Use of High-resolution, Medium Format Aerial Photography for Monitoring Harbor Seal Abundance at Glacial Ice Haulouts

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BACKGROUND

On July 2, 1997 we conducted an experiment to test the feasibility of using medium format, high-resolution aerial photographs to count harbor seals on glacial ice in Johns Hopkins Inlet in Glacier Bay National Park. A second objective was to compare the results of counts from photographs to a simultaneous direct count from an elevated observation site in Johns Hopkins Inlet. This experiment evolved from a collaboration between the Southwest Fisheries Science Center (NMFS, La Jolla, CA), the Alaska Department of Fish and Game, and Glacier Bay National Park. This report describes the methods and the results of the experiment.

INTRODUCTION

In Glacier Bay as well as in other parts of the state where active tidewater glaciers are present, harbor seals appear to prefer glacial ice over terrestrial haulout sites for pupping, nursing, and molting. Sixty to 70 percent of the 6,000-8,000 seals in Glacier Bay are observed in Johns Hopkins Inlet during aerial and shore-based surveys in the summer months (Mathews 1995). In the northeast Gulf of Alaska between Icy Bay and Cross Sound more than 50% of the 3,000-4,500 seals have been found on drifting icebergs, while the rest have been observed at terrestrial sites during aerial surveys in August and September (Loughlin 1994, Mathews and Womble 1997).

Harbor seal numbers in parts of the Gulf of Alaska declined by as much as 85% between 1976 and 1988 (Pitcher 1990), and numbers in the Gulf remain low (Frost *et al.* 1996, Jemison and Kelly 1997). While there is no question that seal numbers have declined in the Gulf of Alaska, the data used to monitor trends in the Gulf come only from terrestrial sites. Because there are active tidewater glaciers in the Gulf of Alaska and these are used by harbor seals, it is important to also monitor seal numbers at glacial ice haulouts in these regions. One of our goals was to determine if high-resolution aerial photography might be used to survey harbor seals in remote glacial fjords.

Glacier Bay is the only place in Alaska where there has been long-term monitoring of harbor seal abundance in glacial fjords (Muir and Johns Hopkins inlets) (Streveler 1979, Calambokidis *et al.* 1987, Mathews 1995, Mathews and Pendleton 1997). The method used in the 12 studies spanning 22 years (1975-1997) has been shore-based counts. The lack of regular survey data from other glacial ice fjords is largely due to the logistic complications of getting a field crew into these remote areas, or the lack of elevated observation sites that provide a sufficient view of the fjord. While 35mm cameras equipped with long lenses have been used for many years to photograph and count pinnipeds on terrestrial haulouts (Mathisen and Lopp 1963, Bonner 1976, Everitt and

Braham 1980), such systems do not cover areas large enough and with adequate resolution to count seals that are widely distributed over several square kilometers. High-resolution, military reconnaissance cameras, like the one used in this study, have been used to survey pinnipeds at terrestrial sites (DeMaster *et al.* 1988, Westlake *et al.* 1997); however this is the first application of this technique for counting harbor seals on glacial ice of which we are aware.

Johns Hopkins Inlet is where the vast majority of harbor seals aggregate in Glacier Bay during the breeding season. Because this species is the most abundant marine mammal in the bay, and because this inlet has elevated observation sites close to areas where seals and ice concentrate, the National Park Service conducted monitoring studies from 1975-1978 (Streveler, 1979), shortly after subsistence and bounty hunting the Park had ceased. Calambokidis et al. (1987) conducted research, which included several counts each day, on harbor seals in Johns Hopkins Inlet in the summer of 1984. Seasonal counts from shore were also made by NPS staff between 1983 and 1991, but in most cases the specific methods used are not known. Systematic monitoring supported by the NPS and the University of Alaska was initiated in 1992 and it has continued through 1997 (Mathews and Dzinich 1997).

METHODS

Study Area

Johns Hopkins Inlet is located in the northwest arm of Glacier Bay (58ºN, 138º30'W) (Figure 1). It is used by approximately 60-70% of the seals in Glacier Bay during pupping, breeding, and molting periods from spring to early fall (Mathews 1995). The shore-based observation site is located on an elevated (ca 30 m) knoll along the north shore of the Inlet, approximately 2.5 km east of the glacier face (Figure 1b).

Aerial Photography

On July 2, between 11:15 and 11:30 we took aerial photographs of seals in Johns Hopkins Inlet with a KA-76 military reconnaissance camera that we mounted vertically over a hole in the fuselage of a twin-engine AeroCommander aircraft. This camera has a fixed-focus 152 mm lens and an image motion compensation system that eliminates the loss of image resolution caused by the forward motion of the aircraft while the shutter is open. This system requires that the aircraft be equipped with a 28 volt DC system.

All photographs were taken using Kodak Aerochrome HS (SO-359) aerial film from an altitude of approximately 610 m (2000 ft). The cycle rate of the camera was adjusted to provide 60% overlap between sequential frames, and each frame covered a square area about 455 m X 455 m (1,500 ft X 1,500 ft). Four parallel passes were required to completely photograph the 1 km wide section of the inlet where seals were resting on ice. Each pass overlapped with the previous transect by approximately 15%. We began photographing each strip at the face of the glacier and stopped photographing when an observer looking out the side of the plane saw no more seals on the ice below or ahead of the transect.

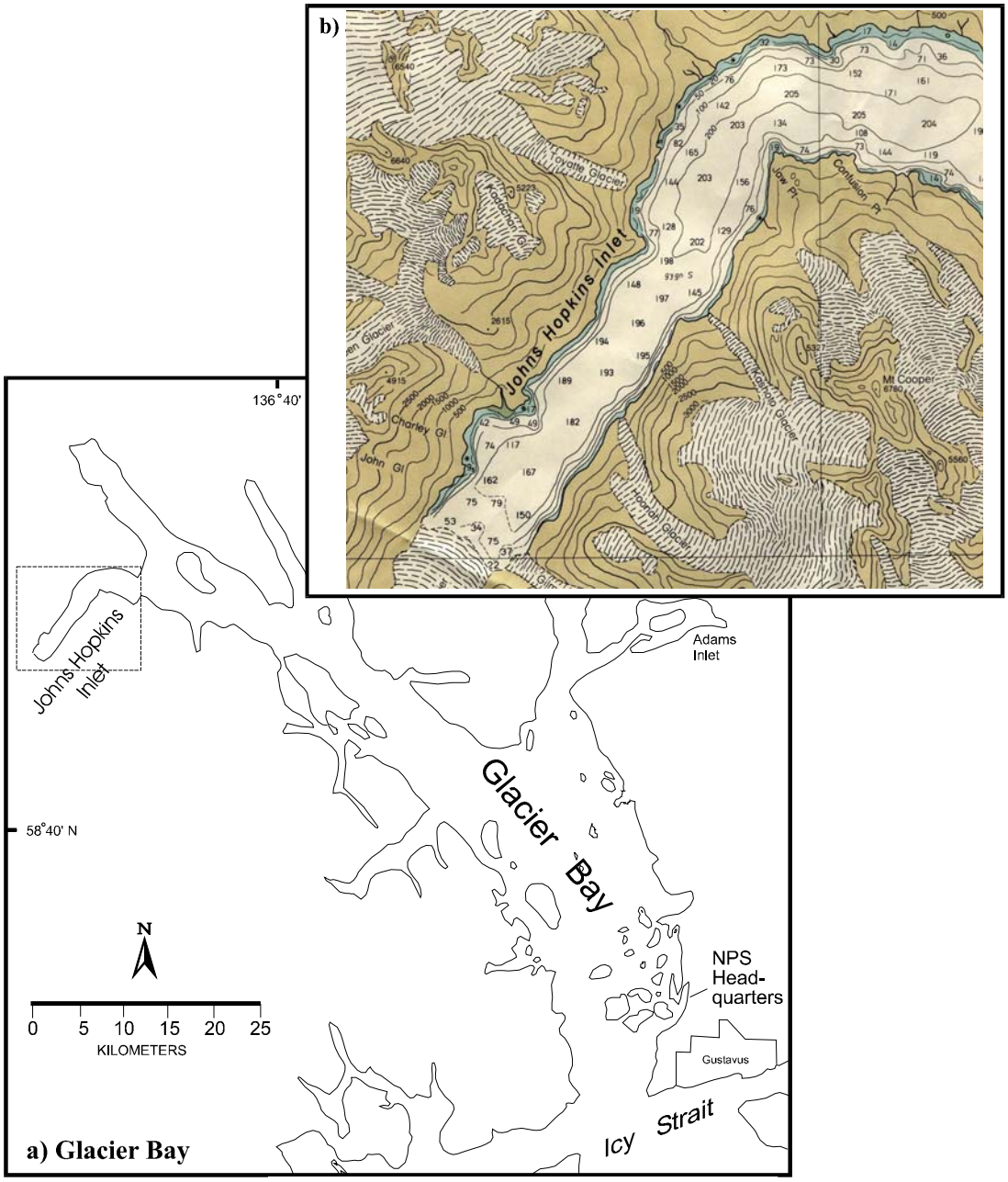

Figure 1. Map of Glacier Bay (1a) with a detail of Johns Hopkins Inlet (1b), an active tidewater glacial fjord.

Counts from Aerial Photographs

Seals were counted by viewing the original color transparencies through a dissecting microscope over a light table. A clear acetate sheet was attached over the first image in a pass series and each visible seal was marked on the acetate sheet and counted. No age class distinctions (i.e., pup vs. non-pup) were made during this assessment, although we plan to have experienced field observers count from these images so that pups and non-pups can be categorized.

As counts of seals in each frame within a pass were completed, the acetate sheet was moved to the next image on that pass and all marks of seals present in both images were checked and new seals were added to the count. Ice flows within the inlet were also outlined on the overlay to maintain orientation between frames and to help avoid duplicating counts of seals from adjacent passes.

Shore-based Counts of Seals

About an hour before the aerial photographs were taken on July 2, two experienced observers simultaneously counted seals in Johns Hopkins Inlet from the elevated observation (ca 30 m) site at the head of the Inlet (Figure 1b). The observers conducted their counts from 10:00-11:00 using methods similar to those employed at this site for several years (Mathews 1995, Mathews and Dzinich 1997). Observers categorized seals on ice as pups and non-pups (adults and juveniles). In addition to the paired count during the aerial photographic survey, the observers conducted 2 more paired counts on that same day. For each count, the observers began counting at the same time, and they did not consult with one another on their results until the end of the day.

After a count was completed, observers recorded a subjective ranking of the quality of their counts. The 'count quality' variable encompasses environmental conditions (i.e., lighting, heat waves), subtle distractions, and known disruptions (such as bumping the tripod or a distracting radio call) during a count. Ratings range from 1 for excellent to 7 for very poor, and ratings less than 4 have been excluded from abundance estimates and trend analyses. The observers had also conducted 2 paired counts of seals and pups on June 30 and July 1, 1997.

In Johns Hopkins Inlet, seals are typically dispersed over an area of more than 2 to 3 square miles, making systematic coverage of the long fjord with a narrow-field spotting scope or hand-held binoculars extremely difficult. To reduce errors associated with trying to systematically cover such a large area, we use 20 X 60 Ziess binoculars mounted on tripods, so that they can be moved systematically from side to side and then carefully lowered exactly one field of view. Compared to spotting scopes, the Zeiss binoculars have a sharper, larger field of view, and they greatly reduce eye strain. Additional details on the methods used during the shore-based counts are provided in other reports (Mathews 1995, Mathews and Dzinich 1997)).

During the shore-based counts, observers categorized seals as non-pups (adults and juveniles) or pups. Most pups were at least 3 weeks old by the time that the survey was

conducted. Pups at a distance are more likely to be missed than are seals on nearby icebergs, because they may be blocked from an observer's view by their mother or by a protruding piece of ice (Mathews 1995). To correct for this known bias, we routinely count a subset of 100 seals that happen to be within about ½ - 1 mile of the observation site. Five pup proportion assessment counts were made on July 2 between 11:12 and 11:34, within 15 minutes of the aerial photography of the Inlet.

Cost Comparison of the Two Survey Methods

In order to begin assessing the cost effectiveness of the 2 methods, we estimated the expenses for each method based primarily on how the work was accomplished for this pilot study, and as if one agency were planning on absorbing the full cost of the study. In 1997, 3 agencies (Southwest Fisheries Science Center, NMFS; Alaska Department of Fish and Game; and the National Park Service) contributed staff and funding to this pilot project, which was completed as an opportunistic addition to a sea lion pup survey in Southeast Alaska. As such, we do not have an exact accounting for the work.

In addition to a per day estimate for both methods, we have calculated the total costs for 3 days of surveys – considered a bare minimum for population estimation and inadequate for trend analysis – and for 8 days – considered adequate for population estimation or trend analysis. Multiple survey days are necessary due to the high between day variance in numbers of seals present. Because some expenses, such as travel, are fixed, the per-day costs decrease with additional survey days.

The assessment in Table 1 summarizes the total estimated costs of the 2 methods. Such information could be used in a cost-benefit analysis for implementing one or the other method based on budgetary considerations and the desired accuracy and precision of the results, assuming that both methods were an option.

Because costs could be reduced for each method, we also calculated a more conservative estimate for each method (Table 2). In Table 2, we assume that less time might be required for some of the photographic analysis after more experience was gained, and we used a lower hourly rate ($400/hr in Table 2) than the $550/hr charter rate quoted for a twin-engine aircraft out of Juneau.

During the shore-based counts for this project, one paid individual was in the field with the volunteer. Typically, during our work in Johns Hopkins Inlet, the principal investigator is also present for at least half of the 8 –14 day field sessions. Thus, for the purposes of comparing the estimated costs of the 2 methods, the principal investigator's salary is included for all days in the 3-day example and for only half of the time for the 8-day example (Tables 2 and 3).

RESULTS

Aerial Photography

Harbor seals were visible in the photographs taken from 610 m (2000 ft). The total number of seals observed in the aerial photographs was 2,153, including pups and non-pups as well as seals observed in the water; however, very few seals were visible in the water.

Shore-based Counts

The numbers of seals hauled out on ice and counted by the 2 observers during the flight on July 2 were 1,737 and 1,656 seals and pups (Table 3). The mean proportion of pups observed in nearby sub-samples was 24.5% (SD = 2%, n = 5). To derive a corrected count, we multiplied the number of non-pups observed by 24.5% and added this value to the number of non-pups. The corrected totals for each of these counts were 1,916 and 1,960 seals and pups (Table 3). Table 3 also includes the counts from the other 2 days.

Table 3. Results of shore-based counts of harbor seals in Johns Hopkins Inlet from June 30 to July 2, 1997. The aerial photographic survey was flown from 11:15-11:30 on July 2.

									W/ Corrected Pup Proportion*			
	Count Duratio	Hauled Out		In the Water		Uncorrected Totals					Count	
Date	Start - End	Non-Pups	Pups	Non-Pups	Pups	Non-Pups	Pups	TOTAL	Pups	TOTAL	Qual	Obsrvr
6/30	9:45 - 10:53	1387	118	14	2	1401	120	1521	343	1744	2.5	1
	9:58 - 11:02	1492	284	4	0	1496	284	1780	367	1863	4	2
	14:12 - 15:13	1894	151	8	0	1902	151	2053	466	2368	3	1
	14:17 - 15:25	2086	97	4	0	2090	97	2187	512	2602	3	2
7/1	9:57 - 10:53	1660	125	9	0	1669	125	1794	409	2078	1.5	1
	10:05 - 11:01	1724	129	11	0	1735	129	1864	425	2160	2	2
	13:42 - 14:38	1630	172	7	1	1637	173	1810	401	2038	3	1
	13:54 - 14:49	1699	136	9	0	1708	136	1844	418	2126	3	2
7/2	**10:00 - 10:55**	**1531**	**197**	**8**	**1**	**1539**	**198**	**1737**	**377**	**1916**	**1.5**	**1**
	10:09 - 11:01	**1569**	**82**	**5**	**0**	**1574**	**82**	**1656**	**386**	**1960**	**2**	**2**
	13:32 - 14:34	1713	207	23	1	1736	208	1944	425	2161	2	1
	13:41 - 14:44	1652	193	11	0	1663	193	1856	407	2070	2	2
	16:58 - 17:50	1227	107	29	0	1256	107	1363	308	1564	2	1
	17:05 - 18:01	1491	100	16	0	1507	100	1607	369	1876	2	2

DAYS ANALYZED	UNCORRECTED TOTALS		CORRECTED TOTALS
ALL COUNTS (n=14)	**Mean =**	1787	2038
	St Dev =	210	257
	95% CI =	1376-2198	1534-2540
JULY 2 COUNTS (n=6)	**Mean =**	1531	1925
	St Dev =	169	206
	95% CI =	1199-1862	1521-2327
JULY 2 (n=2)	**Mean =**	1550	1938
	St Dev =	27	31
	95% CI =	1199-1862	1822-1998

Comparison of the Results from the Two Methods

The aerial photographic count (2,153) of seals (pups + non-pups) was 21% higher than the average of the 2 observer's uncorrected counts (1,697) and 10% higher than the average of their corrected counts (1,938). If we use the higher of the 2 shore-based counts, rather than the mean, the differences are 19% and 9%, respectively (Figure 2).

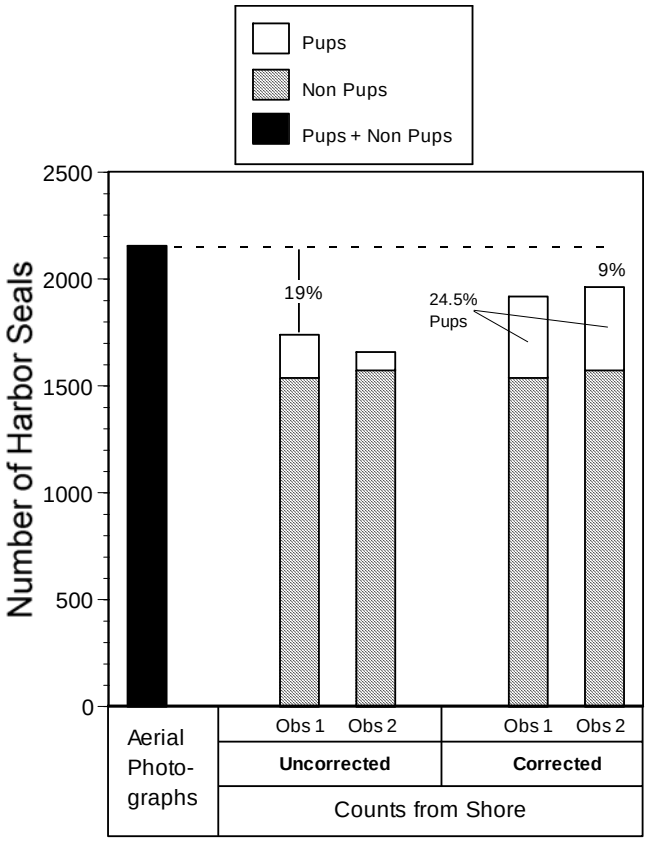

Figure 2. Comparison of results from counts of harbor seals from high-resolution aerial photographs and from shore-based counts by 2 observers that have not been corrected for missing pups and those that have been corrected for missed pups. The counts were all made within an hour of one another on July 2, 1997 in Johns Hopkins Inlet. The percent difference between the high uncorrected and corrected counts were 19% and 9%

Cost Comparison of the Two Methods

The shore-based counts were much less expensive than counts from aerial photographs (Tables 2 and 3). The estimated cost of conducting 3 aerial photographic surveys and analyzing the photographs is approximately $8,500, compared to about $1,550 for the same number of days of shore-based surveys (Table 2). Eight aerial photographic counts from different days were estimated at $21,350, compared to $2,720 for 8 days of shore counts which would produce 2 – 3 paired counts per day (Table 2). Thus, aerial photographic surveys would cost about 6 times more than shore-based surveys for 3 days, and 8 times more for an 8-day survey (Table 2). Due to fixed project costs, proportional differences change with additional survey days.

If cost-saving measures are employed for each study, then the proportional differences between the two methods are slightly less. A 3 day photographic survey would be about 4 times more than shore counts, and an 8 day survey would cost about 6 times more (Table 3).

Table 2. Cost estimates for counts of harbor seals at a glacial ice haulout using medium format aerial photography (A) compared to direct counts from an elevated field camp (B).

A. Counts from Aerial Photographs (1 count per day)

	Costs For:		
Salaries and Per Diem	**1 day**	**3 Days**	**8 Days**
Photographer, GS 11, permanent	$224	$672	$1,792
Per Diem, Photographer and Pilot	$220	$660	$1,760
Analysis, GS 5 (3 days per survey day)	$312	$936	$2,496
Photography			
Film, Kodak Aerochrome (~1/3 Roll)	$288	$865	$2,307
Developing (~1/3 roll)	$150	$450	$1,200
Charter, Twin Engine (2.5 hrs, $550/hr)	$1,375	$4,125	$11,000
Transportation (Fixed Expense)			
Airfare, Photographer (California-Alaska)	$800	$800	$800
Totals =	**$3,369**	**$8,508**	**$21,355**

B. Counts from an Observation Site (2-3 paired counts per day)

	Costs For:		
Salaries and Per Diem	**1 day**	**3 Days**	**8 Days**
Principal Investigator, GS 11 seasonal	$192	$576	$1,152
Biotechnician, GS 5 seasonal	$104	$312	$624
Data Entry (1 hr per field day)	$16	$48	$96
Food and Supplies			
Food (3 people)	$30	$90	$180
Field Supplies, miscellaneous	$50	$150	$300
Transportation (Fixed Expenses)			
Airfare, Volunteer	$120	$120	$120
Transport to/from Field Site	$250	$250	$250
Totals =	**$762**	**$1,546**	**$2,722**
Ratio of Cost of Aerial Photography to Cost of Shore-based Count =	**4**	**6**	**8**

Table 3. Minimal cost estimates for counts of harbor seals at a glacial ice haulout using medium format aerial photography (A) compared to direct counts from an elevated field camp (B).

A. Counts from Aerial Photographs (1 count per day)

	Costs For:		
Salaries and Per Diem	**1 Day**	**3 Days**	**8 Days**
Photographer, GS 11, permanent	$224	$672	$1,792
Per Diem, Photographer and Pilot	$150	$450	$1,200
Analysis, GS 5 (2 days per survey day)	$208	$624	$1,664
Photography			
Film, Kodak Aerochrome (~1/3 Roll)	$288	$865	$2,307
Developing (~1/3 roll)	$150	$450	$1,200
Charter, Twin Engine (2.5 hrs X $400)	$1,000	$3,000	$8,000
Transportation (Fixed Expense)			
Airfare, Photographer (California-Alaska)	$800	$800	$800
Totals =	**$2,820**	**$6,861**	**$16,963**

B. Counts from an Observation Site (2-3 paired counts per day)

	Costs For:		
Salaries and Per Diem	**1 Day**	**3 Days**	**8 Days**
Principal Investigator, GS 11 seasonal (* PI on site for 4 of 8 days)	$192	$576	768*
Biotechnician, GS 5	$104	$312	$832
Data Entry (1 hr per field day)	$16	$48	$128
Food and Supplies			
Food (3 people)	$30	$90	$240
Field Supplies, miscellaneous	$50	$150	$400
Transportation			
Airfare, Volunteer	$120	$120	$120
Transport to/from Field Site	$150	$150	$150
Totals =	**$662**	**$1,446**	**$2,638**
Ratio of Cost of Aerial Photography to Cost of Shore-based Count =	**4**	**5**	**6**

DISCUSSION

The counts from the medium format aerial photographs were 19% (uncorrected) to 9% (corrected count) higher than the higher of the 2 shore-based counts. Because seals were unlikely to have been missed from the vertical vantage in the high-resolution photographs, we believe that the count of harbor seals on glacial ice from aerial photographs was more accurate than the systematic counts from shore. In areas where counting seals from an elevated shore site is an option, the high relative cost of medium format aerial photography as used in this study may preclude its use for annual monitoring. Yet, aerial photographs should be considered for testing the accuracy and precision of other methods for surveying harbor seals on glacial ice, and in many areas aerial photography may be the only method that can provide accurate counts in these habitats. In addition, there may be ways to modify the methods used in this study to reduce the costs and analysis time for medium-format aerial photography.

Because we only had data to compare one survey day, we do not yet know the precision of the shore-based counts. If these are determined to predictably underestimate the actual numbers of harbor seals in Johns Hopkins Inlet, then a correction factor (with an associated coefficient of variation) could be calculated and applied. We recommend that a follow-up study be conducted to determine the precision of the shore-based counts, as their relative low cost makes them an optimal monitoring method for some glacial fjords.

Pups were not distinguished from non-pups in the aerial photographs, mainly because the person who counted seals from these images had no on-the-ground experience making these distinctions. We plan to test our assumption that much of the error in the shore-based counts was from pups that were not visible to the observers due to their low angle relative to water level.

In Glacier Bay, seal numbers in Johns Hopkins Inlet in August increased by 7% (95% CI= 1.7 – 12.4%) per year from 1992-1996, yet the trend in abundance at terrestrial haulouts in other parts of Glacier Bay from 1992-1996 declined by 8.6% (-11.7 to -5.6%) per year (Mathews and Pendleton 1997). If surveys in Glacier Bay had not included Johns Hopkins Inlet, we might have concluded that there was an overall decline in seal abundance at haulouts in the Park. Yet, it appears that seal numbers throughout Glacier Bay are stable or possibly increasing. Monitoring seal abundance in glacial fjords is necessary to avoid confusing a real decline in a population with a possible shift in distribution.

We believe that the use of medium format aerial photography has several beneficial applications for monitoring harbor seals that haul out on glacial ice in Alaska. In areas where an elevated shore site with a full view of the seals is not available or where the logistics and costs required for establishing a field camp are prohibitive, aerial photographic surveys using a high-resolution, medium format camera can provide accurate counts of seals in these important habitats.

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We are very grateful to Betsy Kunibe who volunteered for several days to assist with the counts of harbor seals from shore. We thank our pilot, Tom Blaesing, for his skill and safe flying. This opportunistic project would not have happened without Ken Pitcher's, Lloyd Lowry's, and Bob Small's (Alaska Department of Fish and Game) support. Margaret Goodro (NPS) graciously provided essential logistic support for the field crew, and we thank Morgan Lynn (SWFSC, NMFS) for his analysis of the aerial photographs. Rusty Yerxa's (NPS) comments improved an earlier draft of this report.

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