Pages 57-76 *in* Small, R.J. (ed.). 1997. Harbor Seal Investigations in Alaska, Annual Report, Alaska Department of Fish and Game, Division of Wildlife Conservation, 333 Raspberry Road, Anchorage, Alaska 99518

ESTIMATION OF TRENDS IN ABUNDANCE OF HARBOR SEALS AT TERRESTRIAL AND GLACIAL ICE HAULOUTS IN GLACIER BAY NATIONAL PARK, SOUTHEAST ALASKA, 1975-1996

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INTRODUCTION

Johns Hopkins Inlet, a tide-water glacial fjord in Glacier Bay National Park in Southeast Alaska, is used by approximately 3,000-4,000 harbor seals *(Phoca vitulina richardsi)* during pupping and molting, and it currently comprises the largest documented breeding aggregation of harbor seals remaining in Alaska due to declines in other parts of the state (Calambokidis *et al.* 1987, Hoover-Miller 1994, Mathews 1995). Approximately 70-80% of the seals in Glacier Bay rest, give birth, nurse, or molt on drifting icebergs in Johns Hopkins Inlet. In addition, roughly 1,000-1,500 (20-30%) seals rest and pup at 20-30 terrestrial haulouts in other parts of the bay (Mathews 1995). Park-wide counts of seals that rest on these two different substrates were initiated in 1992 through a collaboration between the National Park Service (NPS) and the National Marine Mammal Lab of NMFS (Mathews 1992, Mathews 1995).

Harbor seal numbers in parts of the Gulf of Alaska declined by as much as 85% between the mid-1970s and 1988 (Pitcher 1990), and declines at terrestrial haulouts in Prince William Sound have also been detected (Frost *et al.* 1996). Declines have not previously been detected in Southeast Alaska where harbor seal numbers have appeared to be stable or increasing (Lewis *et al.* 1996, Mathews 1995). Although declines in harbor seals as well as sea lions and sea birds have been linked to changes in prey abundance or availability, the specific causes of these declines in the Gulf of Alaska, Aleutian Islands, and the Bering Sea have not been fully elucidated (Loughlin and Merrick 1988, Merrick 1995, Springer 1993).

The status of harbor seals in Glacier Bay is of local as well as regional interest, because at least three factors that could influence population trends are unique to the Park as compared to other parts of Alaska. Glacier Bay National Park is the only place where subsistence hunting of harbor seals is prohibited in Alaska. A second potential factor is that NPS regulations prohibit all vessels from entering Johns Hopkins from June 1 to July 31, during the peak of pupping and the 3-6 week lactation period (Bigg 1969). Finally, surveys of harbor seals in Johns Hopkins Inlet – the only glacial ice haulout for harbor seals that has been monitored for more than a few years – span more than two decades and provide a valuable opportunity to evaluate long-term trends in seal numbers at this important breeding site (Calambokidis *et al.* 1987, Streveler 1979, unpublished NPS reports).

To assess long-term and recent trends in harbor seal numbers in Glacier Bay, we analyzed data from 1975-1978 (Streveler 1979), 1983 (Sharman and Babcock unpublished NPS data), 1984 (Calambokidis unpublished data), and 1992-1996. We used continuous covariates to improve the sensitivity of the surveys to detect changes in numbers of seals; this type of analysis reduces the variation in counts resulting from factors not related to real changes in population abundance. Improved sensitivity to changes in the numbers of seals at glacial ice and terrestrial haulouts in Glacier Bay is desirable both because harbor seal numbers have declined significantly in other parts of the State, and because national parks are mandated to monitor and preserve their natural resources.

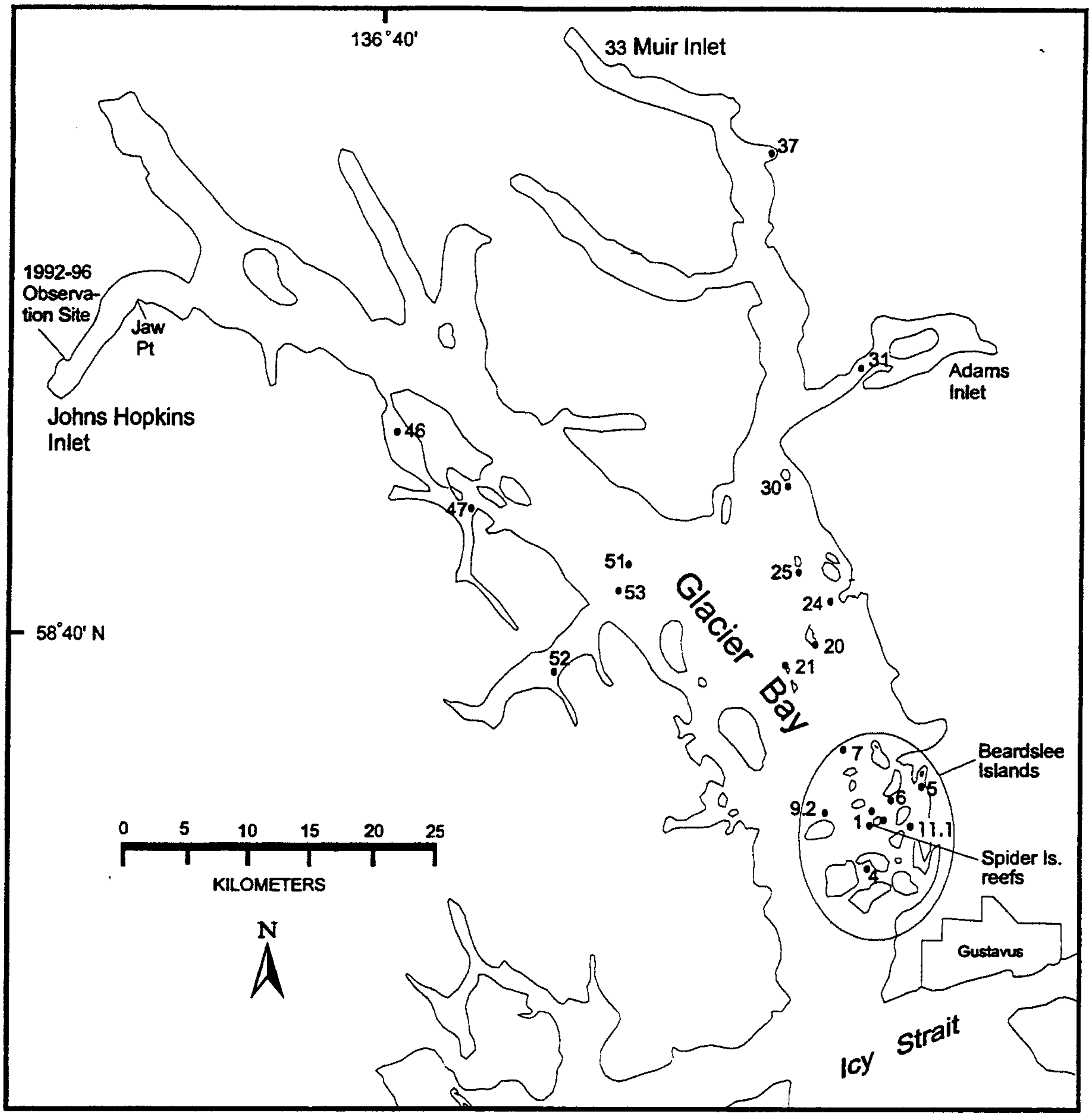
In this report we present the results of an analysis of recent surveys of both the glacial ice and terrestrial habitats used by harbor seals in Glacier Bay, and we compare recent counts from Johns Hopkins Inlet to survey data spanning more than two decades.

METHODS

Study Area

Johns Hopkins Inlet is located in the northwest arm of Glacier Bay (58°N, 138°30'W) (Figure 1). It is used by approximately 70% of the seals in Glacier Bay during pupping, breeding, and molting periods from spring to early fall (Mathews 1995). Glacial ice bergs in the upper reaches of Muir Inlet (Figure 1) were used by up to 1,000 seals during pupping and molting from the mid-1970s (Streveler 1979) to as recently as 1984. (Calambokidis *et al.* 1987). But, by 1992 the tide-water glacier at the head of the inlet had grounded and no seals have been observed on icebergs at this site since then (Mathews 1995)

In addition to Johns Hopkins Inlet, there are 20-30 regularly used terrestrial haulouts throughout the bay that have been identified in the last two decades (Lentfer and Maier 1989, Mathews 1992, NPS unpublished data); however, only about 20 of these have been occupied during the August surveys described in this report (Figure 1). More than half of the seals observed at terrestrial haulouts during the August surveys have been found on the reefs and low islands to the west of Spider Island, in the Beardslee Island Wilderness area (Site 1, Figure 1).



1) Spider Island reefs
4) Secret Bay
5) Hutchins Bay
6) Link Is, reef to SE
7) Flapjack Island
9.2) Sita Reef
11) Kidney Stone Islet
20) Leland Island
21) N. Marble Island
24) Sandy Cove Rock
25) Sturgess Island
30) Garforth Island
31) Adams Inlet
33) Muir Inlet (ice)
37) McBride Glacier (ice)
46) Skidmore Inlet
47) Hugh Miller Inlet
51) Lone Island
52) Tyndall Rock
53) Geikie Rocks

Figure 1. Map of Glacier Bay with the main terrestrial haulout sites used during August surveys between 1992 and 1996. Johns Hopkins and Muir Inlets are tidewater glacial fjords where seals currently (Johns Hopkins Inlet) or historically (Muir Inlet) have congregated in large numbers during spring and summer.

Shore-based Counts of Seals on Glacial Ice, 1975-78 and 1983-84

Each year from 1975 through 1978, Streveler (1979) counted harbor seal pups and non-pups (adults, juveniles, and yearlings) using a 30 power tripod-mounted spotting scope from three different elevated observation sites in Johns Hopkins Inlet for two to four days in mid-June (Table 1). Because seals were widely distributed in the Inlet and beyond Jaw Point (Figure 1), each count required one or two relocations to a different overlook. Thus, there was only enough time for one count in the morning and a second in the afternoon. G. Streveler conducted all of the counts, while an assistant recorded the data (Streveler pers. comm.). Prior to these counts, Streveler had several years of experience from counting and observing seals in Muir Inlet and elsewhere in Glacier Bay. We felt that these counts were reliable for evaluating long-term trends for several reasons: (1) all counts were by one experienced individual; (2) the daily variance of the counts was relatively low (Table 1); and (3) there were written methods available describing the work.

Table 1. Dates, methods, haulout substrate, and sources of harbor seal survey data included in this analysis. For the counts of seals in Johns Hopkins Inlet (JHI), n = sum of daily counts; for the aerial surveys, n = number of survey days.

Substrate (method)	Year	Month	Days of Mo.	n	Mean	St Dev	95% Conf Int
1) Glacial Ice, JHI	1975	June	19-20	2	1442	19	1403 - 1480
(shore-based counts)	1976	June	19-22	7	1923	183	1556 - 2289
	1977	June	15-18	4	2330	211	1908 - 2751
	1978	June	18-20	3	3305	128	3050 - 3560
2, 3) Glacial Ice, JHI	1983	August	10-13	12	2750	621	1508 - 3993
(shore-based counts)	1984	August	7-16	10	3464	1150	1165 - 5764
4) Glacial Ice, JHI	1992	June	17-18	3	2565	13	2538 - 2565
(shore-based counts)	1993	June	14-17	6	3260	1025	1209 - 3260
	1994	June	16-20	18	2497	273	1951 - 2497
	1995	June	14-17	14	2280	394	1492 - 2280
	1996	June	13-18	13	2975	501	1974 - 2975
5) Glacial Ice, JHI	1992	August	20-23	14	3833	983	1868 - 5799
(shore-based counts)	1993	August	23-24	3	3361	1032	1297 - 5425
	1994	August	10-16, 29-30	28	3065	549	1966 - 4163
	1995	August	9-21	40	3170	552	2065 - 4275
	1996	August	13-20, 21-26	32	3430	531	2367 - 4493
6) Terrestrial	1992	August	27, 28	2	1705	164	1377 - 2033
Haulouts	1993	(no survey)					
in Glacier Bay	1994	August	10-12	4	2095	296	1503 - 2688
(aerial surveys)	1995	August	1,8,10	3	2169	260	1649 - 2689
	1996	August	11,19-21,29,31	6	902	668	0 - 2239

References: 1) Streveler 1979, 2) 1983: Sharman and Babcock, NPS unpublished data,
3) 1984: Calambokidis, 4-6) Mathews

In 1983 from August 10-13, L. Sharman and E. Babcock (described in Dudgeon and Swartbeck 1988, unpublished report) counted seals in Johns Hopkins Inlet following methods similar to those described by Streveler (1979), although they were able to count from the same single elevated site used in recent surveys rather than having to move from one site to another. The two observers took turns counting and recording, so no simultaneous paired counts were made. We included these data in our trend analysis because one of the observers (Sharman) had previously conducted counts of seals in Johns Hopkins Inlet, and there were clear descriptions of their methods, which were similar to those used by Streveler (Sharman and Brown 1983 and Dudgeon and Swartbeck, 1988, NPS unpublished reports).

In 1984, J. Calambokidis led a team of students in a multifaceted study of harbor seals in Glacier Bay, including daily counts of seals in Johns Hopkins Inlet from August 7 to 16 (Calambokidis *et al.* 1997). One to three counts per day were made by an individual using binoculars or spotting scopes from several elevated sites on shore between 07:00 and 22:00.(Calambokidis *et al.* 1987). Only the daily high counts were used in this analysis, and we did not have the time of each count as we did for other data sets (Calambokidis, unpublished data). We included these data in our trend analysis because: 1) Calambokidis and his assistants had also conducted studies of seals in Muir Inlet prior to 1984, 2) observers were trained by these experienced observers, and 3) the methods and results from this work have been published. The mean value and 95% confidence intervals from these daily high counts are summarized in Table 1.

Shore-based Counts of Seals on Glacial Ice, 1992-1996

From 1992 to 1996, we conducted shore-based counts of harbor seals in Johns Hopkins Inlet and aerial surveys for seals at terrestrial haulouts throughout Glacier Bay; results from some of this work have been reported elsewhere (Mathews 1992, Mathews 1995, Mathews and Kelly 1996). Since 1992, aerial surveys and shore-based counts in Johns Hopkins Inlet have been conducted in August, during the annual molt when seals spend a higher proportion of time at haulouts (Calambokidis *et al.* 1983, Johnson 1979). We also conducted shore-based counts of seals in Johns Hopkins Inlet in mid-June, after most pups are born, from 1992-1996.

From mid-June and mid-August of 1992 through 1996, a team of observers has counted seals in Johns Hopkins Inlet from an elevated (ca 20 m above sea level) land site located about 2.5 km from the face of the glacier (Figure 1). Two observers simultaneously count seals from this elevated site. Typically two to four paired counts were made each day with at least one paired count between 10:00 and 14:00, because Calambokidis *et al.* (1987) found that seal numbers in Muir and Johns Hopkins Inlet peaked around midday during summer months. For the June counts, seals were categorized as adults or pups in all years except 1993 when only adults were counted. In August, no age class distinction was made, because older weaned pups are difficult to distinguish from adults at a distance.

In Johns Hopkins Inlet, seals are typically dispersed over an area of more than two to three 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 losing one's place during a count, we mounted either monocular spotting scopes (1992 and 1993) or 20 X 60 Ziess binoculars (1994-1996) on tripods and also divided our field of view into four subsections for more systematic counting. The 20 X 60 binoculars are optically superior to the spotting scopes. Details of the methods used during these counts are provided by Mathews (1995).

Aerial Photographic Counts of Seals at Terrestrial Sites, 1992-96

In 1992 and from 1994-1996 aerial surveys of the terrestrial haulouts in Glacier Bay were flown during monthly low tide cycles during the molt in August. Aerial surveys of terrestrial haulouts were scheduled to occur while there was a field crew in Johns Hopkins Inlet, although in 1992 the surveys occurred four days after the counts in Johns Hopkins Inlet (Table 1).

During aerial surveys we attempted to check all known haulouts and to search for undocumented or new haulouts; however, weather conditions occasionally prevented complete surveys of the bay. Surveys were flown at about 303 m (1000 ft), and observers scanned each haulout, often with binoculars, for seals. When seals were located, we reduced our altitude to about 212 m (700 ft) with the haulout at about a 45 degree angle from the photographer's side of the plane. Photographs were taken through an open window with an SLR camera equipped with a motor drive and either an 80-200 mm zoom lens, or a 300 mm fixed lens. We used 200-400 ASA slide film, and most photographs were taken at 1/250 second or faster.

For each haulout we recorded the location, time, film frame numbers, and made a visual estimate of the number of seals. For known haulouts, we also noted if seals were not present (a '0' in the database), or if we were unable to survey a haulout due to bad weather (a null value). We also made general comments about weather conditions, and beginning in 1995 we recorded outside air temperatures periodically during surveys.

Groups of seals at all haulouts were small enough to fit in one frame, except at the Spider Island reefs where we took a series of overlapping photographs to include all seals on the haulouts. The sharpest slide or slide series was selected for counting seals. We counted seals by projecting slide images onto white paper so that each animal could be marked. Verification counts were made for each haulout until two identical counts were obtained or, for haulouts with >100 seals, until at least two counts differed by no more than four seals. We found that counting accuracy of the larger haulouts is improved by using a handheld digital counter.

Because the earlier counts (1975-1978) were conducted in June, whereas those from 1983, 1984 and 1992-1996 were made in August, not all time periods could be compared to others. The time periods included in the trend analysis are summarized in Table 2.

Table 2. Time periods, month, and age groups counted during surveys for harbor seals in Glacier Bay by haulout substrate, survey method used, and location (JHI: Johns Hopkins Inlet, Muir: Muir Inlet, and GB: Glacier Bay, excluding Johns Hopkins Inlet).

Glacial Ice (shore-based counts):

Loc	Years	Month	Groups Counted
JHI	1975-1978	June	non-pups and pups
JHI	1983-1996	Aug	all seals
JHI	1992-1996	Aug	all seals
JHI	1992-1996	June	non-pups only
Muir	1973-1978	June	non-pups and pups

Terrestrial Haulouts (aerial surveys)

Loc	Years	Month	Groups Counted
GB	1992, 1994-96	Aug	all seals

Estimation of Trends in Seal Numbers

During all surveys, some harbor seals are in the water and unavailable for counting. Consequently, aerial and shore-based surveys of seals at their haulouts measure only a proportion of the population. If survey methods and timing are standardized and the proportion of animals counted remains fairly constant, such surveys can be used as reliable indices of population trends. Yet, pinniped surveys are inherently fraught with the potential for high variance between days and years, due to environmental and behavioral factors that influence the number of seals at haulouts. In addition, harbor seals respond to environmental variables differently depending upon the haulout substrate. For example, seal numbers at glacial ice haulouts, unlike most terrestrial sites, do not fluctuate with tide height; instead, they tend to peak around midday (Calambokidis *et al.* 1987) or they may remain relatively high from mid-morning to evening (Calambokidis *et al.* 1983). Thus, we considered a different set of potential environmental and observer-related covariates for surveys of seals resting on these two substrates. In addition, the two methods used to survey seals in Glacier Bay, aerial photography at the terrestrial sites and shore-based counts at the primary glacial haulout, present different potential sources of variation.

An estimate of population trend based on aerial or shore-based surveys must account for the variation in those counts which results both from real changes in population abundance as well as factors that affect the proportion of the population visible during surveys. Rather than assume a constant proportion of seals was visible, and thus observed during each survey, we modeled counts as a function of environmental (e.g., height of low tide, time of day) and other (e.g., optical equipment used during shore-based counts, observer skill level, and count quality) variables. The environmental covariates used in our analysis of the data from aerial surveys of terrestrial haulouts from 1992 –1996 included date, time of day, tide height at the nearest (in time) low tide, time relative to low tide, and time relative to sunrise. These are the same covariates investigated by Frost *et al.* (unpublished), however we structured all covariates as continuous whereas they used categorical versions of these variables.

We considered an overlapping, but different suite of covariates in the analysis of seal count data from shore-based surveys of glacial ice haulouts in Johns Hopkins Inlet. These were: date, time of day, observer experience, count quality, and two categories of optical equipment.

Observer levels in most cases changed with time, and they were categorized in all years as follows:

Level 1: experienced harbor seal observer or an individual who had conducted at least four counts and whose results were within at least 20% of those of a more experienced observer on at least two recent counts.

Level 2: moderately experienced observers who had completed at least two counts and whose previous counts were within at least 20% of those of a more experienced observer or within 20% of a same-day count; any observer who had counted seals in more than one season.

Level 3: beginning observers are individuals who had not yet counted more than twice, or individuals whose counts had not been within 20% of a more experienced observer's counts for at least two recent counts. Counts by Level 3 observers were not used in this analysis.

Count quality was a subjective rating used by Level 1 and 2 observers only during counts from 1992 to 1996 to assess the quality of their counts. This variable encompassed environmental conditions (i.e., lighting, heat waves), subtle distractions, and known disruptions during a count. Ratings ranged from 1 for excellent to 7 for very poor. Count quality ratings less than 4 were not used in this analysis. The two categories of optical equipment for all shore-based surveys were 1) monocular spotting scopes on tripods or hand-held binoculars, and 2) high-powered binoculars mounted on tripods (used from 1994-1996).

In addition to the linear form of covariates, we included date and time as quadratic covariates (i.e., date squared and time squared), and the three following two-way interaction covariates for counts from aerial surveys: 1) date * tide, 2) time * tide height, and 3) time * time relative to low tide. These quadratic and interaction covariates were chosen because of known or suspected patterns in seal haulout behavior. The total number of covariates we considered was constrained by the number of counts and limitations on computing resources. Models with both linear and quadratic population trajectories (i.e., change in population across years on the log scale) were tested.

Using the two different sets of covariates, we then estimated the population trend for a series of annual counts using overdispersed multinomial models (Link and Sauer 1997). With this type of model, counts (Y_{ij}, i indicates site and j indicates replicate) are assumed to be overdispersed Poisson random variables (i.e., negative binomial) with expected values (m_i) that have the relationship $\ln(m_i) = h(i) * g_i(\underline{x}) * f_i(t)$. In this equation, h(i) represents site effects, which are treated as a multiplicative 'nuisance' parameter, $g_i(\underline{x})$ is a loglinear function of the covariates ($\underline{x}$) that are unrelated to population change, and $f_i(t)$ is the population trajectory with t indicating year.

Each population trajectory can be thought of as a smoothed version of the actual population size across years. Because trajectories were not always linear (i.e., the rate of change varies through time) on the log scale, we defined trend as the geometric mean rate of change over the interval of interest. Trend is therefore a single-number summary of the average change in the trajectory for a selected period of time. Because the actual population sizes are unknown, the height of the trend on the y-axis was arbitrarily chosen such that it passed through the mean count in approximately the middle of the survey period for each area or time period. Overall, the advantages of this modeling approach are that counts are adjusted for the effects of environmental and other covariates simultaneously with the estimation of the population trajectory, and that variability not accounted for by the covariates can differ among sites.

The combination of covariates and degree of polynomial used to produce each trajectory, and subsequent trend estimate, was determined by first starting with a model containing all appropriate (by survey method) covariates and a quadratic trajectory. Covariates were then eliminated one at a time based on the likelihood ratio tests until all remaining covariates were significant ($P<0.05$) or were a component of a higher order term (i.e., quadratic or interaction) that was significant. For example, time was retained in the final model for 1992-1996 August aerial counts because time^2 was significant. Final models for each of the seven time periods/areas were used to estimate a trajectory and associated trend estimate for each time period and study area.

RESULTS

Counts of harbor seals in Johns Hopkins Inlet during both June and August surveys showed a positive annual trend for all of the time periods tested (Table 3). Most of the increase since 1975 appears to have occurred within the first four years, when an annual trend of 30.7% was observed (Figure 2). The trend in numbers at Johns Hopkins Inlet, the primary glacial ice haulout area during August was positive (7.1%) between 1992 and 1996, whereas the trend at the terrestrial haulouts during the same month and time period was negative (-8.6%) (Table 3, Figure 3). For the 1992-1996 period when data collection methods were nearly identical each year, June counts of non-pups increased at a steeper rate (13.1% vs. 7.1%) than counts of all seals during the August molt (Table 3, Figure 4).

Table 3. Estimates of trends in numbers of seals at glacial ice haulouts (Johns Hopkins Inlet, JHI and Muir Inlet) and terrestrial haulouts (Gl Bay) during different periods of time. The environmental (1-4) and other (10-12) covariates selected for harbor seal trend models from land-based counts in Johns Hopkins Inlet (JHI) and Muir Inlet and from aerial photographic surveys of terrestrial haulout sites in Glacier Bay (Gl Bay) are listed for each survey area and time period. A list of all potential covariates tested is provided below.

Location	Years	Month	Age Category	Trend (% / yr)	95% Conf. Interval	*p*	*DF*	*t, crit*	Linear/ Quad	Covariates Selected by Models							
										1	2	3	4	5	10	11	12
JHI	1975-96	June	All Seals	+ 3.9	2.4 - 5.3	< 0.001	83	5.377	Q			X			X	X	
JHI	1975-78	June	All Seals	+ 30.7	24.3 - 37	<0.001	13	10.457	L								
JHI	1983-96	August	All Seals	+ 2.6	1.18 - 4.12	<0.001	136	3.566	L						X		
JHI	1992-96	June	Non Pups	+ 13.1	8 - 18.3	<0.001	42	5.118	L	X		X			X		
JHI	1992-96	August	All Seals	+ 7.1	1.7 - 12.4	<0.01	112	2.635	L						X		X
Gl Bay*	1992-96	August	All Seals	- 8.62	(-11.7) - (-5.6)	<0,001	141	-5.57	L	X	X	X	X				
Muir In	1973-78	June	All Seals	- 5.8	(-12.6) - (0.9)				L								
Muir In	1973-94	Jun/Aug	All Seals	- 9.4	(-12.6) - (-6.3)	<0.001	52	-6.001	L	X							

* Mainly terrestrial haulouts; all others are from glacial ice.

Covariates considered in the models:

1) date of survey relative to the mean survey date of counts on that route,
2) relative survey date squared,
3) time-of-day of survey relative to the mean time-of-day for all surveys,
4) relative time-of-day squared,
5) tide height at the low tide closest in time to the survey,
6) survey time relative to the time of the closest low tide,
7) survey time in relation to sunrise,
8) time-of-day/tide height interaction, and
9) time relative to low tid/tide height interaction
10) optical equipment used during land-based counts (applies to Johns Hopkins Inlet only)
11) observer's level of experience at counting harbor seals on glacial ice (applies to JH Inlet only)
12) subjective ranking of count quality by observers; used from 1992-1996.

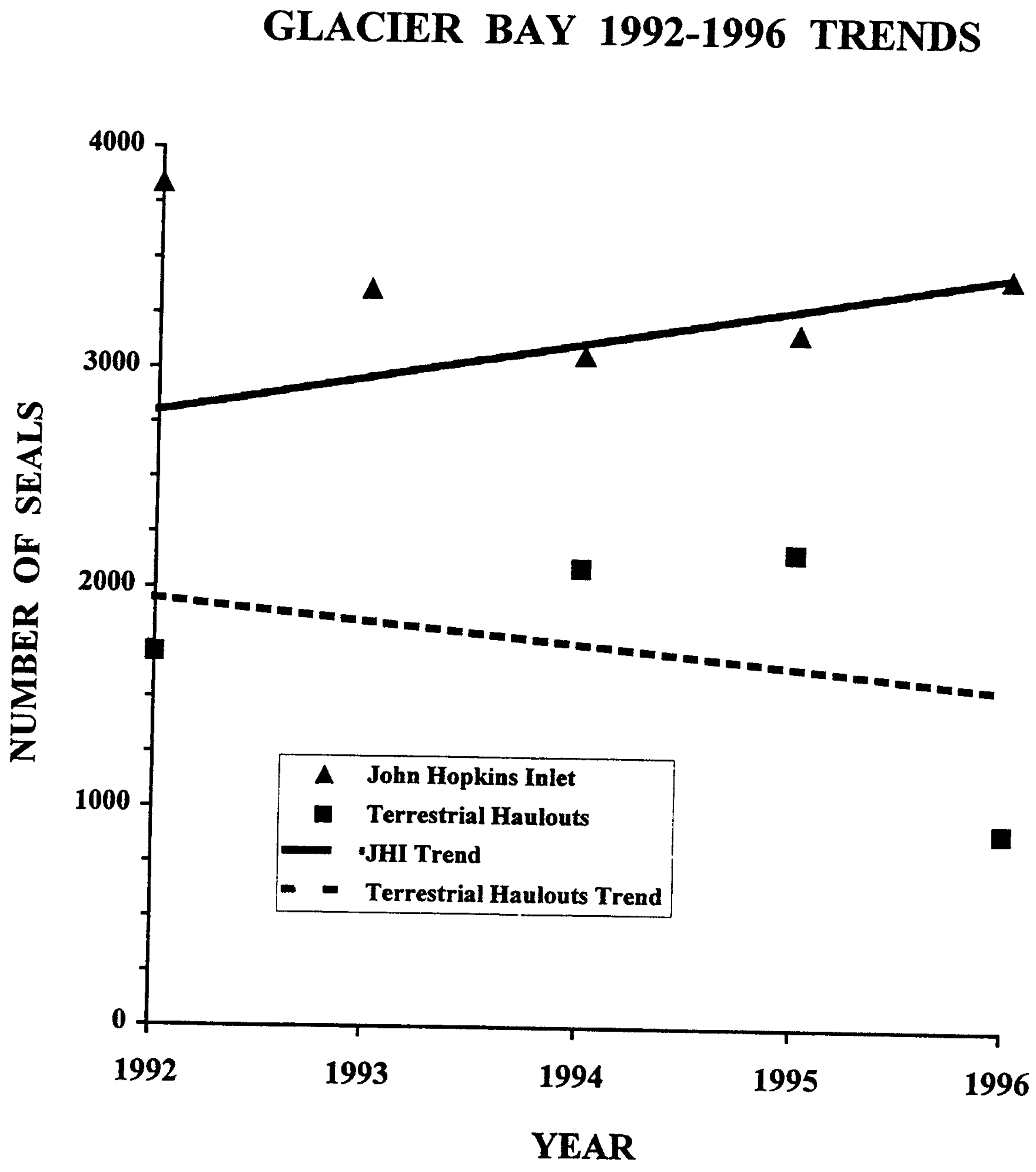


Figure 2. Trends in harbor seal numbers at glacial ice (Johns Hopkins Inlet, triangles) and terrestrial haulouts (circles) throughout Glacier Bay from August surveys, 1992-1996. Symbols are mean values from shore-based counts (glacial ice substrate) and aerial surveys (terrestrial haulouts); mean values are not corrected for incomplete coverage or environmental factors.

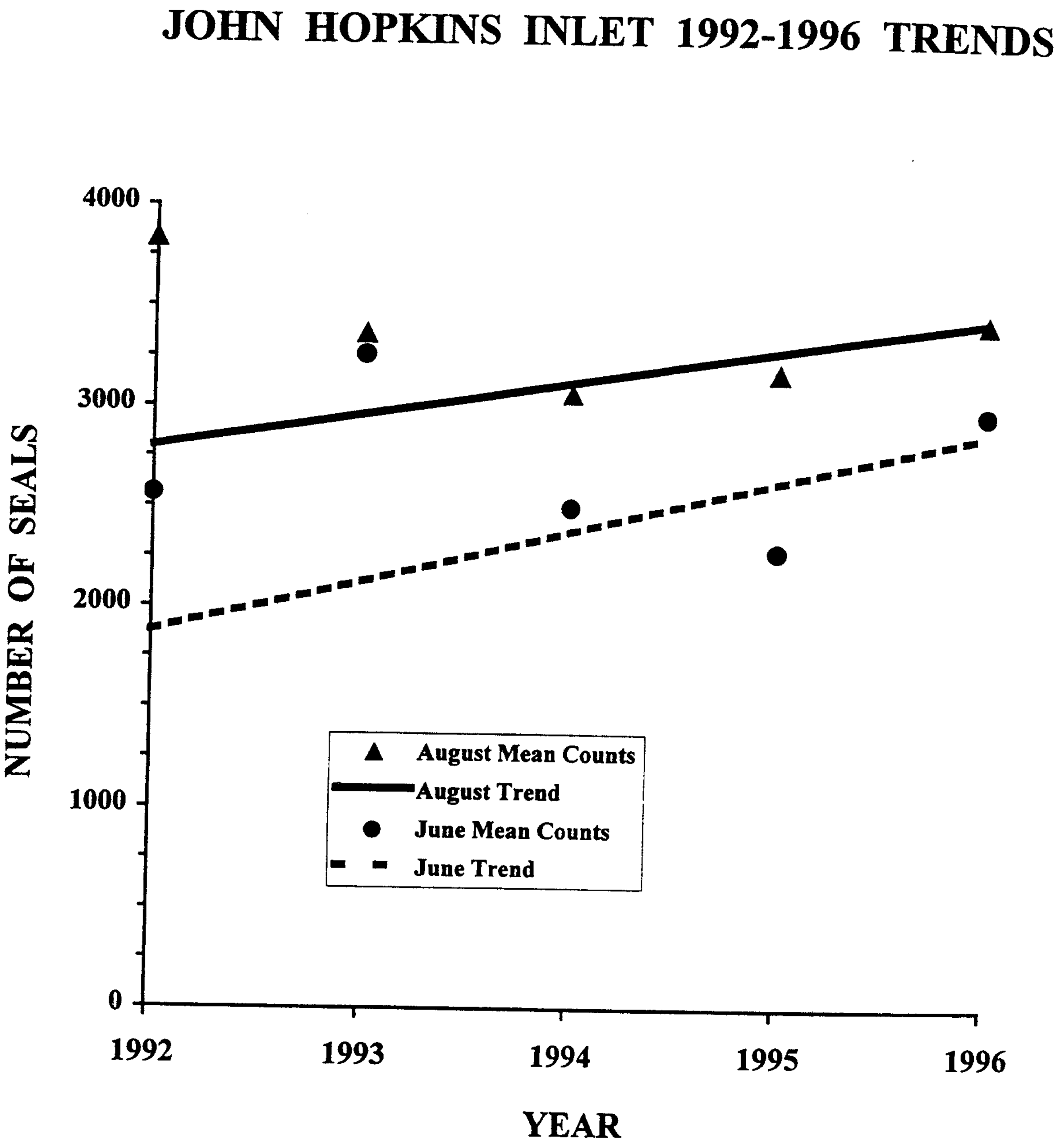


Figure 3. Trends in harbor seal numbers in June and August 1992-1996 at Johns Hopkins Inlet, the primary glacial ice haulout in Glacier Bay. Symbols are mean values from shore-based counts of non-pups in June (circles) and of all seals in August (triangles); mean values are not corrected for incomplete coverage or environmental factors.

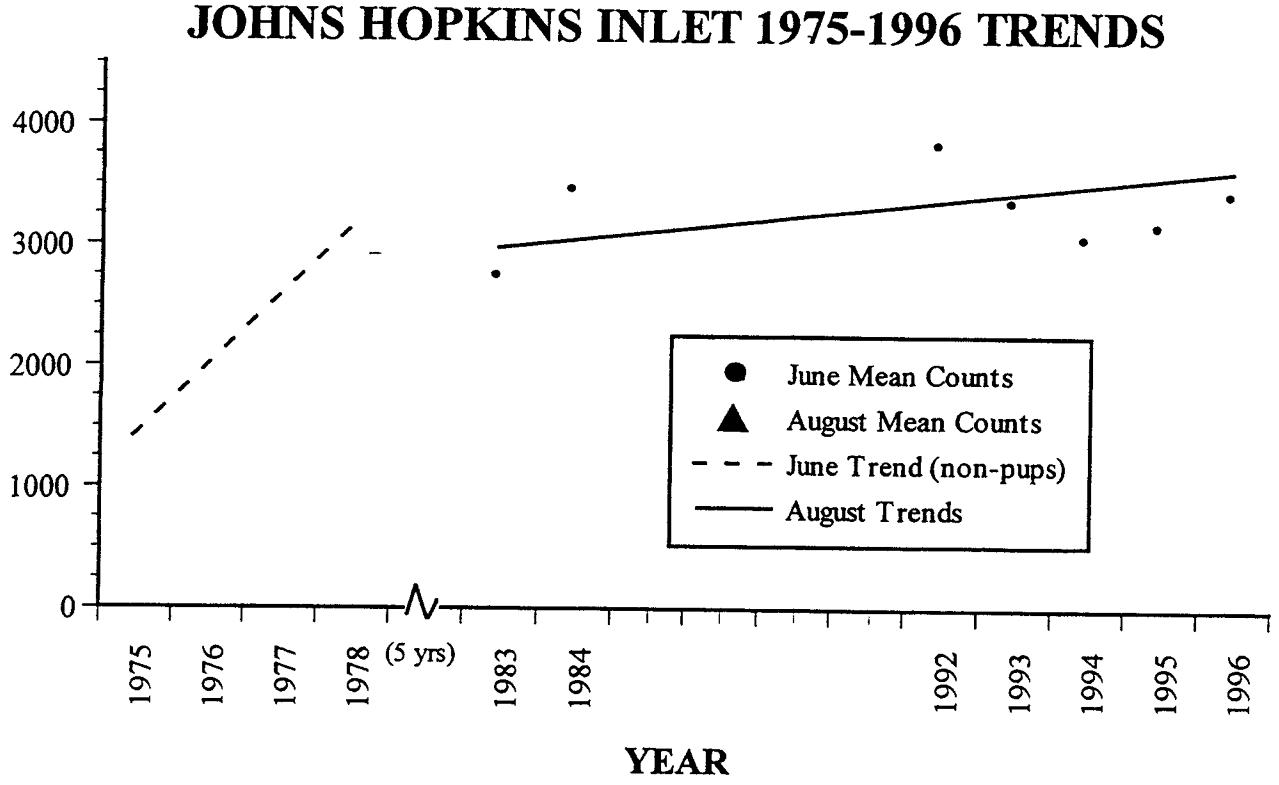


Figure 4. Long-term trends in numbers of harbor seals in Johns Hopkins Inlet, the primary haulout area in Glacier Bay. Symbols are mean values from shore-based counts that are not corrected for incomplete coverage or environmental factors. Data are from Streveler (1979), Sharman and Babcock (1983), Calambokidis (1984, unpublished data), and Mathews (1995 and current report).

DISCUSSION

Recent Trends, 1992-1996: Use of Glacial Ice and Terrestrial Haulouts

Between 1992 and 1996 harbor seal numbers at terrestrial sites in Glacier Bay exhibited a negative trend (-8.6%), whereas in Johns Hopkins Inlet the trend was positive (+7%) during this same time period and month (Table 3, Figure 2). This suggests that seal distribution may have shifted from terrestrial to glacial ice haulouts, although there are other potential explanations for the divergent trends noted at the two different substrates. Survival and/or site fidelity may be higher for seals in Johns Hopkins Inlet, and/or immigration to Johns Hopkins Inlet from areas outside of Glacier Bay, as well as from within the Park, may have occurred. Another potential factor that may have contributed to the negative trend at terrestrial sites is that the primary terrestrial haulout (Spider Island reefs, Figure 1) appears to have been exposed to increasing levels of human disturbance in 1996 (and 1997) (Mathews 1997b). In addition, survey coverage of the terrestrial sites in August was incomplete on all days in 1996. If, on the other hand, some of the increase in Johns Hopkins Inlet can be attributed to changes in distribution from terrestrial to glacial haulouts, the degree of the decline at the terrestrial sites (8.6% of 1,000-2,000 seals, or approximately 86-170 seals/year) does not fully explain the increase observed at the glacial ice site (7% of 3,000-4,000 seals, or approximately 210-280 seals/year) (Table 1).

The combined effect of the negative trend at terrestrial haulouts and the positive trend in Johns Hopkins Inlet is that numbers in Glacier Bay overall appear to be stable or possibly increasing. The negative trend rates for harbor seals in areas of the Gulf of Alaska where declines are considered serious ranged from 7 to 7.7% between 1976 and 1988 (Tugidak Island: Pitcher, 1990) and between 1984 and 1992 (Prince William Sound: Frost and Lowry 1993, Pitcher 1989, overall trend cited in Hill *et al.* 1996). If we had not conducted surveys of harbor seals in the ice habitat, we would have concluded that harbor seals in Glacier Bay had declined between 1992 and 1996 at annual rates higher than those observed in the Gulf of Alaska.

Recent Trends, 1992-1996: June versus August Counts, Johns Hopkins Inlet

The trend in seal numbers in Johns Hopkins Inlet for both the June (pupping) and August (molting) counts was positive, although the rate of increase was almost twice as high (13%/yr vs 7%/yr) for the June surveys, which did not include pups due to the higher error in counting them. On average, 29% (SD=6%) of the animals in Johns Hopkins Inlet during our mid-June surveys were females with dependent pups. Thus, close to half of the seals considered in the trend estimate (which excludes pups) for June were parturient females. In Glacier Bay, glacial ice habitat is used by significantly more females with pups than are terrestrial sites (Streveler 1979, Calambokidis *et al.* 1987, Mathews 1997a), and some females may be immigrating into the Inlet to give birth.

Long-term Trends, 1975-1996: Johns Hopkins Inlet

Harbor seal numbers in Johns Hopkins Inlet increased steeply (30.7%/yr) between 1975 and 1978, and then the rate of increase slowed to an estimated average of 2.6%/year for the period 1983-1996. Recent trends (+2.6% for 1983-1996 and +7% for 1992-1996, Table 3) are well within observed and theoretical net growth rates for harbor seal populations, although Johns Hopkins Inlet is clearly not a closed population.

The steep annual rate of increase observed between 1975 and 1978 in Johns Hopkins Inlet may be a result of one or more of the following factors: 1) increased birth rates, 2) decreased mortality, and/or 3) immigration into the Inlet. In the sections that follow we consider each of these potential contributors to the rapid expansion observed in Johns Hopkins Inlet, and we suggest that at least two factors, decreased mortality and immigration, were involved.

There is no evidence for increased birth rates in Johns Hopkins Inlet between 1975 and 1978; the proportion of females with pups in this glacial fjord was consistently high (28%) during all 4 survey years (Mathews 1995).

The observed annual rate of increase does not appear to be due to decreased mortality alone, although it is a probable co-factor. Streveler (1979) counted an average of 28% (SD = 2.2%; data summarized in Mathews, 1995) pups during his June surveys in these four years, so the observed 30% annual increase would suggest that there had been close to 100% survival of pups born in this Inlet in four consecutive years – a very unlikely prospect given that the maximum theoretical net productivity rate for pinnipeds is estimated to be 12% (Wade and Angliss 1996). In addition, one of the highest documented population growth rates (12.5%) for harbor seals was observed in British Columbia between 1973 and 1987, and it occurred after management culling and commercial hunting of seals was ended in 1970 (Olesiuk *et al.* 1990). The authors attributed this high rate of growth to population recovery from harvest. The rate of increase in Johns Hopkins from 1975 to 1978 was more than two times that observed in British Columbia; thus, the observed increase in seal numbers in Johns Hopkins Inlet is likely to have involved more than just a decrease in mortality.

We might assume that seals, particularly mature females, accustomed to using glacial ice would tend to relocate to another glacial fjord if ice habitat in one location declined, as it did in Muir Inlet in the late 1970s and mid 1980s (Streveler 1979, Calambokidis *et al.* 1987). By 1992 no more than 200 seals were observed in Muir Inlet, and by 1994 the receding glacier had grounded and no seals have been observed on icebergs in this area since then (Mathews 1992, and pers. observ.). While some seals that could no longer find adequate ice substrate in Muir Inlet may have moved to Johns Hopkins Inlet to breed, the increase in Johns Hopkins from 1975 to 1978 cannot be explained solely by emigration from Muir Inlet, although it may have contributed slightly. The annual rate of decrease in Muir Inlet was estimated to be 5.8% (95% CI = -12.6 to –0.9%/yr) between 1973 and 1978 (Table 3), and only about a 1,000 seals were observed during June counts in the mid-1970s (Streveler 1979). Thus, if all of the seals that left Muir were detected in Johns Hopkins Inlet, this would account for only about 2-4% (5.8% x 1,000/3,300 to 5.8% x 1,000/1,440; Table 1) of the 30%/yr increase observed in Johns Hopkin Inlet.

Immigration from areas other than Muir Inlet remains a likely co-factor (with decreased mortality) in the observed rapid increase in Johns Hopkins Inlet between 1975 and 1978. Because there were no surveys of terrestrial haulouts before 1992, we cannot determine if there were shifts in seal distribution between glacial ice and terrestrial haulouts in Glacier Bay between 1975 and 1978, as may have occurred between 1992 and 1996 (Figure 4). Close to 70% of the seals in Glacier Bay, and at least 50% of seals in the northeast Gulf of Alaska (Mathews and Womble 1997, this volume) select glacial ice habitat when it is accessible. Thus, an understanding of seal use of glacial ice habitat is essential if trend surveys are to be conducted in nearby waters. If glacial ice haulouts are not monitored, large changes in numbers at terrestrial haulouts may be misinterpreted as population growth or decline, rather than shifts in distribution between habitats.

Several factors may have contributed to the recent and long-term trends in numbers of harbor seals in Glacier Bay. The cessation of subsistence hunting in Glacier Bay began in 1973 and may have contributed to the steep increase in seal numbers observed in Johns Hopkins Inlet between 1975 and 1978, but it is unlikely that it was the only factor involved. Immigration from Muir Inlet and from terrestrial sites are likely contributors to the 30%/year trend. Since 1988, Johns Hopkins Inlet has been closed to all vessel traffic during pupping and early stages of nursing. The extent to which reduced disturbance of females with dependent young might increase the survival or overall fitness of pups is not known, but it is likely to have a positive energetic effect and this might explain some of the continued positive trend in seal numbers in Johns Hopkins Inlet. NPS regulations currently limit vessel approaches to ¼ mile from the primary terrestrial haulout (Spider Island reefs) in Glacier Bay during pupping and molting. Yet, this regulation may not be preventing frequent disturbance of seals at these reefs. Recent increases in human disturbance (Mathews 1997b) may have contributed to the negative trend in seal numbers at terrestrial sites and possibly to the increases observed in Johns Hopkins Inlet through displacement of seals; however, the long-term effects of human activities on haulout patterns and site fidelity remain to be elucidated in Glacier Bay. In addition to immigration and emigration, changes in mortality, and human disturbance, shifts in prey distribution or availability may have influenced the diverging trends in seal numbers at terrestrial and glacial ice haulouts between 1992 and 1996.

CONCLUSIONS

The analysis of harbor seal survey data from both terrestrial and glacial ice haulouts in Glacier Bay indicates that since 1992 overall numbers have been stable or may be increasing slightly, and that there was a high rate of growth at the primary glacial haulout from 1975-1978. However, the negative trend at terrestrial sites between 1992-1996 should be closely monitored, since it is not known if the decline is the result of a shift in distribution, a decrease in birth rate, an increase in mortality, or a result of increased human disturbance. Trend routes adjacent to active tidewater glacial fjords used by significant numbers of seals need to include surveys of seals on glacial ice to avoid misinterpreting a shift in distribution as a decline or increase in overall population abundance.

ACKNOWLEDGEMENTS

We thank Lara Dzinich for her devotion to the project and her significant contributions to data collection and slide analysis. We are indebted to several hard-working field crews comprised of University of Alaska students, volunteers, and NPS staff who assisted with the counts in Johns Hopkins Inlet. These vital contributors include B. Kunibe, J. Driscoll, R. Morris, C. Coyle, S. LeGros, C. Pohl, N. Ratner, A. Knuth, C. Knight, J. Danner, H. Dedeitus, and L. Wolstenholme. E. Hooge, K. Wilson, D. Williams, A. Maselko, P. Wald, T. Farrell, J. Doherty, and A. vanDusen assisted with aerial surveys and we thank them for their generous help. Crucial logistic support was provided by NPS staff (T. Gage, J. Williams, R. Yerxa, C. Young, M. Goodro). We thank our pilots (M. Sharp, S. Wilson, and C. Shroth) for their assistance with spotting seals and for returning us home safely. Drafts of this report were improved by constructive comments from Chris Gabriele, Elizabeth Hooge, Lauri Jemison, Mary Kralovec, Bob Small, Una Swain, and Jim Taggart,.

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