Exxon Valdez Oil Spill
Restoration Project Final Report

Relative Abundance of Adult and Juvenile Marbled Murrelets in Prince William Sound, Alaska: Developing a Productivity Index

Restoration Project 95031
Final Report

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Study History: Restoration Project 95031 was initiated to develop a way to monitor the reproductive success of murrelets in the oil spill zone. This project builds on Project 94102 (Marbled Murrelet Foraging Patterns and a Pilot Productivity Index for Murrelets) and part of Project 93051B (Pilot Study on the Capture and Radio Tagging of Murrelets). Murrelet dispersal at sea also was examined in Project R15 (At-Sea Abundance and Distribution of Marbled Murrelets in the Naked Island Area). Earlier studies described nesting habitat; projects 93051B (Information Needs For Habitat Protection: Marbled Murrelet Habitat Identification) and R15 (Identification of Marbled Murrelet Nesting Habitat in the *Exxon Valdez* Oil Spill Zone). Portions of this report will be published (K. J. Kuletz and S. J. Kendall. In press. A productivity index for marbled murrelets in Alaska based on surveys at sea. J. Wildlife Management).

Abstract: To monitor the reproductive success of marbled murrelets (*Brachyramphus marmoratus*), we investigated a productivity index that uses at-sea counts of hatching-year (HY) birds and after-hatch-year (AHY) birds. Our objectives were to define seasonal patterns of abundance by age class and develop a protocol for estimating productivity. We integrated a 1994 pilot study with replicate surveys of 6 sites in Prince William Sound in summer 1995. At all sites, numbers of AHY birds peaked in late July and declined throughout August, whereas HY birds increased after 28 July and peaked by 9 August. As a result, the percentage of juveniles increased; thus, HY density may be a better index than juvenile:adult ratios because of migration by post-breeding adults . HY densities were highly correlated with June AHY densities, suggesting that the June population reflects the number of locally breeding birds. The regression of June AHY vs. July-August HY counts may also index regional murrelet reproductive success. Based on our data, power to detect a 50% change in juvenile abundance is generally greater than 80% when 5 surveys occur each year for 10 years. Compared to 1994, the peak in 1995 juvenile density was earlier and significantly higher, whereas adult densities remained stable. Juveniles preferred waters <200 m from shore and were rarely found along highly exposed coasts.

Key Words : at-sea distribution, *Brachyramphus marmoratus*, foraging, juvenile: adult ratios, marbled murrelet, marine habitat, Prince William Sound, productivity, reproductive success.

Project Data: *Description of data* - Digital data consist of : (1) geographic information system (GIS) coverage of the study areas, with transects and bathymetrics available; (2) environmental conditions collected during the surveys (date, time, tides, temperature, salinity, wind, seas, weather); (3) the numbers and species of birds observed on transect; and (4) details on each potential juvenile observed, including location. *Format* - Data regarding environmental conditions, counts and descriptions of juveniles are in Paradox 6.1 for Windows. Data on transects, bathymetrics and locations of juveniles are in Atlas/GIS. Text files are in WordPerfect

6.1. *Custodian* - Contact Katherine Kuletz through the Office of Migratory Bird Management, U.S. Fish and Widlife Service, 1011 E. Tudor Rd., Anchorage, Alaska 99503 (work phone: (907)-786-3453, fax: (907)-786-3641 or e-mail at kathy_kuletz@mail.fws.gov). *Availability* - Requests for data can be made through the lead author.

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EXECUTIVE SUMMARY

We surveyed *Brachyramphus* murrelets at 6 sites in Prince William Sound, Alaska, in summer 1995. The sites, each with 45-60 km of shoreline, were distributed to overlap with the APEX forage fish study areas, and to minimize foraging overlap by murrelets breeding in different areas of Prince William Sound. We conducted replicate boat surveys in June, July, and August.

Numbers of adults peaked in late July and declined throughout August. Murrelets declined in offshore waters as well, indicating that the birds were not simply moving offshore. Juvenile numbers increased after 28 July and leveled off by mid-August. As a result, the percentage of juveniles increased, even if absolute numbers of juveniles remained stable or decreased. We found significant concordance among sites in adult and juvenile occurrence during a season, suggesting that these patterns of abundance occurred throughout the Sound. However, among sites, peak juvenile occurrence varied by up to a week, and may have been reflecting slight differences in chronology due to local conditions. Most importantly, we found a strong and significant correlation between numbers of adults at a site in early June (incubation phase) and the number of juveniles present in late summer; no such relationship existed between adults and juveniles counted during the same surveys in late summer.

Among sites, the average percentage of juvenile murrelets ranged from 2% to 13% of the total murrelets. Compared to 1994 surveys at Naked Island and Port Nellie Juan, 1995 peak juvenile occurrence was at least 1 week earlier and significantly higher in juvenile density and ratio to adults; adult densities remained stable. The interannual difference in fledging dates could have been due to environmental conditions such as the earlier spring plankton bloom in 1995.

Juveniles preferred waters <200 m from shore, and occurred least often along highly exposed coasts. However, juvenile abundance did not vary significantly with most measurable habitat features, and sites with very different habitats had comparable productivity. There is qualitative evidence that food availability was a factor in the differences between sites and years.

Because adult murrelets begin to migrate once fledging begins, a false indication of annual productivity could result from interannual variation in migration patterns of adults. Comparing juvenile densities is one way to minimize the effect of adult movements. We propose that early June counts of adults best represent the local breeding population of murrelets. The relationship between numbers of adults present during incubation and juveniles present in July-August may provide a statistically rigorous index of murrelet productivity within a region such as Prince William Sound. However, with only one year of data on multiple sites, the results should be considered preliminary.

PREFACE

As the most abundant seabird in Prince William Sound (PWS), the marbled murrelet (*Brachyramphus marmoratus*) is an important indicator of the health of the marine environment. Since the early 1970's, their population has declined significantly and there has been no significant increase in the PWS murrelet population since 1989 (Agler et al. 1994, Klosiewski and Laing 1994). Although murrelets suffered high mortality in the *Exxon Valdez* oil spill (Piatt et al. 1990, Carter and Kuletz 1995, Kuletz 1996), the spill cannot account for the entire 67% reduction in numbers observed in post-spill years (Klosiewski and Laing 1994). The ultimate goal of this project is to determine if low reproductive success is limiting the recovery of marbled murrelets in Prince William Sound, and, if so, is food limitation responsible. The first step toward this goal will be to develop a method to monitor reproductive success of the marbled murrelet.

In other areas the decline of marbled murrelet populations coincided with the loss of old-growth forest nesting habitat (Ralph et al. 1995). However, only a small proportion of potential nesting habitat has been harvested in PWS. Because murrelets are likely long-lived (Beissinger 1995), one possible factor - low reproduction success - would not be evident in population surveys for a decade or more after chronic low productivity. Because concurrent declines have occurred in other piscivorous apex predators (Klosiewski and Laing 1994, Loughlin et al. 1994, Kuletz et al. in press), changes in the food supply affecting reproductive success have been hypothesized as limiting factors in the recovery of species affected by the *Exxon Valdez* oil spill.

Eventually, we will compare murrelet productivity to fish abundance, to determine if food availability is limiting the recovery of the PWS murrelet population. This report presents a cost-effective means of assessing reproductive success of the murrelet population. A murrelet productivity index, once it is refined and tested over several years, could be used as part of an integrated monitoring program for the spill zone.

In addition to the relative abundance of adults and juveniles, we want to know what physical or environmental characteristics affect the distribution of murrelets. Adults and juveniles could have different migration patterns and habitat preferences, thus affecting the monitoring protocol. Identifying the features that influence murrelet distribution and abundance will assist in future management decisions. Because annual fluctuations in the environment can mask important relationships, multiple years of data will be required to evaluate the influence of specific variables on murrelet abundance. Thus, for this year of the murrelet project, most of the environmental parameters are presented in the appendix of this report.

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INTRODUCTION

Marbled murrelets (*Brachyramphus marmoratus*) are small diving seabirds that are non-colonial, widely dispersed, and crepuscular in breeding activity and cryptic in breeding plumage. These characteristics distinguish them from most other Alcidae and have hindered study of their reproduction. The lack of information on marbled murrelet productivity is a concern because the species is listed as Threatened under the Endangered Species Act in California, Oregon and Washington (Stein and Miller 1992), and is threatened in British Columbia, Canada (Rodway 1990). In Alaska, where most of the world population breeds (Mendenhall 1992, Piatt and Naslund 1995), murrelet numbers in some regions have declined since the early 1970's (Klosiewski and Laing 1994, Piatt and Naslund 1995). The marbled murrelet also suffered high mortality in the 1989 *Exxon Valdez* oil spill (Piatt et al. 1990, Kuletz 1996).

Despite years of effort, only 32 nests with known outcome have been examined for reproductive success (Nelson and Hamer 1995a). It is likely that at-sea surveys are the only practical option for marbled murrelets. Recent attempts have been made to develop an index of marbled murrelet productivity that uses the ratio of hatching-year (HY) to after-hatching-year (AHY) birds at sea during the fledging period (Beissinger 1995, Ralph and Long 1995, Strong et al. 1995). The AHY birds include an unknown proportion of subadult and nonbreeding birds in alternate plumage (Sealy 1975, Carter 1984). Thus, the ratio of juveniles to adults does not provide a measure of chicks per breeding pair. However, the ratio incorporates the cumulative effects of nest initiations and the loss of eggs and chicks.

In California and Oregon, several problems became evident when measuring juvenile-to-adult ratios. First, juveniles were difficult to distinguish from adults in winter plumage, particularly in late August (Carter and Stein 1995). Second, because murrelets were less synchronous than colonial seabirds (DeSanto and Nelson 1995) and fledging occurred from late May to late September (Hamer and Nelson 1995), the optimal survey period was not well defined. Third, the post-fledging movements of juveniles and adults were unknown, so the interpretation of ratios were uncertain (Beissinger 1995). Finally, the small population, and low percentage of juveniles (usually <5%), made rigorous statistical analysis difficult (Anderson and Beissinger 1995, Ralph and Long 1995).

In contrast, PWS has a high murrelet population, so substantial numbers of birds can be encountered. The breeding season here is brief, with most fledglings appearing between late July and August (Hamer and Nelson 1995, Naslund et al. 1995). Additionally, information on the foraging range of breeding adults was available from murrelets radio-tagged in 1993 and 1994 (Kuletz et al. 1995a). This information indicated how far apart study sites would need to be to maintain discreet units.

In developing a protocol for PWS, the first step was to determine patterns of murrelet abundance during the summer. PWS is the northernmost extension of coniferous rainforest in north America and consequently it has a relatively brief snow-free breeding season. In a 1994 pilot study, we observed changes in murrelet abundance suggesting that adult birds leave soon after breeding, but juveniles remain at least until mid-September. Based on our 1994 observations, we hypothesized that the June population at a site was most representative of locally breeding birds and would therefore correlate with August juvenile counts. In 1995, we surveyed six study sites to enable us to make spatial as well as temporal comparisons of adult and juvenile abundance patterns. We also examined the use of juvenile densities as an index. Here we report the results of both 1994 and 1995 seasons, evaluate the murrelet productivity index, and recommend a protocol for south central Alaska.

OBJECTIVES

Our objectives were to:

1. Develop an index of murrelet reproductive success for PWS.
2. Determine what factors influence abundance and distribution of juveniles at sea.

This report primarily addresses the first objective. The second objective is included where appropriate but will require additional years of data, and therefore, the results from 1995 surveys are presented as appendices.

METHODS

Study area

Prince William Sound is a large embayment in the northern Gulf of Alaska characterized by deep, protected waters and numerous islands, bays and fjords (Fig. 1). It is bordered by the Kenai mountains (1200-2100 m) on the west and the Chugach mountains (2100-4000 m) on the north and east (Isleib and Kessel 1973). Glacial influence is greatest in the northern and western mainland fjords. Tree line is 30-600 m and forests consist of Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*) and mountain hemlock (*T. mertensiana*). Unforested areas include bog meadows, willow, alder and barren rock. Most of PWS land is uninhabited and much of it is part of the Chugach National Forest.

Our study sites (Fig. 2) included sections of eastern Valdez Arm (Valdez), lower Unakwik Inlet (Unakwik), all of Naked Island (Naked), central Port Nellie Juan (PNJ), northeastern Knight Island (Knight), and Dangerous Passage / Jackpot Bay (Jackpot). Unakwik, a mainland fjord, has a tidewater glacier at its terminus and water depths to 350 m. There is a salmon hatchery mid-way up Unakwik, which supports a commercial fishery. Valdez includes two large bays off the main channel, which is 400 m deep. Valdez has vessel traffic from the trans-Alaska oil pipeline terminal near the town of Valdez. Naked and Knight are large islands in west-central PWS. Naked is forested to its 400 m summit and has four large bays and exposed shoreline on the east side. Naked is surrounded by water <100 m deep within 1 km of shore. Knight has shoreline exposed to easterly winds and water depths to 200 m within 1 km of shore. Knight also had shallow protected waters in the highly convoluted Bay of Isles and a narrow passage between Knight and Ingot Island. PNJ, on the western mainland, is a large deep-water fjord bordered by steep mountains to 1700 m, with two tidewater and seven hanging glaciers. Port Nellie Juan has numerous bays and coves with the main channel up to 700 m deep. Jackpot, in southwest PWS, includes Dangerous Passage with water to 170 m deep and two sheltered bays.

During our studies, average air temperature at the sites ranged from 12.4-14.1 ^{0}C, surface water was 8.9-13.0 ^{0}C and salinity was 9.5-25.2 $^{0/00}$. Unakwik and PNJ had floating ice all summer: 3 % and 0.1 % of area, respectively. Among these sites, average air temperature, weather, and surface sea state were not significantly different, but swell height, water temperature, salinity and water clarity varied significantly (Appendix A). The difference in swell height was primarily due to the exposed eastern side of Naked and, to a lesser degree, at Knight. Water was cooler, more silty and less saline in the fjords with tidewater glaciers - Unakwik and PNJ. Tide range during the study was 5 m.

Sites were distributed to overlap with a concurrent forage fish study (Haldorson et al. 1996, Ostrand and Maniscalco 1996), but also to minimize overlap by foraging birds that were nesting in different study sites. Sites were >16 km apart, the average foraging range for radio-tagged murrelets in PWS (Kuletz et al. 1995a), and greater than the distance a radio-tagged juvenile moved from its nest over a 2 week period (Kuletz and Marks 1997).

Data collection

Newly fledged juvenile marbled murrelets usually are solitary but occasionally mix with adults in late summer (Sealy 1975, Sealy and Carter 1984). Because previous studies had suggested that juveniles occur closer to shore than do adults (Sealy 1975, Carter 1984, Anderson and Beissinger 1995, Ralph and Long 1995, Strong 1995), we concentrated our efforts within 200 m of shore.

We used pre-established shoreline transects digitized in a geographic information system (Atlas/GIS [Strategic Mapping, Inc. 1992]). Each site had 9-18 transects that averaged 4.7 km; a total of 45-60 km of shoreline comprised each site. In 1994, surveys were conducted by 2 or 3 people from a 7.7-m fiberglass boat and half of the Naked surveys were done with a 5-m inflatable. Earlier tests at Naked found no significant difference in murrelet counts between the inflatable and fiberglass platforms under normal conditions (Kuletz 1994), so they were considered comparable. In 1995, surveys were conducted by 2 crews of 3 people each, both operating from 7.7-m fiberglass boats.

Because murrelet counts vary significantly earlier or later in the day (Carter and Sealy 1990), we surveyed between 0600-1600 hours. The vessel traveled 100 m from shore at a speed of ~10 km/hr. Observers counted all birds and mammals on 100 m either side and ahead of the vessel. Transect width was calibrated by radar to maintain distance from shore, and by training observers to estimate distances by towing a duck decoy.

Observers used binoculars to identify species and plumage. One person recorded observations on transect data sheets. Prior to each transect we recorded time, weather, seas, temperature, salinity and water clarity (by Secchi disk). The relationships between habitat, environmental conditions and murrelet abundance will be examined in greater detail in a separate paper (see Appendices A-J for preliminary data). However, among sites there were no sampling biases related to tide, time of day or weather (Kuletz, unpubl. data).

Other investigators have suggested that juveniles remain closer to shore than adults (Sealy 1975, Carter 1984, Anderson and Beissinger 1995, Ralph and Long 1995). In 1995, to determine if adults and juveniles occupied waters >200 m offshore in PWS, we conducted pelagic surveys at PNJ and Naked. Within a zone 0.2-2.0 km from shore, we randomly selected 25 pelagic transects of 1 km length, from a GIS grid overlaid on each site (Appendix B). We surveyed each of these two sites (i.e., 25 transects) once/week during June and July-August survey periods. We used the same transects on all surveys, navigating with a Geographic Positioning System (GPS). If a transect ran all the way to shore, birds <200 m from shore were not included in the pelagic population estimates. The pelagic population estimates and variances were calculated for each survey using the area within the entire grid (calculated by GIS), and a ratio estimator (Cochran 1977).

In 1994, we conducted one survey at Naked on 30 May, and one on 9 July at PNJ. The remaining 1994 surveys were conducted from 16 July-8 September at Naked (n = 14d) and PNJ (n = 12d). In 1995 we surveyed all 6 sites between 3-17 June (4 replicates/site, except 3 for Valdez) and 18 July-28 August (7-10 replicates/site). We attempted to survey each site twice per week, with crews rotating among sites to minimize observer bias and temporal effects. Due to weather and logistic delays, we missed some sites during a survey rotation.

Plumage classification. -- Observers scored birds by plumage and behavioral characteristics using guidelines from Carter and Stein (1995) and Strong (1995), photographs and study skins, field guides and field training. In 1995, we used a separate data sheet to record details on each black-and-white (BW) bird. We allowed up to 10 min (x = 6 min) observation per BW bird, during which time the transect was temporarily halted (see Appendix C). For BW birds we attempted to recorded 18 physical and behavioral properties of the bird, including: duration of the observation, the presence/absence of an egg tooth, amount of white on the upper mandible, presence/absence of a dusky or speckled breast band, speckling on the neck or flanks, dark blotchy patches on neck or breast, back color, missing or rounded primaries and tail feathers, relative body size, and behavior. We categorized BW birds on site to one of 5 categories: definite AHY, probable AHY, unknown, probable HY, definite HY.

Kittlitz's murrelets (*Brachyramphus brevirostris*) coexist with marbled murrelets in PWS and are not easily distinguished. Prior to our surveys we trained observers by visiting areas with high densities of Kittlitz's murrelets (Blackstone Bay and upper Unakwik). During surveys we recorded murrelets not identified to species (5%) as *Brachyramphus* murrelets. At our sites, few identified murrelets were Kittlitz's murrelets (<0.4% total, <1% in Unakwik and PNJ), therefore, we included unidentified *Brachyramphus* murrelets in our analyses.

Data analysis

Seasonal trends in abundance. -- To examine trends in murrelet abundance for all of PWS, we first graphed abundance for all sites combined. We did this by standardizing counts at each site relative to the maximum number recorded at that site (in a given year). If two sites were surveyed on the same day, we used the average of their standardized percentages. We tested the correlations of AHY and HY densities to date with a Spearman's correlation (r_s). In 1995, we also examined seasonal patterns of abundance among sites by dividing the fledging season into six one-week periods. If a site was surveyed twice in the same week, the counts were averaged. For each week, we ranked sites by AHY or HY abundance and tested for concordance over the season with Kendall's coefficient of concordance, or *W* (Siegel and Castellan 1988).

Productivity indices. -- Study sites were treated as independent units and the total number of birds counted on a survey as one sample. We assumed that the majority of breeding birds did not typically forage at the other study sites and that the juveniles at a site originated there or nearby. For analysis, ratios refer to HY/AHY birds, because ratios are more appropriate for statistical analysis than the percentage of juveniles relative to total birds (HY/HY+AHY). We occasionally present the percentage of juveniles in the population for comparison to other studies.

We examined HY:AHY ratios for both years in two stages. First, we included all July-August surveys, to determine the coefficient of variation (CV) for the entire fledging period. Second, to minimize the effects of zero values obtained early or late in the fledging period, we also determined CV during a 'core survey' period for each site. Our criteria for selecting core surveys were that: (1) surveys occurred prior to 23 August (about 1 month after the earliest juvenile sightings); (2) surveys were consecutive, to incorporate variability during peak fledging and; (3) the core surveys included at least one survey with maximum numbers of juveniles for that site. The number of surveys that met all these criteria for every site was 5, so that was the 'core' sample size for each site. Core survey dates varied slightly among sites but all occurred between 25 July and 22 August. Final comparisons among sites (and between years for Naked and PNJ), used these 5 core surveys, because CV's were considerably higher for the entire survey period.

We made paired comparisons of HY:AHY ratios using the standard errors of the ratios

(Manly et al. 1993:38) for each combination of sites (and years for Naked and PNJ) with a Z-test ($\propto < 0.05$). We did not adjust for multiple paired comparisons, because we preferred to avoid Type II statistical errors at this developmental stage of the productivity index.

We standardized murrelet counts as densities (birds/km^2) to compensate for differences among sites in the total shoreline surveyed, and for the occasional inability to complete sections of shoreline due to rough seas. We tested for differences in HY densities among sites with ANOVA (SAS 1988) and the Tukey multiple comparisons. To compare 1994 and 1995 at Naked and PNJ, we used a 2-way ANOVA for unbalanced data (general linear model; SAS 1988).

In 1995, we were able to test the relationship between adult abundance in June and juvenile abundance later in the summer. To do this we regressed the average density of HY birds on 5 core surveys in July-August at each site with the average density of AHY birds in June at that site. We also regressed the average July-August AHY densities to average HY densities. We refer to the combination of June counts with July-August HY counts as 'sequential' surveys, and the simultaneous counting of AHY and HY birds on the same July-August survey as 'concurrent' surveys.

Power analysis -- To examine our ability to detect changes in HY densities or ratios we did a power analysis using Gerrodette's (1987) 'TRENDS' model. The model relies on the coefficient of variation (CV), the number of years in which surveys are conducted, the number of surveys in each year, and the total percent change to be detected. The model assumes that change is a straight line slope (linear) over time, that surveys are conducted every year, and that the variance of yearly abundance estimates is proportional to true abundance (Gerrodette 1987; equation 8). Because the ratios for Unakwik and Valdez approached zero, with corresponding small variances, we calculated the mean of the variances of the remaining 4 sites, all of which had similar, high variances, to produce a conservative analysis (L. L. McDonald, West, Inc., Cheyenne, pers. comm.). We did this to ensure reasonable power in future surveys to detect trends in areas with moderate to high juvenile ratios and densities (as defined by the PWS data).

For each site we calculated the CV for HY densities for all July-August surveys, and again for the 5 core surveys. To derive a CV for PWS in a given year, we calculated weekly HY density by averaging HY densities from all sites for each of 5 weeks (25 July-22 August). In this case, the weekly HY density is equivalent to a survey. For the power analysis, we rounded all CVs to the nearest 0.10 and applied them to hypothetical time frames of 5 or 10 years, to approximate the statistical power of detecting trends at $\propto = 0.10$.

RESULTS

Plumage classification

In June, we counted 14 BW birds (0.3%) of 4051 murrelets that were AHY. In July-August we recorded 554 BW birds among 10,154 murrelets. Of BW birds observed in July-August, we categorized, on-site, 2% as definite AHY, 10% as probable AHY, 28% as unknown, 44% as probable HY, and 16% as definite HY. We were conservative in categorizing birds as juveniles on-site. Thus, after review of the BW data sheets, we later recategorized 51 (9%) of the July-August BW birds due to inconsistencies in descriptions of the birds and the category they had been placed in; we changed 27 from unknown to probable HY and the remainder from AHY to unknown or HY categories.

We found evidence of potential observer bias, primarily due to inexperience. The two boat crews differed in the proportion of probable AHY and HY birds ($X^2 = 85.4$, df = 4, $P < 0.001$), but not for other categories. Because the crews rotated among sites, and observers were less uncertain as the season progressed, the differences in categorization did not appear to reflect real spatial differences in the proportion of HY birds. Based on the birds that we recategorized and the data sheets for individual BW birds, some observers were conservative in identifying probable or definite HY birds, i.e., BW birds categorized as probable AHY could have been HY, but not the reverse. Most birds categorized as unknown were due to insufficient viewing time.

Because our on-site calls were conservative, and the numbers of definite AHY birds in basic plumage in August have been low in other studies (Carter and Stein 1995), we treated all BW birds, not categorized as definite AHY birds, as HY birds. Exploratory analyses that used only definite or probable juveniles did not alter test results, and the total numbers were more appropriate for comparisons among years and other regions.

Seasonal trends in abundance

In 1994, peak murrelet abundance occurred between approximately 20 and 31 July at Naked and PNJ. Total numbers declined steadily after late July, and were <5% of peak July numbers by 8 September (Fig. 3A). In 1995, murrelet abundance in June was lower than it was in July and the late-summer trend was similar to that in 1994 (Fig. 3B). In 1995, peak murrelet abundance occurred 25 July-3 August, and correlated negatively with date throughout the July-August surveys ($r^s = -0.47$, $P < 0.001$).

In 1994, we observed the first HY birds on 22 July, 5 days after surveys began. The first substantial increase in HY densities occurred 8-10 August, with a second peak on 1 September (Fig. 3A). In 1995, we first observed HY birds on 18 July (the first survey), and the first substantial increase in HY birds occurred 26-31 July (Fig. 3B). Although daily numbers of HY birds varied, they remained fairly high until the last survey on 28 August. Numbers of HY birds had a weak but significant positive correlation with date ($r_s = 0.19$, $P < 0.001$).

In 1995, seasonal trends in AHY abundance in offshore waters (0.21-2.00 km from shore) reflected those observed on shoreline surveys. At Naked, murrelet abundance on pelagic surveys declined after 18 July (Fig. 4), as it did on shoreline surveys. At PNJ, few murrelets were in offshore waters, with a slight increase on 28 July, when murrelet numbers also peaked nearshore. Few to no murrelets occupied offshore waters at PNJ by late August (Fig. 4). HY birds were extremely rare offshore: we found 1 at PNJ and 2 at Naked.

Site-specific trends in seasonal abundance

In both years and at most sites, because AHY numbers declined throughout August (Fig. 5A,B & 6A), the percentage of HY birds increased in late summer even though HY numbers remained stable or decreased (Fig. 5C,D & 6B). In 1995, there was concordance among the sites in weekly AHY abundance ($W = 0.755$, $P < 0.05$). Differences in patterns of abundance did occur, however. Total murrelet density peaked earlier at Naked compared to PNJ in both years, and in 1995, Naked and Unakwik peaked earlier than at all other sites (Fig. 5A & 6A). Naked showed evidence of a bimodal peak in HY density in both years (Fig. 5C & 6B). In 1995, the peak in HY density at PNJ in late August occurred when most other sites already showed a decline (Fig. 6B). At Valdez and Knight, densities of HY birds declined after 20 August.

Ratio of HY to AHY birds. -- Using all July-August surveys for each site, HY:AHY ratios ranged from 0.02 to 0.09, with CI's close to 100% of the ratio means (Table 1). For the 5 core surveys, (from which very early or late surveys were omitted from analysis), HY:AHY mean ratios were higher, ranging from 0.020 to 0.118, and the half-width of most 95% CI's was reduced, relative to CI's for the overall mean ratios (Table 1). For the core surveys, PNJ and Naked had the highest ratios, although the Knight ratio was not significantly lower (Z-test, $P > 0.05$; Table 2). The Valdez ratio also was lower than ratios at Jackpot and Unakwik (all $P < 0.05$; Table 2).

Density of HY birds. - For core surveys, HY densities at sites averaged 20-29 % higher, and CV's were lower, than results for the entire season (Table 3). Mean HY densities for the 5 core surveys varied significantly among sites (ANOVA; $F = 8.54$; df = 5,47; $P < 0.001$). PNJ had the highest HY density, but not significantly higher than HY densities at Unakwik or Naked. Naked, Jackpot and Unakwik all had higher HY densities than at Valdez.

The HY:AHY ratios obtained by using sequential surveys (average HY density:average June AHY density) ranged from 0.13 at Naked to 0.04 at Valdez. In paired comparisons, however, the differences in $\mathrm{HY{:}AHY_{June}}$ were not significant between any of the sites (all Z's < 1.4, all P's > 0.08).

Between-year comparisons at Naked and PNJ. -- The density of AHY birds at PNJ and Naked did not vary between years during the core surveys ($F = 2.36$, $df = 3, 19$, $P = 0.11$). In 1994, the July-August average density (birds/km^2) of AHY birds at Naked was 18.5 (SD = 9.5) and in 1995 it was 16.0 (SD = 10.6). At PNJ the AHY density averaged 23.5 (SD = 18.8) in 1994 and 19.0 (SD = 14.3) in 1995.

In 1994, the July-August HY:AHY ratio at Naked (0.19 ± 0.06 95% CI) was significantly higher than at PNJ (0.04 ± 0.01 95% CI; $Z = 4.65$; $P < 0.001$). Both sites had lower HY:AHY ratios in 1994 than in 1995 (Naked, $Z = 1.76$; $P < 0.05$; for PNJ, $Z = 3.50$; $P < 0.001$).

In 1994, HY density at Naked averaged 1.88 (SD = 0.73) and at PNJ, 0.57 (SD = 0.36). In 1995, Naked and PNJ had similar HY densities (Table 3). There was a significant difference in HY density between years ($F = 3.92$, $df = 1$, $P = 0.065$) but there was an interactive effect ($F = 17.94$, $df = 1$, $P < 0.001$), because of the greater increase at PNJ.

Ability to detect long-term trends

Relationship between June birds and fledglings. -- We found a strong correlation among sites between June AHY densities and late summer HY abundance. The average density of AHY birds at a site in early June explained a significant amount of the variation among sites in HY birds present in July-August ($r^2 = 0.91$, $P = 0.003$; Fig. 7A). Although only 1 survey was conducted in early June 1994 at Naked, the relationship between that AHY count and the 1994 HY count was consistent to the Naked data point for 1995. In contrast, we found no relationship between average July-August AHY density at a site and average HY density obtained during concurrent surveys ($r^2 = 0.09$, $P = 0.56$; Fig. 7B).

After-hatching year abundance. -- Based on 1995 surveys, the CV's for AHY densities at 4 of the 6 sites were <0.25, and Naked and Valdez had CV's of 0.58 and 0.44, respectively. These relatively small CV's, particularly those <0.25, resulted in reasonable power (≥80%) to detect changes in AHY densities of ≥30% over 5 or 10 years (Fig. 8A). This calculation assumes at least 5 surveys/site/year.

Hatching-year abundance. -- The probability of detecting trends in HY abundance over time was usually much lower than for AHY birds, and varied considerably among sites. At PNJ, with a CV = 0.18, power to detect changes in HY density was similar to that for AHY densities. At the other extreme, Valdez had a CV = 0.86, with an approximately 50% chance of detecting a 90% change in 5 years or 65% chance of detecting the same change over 10 years using 5 surveys per year. These results reflect the fact that detection of any change, large or small, is difficult in the presence of high variation within years. Additionally, detecting change in a small value is more difficult than detecting change in a large value.

Regional murrelet productivity. -- Averaging the densities among sites for the core period resulted in a CV = 0.42, with an approximately 60-80% chance, over 5 or 10 years respectively, of detecting a 50% change in HY density assuming 5 surveys each year. By using the average HY density for each week to calculate a CV for PWS (omitting the first week, when juveniles were rare), CV = 0.17. This low CV resulted in power to detect changes similar to that for high-density sites such as PNJ. Increasing the monitoring effort from 5 to 10 years increased power to detect trends by 5-20% (depending on the amount of change), as did increasing the number of surveys within each year (Fig. 8B). However, the greatest improvement in power was obtained from reduced variance (lower CV's) for within-site or within-year surveys (see Fig. 8A).

DISCUSSION

Seasonal trends in adult and juvenile abundance

We found general synchrony in seasonal patterns of adult and juvenile abundance among sites. The similarity in patterns of abundance among sites provides a solid basis for development of a murrelet productivity index for PWS, and possibly for south central Alaska. Our results show peak numbers of AHY birds after mid July, once fledging begins, followed by an exodus throughout August. The pelagic surveys indicated that AHY murrelets were not moving farther offshore in late summer, but were leaving the area.

The pattern of decreasing murrelet numbers after the breeding season appears to be universal in PWS. Surveys in 1978-1981 and 1991-1992 around Naked, Storey and Peak islands also showed an August decline in murrelets, especially in pelagic zones (Kuletz 1994, Kuletz et al. 1994). In 1989 and 1990, USFWS boat surveys of PWS found the August murrelet population was 57% and 37%, respectively, of July estimates (Klosiewski and Laing 1994). Adult marbled murrelets appeared to leave the study sites before going into advanced molt. In Barkley Sound, British Columbia, most adult birds also left in August, after the breeding season and prior to molting (Carter 1984).

The pattern of juvenile occurrence was consistent with other indicators of murrelet chronology in PWS. In PWS, the nestling period is primarily in late June to late August, based on nests observed (Naslund et al. 1995, Hamer and Nelson 1995, Kuletz, unpubl. data) and fish-holding behavior of adults. In 1994, we observed birds holding fish (presumably to deliver to chicks) from 9 July to 26 August, with the peak on 26 July (Kuletz et al. 1995a; Fig. 11). The earliest observations coincided with the first increases in juveniles on the water a month later, which is, roughly, fledging age. The peak in fish-holding occurred when most chicks were hatched and few had fledged that year. Thus, for PWS and other regions, adults holding fish may be a useful indicator of the best survey dates for HY birds.

We found slight differences in the abundance patterns of HY birds that suggested possible differences in chronology or juvenile dispersal. At sites with low juvenile ratios (Knight and Valdez) juveniles were absent late in the fledging period and may have died or emigrated due to poor local foraging conditions. The stable or increasing numbers of juveniles at Naked and PNJ could have reflected better early survival and immigration of juveniles from other areas.

At Naked, where fledging appeared to be earlier relative to other sites, juvenile abundance suggested a bimodal pattern. A similar pattern has been noted in California and Oregon, where a second wave of juveniles appeared 6-11 days after the first peak, perhaps due to renesting (Hamer and Nelson 1995). We have some evidence of renesting at Naked in 1992, when Naslund et al. (1995) concluded that a murrelet incubating on 27 July was likely from a failed nest 10 m away.

Environmental influences on juvenile abundance

Because some sites showed an increase in juveniles after mid-August while others declined, it is possible that juveniles moved to higher-quality sites. For example, juvenile abundance was high at Naked early in the fledging period and high late in the fledging period at PNJ. Both sites, however, had high juvenile densities throughout August and it is unlikely that juveniles traveled from Naked to PNJ, a distance of 35 km. Despite daily transits among study sites we never encountered black-and-white murrelets in open water. Flight was not typical for newly-fledged juveniles; from behavioral observations recorded for 465 HY birds, 9 flew and 23 made weak attempts or flew briefly.

Juvenile movements within a 12 km^2 area may be more typical (Kuletz and Marks 1997). At Naked, juveniles could have drifted from nearby Storey and Peak islands. Although murrelets nest on all three islands (Kuletz et al. 1995b, Naslund et al. 1995) Naked has more protected, shallow water (Appendix D), compared to its smaller neighbor islands. Additionally, in August 1995, Naked had abundant capelin (*Mallotus villosus*) that attracted many seabirds (Haldorson et al. 1996, Ostrand and Maniscalco 1996). The foraging activity of birds or abundance of fish might have drawn juvenile murrelets. Naked also has proportionally more exposed, rocky coastline than the other 5 sites (Appendix E), but also large semi-protected bays. Both of these habitat features were positively correlated with HY density (Appendices F- I).

The habitat at PNJ differed considerably from that at Naked (Appendices A, D, E), but juvenile abundance was high there as well. Newly-fledged juveniles may have been drawn to central PNJ from adjacent mainland areas in late August by high food resources. Although PNJ was not part of the Trustee Council-sponsored forage fish study (Haldorson et. al. 1996), circumstantial evidence suggests that prey were abundant there. The central bend of PNJ was one of the areas most frequently visited by radio-tagged adult murrelets (Kuletz et al. 1995a) and often had high densities of AHY murrelets during our surveys. The juvenile radio-tagged in PNJ in 1994 remained in this area at least 2 weeks (Kuletz and Marks 1997). In contrast, fish abundance at Valdez, which had the lowest juvenile density, was low (Haldorson et al. 1996), although fish abundance was high 10-20 km south of our study site. Near Knight, where juveniles were absent in late August, fish were primarily in deep offshore waters and likely inaccessible to seabirds (Haldorson et al. 1996).

We found few juveniles along the highly exposed portions of eastern Naked, Knight and Valdez (Appendix J). Most environmental variables, however, were highly correlated to date and thus seasonal patterns were the primary predictors of density. Based on our preliminary results and qualitative information from the APEX forage fish study, the strongest influence on murrelet productivity appears to be the availability of prey. Multi-year and quantitative analyses of fish biomass and prey accessibility will be needed to fully examine this hypothesis.

Intra- and interannual differences in chronology and productivity

At PNJ and Naked, where we had two years of data, we found slight variations in chronology and interannual differences in productivity. In both years, fledging occurred later at PNJ than at Naked. Differences in available nesting habitat might affect chronology. Port Nellie Juan has steep topography and a low proportion of forest cover, which results in snow cover remaining later in to the breeding season than at Naked. By our estimate, Naked is snow-free at least 2 weeks earlier than PNJ. A larger proportion of murrelets in PNJ may nest in crevices or on the ground and ground nesting birds would be more affected by snow cover than birds nesting in trees. From 1991-1994 we located 10 tree nests and one ground nest at Naked (Naslund et al. 1995; Kuletz, unpubl. data), but three nests in trees and three on the ground at PNJ (Kuletz et al. 1995a). The marine habitat may also have influenced breeding; during our surveys water temperature was cooler and peaked later at PNJ than at Naked (Appendix G).

Despite differences in habitat and chronology at Naked and PNJ, we found more variation in productivity between years than between sites, suggesting that both sites were responding to a large-scale environmental phenomena. Delayed food availability may have resulted in late nesting in 1994. The PWS spring plankton bloom in 1994 was one week later than 1995, and two weeks later than in 1993 (S. Vaughn, Prince William Sound Science Center, Cordova, pers com). About two weeks after the phytoplankton bloom, zooplankton and copepods appear and provide food for the fish on which the murrelets depend. Water temperature also was warmer and more saline in 1994 and there was no large-scale influx of upwelling water from the Gulf of Alaska (S. Vaughn, pers. com.). Sea surface temperature affects seabird egg-laying dates, presumably because of its effect on prey (review in Birkhead and Harris 1985).

Earlier fledging of murrelets in 1995 coincided with higher HY ratios and densities. Earlier breeding dates often correlate with higher productivity in seabirds (reviews in Gaston and Nettleship 1981, Nettleship and Birkhead 1985, Ainley and Boekelheide 1990). Another theory is that poor conditions for egg development (e.g. lack of food or rough seas that affect foraging) cause many pairs to delay breeding and a higher proportion of hatchlings do not have time to fledge (Birkhead and Harris 1985). The earlier peak in fledging in 1995 also could have been due to shorter nestling periods that year. Murrelet chicks hatch 27-30 days after egg-laying (Sealy 1974, Nelson and Hamer 1995b), but known fledging ages range 27-40 days (Nelson and Hamer 1995b). For many seabirds, fledging age fluctuates with environmental conditions or prey availability (Gaston and Nettleship 1981, Barrett and Rikardsen 1992).

Ratios vs. densities and sequential vs. concurrent surveys

The HY:AHY ratio is sensitive to the post-breeding patterns of adults and identifying adult seasonal patterns was an important step toward development of a murrelet productivity index. Our results indicate that the numbers of birds in June more accurately reflects the number of breeders that produce the fledglings present in July and August than do concurrent AHY counts in late summer. Thus, for any region, sequential surveys that establish a baseline count during incubation, followed by surveys during the fledging period, may provide the most accurate assessment of the ratio of newly fledged juveniles to breeding adults.

The post-breeding presence of AHY birds is likely influenced by local food resources and overall breeding success. If local conditions are favorable, sub-adults and post-breeding seabirds may remain in an area beyond the fledging period (Birkhead and Harris 1985). Locations with high prey availability may draw non-breeders or failed breeders from outlying areas, artificially lowering HY ratios. For example, Unakwik had high densities of AHY birds late in the season and, despite high HY densities, the HY:AHY ratio was low. Using sequential surveys (counts during incubation and juvenile counts) to derive HY:AHY ratios would reduce the impact of fluctuations in AHY abundance in July and August.

For some applications, the absolute abundance or density of HY birds may be a better measure of productivity than ratios. If, for example, it was not possible to conduct June surveys, then HY:AHY ratios derived from concurrent surveys could be augmented with HY densities. Comparing HY densities among areas minimizes the effects of different adult dispersal patterns. The disadvantage of using HY densities to index productivity is that it does not incorporate local population size. A site with few murrelets could have high reproductive success per pair but it would not compare favorably with a region of high murrelet abundance. To interpret trends indicated by a productivity index, the regional population should be monitored as well. In PWS, a seabird monitoring scheme is conducted periodically (Agler et. al. 1994).

A regional productivity index. -- The regression derived from the combined sequential surveys of multiple sites (see Fig. 7A) suggests an alternate means of comparing murrelet productivity among regions or years. The correlation among sites that we found in 1995 suggests that productivity was roughly equivalent throughout PWS, if we incorporate the number of birds present during the incubation period. The results presented here, however, should be considered preliminary until additional years of data indicate whether this relationship is consistent. If this relationship persists, the slope of the line for 1995 in PWS could be compared to similar data sets in subsequent years or to other regions.

The concurrent July-August HY:AHY ratios we found in PWS were generally higher than those reported in British Columbia, California and Oregon. The sites in PWS with the lowest ratios (Jackpot, Unakwik, Valdez), had ratios similar to those typically recorded farther south. The only ratios equivalent to the high-density sites in PWS (Naked and PNJ), were shoreline and kelp bed surveys where HY counts had been adjusted with a correction factor for survey date (see

Beissinger 1995). The comparatively low HY:AHY ratios found in most surveys from California and Oregon populations, in particular, might be indicative of 'sink' populations. Beissinger's (1995) model, based on the HY:AHY ratios and life history patterns of murrelets, suggested that the southern population can not be sustained at current productivity levels. If 1995 is representative of PWS, some northern regions could serve as 'source' populations.

Estimating the proportion of breeding birds. -- The productivity index is partially dependent on the proportion of non-breeding birds in the population. The June population, although best representative of the breeding population, includes subadults and non-breeders. We attempted to approximate the percentage of non-breeding birds by using the difference between early June and peak July counts. Because of July movements by AHY birds, we used the average number of birds counted in early June at all 6 sites combined (x = 1,000 birds) and the difference between that and the average number counted during the July peak (1,730 birds). We assumed that one member of all breeding pairs was incubating in June, both birds were on the water in July and nonbreeding birds were always present. Assuming that the 'additional' birds counted in July (730) were the incubating mates of breeding birds counted in June, doubling this number (1,460) and dividing it by the peak July count should provide an index of the percentage of breeding birds. Based on this exercise we estimated that approximately 16% of the murrelets in PWS did not breed in 1995. This proportion is close to the 15% found by Sealy (1975) from 104 murrelets collected in British Columbia in 1970-71 and in the upper range for all alcids (5-16 %; Hudson 1985).

Improving sampling and protocol

The timing of juvenile surveys is important whether using the ratio or the density method in that both were sensitive to temporal variations in fledging dates. For several alcids, fledging date varies more than the departure date of AHY birds (Birkhead and Harris 1985). In our surveys, AHY birds showed a much stronger, negative correlation with date than the positive correlation of HY birds (Appendix H). To avoid encountering AHY birds in basic plumage, which can be misidentified as HY birds, Carter and Stein (1995) and Ralph and Long (1995) recommended that juvenile surveys cease by mid-August. This recommendation was based on the plumage changes in juveniles, which after about a month at sea, are less distinguishable from AHY birds in basic plumage. We included surveys up to 22 August in our analyses because we did not observe increased numbers of birds in transitional molt (Kuletz, unpubl. data), AHY birds appeared to be leaving the area before molting, and the earliest observations of juveniles in PWS occurred only 30 days earlier. Survey periods that are 'safe' from overlap with molting AHY birds must be adjusted for local chronology and even later dates may prove appropriate for some areas of south central Alaska.

Because of the protracted fledging period and recommended cut-off dates to avoid AHY birds in basic plumage, some proportion of late-fledging juveniles will not be included in this estimate of productivity. In the murrelet's southern range, Beissinger (1995) proposed extrapolating from known fledging dates to derive a seasonal correction factor for ratios, to compensate for missing the late fledglings. Because of the more compressed breeding season for marbled murrelets in Alaska (Hamer and Nelson 1995), our survey period included nearly the entire fledging period, and a correction factor may not be necessary for south central Alaska. Further, annual variation in peak fledging dates in northern regions probably would eclipse a correction factor that is of low precision, because the correction is based on the fledging dates of a few nests found in different years throughout the murrelet's range.

The preference of marbled murrelet juveniles for nearshore waters could impact the productivity index, if it is the only habitat surveyed and if adults are not consistent in their post-breeding habitat preferences. In PWS, however, few AHY birds occurred offshore during the core fledging period, which minimized the problem of differential habitat selection between age classes. Additionally, previous surveys in the Naked Island area indicate that the pattern of inshore movement in August is typical (Kuletz et al. 1994). Murrelets in British Columbia are similarly concentrated nearshore in late summer (Carter 1984, Carter and Stein 1995). In Oregon, however, murrelets shifted offshore in late summer in one of two years surveyed (Strong et al. 1995). Thus, local habitat use by post-breeding birds must be determined to correctly interpret productivity indices based on ratios.

By analyzing only core surveys, we reduced variation and thus the sample sizes required to detect changes. The core survey period may vary slightly among sites, but in PWS, should encompass the approximately 3 weeks during which most chicks fledge. Because of spatial and temporal variation in peak fledging, however, it is advisable to sample over a five week period, to 'capture' the core period. Selecting the core survey period must be an objective process. Although we developed our criteria post-hoc, additional information about environmental effects on murrelet breeding phenology will likely result in better predictors of peak fledging dates (e.g., spring sea-surface temperature or dates of plankton blooms). Survey dates could also be guided by observations of adult murrelets holding fish.

Our results indicate that, for PWS, the core survey period can provide a regional CV of $\leq$0.42. Under Gerrodette's model, and assuming 5 surveys are conducted each year, this will have a moderate probability ($\leq$80%) of detecting changes in HY abundance of magnitude less than 50% in fewer than 10 years. In five years, a change of 70% can be detected with 80% probability if 5 surveys are conducted each year. Under the assumptions of Gerrodette's model, changes of $\geq$50% can be detected with 80% certainty in five years if 8 surveys are conducted each year, or in three years if 10 surveys are conducted each year. In PWS our results indicate that it will be easier to detect trends at sites with high murrelet densities because high murrelet densities generally resulted in lower CV's. In large regions, power can be improved by pooling multiple sites of similar quality and using the weekly ratio or HY density to calculate a regional variance during a core fledging period. As habitat preferences are defined, stratification by habitat might further reduce variance. For example, our data indicate that in PWS, offshore waters should be a separate survey strata or be omitted from the survey design.

The statistical power of the productivity index to detect changes would be improved by reducing the variance in murrelet counts, which includes determination of important habitat strata. A large region such as PWS could be stratified by average murrelet density as well. For example, the sampled areas should include sites with high abundance that appear to contribute disproportionately to regional productivity (e.g., Naked and PNJ). Intermediate sites, such as Knight and Jackpot, may reflect ecosystem changes before they become apparent at higher-quality sites. A third category might include sites of special interest, such as Unakwik. Unakwik attracted large numbers of murrelets and appeared to be an important feeding area for AHY birds. Additionally, Unakwik may be influenced by the local gillnet fishery (Wynne et al. 1992) and, as such, warrants attention.

CONCLUSION

Because of the late summer movements of AHY birds out of PWS, and the consequent increase in the proportion of HY birds, the HY:AHY ratios derived from concurrent surveys must be used with caution. Clearly, unless the timing of migration is consistent between years, a false indication of annual productivity could result from factors affecting the AHY population. We suggest that the numbers of AHY birds present during early incubation more accurately reflects the local breeding population than those present in late summer. Thus, HY:AHY ratios would optimally be derived from surveys conducted during early incubation to derive AHY abundance, and again during a core fledging period to obtain HY abundance (sequential surveys). Ideally, the total murrelet population of a region would be monitored as well, to compliment the productivity index.

If sequential surveys are not possible, relying on HY densities or absolute abundance, would minimize the effects of post-breeding migration by AHY birds. In general, using ratios or HY densities to compare productivity among the PWS sites (and between years, for Naked and PNJ) gave us similar results. Therefore, either index may be acceptable, but there are disadvantages particular to each index, and until further research indicates otherwise, both ratios and densities should be obtained.

We propose surveying multiple sites and using the regression of HY vs. June AHY densities as an alternative productivity index for a region such as PWS. Additional years of data will be required to determine if the relationship between counts during incubation and fledging periods is consistent, and if the slope of the line reflects murrelet productivity of a region. Surveying multiple sites would also increase the likelihood of detecting trends, since power to detect trends at a single site is generally low.

The generally low power to detect moderate trends in HY abundance at some sites does not invalidate the productivity index for among-site or between-year comparisons. Adult seabird numbers tend to be stable unless there is a long-term trend occurring, but reproductive success can vary radically from year to year (Nettleship and Birkhead 1985, Furness and Monaghan 1987, Vermeer et al. 1993). Long-term trends, however, would be measurable with a regional productivity index based on juvenile counts at sea, particularly as methods of reducing variance in counts are refined.

Adult marbled murrelets have low reproductive potential and are likely long-lived (Beissinger 1995). Low productivity may not be evident from total population surveys for a decade or more. With further development, the productivity index could be one tool to identify causes of change in the population, or reasons for the lack of recovery. Our results provide a baseline, and suggest a methodology, towards the goal of monitoring marbled murrelet productivity.

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Figure 1. The study area for Restoration Project 95031, Prince William Sound, Alaska.

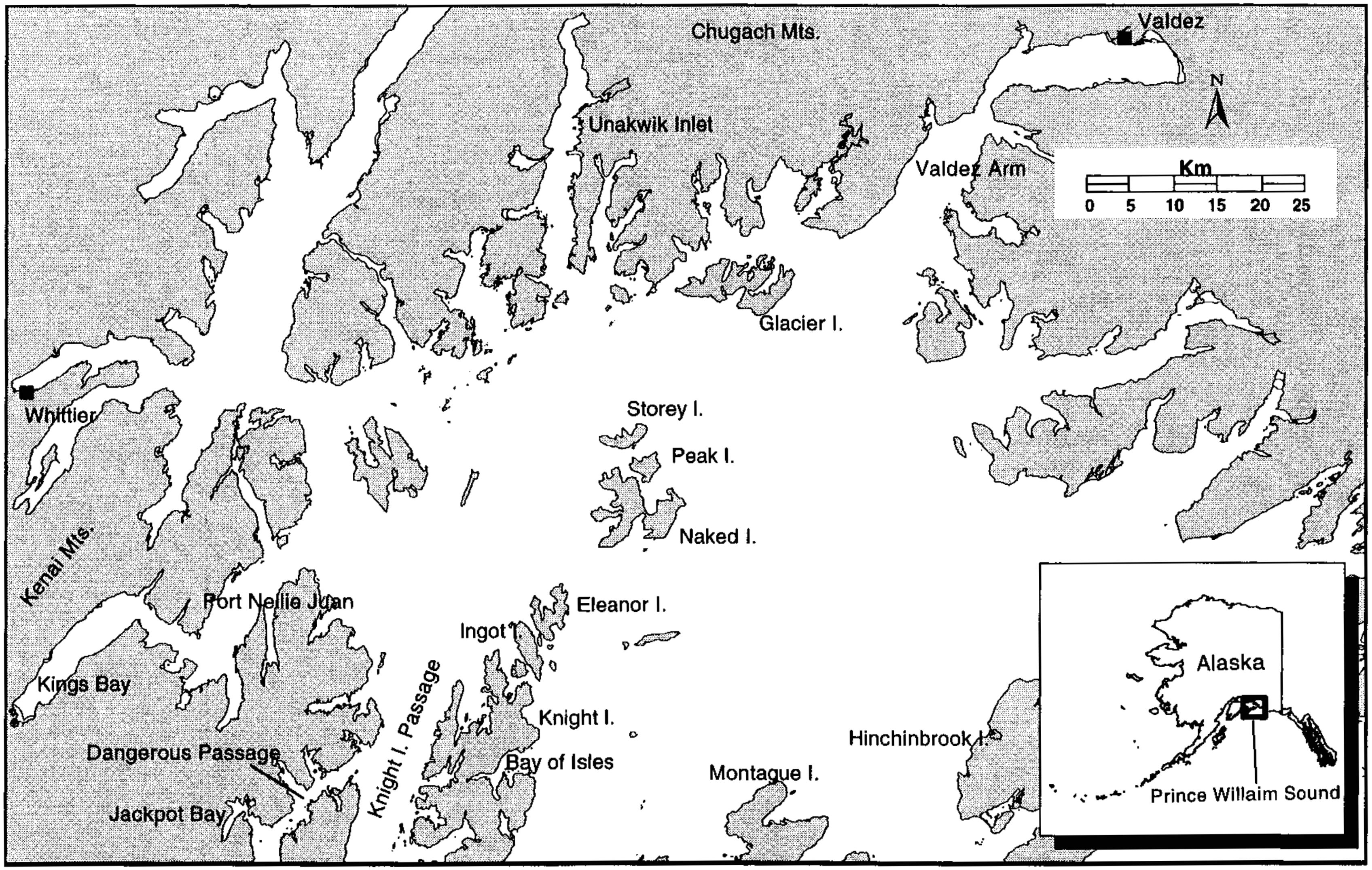


Figure 1. Prince William Sound study area.

Figure 2. The six study sites surveyed for marbled murrelet productivity in 1995. Port Nellie Juan and Naked Island were also surveyed in 1994.

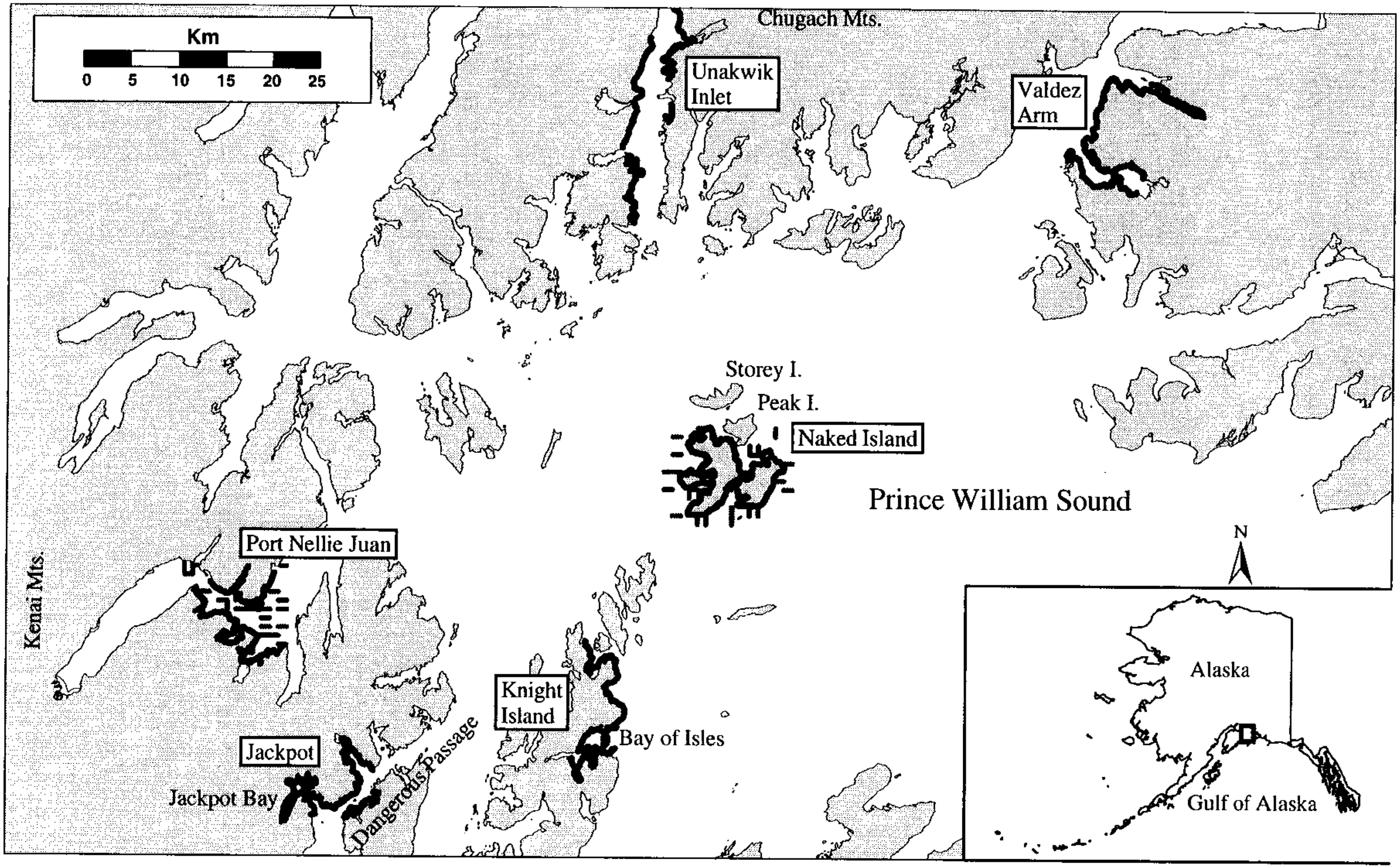

Km
0 5 10 15 20 25
Chugach Mts.
Unakwik Inlet
Valdez Arm
Storey I.
Peak I.
Naked Island
Prince William Sound
N
Port Nellie Juan
Kenai Mts.
Knight Island
Bay of Isles
Jackpot
Jackpot Bay
Dangerous Passage
Alaska
Gulf of Alaska

Figure 3. (A) Standardized densities (bars) of total AHY marbled murrelets and HY murrelets (black line) in 1994 at Naked and PNJ combined, and (B) in 1995 at 6 study sites combined.

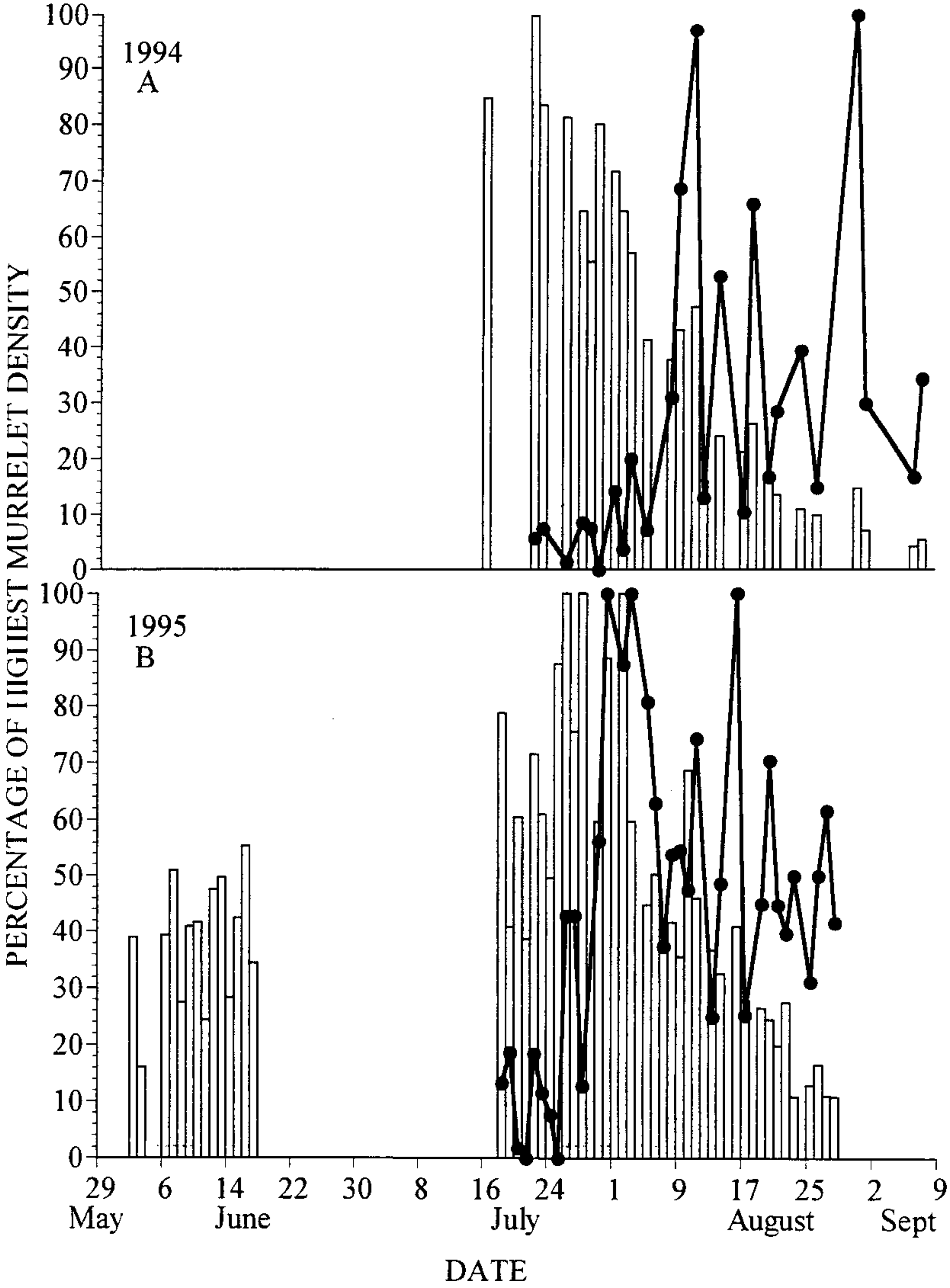

PERCENTAGE OF HIGHEST MURRELET DENSITY
1994
A
1995
B
100
90
80
70
60
50
40
30
20
10
0
29 May
6
14 June
22
30
8
16 July
24
1
9
17 August
25
2 Sept
9
DATE

Figure 4. Seasonal changes in the estimated marbled murrelet population (± 95% CI) in waters 0.21-2.00 km from shore at Naked and PNJ in summer, 1995, based on randomly selected pelagic transects.

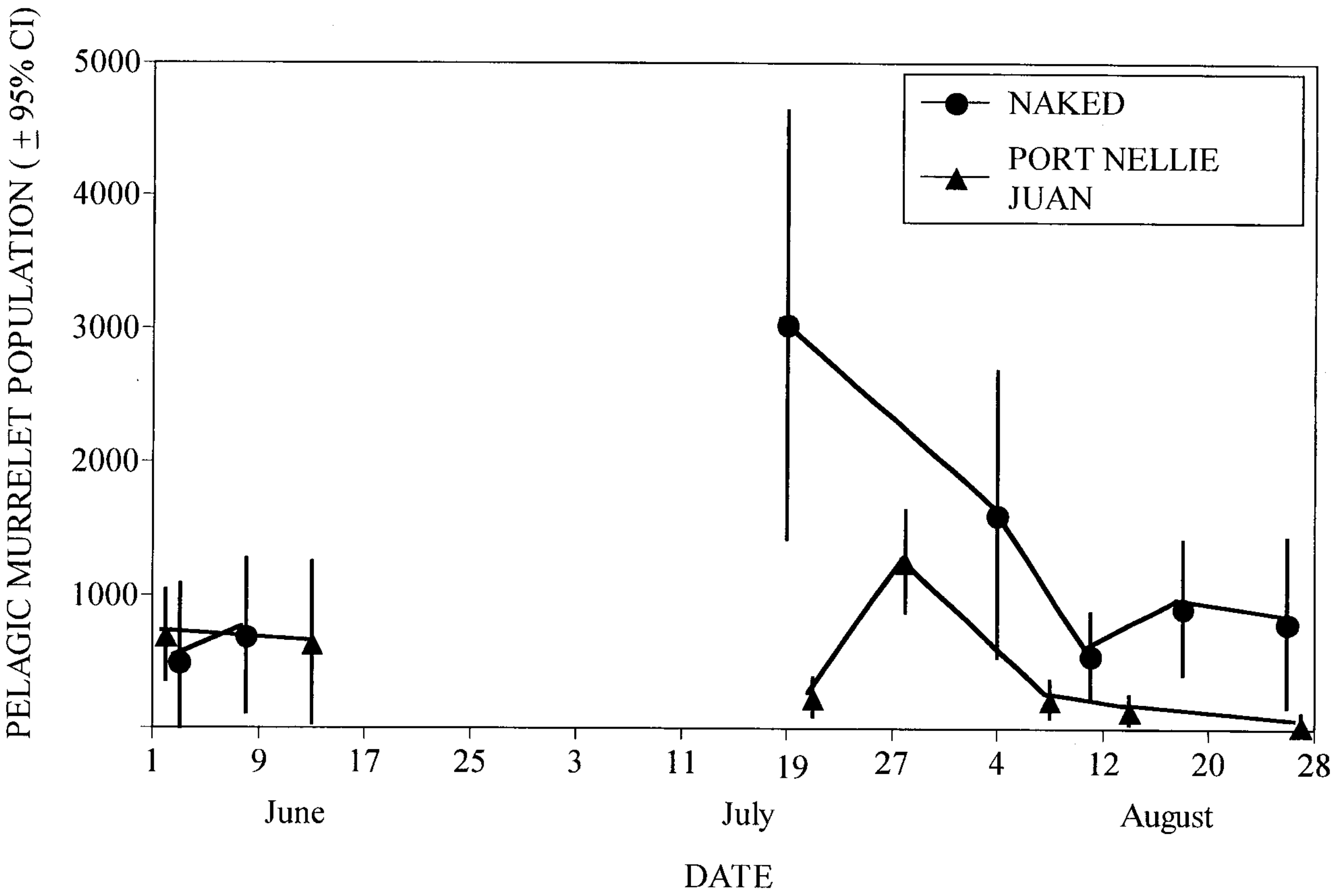
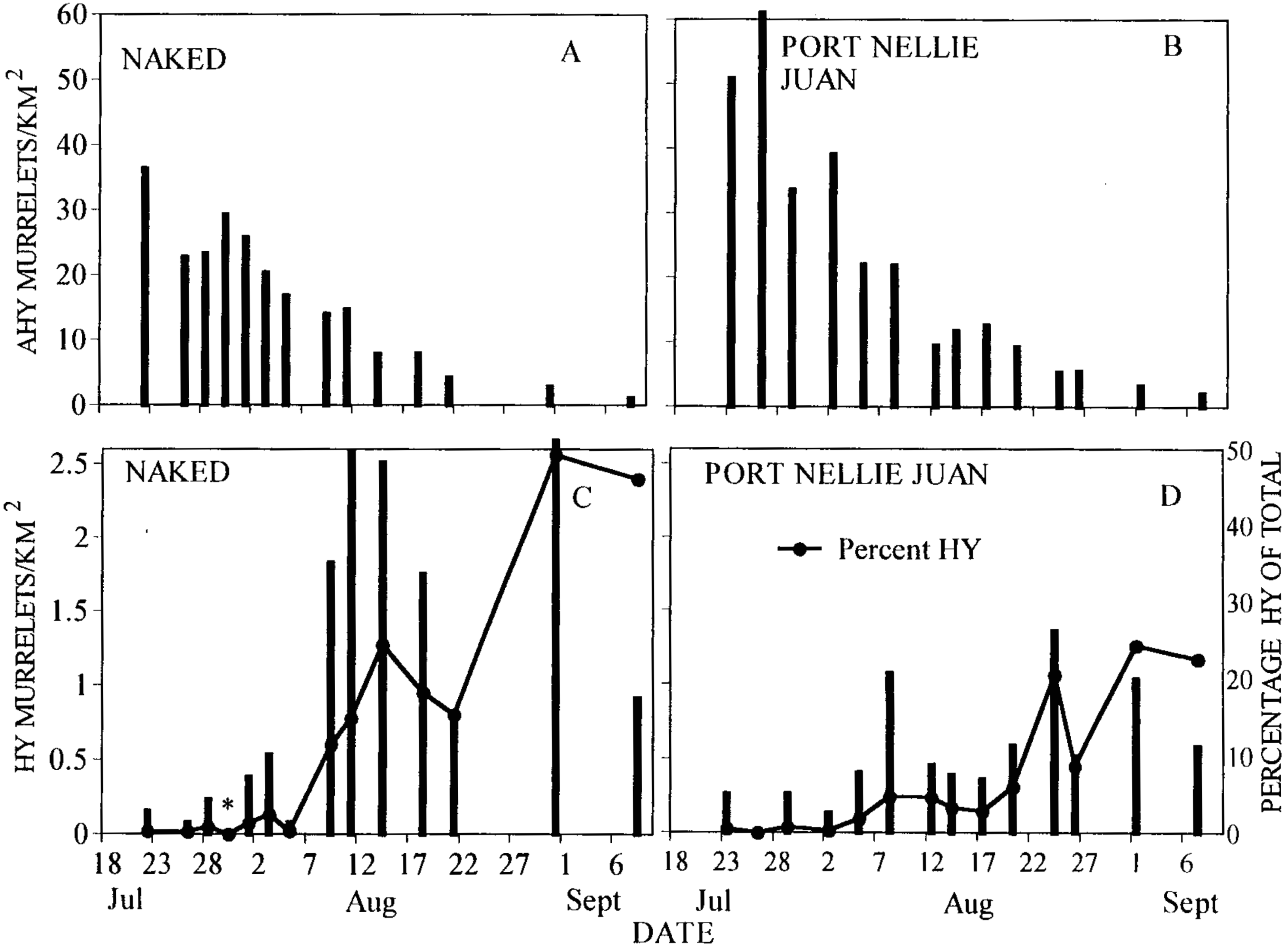

PELAGIC MURRELET POPULATION (± 95% CI)
5000
4000
3000
2000
1000
NAKED
PORT NELLIE JUAN
1
9
17
25
3
11
19
27
4
12
20
28
June
July
August
DATE

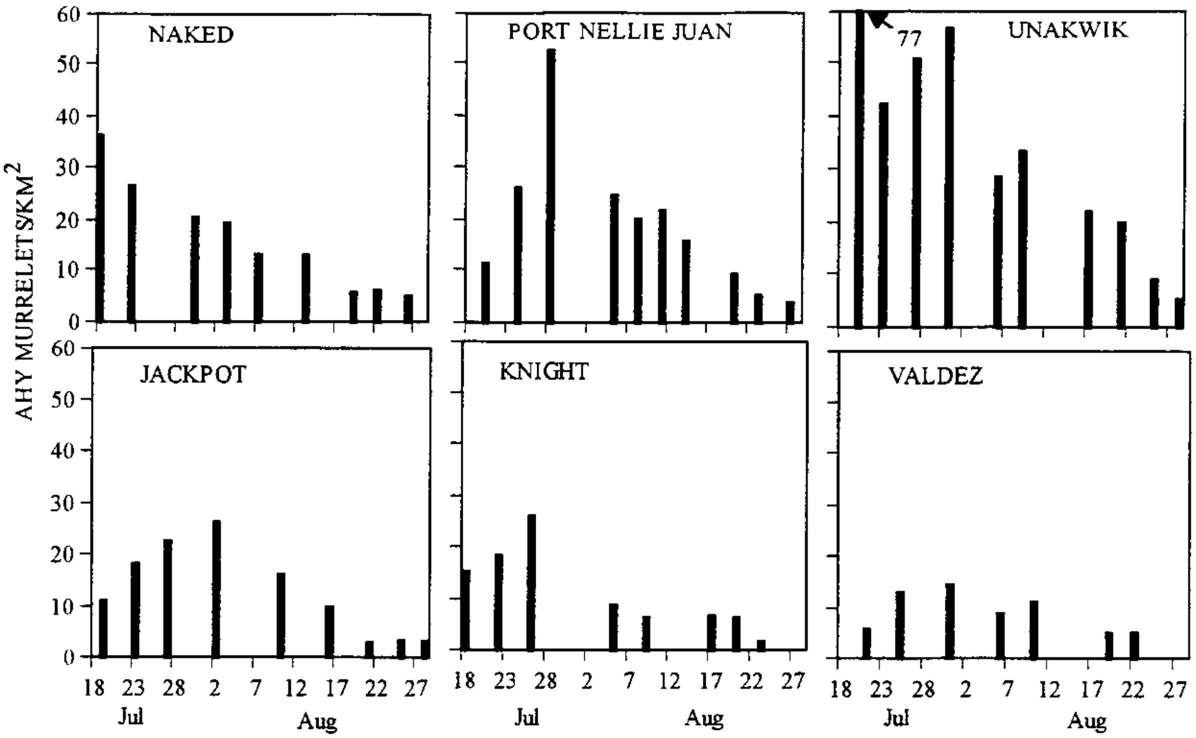
Figure 5. Density (birds/km^2) of AHY marbled murrelets at (A) Naked and (B) PNJ in July, August and September, 1994 and density of HY murrelets at those sites (C and D, respectively), during the same surveys. Asterisks indicate survey days where no HY birds were observed. The percentage of HY murrelets (C and D) of the total murrelet counts for each survey is also shown (filled circles).



NAKED
A
PORT NELLIE JUAN
B
AHY MURRELETS/KM^2
60
50
40
30
20
10
0
NAKED
C
PORT NELLIE JUAN
D
Percent HY
HY MURRELETS/KM^2
2.5
2
1.5
1
0.5
0
PERCENTAGE HY OF TOTAL
50
40
30
20
10
0
*
18
23
28
2
7
12
17
22
27
1
6
Jul
Aug
Sept
DATE

Figure 6. Density (birds/km^2) of (A) AHY marbled murrelets at each of 6 study sites in Prince William Sound, Alaska, July-August, 1994 and (B) density of HY murrelets at those sites during the same surveys. Asterisks indicate survey days where no HY birds were observed. The percentage of HY murrelets of the total murrelet counts for each survey is also shown (filled circles).

A. TOTAL MURRELET DENSITY - 1995



B. HY DENSITY AND PERCENTAGE OF HY MURRELETS - 1995

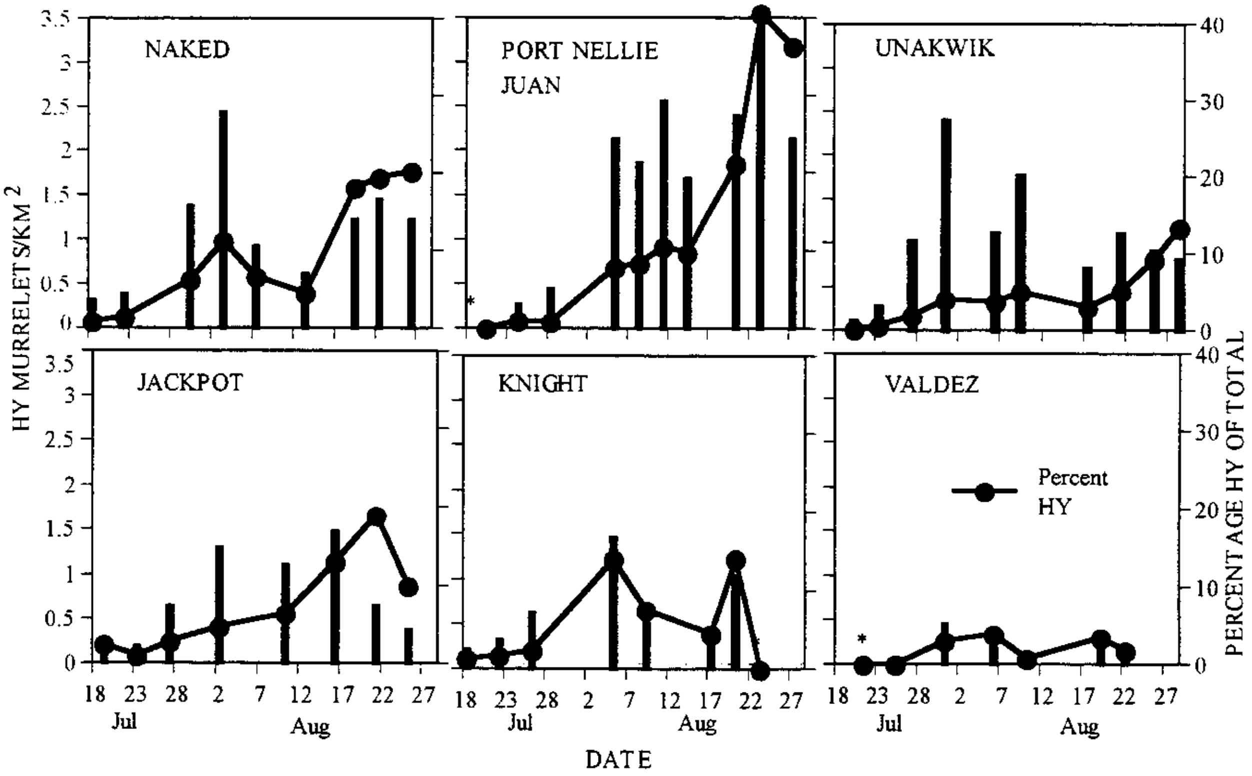
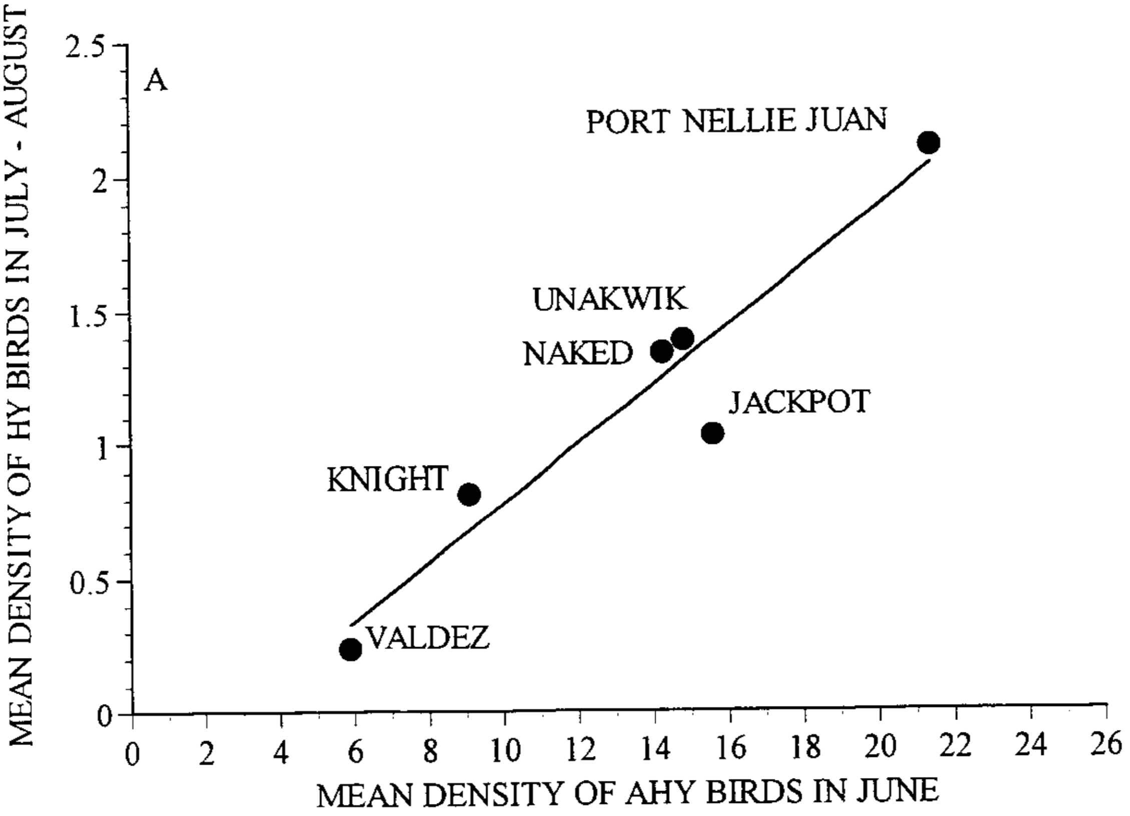


Figure 7. (A) Relationship between average AHY density (birds/km^2) at study sites in June and the average HY density at the same sites in July-August during the core survey period. (B) Relationship between average AHY density at study sites in July-August and the average HY density at the same sites during those surveys.


A
PORT NELLIE JUAN
UNAKWIK
NAKED
JACKPOT
KNIGHT
VALDEZ
MEAN DENSITY OF HY BIRDS IN JULY - AUGUST
0
0.5
1
1.5
2
2.5
0
2
4
6
8
10
12
14
16
18
20
22
24
26
MEAN DENSITY OF AHY BIRDS IN JUNE

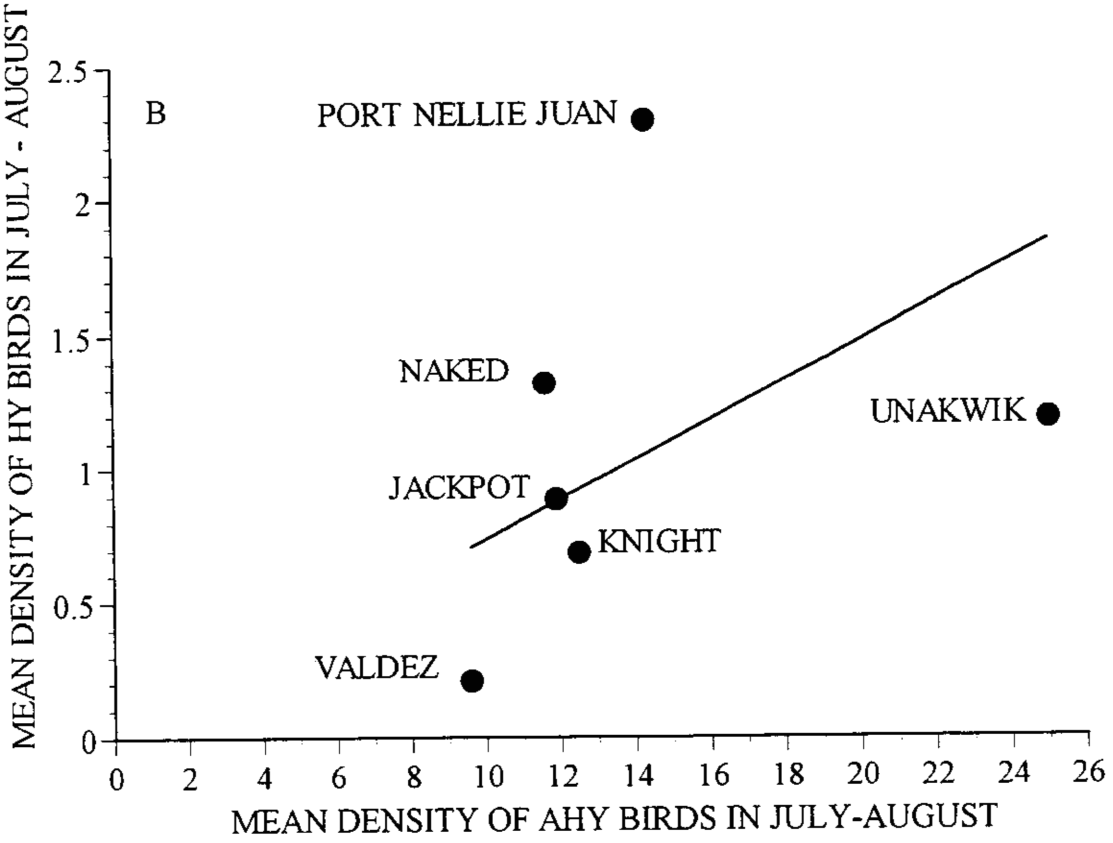

B
PORT NELLIE JUAN
NAKED
UNAKWIK
JACKPOT
KNIGHT
VALDEZ
MEAN DENSITY OF HY BIRDS IN JULY - AUGUST
0
0.5
1
1.5
2
2.5
0
2
4
6
8
10
12
14
16
18
20
22
24
26
MEAN DENSITY OF AHY BIRDS IN JULY-AUGUST

Figure 8A. Probability (Y-axis) of detecting changes in HY densities (X-axis) at the end of 5 years (circles) and 10 years (triangles) at CV's of 0.2 (dashed line), 0.4 (solid line) and 0.8 (dash-dot line), at alpha = 0.10. Calculations were based on the coefficient of variation (CV) for densities derived from the 5 core surveys at sites in PWS and assuming 5 surveys are conducted each year.

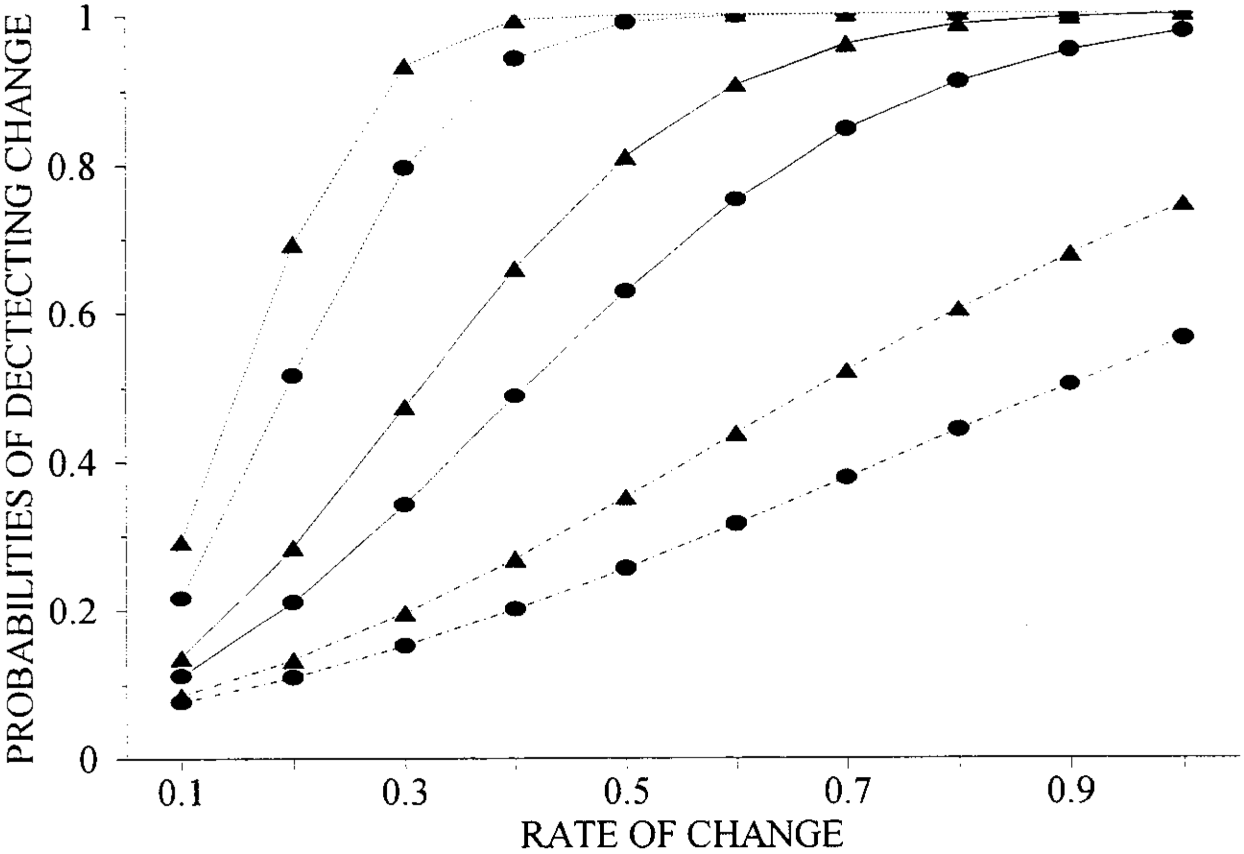

PROBABILITIES OF DECTECTING CHANGE
1
0.8
0.6
0.4
0.2
0
0.1
0.3
0.5
0.7
0.9
RATE OF CHANGE

Figure 8B. Probability (Y-axis) of detecting changes in HY densities (X-axis) at the end of 5 years assuming 3 (dot-dash line), 5 (solid line) and 8 (dashed line) surveys within each year. For this figure, CV = 0.4 and alpha = 0.10.

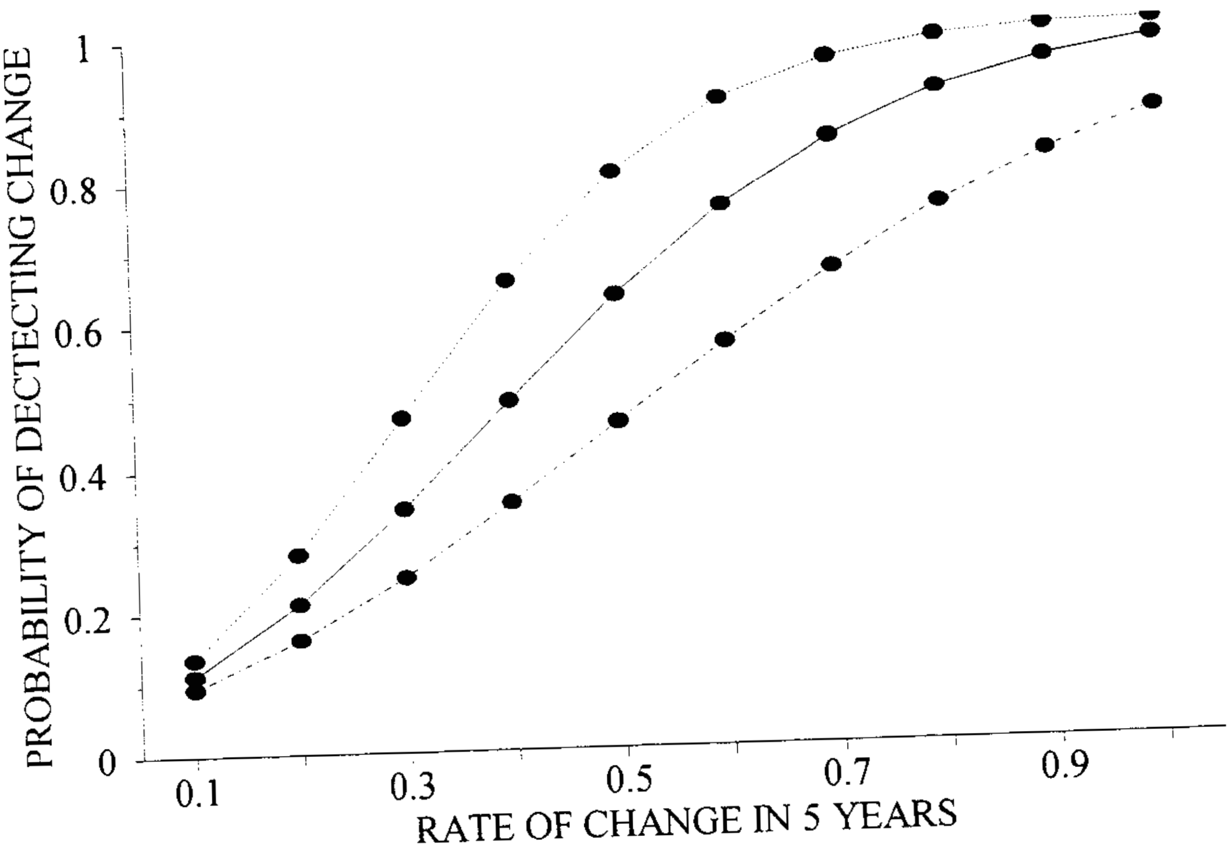

PROBABILITY OF DECTECTING CHANGE
1
0.8
0.6
0.4
0.2
0
0.1
0.3
0.5
0.7
0.9
RATE OF CHANGE IN 5 YEARS

Table 1. HY:AHY ratios for marbled murrelets during all July-August surveys and during the 5 core surveys at 6 sites in Prince William Sound, Alaska, 1995. Sites are presented from highest to lowest values of ratios during the core surveys. The ratios and confidence intervals were derived from the daily ratios; the total numbers of birds are presented here for reference only.

	Total no. birds for all surveys					Total no. birds for core survey period			
Site	n	AHY	HY	Ratio	Core Survey Dates	n	AHY	HY	Ratio
Naked	9	1891	134	0.069 ± 0.055[a]	(3 Aug - 22 Aug)	5	738	89	0.118 ± 0.055[a]
PNJ	10	2140	191	0.089 ± 0.081	(5 Aug - 20 Aug)	5	1033	120	0.116 ± 0.039
Knight	8	856	46	0.050 ± 0.045	(26 Jul - 20 Aug)	5	522	41	0.073 ± 0.066
Jackpot	9	1228	75	0.059 ± 0.050	(27 Jul - 21 Aug)	5	842	57	0.066 ± 0.038
Unakwik	10	3328	93	0.028 ± 0.019	(31 Jul - 21 Aug)	5	1519	62	0.043 ± 0.006
Valdez	7	711	15	0.018 ± 0.015	(25 Jul - 19 Aug)	5	647	14	0.020 ± 0.016
All Sites	6	10,154	554	0.054	(25 Jul - 22 Aug)	6	5301	383	0.075 ± 0.037

[a] HY:AHY ± 95% confidence interval

Table 2. Statistics (Z-test on the standard error) for pair-wise (between site) comparison of the daily HY:AHY ratios for marbled murrelets, using 5 core surveys in Prince William Sound, Alaska, 1995.

Site	Naked	PNJ	Knight	Jackpot	Unakwik
PNJ	0.04				
Knight	1.02	1.12			
Jackpot	1.49	1.79*	0.17		
Unakwik	2.61*	3.62**	0.88	1.18	
Valdez	3.29**	4.46**	1.52	2.19*	2.59*

* $P < 0.05$

** $P < 0.005$

Table 3. Mean HY densities (birds/km^2) for all July-August surveys and for 5 core surveys at 6 sites in Prince William Sound, Alaska, 1995. Sites are presented highest to lowest in HY density during the core surveys. Vertical lines join sites that were not significantly different at $P < 0.05$.

All July-August Surveys					Core Surveys only (all n=5)					
Site	n	Mean	SE	CV	Mean	SE	CV			
PNJ	10	1.69	0.35	0.66	2.12	0.16	0.17	│		
Unakwik	10	1.00	0.21	0.67	1.40	0.31	0.47	│	│	
Naked	9	1.10	0.22	0.60	1.32	0.30	0.53	│	│	
Jackpot	9	0.74	0.15	0.61	1.02	0.17	0.37		│	│
Knight	8	0.56	0.17	0.85	0.79	0.20	0.58		│	│
Valdez	7	0.17	0.07	1.05	0.21	0.08	0.86			│

Appendix A. Average environmental conditions during surveys at six study sites in Prince William Sound, Alaska, in June, July and August 1995. An ANOVA test was used, with a Student-Newman-Keuls test, to determine which sites were significantly different. Lines connect sites not significantly different.

Water Clarity by Secchi Disk (m):

AREA	N	Mean	F	df	p
Naked	13	6.8	6.08	5,75	0.0001
Knight	12	6.6			
Jackpot	13	6.1			
Valdez	10	4.6			
PNJ	14	3.5			
Unakwik	14	2.9			

Salinity (ppt):

AREA	N	Mean	F	df	p
Naked	10	25.2	56.87	5,56	0.0001
Knight	8	24.6			
Unakwik	11	22.2			
Jackpot	10	18.5			
Valdez	7	16.7			
PNJ	11	9.5			

Surface Water Temperature (°C):

AREA	N	Mean	F	df	p
Valdez	10	13.0	8.89	5,75	0.0001
Knight	12	12.6			
Jackpot	13	12.0			
Naked	13	11.6			
PNJ	14	10.9			
Unakwik	14	8.9			

Swell Height (m):

AREA	N	Mean	F	df	p
Naked	13	0.5	10.11	5,75	0.0001
Knight	12	0.2			
Valdez	10	0.2			
Unakwik	14	0.1			
Jackpot	13	0.0			
PNJ	14	0.0			

Appendix A. Continued.

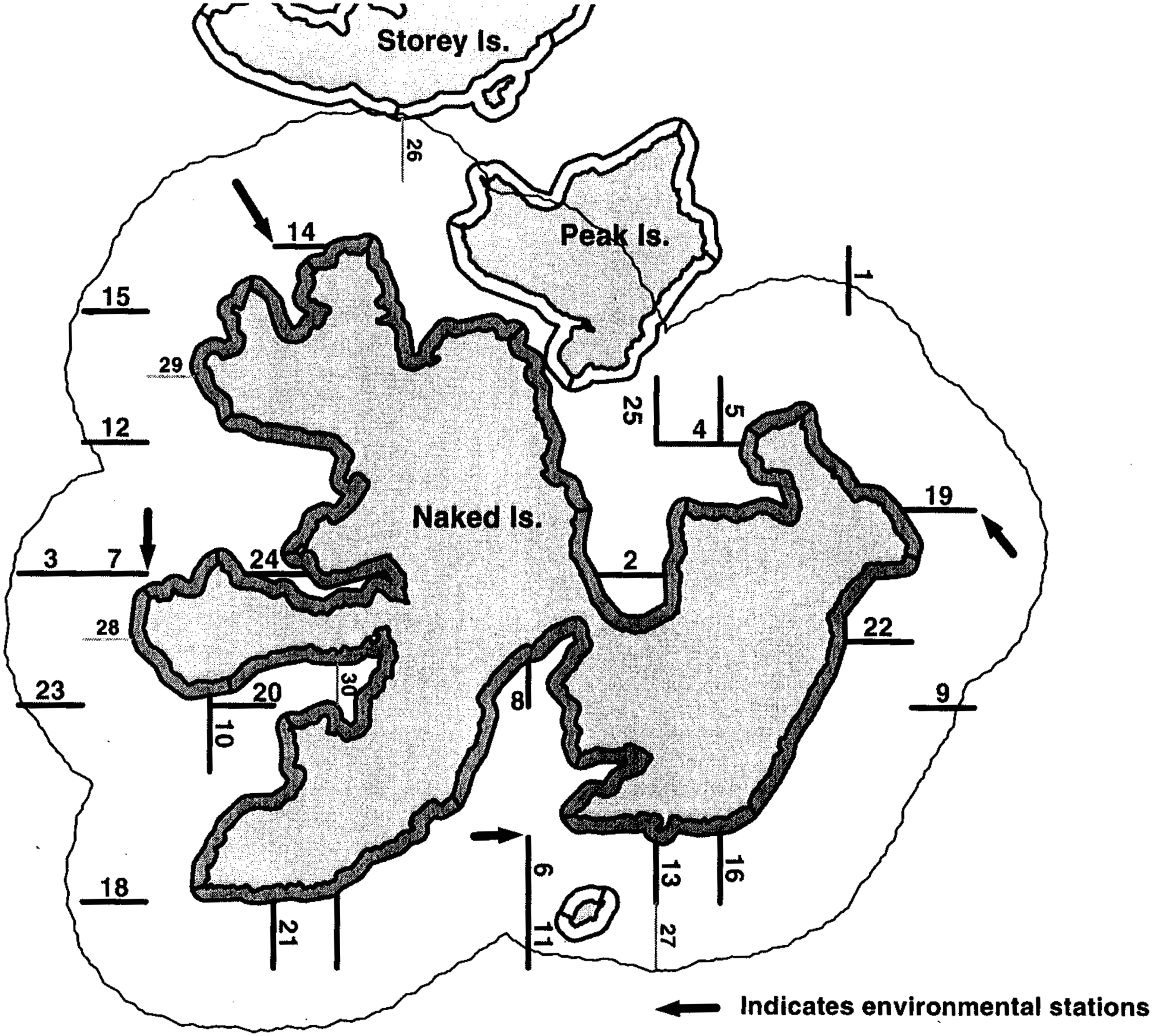
% Ice on Water on Transects:

AREA	N	Mean	F	df	p
Unakwik	14	2.6	7.58	5,75	0.0001
PNJ	14	0.1			
Naked	13	0.0			
Knight	12	0.0			
Jackpot	13	0.0			
Valdez	10	0.0			

Appendix B. Latitude and longitude of pelagic transects at Naked Island and Port Nellie Juan surveyed in summer 1995.

Transect Number	Lat. or Lon. of Line	North/West End	South/East End
Naked Island			
1	147° 19'	60° 42'	60° 41' 30"
2	60° 39' 30"	147° 22' 56" (shore)	147° 21' 52 " (shore)
3	60° 39' 30"	147° 32'	147° 31'
4	60° 40' 30"	147° 22'	147° 20' 39" (shore)
5	147° 21'	60° 41'	60° 40' 30"
6	147° 24'	60° 37' 30"	60° 37'**
7	60° 39' 30"	147° 31'	147° 30'**
8	147° 24'	60° 38' 51" (shore)	60° 38' 30"
9	60° 38' 30"	147° 18'	147° 17'
10	147° 29'	60° 38' 34" (shore)	60° 38'
11	147° 24'	60° 37'	60° 36' 30"
12	60° 40' 30"	147° 31'	147° 30'
13	147° 22'	60° 37' 28" (shore)	60° 37'
14	60° 42'	147° 28'**	147° 27' 11" (shore)
15	60° 41' 30"	147° 31'	147° 30'
16	147° 21'	60° 37' 32" (shore)	60° 37'
17	147° 27'	60° 37' 04" (shore)	60° 36' 30"
18	60° 37'	147° 31'	147° 30'
19	60° 40'	147° 18' 09" (shore)	147° 17'**
20	60° 38' 30"	147° 29'	147° 28'
21	147° 28'	60° 37' (shore)	60° 36' 30"
22	60° 39'	147° 19' 02" (shore)	147° 18'
23	60° 38' 30"	147° 32'	147° 31'
24	60° 39' 30"	147° 28' 27" (shore)	147° 27' 28" (shore)
25	147° 22'	60° 41'	60° 40' 30"
26	147° 26'	60° 42' 59" (shore)	60° 42' 30"
27	147° 22'	60° 37'	60° 36' 30"
28	60° 39'	147° 31'	147° 30' 17" (shore)
29	60° 41'	147° 30'	147° 29' 15"(shore)
30	147° 27'	60° 38' 49" (shore)	60° 38' 30" (shore)

** Collect environmental data

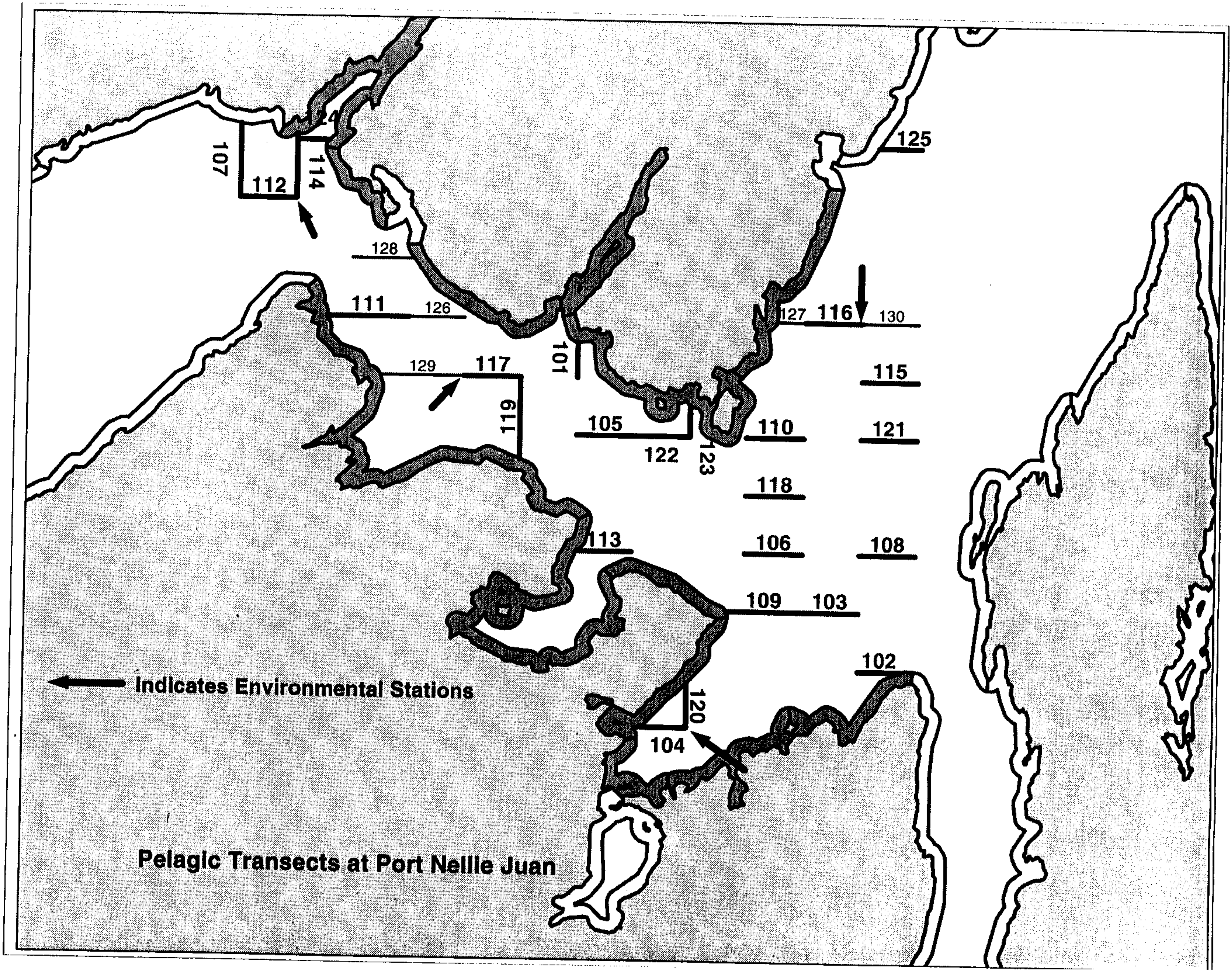


Pelagic Transects at Naked Island

Appendix B. Latitude and longitude of pelagic transects at Naked Island and Port Nellie Juan surveyed in summer 1995.

Transect Number	Lat. or Lon. of Line	North/West End	South/East End
Port Nellie Juan			
101	148° 22'	60° 32' 18" (shore)	60° 32'
102	60° 29' 30"	148° 17'	148° 16' 14"
103	60° 30'	148' 18"	148° 17'
104	60° 29'	148° 20' 48" (shore)	148° 20'
105	60° 31' 30"	148° 22'	148° 21'
106	60° 30' 30"	148° 19'	148° 18'
107	148° 28'	60° 34' 08" (shore)	60° 33' 30"
108	60° 30' 30"	148° 17'	148° 16'
109	60° 30'	148° 19' 18" (shore)	148° 18'
110	60° 31' 30"	148° 19'	148° 18'
111	60° 32' 30"	148° 26' 26" (shore)	148° 25'
112	60° 33' 30"	148' 28'	148° 27'**
113	60° 30' 30"	148° 21' 59" (shore)	148° 21'
114	148° 27'	60° 34' 03" (shore)	60° 33' 30"
115	60° 32'	148° 17'	148° 16'
116	60° 32' 30"	148° 18'	148° 17'**
117	60° 32'	148° 24'**	148° 23'
118	60° 31'	148° 19'	148° 18'
119	148° 23'	60° 32'	60° 31' 17" (shore)
120	148° 20'	60° 29' 23" (shore)	60° 29'**
121	60° 31' 30"	148° 17'	148° 16'
122	60° 31' 30"	148° 21'	148° 20'
123	148° 20'	60° 31' 46" (shore)	60° 31' 30"
124	60° 34'	148° 27'	148° 26' 26" (shore)
125	60° 34'	148° 16' 46" (shore)	148° 16'
126	60° 32' 30"	148° 25'	148° 24'
127	60° 32' 30"	148° 18' 29" (shore)	148° 17'
128	60° 33'	148° 26'	148° 24' 54" (shore)
129	60° 32'	148° 25' 29" (shore)	148° 24'
130	60° 32' 30"	148° 17'	148° 16'

** Collect environmental data



Indicates Environmental Stations

Pelagic Transects at Port Nellie Juan

Appendix C. Protocol for 1995 Juvenile Murrelet Surveys At-sea.

General:

1. See FWS standard protocol. See codes below for weather.
2. Facing forward, focus approximately 100m out from boat and scan 180^0
3. Do not stop to identify small groups of birds to species that are not murrelets
4. Can stop for large groups to scan and get number or % of different species
5. Tell driver to adjust speed if conditions require
6. When possible, driver helps with spotting birds, especially ahead of boat
7. For all birds, especially murrelets, watch for birds flushing ahead (count them if on the transect line), and the direction birds fly (so they don't get counted twice).
8. On shoreline transects the inside observer calls out birds <100m from shore (recorded under INSIDE SHORELINE column). The outside observer records for everyone and observers birds 100-200 m from shore (under OUTSIDE SHORELINE column).
9. On pelagic transects all birds >200m offshore are recorded in the left hand column (marked 'INSIDE SHORELINE or >200m offshore for Pelagics'). At the end of transects that abutt shore, birds within 200m of shore are recorded in the right hand column (marked 'OUTSIDE SHORELINE or <200m offshore for Pelagics').

Murrelets:

1. Birds that obviously just took off water or were flushed, even if you didn't see them on the water, are counted as 'on water'. Birds landing are also counted as 'on water'.
2. Murrelets are recorded in appropriate box (BRMU, MAMU or KIMU) and group size.
    * Unless otherwise noted, both birds in a pair are asumed to be the same species if one is identified.
    * Mixed groups, including groups where only some birds were identified, are recorded in box marked 'Mixed Groups', as BRMU / MAMU / KIMU ; (record zeros).
3. Hash marks in correct box are used for singles and pairs, numbers are used for groups.
4. 'Singles' are separated from other murrelets by at least 2 m.
5. Count as 'Pair' if <2m apart, or as a 'Group' if ≥3 individuals are <2m from nearest bird.
6. Behaviors: On water or flying, and if appropriate -'Fish holding' (subscript F), Pair bonding, as in synchronous neck-stretching, courtship feeding, billing etc (subscript C) and Diving as in foraging (subsc. D). Put details in notes.

Murrelet Plumages

Default plumage is *class 1* - alternate (breeding/summer) plumage (see categories).

Transitional birds are *class 2* or *class 3*- subscript hash mark with (T2) or (T3), respectively.

Some of these may need to be checked out briefly- but don't spend much time.

Black & white birds are *class 4* - subscript hash mark with (BW or J [if certain])

These need to be checked out, using following procedure:

1. Enter a waypoint on GPS if possible, or note location by landmarks.
    This point will be returned to later, to resume transect.
    Record time and depth if possible.
    Don't record other birds, just make notes of other feeding activity, etc.
2. Approach so sun is to observer's back to improve visibility.
    Secondarily: *to determine species* -- maneuver downwind and get close and flush bird and watch outer tail feathers on take off.
    to determine age -- maneuver upwind of bird to avoid flushing and encourage bird to face observer (into wind).
3. Maneuver obliquely towards bird, as close as possible.
4. Make observations on plumage and behavior as you go- whenever you get a view.
5. Do not exceed 10 min per bird. Record stop time. Return to waypoint and resume transect.

Appendix C. Protocol for 1995 Juvenile Murrelet Surveys At-sea.

MOLT CATEGORIES:

CLASS 1......Very little or no molt, entirely in alternate (breeding) plumage.
CLASS 2......Obvious body molt but estimated < 50% of alternate feathers lost.
CLASS 3......Over 50% of alternate plumage lost or replaced, but still distinguishable from HY juveniles by brown feathers on back, breast or remiges.
CLASS 4.....Appears as basic (black & white) plumage from a distance. Requires examination to determine age.

Notes on Molting

Molt begins in neck and throat -- dark feathers replaced with white.
Followed by breast, belly, sides and lower belly.
Conspicuous gap in wings on adults midway in molt,
first 6 primaries lost simultaneously (bird flightless).
Remaining flight feathers lost soon thereafter -- wing tips ragged, blunt
In breeding adults and Juveniles -- pointed wing tips.
Further in molt, dark blotches become fewer, but remain as blotches until molt is complete.
Winter-plumaged adult -- clean white neck, breast and belly.
Young juvenile -- Neck and breast have fine dark markings, or 'speckling' on feather tips.
May have neck band (highly variable).
Egg tooth still present (but very difficult to see on water)
Visibly smaller in body size (50-70 % of adult weight)
Little or now white on upper mandible
Older juvenile -- Loose fine markings, more clean black and white
Flight feathers still pointed and are a complete set.
May still be small next to adult

CODES

Weather

0 = < 50% clouds
1 = > 50% clouds
2 = patchy fog
3 = solid fog
4 = mist / light rain
5 = med - heavy rain

Seas

0 = glassy, slight ripple
1 = calm, rippled, no whitecaps
2 = wavelets < 2 ft, occassional whitecaps
3 = 2' to 4 ', choppy, some whitecaps (may not survey)
4 = 4' to 8', whitecaps, rough (can't survey)

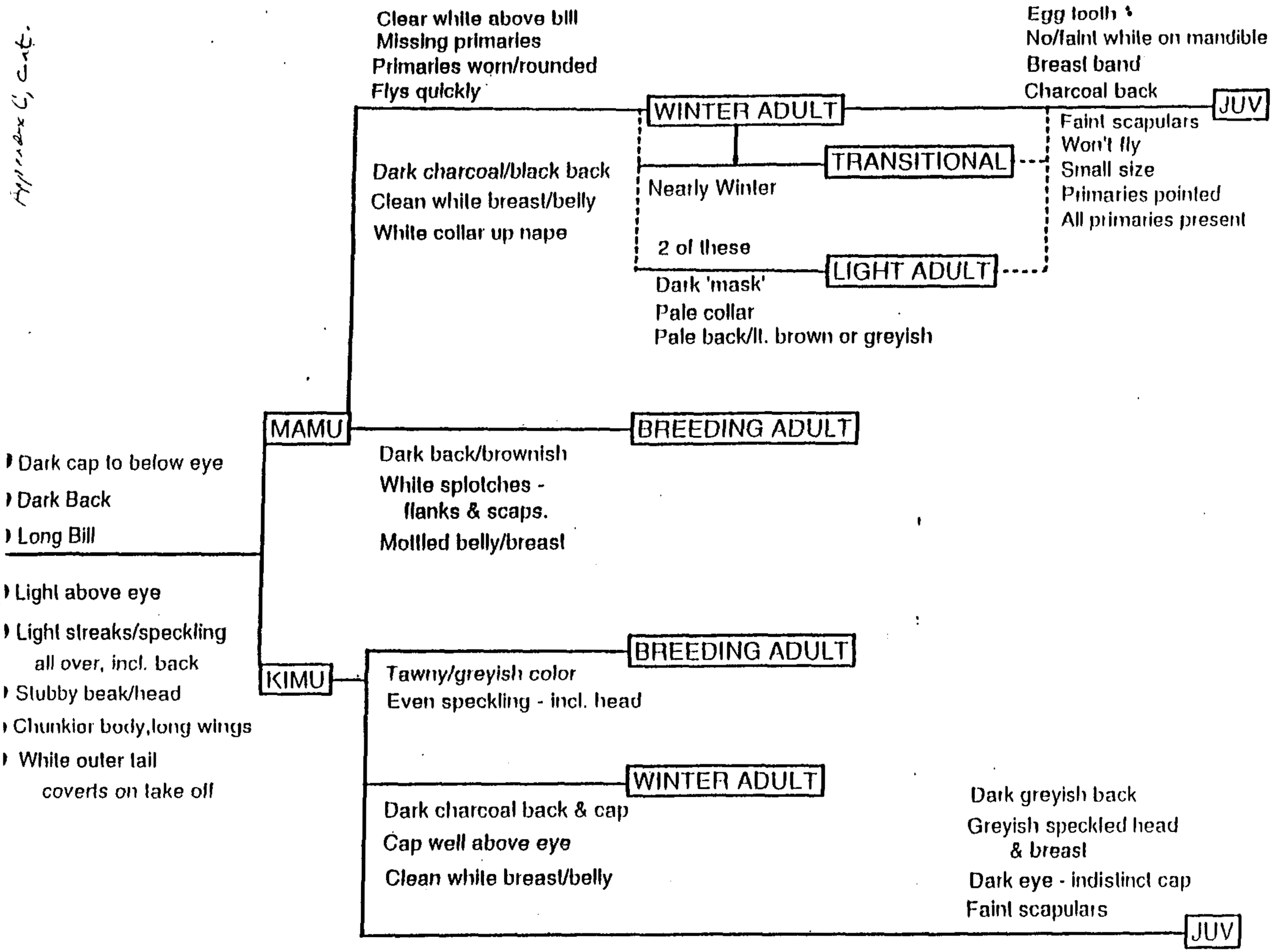
Glare

0 = none
1 = slight / grey
2 = bright / 1 side
3 = bright / forward

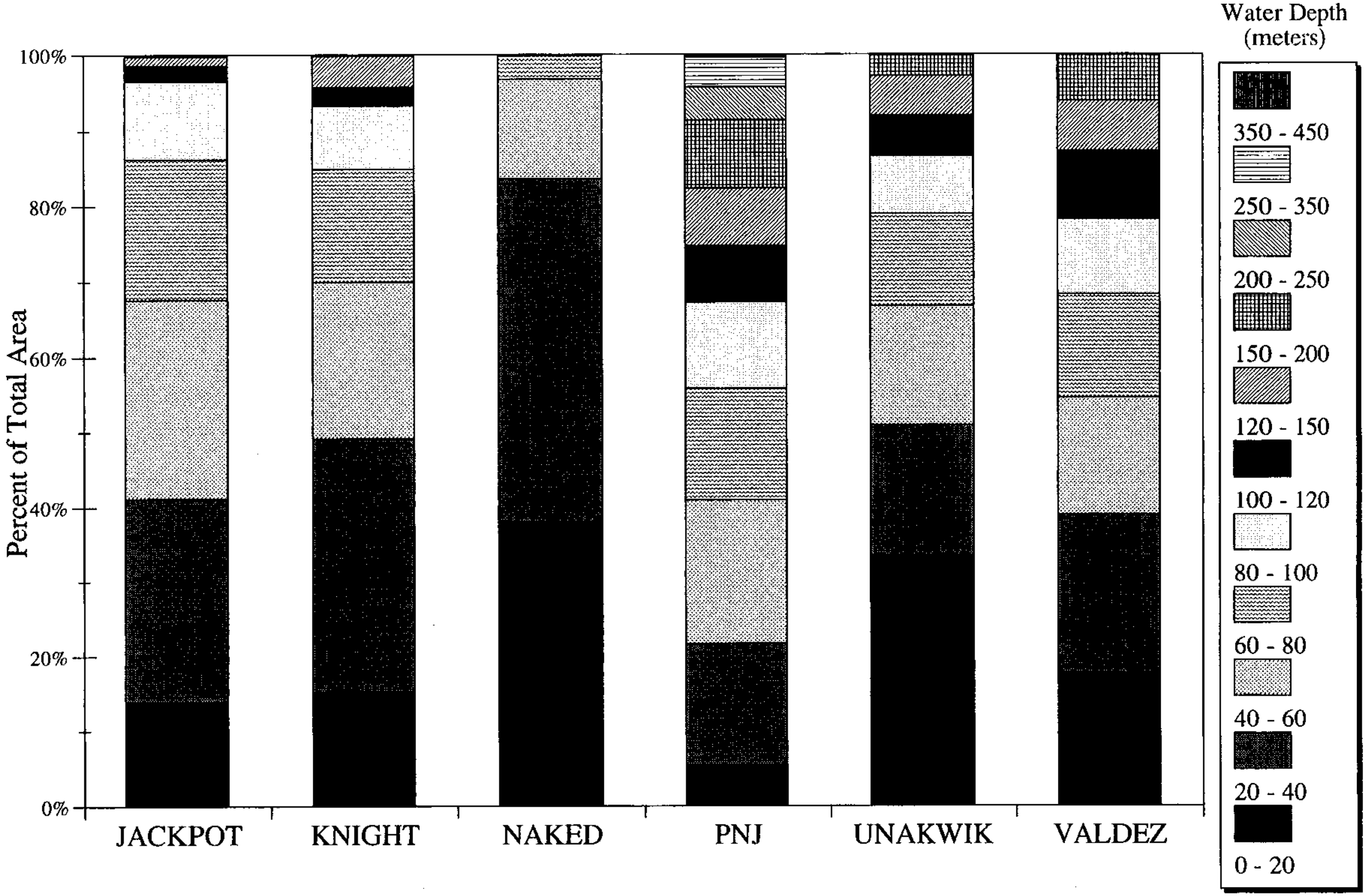
Sighting Shorthand

none = on water
$\underline{\underline{1}}$ = on land
1 = in air
1 = following vessel
1 = on floating object

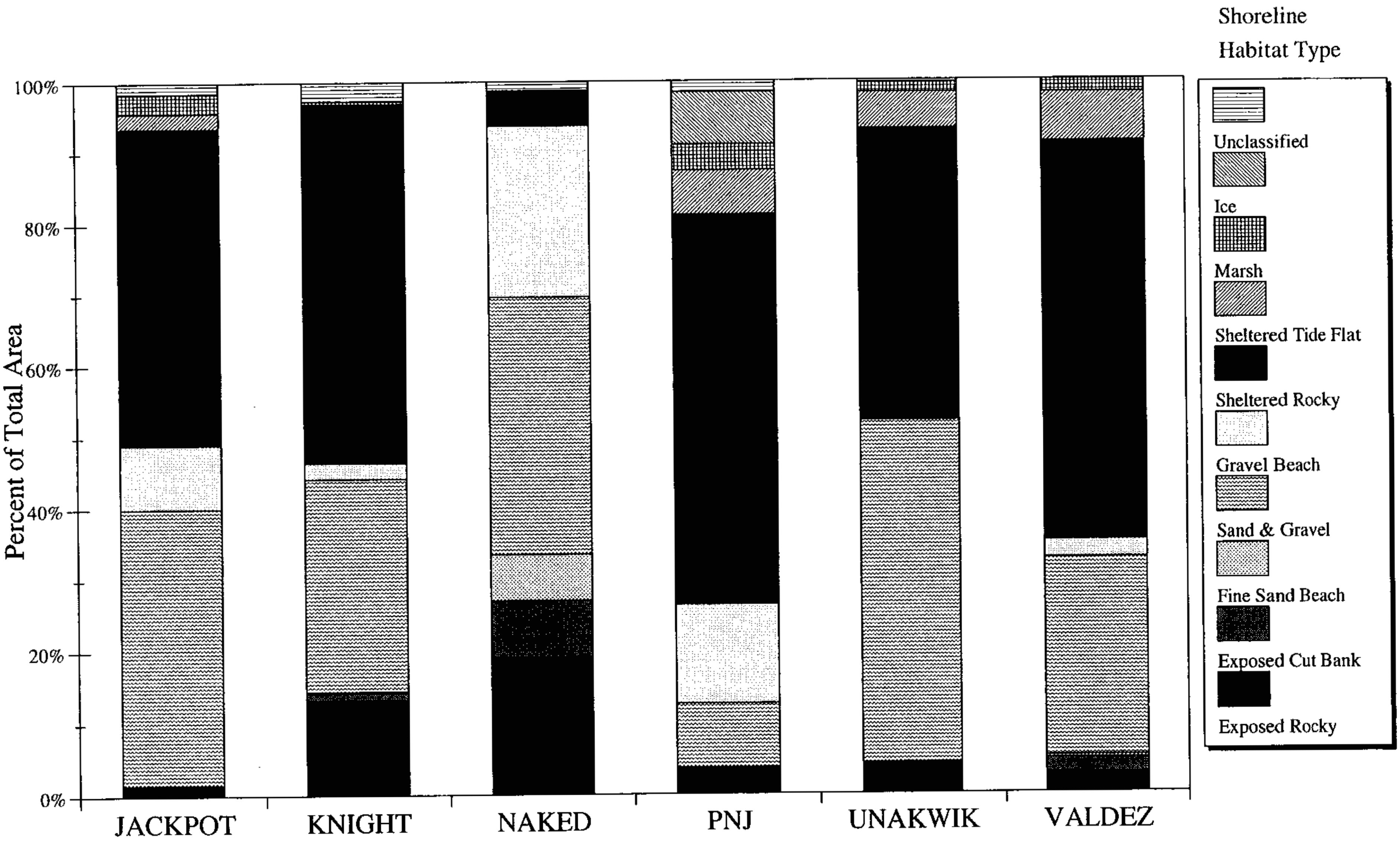
Appendix C, cont.



Appendix D. Percent of total area (within 200 m of shoreline) of water depth categories at the six study sites in Prince William Sound.


Water Depth (meters)
350 - 450
250 - 350
200 - 250
150 - 200
120 - 150
100 - 120
80 - 100
60 - 80
40 - 60
20 - 40
0 - 20
Percent of Total Area
100%
80%
60%
40%
20%
0%
JACKPOT
KNIGHT
NAKED
PNJ
UNAKWIK
VALDEZ

Appendix E. Percent of total shoreline consisting of various shoreline habitats.

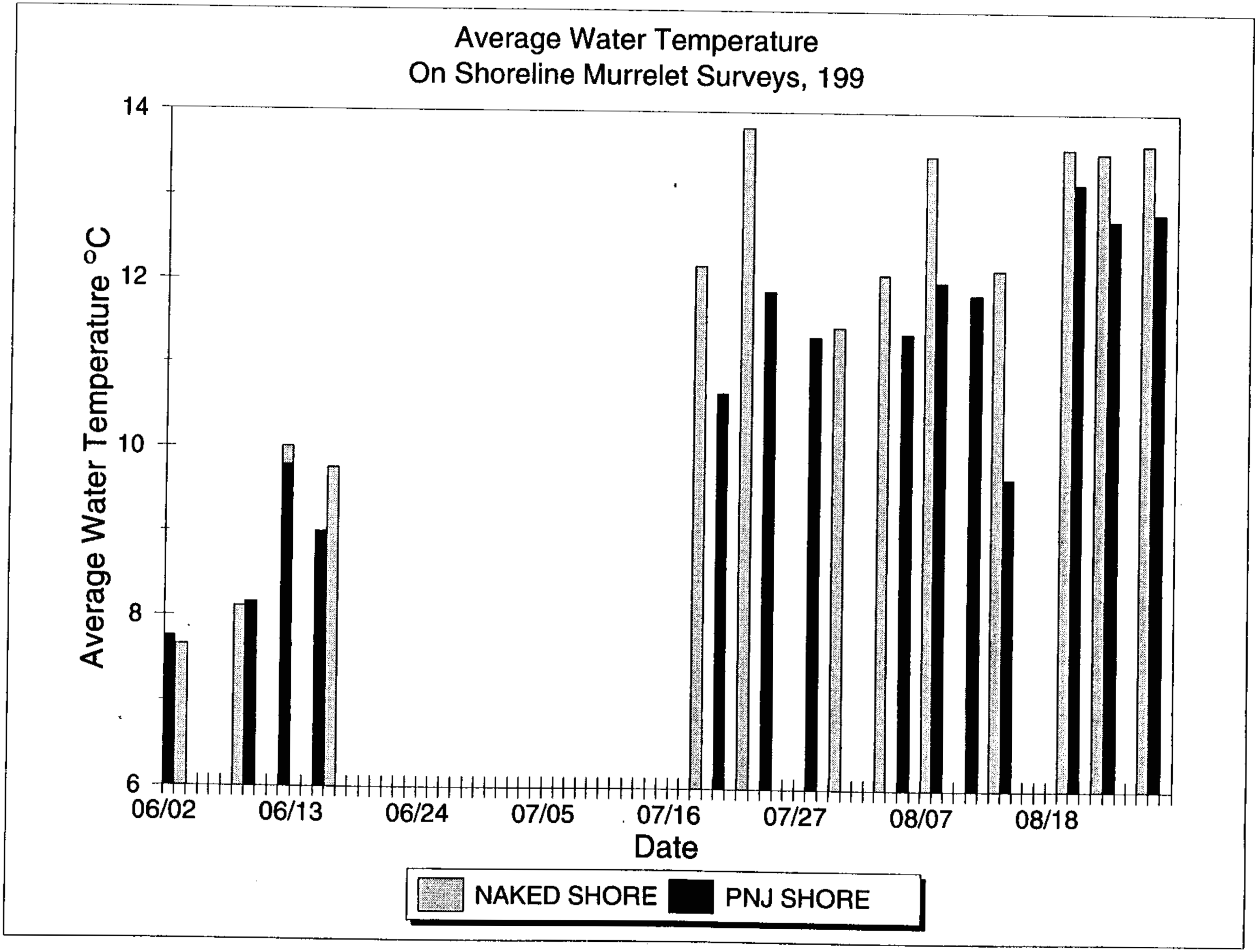

Shoreline
Habitat Type
Unclassified
Ice
Marsh
Sheltered Tide Flat
Sheltered Rocky
Gravel Beach
Sand & Gravel
Fine Sand Beach
Exposed Cut Bank
Exposed Rocky
Percent of Total Area
100%
80%
60%
40%
20%
0%
JACKPOT
KNIGHT
NAKED
PNJ
UNAKWIK
VALDEZ

Appendix F. Mean density of HY marbled murrelets (HY birds/km^2) relative to weather, tide and habitat features, based on shoreline surveys of six study sites in Prince William Sound, Alaska, July and August 1995. Each sample is a shoreline transect, with a GLM test for significance.

VARIABLE	CATEGORY	N	Mean	SD	Max.	F	p
Weather	<50% clouds	150	1.51	2.23	16.42	3.90	0.0017
	>50% clouds	371	0.86	1.73	12.40		
	patchy fog	5	0.63	1.22	2.79		
	solid fog	1	0.00		0.00		
	light rain	126	0.64	1.22	6.35		
	medium-heavy rain	43	1.26	2.73	14.63		
Seas	glassy	287	1.04	1.90	16.42	1.28	0.2779
	rippled	303	0.96	1.77	12.40		
	wavelets <2'	89	1.05	2.19	14.63		
	2', some whitecaps	11	0.00	0.00	0.00		
	2-4', whitecaps	6	0.00	0.00	0.00		
Glare	none	22	1.00	1.93	7.94	1.51	0.2098
	slight	455	0.89	1.82	14.63		
	bright, one side	141	1.25	1.99	16.42		
	bright, front	68	1.15	1.97	7.65		
Tide (2 Hr blocks)	2 hrs low tide	130	1.21	2.44	14.63	0.74	0.6175
	low flood	145	0.97	1.99	16.42		
	high flood	140	0.82	1.55	7.18		
	2 hrs high tide	106	1.06	1.82	8.92		
	high ebb	83	0.89	1.46	7.65		
	low ebb	92	0.91	1.52	7.94		
Tide (6 Hr blocks)	flood	415	1.01	1.97	16.42	0.25	0.6140
	ebb	281	0.94	1.70	12.40		
Shoreline Substrate	bedrock and boulders >75%	375	1.01	1.95	16.42	0.78	0.5863
	vertical rock and gravel 25-75%	49	0.98	1.38	4.92		
	horizontal rock and gravel 25-	11	0.84	1.26	3.08		
	75%	30	1.61	2.22	5.74		
	boulder and gravel >75%	189	0.86	1.89	14.63		
	gravel and sand >75%	21	0.75	1.00	3.18		
	sand >75%	21	0.97	1.45	5.67		
	tidal flats >75%						
Exposure	bay/fjord <1 km	177	0.81	1.36	7.94	2.65	0.0323
	* pass <1 km	8	0.00	0.00	0.00		
	* bay/fjord 1-5 km	325	1.20	2.17	16.42		
	pass 1-5 km	68	0.67	0.97	3.57		
	>5 km open	118	0.88	1.99	14.63		

* significantly different at $\alpha=0.05$

Appendix G. Average water temperature (taken on each transect) during shoreline surveys at Naked and Port Nellie Juan in June, July and August, 1995.


Average Water Temperature
On Shoreline Murrelet Surveys, 199
Average Water Temperature °C
14
12
10
8
6
06/02
06/13
06/24
07/05
07/16
07/27
08/07
08/18
Date
NAKED SHORE
PNJ SHORE

App. 5

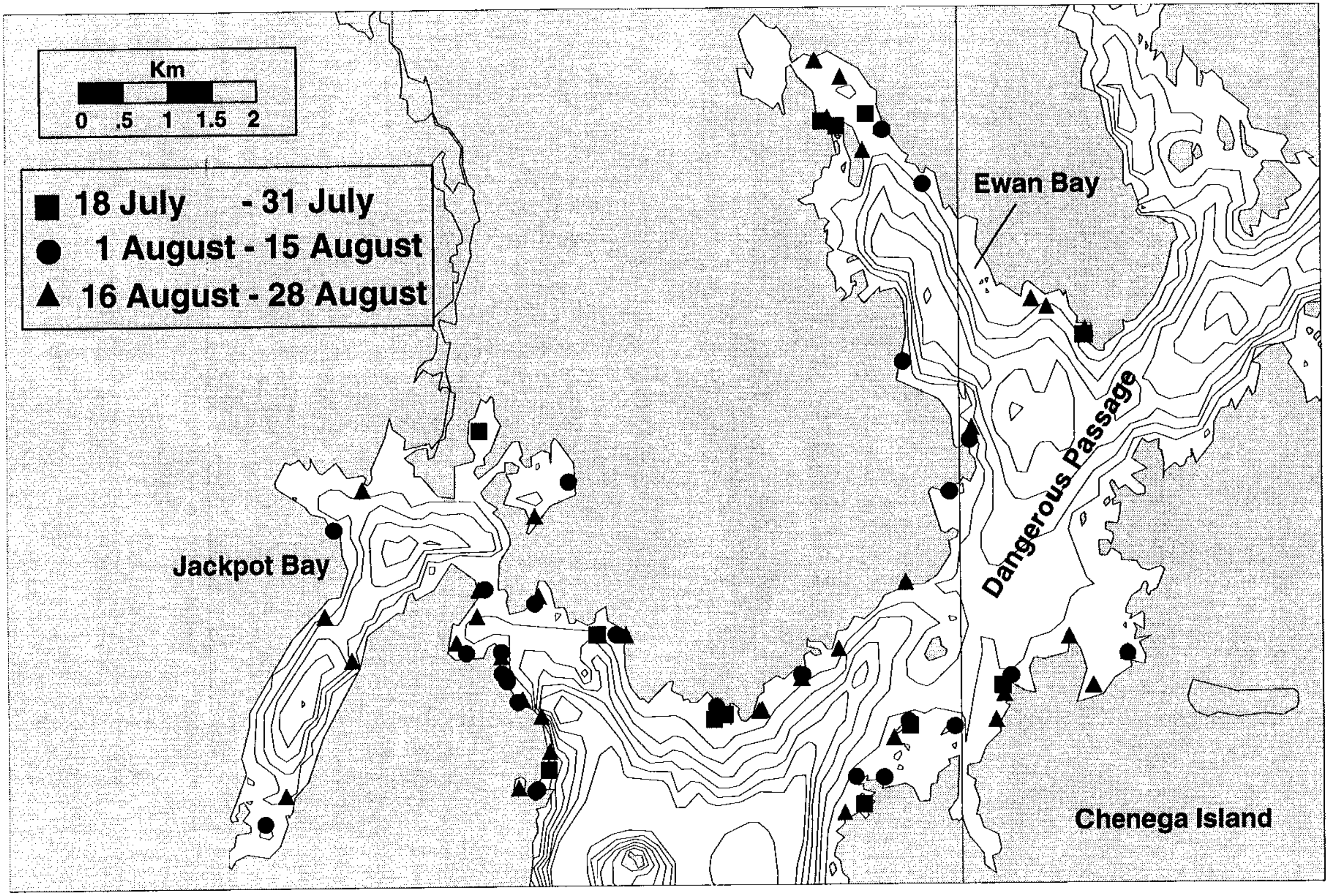
Appendix H. Spearman Correlation Coefficients for HY and AHY marbled murrelets relative to weather, tide, area and seasonal variables, during at sea surveys in Princ William Sound, Alaska, July and August 1995. Top=Spearman rank correlation, bottom=probability; sample sizes ranged from 630 to 642.

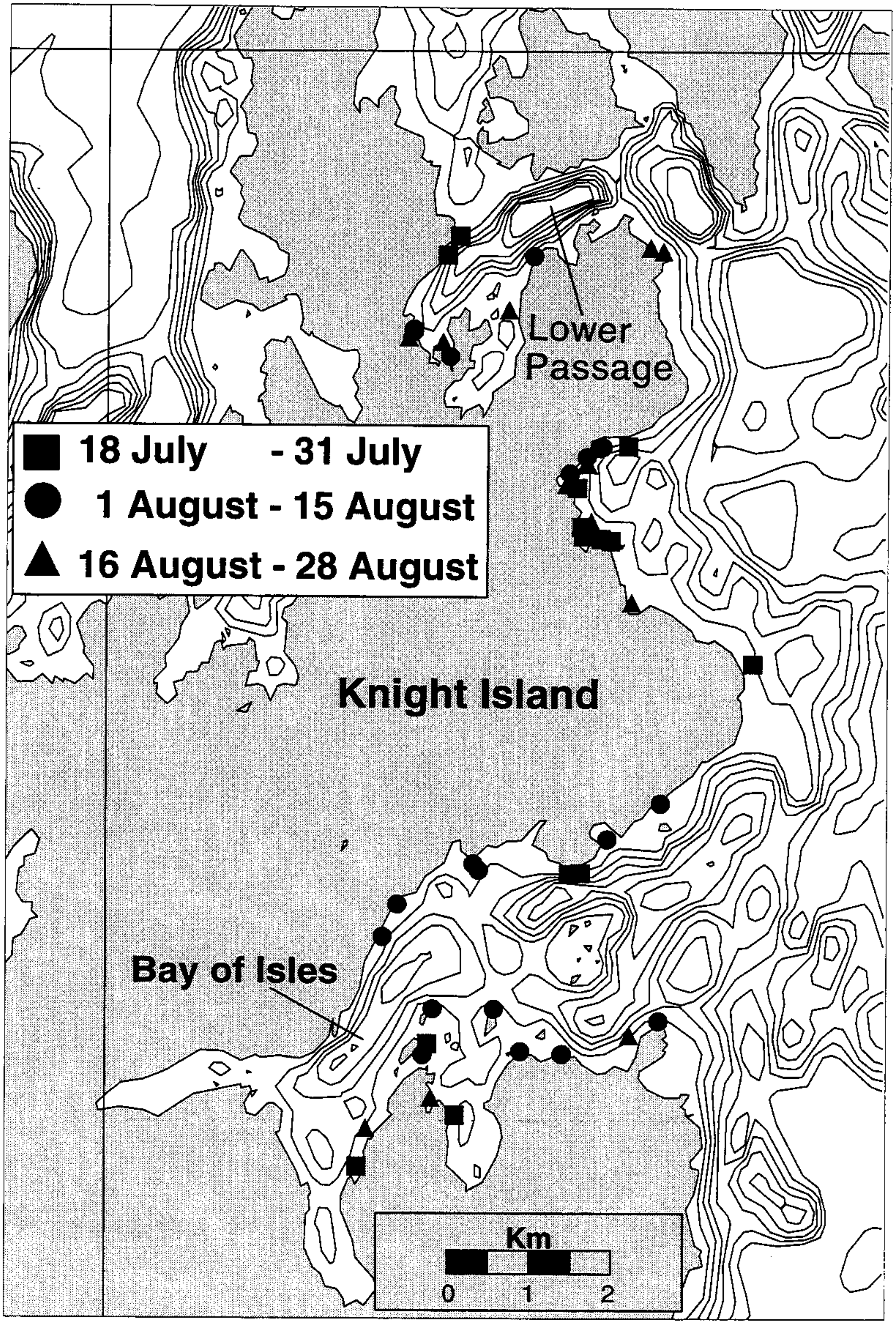
VARIABLE	AHY Murrelets	HY Murrelets
Area	0.145	0.071
	0.0002	0.073
Transect	0.148	0.118
	0.0002	0.003
Day	-0.473	0.199
	0.0001	0.0001
Tide (2 Hr block)	-0.012	-0.017
	0.758	0.668
Tide (ebb vs. flood)	-0.081	-0.006
	0.039	0.873
Weather	0.221	-0.127
	0.0001	0.001
% Cloud Cover	0.166	-0.204
	0.0001	0.0001
Glare	-0.184	0.113
	0.0001	0.004
Surface Water Temperature (°C)	-0.442	-0.204
	0.0001	0.0001
Air Temperature (°C)	-0.140	-0.021
	0.0004	0.596
Seas	-0.129	-0.049
	0.0011	0.210
Swell Height	-0.063	-0.021
	0.114	0.603
Wind Speed	-0.079	-0.073
	0.456	0.064
Water Clarity by Secchi Disk (m)	-0.474	0.044
	0.0001	0.265
Water Salinity (ppt)	-0.016	-0.162
	0.674	0.0001
% Ice on Water on Transects	0.145	0.040
	0.0003	0.312
Hours from Sunrise	-0.473	0.199
	0.0001	0.0001

Appendix I. Kendall Taub Correlation Coefficients for HY and AHY marbled murrelets, rleative to water depths on transects during at sea surveys in Prince William Sound, Alaska, July and August 1995. Top=Taub, bottom=probability; sample sizes ranged from 634 to 642.

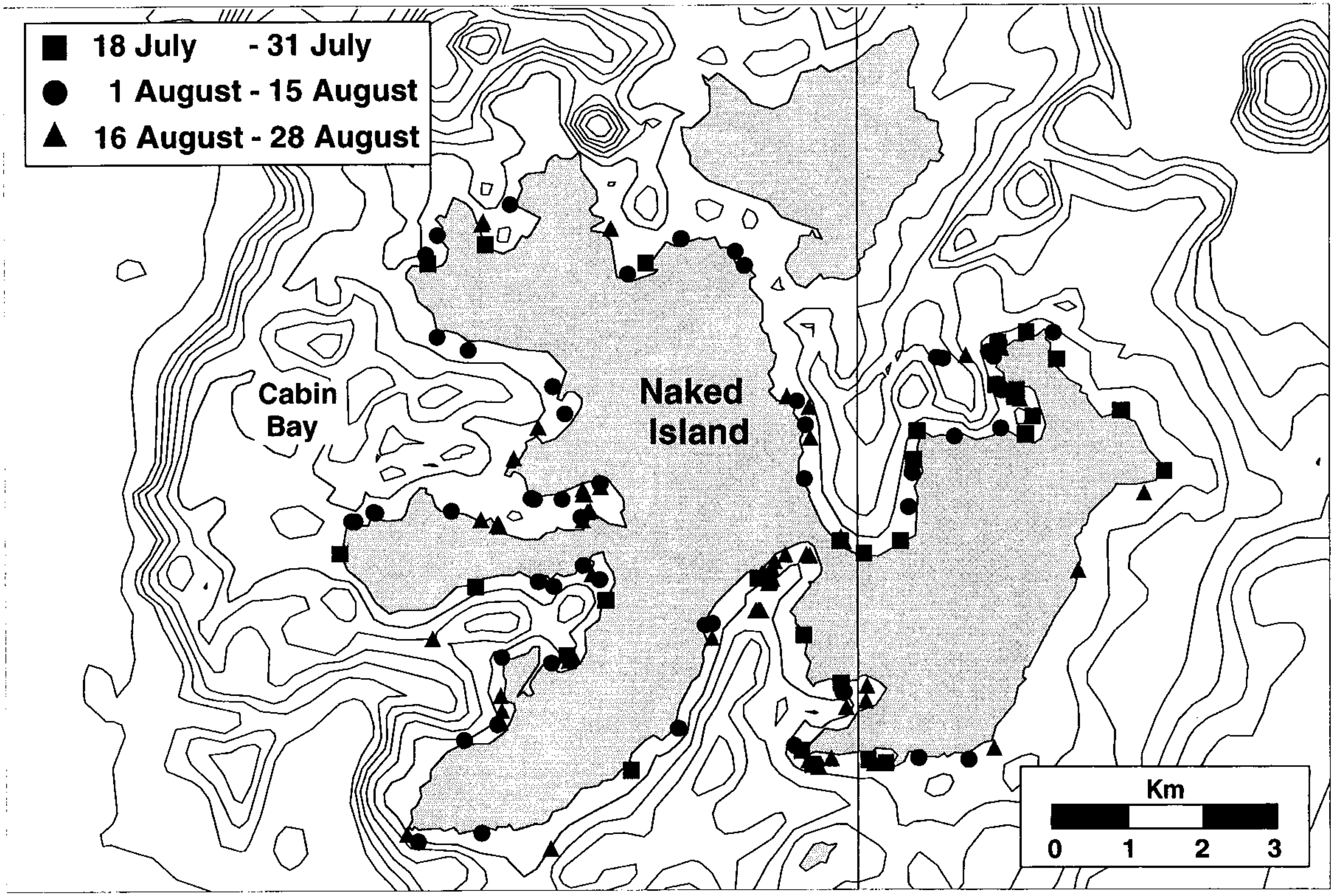
VARIABLE	AHY Murrelets	HY Murrelets
Number of depth categories on transect (0-200 m offshore)	-0.0115 0.689	0.0265 0.401
Average weighted depth of transect (0-200 m offshore)	-0.026 0.335	0.008 0.798
Number of depth categories on transect (0-500 m offshore)	0.042 0.134	0.089 0.004
Average weighted depth of transect (0-500 m offshore)	0.012 0.657	0.081 0.006
Relative to number of AHY on transect or number of HY on transect	0.136 0.0001	0.136 0.0001

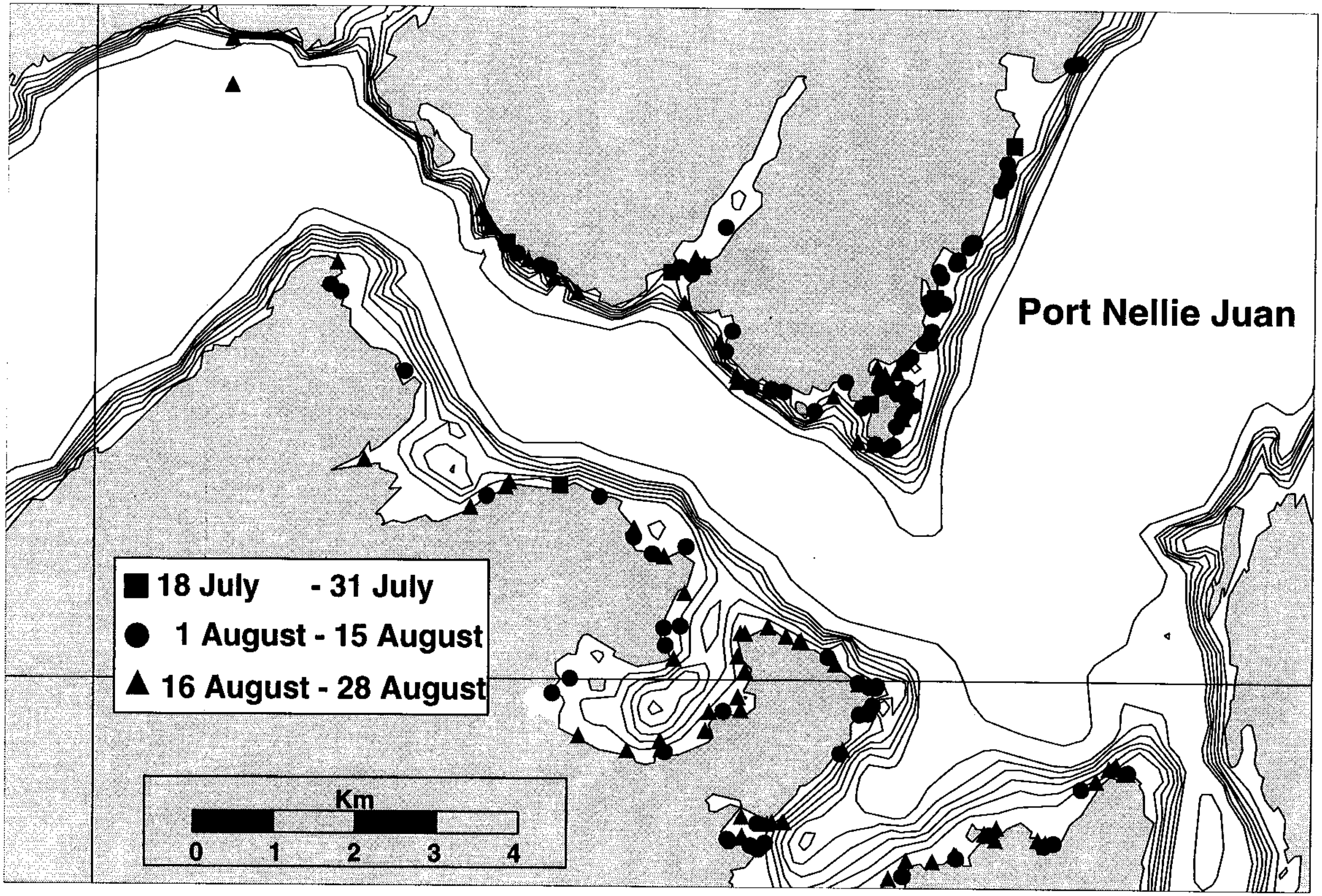
Appendix J. Locations of juvenile marbled murrelets sighted during 1995 surveys at six sites in Prince William Sound, Alaska. Contour lines represent bathymetric features from GIS coverage.

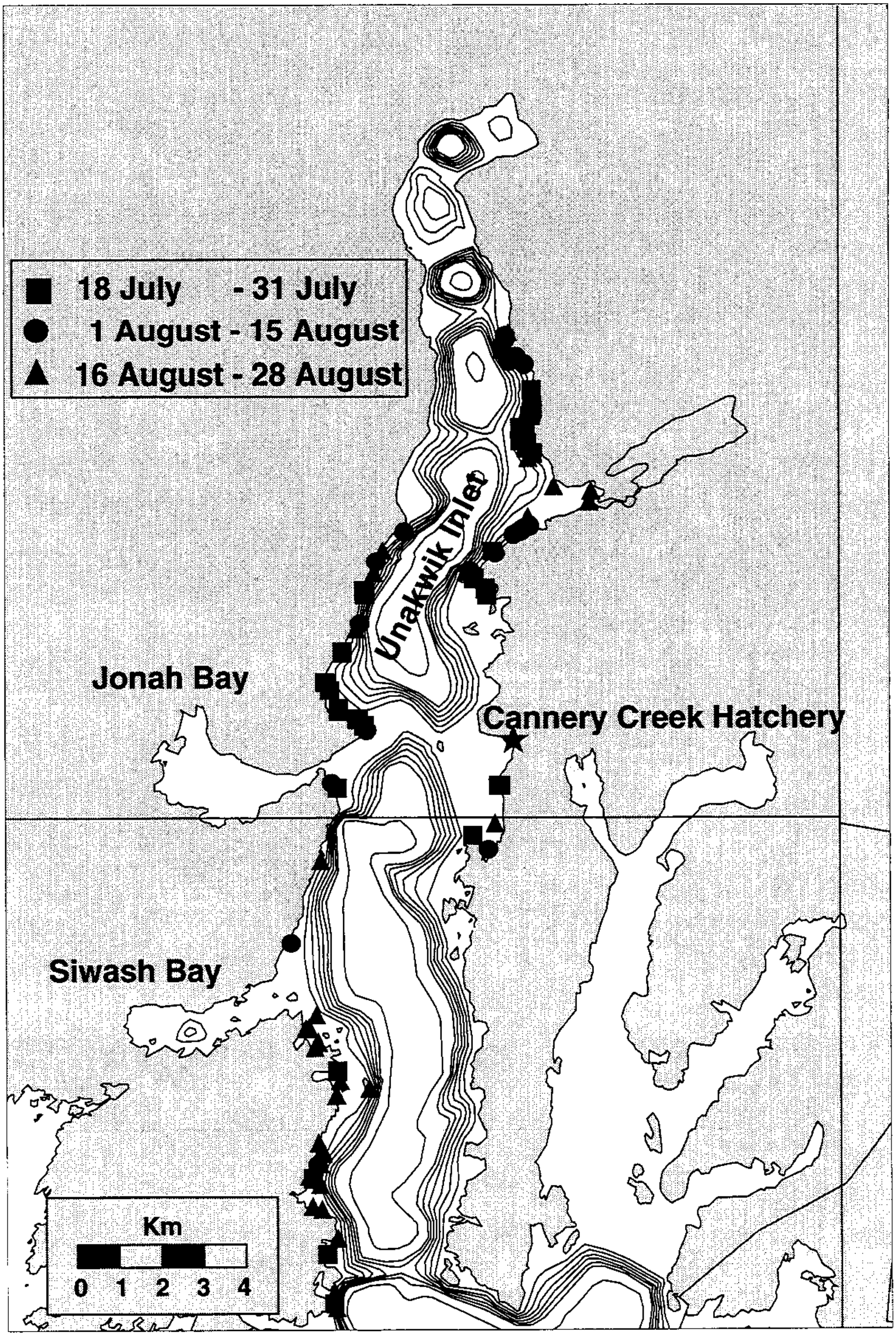

Km
0 .5 1 1.5 2
■ 18 July - 31 July
● 1 August - 15 August
▲ 16 August - 28 August
Ewan Bay
Jackpot Bay
Dangerous Passage
Chenega Island

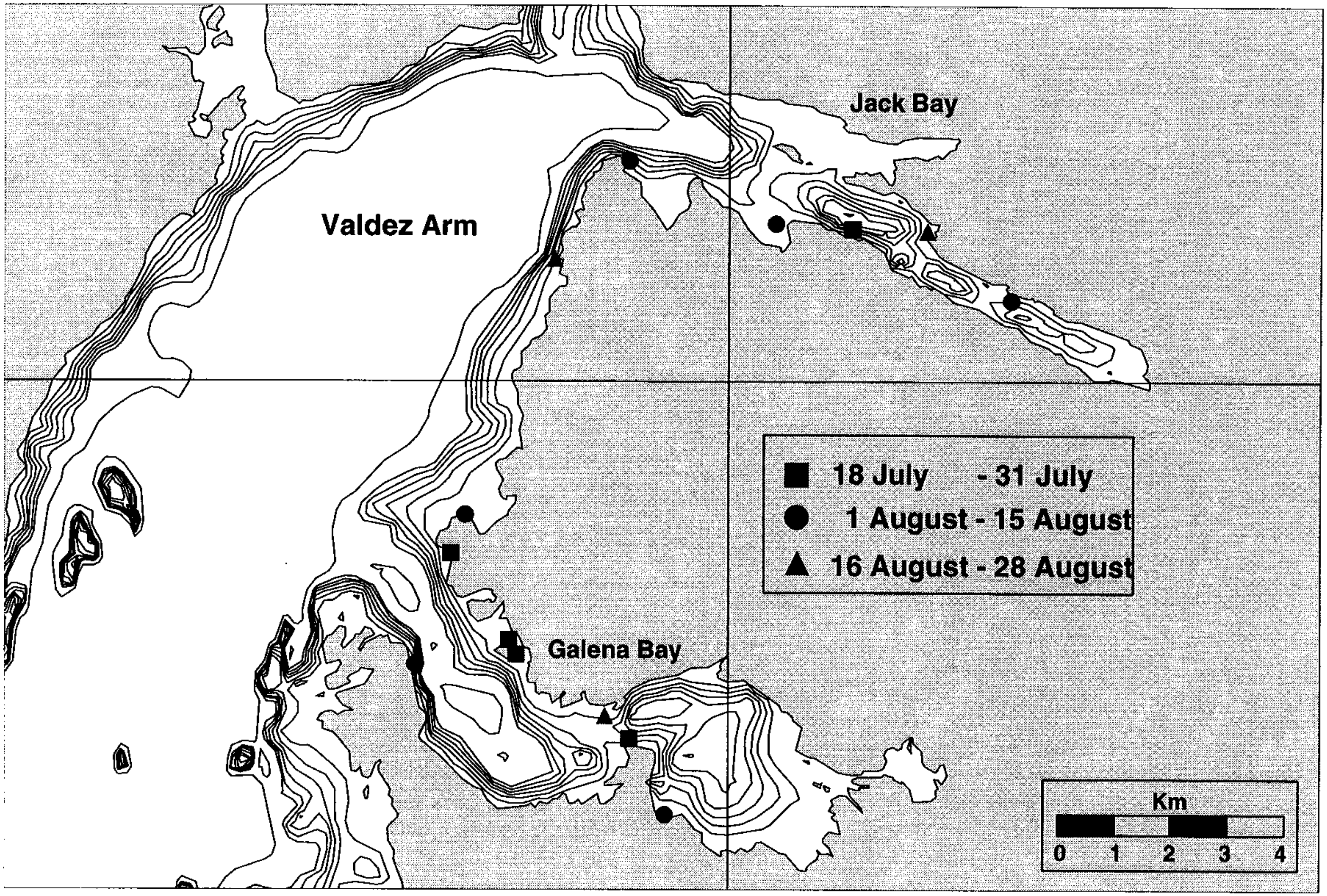


■ 18 July - 31 July
● 1 August - 15 August
▲ 16 August - 28 August
Lower Passage
Knight Island
Bay of Isles
Km
0
1
2


■ 18 July - 31 July
● 1 August - 15 August
▲ 16 August - 28 August
Cabin Bay
Naked Island
Km
0
1
2
3


Port Nellie Juan
■ 18 July - 31 July
● 1 August - 15 August
▲ 16 August - 28 August
Km
0
1
2
3
4


■ 18 July - 31 July
● 1 August - 15 August
▲ 16 August - 28 August
Unakwik Inlet
Jonah Bay
Cannery Creek Hatchery
Siwash Bay
Km
0 1 2 3 4


Jack Bay
Valdez Arm
Galena Bay
■ 18 July - 31 July
● 1 August - 15 August
▲ 16 August - 28 August
Km
0
1
2
3
4