Comparing Harbor Seal Survey Methods In Glacial Fjords

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Observers with the University of Alaska Southeast conducting shore-based counts of harbor seals in Johns Hopkins Inlet, Glacier Bay, Alaska.

Harbor seals (*Phoca vitulina richardsi*) 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 3,500 km east to west) and from 51°N to 61°N (over 1,000 km north to south), hauling out on a variety of substrates including sand, rock, and ice. Aerial surveys of harbor seals are most often conducted when peak numbers are hauled out, which usually occurs during the seals' annual molt during late summer. These surveys utilize low-altitude (100-300 m) photographs of harbor seal groups, from which seal counts are made.

Alaska harbor seal populations have declined at several locations in recent decades. For example, counts of harbor seals at Tugidak Island (southwest of Kodiak Island) declined 85% between 1976 and 1988, and counts in Prince William Sound suggest population declines of approximately 63% between 1984 and 1997.

More recent evidence indicates that harbor seals near Kodiak Island, including those at Tugidak Island, have increased 6.6% per year during 1993-2001, but seals in Prince William Sound have continued to decline at 3.3% per year during 1988-99. In Glacier Bay, harbor seal numbers declined by 75% (-14.5%/yr) from 1992 to 2002 at terrestrial resting sites and by 64% (-9.6%/yr) from 1992 to 2001 in Johns Hopkins Inlet, Glacier Bay, the primary breeding site, which is a glacial fjord.

Surveying seals in glacial fjords is difficult because the ice upon which seals haul out moves, large expanses of scattered ice offer little spatial reference to aid in counting seals, and there is often insufficient maneuvering room for low-altitude aerial surveys in the fjords. Because it is estimated that 10% or more of harbor seals in Alaska use glacial ice habitats during the molting season (August – September) each year, there is a pressing need to develop reliable survey techniques to assess harbor seal abundance in such areas. Here we evaluate two such survey methods: shore-based counts and large-format aerial photography.

Surveys of harbor seals in two glacial fjords in Glacier Bay National Park have been made from elevated shore sites in the past three decades and in Aialik Bay, a glacial fjord in the Gulf of Alaska.

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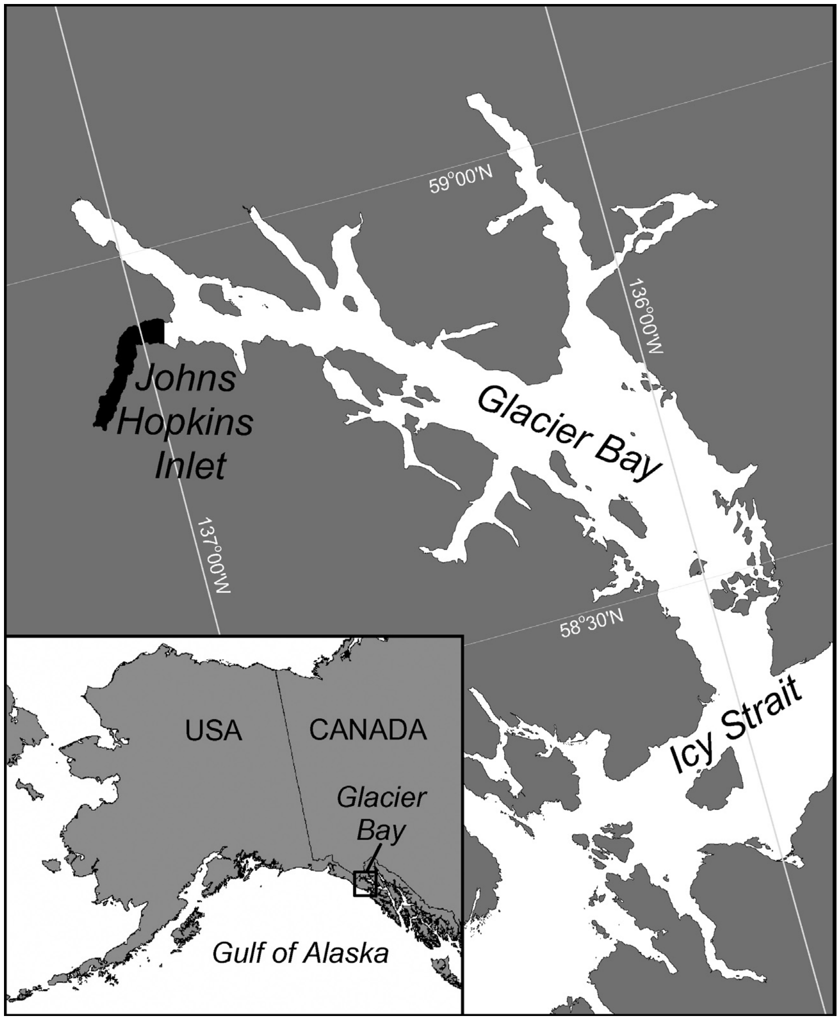

Figure 1. Glacier Bay, Alaska, showing Johns Hopkins Inlet and Johns Hopkins Glacier.

Until recently, a good method to compare to shore counts was not available. In 1997 a pilot study conducted by the Alaska Department of Fish and Game in Johns Hopkins Inlet 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 the current study we employed higher resolution film, conducted three simultaneous aerial and shore surveys (vs. one), and used different altitudes to test for sources of counting error within aerial photographs.

Methods

Study Area

Johns Hopkins Inlet is located in the northwest arm of Glacier Bay (58ºN, 138º30'W) (Fig. 1). At the head of the inlet is an active tidewater glacier, which currently is advancing. Harbor seals rest, nurse, and molt on ice calved from the glacier. 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.

Shore-Based Surveys

Observers counted seals from an elevated (ca 35 m above sea level) site located 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 northeastern edge of the inlet and a small area near the glacier face were not visible to the shore observers due to obstruction by headlands and other geographic features (i.e., "blind spots," Fig. 2a). Icebergs in the inlet, however, more commonly drifted closer to the east vs. west shore due to current and wind patterns, and this is one reason that the location of the observation site was selected. For each daily survey, two of the four observers involved in the survey simultaneously counted seals two or three times each day between 12-23 August 2001 and 9–26 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 photographic surveys conducted on 15 August 2001, 16 August 2001, and 15 August 2002. Surveys targeted the period around solar noon when the largest number of seals haul out on glacial ice.

Observers counted seals using 20 X 60 binoculars mounted on tripods. After the tripod was leveled, each observer 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 of the study area, observers divided the field of view into three or four subareas using either landmarks, natural breaks in the ice coverage, or arbitrary borders defined by sighting along tarp-supporting poles in front of the observation site. When a section pole or natural 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. 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 Photographic Surveys

Aerial photographic surveys were conducted on 15 and 16 August 2001 and 15 August 2002 by a commercial photographic surveying company (Aeromap U.S., Anchorage, AK). In 2001, three transects were flown over Johns Hopkins Inlet during each survey: two transects at 1,465 m altitude, covering the entire inlet, and an additional transect at 915 m altitude, covering the central portion of the inlet from Johns Hopkins Glacier to the point north of Jaw Point (Fig. 2b). In 2002, two transects were flown at 1,465 m covering Johns Hopkins Inlet from the glacier to Jaw Point; a lower-altitude, central transect was not flown (Fig. 2c).

During each survey, large-format (23 X 23 cm) photographic images were taken automatically at a predetermined rate on Agfa Aviphot Color X100 PE1 negative film, using a belly-mounted Zeiss RMK TOP 15 camera with forward-motion compensation (15 August 2001) or Zeiss RMK A 15/23 camera (16 August 2001 and 15 August 2002). The frame widths of the resulting images were 2,200 m for high-altitude (1,465 m) images and 1,400 m for low-altitude (975 m) images. The images had approximately 10% endlap within transects, 20% sidelap between high-altitude transects, and 75% sidelap between the central transect in 2001 and the

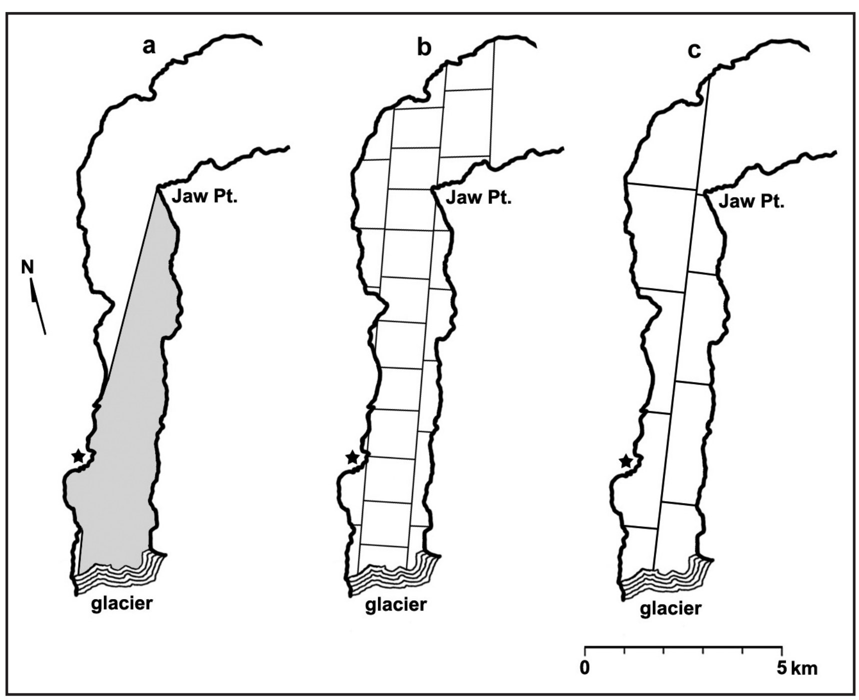

Figure 2. Survey coverage of Johns Hopkins Inlet, Glacier Bay, achieved by each survey type in this study. (a) Field of view (shaded area) observed from shore-based observation site (indicated with a star). Note that the northwestern edge of the inlet and a small area near the glacier are obscured from view ("blind spots") by geographic features. 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, endlap and sidelap between neighboring photographs is ignored in this figure, only the nonoverlapping areas of each image are shown. The central transect was flown at a lower altitude (915 m) than the two adjacent transects (1,465 m). (c) Photographic coverage of aerial transects (1,465 m altitude) flown on 15 August 2002, with overlap between neighboring photographs ignored.

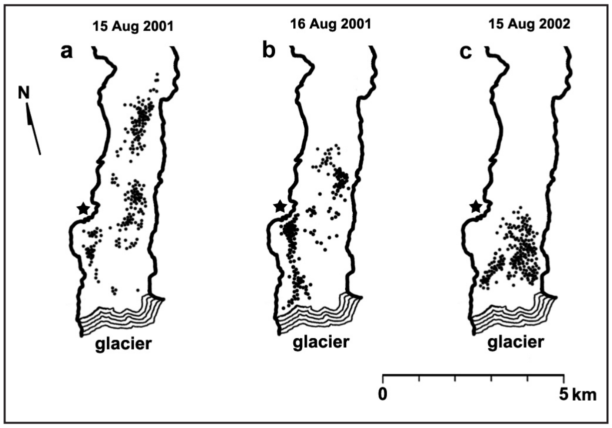

Figure 3. Relative distribution of patches of harbor seals in Johns Hopkins Inlet, Glacier Bay, determined by aerial photography, on a) 15 August 2001, b) 16 August 2001, and c) 15 August 2002. Dots indicate groups of seals and are meant to illustrate generalized locations of seals rather than a precise indication of seal abundance. The shore-based observation site is indicated with a star.

neighboring high-altitude transects. Large-format negatives were scanned at 1600 dpi using a digital scanner. The pixel resolutions of the resulting digital images were 0.10 m and 0.15 m for low- and high-altitude transects, respectively.

Seals were counted from the digital images 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 overlap 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 overlap zones was complex, particularly when ice moved substantially during the time that elapsed between neighboring photographs. Seals in overlap zones were only counted 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, so 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 tallying all the seals counted in each image. 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: 21 images on 15 August 2001, 30 images on 16 August 2001, and 11 images on 15 August 2002. Seals were counted independently for each replicate, and all replicates were counted by one analyst. 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. By comparison, the variance for shore-based counts was estimated as the variance among observers' total counts rather than subarea counts because the subareas were not necessarily consistent among observers for each survey.

Comparison of Seal Detection Rates at Different Altitudes

To compare the seal 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 the appropriate low- and high-altitude images, and classified seals as either: a) counted in both images, or b) counted in only one of the images. Seals counted in only one of the images were further categorized as follows: a) light-colored seal not detected in the other image; b) seal in a group not resolved as an individual in the other image; c) seal definitely not present in other image (e.g., seal went into the water or hauled out between transects); or d) 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. These 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 using aerial photography (Table 1). In contrast, both counting methods produced similar results in 2002. The standard errors (SEs) and coefficients of variation (CVs) presented in Table 1 reflect variance between counts

Table 1. Shore-based and aerial photographic counts of harbor seals at Johns Hopkins Inlet, Glacier Bay, 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	Mean count	SE	CV
15 Aug 2001	Shore-based	1406-1449	1,970	57.0	0.029
	Aerial	1457-1512	1,581	20.0	0.013
16 Aug 2001	Shore-based	1401-1439	1,906	192.5	0.101
	Aerial	1421-1442	1,294	25.6	0.020
15 Aug 2002	Shore-based	1249-1349	1,562	4.0	0.003
	Aerial	1231-1245	1,511	46.6	0.031

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 CVs were less than 0.08. Imprecision or inaccuracies 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 occurred in aggregations, although solitary seals were frequently observed outside of the main seal concentrations shown in Figure 3. On 15 August 2001, seals were distributed in groups of 200-500 animals, ranging from 1 km 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; another group of 300-400 seals occurred 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 occurred on the southwest side of the inlet, and the remaining 1,100-1,200 seals formed a dense concentration on the east side of the inlet (Fig. 3c). No seals were located in the shore observers' blind areas on any of the three survey days (Figs. 2a and 3).

Comparison of Seal 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. For the 15 August 2001 survey, 32.7% of the seals counted in the low-altitude images were misclassified in the high-altitude images, including 8.6% that were shadows or dirty ice misidentified as seals and 24.1% that were not detected in the high-altitude imagery; (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 resolved 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 for counts from higher-altitude images to underestimate the number of seals relative to those from lower altitudes.

Discussion

Comparison of Total Counts

Both shore-based and aerial counts indicate that more than 1,500 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. The total number of seals that utilize the inlet probably is 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 using 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 Method

Both counting methods were susceptible to common errors of either double-counting or missing seals. These errors were most likely within overlap zones between neighboring photographic images, between parallel passes with binoculars, or between shore-based counts of subareas. If overlap zones were not accurately delineated, individual seals within the overlap zone could be counted twice or missed entirely. The permanent record provided by photography allowed for careful delineation of overlap zones based on the relative positions of identifiable pieces of ice on adjacent images. Shore-based methodology did not allow reidentification of individual pieces of ice, so shore-based observers attempted to eliminate overlap by adjusting binoculars carefully. Seals could be missed, however, if the binoculars were lowered more than one field of view. Similarly, seals could be counted twice, if the binoculars were not lowered exactly one field of view before the second survey pass.

Counting errors could also be caused by movement of ice on which seals were hauled out. 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 on 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 context clues from recognizable pieces of ice aided identification and made us confident that seals on moving ice were properly counted. Shore-based observers could not track the movement of ice during each survey, so 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.

The distribution of seals could also influence counting errors. On both days surveyed in 2001, ice was distributed up to 6 km from the glacier terminus (Figs. 3a,b). In the aerial imagery, we observed considerable movement of ice between transects on these dates, 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-counted seals. In addition, seals were located up to several km from the shore-based observation site, increasing the likelihood of counting errors. These factors might explain the higher counts recorded by the shore-based observers in 2001 compared to the aerial photography results (Table 1). In contrast, the ice was more densely packed near the glacier terminus and was less mobile during the 2002 survey day than in 2001. Seals were located relatively close to the shore-based observation site, and in the absence of ice movement, the counts recorded by both methods were very similar (Table 1).

Counting errors could also be caused by misidentifying seals as shadows or dirty ice. Occasionally, ice ridges cast shadows that looked remarkably similar to seals. Some glacial ice contained veins of dirt that also had similar shape and color to 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 lower seal counts. 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, though this ability 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 similarly sized rocks or dirt.

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. Counts can also be made from land under suboptimal weather conditions, when aerial surveys are either impossible or when the resulting photography would be poor quality. Repeated surveys allow assessment of changes in seal counts related to covariates such as time of day, ice conditions, and weather. As noted above, real-time observations allow the observer to distinguish between actively moving seals and shadows or dirty ice, which is not possible with the static "snapshot" available from aerial photographs. If surveys are conducted when pups are nursing (generally during June in Alaskan waters), shore observers can identify seal pups based on size and relative position of seals within a group on an iceberg. By August, almost all pups are weaned, and the sizes of groups of seals on icebergs are much larger than in June, making it much more difficult to distinguish weaned pups or juveniles from adults except at very close range. The resolution of the aerial photographs in this August study was also 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 and without potential blind spots caused by land or ice features. Photographs can be taken with overlap so that a mosaic of the complete study area can be obtained for each sampling event, with ice movement 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, which allows recounts or reanalyses 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 also was able to count seals in a subsample of the same images to provide independent verification of the final estimates. Aerial photography also offers the ability to evaluate the spatial distribution of seals within a study area relative to each other (e.g., social interactions) and environmental features (e.g., ice types or shifting ice patterns). A final advantage to using aerial photography is that researchers are not required to establish and maintain a remote field camp throughout the study period.

Conclusion

Developing reliable methods for surveying harbor seal abundance in glacial ice habitats is a fundamental requirement for estimating the seals' population size 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 suggest that as many as 20,000 to 25,000 additional harbor seals may be using glacial ice habitats. If 10% or more of Alaska's harbor seal population is 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 subsistence hunters in the Alaska Native community. In some regions, a much larger proportion of harbor seals may utilize glacial ice habitats. Within Glacier Bay National Park, an average of 72% of harbor seals surveyed between 1992 and 2001 (2,400-4,700 seals per year) were found within glacial fjords during breeding. 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: a) some local seal populations may be declining, b) the fjords are important hunting areas to Alaska Natives, and c) logistical difficulties have hampered past efforts to monitor changes in seal abundance using traditional methods.

Both shore-based counts and aerial photography are valuable methods for monitoring seals in glacial fjords; however, 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 work presented here demonstrates that large-format aerial photography is a promising method for surveying the abundance of harbor seals using glacial ice habitats in Alaska.