Declining Trends in Harbor Seal *(Phoca vitulina richardsi)* Numbers at Glacial Ice and Terrestrial Haulouts in Glacier Bay National Park, 1992-1998

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FINAL REPORT TO:

Glacier Bay National Park and Preserve
Resource Management Division
P.O. Box 140
Gustavus, Alaska 99826

FOR:

Cooperative Agreement 9910-97-0026

Submitted: July, 1999

Comments Received: February, 2000
Final Report: September, 2000

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ABSTRACT

Numbers of harbor seals on haulouts (resting areas) in Glacier Bay (GB) National Park declined by 25-48% between 1992 and 1998. GB has had one of the largest breeding colonies of harbor seals in Alaska. This aggregation is found in Johns Hopkins Inlet (JHI), a tidewater glacial fjord where seals rest on icebergs calved from glaciers. From 1992-1998 we counted seals in JHI in June and August from an elevated shore site and used aerial photography to count seals at terrestrial haulouts throughout the rest of the bay in August. We counted 6,300 to 4,500 harbor seals on haulouts with 62-74% in JHI. We estimated trends in numbers at the glacial and terrestrial haulouts using models that control for environmental and observer-related covariates. We detected declining trends from 1992-1998 for both the glacial fjord June (-25%/7 yrs; -4.9% per year) and August (-34%/7 yrs; -6.8% per year) survey periods and for the August surveys of terrestrial sites (-48%/7 yrs; -10.9% per year). Trends in numbers of harbor seals in GB are of regional interest because: 1) seal populations have declined by up to 85% in central and western Alaska, while numbers in southeastern Alaska have been considered stable or increasing, 2) GB has been used by >6,300 seals, 3) GB is the only area in Alaska where subsistence hunting of seals is not authorized and 4) where there are vessel closures and distance regulations for minimizing disturbance of seals during breeding, and 5) JHI is the only glacial system where there has been long-term monitoring. Causes of the declines could be due to seals spending more time in the water or to reduced birth rates, increased mortality or emigration, or combinations of factors, and declines may be responses to ecosystem changes. Human disturbance appears to be a partial cause of lower numbers on haulouts, but it only explains a small proportion of the decline at terrestrial sites. Numbers of harbor seals in GB are declining despite efforts to protect them from hunting and disturbance.

KEY WORDS: aerial surveys, Glacier Bay, glacial ice haulout, shore-based counts, harbor seal, *Phoca vitulina*, population monitoring, trend analysis

INTRODUCTION

Glacier Bay (GB) National Park has had one of the largest breeding colonies of harbor seals *(Phoca vitulina richardsi)* in Alaska. This aggregation is found in Johns Hopkins Inlet (JHI), a tidewater glacial fjord where seals haul out on icebergs (Calambokidis et al. 1987, Hoover-Miller 1994, Mathews 1995). Since 1992, the minimal number of seals estimated in GB has declined from 6,300 to 4,500 during summer. Of these seals, 62-74% rest, give birth, nurse, or molt on drifting icebergs in JHI. In 1996 (Mathews and Womble 1997) and 1997 (Small 1998) approximately 50% of seals counted during aerial surveys of the northeast Gulf of Alaska were found on glacial ice. Although seals appear to prefer glacial ice for pupping and molting where it is available, JHI is the only glacial system in Alaska where there is long-term monitoring of seals. Other important glacial ice breeding sites, such as Icy Bay, have not been monitored largely because of the difficulty in counting seals on drifting ice and because of difficult access to these remote areas. Surveys of seals from the steep shores of JHI have been conducted during several years since 1975 (Calambokidis et al. 1987, Streveler 1979) and in all years since 1992 (Mathews 1992, Mathews 1995, Mathews and Pendleton 1997). Two factors have promoted long-term monitoring of seals in this glacial fjord: 1) the topography of JHI allows an extensive view of seals in the inlet such that reliable counts can be made from a field camp, and 2) the National Park Service (NPS), the University of Alaska Southeast (UAS), and other agencies have supported the research.

In addition to the seals in JHI, approximately 1,200-2,500 (25-36% of total number in GB) harbor seals rest and pup at 20-30 different terrestrial haulouts in other parts of Glacier Bay (Mathews 1995). Park-wide counts of seals that rest on these two different substrates (glacial ice and terrestrial haulouts) were initiated in 1992 through a collaboration between the NPS and the National Marine Mammal Lab (National Marine Fisheries Service, NMFS, Seattle, WA) (Mathews 1992, Mathews 1995). Studies have continued through support from the NPS and UAS.

In the Gulf of Alaska, harbor seal numbers on Tugidak Island– previously the largest haulout in Alaska – declined by 85% (from approximately 7,000 to 1,000 seals) between 1976 and 1988 (Pitcher 1990). From 1984 to 1992, a decline of 57% was documented at terrestrial haulouts in Prince William Sound (PWS) in the Gulf of Alaska (Frost et al. 1996). Declines during pupping (-31%) and molting (-19%) have also been documented in PWS between 1989-1995 (Frost et al. 1996). A more recent analysis of harbor seal trends in PWS uses aerial survey counts from 1990-1997 and models based on a generalized linear regression (Frost et al. 1999). Results from this work indicate a decline of 4.6% per year with a total estimated decline in seals of 63% for 1984-1997.

To update our analysis of harbor seal population trends from 1992-1996 (Mathews and Pendleton 1997), we analyzed survey data from 1992-1998 for June (pupping) and August (molting) counts in JHI and of terrestrial sites during August. We used continuous covariates to improve the sensitivity of surveys to detect changes in numbers of seals. This type of analysis reduces variation in counts resulting from factors not related to real changes in population abundance (Link and Sauer 1998). Minimal population estimates (MPE) derived from uncorrected high counts for all of Glacier Bay from the August surveys were also determined for all survey years.

METHODS

Study Areas

Johns Hopkins Inlet is located in the northwest arm of GB (58ºN, 138º30'W) (Figure 1). It is used by approximately 62-74% of the seals counted in GB during pupping, breeding, and molting periods from spring to early fall. In addition to JHI, approximately 30 terrestrial haulouts throughout the bay have been identified in the last two decades (Lentfer and Maier 1989, Mathews 1992, Mathews and Pendleton 1997). About 20 of these sites are typically occupied during August surveys, and approximately 50% of the seals on terrestrial haulouts are found on reefs near Spider Island, in the Beardslee Island Wilderness area (Figure 1, Appendix A).

Shore-based Counts of Seals on Glacial Ice in JHI, 1992-1998

From 1992 to 1998, we conducted shore-based counts of harbor seals in JHI in June, when harbor seal females give birth, and in August during the annual molt (shedding), when seals may spend a higher proportion of time on haulouts (Calambokidis et al. 1983, Johnson 1979). In 1998 we lengthened the June survey window by about 10 days to improve the likelihood that our counts would include the peak in numbers of seals and pups. Jemison and Kelly (in press) observed that the onset and peak in harbor seal births on haulouts on Tugidak Island occurred 6-18 days later during the mid-1970s, when numbers were declining, compared to the 1990s, when numbers had stabilized at 72-85% below historic levels. Jemison and Kelly hypothesize that this relationship may be related to a change in prey availability or quality between the two time periods.

In June and August, 1992-1998, a team of observers counted seals in JHI from an elevated (ca 20 m above sea level) site located about 2.5 km from the face of the glacier (Figure 1). Two observers simultaneously counted seals from this site, and two to four paired counts were made each day with at least one between 10:00 and 14:00. For the June counts, seals were categorized as non-pups or pups in all years except 1993 when only non-pups were counted. In August, no age class distinction was made, because older weaned pups are difficult to distinguish from adults at a distance. In JHI, seals are typically dispersed over an area of about 5-10 km^2, 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 (1994-1998) on tripods and divided our field of view into four subsections for more systematic counting. Mathews and Dzinich (1997) describe methods for counting seals on glacial ice.

<u>Counts of Seals from Aerial Surveys, 1992-98</u>

In 1992 and 1994-1998 aerial surveys of terrestrial haulouts in Glacier Bay were conducted during August low tide cycles which occurred during the seal's annual molt (shedding). Aerial surveys of terrestrial haulouts were scheduled to occur while there was a field crew in JHI, although in 1992 flights occurred four days after counts in JHI due to weather (Appendix A).

During aerial surveys we checked all known haulouts that could be approached and searched for undocumented or new haulouts; weather conditions occasionally prevented complete surveys of the bay. Surveys were conducted from single engine aircraft at about 305 m altitude, and observers scanned each haulout, often with binoculars, for seals. When seals were located, we approached the haulout such that the photographer was positioned with the haulout at about a 30-45 degree angle from 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 in recent years, a 300 mm fixed lens. We used primarily 400 ASA slide film and occasionally 200 ASA; most photographs were taken at 1/500 – 1/1000 second.

For each haulout we recorded location, time, film frame numbers, and a visual estimate of the number of seals. We also noted if there was evidence of a recent disturbance (e.g., kayakers or campers adjacent to an empty haulout coupled with impressions from seals in the sand on a vacated haulout) or if the survey plane caused seals to escape into the water. For known haulouts, we noted if seals were not present (a '0' in the database), or if we were unable to survey a haulout due to bad weather. We also made general comments about weather conditions, and beginning in 1995 we recorded outside air temperatures periodically during surveys. A haulout substrate category – either rock, sand, or ice (described below)– was entered into the database for all sites in GB.

Groups of seals at all terrestrial haulouts were small enough to fit in one field of view (i.e., photographic frame), except at the Spider Island reefs where we took a series of overlapping photographs to include all seals. The sharpest or best 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 from slides 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 5%. Counting precision of the larger haulouts was improved by using a handheld tally counter.

Minimal Population Estimate, 1992-1998

To calculate the minimal population estimate (MPE) for harbor seals throughout Glacier Bay, we added the maximal count from the August aerial surveys of all sites except JHI to the mean of the three high counts of seals in JHI from August. The mean of the three highest counts from different days from JHI was used because the number of seals increases, peaks, and then declines during both pupping and molting. Thus, a mean of all counts from JHI is not an informative number, since it would become lower and have increasing variance with increasing effort. The date(s) of the three highcounts from JHI did not necessarily occur on the same day as the highest count from aerial surveys. Thus, the addition of these two counts for a MPE is based on the assumption that there is minimal movement between JHI and the sites surveyed by air. The dates of the two counts (aerial survey and JHI shore-based) used to determine the MPEs differed by 1-5 days (mean = 4 days), with the exception of 1995 when maximal counts in the two areas were 14 days apart. No aerial survey was conducted in August, 1993, so there is no MPE for this year.

Trends in Seal Numbers: Covariate Analysis

During all surveys, some harbor seals are in the water and cannot be counted. 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. Even so, 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 on glacial ice, unlike most terrestrial sites in Alaska, 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 two different sets of potential environmental and observer-related covariates for surveys of seals resting on ice vs. terrestrial substrates.

The environmental covariates used in our analysis of the aerial survey data included date (Julian), relative time of day (relative to solar noon = [sunrise + sunset]/2), tide height at the survey time for each site, and time from low tide (tide time). These main effect covariates were the same as those investigated by Frost et al. (1999) who used categorical versions of these variables rather than the continuous forms we used. In addition to the linear form of covariates we also included quadratic effects (e.g., $date^2$) for date, time, tide height, and tide time and allowed the effect of tide height to vary by site (e.g., site x tide height interaction). The quadratic and interaction covariates were chosen because of known or suspected patterns in seal haulout behavior. Models with both linear and quadratic population trajectories (i.e., change in population size across years on the log scale) were tested. Each population trajectory can be thought of as a smoothed version of the actual population size across years. However, trajectories were not always linear (i.e., the rate of change varies through time) on the log scale, so 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 (i.e., percent change per year or percent change from 1992-1998).

The aerial surveys primarily monitor seals on terrestrial haulouts; however, in 1992 we counted seals on glacial icebergs in Muir Inlet (Muir Glacier grounded around 1993 and icebergs are no longer produced there), and from 1995 to 1998 we have photographed seals on icebergs in McBride Inlet where fewer than 200 seals are typically found. Thus, the aerial survey method in most years includes one relatively small glacial haulout. Because there were usually fewer than 100 seals at these tidewater glaciers, counts from aerial photographs or from visual counts were feasible. In contrast, visual counts or photograph using a standard camera from an airplane are not feasible for counting seals on ice in JHI where there are typically more than 2,000-3,000 animals distributed over a large area (i.e., 5-8 km^2).

The variables tested for effects in the trend models for counts in JHI were: date, time of day, observer experience level, and count quality. Observer experience level in most cases improved over time. Observer levels were categorized 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 observer 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 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 trend analyses.

Count quality was a subjective rating used by Level 1 and 2 observers to assess the quality of their counts. This variable encompassed environmental conditions (e.g., lighting, shimmer from heat waves), subtle distractions or distinct disruptions during a count. Ratings ranged from 1 for excellent to 7 for very poor counts. Only counts with quality ratings less than 4 were used in these analyses.

For each analysis, we fit models with all combinations of covariates and trajectories. Final trend estimates and standard errors were obtained as a weighted average of estimates from the individual models with weights based on corrected Akaike's Information Criteria (AIC) (Burnham et al. 1995, Hurvich and Tsai 1989). This model averaging procedure (Burnham and Anderson 1998) incorporates the uncertainty in which model is most appropriate into the trend estimate and its variance.

To evaluate the effect of individual covariates on the final trend estimate, we computed model averaged trend estimates with subsets of the models not containing individual variables (e.g., without date and $date^2$). We then calculated the percent change in model averaged trend when the variable was omitted, compared with the full set of models.

Controlling for a Change in Distribution of Seals Near Spider Island

Since 1996, numbers of seals on the 3 main reefs just southwest of Spider Island plummeted from mean counts of about 1,000 seals to less than 250 seals in 1997 and 1998 (Appendix A). In 1997, approximately 500 seals began using a new (at least within the last decade) haulout in August within 1 km of the 3 vacated reefs. In our trend analysis for 1992-1998, newly colonized sites (and all sites with fewer than 3 years of data) were not included, since trend assessment requires at least 3 years of data to be meaningful. Thus, if many of the seals at the new site moved to it from the Spider Island reefs, as is most likely the case, then our estimate of trend for the terrestrial haulouts is negatively biased. To control for this potential bias and to determine how much of an effect the observed local shift in distribution had on the trend for terrestrial sites, we also analyzed data from aerial surveys without including the traditional or new reefs in the Spider Island area.

RESULTS

Minimal Population Estimate (MPE), 1992-1998

High counts of seals in JHI in June declined in all years between 1993 and 1998 except 1996. There was little difference between the high counts for June 1992 and 1998, although our effort increased substantially from 2 to 18 days (Table 1a, Fig. 2). For August, the mean of the 3 high counts from 1993-1996 in JHI increased and then declined from 1996-1998 (Table 1b, Fig. 2).

The high counts of seals on mainly terrestrial haulouts during aerial surveys in August declined between 1994 and 1997 (there was no aerial survey in 1993), with a slight increase between 1997 and 1998. Low numbers of survey days (n = 2) in 1992 in JHI in June and at terrestrial sites in August make the maximal counts for 1992 less reliable than subsequent years when seals were surveyed on more days. There are no corrections in Table 1b for incomplete coverage of the bay during aerial surveys of the terrestrial sites. As such, the highest total count (bottom row in Appendix A) on a single day is a conservative estimate of the minimal number of seals on haulouts (excluding JHI) in GB each year.

The MPE for seals in GB increased from 1992-1995 and then declined from 1995-1998, with an overall change from 6,291 to 4,466 seals (Table 1b, Figure 2). Because some proportion of seals is known to be in the water during surveys, the MPE for each year is a very conservative (i.e., minimal) estimate of the number of seals in GB.

Trends in Seal Numbers: Covariate Analysis

Trends in numbers of harbor seals were negative for all sites and survey periods from 1992 to 1998 (Table 2, Figure 3). Numbers of non-pups in JHI in June decreased by 25% during the 7 year period (-4.9% per year); numbers of all seals in JHI in August decreased by 34% (-6.8% per year) (Table 2, Figure 3b). During this same time period, we detected a 48% (-10.9% per year) decline in seals counted on all of the other (mainly terrestrial) haulouts in the Bay (Table 2, Figure 3a).

In JHI, the covariates that had the most influence on seal numbers counted were $date^2$ and $year^2$ for both the June and August counts, and relative time of day squared (trm^2) for the August counts only (Table 2). Two covariates -- relative time of day and observer level -- also influenced the number of seals counted in more than half of the models for the JHI August counts. The covariates that influenced numbers of seals visible on haulouts during aerial surveys were $date^2$, $year^2$, time relative to low tide (trt), and trt^2 (Table 2).

Effects on Trend of Change in Distribution of Seals

Seal numbers at terrestrial haulouts in GB declined by 10.9% per year or -48% from 1992-1998 (Table 2). Excluding the seals near Spider Island reduced the decline rate to -8.3% per year or -42% overall. Thus, local changes in haulout distribution in the Spider Island area accounted for about 6% of the overall decline observed at the terrestrial haulouts.

DISCUSSION

Trends at Glacial Ice and Terrestrial Haulouts

We believe that the declining trends reflect real changes in seal numbers or haulout use in Glacier Bay for several reasons. First, the trend analysis used includes corrections for the effects of survey timing -- both within a day and between years -- and for environmental factors (e.g., height of tide at time of survey) and for differences in observer skill. As such, this analysis is more likely to reflect real changes in numbers of seals on haulouts, rather than other factors such as changes in the timing of surveys. Second, declines in JHI were detected during both the pupping (June) and molting (August) periods. Since proportionately different cohorts of seals are represented on haulouts during these periods, the consistency in the decline between June and August is mutually reinforcing. Third, trend analysis of the aerial survey data for 1992-1996 (Mathews and Pendleton 1997), 1992-1997 (Mathews and Pendleton, unpublished data), and 1992-1998 all detected negative trends. Negative trends for JHI were detected for 1992-1997 and 1992-1998. Finally, the MPEs for harbor seals throughout Glacier Bay declined from 1995-1998 (Table 1b, Fig. 2) even though survey effort has increased in recent years (Table 1).

In our first analysis of the trend in harbor seal numbers in Glacier Bay for 1992-1996 we reported a 8.6% (95% CI = -11.7 to –5.6%) per year negative trend at terrestrial haulouts and a 7.1% (95% CI = 1.7 to 12.4%) per year positive trend in JHI (Mathews and Pendleton 1997). We suggested that numbers in GB overall were stable or possibly increasing, since JHI is used by about three times as many seals as are found at all other sites combined. Subsequent analyses of these data (G.W. Pendleton, unpublished data), suggest that the increasing trend in JHI was an artifact of the statistical model used at the time and was likely erroneous (i.e., the actual trend was negative). The addition of two years of data and improved trend analysis changes the view of the overall trend in GB rather dramatically.

Aside from the decline we reported for the terrestrial sites from 1992-1996 in GB (Mathews and Pendleton 1997), declines had not previously been reported in southeastern Alaska, where harbor seal numbers have otherwise appeared to be stable or increasing (Lewis et al. 1996, Mathews 1995, Small et al. 1998). Declines in harbor seals, Steller sea lions *(Eumetopias jubatus),* and sea birds in the Gulf of Alaska and Aleutian Islands (Braham et al. 1980, Loughlin et al. 1992, Merrick et al. 1987) have been linked to changes in prey abundance or nutritional quality (Calkins and Goodwin 1988, Merrick 1995, NMFS 1995, Merrick and Loughlin 1997). Several lines of evidence suggest that reduced juvenile survival is a factor in the Steller sea lion declines (Calkins et al. 1998, Merrick 1995, Merrick et al. 1997, Merrick and Loughlin 1997), and possibly in the harbor seal declines (Jemison and Kelly, in press); however, the specific causes of sea lion, seal, and other marine vertebrate declines in the Gulf of Alaska, Aleutian Islands, and the Bering Sea are not well understood (Loughlin and Merrick 1988, Springer 1993, Merrick 1995).

Possible Causes of Declines

The observed declines in seals counted on haulouts throughout Glacier Bay could be due to either changes in the population dynamics (i.e., lower birth rates, increased mortality, or increased emigration) or to increased time spent in the water, or to a combination of these factors.

Changes in haulout behavior that could result in reduced numbers of animals on haulouts, but no reduction in the number of total seals present, during surveys include:

1) some seals may have reduced their use of or abandoned haulouts (e.g., Spider Island reefs) in GB in response to increasing human disturbance (Mathews 1997b) or other factors,
2) harbor seals may be shifting their use of haulouts from within GB to areas outside the bay, and/or
3) seals may be spending more time in the water than on haulouts during August surveys, perhaps due to reduced prey availability, abundance, or quality. (Reduced

prey quality or abundance, if prolonged, could eventually result in changes in population dynamics.)

Human disturbance is a factor that is likely to have contributed to the 10.9% per year negative trend at the terrestrial sites. From May 1 – August 31, the NPS restricts vessel approaches to the primary terrestrial haulout (Spider Island reefs) to >0.5 (1/4 nm) km, a period which brackets most pupping and weaning. Yet, this closure does not prevent disturbance of seals. There was evidence of human disturbance at the Spider Island reefs during surveys in 1997, and numbers of seals photographed on these haulouts had already begun to decline notably in August, 1996 (Mathews 1997b) (Appendix A). In at least the last two decades, the Spider Island reefs have been the largest terrestrial breeding haulout in GB (Calambokidis et al. 1987; Mathews 1995; Mathews and Pendleton 1997). In addition, these 3 reefs are used by the largest number of females with young at a terrestrial site in GB (Mathews 1997a). In the San Juan Islands, off Washington State, harbor seals with pups were less tolerant of disturbance from vessels than were seals at haulouts with fewer pups (Suryan and Harvey 1998). In addition, kayakers were significantly more likely to disturb seals on haulouts than were powerboat operators. Fifty-five percent of kayakers caused seals to leave the haulout, while only 9% of powerboats disturbed seals. These results are similar to those from vessel interaction studies on harbor seals (Mathews 1997b) and on Steller sea lions (Mathews 1997c) in GB. While harbor seals will readily abandon a haulout if a kayaker approaches, the longterm effects of human activities, such as kayaking, on seal haulout patterns, site fidelity, and pup survival in Glacier Bay and the extent to which the observed declines may be explained by human disturbance remain unclear. Analysis of available data on kayak use in GB will be included in a subsequent report on seal trends.

Four factors that could influence population trends or numbers of seals on haulouts are unique to Glacier Bay relative to other parts of Alaska. First, Glacier Bay National Park is the only place in Alaska where subsistence hunting of harbor seals is not authorized. Although some seals in GB are likely to leave the bay during fall and winter, when most subsistence hunting occurs, it is likely that the overall probability of being harvested for a seal from GB is lower than for seals that do not spend a significant amount of time in GB. Second, since approximately 1987 (Gary Vequist[1], personal communication) the NPS has prohibited all vessels from entering Johns Hopkins Inlet during May and June, a period that typically includes the peak of pupping and the beginning of the 3-6 week lactation period (Bigg 1969). Third, the NPS also requires that vessels remain further than 0.5 km (¼ nautical mile) from seals on ice in JHI after the pupping closure is lifted and until September 1. The NPS has similar distance limits for the Spider Island reefs where 400-1000 seals typically rest during pupping, breeding, and molting. If visitor compliance with NPS wildlife regulations is high, disturbances of seals during breeding and molting should be lower as should mortalities that result from female-pup separations or increased exposure to predators. If all else is equal within southeastern Alaska, we would thus predict that seals in GB should have higher reproductive success and be less

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likely to emigrate from the Bay in response to disturbance. However, a fourth factor may be at odds with the NPS's efforts to protect wildlife from human disturbance. By virtue of being a national park, it is possible that more people on average recreate in GB waters than in other areas of southeastern Alaska. In addition, compliance with NPS wildlife regulations would need to be high for wildlife regulations and closures to be effective. Disturbances of seals, in which they abandon an iceberg in response to an approaching vessel, often occurs in JHI during August (personal observation) and disturbances of seals at the Spider Island reefs, where more than 1,000 seals may be found, have been documented (Mathews, 1997b). Compliance with an NPS 100 yd distance limit at a Steller sea lion haulout in Glacier Bay was about 80% over a three year study period in which approximately 100 vessels were monitored (Mathews 1997c). Compliance levels for harbor seals at key haulout sites are not currently available, although data on vessel interactions in JHI and near Spider Island have been collected and reports on this work should become available (Mathews, in progress).

A shift in prey availability could result in reduced time on haulouts, if seals need to forage longer or farther away from a preferred haulout (Green et al. 1995). While some data have been collected on the prey of harbor seals in GB (Cottrell et al. 1991, Mathews unpublished data), we do not have enough information on harbor seal diets to ascertain whether or not changes in prey availability or quality are a driving force behind the observed declines. In the Antarctic, a negative correlation was found in the number of Weddell seals *(Leptonychotes weddellii)* counted on the fast ice during aerial surveys and the occurrence of pelagic (vs. nearshore benthic) prey in scat (fecal) samples (Green et al. 1995). Counts were significantly higher in years when seals fed mainly on nearshore prey compared to years when they were feeding on prey found in more distant waters. In the Gulf of Alaska, changes in the diet of Steller sea lions have been proposed as a primary cause of the steep decline in numbers of sea lions (Alverson 1992).

Limitations of the Trend Analysis Models

A portion of the decline measured by aerial surveys may be due to the inability of the current trend model to account for shifts in seals from one haulout site to another. In 1997, campers were observed on Spider Island during the first two days of the August surveys (Mathews 1997b) and in this year the mean count of seals on the Spider Island reefs plunged to 57, compared to 1,000 for previous survey years (1992, 1993-1998). During the August, 1997 surveys we also counted up to 557 seals (mean count = 388, n=4) on a previously unoccupied islet approximately one kilometer northwest of the Spider Island reefs. While some of the decline in numbers of seals on terrestrial haulouts may be due to the current model's inability to account for shifts to new sites, it appears that this effect explains only a small portion of the estimated –10.9% trend for terrestrial sites. When seals near Spider Island were excluded from the analysis for terrestrial sites, the trend was –8.9% (Table 2).

Another limitation in any model is whether the covariates that have a large influence on the numbers of seals on haulouts have been tested. While we have tested for the effects of several variables known or suspected to influence the number of seals on glacial ice or on reefs and beaches, the amount of ice available to seals as haulout substrate has not been incorporated into the analysis of trends in JHI. It does not currently appear that ice suitable for hauling out has been limited during the years surveyed, but iceberg surface area could become an important covariate if Johns Hopkins glacier begins receding. Seal density on icebergs from Johns Hopkins glacier, one of the few tidewater glaciers in GB that is advancing, appears to be much lower in JHI than in McBride glacier fjord where space on icebergs may be limiting on certain days (personal observation).

Recommendations for Survey Frequency

Surveys for harbor seals done each year at approximately the same time and using the same methods and observers with comparable skill levels are valuable for detecting population changes. However, even systematic counts only provide an index of the population size. Incorporation of additional ecological, temporal, and other factors that influence the proportion of animals ashore as covariates improves the sensitivity of trend analyses (Link and Sauer 1998). In areas where a positive trend in seal numbers has been measured for 5 to 6 years and where systematic survey methods have been established and followed during that time, an every other year survey schedule should provide enough precision to detect a change in trend. In contrast, in areas experiencing a decline, annual surveys are recommended to better track the trend. In addition, data on population demography, such as pup production, the timing of pupping (Jemison and Kelly, in press), and diet assessment (Green et al. 1995) are recommended for a better understanding of the cause(s) of changes in population trend.

Conclusions

The number of seals on haulouts in GB National Park declined by 25%-48% from 1992-1998 at the primary breeding area (JHI) and at terrestrial sites. Numbers of seals on haulouts in Glacier Bay National Park are declining at fairly rapid rates, based both on trend analysis and raw counts. During all years of this study, the NPS has had closures and distance limits for primary harbor seal haulouts during much of key reproductive activities. The extent to which reduced disturbance of females with dependent young might improve the survival or overall fitness of pups is not known, but it is likely to have a positive effect on the energetics of lactating females and their pups. In light of the fact that subsistence hunting is not authorized in Glacier Bay and that this is the only area in Alaska where seals are actively protected from some human disturbances, it is particularly disconcerting that we are observing declines in harbor seals in Glacier Bay National Park.

Possible causes of declining numbers of seals on haulouts include increased mortality, reduced birth rates, and/or emigration from GB. Further, increased time in the water, possibly as a result of increased human disturbance or shifts in prey distribution, abundance, or quality, could cause declining trends in seals on terrestrial and glacial ice haulouts in GB. Determining if the observed declines in harbor seals in Glacier Bay National Park are the result of natural fluctuations in the marine environment or due to human activities should be the focus of future research.

ACKNOWLEDGEMENTS

We thank L. Dzinich for her major contributions to data collection and careful counts of seals from slides. We thank our field crews comprised of University of Alaska students, volunteers, and NPS staff: 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. We thank several people for their help with aerial surveys: J. Doherty, K. Wilson, E. Hooge, D. Williams, A. Maselko, P. Wald, T. Farrell, and A. vanDusen. Logistic support was provided by NPS staff (T. Gage, J. Williams, R. Yerxa, C. Young, and M. Goodro). We thank our pilots (M. Sharp, C. Shroth, and S. Wilson) for their assistance with spotting seals and for returning us home safely. Drafts of this report were improved by comments from Larry Basch, Jim Taggart, Mary Beth Moss, and Carol Wilson.

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Table 1. Summary results of counts of harbor seals in Glacier Bay, 1992-1998. **a)** Mean of 3 high counts for Johns Hopkins Inlet (JHI) in June, and b) mean of 3 high counts in JHI from different days during August with annual high counts from August surveys of terrestrial haulouts.

a) JUNE, JHI, non-pups

	JHI (counts from shore)		
Year	**Mean (high 3)**	**n, days**	**CV**
1992	2573	2	1%
1993	3657	4	15%
1994	2894	5	3%
1995	2646	4	2%
1996	3667	6	5%
1997	2866	8	3%
1998	2337	18	6%

b) AUGUST

	JHI (counts from shore)			Terrestrial Sites (aerial surveys)		MPE
Year	**Mean (high 3)**	**n, days**	**CV**	**Max**	**n, days**	**All Sites**
1992	4470	3	21%	1821	2	6291
1993	3361	2	31%	(no survey)	0	
1994	4046	9	10%	2507	4	6553
1995	4284	13	8%	2457	3	6741
1996	4381	13	8%	1832	5	6213
1997	3820	9	6%	1225	5	5045
1998	3092	14	5%	1374	6	4466

Table 2. Summary of trends in numbers of harbor seals in Johns Hopkins Inlet (JHI), a glacial fjord, and at the remaining terrestrial haulouts in Glacier Bay from 1992-1998. Variables tested for influencing counts in JHI were: 1=yr^2, 2=date, 3=date^2, 4=relative time of day (trm), 5=trm^2, 6= count quality, and 7=observer level. Variables tested for the terrestrial haulouts were: 1=yr^2, 2=date, 3=date^2, 4=trm, 5=trm^2, 6=time relative to low tide, and (trt), 7=trt^2. Variables contained in the top 10 trend models for JHI (by percentage of models in which they were influential), and those influential in the one model for terrestrial sites, are summarized.

							Variables Contained by Models[b]						
Loca-tions	**Month**	**Age Category**	**trend (%/yr)**	**95% CI (%/yr)**	**total trend (%/7yrs)**	**mod[a]**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
JHI	June	non-pups	-4.9	-7.3, -2.5	-25%	6	100%	30%	100%	40%	30%	10%	20%
JHI	Aug	all	-6.8	-8.8, -4.8	-35%	9	100%	30%	100%	60%	100%	30%	60%
Terr	Aug	all	-10.9	-16.4, -5.0	-48%	1[c]	x		x			x	x
Terr w/o Sp Is	Aug	all	-8.3	-14.9, -1.7	-42%	1[c]							

[a] The number of models with AIC weights >=0.05; models with smaller weights have little influence on trend estimates.
[b] The proportion of the top 10 models that contain this variable.
[c] Analysis of the terrestrial sites is based on only 1 model.

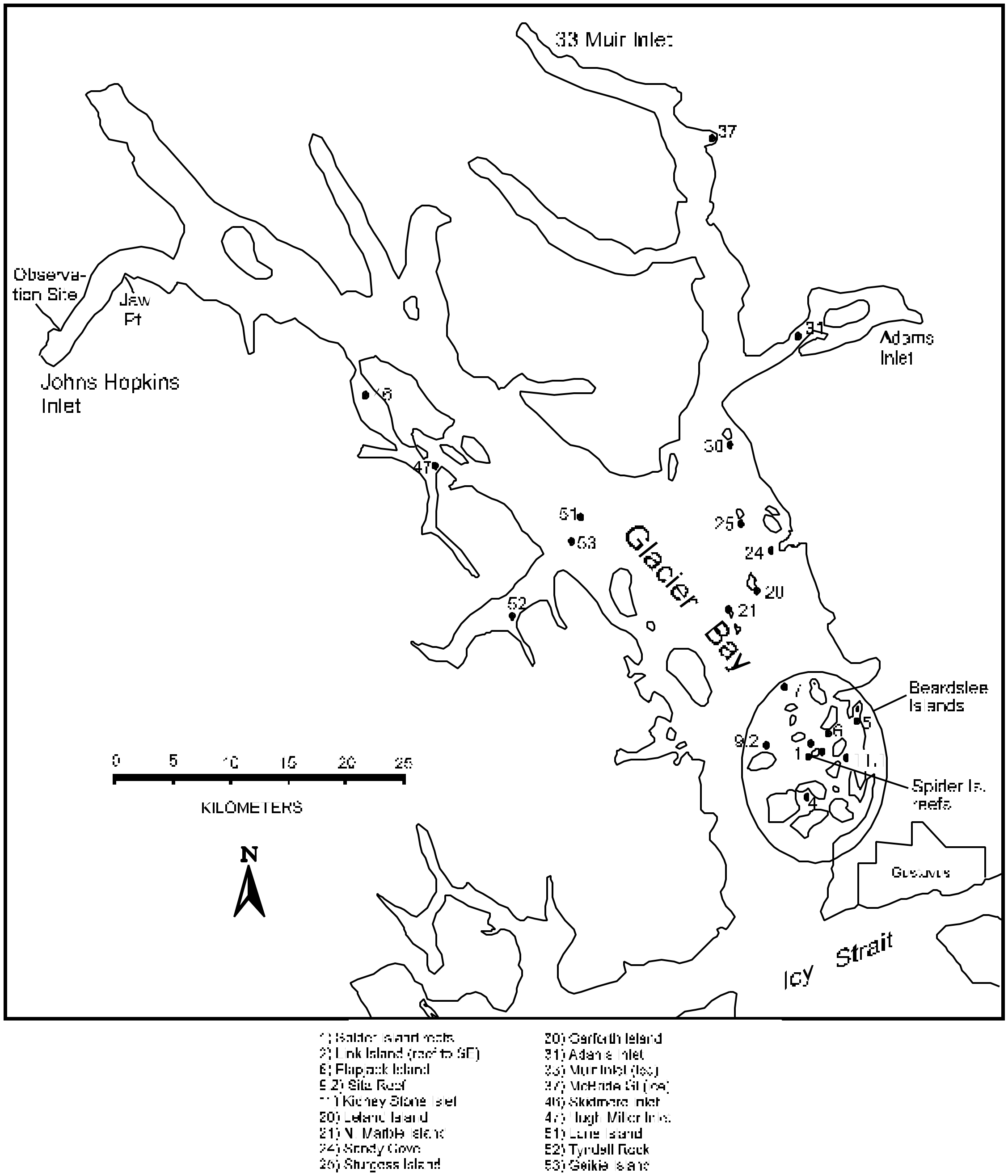


Figure 1. Map of Glacier Bay with the main terrestrial haulout sites surveyed in August between 1992 and 1998. Johns Hopkins Inlet and McBride Glacier inlets are tidewater glacial fjords where seals congregate to give birth, breed, and molt during spring and summer.

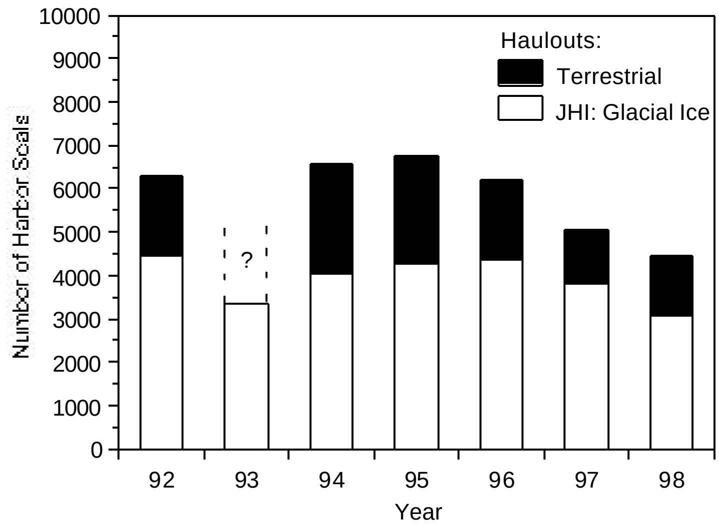
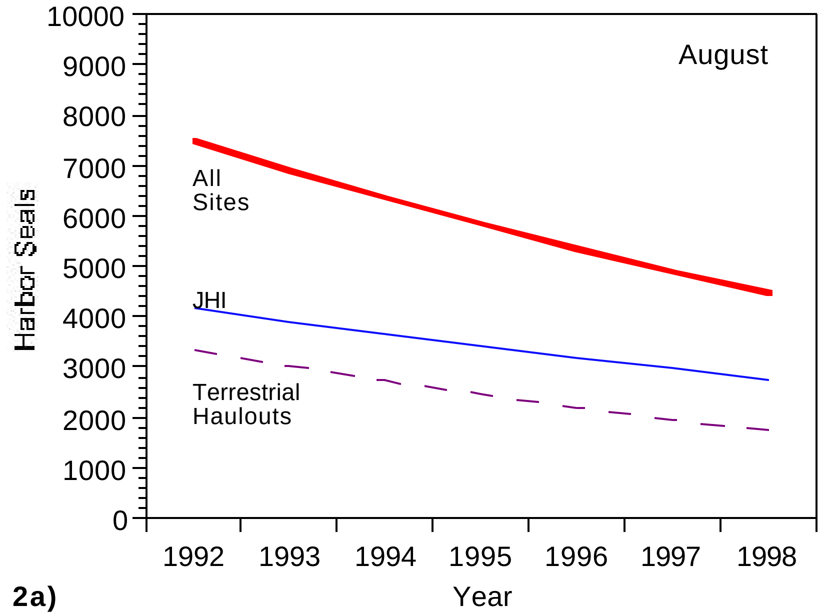


Figure 2. Minimal population estimate (MPE) of the number of harbor seals on haulouts in August, 1992-1998 in Glacier Bay. Data are uncorrected high counts from aerial surveys of all terrestrial sites and one small glacial ice haulout (Terrestrial Sites) and the mean of the three highest counts from shore-based surveys of seals on icebergs in Johns Hopkins Inlet (JHI). There was no aerial survey in 1993.



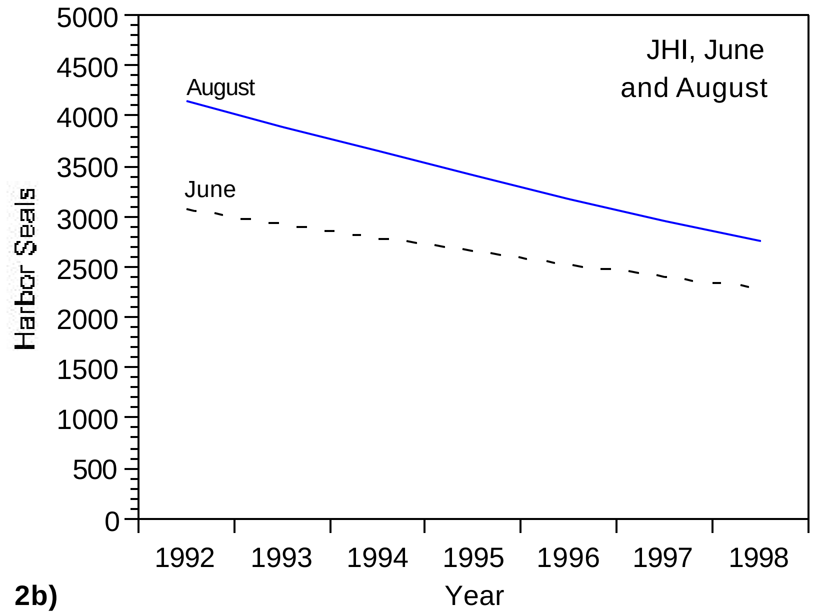


Figure 3. a) Trends in numbers of harbor seals in Johns Hopkins Inlet, a tidewater glacial fjord (-35% overall; -6.8% per year, solid, thinner line), at terrestrial haulouts in Glacier Bay (-48% overall; -10.9% per year, dashed line), and for JHI and terrestrial sites combined (=All Sites: solid, bold line) during surveys in Glacier Bay during August. **b)** Trends in numbers of harbor seals in Johns Hopkins Inlet, a tidewater glacial fjord during shore-based-based counts in June (-25% overall; -4.6% per year, dashed line) and August (-6.8% per year, solid line). Trend lines are centered on the best counts for each survey method in 1995. (See Table 2 for 95% Confidence Intervals for each trend.)

Appendix A. Summary of harbor seal survey results from 1992-1998 in Glacier Bay.

	Max	August 1992				August 1994						August 1995				
Location	**92-98**	**27**	**28**	***Mean***	***Max***	**8**	**10**	**11**	**12**	***Mean***	***Max***	**1**	**8**	**10**	***Mean***	***Max***
Spider_Rfs	1522	1094	1017	*1056*	*1094*	1522	1489	1252	1271	*1384*	*1522*	1163	1077	1037	*1092*	*1163*
Spider_W_Is	557															
Spider_NNW	83										*0*					
Geikie_Rks	446	116	203	160	203	100	131	136	239	151.5	239	303	91	288	227	315
S_Leland	361	209	243	*226*	*243*	361		236	0	*199*	*361*	302	285	341	*309*	*341*
Lone Is	261	109	145	127	145	183	154	143	138	154.5	239	150	101	85	112	150
SecretBay	251	0	0	*0*	*0*	0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
Flapjack	228	61	126	*94*	*126*	228	0	0	124	*88*	*228*	194	208	166	*189*	*208*
Adams	225		0	*0*	*0*	0	0	110	99	*52*	*110*	0	0	0	*0*	*0*
McBride_Ice	217											6	18		*12*	*18*
Kidney_Stn_Rf	139		0	*0*	*0*	0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
Sturgess_S	109	0	0	*0*	*0*	71	60	0	109	*60*	*109*	81	0	49	*43*	*81*
Boulder	93					0				*0*	*0*	0	93	0	*31*	*93*
Skidmore In	89	0	0	0	0	0	0	0	32	8	32	59	35	0	31.3	59
Muir_Ice	87		87	*87*	*87*	0				*0*	*0*					
SandyCove	70	0	0	*0*	*0*	0	0	0	70	*18*	*70*	27	24	40	*30*	*40*
Tyndall	63	0		*0*	*0*	0				*0*	*0*	63		51	*57*	*63*
N_Marble	59	0	0	*0*	*0*	24	26	23	32	*26*	*32*	59	20	10	*30*	*59*
Carolus	31													31	*31*	*31*
Garforth_S	26	0	0	*0*	*0*	18	0	0	0	*5*	*18*	26	0	0	*9*	*26*
HughMiller	24	0		*0*	*0*	0		0	0	*0*	*0*	24	0	0	*8*	*24*
Sita Rf	16	0	0	*0*	*0*	0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
Caroline_Sh	6	0	0	*0*	*0*	0				*0*	*0*					
Sealers	1	0	0	*0*	*0*	0				*0*	*0*	0	0	0	*0*	*0*
Berg Bay	0	0				0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
BlueMouse	0	0					0	0	0	*0*	*0*	0	0			
Charpentier	0	0					0	0	0	*0*	*0*	0	0	0	*0*	*0*
Drake Is	0	0	0	*0*	*0*	0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
Eider Is	0	0	0	*0*	*0*		0	0	0	*0*	*0*		0	0	*0*	*0*
Fingers Bay	0	0	0	*0*	*0*	0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
Francis Is	0	0	0	*0*	*0*	0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
Hutchins Rfs	0	0	0	*0*	*0*	0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
Lars Is	0					0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
Link Is Rfs	0	0	0	*0*	*0*	0	0	0	0	*0*	*0*	0		0	*0*	*0*
N_Young Is	0		0	*0*	*0*	0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
Queen In	0					0							0	0	*0*	*0*
Reid In	0					0										
Rendu In	0					0										
S_Marble Is	0	0	0	*0*	*0*	0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
Strawberry Is	0	0	0	*0*	*0*	0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
Tarr In	0					0										
Tidal In	0						0	0	0	*0*	*0*					
Wachusett In	0		0	*0*	*0*	0								0		
Willoughby Is	0	0	0	*0*	*0*	0	0	0	0	*0*	*0*	0	0	0	*0*	*0*
	Totals =	*1589*	*1821*			*2507*	*1860*	*1900*	*2114*			*2457*	*1952*	*2098*		

Appendix A. Summary of harbor seal survey results from 1992-1998 in Glacier Bay.

		August 1996							August 1997							August 1998							
	Location	**11**	**19**	**20**	**29**	**31**	***Mean***	***Max***	**17**	**18**	**19**	**21**	**22**	***Mean***	***Max***	**11**	**20**	**23**	**25**	**26**	**27**	***Mean***	***Max***
1	Spider_Rfs	999	810	1008	357	703	*775*	*1008*	0	75	0	0	203	*56*	*203*	127	399	279	277	240	63	*231*	*399*
2	Spider_W_Is								557	455	515	0		*382*	*557*	185	0	0	0	0	0	*31*	*185*
3	Spider_NNW	74	69	83			*75*	*83*															
4	Geikie_Rks	177			17		97	177	92		74	73	105	86	105	158	98			44		100	256
5	S_Leland	249		101	65		*138*	*249*	201	177	206	161	112	*171*	*206*	306	51	68	100	38	97	*110*	*306*
6	Lone Is	38	0	0	43	0	41	43	27	25	38	71	0	101	109	36	18	0	0	5	0	20	36
7	SecretBay		20	0		1	*7*	*20*		22	25			*24*	*25*	93	0	132	209	207	251	*149*	*251*
8	Flapjack	194	113	139	10	87	*109*	*194*		43	63	42	54	*51*	*63*	38	11	0	35	52	74	*35*	*74*
9	Adams	84					*84*	*84*		22	130	132		*95*	*132*	225	0			223		*149*	*225*
10	McBride_Ice								56	155	132	212		*139*	*212*	143	217			93		*151*	*217*
11	Kidney_Stn_Rf	0	0	0			*0*	*0*					62	*62*	*62*	0	0	74	93	116	139	*70*	*139*
12	Sturgess_S	11		0			*6*	*11*								0	0	0		0	0	*0*	*0*
13	Boulder	0	2	54	0	0	*11*	*54*								0	0	6	0	6	10	*4*	*10*
14	Skidmore In								38		23			31	38	30	20			0		25	30
15	Muir_Ice																						
16	SandyCove	6		29			*18*	*29*								10	0	1		0	0	*2*	*10*
17	Tyndall										18			*18*	*18*	13	0			11		*8*	*13*
18	N_Marble	0		8			*4*	*8*			1			*1*	*1*	0	0	0		0	0	*0*	*0*
19	Carolus			0			*0*	*0*															
20	Garforth_S	0		11			*6*	*11*								0	0	0		0		*0*	*0*
21	HughMiller															0	0			0		*0*	*0*
22	Sita Rf	0	0	0	0	0	*0*	*0*								10	16	0		0		*7*	*16*
23	Caroline_Sh															0	0			6		*2*	*6*
24	Sealers															0	0			0	1	*0*	*1*
25	Berg Bay		0													0							
26	BlueMouse															0	0					*0*	*0*
27	Charpentier															0	0					*0*	*0*
28	Drake Is	0														0					0	*0*	*0*
29	Eider Is	0	0	0		0	*0*	*0*								0	0	0	0	0	0	*0*	*0*
30	Fingers Bay		0													0					0	*0*	*0*
31	Francis Is	0														0					0	*0*	*0*
32	Hutchins Rfs		0	0												0	0	0	0	0	0	*0*	*0*
33	Lars Is															0							
34	Link Is Rfs		0	0												0	0	0	0	0	0	*0*	*0*
35	N_Young Is	0	0	0		0	*0*	*0*								0	0	0	0	0	0	*0*	*0*
36	Queen In																						
37	Reid In																						
38	Rendu In																						
39	S_Marble Is	0		0			*0*	*0*								0	0	0		0	0	*0*	*0*
40	Strawberry Is	0	0	0	0		*0*	*0*								0		0		0	0	*0*	*0*
41	Tarr In																						
42	Tidal In																						
43	Wachusett In															0						*0*	*0*
44	Willoughby Is	0	0				*0*	*0*								0					0	*0*	*0*
		1832	*1014*	*1433*	*492*	*791*			*971*	*974*	*1225*	*691*	*536*			*1374*	*830*	*560*	*714*	*1041*	*635*		