations for cruise tourists.

Harbor seals (*Phoca vitulina richardii*) in Alaska inhabit coastal and estuarine waters from Southeast, Alaska through the Gulf of Alaska to Cape Newenham in the Bering Sea. They haul out to rest, rear pups, and molt on rocky coastlines and outcrops, sandy beaches, and floating ice. Following population declines in the Gulf of Alaska (Pitcher 1990; Mathews and Kelly 1996; Frost et al. 1999; Jemison and Pendleton 2001; Small et al. 2001) and most recently in Glacier Bay National Park (Mathews and Pendleton 2006), it has become increasingly important to understand the factors that affect seal survival and recruitment. Ice emanating from tidewater glaciers serve as important pupping grounds for harbor seals from mid-May to early July, and as molting platforms during August (Streveler 1979; Hoover 1983). Whereas the largest terrestrial haul-out sites rarely exceed several hundreds of animals, many glacial sites have ice fields that are used by thousands of seals (Withrow and Loughlin 1997; Withrow et al. 1998; 1999a; 1999b; 2001).

These seal aggregations have nutritional and cultural importance for Alaska Natives, such as those living in the Yakutat area, who have utilized sealing camps in Yakutat and Disenchantment Bays (Fig. 1) for many generations. Harbor seals were likely an important resource dating back to the earliest known settlements of the Yakutat Forelands – 1,100 years ago (Davis 1996). Despite the importance of these seals, little is known of their trends in abundance or why the animals concentrate in ice fields in such large numbers. Glacial ice may function uniquely as both a refuge from land and marine predators and a reliable platform for resting and rearing young.

Tour vessels were first reported in Disenchantment Bay (60°N 139°32'W) in 1883, though the number of visits probably remained low during most of the 20th century (USFS 2001). More than a century later, in 1989, still fewer than 15 visits occurred per year (Kozie et al. 1996). About a decade later, in 2001, visits had increased 10-fold to 157; ship visits continue to increase to the current level of 170 in 2005 (NWCA; 2001-2005). This amounts to near daily visits from mid-May to September.

Cruise ships typically venture at least as far north as Egg (Haenke) Island, ice and visibility conditions permitting, to afford passengers a close view of Hubbard Glacier (Fig. 1). As many as five ships, which can be nearly 1,000 feet (305 m) long and 100 feet (30 m) wide, visit the bay on peak traffic days. Disenchantment Bay may experience further increases in ship traffic due to several factors: 1) expected increases in the cruise ship fleet; 2) an annual quota for cruise ship visits to nearby Glacier Bay (of 231 visits) with a daily quota of two ships; and 3) the rapid retreat of other tidewater glaciers (e.g., South Sawyer Glacier, Tracy Arm; D. Withrow, Alaska Fisheries Science Center, National Marine Mammal Laboratory (AFSC/NMML), pers. comm.), which, if the glaciers ground and stop calving ice into the water, may cause ships to divert elsewhere.

Alaska Natives from the Yakutat Tlingit Tribe are concerned that the presence of cruise ships in Disenchantment Bay – which peak in numbers during pup rearing and persist through molting season – are having adverse impacts on the distribution and abundance of harbor seals. Many among the Tlingit Tribe consider cruise ships a source of disturbance that may be disrupting the seals' normal behavior during the pup-rearing season, thus leading to reduced survival of offspring and a population decline. Evidence of a population decline comes from Yakutat seal hunters who believe that the availability of seals has declined over the past 10-15 years, as reflected by hunting trips that have progressively been less successful and have required more time (Yakutat Tlingit Tribe, pers. comm.). Hypothesized declines in seal numbers are consistent with trends in subsistence harvests by Yakutat hunters. Seal takes per capita in 2001 were only 38% of the 1993 levels, a steep decline (65%) from a peak in 1996 (Wolfe and Mishler 1993; 1996; Wolfe 2001). Though there has also been a downward trend in harbor seal harvests for the entire Southeast Alaska region, the decline of Yakutat sealing was more than twice the regional average. Part of this trend could be attributed to decreases in hunting effort, but the number of households that use seal has remained consistently high, though falling slightly from 93% in 1993 to 85% in 2001 (Wolfe and Mishler 1996; 2001). Still, Yakutat reports one of the highest annual takes in Alaska (range: 138 [in 2002] to 764 [in 1996]; Wolfe et al. 2003). It is clear that harbor seals are a valued resource for the Tlingit Tribe, one that they perceive has become less available over the period that cruise ship traffic has risen steeply.

The historical traditions of the Tlingit Tribe – as reported by de Laguna (1972) – suggest that harbor seals were typically left undisturbed until pup rearing was underway and post partum females (and their young) were less prone to leave the area. However, contemporary estimates of subsistence hunting suggest that most seals are taken from March to May (Wolfe and Mishler 1993; 1994; 1995; 1996; 1997; 1998; Wolfe and Hutchinson-Scarbrough 1999; Wolfe 2000; Wolfe et al. 2002; 2003; 2004), prior to and in the early stages of pup rearing. Seal takes consist largely of juveniles and adults though pups are sometimes targeted (Yakutat Tlingit Tribe, pers. comm.).

There are no published findings on how seals on glacial ice respond when they are approached by vessels, though studies have been undertaken. In Muir Inlet, Glacier Bay, more harbor seals entered the water in response to smaller boats, such as kayaks, than to cruise ships, though the latter disturbed seals at greater distances (Calambokidis et al. 1985, unpub. ms.). In McBride Fjord, Glacier Bay, researchers found that seals entered the water more often and in larger numbers in response to kayaks than larger skiffs (Lewis and Mathews 2000). In Johns Hopkins Inlet, Glacier Bay, Mathews (1994) reported that harbor seals vacated ice floes at greater distances to cruise ships than boats about one-quarter the size. Similar results on harbor seals at terrestrial haul-out sites support the hypothesis that vessel type may be as important as approach distance in determining the outcome of seal-vessel interactions (Suryan and Harvey 1999; Lelli and Harris 2001). The sensitivity of animals to such factors may also differ depending on experience and their breeding or molting status. Suryan and Harvey (1999) found increasing levels of tolerance among harbor seals to repeated disturbance by small boats, and increasing vigilance and disturbance with number of pups present across three sites. That pregnant and post partum females appear more sensitive to disruptions (Newby 1973; Lawson and Renouf 1985) is likely one reason they tend to haul out at the edges of mixed groups or at separate nursery sites altogether (Jeffries 1982; Allen et al. 1988; Thompson 1989). In Disenchantment Bay, potential sources of human disturbance to harbor seals are mainly the visitation of cruise ships, which occurs from mid-May to September, and subsistence hunting, which occurs mostly from March to August (Wolfe 2001). Charter or private boats reportedly traverse the eastern coastline relatively infrequently to view the Hubbard Glacier, fish, hunt, or visit Egg (Haenke) Island.

The focus of this study was to assess the potential disturbance of harbor seals in Disenchantment Bay by cruise ships that move through and near areas of floating ice where seals are present. The two working hypotheses were: 1) individual seals that are hauled out on floating ice respond behaviorally to approaching vessels (i.e., by becoming agitated or entering the water); and 2) the population of seals in Disenchantment Bay responds to vessels through shifts in spatial distribution and/or by leaving the haul-out area. Of particular importance was evaluating the potential disturbance of nursing females and pups, as they have been shown to be particularly sensitive to disturbance at terrestrial sites (Newby 1973; Lawson and Renouf 1985; Suryan and Harvey 1999). To test these hypotheses, the potential response of harbor seals to vessel traffic was assessed at three spatial and temporal scales: 1) *fine scale* – daily observations of individual seal behavior in relation to vessel approach distance and angle, 2) *medium scale* – weekly aerial surveys of seal distribution and relative abundance in Disenchantment Bay, and 3) *large scale* – monthly aerial photographs of regional seal distribution and total abundance at glacial haul outs of the greater Yakutat area (i.e., in areas with and without [Icy Bay] cruise ships).

This report supersedes and updates the preliminary report issued in February 2003. New results have been integrated with summaries of previous findings, most of which appear here unchanged. For better clarity and organization, starting after a discussion of the study area, the report has been split into three sections to better reflect each of the studies conducted at different spatial and temporal scales. The objective of the first draft report was to summarize the field activities in 2002 and the preliminary findings for the seal behavior observations that were conducted from cruise ships. Since that report, we have continued to process, extract, and analyze statistically the distribution and abundance data from the aerial imagery. In this final report, we add the latest findings from both the medium-scale aerial surveys flown over Disenchantment Bay at roughly weekly intervals, and the large-scale photogrammetry conducted at monthly intervals. Future findings from additional studies conducted in 2004 and 2005 will be submitted directly to peer-review for publication. These complementary studies and the ongoing analyses are summarized in Appendix 2 of this report.

An overarching goal of this study is to produce reliable information on the behavior, distribution, and abundance of harbor seals in areas frequented by tour vessels to assist tribal representatives and the cruise ship industry in their mutual desire to maintain healthy populations of harbor seals in the ecosystems represented by tidewater glacial fjords.

2.0 Study Area

2.1 Overview of Past and Present

Disenchantment Bay (Tlingit: Ateix’) is characterized by two tidewater glaciers, Turner (Sít’ kusa) and Hubbard (Sít’ tłen), of which the latter is the largest of only eight Alaska tidewater glaciers that are currently advancing (out of an estimated 36 total in 2005; JKJ and D. Withrow, AFSC/NMML, unpublished data; Long 1992; Trabant et al. 2002; Fig. 1). In addition to its massive size (123 km long with an 11 km calving face), Hubbard Glacier has attracted steadfast interest for other reasons: 1) for several decades, it has threatened to permanently block the entrance to Russell Fjord putting at risk a local fishery and the Yakutat Airport (Lorenz 1994); 2) it has a two-century written and pictorial record dating back to the earliest European visitors (Barclay et al. 2001); and 3) its geological history is dynamic, distinctly cyclical, and seemingly runs contrary to global climate changes (Trabant et al. 2002). Historical accounts coupled with scientific research since 1890 (Russell 1891) provide evidence of three major expansions (and retreats) of Hubbard Glacier in the last 8,000 years. At the time of the earliest recorded accounts (Malaspina in 1791), Hubbard Glacier was at or nearing its minimum extent. It is currently re-advancing toward the mouth of Yakutat Bay, a distance of 60 km, where it last stopped *ca.* 1,000 years ago (Barclay et al. 2001). At that time, when Hubbard Glacier was calving ice into the open ocean, the earliest known settlements of the Yakutat Forelands area were already established (Davis 1996). The role of harbor seals in the local culture and ecosystem at that time is unknown, but it is clear that a nearby protected embayment with floating ice (i.e., Yakutat Bay) would have been much smaller or may not have existed. Malaspina Glacier, which would have been located near the far western flank of the calving face of Hubbard, may have been retracted enough to provide larger ice-filled embayments (D. Barclay, pers. comm.).

The marine environment of Disenchantment Bay comprises some 70 km^2, reaches depths of 260 m (850 ft), and is bounded by both steeply sloping shorelines and a complex system of submarine moraines which extend south into Yakutat Bay (Fig. 1). At the surface, the bay is dominated by floating ice emanating southward from the two tidewater glaciers. Ice coverage is non-uniform and varies widely – from solidly packed areas with no open water visible, as often occurs in the northern area in front of and between the glaciers, to single floes surrounded by expanses of water. At present, Disenchantment Bay is still connected to Russell Fjord by a narrow channel (Fig. 1), so both strong tidal currents and the wind cause the ice field on which seals haul out to shift rapidly and disperse in the bay. Glaciologists expect that the advancing Hubbard Glacier will permanently block this channel in the near future, as has already occurred for short periods in 1986 and during this study in 2002. In 2002, tidal exchange with Russell Fjord was restricted

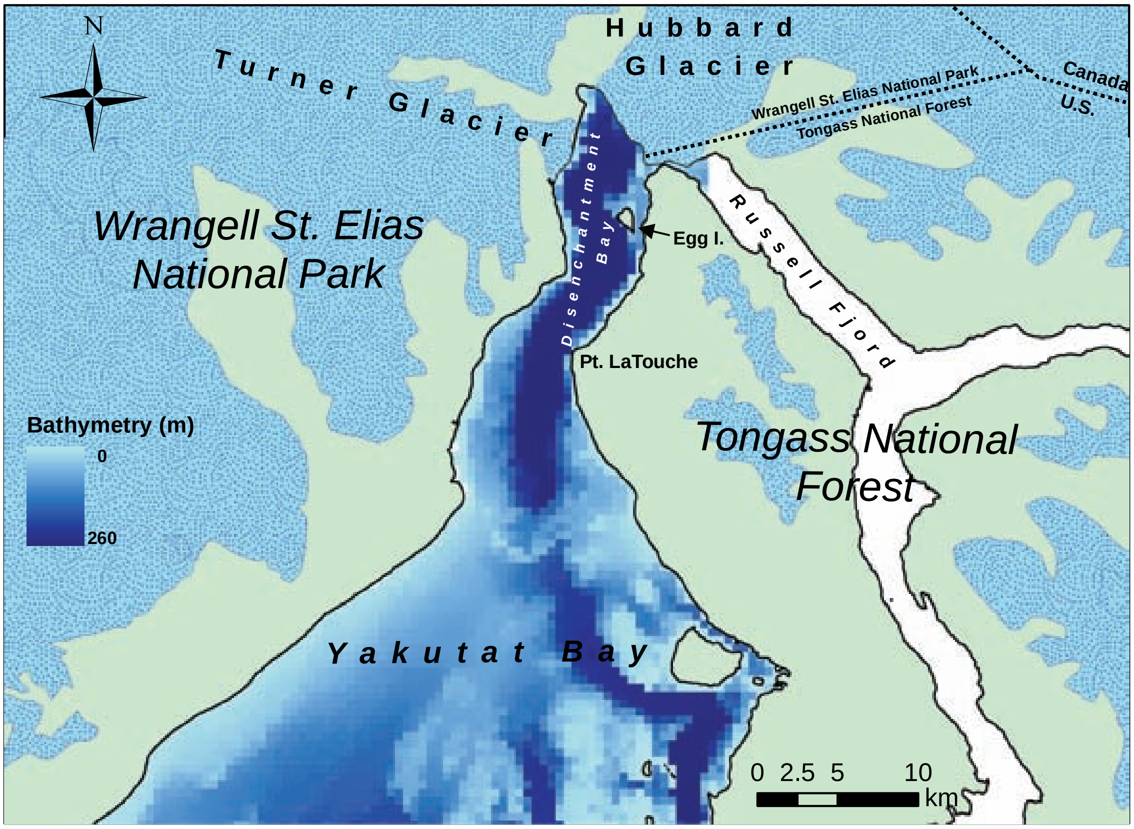


Figure 1. Map of the Yakutat Bay area showing the two tidewater glaciers, Turner and Hubbard. Bathymetry data was acquired from the C-CAP database (NOAA Coastal Services Center 1997) and is shown in gradations of blue, from light (shallow) to dark (deep; see legend). The study area was north of Point LaTouche. The extent of glaciated terrain (light blue) was derived from a 1993 satellite photo. The location of the terminus of Hubbard Glacier was mapped in early June 2002 as part of this study (D. Seagars, USFWS).

from June to mid-August after Hubbard Glacier surged and blocked off the inlet to the fjord. This effectively created Russell Lake which persisted until the moraine dam was breached by rising water on 14 August 2002. Despite this anomaly, the densest concentration of seals was found – prior to and during the formation of the ice dam, and right after it breached – in the northwest area of the bay (NMML, unpublished data; Fig. 1). Aerial sampling conducted in 2004 and 2005 will be compared with 2002 to assess whether ice conditions during the Russell Fjord blockage were typical or not.

Whereas the general distribution of harbor seals in Disenchantment Bay is fairly well known, the numbers of seals using the area is less clear. On ice between the two glaciers is historically where Native hunters have observed the densest aggregations of seals, and also where seals were concentrated during surveys by the National Marine Mammal Laboratory (NMML) in 1993, 1997, and 2001. The earliest historical records from Disenchantment Bay point to a larger population of seals in the past. In mid-June 1899, Grinnell (1995) estimated that among three sealing camps about 1,000 seals had been hunted to allow the Tlingit Tribe to secure their annual supply of oil. In mid-July 1886, Schwatka reported that as many as 1,500 seals had been taken (Schwatka 1891 in de Laguna 1972). These figures represent about four to five times the contemporary subsistence take (Wolfe et al. 2002) and roughly half of the most recent minimum population estimate (this study). Though we cannot know the accuracy of these historical estimates, suspected shifts in the environment may lend further support to larger seal populations in earlier times. Traditional knowledge of the Tlingit Tribe suggests that calving rates of Hubbard and/or Turner Glaciers were declining near the end of the 19th century, thus affecting both the location of optimal hunting grounds and patterns of use of established sealing camps (de Laguna 1972). Under a decline in ice coverage, the ice habitat would have been reduced and may have supported a smaller seal population. Such declines in calving rates and ice coverage are consistent with a reversal of the Hubbard Glacier from retreat (more calving) to advance (less calving) though there is debate among glaciologists about whether the reversal could have occurred as late as the latter half of the 19th century (Barclay et al. 2001; Trabant et al. 2002).

Despite more sophisticated techniques of enumerating seals (e.g., aerial surveys using photography), contemporary estimates of the number of seals hauled out on floating ice are still prone to biases due to the difficulty of counting animals over large areas of scattered, moving ice with no topographical reference. Moreover, the seals that are visible on the ice during an overflight represent only a fraction of the total population since many remain in the water. So, even the most accurate counts must be corrected upward by some factor that integrates the varying propensities of seals to haul out under varying environmental conditions. In Disenchantment Bay, Kozie et al. (1996) derived uncorrected estimates for the pupping period (mid-May) of about 750 harbor seals. During the August molt, estimates range from 467 (Kozie et al. 1996) to 1009 seals (Withrow et al. 1997). Estimates using more accurate techniques for counting (e.g., 100% coverage via high-altitude, high-resolution photographs) yielded an uncorrected August count of 1,778 seals (AFSC/NMML, this study). Still, it is unknown to what extent the seals in Disenchantment Bay use other areas in the greater Yakutat Bay area or mix with other significant nearby populations (e.g., Icy and Dry Bays). Nine radio-tagged harbor seals in Southeast Alaska (South Sawyer Glacier, Tracy Arm) migrated considerable distances between haul-out bouts on the ice. The seals spent more than half of their time in areas outside the fjord (100 km by water), especially by the onset of pupping at which time all tagged seals were outside the fjord; the two-thirds that returned stayed for only brief visits (Jansen et al. 2001).

2.2 Defined Area for this Study

The study area was geographically defined as the region north of Point LaTouche, which essentially marks the boundary between Yakutat and Disenchantment Bays (Fig. 1). Though some ice floes were scattered to the south of this boundary, the densest patches were nearly always north of this boundary, especially in the upper reaches of the bay where the vast majority of harbor seals were located. Elevated concentrations of ice and seals were sometimes observed in Yakutat Bay, and thus shipboard observations sometimes occurred there. The medium-scale aerial surveys were confined to Disenchantment Bay during May, but as ice increased through the season and extended into Yakutat Bay, observers began flying a single transect south of Point LaTouche in areas of dispersed ice. The large-scale aerial photography in Disenchantment Bay was confined to the area north of Point LaTouche. In Icy Bay, the surveys were conducted north of Kichyatt Point (Fig. 2).

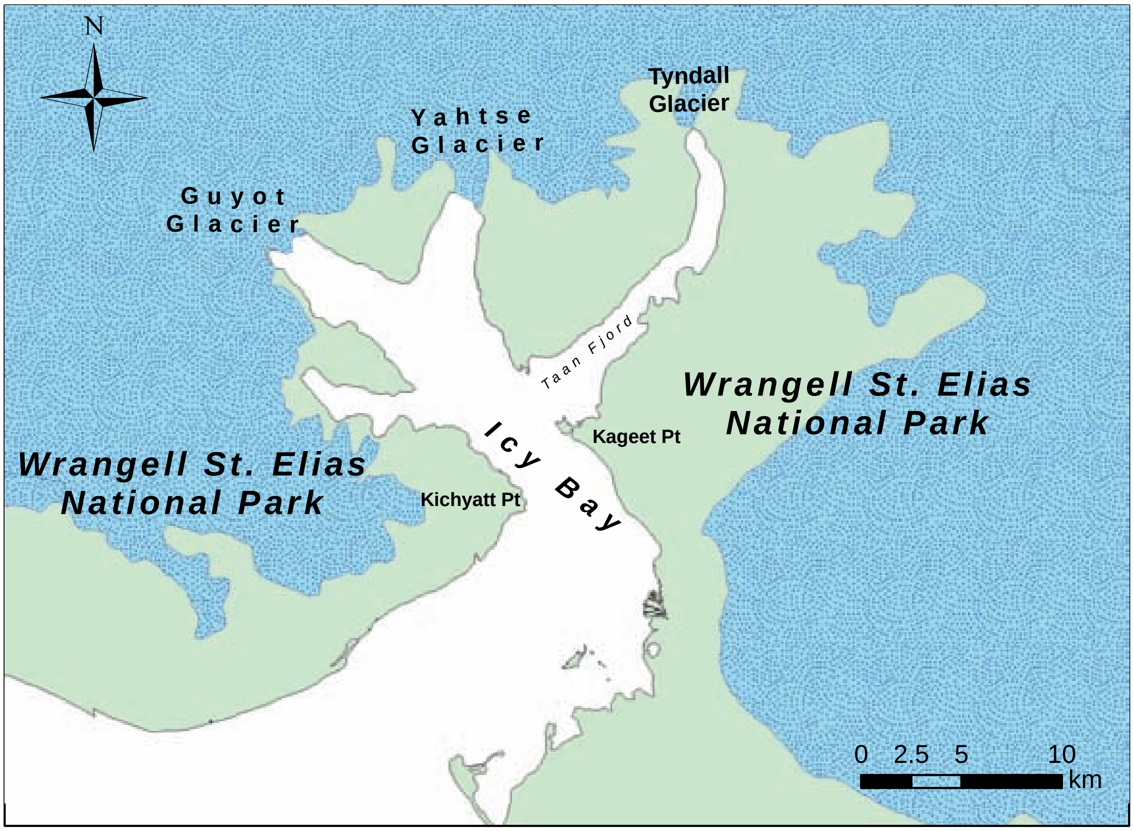


Figure 2. Map of Icy Bay area showing the three tidewater glaciers, Guyot, Yahtse, and Tyndall. The study area was north of Kichyatt Point. The extent of glaciated terrain (stippled) was derived from a 1993 satellite photo (NOAA Coastal Service Center 1997).

2.3 Environmental Conditions – in General and During the Study

2.3.1 Meteorology

The climate of the Yakutat Forelands is distinctly maritime. The surrounding 4,000+ m (13,000+ ft) peaks, in conjunction with exposure to moisture-laden air from the Gulf of Alaska (GOA), contribute to one of the highest average rainfalls in Alaska (330 cm; NOAA-NCDC 2002). The nearby glaciers exert a pronounced influence on the climate particularly when low pressure systems in the GOA cause steep pressure gradients which draw cold air down the glaciers causing localized cloudless conditions. Cloudless or partly cloudy skies immediately downwind of Hubbard and Turner Glaciers are often in sharp contrast to dense clouds and stormy conditions just outside Disenchantment Bay (JKJ and SPD, pers. obs.). Overall, clouds and fog are common around the Yakutat area throughout the year with mean sky cover averaging greater than 80% (NOAA-NCDC 2002).

During the study, weather conditions in Disenchantment Bay were monitored using a HOBO weather station (Onset Computers, Bourne, MA, USA) installed on Egg (Haenke) Island (Fig. 1). From 1 May to 2 August 2002, data on air temperature, barometric pressure, relative humidity, and wind speed were collected at 1-minute intervals which were then averaged into 30-minute observations. Sampling was interrupted from 26 June to 12 July due to a circuit defect in the weather station causing a power drain; no data on precipitation were

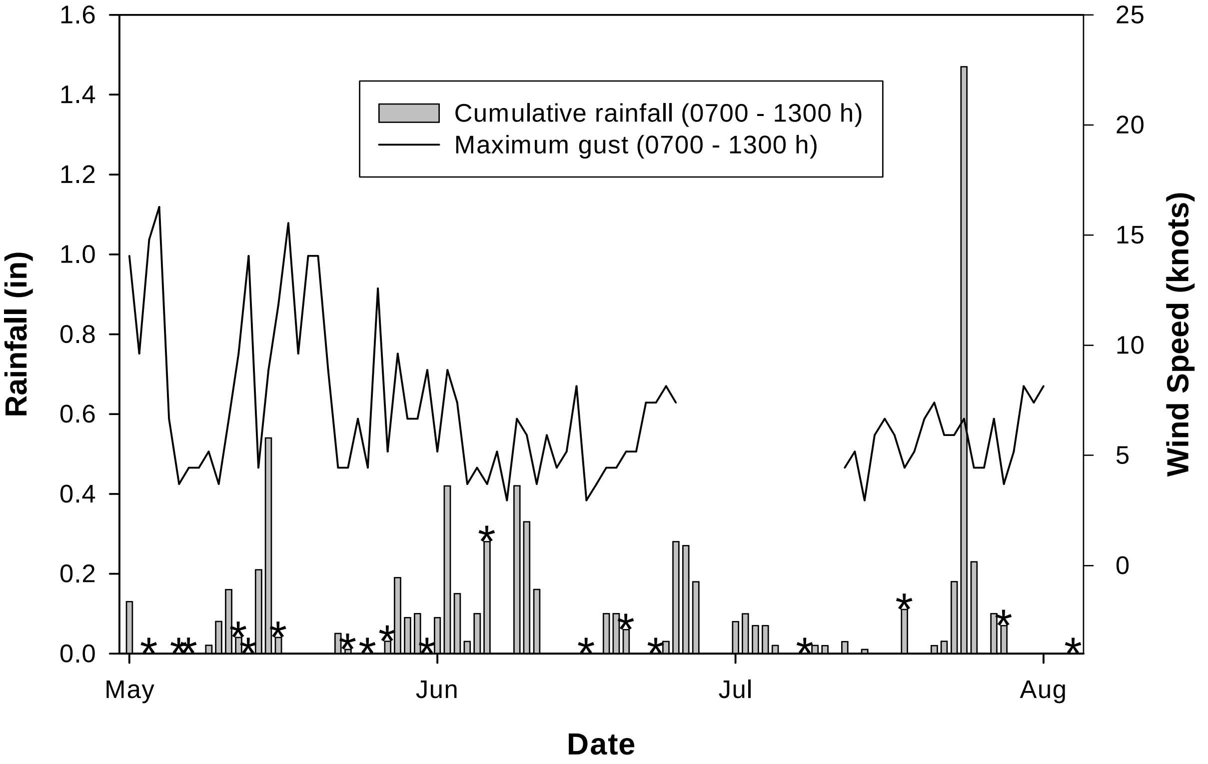


Figure 3. Indices of rainfall and wind speed for Disenchantment Bay, May to early August 2002. Indices were calculated for the 6-hour period preceding aerial surveys, which occurred on days marked with an asterisk. Wind speed was measured in Disenchantment Bay; rainfall was measured at the Yakutat Airport (NOAA-NCDC 2002). An instrument malfunction caused the data gap in wind speed.

collected due to a sensor malfunction. We used precipitation data collected by NOAA's National Weather Service in Yakutat (NOAA-NCDC 2002) as a proxy for rainfall in Disenchantment Bay (Fig. 3). Of primary interest were measures of rainfall and wind speed (Fig. 3) because increased levels are known to reduce the propensity of seals to haul out (Hoover 1983; Boveng et al. 2003).

Overall conditions during the study were unusually dry: for May, June, and July, departures from the 50-year average rainfall (22.8, 15.9, 20.6 cm, respectively) were -14.7, -2.2, -5.8 cm, respectively. Rainfall for May (8.1 cm) approached the record low (6.9 cm; 1951-2001; NOAA-NCDC 2002). Daily temperatures in the bay in early May were typical, fluctuating between the low 30s at night and low 40s (°F) by day. From 16 to 21 May, peak daily temperatures in the bay were above normal reaching 65°F on 20 May; the monthly maximum at the Yakutat Airport was reached the same day (76°F; near the 78°F record in 1963). June was characterized by daily temperatures ranging from the high 30s to the high 40s (°F) frequently peaking above 50°F after 12 June. Daily temperatures in July were generally from 40°F to 50°F with peak temperatures approaching 60°F from 31 July to 2 August (the last day of observations). Maximum daily wind gusts, measured in Disenchantment Bay, ranged from about 3 to 16 knots during the study (Fig. 3).

Because of minimum visibility requirements for flights, our surveys were conducted under better than average conditions (e.g., several flights had to be rescheduled due to rain, poor visibility, and/or high winds). This served to largely control for weather effects in the analysis. Data on hourly precipitation (NOAA-NCDC 2002) and wind speed (this study) were summed for the 6, 12, and 24 hours preceding each aerial survey to be used as a covariate in the statistical modeling of seal distribution and abundance (Fig. 3).

2.3.2 Ice Conditions

Ice floating in Disenchantment Bay emanated from both Hubbard and Turner Glaciers though the vast majority was derived from the former. Turner, with only a third of the calving face (3-4 km) of Hubbard, is retreating and becoming grounded along its north and south flanks (Fig. 1). Its contribution of calved ice to the ice field is also likely diminishing. Though calved ice can be large, exceeding 15 m across and > 5 m above water (termed *icebergs*), most ice in Disenchantment Bay is considerably smaller (termed *bergy bits* [< 15 m across], *growlers* [< 5 m], and *brash* [< 2 m]). Dispersing south from the glaciers on wind and tidal currents, most icebergs melt in a few days; bergy bits, growlers, and brash usually melt in less than a day (Long 1992). Ice in the bay thus indicates active, daily calving, primarily by Hubbard Glacier.

For this study, ice cover was defined as the percent of area that was occupied by ice that was greater than or equal to 2 m at its longest axis (i.e., growlers or larger). Hoover (1983) found that seals in Aialik Bay hauled out in peak numbers on ice that was 1-3 m across; parturient females preferred ice that was > 5 m. Further, we categorized ice cover into three types (or zones): *scattered* ice (1-3 tenths ice cover), *intermediate* ice (4-6 tenths), and *dense* ice (7-10 tenths). See section 3.2.1 for details.

Ice coverage in Disenchantment Bay varied dramatically during the study. In May, the ice-covered area (ICA) for scattered ice or greater varied between 28 and 56 km^2 (*ca.* 65% of the total 70 km^2 area; Fig. 4). During June, ICA peaked at approximately 64 km^2 (~ 90%) and then declined through July to a minimum of about 5 km^2 (~ 7%) on the last survey on 4 August 2002. In general, ICA was dominated by scattered ice, representing 25-45 km^2 (~ 70-80% in proportion); intermediate ice rarely exceeded 15 km^2 (20-30%) and dense ice was typically less than 3 km^2 (<1%). Patterns in the total ICA were driven largely by variation in the area covered by scattered ice. It is unclear whether the blockage of Russell Fjord, and the preclusion of tidal currents through the channel near Gilbert Point, significantly affected ice cover. If ice cover had remained high after the moraine dam had formed in mid-June it would point to reduced tidal circulation, an increased residence time of ice in the upper bay, and ultimately greater ice cover. But the steady decline of ICA despite near zero tidal exchange with Russell Fjord (from late June to the end of the study) suggests that larger-scale factors were driving ice coverage in the bay. An annual pulse in the calving rate of the two glaciers, during peak spring run-off (May-June), likely produced the observed seasonal pattern in ice cover.

2.3.3 Cruise Ships

In 2002, 168 cruise ship visits to Disenchantment Bay were scheduled from 14 May to 24 September (NWCA 2002). Of those, 105 visits occurred during the study and 56 complete navigation tracks were recorded using portable global positioning systems (GPS). For this study, the last ship was tracked on 1 August. Due to the typical 7-day duration of cruises – which embark passengers on weekends from ports 2-3 days travel from the study area – cruise ships tended to arrive midweek (e.g., 81% on Tuesday, Wednesday, or Thursday; Fig. 5). Visits were less frequent late-week (18% on Friday or Saturday) and only one visit (1%)

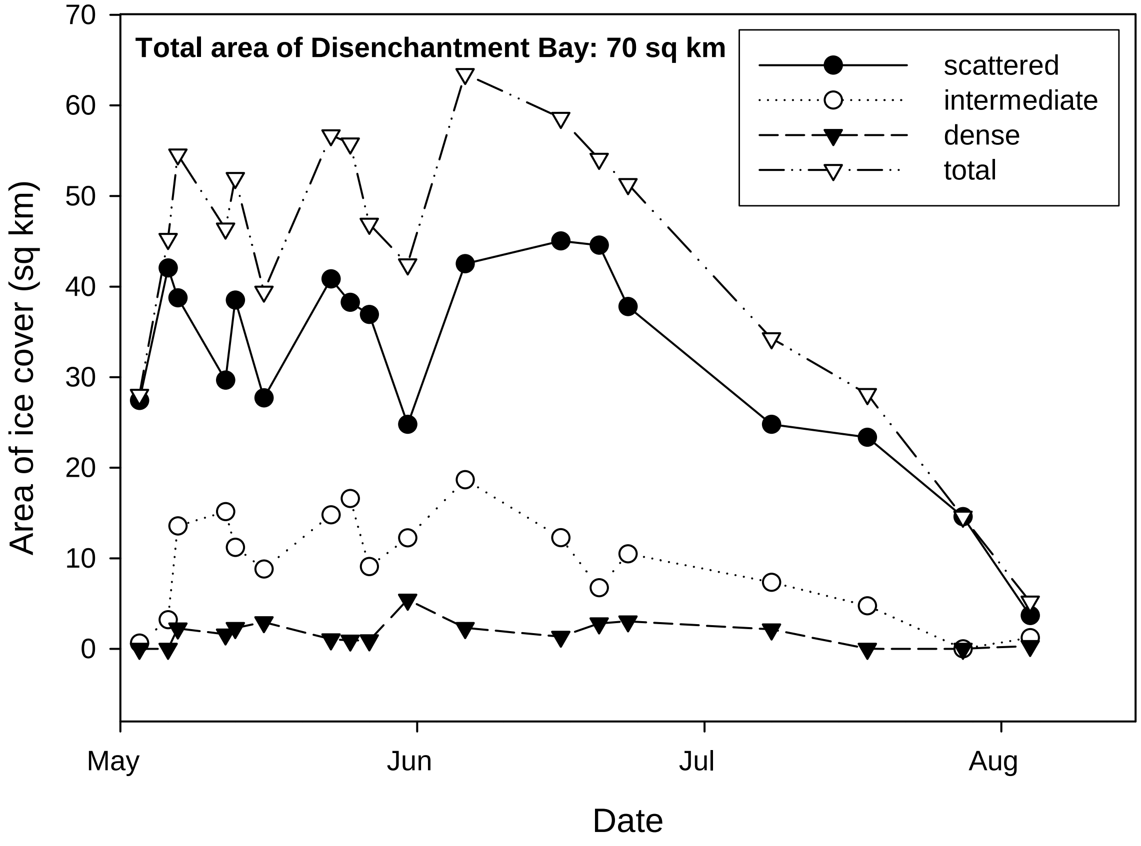


Figure 4. Estimated area of Disenchantment Bay (sq km) represented by different ice cover types, scattered (1-3 tenths), intermediate (4-6 tenths), and dense (7-10 tenths), and all types combined (i.e., ice-covered area [ICA]) from 3 May to 4 August 2002. Estimates of ice cover were averaged within grid cells (when n > 1) and the areas of cells with each type of ice cover were summed (see Section 3.2.1), and then scaled upward (proportionately) based on the percent of the study area that was sampled on a given day.

occurred early-week (Sunday or Monday). About half of the visits (46%) were without other cruise ships present; 42% overlapped with one other vessel (for an average of 1 hour) and the remaining overlapped with two (11%) or three (1%) other vessels. As ships approached Point LaTouche from the south, they typically reduced speed from *ca.* 12 to 6 knots, or lower if ice was in the immediate area. Vessel speed north of Point LaTouche ranged from less than 1 to 6 knots depending on visibility and ice which varied considerably across the bay. Thicker bands of ice would cause ships to temporarily slow to less than 2 knots.

The durations of visits varied widely and were dependent partly on ice conditions and visibility (Fig. 6). It was apparent that vessels had varying criteria for the type and/or size of ice they would negotiate to afford passengers better views of the two glaciers. Vessel captains and pilots were less inclined to penetrate Disenchantment Bay when larger ice spanned the mouth of the bay, usually resulting in shorter visits. Hampered visibility also reduced visit durations especially if Hubbard Glacier was obscured (Fig. 6; see visits in early July during persistent fog). Under such conditions, ships would rarely venture north of Point LaTouche. Based on GPS tracks collected on cruise ships from 14 May to 1 August 2002 (N=56), the average period that vessels were north of Point LaTouche (i.e.,

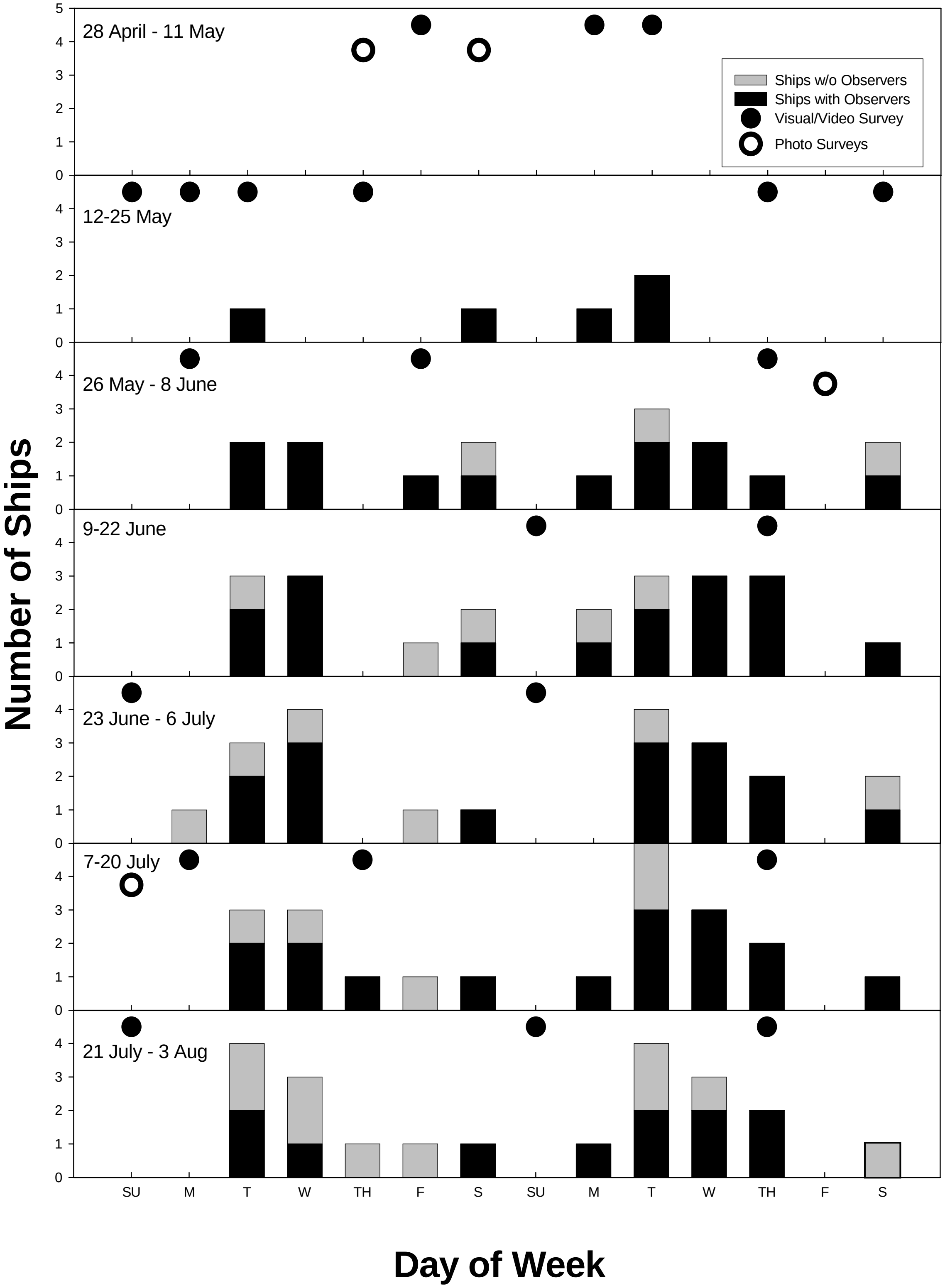


Figure 5. Distribution of cruise ship visits to Disenchantment Bay, with and without observers, and aerial surveys, 28 April to 3 August 2002. Surveys were also flown on 4 August (visual/video) and 14-15 August (photogrammetry). The photogrammetry surveys of Icy Bay were flown on the same day as Disenchantment Bay except for those flown on 4 May and 15 August.

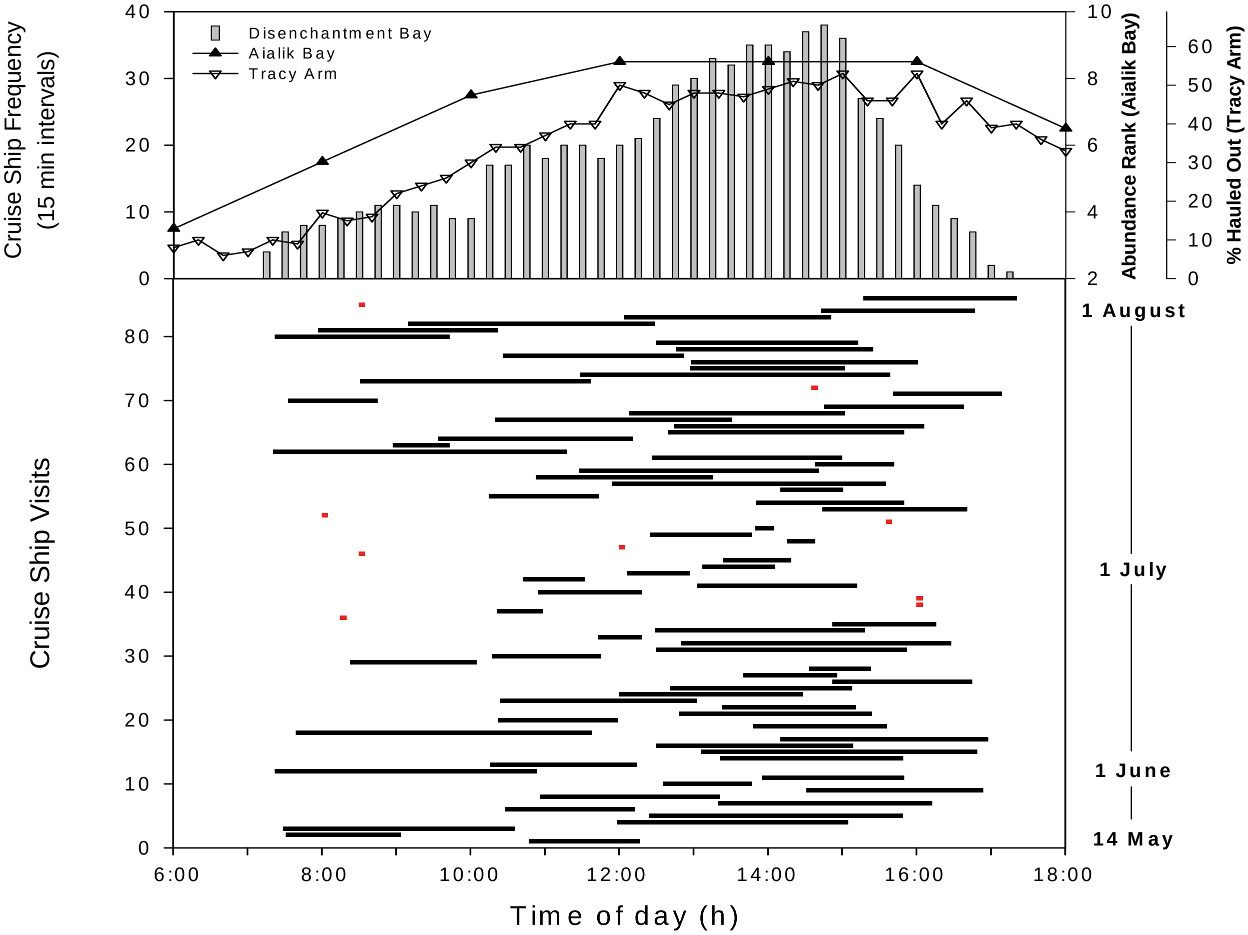


Figure 6. Haulout behavior of harbor seals (top panel) in relation to the timing (bottom) and frequency (top) of cruise ship visits to Disenchantment Bay. Haulout behavior was measured at South Sawyer Glacier, Tracy Arm (proportion of seals hauled out by time of day [ADT]; Jansen et al. 2001) and Aialik Glacier (abundance rank by time of day; Hoover 1983). The horizontal bars indicate the timing and duration of cruise ship visits (N=86) for which data was collected directly (by GPS) or indirectly (by remote observation). For ships that stopped south of the study area, tick marks show the times that ships turned around (N=9). The timeline on the right axis, bottom panel, shows the temporal progression of visits from the first ship on 14 May to early August.

inside the study area) was 2.17 hours (range: 0.25 - 3.98 hours). On average, ships arrived at 1141 h (range: 0721-1541 h) and departed at 1353 h (range: 0904-1721 h).

An examination of the frequency of cruise ship visits by time of day revealed a distinct diel pattern of visitation with a peak in the early afternoon (Fig. 6). At other tidewater glaciers, harbor seals haul out in peak numbers also in the early afternoon, typically between 1200 and 1600 h (Aialik Bay: Hoover 1983; Tracy Arm: Jansen et al. 2001; Fig. 6). Given this consistent pattern, we assumed that harbor seals in this study exhibited similar behavior. We thus expected that the majority of harbor seals in Disenchantment Bay hauled out during periods that coincided closely with cruise ship visits. Direct studies of individual seals in Disenchantment Bay are needed to confirm the extent of temporal overlap between hauled-out seals and ships.

Tracking by GPS showed that cruise ships entered Disenchantment Bay while favoring the eastern shoreline (by Point LaTouche; Fig. 7). In the early season (i.e., May and June), ships would sometimes use the area south of Egg (Haenke) Island, where open water often persisted, in order to maintain higher speed. Later in the season, as ice coverage diminished, cruise ships took more direct routes northward traveling directly up the middle of the bay, past the west side of Egg (Haenke) Island, to approach Hubbard Glacier to within 2 km (< 1 nautical mile [nm]; Fig. 7). Regardless of whether ships stopped because of impenetrable ice or to maintain a safe distance from Hubbard Glacier, they would usually rotate at their northernmost point using side thrusters to enhance viewing for passengers. Most ships exited using the same route, though after a close approach of Hubbard a few ships (for which we do not have tracking data) would depart between Egg (Haenke) Island and the mainland.

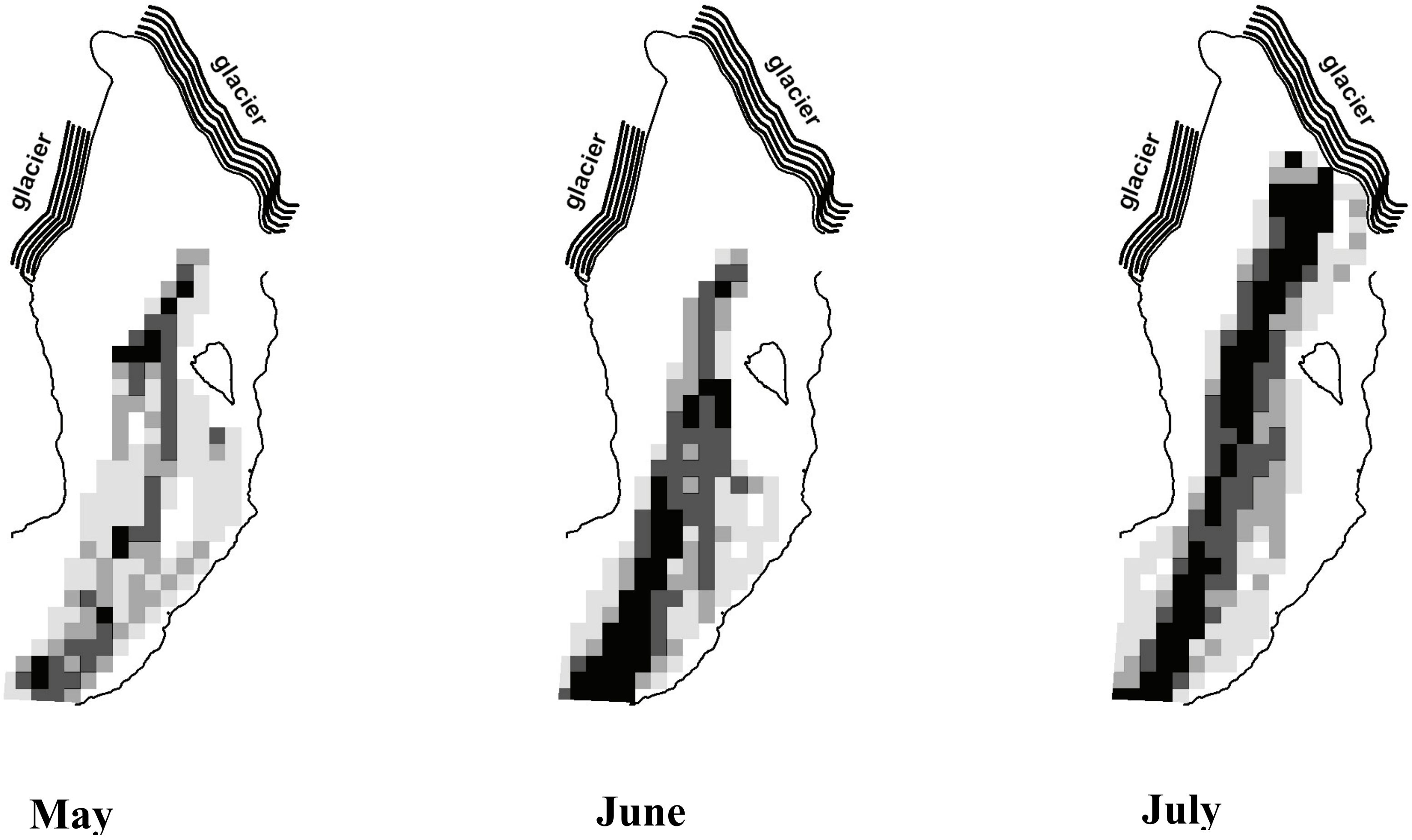
North of Point LaTouche, ships would regularly use a public address (PA) system, audible on most outer decks, to communicate programs to the passengers on the culture and natural history of the region. Most often ships would begin broadcasting prior to and at their deepest penetration in the bay (e.g., while rotating at their turn-around point). During land-based studies in 2004, voices on ships' PA systems were discernable and understandable at distances of at least 1.4 km (0.75 nm). Though beyond the scope of this study, we expect that such sounds are audible to seals at much greater distances and could be a source of disturbance.

2.3.4 Other Potential Anthropogenic Disturbance

Occasionally other watercraft (e.g., skiffs and day charters) were observed in the vicinity of Egg (Haenke) Island and in open areas to the south. Because these sightings were infrequent, usually involved a single boat, and rarely occurred in areas of thicker ice, we deemed the potential for disturbance – as a result of the mere presence or sound emitted by these smaller boats – to be very low.

Subsistence hunting of seals, which is undertaken from small boats, could affect the distribution and abundance of seals. We do not expect that the direct effects of removing seals from the population would affect measurably the survey results on a given day (i.e., on short time scales). However, when hunting does occur, some level of incidental disturbance is expected, particularly as the report from a rifle might elicit a response causing seals to enter the water. We could only monitor the presence of smaller boats in Disenchantment Bay in the course of our aerial surveys or when observers were aboard cruise ships. This effort, though near daily, represents a small fraction of the time available to visit the bay. Moreover, it was impractical to track the movement of observed boats or attempt to surmise the purpose of such visits whether it be hunting or sightseeing. Short- and long-term effects of subsistence hunting on seal behavior or abundance are currently beyond the scope of this study.

Aircraft, including the plane flying surveys for this study, might also cause disturbance. Few studies have systematically examined the effects of fixed-wing aircraft on harbor seals. In Muir Inlet, Glacier Bay, Streveler (1979) showed that seals did not enter the water in response to flights at or above 250 feet (N = 32 flights); less overt reactions were not studied. In our study, the incidence of aircraft other than our survey plane was low and such aircraft were usually operating at altitudes higher than 1,000 feet; however, on one occasion a plane was seen operating at less than 500 feet. In addition, the analysis of video directly below our survey plane did not reveal any overt reactions by seals though the observation window was short and reactions could have occurred in advance of or following an



May

June

July

Figure 7. Patterns of ship movement and residence time in Disenchantment Bay in 2002 (N = 56 cruise ships [of 105 total during study]). Shading of cells represent the cumulative time that visiting ships spent within that cell for each month, May, June, and July (including early August). Four distinct shades, from light to black, reflect increasing residence: < 5 min, 5-10 min; 10-20 min; > 20 min, respectively.

overflight. Based on previous findings, albeit limited, and our own general observations in Disenchantment Bay, we conclude that it is unlikely that our aerial surveys elicited a significant response from seals, particularly one that would bias the results presented here.

3.0 Three Spatio-Temporal Scales for Studying Harbor Seals

3.1 Fine Scale: Observations of Individual Seal Behavior in Relation to Vessel Approach Distance

3.1.1 Methods

Shipboard observations were conducted from 14 May 2002, when the first cruise ship entered Disenchantment Bay, to 1 August 2002 (Fig. 5), by which time we expected pups to have weaned. To ensure full coverage of vessels in the early season, arrangements were made to transport observers to all ships in May including those that did not embark pilots or cultural interpreters from Yakutat. From June to August, when there were more ships than observers on a particular day, higher priority was given to earlier ships provided the tender boat was scheduled. Portable GPS receivers were used to continually log the positions of ships during the observers' visits. Observers were typically onboard for 5-6 hours, which included at least 2 hours of transit to and from the ice field.

Observations were made of seals hauled out on ice during the entire period a ship was within viewing range of animals, which was typically out to a maximum of 800-1,000 m, depending on visibility. There were four possible observation posts onboard, each being described as some combination of port or starboard, and bow or stern. As many as three posts were occupied on a single cruise depending on the number of observers present. Observers noted whether ships were inbound toward Hubbard Glacier, rotating in place, or outbound toward Yakutat Bay. Efforts were made to first locate seal groups at varying distances and bearings from the ship to provide a behavioral contrast between near and distant animals. A seal group was defined as one or more animals hauled out on a single ice floe.

Behavioral observations were recorded during 15-second intervals on data forms or by using a hands-free digital voice recorder. The time that a digital voice recorder was started was noted and recorders ran continuously during observations. Digital voice files were later downloaded, played back via sound editing software that allowed observers to assign times to their observations, and transcribed into a database. For each 15-second sample, observers recorded the distance and bearing (relative to the ship in 15° increments) to the group, total number of animals in a group, and the number of animals that exhibited a particular behavioral state (i.e., level of excitement) during the interval. The behavioral state of seals was recorded as: 1) resting - seal was motionless with head down, 2) alert - seal was stationary but had head up, 3) active - seal moved across the ice floe or interacted with neighbors, or 4) entered water - seal departed ice floe during observation period. Only the highest level of excitement was recorded for each seal (e.g., "enter water" was the highest excitement, "resting" was the lowest). Distances between ships and seals were estimated using laser rangefinder binoculars (Leica VectorTM, Ashbury International Group, Inc., Sterling, VA) or an inclinometer. Data on mothers and pups were recorded separately from other animals and independent of each other. Once chosen for observation, a seal group was observed continuously until the seals either passed abeam of the ship (for groups observed from the bow), entered the water, or passed out of observation range astern (for groups observed from the stern).

For each group observed, additional data were collected on covariates such as ice coverage (estimated in tenths within a 50 m radius of the seal group), ice floe size (longest axis), and other potential sources of disturbance to the seals. Weather conditions were noted at the beginning of observations and whenever significant changes occurred thereafter. Appendix 3 shows the sampling guidelines observers followed. As a separate protocol, observers were sometimes stationed amidships to estimate distances to and size of seal groups abeam of the ship. These data will be used to calculate seal densities as a function of distance from the ship.

In total, observers recorded data on 76 of the 105 cruises (73%) that were scheduled to visit Disenchantment Bay during the study (Fig. 5). Complete navigational tracks were acquired from GPS units on most of these cruises. A total of 772 seal groups were observed comprising 6,008 15-second observations and a total effort of about 207 observer-hours. Observations were taken amidships on 52 cruises and distances were estimated to a total of 1,796 seal groups.

3.1.1.1 Analyses of Shipboard Observations

The analyses presented in this report were based only on data collected during 15-second observation periods while the ships were moving (as opposed to stopped or rotating in place). The data were further focused by considering only the forward-looking (bow) observer positions and by eliminating a few observations for which distance or bearing was not recorded. These criteria produced a data set from 584 seals observed in 307 groups.

Of the four behavioral responses recorded, entering the water was likely to have a stronger relationship to any potential longer-term impacts on the seals' vital rates than the other responses (resting, alert, or active). Also, analysis of the water entry response was simpler because it involved just one transition, from on ice to in the water, whereas the other responses could include reverse transitions and transitions between multiple behavioral states (e.g., a sequence recorded as resting, alert, resting, active, alert, on consecutive 15-second observation intervals). Therefore, we have focused on "entering the water" as the response variable. This choice allowed assignment of unique identifiers to all seals in the data set, even though the data had been recorded simply as counts of the numbers of seals within each group displaying the four behavioral responses. The seals were given individual identifiers by numbering the individuals within a group; the first to enter the water was numbered "1", the second numbered "2", and so on. Remaining seals that did not enter the water while under observation could be numbered arbitrarily because they all had identical behavior records (when considering only the water entry response). Representing the data in this way, there were 5,344 records (15-second observations) from the 584 seals. Each record included the seal and group identifiers, the start and stop times of the 15-second interval, the response (0 if the seal stayed on the ice, 1 if the seal entered the water), and the explanatory variables ("covariates"): distance from the ship to the seal, bearing from the ship to the seal, seal group size, and type of seal (mother, pup, or other).

3.1.1.2 Statistical Modeling of Behavioral Responses

The data we described above are "time to event" data with censoring. The censoring occurred whenever a seal was lost to observation before entering the water, which occurred, for example, when the seal passed abeam of the ship or when the shipped stopped its forward progress while a seal was being observed. For censored time to event data, the Cox proportional hazards model is a natural and widely used technique for estimating the effects of covariates on a response variable (Therneau and Grambsch 2000). In such analyses, the response is often death of the subject under observation, which is why this type of analysis is commonly called "survival analysis", but the technique is equally applicable to other types of binary censored outcomes, such as a seal entering the water. Although the basic Cox model assumes linear relationships and time-constant covariates, we used semi-parametric extensions of the Cox model that allowed the data to suggest the functional form of the covariate effects and that allowed for time-dependent covariates such as distance from the seal to the approaching vessel (Therneau and Grambsch 2000). We used S-Plus® version 6.1 for Windows (Insightful Corp., Seattle, WA) for all Cox regression modeling.

The Cox model is ideal for expressing covariate effects in terms of relative risk. For example, a subject with a value of 10 units for covariate A might be found to have twice the risk of the response outcome as a subject with 15 units of A. However, the absolute risk (e.g., What is the risk that a subject with 10 units of A will experience the outcome?), is not a product of the Cox model. For this initial analysis, we computed simple proportions of seals under observation entering the water for each of several distance bins as an approximate measure of the absolute risk.

We are currently examining other statistical frameworks, such as a repeated measures analysis on ordered categories (McCullagh and Nelder 1994), which have recently been used to test for disturbance effects on wildlife using a sequence of ordered responses from least to most disturbed (Lawler et al. 2005). For our study, such a framework would allow for testing simultaneously relationships between the frequency of harbor seal behaviors, from "head up" to "entering the water", and the vessel and environmental variables collected during cruise ship approaches.

3.1.2 Results

A Cox regression indicated that neither group size nor seal type was significantly related to the risk of seals entering the water ($P > 0.3$). Distance and bearing from the vessel, however, were highly significant explanatory variables for that risk. Figure 8 shows the functional form of the relationship with varying approach distance, obtained using a penalized smoothing spline (Therneau and Grambsch 2000). The Cox regression results are in terms of relative risk; to interpret Figure 8, it is easiest to compare two points. For example, at a distance of about 500 m, the effect curve begins to rise steeply. Because the vertical axis is on a natural-log scale, this point corresponds to a risk of e0.5 = 1.6. Comparing this to the scenario at very small distances, say less than 100 m, where the curve has a value of about 3.7, indicates that a seal approached at less than 100 m is about e3.7/e0.5 = 25 times more likely to enter the water than a seal approached at 500 m. Beyond about 600 m, there appeared to be very little effect of the ship's approach, though the confidence intervals expanded rapidly because of the relatively small number of observations at large distances.

Figure 9 shows the effect of variations in bearing angle on the risk of seals entering the water. Relative to a base risk of e0 = 1 when a seal was directly

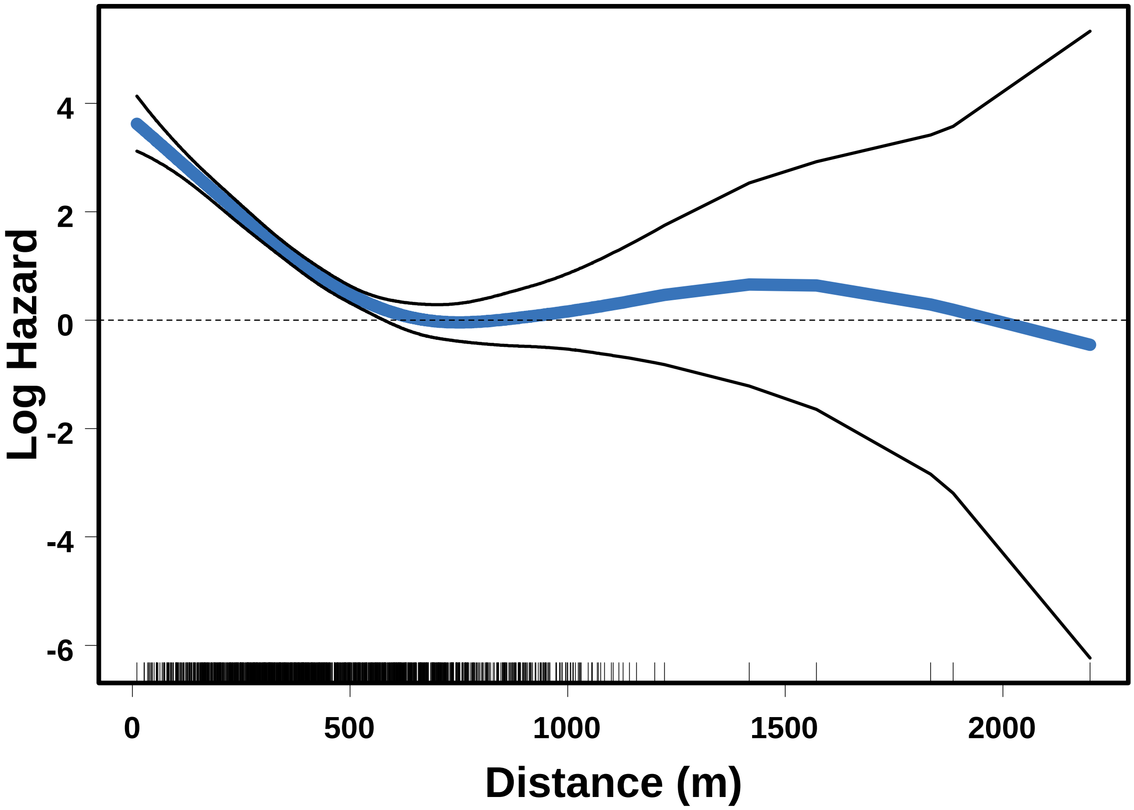


Figure 8. Relative risk, expressed as the logarithm of the hazard, of a harbor seal entering the water (abandoning its ice haul-out platform) in response to varying distances of approach by cruise vessels in Disenchantment Bay, Alaska. Approximate 95% confidence limits are shown by the thin curves. The observation distances are marked by the "rug fibers" plotted at the bottom.

abeam of the observer (90 degrees), the risk of a seal entering the water when approached dead ahead of the vessel was about e1.3 = 3.7 times greater. The risk appeared to be considerably lower for seals observed aft of the observer's position on the bow, but again the confidence intervals increased rapidly because of small sample size.

Because of the potential for interactions between distance and bearing angle (i.e., the response to distance may vary with the bearing), we investigated the shape of the response surface over the two variables simultaneously. This was not possible to do within the Cox regression framework alone. Instead, we fit a Cox regression with no explanatory variables and then used a generalized additive regression (Hastie and Tibshirani 1990) to explore the relationship between distance, bearing angle, and the residuals from the Cox regression. We found there to be no significant interaction between distance and bearing. That is, the increase in the risk of a seal entering the water with decreasing bearing (from 90°[abeam] to 0°[ahead]) was the same across the range of distances (from 0 to 1,000 m). This indicated that seals responded to the approach of the ship, rather than how visible it was; for example, a ship viewed from directly in front would appear smaller (and be less visible) than one viewed from abeam. That is, seals entered the water at shorter distances when ships were bearing down even though the ships appeared smaller.

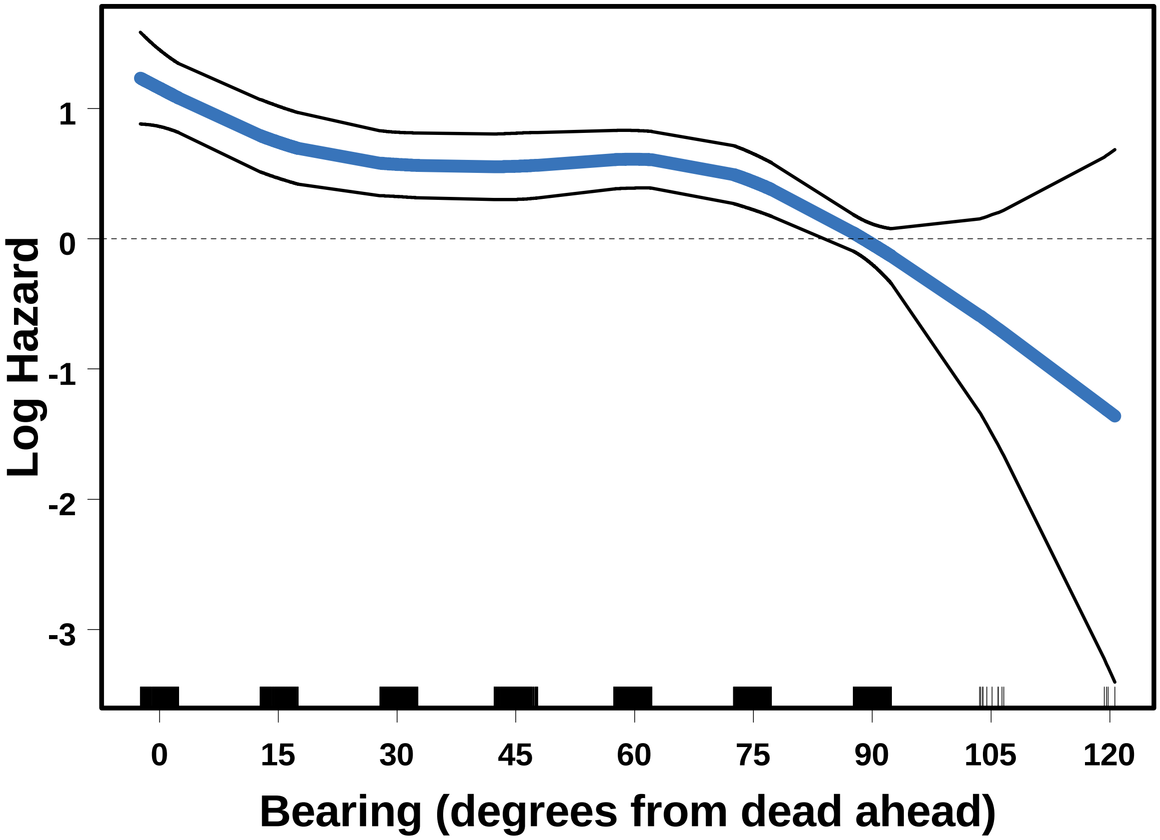


Figure 9. Relative risk, expressed as the logarithm of the hazard, of a harbor seal entering the water (abandoning its glacial ice haul-out platform) in response to varying bearing angles during approach by cruise vessels in Disenchantment Bay, Alaska. Approximate 95% confidence limits are shown by the thin curves. The observation bearings are marked by the "rug fibers" plotted at the bottom, which were jittered to better illustrate the relative sampling densities at the 15 degree measurement increments.

Figure 10 shows estimates of the proportions of seals that entered the water, in 10 distance bins of 100 m width. These estimates were derived from the 526 seals (279 groups) that either entered the water during observation or passed abeam of the ship while still on the ice; seals that were lost to observation for other reasons (e.g., ship stopped moving) were not included. Each proportion was calculated as the simple ratio of the number of seals that entered the water at distances that fell within the 100 m-wide bin, divided by the total number of seals that were observed at distances within the bin. These values provide a means of translating the purely relative (i.e., without units) values of the Cox regression into an absolute measure of the risk of water entry as a function of approach distance. Still, we emphasize that these measures are only approximations because they do not account explicitly for the censored nature of the proportion data (i.e., the seals that passed abeam of the ship and those that were lost to observation do not contribute to the measure), they do not adjust for the simultaneous effect of bearing angle, and they do not account for the amount of time the seals were "exposed" to the ship in each distance bin. Despite this approximation, the estimates in Figure 10 were qualitatively similar to the results of

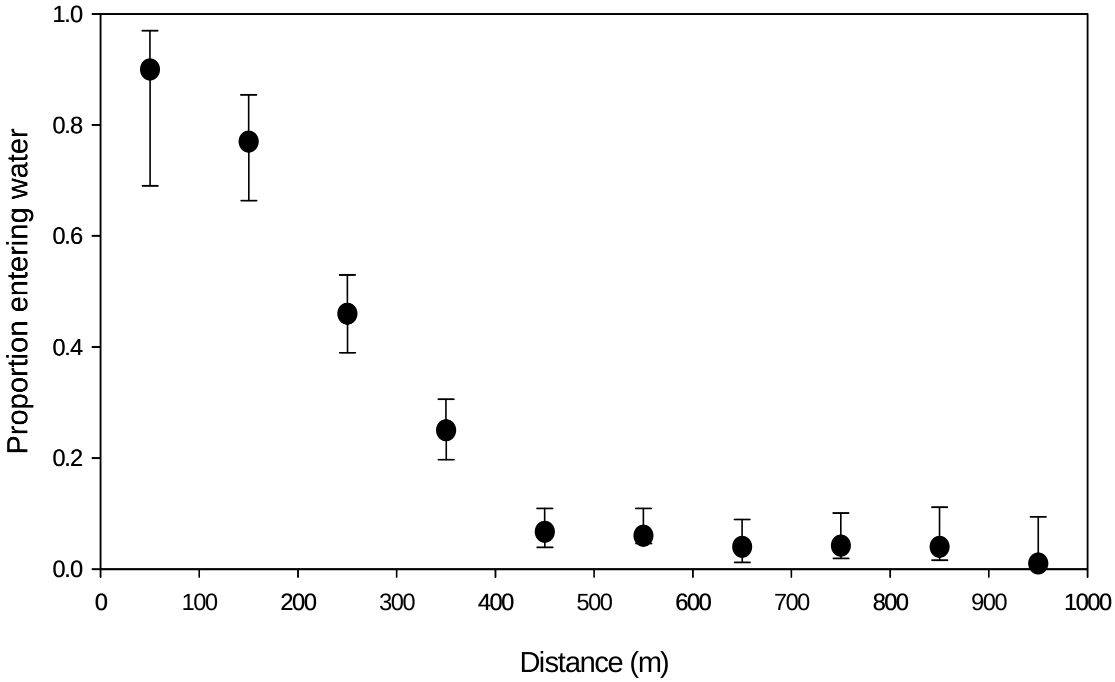


Figure 10. Estimates of the proportions of harbor seals entering the water in response to varying approach distances (in 100 m bins) by cruise ships in Disenchantment Bay, Alaska. Approximate 95% confidence limits (Agresti and Coull 1998) are shown. Note that a given proportion represents only the fraction of seals that entered the water (of those observed) within the relevant distance bin (i.e., a proportion does not represent the number of seals that have accumulated from bins of greater approach distances). The 100 m bins are represented at the midpoint (i.e., the symbol for the 100-200 m bin is plotted at 150 m).

the Cox regression for distance (Fig. 8). In general, there appeared to be little water-entry response by seals to vessels at distances greater than about 500 m, but there was a strong increase in the probability that a seal would enter the water when approached at distances of less than 400 m. That the absolute response by seals appeared to occur at smaller distances than the relative response may be a reflection of the smoothing parameter used in the Cox regression, as well as a reflection of the aforementioned limitations for approximating absolute risks.

Because the estimated proportions of seals entering the water when approached within 100-200 m neared 0.75 (Fig. 8), we conclude that a clear majority of seals approached by ships at 200 m or less were sufficiently disturbed to enter the water.

3.1.3 Discussion

The analyses of the fine-scale studies presented here indicate that harbor seals in Disenchantment Bay respond to the presence of cruise ships. Harbor seals altered their normal behavior in the immediate presence of ships by vacating ice floes with increasing frequency at approach distances less than 500 m (± 100 m). Mothers and pups showed no differences in the distance or bearing to vessels at which they were disturbed compared to other seals. Further analysis of the data collected in 2002 will be used to explore the suite of covariates that may influence the potential responses of seals to vessels, including weather conditions and recent patterns of vessel traffic in Disenchantment Bay. Inclusion of these other covariates may alter slightly the values or functional form of the covariates analyzed in this report. The qualitative form and the general magnitude of the influence of approach distance, however, are likely to be robust features that will not change significantly under refinements to the analysis. At the medium and large scales, we expect that the abundance and spatial analyses planned for the aerial survey data will address what proportion of the population is likely to be disturbed by ships and whether or not these seals (both within and outside the ship traffic corridor) respond by hauling out less often or by altering their distribution.

The results presented here are consistent with Calambokidis et al. 1985 (unpub. ms.) who found that an increasing proportion of harbor seals in Glacier Bay vacated ice floes with decreasing distance to cruise ships under 500 m. On average, more than 50% of the seals entered the water at distances to ships of less than about 300 m, surpassing 90% disturbance at less than 100 m – similar to our estimates. Speed of cruise ships and weather showed no obvious effect, though seals appeared to respond to ships at greater distances on clear, sunny days. Streveler (1979), reporting on eight summers in Glacier Bay, Alaska, was the first to document human disturbance of harbor seals inhabiting tidewater glacial fjords. He focused attention on the potential for disturbance to cause separation between mothers and their dependent pups, which has been shown to be a significant source of pup mortality at terrestrial sites, whether natural or human-induced (Johnson 1977).

Although we observed mothers and pups responding to vessels – showing they had similar rates of water entry compared to other animals – the additional information necessary to document impacts on pup survival was not possible to obtain from shipboard platforms. Still, a general behavioral pattern, similar to Calambokidis et al. 1985 (unpub. ms.), was noted by observers: the mother and pup would enter the water usually within a minute of each other, or if the pup was hesitant, the mother would maintain visual contact until the pup entered some minutes later. The observation would end as the pair became obscured among the floating ice (and the observer focused on finding another group). We did not observe the sudden “crash dives” and lack of mother-pup coordination observed by Streveler (1979) in response to close approaches (< 150 m) by small boats or extremely low-flying (< 61 m) aircraft.

These previous findings and our results indicate that cruise ships disturb the immediate behavior of individual seals (or groups), but evaluating the impacts of such disturbance on individual fitness – and ultimately population vital rates – is more difficult. If seals are compelled to spend more time in the water, then it is important to understand the possible long-term consequences. Pinnipeds begin life on land or ice and subsequently haul out on these substrates. Though all species of pinniped haul out, some do so only to reproduce and molt whereas others, like harbor seals, haul out throughout the year. The propensity to haul out differs relative to environmental conditions (e.g., solar angle and tide height) and across populations (Boveng et al. 2003). For example, harbor seals at terrestrial sites appear to respond primarily to tidal and diel light cycles (Watts 1996), whereas those on floating ice may respond mostly to the latter. Harbor seals in Alaskan glacial fjords exhibit a distinct diel rhythm with peak numbers on ice floes at solar noon (Glacier Bay, Calambokidis et al. 1987) or in the early afternoon (Aialik Bay, Hoover 1983, Withrow and Cesarone 1999*a*; Tracy Arm, Jansen et al. 2001). In Tracy Arm, prior to the tour boat and cruise ship season, radio-tagging studies estimated that 90% of seals hauled out at some point daily, with an average 50-70% hauling out for some period between 1000 and 1700 h (ADT) (Jansen et al. 2001). At Glacier Bay, visual counts indicated that 70-90% of seals hauled out daily over the same period (Calambokidis et al. 1987). Such diel patterns, with numbers of hauled out seals peaking by day and diminishing at night, have been described widely and have been attributed to nocturnal foraging (see Watts 1996). Though night-time feeding is supported by studies examining directly the foraging behavior of Alaska harbor seals (Frost et al. 2001), as Watts (1996) states: "this begs the basic question of why seals should [haul out] when they are not foraging".

The reasons why seals spend time out of the water are poorly understood but two theories predominate: 1) immersion in water is energetically costly; and 2) the threat of being eaten by a marine predator is significant (Watts 1996). It has been suggested that harbor seals are thermally neutral when active in the water (reviewed in Watts 1992). That is, heat production from metabolism approximately equals heat loss. During periods of inactivity, however – as during periods of required rest or sleep – there is likely an energetic cost to staying warm if seals are compelled to remain in the water and do not haul out (Watts 1992). Even while resting, seals must sustain a higher metabolism to maintain body temperature, termed *low-temperature stress.*

However, a recent study of harbor seal pups at terrestrial sites suggests that low-temperature stress is unavoidable when water temperature falls below 4°C (39°F), an effect that is increasingly critical in smaller seals during winter (Harding et al. 2005). The smallest pups, that necessarily had the least insulation, faced low-temperature stress at less than 10° C (50°F). At their study site, temperature varied seasonally between 3° and 17°C (37-63°F). At the coldest temperatures, a 17 kg (37 lb) seal would have to consume an extra 0.5 kg (1.1 lb) of prey daily compared to a 32 kg (71 lb) seal in order to break even energetically. The researchers predicted that if heat loss was not balanced with increased food intake, starvation would occur, and higher mortality during winter would be expected. Not surprisingly, then, the researchers documented a *ca.* 30% decrease in over-winter survival in the lightest pups when compared to the heaviest.

These findings are particularly relevant to Disenchantment Bay because water temperature, due to melting ice and runoff in the warmer months, remains relatively low throughout the year. Water temperature in the upper 30 m probably rarely exceeds 5-7° C (41-45° F), as suggested by conductivity-depth-temperature (CTD) sampling at a similar glacier fjord (Tracy Arm Fjord, NMML, unpublished data) and measurements of sea-surface temperatures (SST) near Yakutat. Even south in Yakutat Bay, where relatively little ice persists, summer SSTs rarely exceed 12° C (54° F) and are commonly below 10° C (University of Alaska SALMON Project 2005). It therefore stands to reason that a significant increase in time that young harbor seals, especially pups, spend submerged, or an interruption of nursing causing lower weaning mass, could have profound effects on energy balance, insulation, and over-winter survival.

The threat of predation to harbor seals has not been rigorously examined, though predation on pinnipeds by killer whales (*Orcinus orca*) and sharks is well documented (Jefferson et al. 1991; Watts 1996; Lucas and Stobo 2000). Calambokidis et al. (1987) reported numerous kills and attempts on harbor seals by killer whales near terrestrial haul-outs in Glacier Bay, and observed them traveling frequently in central and lower parts of the bay. Interestingly, they did not observe any killer whales in ice-filled, seal haul-out areas despite 7 months of continued presence (i.e., observation camps) over 3 summers. Similarly, Streveler (1979) indicated that “killer whales have never been reported in Muir or Johns Hopkins’ icepacks” in his experience in Glacier Bay over 8 years. Moreover, even though cetaceans (i.e., harbor porpoise and beluga) were observed on numerous occasions during the extensive surveys flown for this study, killer whales were not among them. But there have been observations of killer whales moving through loose brash ice in glacial fjords, albeit few. In upper Glacier Bay, two pods (8 and 22 animals) were observed during 9 daylong vessel surveys (1991-1993); the larger pod was a resident group which is believed to feed exclusively on squid and fish (M. Dahlheim, NMML, pers. comm); in Aialik Bay, only one pod (two animals) was observed in 3 weeks (D. Withrow, NMML, pers. comm.). Similarly, killer whales were seen on one occasion in outer Yakutat Bay among dispersed ice floes on which several harbor seals were resting (Yakutat Tlingit Tribe, pers. comm.). Still, the notable absence of accounts of killer whales in densely-packed ice where seals occur in highest concentrations supports the view that such seals benefit from a lower risk of predation. The Inuit have long known that Arctic seals (and narwhals, *Monodon monoceros*) will enter scattered to dense pack ice when pursued by killer whales (Campbell et al. 1988).

The incidence of seals vacating ice floes clearly diminished with ship distance out to at least 400 m, perhaps as far as 600 m. At greater distances, the effect of ship approaches starts to level off suggesting that the frequency of seals entering the water at those distances is nearing ambient levels (i.e., levels expected in seals behaving naturally). However, along with the seeming diminution of responses at greater distances is a sizable increase in the error margins (i.e., 95% confidence limits). This result is an unavoidable consequence of smaller samples resulting from the decreasing detectability of seals with increasing distance from ships. Still, if the inference is correct that the frequency of the most overt response to ships (i.e., seals entering the water) reaches zero at about 500 m, it is logical to predict that harbor seals may respond in other ways (e.g., increased alertness or agitation) at greater distances since these less overt behaviors are usually precursors to entering the water.

3.2 Medium Scale: Weekly Aerial Surveys of Seal Distribution and Relative Abundance in Disenchantment Bay

3.2.1 Methods

Aerial surveys of relative seal abundance and distribution were conducted 3-4 times weekly from 2 to 25 May 2002, beginning 12 days prior to the first entry of cruise ships into the bay. Daily surveys were conducted from 12 to 16 May (except 15 May) to gather additional samples immediately preceding and following the first cruise ship visit of the year (14 May). Subsequent surveys were conducted twice weekly, weather permitting, starting 27 May and ending on 4 August, after the completion of pup rearing. These surveys were timed to facilitate a comparison of seal abundance and distribution between periods of low and high ship visitation. Thus, the first survey in the week was attempted on Sunday or Monday, following a period of reduced ship visitation, and the second on Thursday or Friday, following a period of increased visitation (Fig. 5). Surveys were flown between 1300 - 1500 h (ADT) to coincide with the daily peak in numbers of seals hauling out (Hoover 1983; Calambokidis et al. 1987; Withrow and Cesarone 1999*a*; Jansen et al. 2001). A single engine aircraft (Cessna 206; Yakutat Coastal Airways Inc., Yakutat, AK) was flown at a target speed of 90-100 knots and altitude of 305 m (1,000 ft). Two survey methods were employed simultaneously during overflights of the haul-out areas: observer line-transect and video strip-transect. A standard grid of 14 transects, oriented along the longest axis of the bay and separated by 400 m, was flown over Disenchantment Bay (Fig. 11); a fifteenth transect was added in June to quantify the distribution of animals in southern Disenchantment Bay and northern Yakutat Bay as seals were sometimes observed there in low densities.

For the observer line-transect method, two 50-m strips to the left side of the plane were delineated using a Plexiglass sighting board attached to the aircraft's window (Fig. 12). The observer's eye position relative to the marks was fixed by visually aligning a pair of marks on the sighting board like a gunsight. The sighting board allowed quick measurement of distance intervals so the observer could remain focused on the ice and reduce missed seals. Normally, seals were counted within both of the two 50-m strips; however, when high seal density made accurate counting difficult, the observer focused attention just within the nearest strip. Effort data, time, and geographic position were recorded throughout the survey via a portable GPS unit. Environmental data – such as ice conditions, visibility, and weather – were also recorded by the observer. The single observer surveyed out the port side of the aircraft, recording seal counts, presence of vessels, and conditions in real time on the audio track of the video tape.

For the video survey, a video camera was mounted vertically on the starboard wing strut with the zoom lens preset to record a 70-m strip directly beneath the plane. Time and GPS coordinates were initially imprinted on the tape as an aid in mapping seal and ice distribution during the analysis phase. In June, we discontinued imprinting to optimize the viewing area during playback analysis, then matching the local time of seal sightings (visible in a smaller area on the screen) with locational fixes from the GPS unit using its associated local times. The medium-scale aerial surveys were flown on 23 days comprising nearly 40 hours of observation and 60 hours of flight time.

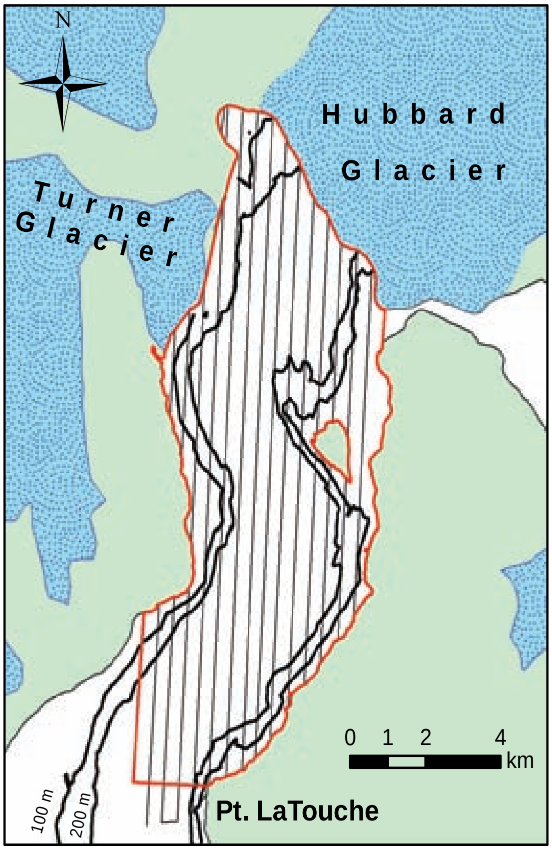


Figure 11. Map of Disenchantment Bay study area (outlined in red). The aerial transect grid for video and visual surveys is shown. The location of the face of Hubbard Glacier was mapped in early June 2002 (D. Seagars, USFWS). Bottom contours are shown in black.

Videotapes were played back and analyzed on a 13-inch video monitor (Sony Trinitron, Model PVM1344Q) by a single observer (S. Dahle). Harbor seals hauled out

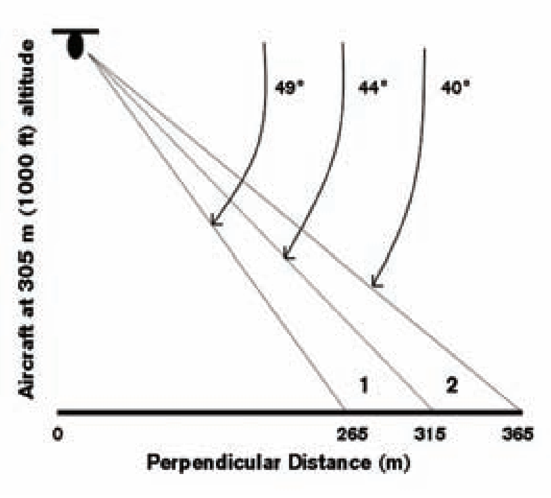


Figure 12. Vertical angle measurements of perpendicular distance of the two sighting bins from the survey aircraft.

on ice were counted as they passed a horizontal line drawn across the bottom third of the screen. This ensured that the virtual width of the survey strip (70 m) was kept constant even though the plane (and the camera) may have rocked side to side and thus recorded, if only briefly, seals that were just outside the strip. This method also standardized the position on the screen, and thus the survey time, at which seals were sighted. Observations were communicated to a separate recorder who entered the number of seals on individual ice floes and the local time (which was related to geographical position), as well as a qualitative estimate of ice coverage (within the frame containing the seals) to the nearest tenth for ice greater than or equal to 2 m at its longest axis. Pups were also identified based on relative size (less than two-thirds the size of the adjacent seal) and proximity (less than the adjacent seal's body length away). In addition, ice coverage was estimated at 15-second intervals when seals were not sighted. Depending on the speed of the plane, this provided a minimum of 0.75 - 1 km × 400 m resolution of ice conditions thus creating intermittent gaps in ice data for the 400 × 400 m grid cells.

Due to electronic problems and condensation, the video camera malfunctioned or produced less than optimal quality video during several surveys. Video recordings that were considered poor were excluded from the analysis (two surveys). Other recordings where the camera stopped operating over areas of typically high densities of seals were also excluded (five surveys). On four other surveys, the camera stopped recording during the last two to four transects at the western side of the bay, just offshore and south of Turner Glacier where few seals are typically sighted. An absence of seals on those transects was visually confirmed on two of those surveys (23 and 25 May 2002); on the other two (16 May and 18 July 2002), the distribution of seals and ice on adjacent surveys made it unlikely that a significant number of seals was missed. Due to condensation, the video taken on 16 June was of marginal quality; thus, seal sightings could be negatively biased though counts were comparable to the preceding and following surveys.

3.2.1.1 GIS Analyses

The video analysis yielded 8,938 distinct observations of seals and/or ice conditions which were mapped into a geographic information system (GIS) as separate point layers. The ice and seal point data were each summarized into a lattice of 400 × 400 m cells for the entire study area (41 × 19 cells). Ice cover observations were averaged when multiple points fell within cell boundaries; seal count observations were summed. Indices of potential cruise ship effect were calculated on the basis of number of visits, ship distance, and activity. The number of visits was determined for the 3 days leading up to and including the day of an aerial survey, and assigned to all cells (i.e., a global variable). Ship distance was defined as the closest approach of a cruise ship to the centroid of each cell containing seal groups (i.e., a cell-specific variable). Ship activity was defined as the amount of time that ships spent within a 1 km radius of the point of closest approach to a seal group. For the distance and activity calculations, we used ship tracks – for those cruise ships that penetrated north of Point LaTouche – that were recorded on the day of the aerial survey and the day prior. It was necessary to use a 2-day window in order to acquire an adequate number of sampling days with ships. There were seven aerial surveys (of 18 total) which coincided with cruise ship visits: two on the same day, three with coinciding ship visits on the same and previous day, and two with coinciding visits only on the previous day. Ships' tracks were used to calculate ship activity for a given survey provided they reached their turn-around point (i.e., the deepest penetration into the bay) prior to the end of the survey. The ship that visited on 3 August, one day prior to a survey, was not tracked and thus we assumed that it followed a path similar to the most recent ship three days prior. From 23 July to 1 August, reduced ice caused ships to follow very similar routes through the middle of the bay to within about 1 km of Hubbard Glacier.

3.2.1.2 Statistical Analyses

3.2.1.2.1 Time Series of Relative Abundance

Because the daily sampling coverage was standardized, the total number of seals sighted during surveys provided a relative measure of abundance from which to examine seasonal trends. Using S-PLUS, Version 6.2 (Insightful Corp., Seattle, WA) we fit a generalized additive model (GAM; Hastie and Tibshirani 1990) to the counts of seals to assess seasonal variation in abundance. The GAM was implemented using a log-link function, a spline smooth term, and a Poisson error distribution. We evaluated the effect of date separately because the spatial-temporal models discussed below (Section 3.2.1.2.2) sought to remove date effects which could have confounded the effects of other covariates that varied by date. GAMs are non-parametric and do not impose a functional expectation on the data, therefore allowing the data themselves to suggest a functional form. This is often necessary for ecological data where complicated functions may be expected (Barry and Welch 2002).

3.2.1.2.2 Space-Time Modeling of Covariate Effects on Seal Counts

Based on the traditional ecological knowledge (TEK) of the Yakutat Tlingit Tribe (pers. comm.), we expected (and generally observed) that harbor seals in Disenchantment Bay form a clustered distribution, tending to aggregate to the west and north of Egg (Haenke) Island. This clustering was confirmed during exploratory analysis of the spatial distribution of seal counts. The tendency for seal counts in adjacent cells to be more similar than distant cells, termed *spatial autocorrelation* (SAC), presents challenges for inference from conventional statistical tests which assume that samples are independent. Assuming independence when SAC exists overestimates the degrees of freedom, biases the coefficients and their standard errors, and can cause the coefficients to be considered significantly different from zero when they are not. It was therefore necessary to model the pair-wise correlations between all seal cell counts to account for the effects of SAC while simultaneously testing for covariate effects on those counts.

Observations can also be correlated in time. As with SAC, assuming temporal independence of serial observations can inflate the actual degrees of freedom resulting in a higher risk of concluding a significant effect when one does not exist. To account for temporal autocorrelation, the effects on seal counts of the global covariates (which varied temporally but not spatially [e.g., wind, rain, and number of ships visiting]) and local covariates (which varied spatially and temporally [e.g., ice cover, closest ship approach]) were modeled separately but simultaneously using a first-order autoregressive model (AR1; see Appendix 1).

A frequent characteristic of large-scale survey data is a large number of zero observations. The seal counts in this study were no exception, with seals occupying less than a third, on average, of the cells containing ice on a given day. Such *zero-inflated* count data, a form of overdispersion (McCullagh and Nelder 1994), if modeled conventionally can also lead to incorrect inference and biased parameters. The recommended approach, adopted in this study, is to model the zero-inflated data in two steps: 1) model the absence-presence component of the data (using a Bernoulli distribution) and 2) model the observed abundance conditional on the response being greater than zero (using a Poisson distribution; Mullahy 1986; Heilbron 1994; Welsh et al. 1996). The zero-inflated, space-time regression was fitted using Markov Chain Monte Carlo (MCMC) in WinBUGS software (Version 1.4, Imperial College & MRC, UK). Details of the regression model used here are provided in Appendix 1. Using this model, our goal was to describe the empirical relationship between the distribution (presence) and abundance (counts) of seals and environmental covariates, such as measures of cruise ship presence, distance, and activity.

3.2.2 Results

3.2.2.1 Potential Biases in Seal Abundance

Despite having standardized daily coverage during the aerial surveys, there were potential sources of bias and imprecision. Firstly, we could not distinguish between seals that left the study area and seals that were present but opted not to haul out during the survey period on a given day. However, because other studies of glacial-fjord seals support a stereotyped behavior of hauling out daily in the early afternoon (see Section 3.2.1) we expect that seals in Disenchantment Bay have a similar propensity. Also, other studies in glacial fjords have shown that when seals were present near the haul-out area they nearly always hauled out (i.e., if they missed hauling out it was because they had left the fjord)(Jansen et al. 2001). We therefore assumed that shifts in seal abundance were caused largely by departures from and arrivals to Disenchantment Bay.

Secondly, researchers have shown that harbor seals in glacial fjords tend to form small groups which in turn form larger-scale aggregations (i.e., seals are not randomly distributed; Bengtson et al. 2004; Simpkins et al. 2005). These aggregations change in size and location across days. In our study, distinct aggregations of seals and the degree to which those aggregations were not sampled equally across days would cause variability, or imprecision, in the estimated abundance. Clustering of seals means that some surveys might miss a significant portion of the population (negative bias), whereas others might over-sample areas of high density (positive bias). The pronounced trends exhibited in the time series of seal abundance suggest strongly that our sampling frequency was adequate to detect real signals in the data thus overwhelming any possible noise generated by this imprecision. We are currently assessing the efficiency of the sampling design used in this study by comparing the relative abundance with a “known” abundance as estimated by the high-altitude photogrammetry.

Sightings of mother-pup pairs may be biased as there is evidence from Aialik Bay that mothers and pups occur in peak numbers on the ice a few hours earlier in the day compared to other seals (Hoover 1983). However, recent findings from Glacier Bay showed that the proportions of mothers and pups hauled out varied by less than 5% over a 15-hour daylight period (Mathews and Pendleton 2006). In our study, the number of mother-pup pairs showed no relationship with the start time of surveys, which ranged from 1300 to 1500 h (ADT). Based on this information, we assumed that mothers and pups had haul-out behaviors similar to other seals.

3.2.2.2 Visual Sampling of Harbor Seals

The visual observations from the two 50-m strips to the side of the plane showed substantial variation across days and between observers in the probability of sighting seals. Using the seals mapped by video during each survey (see Section 3.2.2.2 below), we calculated the “known” seal density for the 70-m video strip and compared it to what would be expected – given comparable densities – in the two 50 m visual strips. We assumed that the sighting probability did not vary between the video strip directly under the plane and the visual strips starting at 264 m to the side of the plane.

Compared to video sightings, visual observers consistently underestimated seal densities. This bias varied between observers with average factors ranging from 0.49 to 0.63. Within observers, factors ranged as wide as 0.16 to 0.83 across days compared to the video sightings. The reduced probability of detecting a seal in the visual strips versus on video may have been due to a *swamping* effect, such that when seal densities were high observers had difficulty counting seals particularly those that were closer and passing relatively faster. Sighting probability could also have been reduced by visual interference caused by the plane’s landing gear which was positioned immediately inboard of the closest strip. These observer biases, though expected, were quite variable across days and warrant further investigation. Because dense aggregations of seals were fairly common in the study area, it may be that visual sighting techniques are impractical here. Because the sightings from the video analysis were largely unbiased (i.e., a single observer made the seal and ice observations and there was no swamping effect), and they provide a verifiable record of observations, we are currently using only the video sighting data to address hypotheses in the medium-scale study.

3.2.2.3 Video Sampling of Harbor Seals

3.2.2.3.1 Time Series of Total Abundance

The fitted GAM model showed that abundance varied significantly by date ($P < 0.01$; Fig. 13) revealing several pronounced shifts during the study. On 3 May, seal abundance appeared to be near peak levels (though prior abundance was unknown) but then declined precipitously to a minimum by mid-May. The decline may have occurred in two stages with a drop of about one-third of the seals followed by a brief pause from 6-13 May and then another steep decline (50%) from 14 to 16 May. The entire decline amounted to a 75% reduction in abundance. Seal numbers remained well below maximum levels until late June when

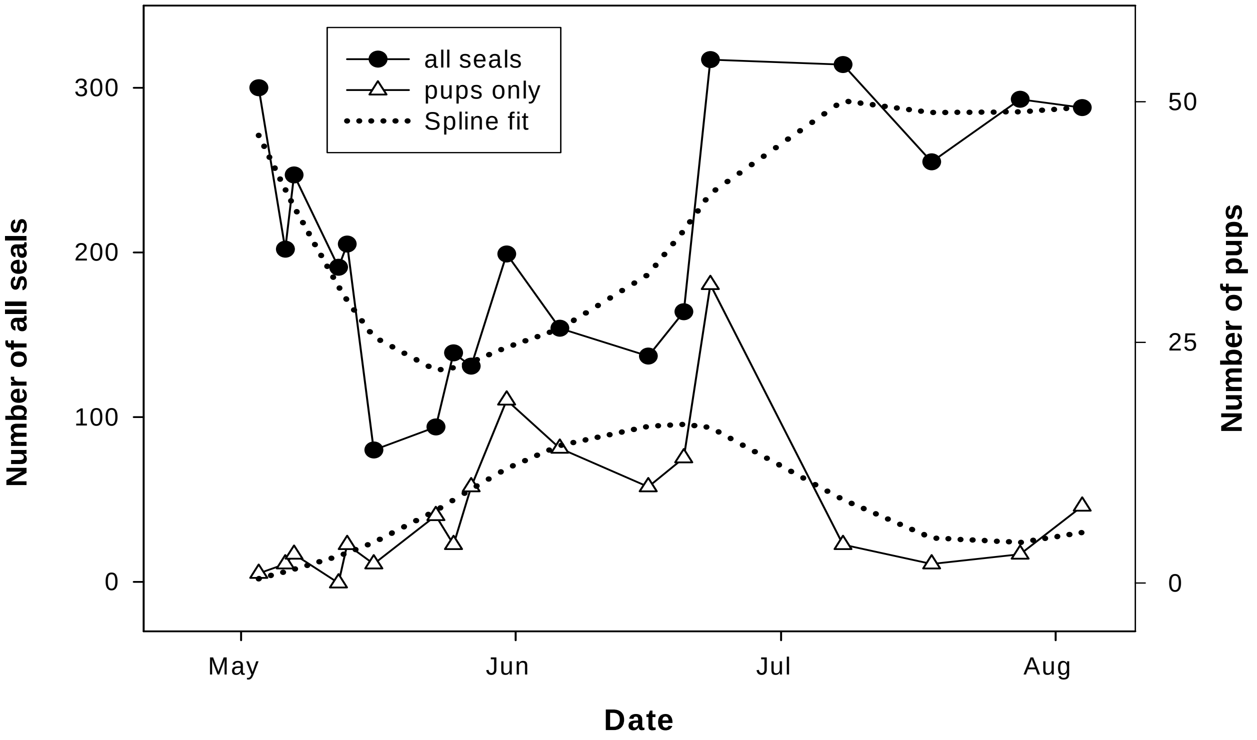


Figure 13. Numbers of all seals and pups, counted in video surveys, in relation to date. The spline curve is the best fit according to the GAM using date as the only covariate on seal and pup counts.

they again peaked and remained high until the last survey on 4 August.

Interestingly, there was a modest rise in seal numbers in early June and then a slight decline before the actual peak count on 23 June. It was during this secondary rise in total seals that numbers of pups showed a steady increase before also peaking on 23 June. Though the peak in total seals and pups coincided, the combined number of mothers and pups contributed only about 20% (10% each) to the total sum. These coinciding peaks suggest that the increase in number of mother-pup pairs occurred in conjunction with increases in the general population. The subsequent rapid drop in sightings of mother-pup pairs in early July, despite high numbers of seals, suggests that weaning was underway and mothers and/or pups were spending more time in the water, or at least were not associating as closely.

3.2.2.3.2 General Patterns in Seal Distribution

There was considerable daily variation in the spatial distribution of seals hauled out in Disenchantment Bay (Figs. 14-19). Overall, seals hauled out in the highest frequency north and west of Egg (Haenke) Island. Seals frequently occurred in smaller numbers south of Egg (Haenke) Island, occasionally even south of Point LaTouche when ice conditions permitted. Distinct aggregations of seals were almost always apparent but the spatial extent and location of higher density areas varied. For example, prior to and during the decline in abundance in early May, seals were confined to a relatively small area to the northwest of Egg (Haenke) Island (Figs. 14-15). In late May, immediately after the minimum in abundance and as seal numbers were rebounding, seals were more dispersed particularly in areas to the south. By June, as seals continued to arrive, they were scattered almost equally in the western half of the bay, north and south of Egg (Haenke) Island. The more scattered distribution of seals in June occurred as ice was reaching maximum coverage. As ice cover steadily declined from late June through early August, seals were increasingly more aggregated in areas closest to the Hubbard Glacier. Their narrowest distribution occurred during the last survey, on 4 August, when seals were in the northernmost area of the bay (Fig. 19).

3.2.2.3.3 Seal Abundance in Relation to Ice Cover

There was no apparent relationship between total seal counts and the overall availability of ice cover in the bay. Seal numbers were high in early May (the first survey) when the ice-covered area (ICA) was reduced and intermediate to dense ice was nearly absent. The steep decline in seal numbers (in the first half of May) occurred as the total ICA varied around intermediate levels and areas of denser ice became more prevalent. Seal numbers reached a minimum during a brief drop in ice coverage (16 May), but comparable drops coincided with high numbers of seals. By 23 May, the ICA, which consisted mostly of intermediate and scattered ice, reached its highest level to that point and seal counts remained low. Moreover, as seal numbers increased later in the season, ice steadily declined to a minimum. By July, with ice cover at less than 50% of the peak – declining to 5% by August – seal abundance had mostly stabilized at high levels. Still, a response by seals to ice availability may only occur at specific “checkpoints” during the year, such as related to life-history constraints. For example, a seal just arriving to Disenchantment Bay may assess conditions and decide whether or not to stay, whereas a seal already in the midst of pupping or molting may not have the same flexibility to respond to changes in ice availability (i.e., depart if conditions turn unfavorable).

Despite no apparent relationship between abundance and total ice availability, seals did appear to vary their use of different types of ice cover through the season, possibly in response to shifts in availability (Fig. 20). On 3 May, virtually all seals occupied the scattered ice zone, as there were scant areas of denser ice. As areas of intermediate and dense ice increased through May, seals shifted disproportionately to these zones despite a consistently high availability of scattered ice (~50% of the study area). By mid-May, when abundance was at a low, seals had mostly abandoned scattered ice in favor of intermediate ice cover. As abundance gradually rebounded (through late-May and June), seals began using the scattered ice zone in greater numbers, though still far less than would be expected by random selection. Interestingly, as seal abundance increased in late June to early July, the zone of highest abundance shifted from scattered to intermediate ice (Fig. 20). We speculate that this dramatic shift in the use of different ice zones reflects a pulse of new arrivals in the scattered ice followed by a gradual movement into denser ice (Fig. 20). Seasonal changes in spatial distribution of seals support this hypothesis: seals were more dispersed when abundance was increasing, and in turn used the scattered-ice zone more frequently, particularly south of Egg (Haenke) Island (Fig. 16-18). At the end of July, the use of the scattered-ice zone again peaked, but in this case (as in early May) the intermediate- and dense-ice zones were severely limited. On the last day of the study, as denser ice again became available (and ICA was less than 5% of the peak), seals shifted back to intermediate or dense ice leaving only 20% of the seals in scattered ice (Fig. 20).

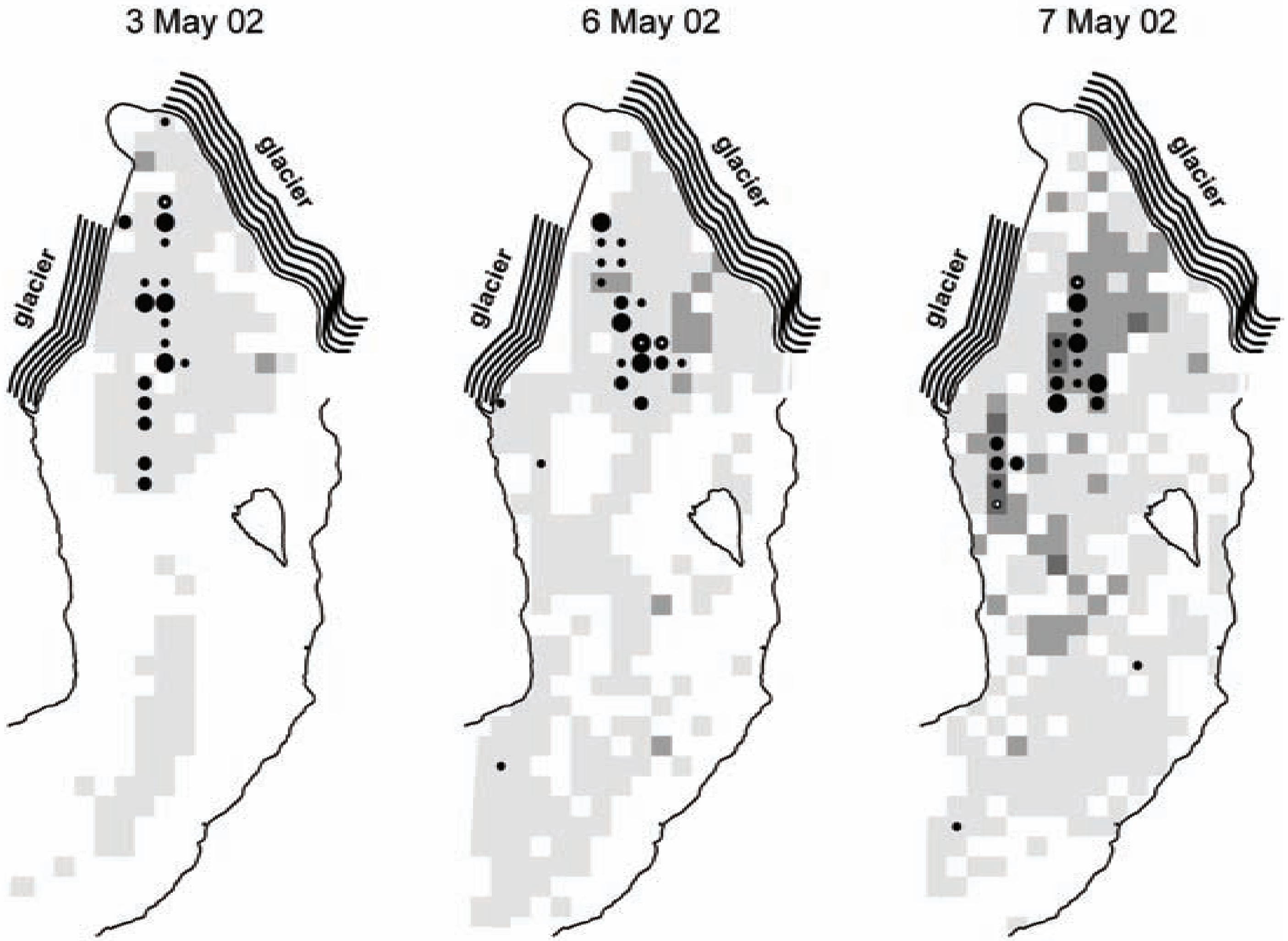


Figure 14. Spatial distribution of harbor seals, ice cover zones, and maximum penetration of cruise ships on the day of surveys (☆) and the previous day (★) for 3, 6, and 7 May 2002. The range of seal counts summed per grid cell is shown in three levels: small dot (< 5 seals), medium dot (5-20 seals), large dot (> 20 seals). Increasing ice cover is represented by a gradient in shading: scattered (light gray), intermediate (medium gray), dense (black). The incidence of at least one mother-pup pair within a grid cell is shown by a white dot. The time of day that ships reached their maximum penetration appears near the location symbol. For this graphic, if cells with no ice data (see Section 3.2.1) were bounded on three sides by cells with ice measures, the average of neighboring cells was used as an estimate.

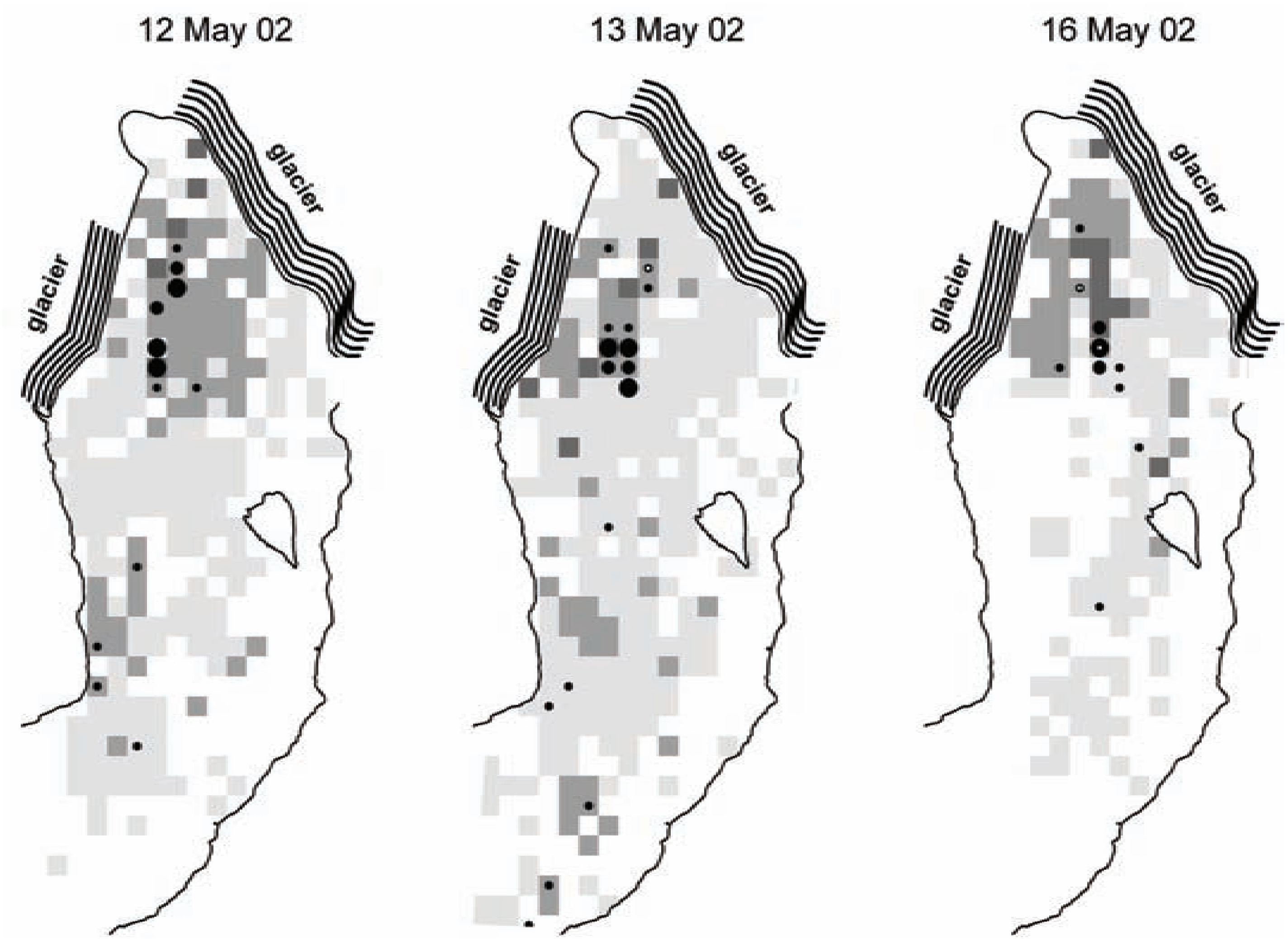


Figure 15. Spatial distribution of harbor seals, ice cover zones, and maximum penetration of cruise ships on the day of surveys (☆) and the previous day (★) for 12, 13, and 16 May 2002. The range of seal counts summed per grid cell is shown in three levels: small dot (< 5 seals), medium dot (5-20 seals), large dot (> 20 seals). Increasing ice cover is represented by a gradient in shading: scattered (light gray), intermediate (medium gray), dense (black). The incidence of at least one mother-pup pair within a grid cell is shown by a white dot. The time of day that ships reached their maximum penetration appears near the location symbol. For this graphic, if cells with no ice data (see Section 3.2.1) were bounded on three sides by cells with ice measures, the average of neighboring cells was used as an estimate.

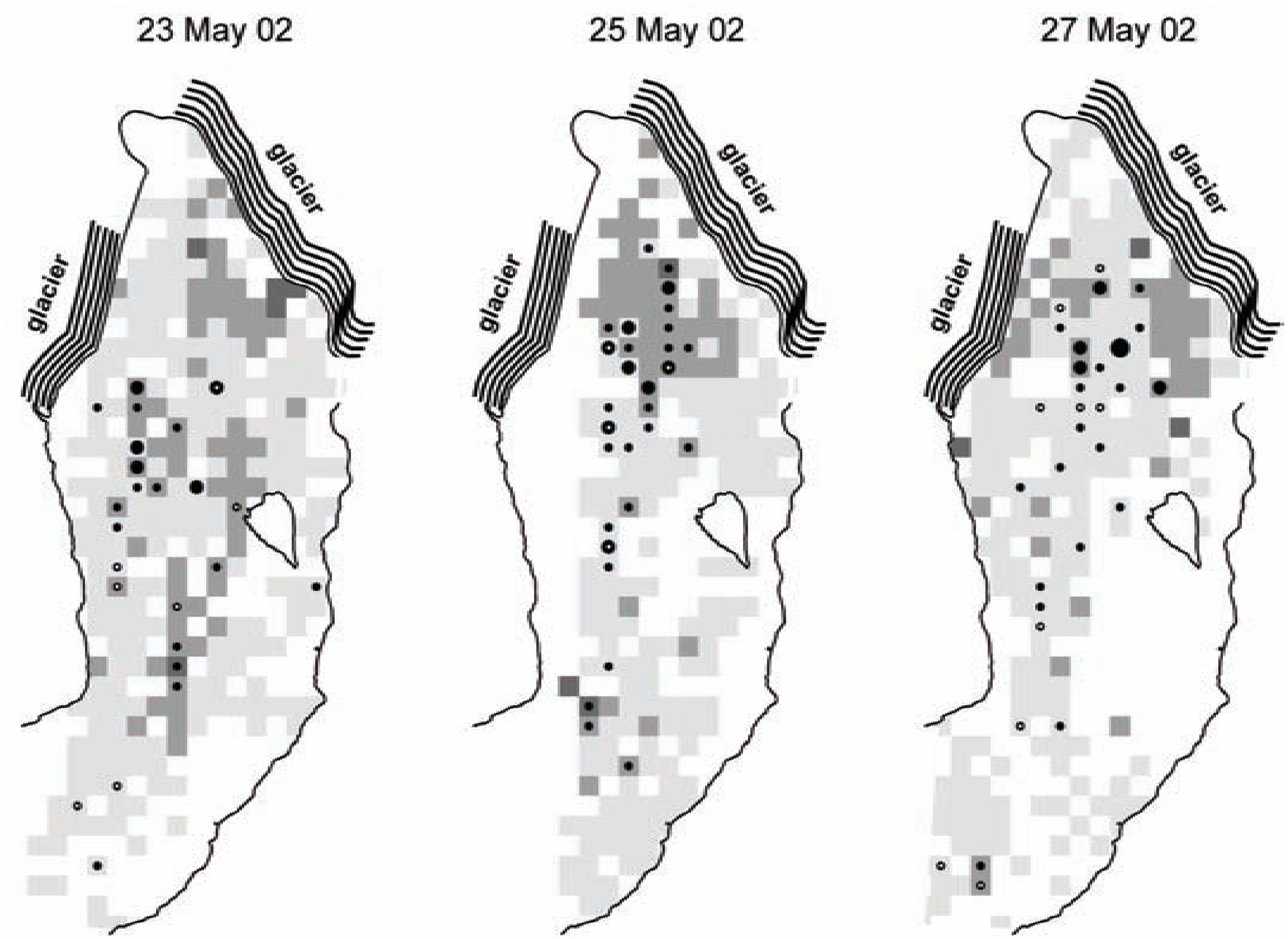


Figure 16. Spatial distribution of harbor seals, ice cover zones, and maximum penetration of cruise ships on the day of surveys (☆) and the previous day (★) for 23, 25, and 27 May 2002. The range of seal counts summed per grid cell is shown in three levels: small dot (< 5 seals), medium dot (5-20 seals), large dot (> 20 seals). Increasing ice cover is represented by a gradient in shading: scattered (light gray), intermediate (medium gray), dense (black). The incidence of at least one mother-pup pair within a grid cell is shown by a white dot. The time of day that ships reached their maximum penetration appears near the location symbol. For this graphic, if cells with no ice data (see Section 3.2.1) were bounded on three sides by cells with ice measures, the average of neighboring cells was used as an estimate.

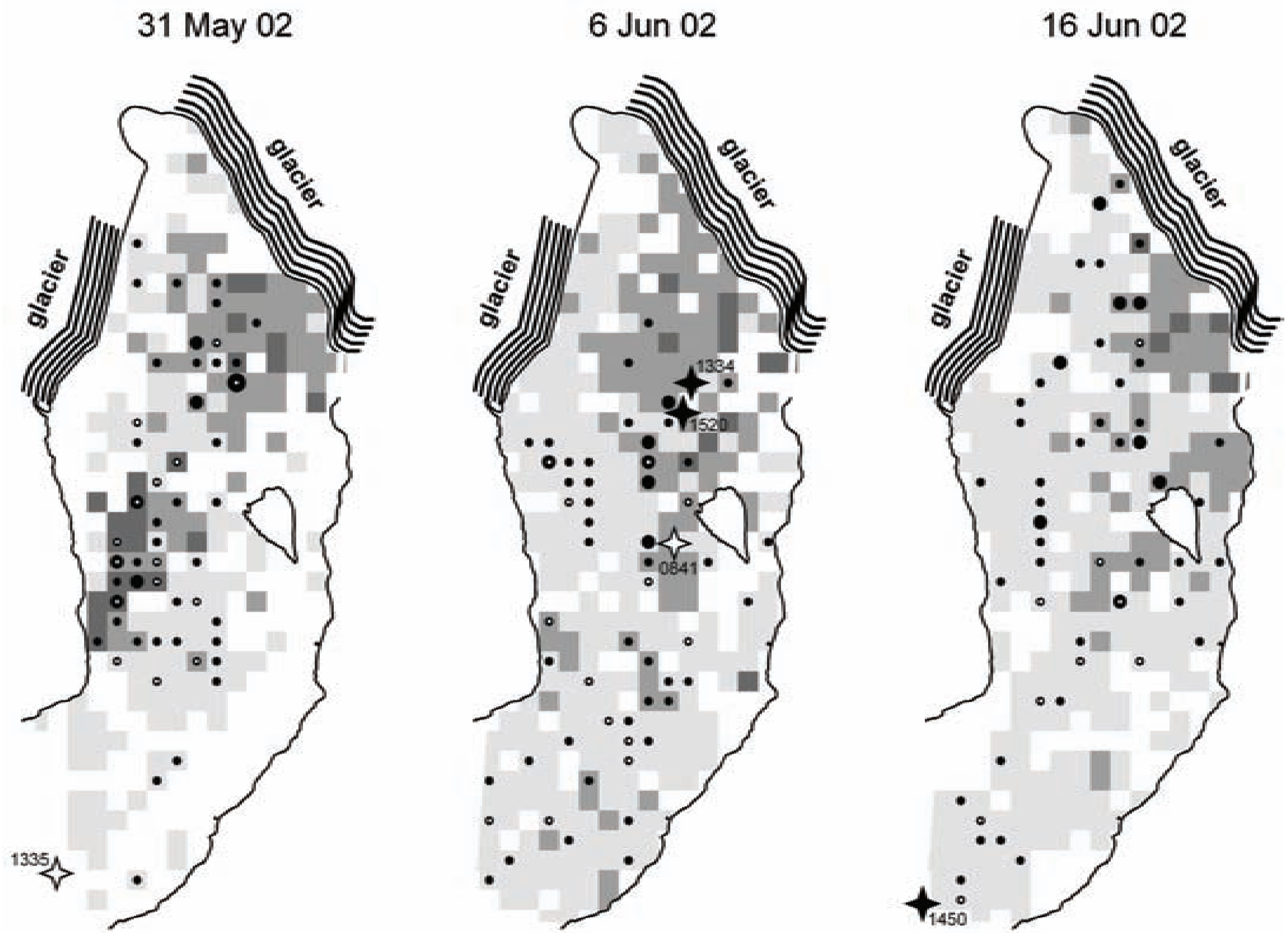


Figure 17. Spatial distribution of harbor seals, ice cover zones, and maximum penetration of cruise ships on the day of surveys (☆) and the previous day (★) for 31 May, 6 and 16 June 2002. The range of seal counts summed per grid cell is shown in three levels: small dot (< 5 seals), medium dot (5-20 seals), large dot (> 20 seals). Increasing ice cover is represented by a gradient in shading: scattered (light gray), intermediate (medium gray), dense (black). The incidence of at least one mother-pup pair within a grid cell is shown by a white dot. The time of day that ships reached their maximum penetration appears near the location symbol. For this graphic, if cells with no ice data (see Section 3.2.1) were bounded on three sides by cells with ice measures, the average of neighboring cells was used as an estimate.

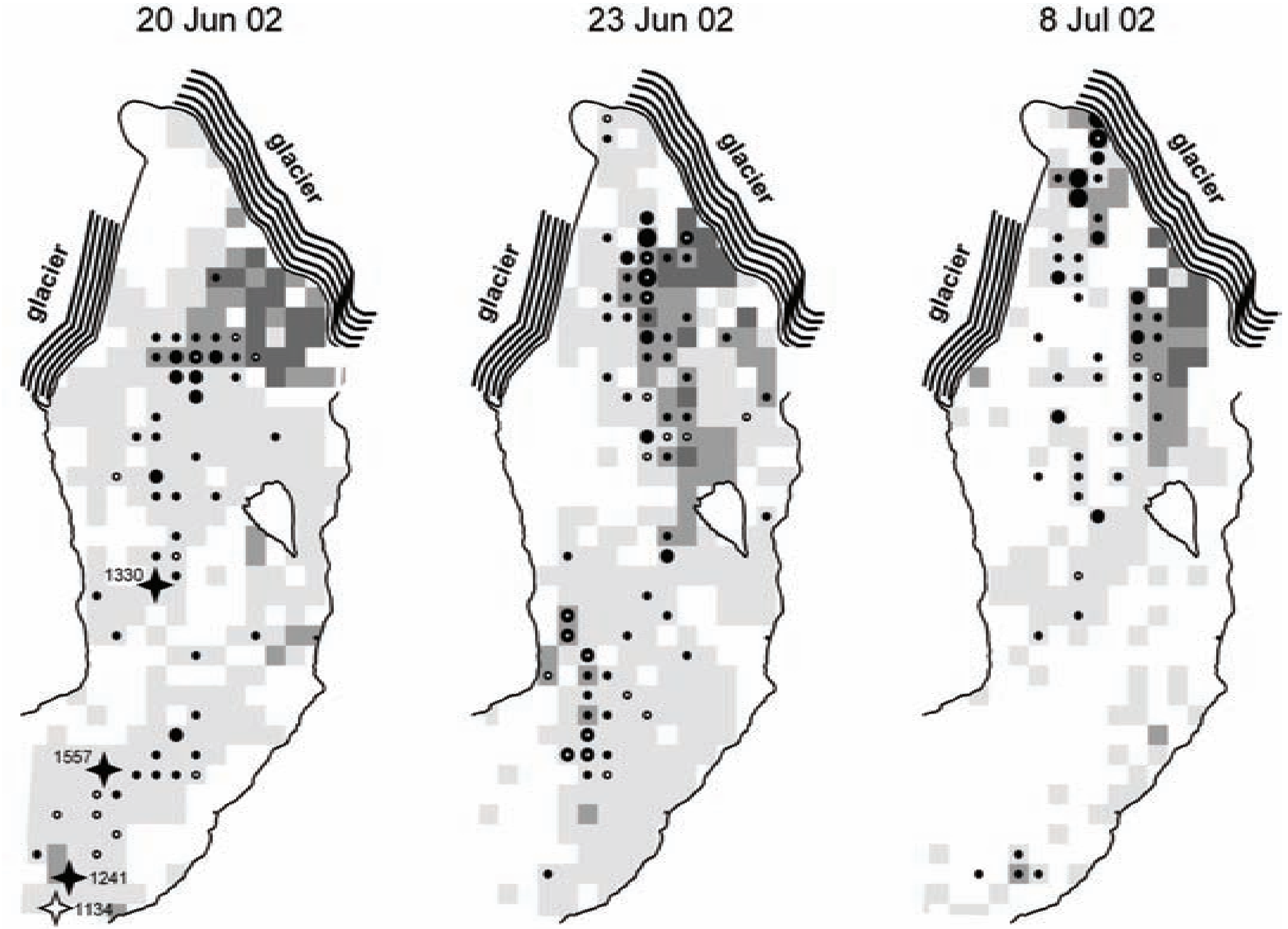


Figure 18. Spatial distribution of harbor seals, ice cover zones, and maximum penetration of cruise ships on the day of surveys (☆) and the previous day (★) for 20 and 23 June, and 8 July 2002. The range of seal counts summed per grid cell is shown in three levels: small dot (< 5 seals), medium dot (5-20 seals), large dot (> 20 seals). Increasing ice cover is represented by a gradient in shading: scattered (light gray), intermediate (medium gray), dense (black). The incidence of at least one mother-pup pair within a grid cell is shown by a white dot. The time of day that ships reached their maximum penetration appears near the location symbol. For this graphic, if cells with no ice data (see Section 3.2.1) were bounded on three sides by cells with ice measures, the average of neighboring cells was used as an estimate.

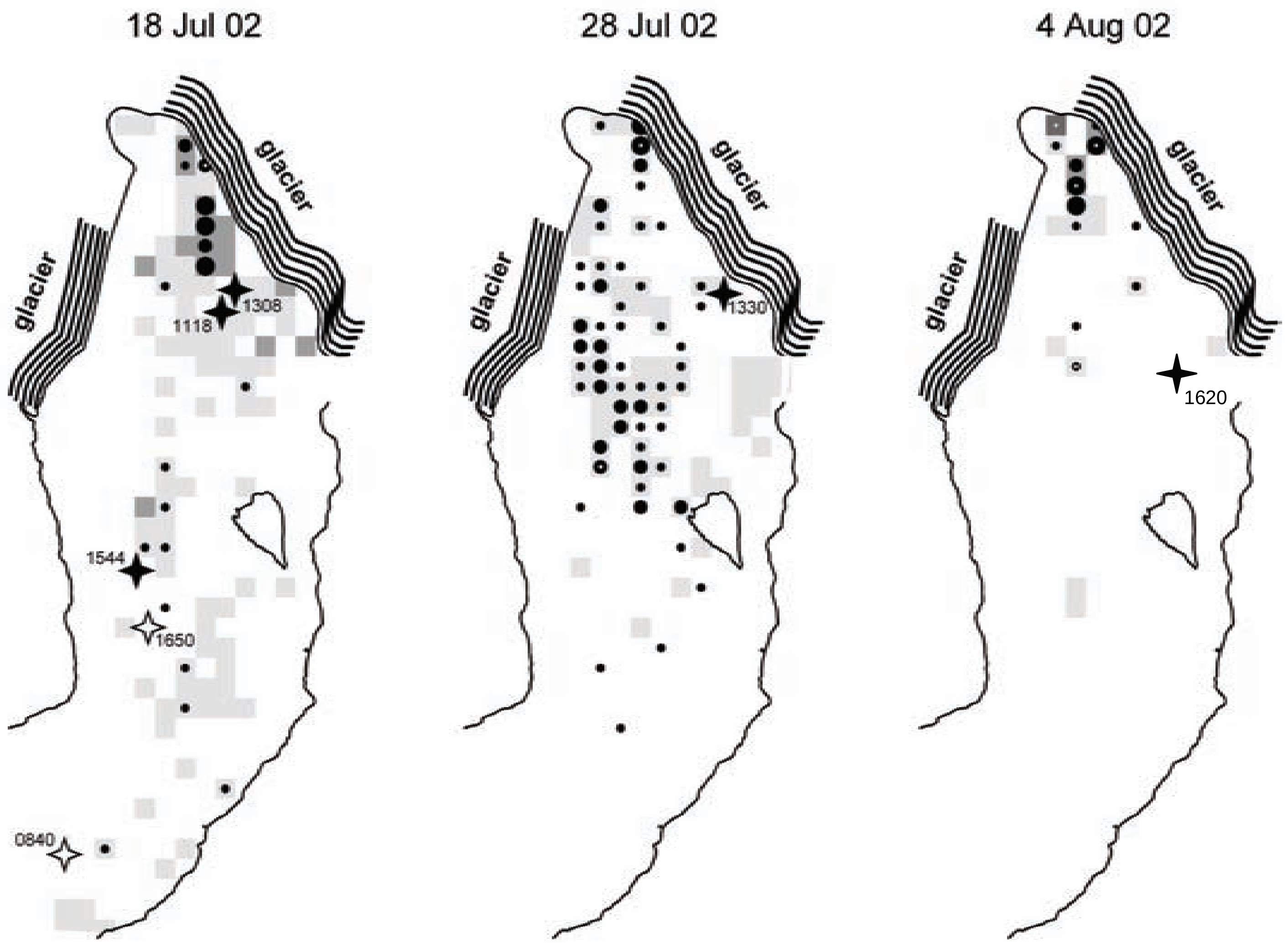


Figure 19. Spatial distribution of harbor seals, ice cover zones, and maximum penetration of cruise ships on the day of surveys (☆) and the previous day (★) for 18 and 28 July, and 4 August 2002. The range of seal counts summed per grid cell is shown in three levels: small dot (< 5 seals), medium dot (5-20 seals), large dot (> 20 seals). Increasing ice cover is represented by a gradient in shading: scattered (light gray), intermediate (medium gray), dense (black). The incidence of at least one mother-pup pair within a grid cell is shown by a white dot. The time of day that ships reached their maximum penetration appears near the location symbol. For this graphic, if cells with no ice data (see Section 3.2.1) were bounded on three sides by cells with ice measures, the average of neighboring cells was used as an estimate.

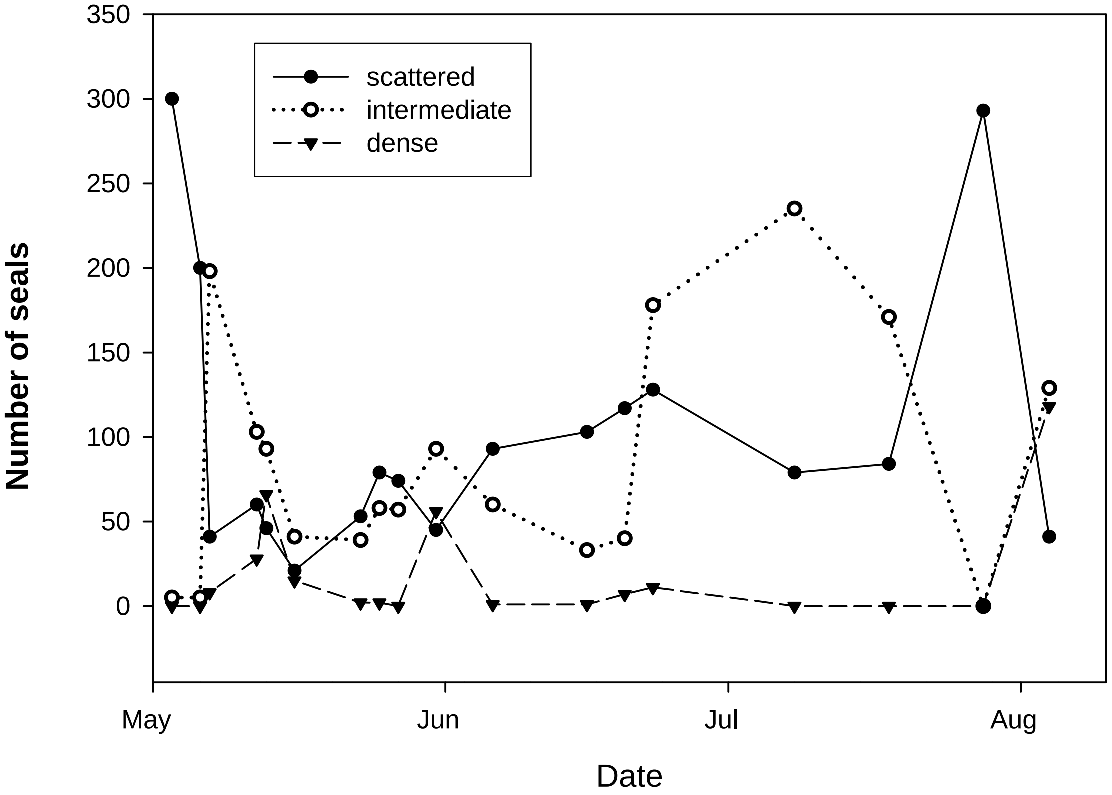


Figure 20. Numbers of harbor seals counted in video surveys within the three ice zones: scattered, intermediate, and dense (see legend), from 3 May to 4 August 2002 in Disenchantment Bay.

Overall, seals used the scattered and intermediate ice zones at similar frequencies even though the latter zone represented less than half of the proportional area of the former (Fig. 4). With the exception of two surveys, the use of areas of dense ice was markedly lower than that of scattered or intermediate ice. This suggests a non-linear relationship between seal abundance and the density of ice cover, with seals showing a preference for intermediate ice. These hypotheses were supported in statistical tests that examined ice cover as a covariate in modeling seal counts (see Section 3.2.2.3.4).

3.2.2.3.4 Space-Time Model of Seal Counts

The first stage of the space-time regression model, which examined the binary response of absence/presence (incidence) of seals in each cell of the lattice, indicated that the effect of ice cover was statistically significant and was the dominant factor explaining the spatial distribution of harbor seals ($P < 0.05$; Appendix 1). Coefficients for individual classes of ice cover were significantly greater than zero for scattered (1-3 tenths coverage) and intermediate ice (4-6 tenths), and for 7 tenths ice cover. The 95% confidence intervals for the densest ice cover (8 and 9-tenths) included zero so were not deemed significant (Appendix 1). Those coefficients that were significant gradually increased from 1 to 5-tenths ice cover, before declining (Fig. 21), indicating a slightly higher incidence of seals in intermediate versus scattered ice cover. Variation in the occurrence of denser ice cover (i.e., 8 and 9 tenths) had no significant effect on the distribution of seals. Overall, this suggests a modest preference by seals for more intermediate ice cover. Other natural variables, precipitation, wind speed, and total ICA (ice-covered area), did not have a significant effect on the distribution of seals in the lattice (Appendix 1).

The occurrence of mother-pup pairs exhibited several patterns but exceedingly small samples and large confidence intervals made inference more difficult. As with the pooled seals, mother-pup pairs showed a peak incidence associated with intermediate ice cover (6-tenths), though there was no indication of a gradually increasing preference with increasing ice cover (Fig. 21). Coefficients for 1-5 tenths, and 8-9 tenths, ice cover were not significant and were highly erratic, suggesting that either sample size was inadequate for a reliable estimate or that mothers more specifically target intermediate ice than the pooled population (Appendix 1). Other natural variables (i.e., precipitation, wind speed, and ICA) did not have a significant effect on the distribution of mothers and pups in the bay.

The effects of distance and activity of cruise ships on the incidence of harbor seals were assessed simultaneously in the same models (Appendix 1). The presence of ships on the survey day and the number of ship visits over the last 3 days did not have an effect on the overall incidence (distribution) of seals in Disenchantment Bay. The closest approach distance of ships was negatively related to the incidence of

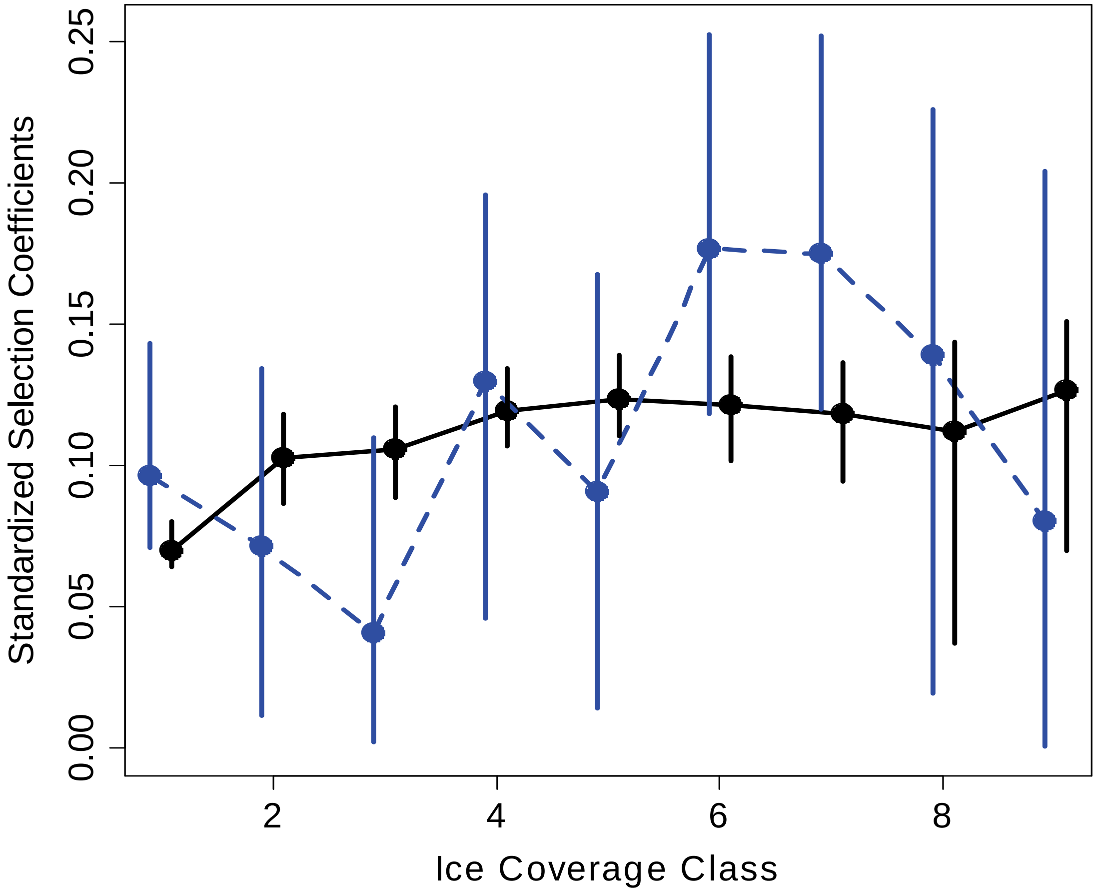


Figure 21. Standardized selection coefficient for ice cover class for the Bernoulli part of the ZIP model (i.e., for the cell-based spatial distribution of seals). The black, solid line is for all seals, and the dashed line is for mother-pup pairs (see Appendix 1)

seals, so that closer approaches were associated with higher incidence of seals. This is likely an artifact of ships using corridors that overlap closely with peak seal densities rather than seals selectively aggregating closer to ships. The lack of a positive effect (i.e., a lesser incidence of seals related to closer approaches) suggests that harbor seals were not adjusting their distribution based on the relative locations of ships within the bay. However, greater ship activity did have a significant negative effect on the incidence of harbor seals ($P < 0.05$; Appendix 1), such that there were fewer grid cells containing seals with increases in the combined time that ships spent within 1 km of a closest approach.

The incidence of mothers and pups was not related to any of the measures of ship distance or activity. As noted above, sightings of mothers and pups were relatively rare making statistical inference difficult. At present, the findings indicate that mothers and pups do not respond any differently to cruise ships compared to the pooled population.

The second stage of the space-time model, which examined the actual counts in cells where seals occurred (abundance), confirmed that the effect of ice cover was a dominant factor ($P < 0.05$; Appendix 1). Coefficients for ice-coverage classes of 3-7-tenths were statistically significant, though the greatest effect was detected in 5-7-tenths

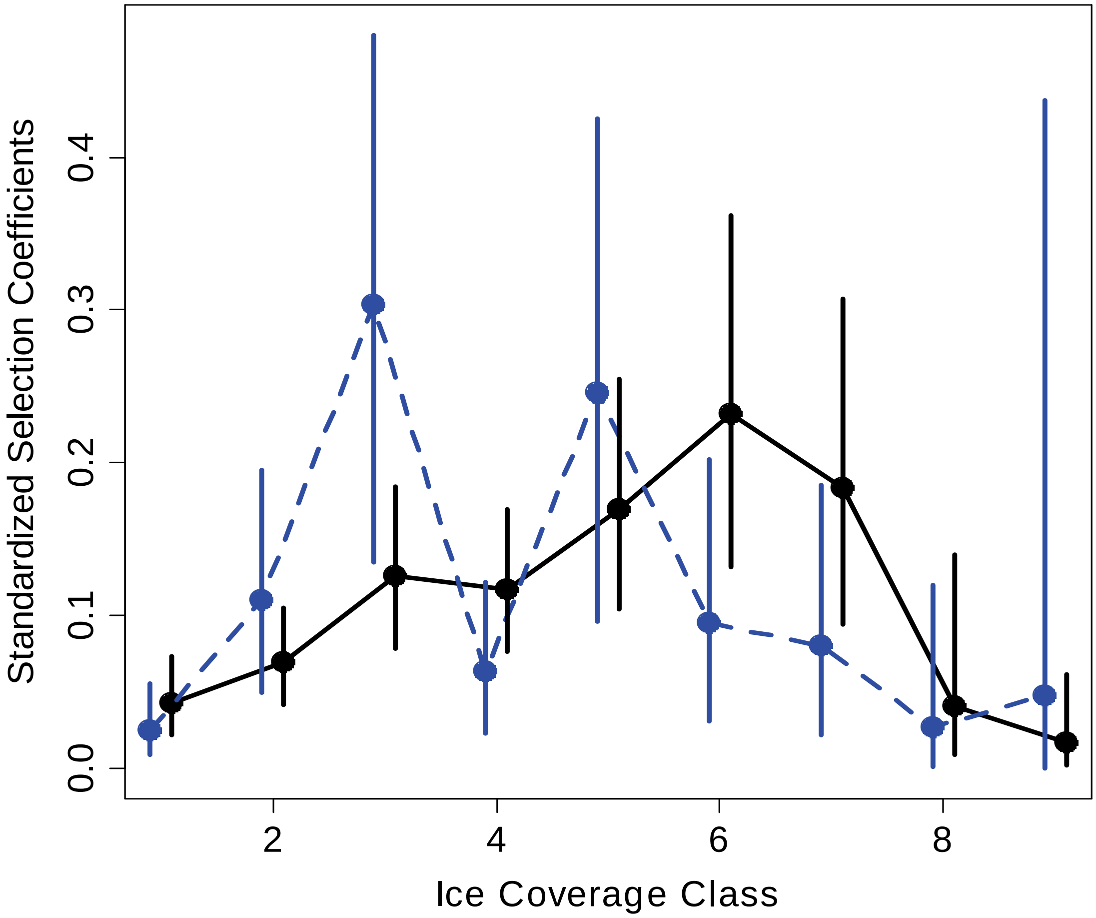


Figure 22. Standardized selection coefficient for ice cover class for the Poisson part of the ZIP model (i.e., for the cell-based abundance of seals). The black, solid line is for all seals, and the dashed line is for mother-pup pairs (see Appendix 1)

ice coverage (Fig. 22). This further supports the contention that intermediate ice cover supports the highest abundance of seals. Other natural variables (i.e., precipitation, wind speed, and ICA) did not have a detectable effect on the abundance of seals. Similar to the first stage of the regression, the ships' closest approach distance was negatively related to seal abundance, which, as noted above, was likely a function of a close proximity of ships' transit corridors to the preferred seal haul-out area. None of the other cruise ship factors, including ship activity, were related to seal abundance.

The abundance of mothers and pups was also related to ice cover ($P < 0.05$; Appendix 1), though the pattern differed slightly in comparison to their overall distribution (incidence). For example, significant coefficients occurred in the 2-6-tenths ice classes (with peak values in 3 and 5-tenths; Fig. 22). This suggests that mother-pup abundance peaked in the upper-scattered to intermediate ice despite the indication in the first stage of the model that overall mother-pup presence was centered on slightly denser ice (6-tenths). Again, higher variation in the coefficients compared to the pooled seals, and larger confidence intervals, point to the need to exercise caution when drawing conclusions regarding mother-pup sightings. The abundance of mothers and pups was not statistically related to any of the measures of ship distance or activity (Appendix 1), suggesting that their attendance in Disenchantment Bay is not affected (in the short-term) by ships – similar to the pooled population.

3.2.3 Discussion

3.2.3.1 Seasonal Patterns in Daily Abundance

The cause of the decline in seal abundance just before pupping is currently unknown. There is no indication that a profound, extended change in the weather caused seals to change their haul-out behavior (Fig. 3). Wind speed and precipitation were below levels, particularly on survey days, where harbor seals in other studies have reduced their frequency of hauling out (Hoover 1983; Boveng et al. 2003). There are also few indications that inadequate ice cover could have caused seals to leave the bay in such large proportions over a short period. Although total ice cover may have been slightly reduced in mid-May, coinciding with a local minima in seal abundance, the seasonal decline of ice cover in late June and July occurred as seal abundance reached its highest levels. At the end of surveys in early August, when seal abundance was at near-peak levels, ice cover was at the absolute minimum with nearly 10-fold less ice than mid-June. It is perhaps not surprising that ice is most available during peak pup-rearing in mid-June, and mothers are increasingly selective about finding a platform for birthing and nursing (Hoover 1983). But there is no evidence that ice availability during pup-rearing or breeding (mid-spring to mid-summer) is a constraint that regulates population size.

The first cruise ship entered Disenchantment Bay on 14 May, at a midpoint of the overall decline in seal abundance. Due to thick ice and poor visibility, this first ship stopped just north of Point LaTouche, barely within the study area and before any seals were within spotting range (*ca.* 1 km). The next ship entered the bay on 18 May, after the decline had stabilized. It is therefore unlikely that cruise ships initiated or influenced the decline observed from 13 to 16 May, even less so the earlier decline from 3 to 6 May. Assuming that the distribution of seals on 14 May, when the first ship entered the bay, was similar to that on adjacent dates (13 or 16 May), the nearest seals to the ship (of group size > 1) would have been at a distance of more than 12 km (7.5 mi; Fig. 15). Direct observations of harbor seals from cruise ships in our study – that were limited to less than 1 km – showed that seals did not enter the water with any greater frequency when ships were 600 m, or more, away. If a significant number of seals on 14 May entered the water and then abandoned the haul-out area for 2-3 weeks due to a single vessel at 12 km, then it is difficult to explain why seal abundance later in the season steadily increased when ship encounters also increased – rather dramatically, in terms of ships per day (reaching 5), number of ship-days per week (reaching 5), and deeper penetration into the bay with diminishing ice cover (Fig. 7).

Alternatively, seals could have left the bay in response to natural factors not measured in this study, such as the abundance and distribution of prey. Harbor seals are commonly seen milling in large numbers in nearby river systems during peak runs of eulachon (*Thaleichthys pacificus*), especially near the mouths of the Situk (70 km from Disenchantment Bay), Lost (70 km), Ahrnklin (80 km), Akwe (110 km), and Alsek Rivers (140 km). Steller sea lions (*Eumetopias jubatus*) aggregate in the Alsek River in large numbers (up to 1,700) in mid-March when spawning eulachon are migrating upriver (Catterson 2005). Harbor seals have been observed hauled out nearby at the same time in numbers exceeding that of the Steller sea lions (J. Capra, Dry Bay Ranger, National Park Service, Yakutat Office, pers. comm.).

In the Situk/Lost/Ahrnklin River System, one of the closest to Disenchantment Bay, the eulachon run reportedly occurs between March and mid-June (Estes 1994) with estimates as high as 500,000 fish (D. Gillikan, Fishery Biologist, U.S. Forest Service, Yakutat District, pers. comm.). A latitudinal cline in the timing of spawning, from Berners Bay in Southeast (mid-April to early May) to the Copper River near Prince William Sound (late May to early June), suggests that peak runs in the Situk Estuary would be expected in mid-May. But large runs have only been recorded from mid-March through April, when eulachon surveys end (D. Gillikan, pers. comm.). However, on 14 May 2002, when seal numbers were nearing the minimum, eulachon were reported to be staging for migration upstream in the Situk Estuary, as indicated by large feeding flocks of seabirds (D. Russell, pilot, Yakutat Coastal Airways, pers. comm.). The size of the run was unknown. Earlier that spring on the Situk River, during the normal peak in eulachon spawning, unusually low numbers of fish were observed (D. Gillikan, pers. comm.). A delay in the peak migration outside the sampling period (i.e., in May) could explain these observations.

Eulachon have been observed within the mouths of all rivers along the Yakutat Forelands, yet the variable timing, pulsed nature, and size of runs have not been systematically examined. Current eulachon surveys, though informative, are focused in the early spring, vary with personnel availability, and are not standardized. The occurrence of eulachon runs in May and June, though supported by local knowledge, has not been rigorously documented. Exploitation of these local eulachon runs by harbor seals can be inferred from anecdotal observations of seals milling in the river mouths, but the overall significance of eulachon to the energy budget of seals inhabiting Disenchantment Bay is unknown. Though not as concentrated and predictable in space as eulachon, other potential prey occur in the area during May: Pacific herring (*Clupea pallasi*) are spawning in Yakutat Bay, Chinook salmon (*Oncorhynchus tshawytscha*) are migrating southward along the coast, and steelhead (*Oncorhynchus mykiss*)are spawning in the Situk River.

The reduced abundance of seals in Disenchantment Bay at the onset of pupping is similar to that observed in Aialik Bay, another Alaskan tidewater glacial fjord. Hoover (1983) conducted the first seasonal counts of seals in Aialik Bay near an apparent minimum in mid-May, similar to Disenchantment Bay. Seal numbers then steadily increased until peak pupping in mid-June. But, in contrast to our study, counts declined through July to levels comparable to mid-May, and then rebounded by early August. Seal numbers at Disenchantment Bay seem to be stable from late-June to early August with only a brief decline in mid-July. In Aialik, the steady rise in abundance during pupping coincided with a pronounced decline in the estimated number of juveniles. This apparent exodus of younger animals was more than offset by an influx of adults causing a peak in overall abundance which coincided with the peak number of pups (Hoover 1983), similar to Disenchantment Bay. A similar departure of juveniles occurred in Tracy Arm Fjord where radio-tagged seals (N = seven juveniles and two adults) left at the onset of pupping (Jansen et al. 2001). The higher resolution imagery collected in 2004 and 2005 will allow examining for potential shifts in population structure in Disenchantment Bay (see Appendix 2).

Despite some similarities in timing, there are apparent differences between Disenchantment Bay and other pupping sites in terms of productivity. At peak pupping in Disenchantment Bay, the proportion of pups relative to the total abundance was 10%, a figure less than half that observed at other glacial haulouts (Aialik Bay: 26% [1980]; John Hopkins Inlet: 25-31% [1975-78], 34-36% [1994-1999]; Muir Inlet: 22-30% [1975-78] and terrestrial haul outs (Tugidak Island: 23% [1976], 27% [1996](Streveler 1979; Hoover 1983; Jemison and Kelly 2001; Mathews and Pendleton 2006). Hypotheses that may explain a lower proportion of females with pups include lower rates of conception (e.g., via disruption of breeding), fewer females implanting and carrying pups to term (e.g., via physiological stress), or a population structure skewed toward other sex and age groups compared to other sites (e.g., via emigration of females or immigration of juveniles).

Though the video imagery in this study was not ideal for distinguishing pups, we believe it unlikely that a negative bias in identifying pups could have caused productivity estimates so dramatically reduced compared to other sites. Based on findings here and at Glacier Bay (Mathews and Pendleton 2006), it is also unlikely there was enough diel variation in mother-pup pairs hauling out – compared to the rest of the population – to bias significantly our estimates of relative productivity. Still, this uncertainty will be addressed further through analyses of the improved imagery collected in 2004 and 2005. The enhanced resolution will aid in determining whether pup productivity in Disenchantment Bay is unusually low, particularly in comparison to nearby Icy Bay.

3.2.3.2 Cell-based Seal Counts in Relation to Environmental Covariates

It was not surprising that ice cover was a key factor affecting seal abundance and distribution because the ability of seals to haul out in these areas, and indeed the haul-out area itself, is defined by ice cover. It is interesting, however, that seals tended to haul out, and in highest abundance, in areas of more intermediate rather than denser ice coverage. This pattern could have resulted from several scenarios: 1) seals may have first hauled out on denser ice which may have then dispersed southward, later being characterized as less dense during our mid-afternoon surveys; 2) harbor seals may prefer some minimum open water to provide greater ease in breathing, swimming at the surface, or “spy-hopping” to find aggregations of animals; and 3) the densest ice may be less desirable because it most often occurs in the northernmost area of the bay (i.e., more distant), very often in close proximity to the calving Hubbard Glacier (i.e., more hazardous).

It was also not surprising that the meteorological measures (i.e., rain and wind) had no measurable effect on seal presence or abundance, particularly since the aerial surveys were constrained by weather. In modeling these covariates, we examined the more immediate effects of weather on the seals’ propensity to haul out (e.g., 6 hours prior to a survey). Though beyond the scope of this study, large-scale weather patterns, such as those associated with the migration of entire weather systems (e.g., atmospheric pressure cells), could influence decisions by seals regarding whether to travel, forage or rest. Hoover (1983) suggested that harbor seals on ice in Aialik Bay avoided hauling out from the day before to the day after a storm. Still, from early May to early August 2002, significant weather events in the greater Yakutat area were few and overall conditions were generally mild. Maximum wind gusts were usually less than 10 knots and exceeded 15 knots on only 3 days (including one survey day). Wind speed never approached levels shown to affect seal haul-out behavior (> 20-25 knots; Hoover 1983; Boveng et al. 2003). Though precipitation has also been suggested to reduce the propensity of seals to haul out (Pauli and Terhune 1987; Olesiuk et al. 1990; Boveng et al. 2003), rain during the study was minimal with most survey days seeing no rain and only a few seeing trace amounts. There were two rain events, however, which shortly preceded surveys and could have influenced seal abundance: 1) on 15 May, during the 36 hours preceding the latter phase of the decline in seal abundance it rained about an inch, but the initial phase of the decline occurred between 3 and 6 May when there was no measurable rain (Figs. 3 and 13); and 2) from 23 to 25 July, it rained more than 3 inches but our next survey 3 days later (28 July) showed that abundance had increased.

It should be noted that the precipitation data used in this study (from the Yakutat Airport near the coast) may have overestimated the conditions in the study area. Disenchantment Bay, being a deep glacial fjord, is afforded some protection from inclement weather by the St. Elias Range (3,000-5,500 m) due to blocking and upslope flow (Papineau 2000). This causes the majority of precipitation to fall along the Yakutat Forelands closer to the outer coast. Prevailing coastal winds also appear to be moderated in Disenchantment Bay: for the days that the weather station on Egg (Haenke) Island was operational, maximum gusts exceeding 15 knots occurred on 7% of the days compared to 47% of the days reported at the Yakutat airport (NOAA-NCDC 2002). Moreover, wind gusts never exceeded 20 knots in Disenchantment Bay though such winds were recorded on several days at the airport, at times exceeding 25 knots.

The finding that higher incidence and abundance of harbor seals occurred in close proximity to ship corridors seemingly conflicts with the shipboard observations of seal disturbance. These results from the aerial surveys suggested that areas closer to ships were more regularly occupied by seals (and higher numbers of seals) than those more distant from ships. Ships generally favored the middle of the bay, as ice cover permitted, and would often navigate through open water or scattered ice that was immediately adjacent to denser ice (i.e., along an ice edge). If this were a regular occurrence, it would tend to put ships in close proximity to areas of denser ice favored by harbor seals and may explain the increasing seal density at decreasing distances to ship corridors. Moreover, it is worth noting that these surveys were designed, and the covariates measured, to examine seal responses at a larger spatio-temporal scale than the shipboard observations. Thus, the resulting seal and covariate measures were intended to test the responses of seals across multiple ship visits and days rather than those triggered by one cruise ship on one day. For example, a total of seven surveys were conducted on days when ships were present, or *had been* present earlier that day, or the previous day. So, the statistical model tested whether harbor seals *integrated* information to decide whether to haul out in an area close to where cruise ships had traveled previously. Testing the "real-time" reactions of seals to ships within the short time frame of a cruise ship visit, and over the whole of the bay, would require more intensive transect sampling on days when cruise ships were present. The studies in 2004 and 2005 were designed to address these shorter-term responses (see Appendix 2). Based on the current analysis, we conclude that harbor seals were not actively avoiding the general areas where cruise ships traveled in Disenchantment Bay, nor were they distributed at greater distances from these general areas when cruise ships were present. Possible avoidance of ship corridors across years (e.g., a long-term habituation) was not measured in this study.

As with approach distance, the potential effect on seal abundance of the number of ships visiting over the preceding 3-day period was expected to integrate any disturbance seals were experiencing across multiple days. The 3-day periods roughly corresponded to the weekly pulses (Tuesday-Thursday) and lulls (Friday-Monday) in ship visits. Our findings showed that the number of vessels that ventured inside the bay was not a predictor of the cell counts of seals (i.e., abundance). This is supported by seasonal patterns in the total relative abundance of seals which were not clearly linked to the onset of, or to increases in, ship traffic. These were most likely driven by either life-history constraints or other more local environmental factors, such as prey availability (see Section 3.2.3.1).

In conjunction with these findings, the negative effect of ship activity on seal distribution suggests that the area occupied by seals decreased with increases in the time ships spent at the closest approach, irrespective of distance. This apparent response did not include a concomitant decrease in abundance. That is, the expected numbers of seals simply occupied less area with increased ship presence in the bay. We conclude that seals were aggregating more closely in response to ship presence. A similar response has been observed in bottlenose and Hector's dolphins, which form tighter aggregations in the presence of boats (Bejder et al. 1999; Buckstaff 2004). The formation of denser aggregations with increased ship presence was probably the result of disturbances of seals both in the path of moving vessels (e.g., within 500 m), and of seals at greater distances that may be more sensitive (e.g., more isolated solitary animals or smaller groups). That we did not see a negative effect of ship distance on seal distribution supports the conclusion that the aggregation effect was experienced by seals regardless of proximity to ships (i.e., seals were responding to ships at distances on the scale of kilometers). It is unknown if increased seal densities occurred: 1) when seals were first deciding when and where to haul out (assuming a ship was already present); 2) when seals were approached directly by ships and relocated; or 3) at some point later, as individual-seal thresholds for ship presence were gradually reached and seals entered the water to relocate. Whatever the case, such responses could result in greater time submerged – either initially finding a desirable area or re-entering the water later to do so – and higher energy expenditures compared to undisturbed seals hauling out in areas where, or on days when, ships are absent. The potential consequences to survival of increased time in the water are discussed in Section 3.1.3.

3.3 Large Scale: Monthly Aerial Photographs of Regional Seal Distribution and Total Abundance at Disenchantment and Icy Bays

3.3.1 Methods

Disenchantment and Icy Bays were surveyed using large-format (9 in × 9 in) vertical aerial photography four times at approximately monthly intervals during the study (Fig. 2). The photogrammetric surveys (AeroMap, Inc., Anchorage, AK) were designed to provide complete coverage of the ice-filled regions of each bay, with 20% endlap and 40% sidelap between neighboring photographs. The surveys were flown at 3000 ft, providing photographs at 1:6000 scale. The surveys were initiated at 1100-1600 h (ADT); the duration of surveys in Disenchantment and Icy Bays was 1-2 hours and 2.5-3 hours, respectively. A total of eight large-scale photographic surveys producing 1,267 images was flown. Photographic negatives from the large-format photographic surveys were scanned at high resolution (1600 dpi), and harbor seals in the resulting digital images were counted using image-processing software (ERDAS Imagine, Version 8.7, Leica Geosystems LLC, Norcross, GA. USA). These counts should be regarded as minimum abundance estimates because a correction factor (to account for the animals that were in the water and not counted) was not applied. These aerial surveys required better conditions than the medium-scale surveys (i.e., a 3000 ft ceiling and good visibility), so it seems unlikely that the minimal variation in weather conditions across days would have led to any differences in the propensity of the seals to haul out.

Cruise ships visited Disenchantment Bay on the day of a survey only during August: there were three visits by cruise ships on 14 August and a total of eight over the previous 3 days. In Icy Bay, cruise ships were not observed during any survey and reportedly only rarely visit the area. Kayakers are fairly common during the summer months, with up to fifty groups estimated in 1995 (Kozie et al. 1996).

3.3.2 Results

3.3.2.1 Potential Sources of Error in High-Altitude Photogrammetry

Aerial surveys provide the only tractable means of observing an entire ice haul-out area in the largest of glacial fjords. Even in smaller fjords, where seals are observable from shore, an aerial perspective is important to eliminate obscuring of seals by ice and land and reduced sightability with distance. Images also provide a permanent record that allow for detailed analyses of distribution in relation to environmental factors. Still, there were potential errors related to identifying and counting seals in high-altitude images that were unavoidable.

The quality of the imagery taken at 3,000 ft varied with atmospheric conditions (e.g., haze reduced contrast) and lighting (e.g., low solar angle produced shadows). Low contrast and shadows in images increased the misidentification of seals, particularly when dirty ice was present. Even under optimal conditions, seals in images appeared as dark shapes on a light background, lacking finer detail and usually color. Thus, the definition of a seal was based largely on shape which did not always set it apart from similar-looking shadows or patches of substrate on the ice. Because identification was partly subjective, what defined a seal varied between observers, and within observers as they gained experience. For example, observers with experience tended to be more conservative in declaring a seal. Future work will include quantifying these biases and correcting for them.

Another potential bias was related to the sequence and timing of images. Because several transects were required, and each took up to 15 minutes to complete, the ice field – which was constantly shifting – differed in overlapping areas of images from adjacent transects. So, it was not possible to create an accurate mosaic of the entire area as the *seams* between transects did not match. Thus, from one transect to the next, we expected that seals would sometimes move from photographed to soon-to-be photographed areas (seals would be counted twice), and vice versa (seals would be missed). Observers attempted to match up ice floes with seals that occurred in both overlap zones of two adjoining images to reduce under- or over-counting.

In the end, biases related to image quality were likely both positive (dirty ice and shadows were mistaken for seals) and negative (seals were mistaken for dirty ice and shadows). Similarly, if ice moved randomly across transects, the biases related to the timing of images would be both positive and negative. In 2005, the medium- and large-scale photogrammetry surveys were flown simultaneously on 3 days to compare seal sightings in order to estimate these biases. Pending that analysis, we assumed that the positive and negative biases discussed above were balanced. Still, it appears that these counts provide the best available estimate of seal abundance in the large, shifting ice fields that characterize tidewater glacial fjords.

3.3.2.2 Seal Counts from Photogrammetry

Table 1 lists the estimated number of harbor seals at both Disenchantment and Icy Bays for the eight high-altitude surveys flown in 2002. Overall, seal counts for Icy Bay were higher than those for Disenchantment Bay, with the exception of during early pup-rearing when seal abundance in Disenchantment Bay was about 50% greater than that at Icy Bay. This difference diminished by mid-pupping (June) when Disenchantment Bay had 18% fewer seals than Icy Bay. From early to mid-pupping, Disenchantment Bay increased 39% and Icy Bay counts more than doubled. From mid-pupping on, the two sites had divergent trends: counts at Icy Bay increased, whereas those at Disenchantment Bay decreased. By the pup-weaning period (July), Disenchantment Bay had 43% fewer seals than Icy Bay and 67% fewer by molting (August). During the entire study, from early May to mid-August, abundance estimates at Icy Bay increased more than 400% (100% from mid-pupping) compared to 15% at Disenchantment Bay.

It should be noted that the extraordinarily low count in May at Icy Bay could have been influenced by limiting the survey to northern areas of the bay closest to Guyot Glacier. Due to flight constraints, areas of scattered ice south of Kichyatt Point were not surveyed (Fig. 2). Though not apparent at the time of the survey, the areas closest to the glacier were then dominated by fast ice and thus less accessible to seals. For example, in May, images showed that ice cover that appeared virtually solid extended 3.3 km (1.8 nm) south from Guyot Glacier (Fig. 2) and the first scattered, small groups of harbor seals were observed at about 2 km (1.1 nm) from the face. This

Table 1. Summary of harbor seal counts (uncorrected) from the high-altitude photogrammetry in 2002. Dates and start times are presented for each survey for Disenchantment (Dbay) and Icy Bay (Icy). The minimum abundance estimates marked with an asterisk may be negatively biased: at Icy Bay in May, there was lesser coverage of scattered to intermediate ice zones; at Disenchantment Bay in August, the survey was conducted late in the day when fewer seals may have been hauled out. The mean of counts (by site) and coefficients of variation (CV) are shown.

Date (Dbay/Icy)	Seal Phenology (Dbay)	Time (ADT) (Dbay/Icy)	Counts	
			Dbay	Icy
2/4 May	Early Pupping	1208/1357	1,544	1,011*
7 June	Mid-pupping	1152/1407	2,149	2,543
7 July	Weaning/Breeding	1147/1436	1,786	3,566
14/15 August	Molting	1557/1318	1,778*	5,435
		Mean	1,814	3,142
		CV	0.14	0.59

contrasts conditions in August when seals were within 0.6 km (0.3 nm) of the glacier in areas of scattered ice. For the one survey in May, it is unknown how many seals may have been missed in areas we were unable to survey. The few reconnaissance flights conducted south of Kichyatt Point when significant ice was present (in 2004) estimated between less than 100 to 300 seals. It is interesting to note that fast ice apparently does not form in Disenchantment Bay in the winter – when calving is at a minimum – nor has it been noted in regard to other tidewater glacial haulouts for Alaska harbor seals.

The seal count in August at Disenchantment Bay may also have been biased low as that survey took place later in the day (1557 h ADT) than in previous surveys (~1200 h ADT). As noted above, patterns at other glacial sites (see Fig. 6) suggest that haul-out frequency peaks in the early afternoon and starts declining some time after 1600 to 1700 h (ADT). Based on this pattern, at most 15% of the seals may have entered the water during the 1.2 hour survey, bringing the potential count for 14 August up to 2,134 seals.

3.3.3 Discussion

These findings suggest differences in the seasonal use of the two glacial sites, and/or in the annual timing of life-history events, such as pup rearing and molting. The comparatively low count at Icy Bay in early pupping (May) could be attributed to a survey bias, as detailed above, or to an actual reduction in the number of seals using the bay in the early pupping stages, such as observed in Disenchantment Bay. If the latter, the early May survey of Icy Bay might have occurred just after the decline rather than before as in Disenchantment Bay; Icy Bay was surveyed 2 days after Disenchantment Bay. If a survey had been flown in late April, seal counts might have been considerably higher, as they were in Disenchantment Bay before its decline. In this case, these seemingly large differences in abundance – by comparing the use of the haul outs at one point in time – may have resulted simply from differences in the timing of seal movements in response to various factors. If seals were migrating in response to localized conditions, like prey availability, the timing of distributional shifts between feeding and haul-out areas would likely differ, perhaps even significantly, between Icy and Disenchantment Bays. Such variation in seal movements across relatively small scales would be consistent with the variable location, timing, and magnitude of prey aggregations reported for the Yakutat Forelands (see section 3.2.3.1).

Alternatively, if seals were migrating largely to accommodate life-history constraints, such as a synchronization of male and female movements during breeding, one might expect less variation in the timing of movements when comparing these nearby glacial fjords. For example, reproductive synchronization in wild and captive female harbor seals has been shown to be affected by the photoperiod just prior to blastocyst implantation (Temte 1994). Females at a given location (i.e., latitude), provided they are in adequate condition, are likely to begin gestation at about the same time (± 2-3 weeks) and thus parturition will be similarly synchronized. This explains the latitudinal gradient in the timing of pupping observed along the West Coast of North America, from Mexico (mid-March; 30° N) to Washington State, U.S.A. (late May/early June on the outer coast; 48° N; Newby 1973; Johnson and Jeffries 1977; Temte et al. 1991). However, because pupping at Disenchantment Bay (60° N) occurs at about the same time as the outer coast of Washington State, local or regional factors must at times mediate intrinsic factors, as proposed by Temte (1994). In Washington State, harbor seals located in the shelter of Puget Sound initiate pup rearing at least a month later than those on the outer coast (Bigg 1969; Newby 1973; Calambokidis et al. 1978). In the Gulf of Alaska, the timing of peak pup rearing, from Glacier Bay to the Alaska Peninsula, is consistently around late May to mid-June (Bishop 1967; Burns 1970; Pitcher 1975; Pitcher and Calkins 1979; Streveler 1979; Hoover 1983; this study). Across multiple years at a single site, the peak of pupping has also been shown to vary within about a two-week period (Tugidak Island, Alaska [56° N]; Jemison and Kelly 2001).

Therefore, based on the similar environments and photoperiods, and close proximity of Icy and Disenchantment Bays, we would not expect large differences in the peak timing of parturition between sites, and therefore in the seasonal use of floating ice by pregnant females. Attendance of adult males at glacial sites is also anchored seasonally because females enter estrous a few days after weaning pups (Bigg and Fisher 1974). Juvenile seals, however, do not participate directly in pup-rearing or breeding and are thus not expected to have the same constraints. So, younger seals are likely to be more flexible in responding to variations in local conditions, such as prey availability and human disturbance. Moreover, juveniles may compose at least a third to half of the seals present on the ice when averaged over the entire period from May to August (Aialik Bay; Hoover 1983). We thus hypothesize that even modest variation in the attendance patterns of juvenile seals alone could cause large differences when comparing seal abundance between neighboring areas. More specifically, we suspect that it was differences in the timing of juvenile seal movements between Icy and Disenchantment Bays that caused the contrasting counts during early pupping. Such movements, as noted above (see Section 3.2.3.1), are consistent with observed fluctuations in the number of juvenile seals present from May to August in Aialik Bay (Hoover 1983). The medium-scale surveys conducted at both sites in 2004 and 2005 during pupping and molting will likely shed light on these hypotheses.

The abundance of hauled out Alaska harbor seals is believed to peak during pup-rearing and molting (Glacier Bay: Calambokidis et al. 1987; Tugidak Island: Jemison and Kelly 2001). In our study, Disenchantment Bay showed a modestly elevated seal count during pup-rearing – but not during molting – and Icy Bay exhibited a pronounced peak during molting – but not during pup-rearing. It should be noted that the monthly resolution of our surveys may have missed finer-scale patterns. Still, the extraordinary increase from May to August at Icy Bay – to more than twice the level observed during pup-rearing – suggests an influx of animals from outlying areas. It may be that Icy Bay serves as a molting site for seals over a broader area though nearby haul outs are scarce due to the exposed coastline southeast to Yakutat Bay (115 km) and west to Seal River/Bering Glacier (120 km) and Kayak Island (160 km). It could also be that a significant segment of the local population at Icy Bay, possibly juveniles, hauls out less frequently or at less predictable times most of the year except during the annual molt.

It is interesting that counts at nearby Disenchantment Bay did not show a similar (pronounced) peak in August (e.g., seal numbers appeared unchanged from July and may have dropped slightly from June). As noted above, the diel timing of the survey on 14 August was delayed compared to earlier surveys but this possible bias alone cannot account for the striking contrast with the peak during molting at Icy Bay. It is worth noting that ice coverage in Disenchantment Bay on 14 August reflected an increase since the minimum had been reached for the medium-scale surveys on 4 August (< 5% of the maximum ICA) and seals were confined to the northernmost part of the bay (Fig. 19). On 14 August, seals were on large patches of denser ice (> 1 km^2) that were distributed as far south as Egg (Haenke) Island. It therefore appears unlikely that ice cover was a factor limiting the abundance of seals during this mid-August survey.

Though the findings at the medium scale indicate that seals do not abandon the haul-out area as a shorter-term response (1-3 days) to the number, proximity, or visit duration of cruise ships, the data collected here cannot address directly a possible avoidance of ships by seals over longer temporal scales. For example, if seals were incurring a direct, constant, even small, energetic cost due to cruise ship disturbance, they may decide over the course of months to years to emigrate to a different area, or adjust their seasonal use patterns to include new areas. Due to a suite of factors, disturbance perhaps among them, some sites may be more suitable for molting, whereas others may be better for pup-rearing or breeding.

4.0 Conclusions

Our results show that harbor seals are sensitive to cruise ships that approach within 500 m – to which they respond by abandoning ice floes – and to the amount of time cruise ships are present in the bay – to which they respond by forming denser aggregations with increasing ship presence. It does not appear that seals change their use of the haul-out area within a season in relation to the movement corridors of cruise ships, or limit their attendance in the bay due to seasonal and weekly patterns of cruise ship visits. Further analyses on the 2004 and 2005 data will be used to confirm these relationships, and test within-day, larger-scale responses to ships.

The comparison with Icy Bay, which had no known visits by cruise ships, points to some differences that deserve further attention. Both the declining abundance at Disenchantment Bay from pupping to molting, and the opposite trend at Icy Bay over the same period, were unexpected. The resulting three-fold difference in abundance between sites during molting highlights the general pattern that Icy Bay attracts many more seals than Disenchantment Bay throughout late spring and summer. More standardized comparisons – which would include environmental measures, such as habitat availability – will be made using data from the 2004 and 2005 field seasons. Nevertheless, a possible movement of seals from Disenchantment Bay to Icy Bay prior to molting should be examined in relation to natural and anthropogenic covariates. It is also notable that pup productivity in Disenchantment Bay appears to be low when compared to other glacial and terrestrial sites. Here again, more detailed comparisons with Icy Bay using data from 2004 and 2005 will shed more light on differences in productivity between the neighboring glacial sites.

Our findings that harbor seal occurrence and behavior in Disenchantment Bay are modified in the presence of cruise ships point to certain demographic mechanisms that could lead to a decline in seal abundance, as has been a concern of the Yakutat Tlingit Tribe and was the impetus for this study. Such mechanisms include: 1) reduced natality due to avoidance of the area by females, disruption of breeding, or poor female condition during implantation or gestation; 2) shifts in the seasonal-use patterns of harbor seals in the greater Yakutat/Icy/Dry Bay Area; 3) emigration of adult males or juveniles due to cumulative disturbance; and 4) reduced survival of seals, especially younger animals, due to altered haul-out behavior and energy balance. Some of these hypotheses will be addressed through analyses of existing data (i.e., for 2004 and 2005) but comprehensive hypothesis testing will require additional data collection, particularly on haul-out behavior and seasonal habitat use of a sample of tagged individuals.

It is also possible that the population decline perceived by some in the Yakutat Tlingit Tribe could have resulted, at least in part, from a reduction in availability of seals to hunters without an actual drop in seal abundance. A shift toward tighter aggregations in response to ships, especially where small groups and individuals at the periphery move inward, could effectively reduce the availability (i.e., perceived abundance) of harbor seals to subsistence hunters. If seals show a pattern of clustering within, or shifting toward, denser ice as a short- or long-term response to cruise ships, we would expect fewer encounters with Native hunters who have to push through the ice in small boats. Seal harvesting in 1992 to 1994 in Disenchantment Bay reportedly occurred predominantly south of Turner Glacier where ice is less dense than north between the two glaciers (Davis 1999). Continued monitoring of abundance will be helpful in determining whether an actual population decline is currently underway.

Our focus has been to document the more proximate effects of cruise ships (e.g., avoidance reactions within a season) while establishing baseline seal abundance for monitoring trends. Gaining these perspectives is a critical first step to formulating timely management strategies and testable hypotheses for longer-term studies of the ultimate impacts of disturbance (e.g., shifts in demography across years). Future study of the possible causes of a population decline in Disenchantment Bay should include other environmental stressors, such as variation in prey availability and subsistence hunting.

Combined with the TEK of the Yakutat Tlingit Tribe, this study sought to characterize the harbor seals in Ateix' (Disenchantment Bay) and their range of interactions with the environment, in particular with cruise ships. The study design was improved by considering the Tlingit Tribe's knowledge and rich history regarding the harbor seal population that has been part of the local culture for probably more than a thousand years. The future conservation of these harbor seals relies on what the Tlingit refer to as "Haa Kusteeyi" (our way of life), which is to say that respect for and wise use of the resources in Ateix' will ensure that future generations will have the same opportunities.

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Appendices

Appendix 1. Details of the Space-Time Model

A1.1 Zero-Inflated Poisson Regression Model

Let the data be denoted $y_{ij} = 0,1,2,\ldots$, for the observation at the *j*th location at the *i*th time period. We will assume that the observed data follow a zero-inflated Poisson regression model,

$$y_{ij} \mid x_{ij} \sim \begin{cases} 0 & \text{if } x_{ij} = 0 \\ \mathrm{Poi}(\lambda_{ij}) & \text{if } x_{ij} = 1 \end{cases}$$

$$x_{ij} \sim \mathrm{Bin}(1, p_{ij}) \, ,$$

where $\mathrm{Poi}(\bullet)$ is a Poisson distribution, $\mathrm{Bin}(1,\bullet)$ is a Bernoulli distribution, and

$$\mathrm{logit}(p_{ij}) = \mu_i + \mathbf{s}'_{ij}\boldsymbol{\alpha} + \delta_{ij} \, ,$$

$$\log(\lambda_{ij}) = \nu_i + \mathbf{s}'_{ij}\boldsymbol{\beta} + \varepsilon_{ij} \, .$$

A1.1.1 Spatial Effects

There were three covariates that varied spatially within a given time period; ice cover type, distance to ship, and ship activity. The values for these three covariates were contained in the vector $\mathbf{s}'_{ij}$ for the *j*th location in the *i*th time period, and we allowed a separate mean response for the Bernoulli distribution (p_{ij}) and the Poisson distribution (λ_{ij}). We denoted $\boldsymbol{\alpha}$ as a vector of parameters for the Bernoulli distribution, and $\boldsymbol{\beta}$ as a vector of parameters for the Poisson distribution.

A1.2 Spatial Conditional Autoregressive Model

We also allowed for spatially-autocorrelated random effects for each mean response. Let $\boldsymbol{\delta}_i$ be a set of random effects at spatial locations for the *i*th time period. We assumed that $\boldsymbol{\delta}_i$ follows a conditional autoregressive model (CAR) as described in Cressie (1993, pg. 407),

$$\boldsymbol{\delta}_i \sim \mathrm{Gau}(\mathbf{0}, \sigma_\delta^2(\mathbf{I} - \rho_\delta \mathbf{C})^{-1}\mathbf{M})$$

where $\mathrm{Gau}(\bullet,\bullet)$ is a (multivariate) Gaussian (normal) distribution. We defined a neighbor of a sample as any other sample with its centroid within 1 km. The weights in **C** were row-standardized (Haining 1990, pg. 82); that is, each row in **C** contained all zeros except for columns that indicate a neighbor, and these values were the inverse of the number of neighbors for that sample. The diagonal elements of **M** also contained the inverse of the number of neighbors. Similarly, let $\boldsymbol{\varepsilon}_i$ be a set of random effects at spatial locations for the *i*th time period. We assumed that $\boldsymbol{\varepsilon}_i$ followed a CAR model, as for $\boldsymbol{\delta}_i$, except it has its own parameters σ_ε^2 and ρ_ε;

$$\boldsymbol{\varepsilon}_i \sim \mathrm{Gau}(\mathbf{0}, \sigma_\varepsilon^2(\mathbf{I} - \rho_\varepsilon \mathbf{C})^{-1}\mathbf{M}) \, .$$

For both $\boldsymbol{\delta}_i$ and $\boldsymbol{\varepsilon}_i$, we assumed that they were independent from each other and across time periods.

A1.2.1 Time Effects

There were five covariates that varied temporally, but not spatially: presence of a cruise ship, number of cruise ships in previous 3 days, precipitation, wind, and number of samples with ice; that is, these covariates operated for all locations at a given time. Thus, we let the intercept for each time period be a function of these covariates,

$$\mu_i = \mu_0 + \mathbf{w}_i\boldsymbol{\gamma} + \tau_i \, ,$$

$$\nu_i = \nu_0 + \mathbf{w}_i \boldsymbol{\eta} + \xi_i .$$

The values for these 5 covariates are contained in the vector $\mathbf{w}_i$ for the *i*th time period, and $\boldsymbol{\gamma}$ is a vector of parameters for the Bernoulli distribution, and $\boldsymbol{\eta}$ is a vector of parameters for the Poisson distribution.

A1.3 Temporal AR1 Model

We allowed for temporally-autocorrelated random effects for each mean response. Let $\boldsymbol{\tau}$ be a set of random effects for all time periods past the first one. We assumed that $\boldsymbol{\tau}$ followed a first order autoregressive model (AR1) as described in Hamilton (1994, pg. 53),

$$\tau_i = \phi_\tau \tau_{i-1} + \sigma_\tau Z_i ;\ i > 1 ,$$

where $\tau_1 = 0$ and $Z_i \sim \mathrm{Gau}(0,1)$ are independent. This yielded a multivariate normal distribution

$$\boldsymbol{\tau} \sim \mathrm{Gau}(\mathbf{0}, \sigma_\tau^2 \boldsymbol{\Omega}(\phi_\tau)),$$

where the correlation matrix $\boldsymbol{\Omega}(\phi_\tau)$ has a special structure (Hamilton 1994, pg. 120), and depends on the parameter ϕ_τ. Likewise, let $\boldsymbol{\xi}$ be a set of random effects for all time periods past the first one. We assumed that $\boldsymbol{\xi}$ also follows a first order autoregressive model (AR1),

$$\xi_i = \phi_\xi \xi_{i-1} + \sigma_\xi Z_i ;\ i > 1 ,$$

where $\xi_1 = 0$ and $Z_i \sim \mathrm{Gau}(0,1)$ are independent. This again yields a multivariate normal distribution

$$\boldsymbol{\xi} \sim \mathrm{Gau}(\mathbf{0}, \sigma_\xi^2 \boldsymbol{\Omega}(\phi_\xi)).$$

A1.3.1 Prior Distributions

We put diffuse priors on all regression parameters: $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, $\boldsymbol{\gamma}$, $\boldsymbol{\eta}$. Because these were modeled on a log scale, there are computation instabilities if they are allowed to get too large, so we let each regression parameter have a normally distributed prior with a variance of 10. The autoregression parameters for both space, (ρ_δ and ρ_ε) and time (ϕ_τ and ϕ_ξ) are bounded from -1 to 1, but we did not expect any negative autocorrelation, so we used uniform priors from 0 to 1. For the variance parameters of the random effects ($\sigma_\delta^2, \sigma_\varepsilon^2\ \sigma_\tau^2, \sigma_\xi^2$), we let the square root be uniformly distributed between 0 and 10; again, to keep the random effects from becoming too large and causing numerical instability.

A1.3.2 Standardized Selection Coefficients

When working with categorical covariates in logistic regression, coefficients are often interpreted on the logit scale, and referred to as "log odds." However, this only facilitates comparing to a single category for a single model. In this study, we wanted to compare the relative importance between categories, and within categories for all seals versus mother-pup pairs. Hence, we created standardized selection coefficients (Manley et al. 2002, pg. 51). These are most easily interpreted back on their original scale. For example, for the 9 categories of ice cover for the Poisson part of the model, we obtain the posterior distribution of,

$$\tilde{\beta}_1^{[k]} = \frac{e^{\beta_1^{[k]}}}{\sum_{k=1}^{9} e^{\beta_1^{[k]}}}$$

where $\beta_m^{[k]}$ is the coefficient for the *k*th category for the *m*th variable. Because this is just a function of the $\beta_m^{[k]}$, it is easy to obtain its posterior distribution through the use of Markov Chain Monte Carlo (MCMC). Likewise, for the Bernoulli part of the model,

$$\tilde{\alpha}_1^{[k]} = \frac{e^{\alpha_1^{[k]}}/(1+e^{\alpha_1^{[k]}})}{\sum_{k=1}^{9}\left(e^{\alpha_1^{[k]}}/(1+e^{\alpha_1^{[k]}})\right)}$$

The standardized selection coefficients can be interpreted as the relative importance of each category, where the categories sum to one.

A1.4 Computation

Models were fit using MCMC in the WinBUGS software. We used a burn-in of 100,000 iterations, and then used 500,000 iterations for estimates and credibility intervals on all parameters and functions of parameters.

A1.5 Results

Table 2. Bernoulli regression estimates for the zero-inflated, space-time Poisson model to examine the cell-based absence/presence (i.e., spatial distribution) of pooled seals. Factors with a * are significantly different from 0.

Bernoulli Regression				
Factor	*Coefficient*	*Estimate*	*2.5% CI*	*97.5% CI*
Ice Cover Type*-1/10th – 2/10th	$\alpha_1^{[1]}$	0	-	-
2/10th – 3/10th	$\alpha_1^{[2]}$	1.061	0.384	1.742
3/10th – 4/10th	$\alpha_1^{[3]}$	1.179	0.427	1.935
4/10th – 5/10th	$\alpha_1^{[4]}$	1.860	1.045	2.747
5/10th – 6/10th	$\alpha_1^{[5]}$	2.161	1.180	3.282
6/10th – 7/10th	$\alpha_1^{[6]}$	2.086	0.839	3.501
7/10th – 8/10th	$\alpha_1^{[7]}$	1.889	0.557	3.392
8/10th – 9/10th	$\alpha_1^{[8]}$	2.456	-1.153	7.176
9/10th – 10/10th	$\alpha_1^{[9]}$	3.481	-0.132	7.855
Distance to Nearest Ship*	α_2	-2.750	-4.792	-0.930
Ship Activity*	α_3	-0.449	-1.113	-0.329
Presence of Ship	γ_1	-1.006	-4.586	2.606
Precipitation (Last 6 Hours)	γ_2	-0.291	-1.593	0.928
Wind (Last 6 Hours)	γ_3	-0.499	-1.594	0.499
Number Samples with Ice	γ_4	-0.632	-2.369	0.947
Number Ships (Last 3 Days)	γ_5	-1.352	-3.501	0.972

Table 3. Poisson regression estimates for the zero-inflated, space-time Poisson model to examine the cell-based abundance of pooled seals. Factors with a * are significantly different from 0.

Poisson Regression				
Ice Cover Type*-1/10th – 2/10th	$\beta_1^{[1]}$	0	-	-
2/10th – 3/10th	$\beta_1^{[2]}$	0.491	-0.057	1.061
3/10th – 4/10th	$\beta_1^{[3]}$	1.090	0.474	1.704
4/10th – 5/10th	$\beta_1^{[4]}$	1.026	0.368	1.696
5/10th – 6/10th	$\alpha_1^{[5]}$	1.390	0.639	2.148
6/10th – 7/10th	$\beta_1^{[6]}$	1.694	0.823	2.547
7/10th – 8/10th	$\beta_1^{[7]}$	1.447	0.530	2.377
8/10th – 9/10th	$\beta_1^{[8]}$	-0.249	-1.634	1.383
9/10th – 10/10th	$\beta_1^{[9]}$	-1.279	-3.183	0.522
Distance to Nearest Ship*	β_2	-1.774	-3.590	-0.155
Ship Activity	β_3	-0.007	-0.443	0.409
Presence of Ship	η_1	-1.082	-4.062	1.617
Precipitation (Last 6 Hours)	η_2	-0.363	-1.142	0.435
Wind (Last 6 Hours)	η_3	0.183	-0.612	0.995
Number Samples with Ice	η_4	-0.049	-0.909	0.837
Number Ships (Last 3 Days)	η_5	-0.515	-1.913	0.788

Table 4. Bernoulli regression estimates for the zero-inflated, space-time Poisson model to examine the cell-based absence/presence (i.e., spatial distribution) of mother-pup pairs. Factors with a * are significantly different from 0.

Bernoulli Regression				
Factor	*Coefficient*	*Estimate*	*2.5% CI*	*97.5% CI*
Ice Cover Type*-1/10th – 2/10th	$\alpha_1^{[1]}$	0	-	-
2/10th – 3/10th	$\alpha_1^{[2]}$	-0.539	-2.998	1.538
3/10th – 4/10th	$\alpha_1^{[3]}$	-1.633	-4.792	0.880
4/10th – 5/10th	$\alpha_1^{[4]}$	1.159	-1.446	4.153
5/10th – 6/10th	$\alpha_1^{[5]}$	0.055	-2.806	3.263
6/10th – 7/10th	$\alpha_1^{[6]}$	3.508	0.313	7.418
7/10th – 8/10th	$\alpha_1^{[7]}$	3.402	0.305	7.462
8/10th – 9/10th	$\alpha_1^{[8]}$	1.919	-2.392	6.834
9/10th – 10/10th	$\alpha_1^{[9]}$	-0.510	-6.612	5.842

Bernoulli Regression				
Factor	*Coefficient*	*Estimate*	*2.5% CI*	*97.5% CI*
Distance to Nearest Ship	α_2	0.394	-2.490	4.262
Ship Activity	α_3	1.103	-1.255	3.320
Presence of Ship	γ_1	-0.860	-5.959	3.958
Precipitation (Last 6 Hours)	γ_2	2.469	-0.106	6.097
Wind (Last 6 Hours)	γ_3	-0.723	-2.880	1.397
Number Samples with Ice	γ_4	-0.839	-3.418	1.548
Number Ships (Last 3 Days)	γ_5	-0.736	-3.760	2.782

Table 5. Poisson regression estimates for the zero-inflated, space-time Poisson model to examine the cell-based abundance of mother-pup pairs. Factors with a * are significantly different from 0.

Poisson Regression				
Ice Cover Type*-1/10th – 2/10th	$\beta_1^{[1]}$	0	-	-
2/10th – 3/10th	$\beta_1^{[2]}$	1.518	0.557	2.477
3/10th – 4/10th	$\beta_1^{[3]}$	2.541	1.430	3.608
4/10th – 5/10th	$\beta_1^{[4]}$	0.943	-0.209	1.983
5/10th – 6/10th	$\alpha_1^{[5]}$	2.312	1.094	3.442
6/10th – 7/10th	$\beta_1^{[6]}$	1.328	0.120	2.444
7/10th – 8/10th	$\beta_1^{[7]}$	1.121	-0.147	2.308
8/10th – 9/10th	$\beta_1^{[8]}$	-0.457	-3.199	1.769
9/10th – 10/10th	$\beta_1^{[9]}$	-1.387	-6.716	3.327
Distance to Nearest Ship	β_2	-1.740	-3.594	0.072
Ship Activity	β_3	0.039	-0.435	0.463
Presence of Ship	η_1	0.490	-2.937	3.956
Precipitation (Last 6 Hours)	η_2	-0.674	-1.544	0.210
Wind (Last 6 Hours)	η_3	0.171	-1.014	1.301
Number Samples with Ice	η_4	0.056	-0.899	1.173
Number Ships (Last 3 Days)	η_5	-0.872	-2.609	0.756

Appendix 2. Data Collection on Harbor Seals in 2004

The Polar Ecosystems Program of the Alaska Fisheries Science Center's National Marine Mammal Laboratory continued its research program in 2004 to examine in greater depth the factors affecting seal abundance and distribution in Disenchantment and Icy Bays. With funding from NOAA and logistical assistance from the Yakutat Tlingit Tribe (Yakutat Tlingit Tribe) and the NorthWest Cruiseship Association, data collection focused on four main elements: 1) Medium-scale aerial surveys were flown using an improved method for imaging and mapping seals. In addition to Disenchantment Bay, these surveys were expanded to include Icy Bay to allow for more detailed comparisons in areas with and without cruise ship traffic; 2) Student interns from the Yakutat Tlingit Tribe continued boarding cruiseships to collect sighting data on seal groups; 3) Cruise ship movements in Disenchantment Bay were again tracked by Yakutat Tlingit Tribe's interns and NMML biologists embarked on vessels; and 4) Large-format photogrammetry was again conducted at Disenchantment and Icy Bays during seal molting to extend the time series of total abundance counts (i.e., for 2001, 2002, 2004) for examination of potential trends.

A2.1 Fine-Scale Study

Under the coordination of NWCA and Cruiseline Agencies of Alaska (CLAA), student interns from the Yakutat Tlingit Tribe and NMML biologists boarded cruise ships from 19 May to 20 July 2004 in conjunction with embarkations of pilots and cultural interpreters from Yakutat. Seal observers were positioned amidships to count harbor seal groups as they passed abeam of the ship and measured their distance from the ship using range finding binoculars (Leica Vector™ or Geovid™, Ashbury International Group, Inc., Sterling, VA) or inclinometers when rain or fog hampered the use of the range-finders. These data will be used to calculate seal densities as a function of distance from ship. Observers also recorded the ship movement using portable GPS units (Garmin 76 or 90, Garmin International Inc., Olathe, KS).

The first three cruise ship visits of the season in Disenchantment Bay (two on 11 May, one on 12 May) did not embark a pilot or interpreters from Yakutat so observers were unable to board. These visits were instead monitored remotely from an observation camp on Egg (Haenke) Island in Disenchantment Bay. Observers used range-finding binoculars to measure distance and bearing to ships at *ca.* 5-minute intervals during their visits. Observers also recorded the behavior of harbor seals hauled out on ice when ships were both present and not. Using spotting scopes, seal groups were observed for 15 seconds each minute and were usually observed for 10 minutes. The behavioral state of each seal in a group was recorded using the same categories as the shipboard observations conducted in 2002 (see methods above). Only the "highest" (or most disturbed) behavioral state was recorded if more than one state was exhibited during the observation. Mothers' and pups' behavior was recorded separately from others when it was discernable. Observers also estimated the longest axis of the ice on which groups were hauled out and the total ice concentration (to the nearest tenth) within 50 m of the seal group.

Observers boarded 50 of the 83 cruise ships that visited Disenchantment Bay during the study period, counting and measuring distances to a total of 2,182 harbor seals in 1,221 groups (Fig. 23). Complete navigational tracks were obtained from *ca.* 40 ships; poor GPS coverage sometimes produced incomplete tracks. Observers on Egg (Haenke) Island recorded

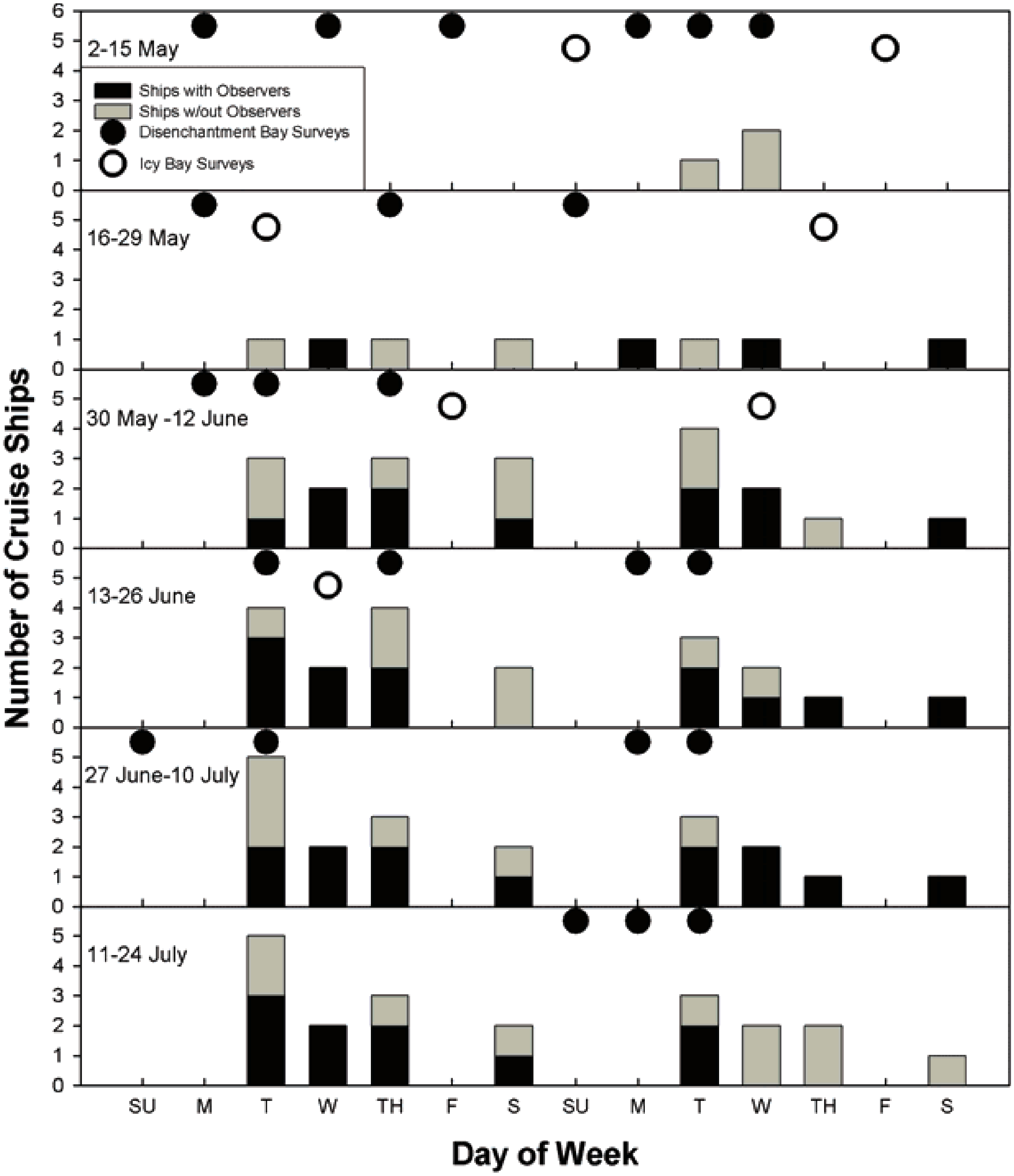

Figure 23. Distribution of cruise ship visits to Disenchantment Bay, with and without observers, and aerial surveys flown at both Disenchantment and Icy bays, 3 May to 20 July 2004.

position data on three cruise ships and collected behavioral data from 31 seal groups, including 16 with and 15 without cruise ships present, respectively. The observations without cruise ships present will provide useful baseline data of the seals' ambient (undisturbed) behavior.

A2.2 Medium-Scale Study

Aerial photographic surveys of harbor seal relative abundance and distribution were conducted in Disenchantment Bay from 3 May to 20 July 2004. Four surveys were flown before the first entry of a cruise ship into the bay and two more were flown on the first 2 days thereafter. Thereafter, we timed the surveys according to the weekly pattern of cruise ship visitation, with one survey flown early in the week during a period of low cruise ship visitation and one survey (or sometimes two, during the pupping season) flown mid-week during days of high cruise ship visitation (Fig. 23). As in 2002, surveys were flown between 1300 and 1500 h (local time) to coincide with the daily peak in number of seals hauled out (Hoover 1983; Calambodkidis et al. 1987; Jansen et al. 2001). We used a different aircraft from the one used in 2002 (a DeHavilland DHC-2 Beaver) to accommodate a new method of mapping seal distribution. The plane was flown at 90-95 knots at an altitude of 305 m (1,000 ft) along a standard grid of 14 transects separated by 400 m (as in 2002; Fig. 11). Adjacent areas outside the study area (i.e., in northern Yakutat Bay and Russell Fjord) were again opportunistically surveyed for seals when they contained significant amounts of ice.

During the aerial surveys, digital photos (3008 x 1960 pixel JPEGs) were taken of the area directly under the airplane using a vertically-aimed digital camera (Nikon D1x, Nikon Inc., Melville, NY) mounted to a platform in the airplane's camera porthole. Using a 60 mm (90 mm digital equivalent) focal length lens at 1,000 ft, each picture captured an area of 78 x 120 m. This configuration provided high resolution photos for relatively easy seal identification and length measurement (Fig. 24).

Figure 24. An example of an aerial photograph with seal groups present. The pink crosshairs are used to standardize the method for estimating ice cover suitable for hauling out (see Methods)

The camera was manually started and stopped at the beginning and end of each transect; during the transects the camera was programmed to take a picture every 2 seconds using a laptop computer with camera-control software (Nikon Capture 4, Nikon Inc., Melville, NY). This resulted in *ca.* 80% photo coverage along the transects, with an approx. 15-20 m gap between photos. Non-overlapping photographs allow for greater efficiency in the analysis because there is no chance of counting the same seal twice in sequential photographs on the same transect, and a very low chance on adjacent transects. The camera was also manually stopped whenever the airplane flew over an area with no ice. Image files were streamed to the laptop's hard drive using a FireWire® cable connection. The camera was also connected to a portable GPS unit (Garmin 76S, Garmin International Inc., Olathe, KS) that embedded the airplane's position within each JPEG file. This later allowed us to georeference the survey photos in a GIS (ArcGIS, ESRI, Inc., Redland, CA). As in 2002, a digital video camera (Sony TRV-900, Sony Electronics Inc., San Diego, CA) was mounted vertically in the porthole and used as a back up to the digital camera system. It was set to record a 70 m wide strip below the airplane and recording was switched on and off at the same times as the digital camera.

Aerial surveys were also conducted in Icy Bay from 9 May to 16 June 2004 using the same survey equipment and methods as in Disenchantment Bay, except that surveys were flown weekly (Fig. 23). The Icy Bay survey grid also contained 14 transects that were aligned lengthwise with the main ice field flowing from the Guyot Glacier (Fig. 25).

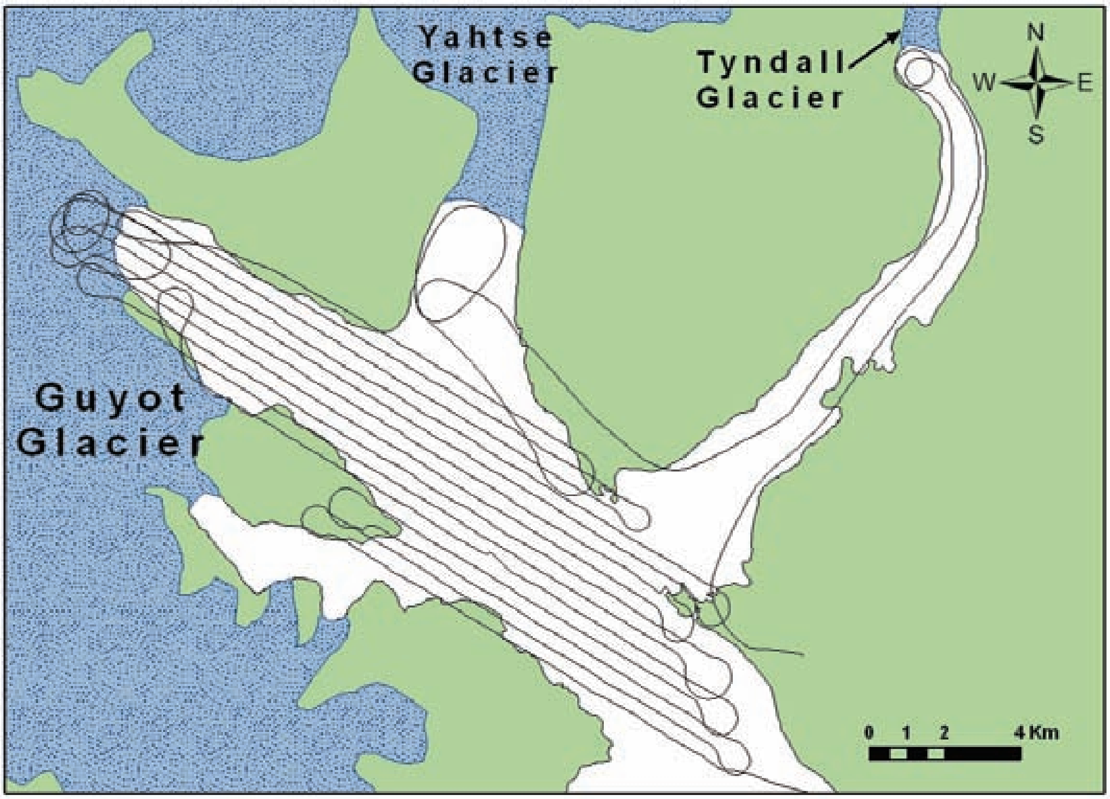

Figure 25. Map of the Icy Bay study area showing the aerial transect grid for the medium scale photogrammetric surveys.

Since Icy Bay does not receive visits from cruise ships, it was used as a "control" site from which to compare results from Disenchantment Bay.

Once archived, the survey photographs were georeferenced using GIS software (ArcGIS 9, ESRI Inc., Redlands, CA)(i.e., overlaid on GIS covers of coastline in the actual location, orientation, and scale at which they were taken). The number and location of each seal group sampled was then recorded, along with the number of seals per group, the number of mother-pup pairs per group, and the longest axis of the iceberg each group is hauled out on. Mother-pup pairs were defined as two seals that were within an adult body-length of each other with the smaller seal being less than two-thirds the total length of the larger seal. This method will be refined as we explore the possibility of assessing population structure using body length. Finally, two different measures of ice cover were estimated in all photographs with seals and every 400 m along the transects when seals were not present, and for the first and last photographs of each transect. First, the area of ice cover (≥ 2 m longest axis) was estimated visually to the nearest tenth. Secondly, a more standardized ice cover was estimated by overlaying a 4 X 5 grid and counting the number of intersections (of 20 total) at which ice greater than or equal to 2 m overlaps (quadrat sampling; Fig. 24). In total, 23 aerial surveys were conducted in Disenchantment Bay and seven were conducted in Icy Bay. On average, 1,818 photos were taken during Icy Bay surveys and 1,300 photos were taken during Disenchantment Bay surveys. The analysis of these photos is currently underway.

A2.3 Large-Scale Study

Large-format (9 x 9 in) aerial photogrammetric surveys were conducted in Disenchantment and Icy Bays on 9, 10, and 23 August 2004 by AeroMap, Inc. (Anchorage, AK).

Appendix 3. Harbor Seal Behavioral Observation Guidelines

(Instructions to observers on cruise ships for collecting behavioral data)

1. Selecting an observation post: Each observer should perform their observations in one of the four quarters of the ship (i.e., some combination of port, starboard, bow, stern). For example, if you select the port bow post, observe seals from the time that you can first view them well until they pass abeam of the ship. If you select the starboard stern, you would begin your observations as the seals come aft of the ship's beam, continuing your observations until you can no longer see the seals well.

2. Selecting seal groups: At the beginning of the in-ice observation period, select a group of seals hauled out on ice. A "group" can be one or more seals on a single ice floe. Assign that group an ID number, from 1 through whatever number of groups you, as an individual, observe that day on that ship. Remember to include both small and large groups in your sample. Also include groups that are both close and far from the ship's track. Number groups sequentially per ship visit (event), starting with 1. Use an observation position prefix for port bow (PB) port stern (PS), starboard bow (SB), and starboard stern (SS). Example: PB-1, PB-2, PB-3, etc.

3. Mothers and pups: Whenever possible, select seal groups for observation that include mothers and pups. Don't assume that all small seals are pups; yearlings can be nearly the same size as pups. Pups can be identified by their bright, shiny, fresh pelage (yearlings have duller pelage, which they will be molting in the coming weeks) and by close physical proximity to adult females.

4. Observation sampling: This study's experimental design calls for continuous monitoring, with independent observations of a seal group (or individual) being allotted into 15 seconds intervals, separated only by the amount of time necessary to record the data. Use a countdown timer to start and end the 15 second observation period. When the group passes out of your observation area (ship's quarter), select another group when it becomes available.

5. Recording observations: For each 15 second observation period, record the group ID number, the start time of the observation, and the group size (note that this may have changed since the last observation if seals entered the water). Record the number of seals that showed each level of excitement during the period. Score only the "highest" level of excitement for each seal during that period (head up is the least excited, entering the water is the most excited). For example, a seal that was resting at the beginning of a 15 second period, but then raised its head, moved across the ice, and then entered the water during that 15 seconds would be scored as "enter water." Record counts for mothers, pups, and other seals separately.

6. Distance and bearing: Estimate distance using the range-finding binoculars or inclinometer (record degrees of inclination for the latter). Also record the approximate relative bearing to the ship's course in 15° increments. For example, straight off the bow would be 0° or 360°, the port beam is 270°, aft is 180°, the "2 o'clock" position is 60°, and the "7:30" position is 225°.

7. Other covariates: For each seal group observed, enter estimates of ice coverage (in 10ths within a 50 m radius of group) and ice floe size (longest axis). Note weather conditions at the beginning of observations and then as significant changes occur. Note the incidence of other potential sources of disturbance (e.g., ships, boats) at the time they are first observed.