Abstract—The importance of glacial ice habitats to harbor seals (*Phoca vitulina)* in Alaska has become increasingly apparent. However, enumerating harbor seals hauled out on ice in glacial fjords has been difficult. At Johns Hopkins Inlet in Glacier Bay, Alaska, we compared a shore-based counting method to a large-format aerial photography method to estimate seal abundance. During each aerial survey, shore-based observers simultaneously counted seals from an observation post. Both survey methods incurred errors in double-counting and missing seals, especially when ice movements caused seals to drift between survey zones. Advantages of shore-based counts included the ability to obtain multiple counts for relatively little cost, distinguish pups from adults, and to distinguish mobile seals from shadows or glacial debris of similar size. Aerial photography provided a permanent record of each survey, allowing both a reconciliation of counts in overlapping zones and the documentation of the spatial distribution of seals and ice within the fjord.

Manuscript submitted 2 December 2005 to the Scientific Editor's Office.

Manuscript approved for publication 20 December 2006 by the Scientific Editor.

Fish. Bull. 105:348–355 (2007).

Comparison of survey methods for estimating abundance of harbor seals (*Phoca vitulina*) in glacial fjords

John L. Bengtson (contact author)[1]
Alana V. Phillips[1]
Elizabeth A. Mathews[2]
Michael A. Simpkins[1,3]

E-mail: John.Bengtson@noaa.gov

[1] National Marine Mammal Laboratory
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA
7600 Sand Point Way NE
Seattle, Washington 98115

[2] University of Alaska Southeast
Department of Natural Sciences
11120 Glacier Highway
Juneau, Alaska 99801

[3] Marine Mammal Commission
4340 East-West Highway, Rm. 905
Bethesda, Maryland 20814

Harbor seals (*Phoca vitulina)* in Alaska occupy a geographically extensive range and topographically diverse haul-out habitats. They are present in U.S. waters from approximately 172°E to 130°W (over 3500 km east to west) and from 51°N to 61°N (over 1000 km north to south), hauling out on a variety of substrates including sand, rock, and, in Alaska, glacial ice. Alaska harbor seal populations have declined at several locations since the late 1970s. For example, counts of harbor seals at Tugidak Island (southwest of Kodiak Island, Alaska) declined 85% between 1976 and 1988 (Pitcher, 1990), and counts in Prince William Sound indicate population declines of approximately 63% between 1984 and 1997 (Frost et al., 1999). Additional evidence indicates that harbor seal numbers near Kodiak Island, including those at Tugidak Island, increased 6.6%/yr during 1993–2001 (Small et al., 2003), but that seals in Prince William Sound have continued to decline 3.3%/yr during 1988–99 (Ver Hoef and Frost, 2003). In Glacier Bay, Alaska, harbor seal numbers declined by 75% (–14.5%/yr) during 1992–2002 at terrestrial resting sites and by 64% (–9.6%/yr) from 1992 to 2001 in Johns Hopkins Inlet, the primary breeding site, which is a glacial fjord where seals haul out on floating ice (Mathews and Pendleton, 2006). Because it is estimated that 10% or more of harbor seals in Alaska use glacial ice habitats during the molting season (August–September) (J. L. Bengtson, unpubl. data), there is a pressing need to develop reliable survey methods to assess harbor seal abundance in such areas. Here we evaluate two such survey methods: counts from shore-based observations and counts from large-format aerial photography.

Shore-based surveys of harbor seals in two glacial fjords in Glacier Bay National Park, Alaska, have been made from elevated shore sites over the past three decades (Calambokidis et al., 1987; Mathews, 1995; Mathews and Pendleton, 2006) and in Aialik Bay, a glacial fjord in the Gulf of Alaska (Hoover, 1983). In 1997, Mathews et al.[1] conducted a pilot

[1] Mathews, E. A., W. L. Perryman, and L. B. Dzinich. 1997. Use of high-resolution, medium-format aerial photography for monitoring harbor seal abundance at glacial ice haulouts, 15 p. Unpubl. report to Glacier Bay National Park and Preserve, P. O. Box 140, Gustavus, AK 99826. Website: http://www.uas.alaska.edu/biology/faculty/mathews/publications.html (accessed 1 December 2006).

study in Johns Hopkins Inlet, Glacier Bay, and determined that it was feasible to count harbor seals on glacial ice from medium-format aerial photographs, and comparisons of these counts were made to simultaneous shore counts. In our study, we employed higher resolution (large-format) film, conducted three simultaneous aerial and shore surveys (vs. one in the pilot study), and used data from different altitudes to assess sources of counting error within aerial photographs.

Aerial surveys of harbor seals are most often conducted when peak numbers are hauled out, which usually occurs during the annual molt in late summer. During such surveys, low altitude (100–300 m) photographs of harbor seal groups are obtained, from which seal counts are made (Olesiuk et al., 1990; Boveng et al., 2003). Surveying seals in glacial fjords is more difficult than on terrestrial sites because the moving, large expanses of scattered ice on which seals haul out offer little spatial reference to aid in counting seals. Furthermore, there is often insufficient maneuvering room for low-altitude aerial surveys in the fjords. The main objective of our study was to compare the relative effectiveness of shore-based and aerial survey methods to estimate harbor seal abundance.

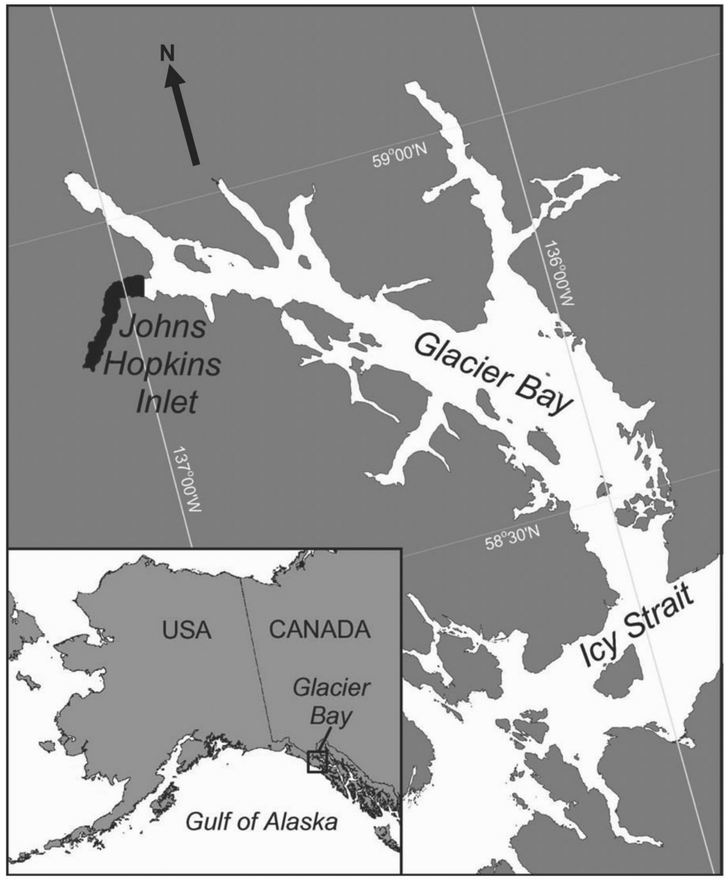

Figure 1
Map of Glacier Bay, Alaska, showing Johns Hopkins Inlet (shaded).

Materials and methods

Study area

Johns Hopkins Inlet is located in the northwest arm of Glacier Bay (58°N, 138°30′W) in southeastern Alaska (Fig. 1). At the head of the inlet is an active tidewater glacier that is currently advancing. The fjord walls are steep, rising to 640 m and 884 m within one km of the western and eastern shores, respectively. Harbor seals rest, nurse, and molt on ice calved from the glacier. Pieces of ice occupied by seals are typically around 8–24 m^2, although they vary widely in size and can be much larger (up to ~890 m^2, n=105) (E. A. Mathews, unpubl. data). Ice that has above-water features taller than about 2 m is rarely occupied. The percent of ice cover in the inlet was estimated by shore observers before seal counts during August for the years 1995–2001; for most surveys, 6–25% or 26–50% of the inlet was covered by ice (n=83 shore surveys). Approximately 60–70% of harbor seals in Glacier Bay use glacial ice in Johns Hopkins Inlet during the pupping, breeding, and molting periods from spring to early fall (Mathews, 1995).

Shore-based surveys

Observers counted seals from an elevated (~35 m) site located along the western shore of the inlet about 2.5 km from the terminus of Johns Hopkins Glacier (Fig. 2A). From this site, the observers' field of view comprised approximately 9 km (from the glacier to Jaw Point). The northwestern edge of the inlet and a small area near the northwest edge of the glacier face were not visible to the shore observers because of obstruction by headlands and other geographic features (i.e., "blind spots," Fig. 2A). Ice in the inlet more commonly drifted closer to the east than the west shore because of current and wind patterns; therefore, the location of the observation site along the western shore was selected as the observation site. Two of the four observers involved in this study simultaneously counted seals 2 or 3 times each day between 12 and 23 August 2001 and 9 and 26 August 2002. Seals on ice and in the water were tallied, but only seals on ice were included in this analysis. Observers conducted shore-based counts of harbor seals in Johns Hopkins Inlet during, or within an hour of, the aerial surveys conducted on 15 and 16 August 2001, and 15 August 2002. Surveys targeted the period around solar noon when the largest number of seals hauls out on glacial ice (Hoover, 1983; Calambokidis et al., 1987).

Observers counted seals using 20×60 binoculars mounted on tripods. After each tripod was leveled, observers locked the vertical orientation of the tripod head and counted all seals in the field of view as the binoculars were pivoted horizontally in one direction. To facilitate systematic counting in the study area, observers visually divided the field of view into three or four subareas using markers such as landmarks or natural breaks in the ice as viewed from the observation site. When a marker came into the field of view, the binoculars were lowered exactly one field of view, locked again, and a pass in the opposite direction was made (Mathews, 1995). Each of the subareas typically required only two nonoverlapping, parallel passes across ice habitat to completely cover the width of a subarea. Counts from all subareas were summed for each observer to estimate total counts, and the two observers' total counts were then averaged to estimate the total count for each survey. The variance for each survey's total count was estimated as the variance among the two observers' total counts.

Aerial surveys

Aerial surveys were conducted from a twin engine aircraft on 15 and 16 August 2001 and 15 August 2002 by a commercial photographic surveying company (Aeromap U.S., Anchorage, AK). In 2001, each aerial survey over Johns Hopkins Inlet was completed in three transects: two transects at 1465 m altitude covering the entire inlet, and an additional transect at 915 m covering the central portion of the inlet a second time from Johns Hopkins Glacier to the point north of Jaw Point (Fig. 2B). In 2002, the survey aircraft flew two transects at 1465 m covering Johns Hopkins Inlet from the glacier to Jaw Point; a lower-altitude, central transect was not flown (Fig. 2C). Shore observers observed no reaction by the seals (e.g., entering the water) to the aerial surveys.

During each survey, large-format (23×23 cm) photographic images were taken automatically at a predetermined rate on Agfa Aviphot Color X100 PE1 negative film (Agfa Corp., Ridgefield Park, NJ), with a belly-mounted Zeiss RMK TOP 15 camera (Carl Zeiss, Inc., Thornwood, NY) with forward-motion compensation (15 August 2001) or with a Zeiss RMK A 15/23 camera (Carl Zeiss, Inc., Thornwood, NY) (16 August 2001 and 15 August 2002). We did not notice any substantial improvement with the use of forward-motion compensation. The resulting photographic frame widths (i.e., the on-the-ground width of the area photographed in each photo frame) were 2200 m for high-altitude (1465 m) images and 1400 m for low-altitude (915 m) images. The images had approximately 10% endlap (i.e., overlapping duplication of the same area in separate, successive images) within transects, 20% sidelap between high-altitude transects, and 75% sidelap between the central transect and the neighboring high-altitude transects in 2001. Large-format negatives were scanned at 1600 dpi (the maximum resolution available to us) with a digital scanner and converted to positive-color digital images. The pixel resolutions of the resulting digital images were 0.10 m and 0.15 m for low- and high-altitude transects, respectively. At that resolution, we found that seals could be identified from the scanned imagery, and we were satisfied with this resolution for the purposes of counting seals.

Seals were counted from the digital images by using the "geospatial light table" feature of ERDAS Imagine 8.6 software (Leica GeoSystems Inc., Atlanta, GA). No distinction was made between adults, pups, or juvenile seals. A virtual mosaic was created by delineating overlapping zones on adjacent images based on the relative positions of identifiable pieces of ice. This mosaic allowed the analyst to account for ice movement when counting seals. In some cases, delineation of overlapping zones was difficult, particularly

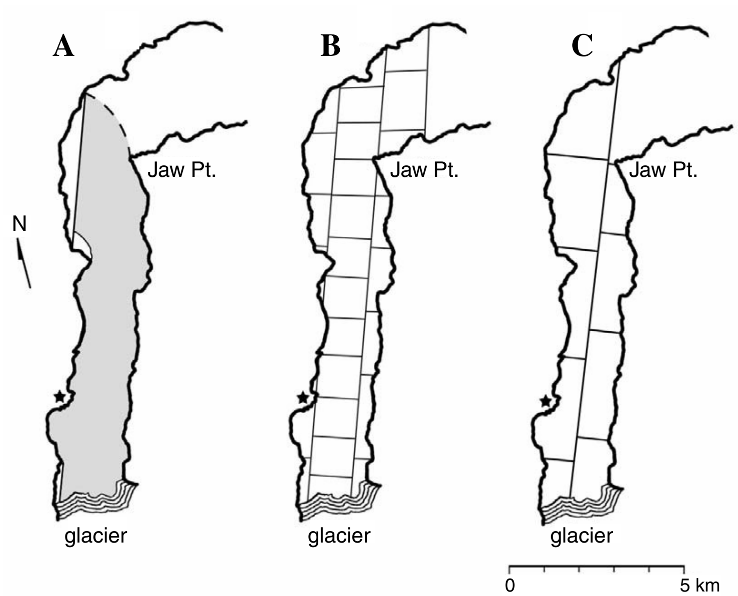

Figure 2

Survey coverage of Johns Hopkins Inlet, Glacier Bay, achieved by each survey type in this study. (**A**) Field of view (shaded area) observed from shore-based observation site (indicated with a star). Note that the northwestern edge of the inlet and a small area near the glacier are obscured from view ("blind spots") by geographical features. The outer range of visibility varied with conditions and is denoted by a dashed, curved line. (**B**) Photographic coverage of aerial transects flown on 15 and 16 August 2001. The straight lines in the inlet reflect the approximate boundaries between photographs. For simplicity, only the nonoverlapping areas (i.e., no endlap or sidelap) of each image are shown. The central transect was flown at a lower altitude (915 m) than the two adjacent transects (1465 m). (**C**) Photographic coverage of aerial transects (1465 m altitude) flown on 15 August 2002; the overlap between neighboring photographs was ignored.

Table 1

Shore-based and aerial photographic counts of harbor seals (*Phoca vitulina*) at Johns Hopkins Inlet, Glacier Bay, Alaska, in 2001 and 2002. Means, standard errors (SE), and coefficients of variation (CV) are derived from two simultaneous counts during each shore-based census and from three independent counts of aerial survey imagery (times are given in local solar time).

Date	Survey type	Survey time (h)	Mean count	SE	CV
15 Aug 2001	Shore-based	1406–1449	1970	57.0	0.029
	Aerial	1457–1512	1581	20.0	0.013
16 Aug 2001	Shore-based	1401–1439	1906	192.5	0.101
	Aerial	1421–1442	1294	25.6	0.020
15 Aug 2002	Shore-based	1249–1349	1562	4.0	0.003
	Aerial	1231–1245	1511	46.6	0.031

when ice moved substantially during the time that elapsed between neighboring photographs. Seals in overlapping zones were counted only once (i.e., only counted in one of the overlapping images). In 2001, the resolution in the low-altitude transects was superior to that in the high-altitude transects; therefore we counted all seals within the low-altitude imagery first and then added counts of seals in the nonoverlapping portions of the high-altitude imagery. Three replicate total counts were calculated for each survey by counting the seals in each image three separate times and tallying the resulting counts for each replicate. All replicates were counted by a primary analyst, and at least one week elapsed between each replicate count to minimize bias caused by the analyst remembering the location of seals from previous replicate counts. The number of images analyzed varied between surveys, depending on the survey tracks flown and the distribution of ice. Sixty-two total images were analyzed: 15 August 2001=21 images, 16 August 2001=30 images, and 15 August 2002=11 images. A subsample of five images from Johns Hopkins Inlet was also counted by a secondary analyst to provide independent verification of counts. The mean count (of the three counts by the primary analyst) for each image was calculated, and the mean counts for all images from each survey were summed to estimate the total survey count. The variance of the total count estimate was estimated as the sum of the variances for each mean count included in the total estimate.

Comparison of detection rates at different altitudes

To compare the detection rates in low- and high-altitude imagery from 2001, we counted all seals in the overlapping zones of low- and high-altitude images. Next, we visually compared the location of each seal in the overlapping portions of low- and high-altitude images and classified seals as either 1) counted in both images or 2) counted in only one of the images. Seals counted in only one of the images were further categorized as follows: 1) light-colored seal not detected in the other image, 2) seal in a group not resolved as an individual in the other image, 3) seal definitely not present in the other image (e.g., seal went into the water or hauled out between transects), or 4) shadow or dirty ice classified as a seal in other image. These comparisons were conducted to help us understand the relative accuracy of counting seals from images taken at different altitudes. The less accurate high-altitude counts were not used when estimating mean counts for each survey; mean counts were estimated by triplicate counts with priority given to low-altitude counts as described above.

Results

Comparison of total counts

In 2001, counts made from shore were consistently higher than counts made with the use of aerial photography (Table 1). In contrast, both counting methods produced similar results in 2002. The standard errors and coefficients of variation (CV) presented in Table 1 reflect variance between counts by shore-based observers or between independent counts of aerial photographs. Although the CVs for counts of individual images were generally larger than the CVs for total estimates, 91% of the CVs for individual images were less than 0.1. Of the five images counted by a secondary analyst, all counts were within 8% of the mean of the three replicate counts conducted by the primary analyst. Imprecision or inaccuracies in counts caused by the distance of seals from the observation site or the altitude of the aerial survey were not easily quantified, although altitude-related errors were evaluated separately by comparing counts of seals in overlapping low- and high-altitude images.

Spatial distribution of seals in Johns Hopkins Inlet

The distribution of seals in Johns Hopkins Inlet was different during each of the surveys and appeared to be associated with the pattern of ice in the inlet. Generally, seals were found in aggregations, although solitary seals were frequently observed outside of the main seal concentrations (Fig. 3). On 15 August 2001, seals were distributed in groups of 200–500 animals, ranging from 1 to 6 km from the glacier terminus (Fig. 3A). On 16 August 2001, a large group of 800–900 seals was aggregated in a band stretching from 0.5 km from the glacier terminus to the shore-based observation site, and another group of 300–400 seals was found 3–5 km from the glacier (Fig. 3B). On 15 August 2002, all of the seals were within 3 km of the glacier face between the glacier and the shore-based observation site (Fig. 3C). Of these, a group of 350–450 seals was observed on the southwest side of the inlet, and the remaining 1100–1200 seals formed a dense concentration on the east side of the inlet. No seals were located in the blind areas (from the view point of the shore-based observers) on any of the three survey days (Figs. 2A and 3).

Comparison of detection rates at different altitudes

An examination of seals in overlapping zones of low- and high-altitude images revealed a difference in the rates of seal detection between the two altitudes. Seals were more easily detected and confirmed to be seals in the low-altitude imagery; therefore, seals identified in low-altitude imagery were considered to be "true" observations for comparison to seals counted in high-altitude imagery. For the 15 August 2001 survey, 32.7% of the seals counted in the low-altitude images (i.e., "true" seals) were misclassified in high-altitude images: 8.6% were counted as seals when no seals were present (i.e., shadows or dirty ice misidentified as seals) and 24.1% were not counted as seals when seals were present (i.e., 23.3% were dark seals dismissed as shadows or dirty ice, 0.5% were light-colored seals that were not detected, and 0.3% were so close to other seals that they could not be identified from their neighbors). In the 16 August 2001 survey, 34.3% of the seals counted in the low-altitude images were misclassified in the high-altitude images, including 12.5% that were shadows or dirty ice misidentified as seals and 21.8% that were not detected in the high-altitude imagery (21.5% dark seals and 0.3% light-colored seals). The net effect of the misclassifications was that counts from higher-altitude images were underestimates of the number of seals compared to counts from lower altitudes (i.e., the proportion of seals missed exceeded the proportion of false identifications).

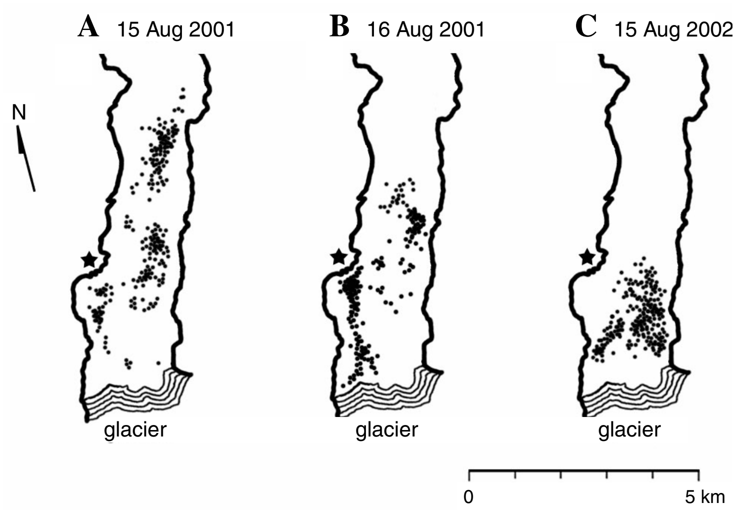

Figure 3

Relative distribution of patches of harbor seals (*Phoca vitulina*) in Johns Hopkins Inlet, Glacier Bay, determined by aerial photography, on (**A**) 15 August 2001, (**B**) 16 August 2001, and (**C**) 15 August 2002. Dots indicate groups of seals and are meant to illustrate generalized locations of seals, rather than a precise indication of seal abundance. The shore-based observation site is indicated with a star.

Discussion

Comparison of total counts

Both shore-based and aerial counts indicated that more than 1500 seals haul out on glacial ice in Johns Hopkins Inlet in mid-August, making the inlet one of the most important haul-out sites in Glacier Bay (as suggested by Mathews [1995]). The total number of seals that use the inlet might be substantially larger because some unknown proportion of seals was in the water (i.e., not hauled out on ice) during the surveys. In 2001, counts made from shore were consistently higher than counts made with aerial photography (Table 1). In contrast, both counting methods produced similar results in 2002. Several sources of error for each method likely contributed to these inconsistencies in results between the two methods.

Sources of error for each survey method

Both counting methods were susceptible to common errors of either double-counting or missing seals. These errors were most likely to occur within overlapping zones between neighboring photographic images, between parallel passes with binoculars, or between shore-based counts of subareas. If overlapping zones were not accurately delineated, individual seals within the overlapping zone could be counted twice, or missed entirely. The permanent record provided by photography provided the best opportunity to minimize such errors by allowing for careful delineation of overlapping zones based on the relative positions of identifiable pieces of ice on adjacent images. The shore-based method did not allow re-identification of individual pieces of ice; therefore shore-based observers attempted to eliminate overlapping by adjusting binoculars carefully. Seals could be missed, however, if the binoculars were

Table 2

Comparison of the percent difference ([shore-based count - aerial photography count]/shore-based count) in the number of harbor seals (*Phoca vitulina*) counted by two survey methods. Potential sources of error for harbor seal counts in Johns Hopkins Inlet included maximum distance between harbor seals and shore observers, degree of clumping of harbor seals on ice, and the degree of movement of ice.

Date	Percent difference in counting method	Maximum distance between seals and shore site (km)	Degree of seal clumping	Degree of ice movement
15 Aug 2001	25%	4.25	moderate	high
16 Aug 2001	47%	2.40	high	high
15 Aug 2002	3%	2.75	low	high

lowered more than one field of view. Similarly, seals could be counted twice, if the binoculars were lowered less than one field of view before the second survey pass.

Counting errors could be caused by movement of ice on which seals were hauled out. Shore-based observers could not track the movement of ice between parallel passes; therefore some counting errors caused by ice movements were unavoidable. Depending on ice drift patterns, seals that were already counted could drift into an uncounted zone and be double counted, or uncounted seals could drift into a counted zone and be missed. On both days surveyed in 2001, we observed considerable movement of ice between aerial transects, particularly along the eastern side of the inlet, farthest away from the shore-based observation site. Thus, it is likely that seals would have drifted between the shore-based observers' counting areas, resulting in either missed or double counts. In contrast, the ice was less mobile during the 2002 survey day. Ice did not drift much between adjacent photographic images along a transect because only 5–10 seconds elapsed between each image. However, ice sometimes drifted substantially between images along neighboring transects, which were typically separated by 10–15 minutes. Although such ice movements sometimes made identification of individual seals between neighboring images more difficult, spatial clues from recognizable pieces of ice aided identification and made us confident that seals on moving ice were properly counted.

The distribution of seals could also influence counting errors for both survey methods. In 2001, ice was distributed up to 4.5–6 km from the glacier terminus and seal distribution was clumped (Fig. 3, A and B). In contrast, during the 2002 survey day the ice was more densely packed near the glacier terminus and seals were more evenly distributed (Fig. 3C). The distance between the shore observers and seals was also expected to affect shore counts, and to produce greater error as distance increased. Our results, however, did not exhibit a clear pattern in the percent difference between counting methods and distance between shore observers and seals. In 2001, seals were within 4.25 km of observers on 15 August and within 2.4 km on 16 August; during the 2002 survey seals were located within 2.75 km (Table 2). Overall, the counts recorded by both methods were most similar when ice movement and seal clumping were minimal (Table 2).

Counting errors could also be caused by misidentifying seals as shadows or dirty ice. Occasionally, ice ridges cast shadows that looked remarkably like seals. Some glacial ice contained veins of dirt that also had the similar shape and color of seals. When comparing seals identified in overlapping imagery from the two aerial survey altitudes, we found that 22–24% of seals counted in the low-altitude (high-resolution) imagery either were not detected or were dismissed as shadows or dirty ice in counts of the high-altitude imagery. However, 9–13% of seals counted in the high-altitude imagery were actually shadows or dirty ice, according to the low-altitude imagery. These two types of errors tended to offset each other, although high-altitude counts still exhibited a general bias toward 10–15% lower seal counts. As a result, the aerial counts (especially from high-altitude imagery) likely produce underestimates of the actual number of seals hauled out on ice. The aerial counts from 2001 were based primarily on low-altitude counts, and, thus probably represent less biased estimates than the counts for the 2002 survey, which was based solely on high-altitude imagery. No correction was applied to the high-altitude counts because the likelihood of misidentifying or missing seals varied according to conditions specific to each image (e.g., dirty ice and shadows); therefore applying a correction based on images from one part of the fjord probably was not applicable to images from other parts of the fjord, let alone images from an entirely different day. Further, no correction was available for the proportion of seals misidentified or missed in the low-altitude imagery and for an unknown number of seals that were in the water during the surveys.

Shore-based observers had the advantage of a three-dimensional "live" view of seals and were able to distinguish between actively moving seals and shadows or dirty ice, although this advantage probably diminished with distance. Stationary seals could still be difficult to distinguish at any distance, although their characteristic profiles and the reflectivity of their fur helped to distinguish seals from rocks or dirt of similar size. As was the case for the aerial estimates, no correction was available for seals missed or misidentified by shore-based observers, and some unknown number of seals were in the water during the observation periods.

Advantages of each method

Shore-based counts The main benefit associated with counting harbor seals from land is the ability to obtain multiple counts throughout the day, and on successive days, relatively inexpensively.[1] Counts can also be made from land under suboptimal weather conditions, when aerial surveys are impossible or when the resulting photographs would be of poor quality. Repeated surveys allow an assessment of changes in seal counts related to covariates such as time of day, ice conditions, and weather (Mathews and Pendleton, 2006). The number of harbor seals counted on ice in Johns Hopkins Inlet varies from day to day and thus increases the probability that a small number of aerial surveys could yield misleading results. For example, on 10 consecutive days in August 1999 the number of seals counted from shore near midday ranged from 1465 to 2534. If surveys are conducted when pups are nursing (generally during June in Alaskan waters), shore observers can identify seal pups based on size, shape, and relative position of seals within a group hauled out on ice. By August, however, almost all pups are weaned and the number of seals in groups on ice is much larger than in June, making it much more difficult to distinguish weaned pups or juveniles from adults except at very close range. With the aerial surveys there were also difficulties in distinguishing pups and juveniles (i.e., the resolution of the aerial photographs in the August study was not high enough to distinguish weaned pups, and no large-format aerial surveys were conducted during June when dependent pups are more likely to be distinguishable from adults).

Aerial photography Large-format aerial photography allows investigators to count seals from a set of images taken at a consistent distance (altitude) from the seals without potential "blind spots" caused by land or ice features. Photographs can be taken with overlapping images so that a mosaic of the complete study area can be obtained for each sampling event, and so that ice movement can be taken into account. The ability to view seals from a vertical perspective, rather than obliquely from a shore-based observation site, removes many of the potential biases associated with sighting seals at variable distances from the shoreline. The photographs also represent a permanent record of the distribution of the seals within a fjord—a record that allows recounts or re-analyses of images. For example, the primary analyst was able to count seals in each image independently three times to estimate variance in the number of seals recorded; a secondary analyst was also able to count seals in a subsample of the same images to provide an independent verification of the final estimates. Aerial photography also offers one the ability to evaluate the spatial distribution of seals within a study area in relation to other seals (e.g., social interactions) and to environmental features (e.g., ice types or shifting ice patterns). A final advantage of using aerial photography is that researchers are not required to establish and maintain a remote field camp throughout the study period.

Future surveys of harbor seals in glacial fjords

The development of reliable methods for surveying harbor seal abundance in glacial ice habitats is a fundamental requirement for estimating the population size of these seals in Alaska. Conventional aerial surveys of harbor seals at terrestrial haul-out sites indicate that approximately 180,000 seals may be found at terrestrial sites. Preliminary counts of harbor seals from large-format photographs taken in glacial ice habitats throughout Alaska indicate that as many as 20,000 to 25,000 additional harbor seals may be using glacial ice habitats (J. L. Bengtson, unpubl. data). If 10% or more of Alaska's harbor seal population are using glacial ice habitats at various times of the year, monitoring trends in seal abundance in these areas will be very important to resource managers and to subsistence hunters in the Alaska Native community. In some regions, a much larger proportion of harbor seals may use glacial ice habitats. Within Glacier Bay, an average of 72% of harbor seals surveyed between 1992 and 2001 (2400–4700 seals per year) were found within glacial fjords during the breeding season (Mathews and Pendleton, 2006). At present, there are about 20 sites in Alaska where harbor seals are known to haul out in glacial ice habitats. Several of these fjords are of special interest to resource managers because 1) some local seal populations may be declining, 2) the fjords are important hunting areas to Alaska Natives, and 3) logistical difficulties have hampered past efforts to monitor changes in seal abundance with standard survey methods.

In the future, which survey methods seem most appropriate for monitoring the abundance of harbor seals in glacial ice habitats? Both shore-based counts and aerial photography are valuable methods for monitoring seals in glacial fjords, and each method has different limitations and potential applications. Unlike Johns Hopkins Inlet, many glacial fjords in Alaska do not have an overlook with such a full view of seal habitat, and thus large-format aerial photography may be the only option for surveying seals in these important breeding areas. The present study demonstrates that large-format aerial photography is a promising method for surveying the abundance of harbor seals using glacial ice habitats in Alaska.

Acknowledgments

L. Dzinich, O. Harding, K. Blejwas, and N. Tex provided field assistance with shore-based counts at Johns Hopkins Inlet. Funding for this project was provided by the National Park Service to E. A. Mathews and J. L. Bengtson and by the National Oceanic and Atmospheric Administration and the National Park Service to J. L. Bengtson. We thank M. Kralovec and M. B. Moss at the Glacier Bay National Park for their support in helping to secure funding. S. Slade at Leica GeoSystems provided technical assistance for Erdas Imagine for the aerial photography counts. S. Tackley produced Figures 2 and 3. This manuscript was improved by comments from J. K. Jansen, J. M. Waite, and three anonymous reviewers. This research was conducted under Marine Mammal Protection Act permits 527-1461, 782-1355, and 782-1676.

Literature cited

Boveng, P. L., J. L. Bengtson, D. E. Withrow, J. C. Cesarone, M. A. Simpkins, K. J. Frost, and J. J. Burns.
2003. The abundance of harbor seals in the Gulf of Alaska. Mar. Mamm. Sci. 19(1):111–127.

Calambokidis, J., B. L. Taylor, S. D. Carter, G. H. Steiger, P. K. Dawson, and L. D. Antrim.
1987. Distribution and haul-out behavior of harbor seals in Glacier Bay, Alaska. Can. J. Zool. 65:1391–1396.

Frost, K. J., L. F. Lowry, and J. M. Ver Hoef.
1999. Monitoring the trend of harbor seals in Prince William Sound, Alaska, after the *Exxon Valdez* oil spill. Mar. Mamm. Sci. 15(2):494–506.

Hoover, A. A.
1983. Behavior and ecology of harbor seals *(Phoca vitulina richardsi)* inhabiting glacial ice in Aialik Bay, Alaska. M.S. thesis, 132 p. Univ. Alaska, Fairbanks, AK.

Mathews, E. A.
1995. Longterm trends in abundance of harbor seals (*Phoca vitulina richardsi*) and development of monitoring methods in Glacier Bay National Park, Southeast Alaska. *In* Proceedings of the third Glacier Bay science symposium, Glacier Bay National Park & Preserve, P.O. Box 140, Gustavus, Alaska, U.S.A., Sept. 15–18, 1993 (D. R. Engstrom, ed.) p. 254–263. U.S. National Park Service, Anchorage, AK.

Mathews, E. A., and G. W. Pendleton.
2006. Declining trends in harbor seal *(Phoca vitulina)* numbers at glacial ice and terrestrial haulouts in Glacier Bay National Park, 1992–2002. Mar. Mamm. Sci. 22(1):167–189.

Olesiuk, P. F., M. A. Bigg, and G. M. Ellis.
1990. Recent trends in the abundance of harbor seals, *Phoca vitulina*, in British Columbia. Can. J. Fish. Aquat. Sci. 47:992–1003.

Pitcher, K. W.
1990. Major decline in the number of harbor seals *(Phoca vitulina)* on Tugidak Island, Gulf of Alaska. Mar. Mamm. Sci. 6(2):121–134.

Small, R. J., G. W. Pendleton, and K. W. Pitcher.
2003. Trends in abundance of Alaska harbor seals, 1983–2002. Mar. Mamm. Sci. 19(2):344–362.

Ver Hoef, J., and K. J. Frost.
2003. A Bayesian hierarchical model for monitoring harbor seal changes in Prince William Sound, Alaska. Environ. Ecol. Sta. 10:210–219.