

Exxon Valdez Oil Spill
Restoration Project Annual Report

Marbled Murrelet Productivity Relative to Forage Fish Abundance and Chick Diet

Restoration Project 98163R
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

Katherine J. Kuletz

U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, AK 99503

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Study History: This project was originally funded in 1997 as a separate restoration project that was coordinated with the APEX study and is currently part of APEX as 98163R. Therefore, 1997 results are incorporated into the 1998 APEX annual report. Project 98163R follows a study that developed the murrelet productivity index (Project 95031; see also Kuletz and Kendall 1998a). Some analyses presented in this report include data from the 1995 project. A pilot murrelet productivity study was presented in Project 94102. Previous murrelet restoration studies, which will be incorporated in the final synthesis for this project, pertained to murrelet nesting habitat; these include Trustee reports 93051B, R15, and various publications.

Abstract: In Prince William Sound (PWS), Alaska, marbled murrelets (*Brachyramphus marmoratus*) are the most abundant and widely dispersed seabird, but they have not shown recovery since the 1989 oil spill. To determine if food availability is limiting murrelet recovery, we tested for spatial and temporal differences in murrelet productivity in PWS relative to diet and fish abundance. We conducted at-sea surveys to determine juvenile murrelet densities. Forage fish abundance was measured by hydroacoustic surveys (Project 98163A) and aerial counts of fish schools (98163T). In 1995-97 average juvenile murrelet densities at sites were positively correlated with both fish abundance and numbers of fish schools. Data will be reanalyzed with 1998 murrelet data when target strength studies are completed. As in 1997, chicks at Naked were fed primarily Pacific sand lance (88%) and juveniles appeared earlier in the season and were more abundant there (1.53/km²) than at Jackpot (0.49/km²), where chicks received 88% Pacific herring. Galena continued to have the lowest juvenile density (0.21/km²). Fish caught below foraging adults at Naked (N=14 net samples) showed equal amounts of herring and sand lance, however, herring (20-60 mm) were smaller than sand lance (60-90 mm) and may not have been adequate for chick-feeding. The single catch at Jackpot had large herring (120-130 mm), similar to those caught by murrelets at twilight for their chicks. Relative measures of productivity remained consistent among the 3 sites. Peak fledging was later in 1998 than in 1997 and may not have occurred until early September at Jackpot, which was beyond our survey window. Although juvenile murrelet density has not shown extreme fluctuations over 3-5 years (depending on site), it has been sensitive to changes in average fish biomass within a narrow range of approximately 0.4-1.7 g/m².

Key Words: *Ammodytes*, *Brachyramphus*, *Clupeidae*, diet, *Gadidae*, forage fishes, foraging patterns, hydroacoustics, juveniles, marbled murrelet, marine surveys, Prince William Sound, productivity.

Project Data: To be addressed in the final report.

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INTRODUCTION

Marbled murrelets (*Brachyramphus marmoratus*) suffered high mortality in the 1989 spill (Piatt et al. 1990, Kuletz 1996), but the spill cannot account for the 67% reduction in numbers observed in post-spill years. The population has not increased since 1989 (Agler et al. 1994) and has shown a downward trend since 1993, with the 1998 population estimate lower than that for 1989 (D. Irons, unpubl. data). Recovery of the PWS marbled murrelet population may be inhibited by an apparent shift in the marine ecosystem of southcentral Alaska that began in the late 1970s (Piatt and Anderson 1997, Kuletz et al. 1997). Seabird productivity is generally acknowledged to be linked to prey abundance, but it is not known if or how the reproductive success of birds in PWS has been restricted by the abundance of forage fish. The goal of this project is to examine the relation between marbled murrelet productivity, diet, and forage fish abundance.

The adaptiveness of seabird behavior, including the implications of central-place foraging and population regulation, have largely been examined through studies of highly colonial seabirds (Furness and Monaghan 1987, Wittenberger and Hunt 1985). Little is known about how these results apply to non-colonial seabirds such as the marbled murrelet. The low density of marbled murrelet nests and the scattered distribution of murrelets at sea suggest a species that exploits spatially dispersed prey, perhaps at prey densities unsuitable for colonial seabirds. Selection of habitat (Kuletz and Kendall, ms) and fish schools (Ostrand et al. 1998) support this premise, although the implications to murrelet reproductive success remain speculative. In addition to the relation between murrelets and prey abundance, this study examines murrelet diet and its possible effects on murrelet chronology and productivity. These questions will be examined at spatial and temporal scales within PWS, and will ultimately be compared to other areas of the spill zone.

Preliminary analyses found a significant positive relationship between fish abundance and murrelet productivity (Kuletz and Kendall 1998a). We also found concordance between murrelet chick diet, chronology and productivity in 1997 and 1998. These results are preliminary, however, and await final data on fish biomass for further analysis.

METHODS

Study Area

All study sites were in Prince William Sound (PWS), Alaska, a 10,000 km² embayment

along the north coast of the Gulf of Alaska. In 1998 we continued monitoring the 3 study sites used in 1997 and in previous murrelet studies. The sites, each approximately 50 km of shoreline, were in the northeast, central and southwest portions of PWS (Fig. 1). In 1995 the murrelet study included 3 additional study sites. These were Unakwik Bay (Unakwik), northern Knight Island (Knight) and Port Nellie Juan (PNJ) (Fig. 1). Of these, only Knight overlapped with the hydroacoustic surveys. In 1996, no field work was funded for the murrelet project, but the U.S. Fish and Wildlife Service conducted limited surveys at Naked. Thus, comparisons between murrelets and fish biomass were available for 4 sites in 1995, 1 site in 1996, and 3 sites in 1997. For the 1998 annual report, the only fish data available was the number of fish schools observed during aerial surveys.

The boundaries of the Galena and Naked sites were adjusted in 1997 from those of the 1995 surveys to accommodate changes in nearshore coverage by the hydroacoustic surveys (Galena) or time constraints (Naked). At Galena, we surveyed Galena Bay and shorelines south of Galena, whereas in 1995 we had surveyed Galena Bay and north along Valdez Arm. We treat 1995 and 1997-98 boundaries for the northern area as the same site, because habitats are similar and preliminary analyses showed no significant difference in murrelet abundance or distribution. At Naked, the entire island had been surveyed in previous years (1994-1996) and the east side of Naked, which was not surveyed in 1997-98, had consistently low numbers of murrelets and no juveniles. To avoid bias in among-year comparisons we equalized 1995 and 1996 data by recalculating murrelet densities without the 3 east side transects. At Jackpot, boundaries have remained the same.

Methods

Murrelet productivity

Because marbled murrelet nests are hard to find, we use an index of productivity based on at-sea surveys to obtain juvenile densities and the ratio of juveniles-to-adults (see Kuletz and Kendall 1998b). Because adult murrelets leave breeding areas in August, we counted adults in early June (incubation) and both adults and juveniles in July-August (fledging period). There is a positive correlation between the early June counts and the numbers of fledglings at a site (Kuletz and Kendall 1998a,b)

In 1997 we surveyed each of the 3 study sites 3 times during 31 May-15 June, and 6-8 times during 25 July - 26 August. Each survey took a full day (0700 - 1600 h). We surveyed from 7.5 m vessels traveling 100 m from shoreline. A boat operator and 2 observers recorded all birds and marine mammals 100 m either side of and ahead of the boat. In 1997 and 1998 we entered observations into a laptop computer using the program DLOG (Ecological Consulting, Inc.). The program was integrated with a Global Positioning System, so that every observation had a corresponding latitude and longitude. We also entered behavior codes for each entry indicating if the bird was diving, on water, flying or part of a forage flock.

For murrelets we also recorded plumage, ranging from full breeding to black-and-white in four categories. When we encountered potential juvenile murrelets (black-and-white plumage) we paused to identify the age class and record behavior of the bird, marine and shoreline habitat, and water depth. We assumed that most juveniles observed at a site originated there or nearby. Current information suggests that in PWS the assumption is reasonable during July-August (see Kuletz and Marks 1997, Kuletz and Kendall 1998a). We used the changes in daily numbers of juveniles counted during the July-August surveys as a measure of nesting chronology. Another means of estimating hatching and egg-laying (by backdating) was the numbers of birds holding fish earlier in the summer (see Diet, below).

Fish abundance and species composition

Prior to 1998, we examined fish biomass within specific murrelet study sites by extracting nearshore hydroacoustic transects within a 10 km radius of the center of each murrelet study site. Although we can not be certain that most adult murrelets on the water at our study sites nested in the vicinity, we used the 10 km radius to objectively identify which hydroacoustic transects to include. The 10 km radius was the average straight-line distance traveled between consecutive days for radio tagged murrelets in 1993 and 1994 (Kuletz et al. 1995). For 1995 we used fish biomass values presented in Haldorson et al. (1996). Ken Coyle (Univ. Of Alaska, Fairbanks) provided the 1996 and 1997 data. Once acoustic target-strength studies are completed, we will use that data and re-analyze the earlier relation between juvenile density and fish biomass.

Fish biomass was determined for each transect by K. Coyle as average prey biomass per m^2 . Each nearshore hydroacoustic survey block (~ 10 km in length) consisted of a zig-zag series of approximately 1.2 km-long transects. We calculated biomass for each study site using the mean biomass of all transects in the selected nearshore blocks. In 1995, APEX conducted two surveys, of which we used the earlier July survey that best matched the timing of murrelet chick rearing.

A second index of fish abundance was obtained from aerial surveys of PWS conducted by E. Brown (Project 98163T). The aerial surveys provided numbers of schools, and in most cases, school size (surface area), and species identification. In 1997 and 1998 the murrelet crew participated in ground-truthing species identification by filming and sampling fish located by E. Brown. The full use of these data, particularly for fine and micro scale analyses with murrelet data, will not be presented here pending finalization of the data by E. Brown and G. Ford.

Murrelet diet

In 1997 and 1998 we determined chick diet by observing murrelets on the water that were holding fish near dusk. At these times, adults are most likely to capture prey for their chicks and they often hold the single fish on the water for extended periods (Carter and Sealy 1987). Between 6 July and 18 August we conducted 38 'diet cruises', between 1800 - 2200 h, from a 5 m or 7.5 m vessel by slowly traveling through nearshore waters of our study sites. We identified all fish held by murrelets to the nearest taxon possible using binoculars and estimated fish length by the bill length of the bird. We also recorded all murrelets encountered during a diet cruise to obtain a percentage of birds feeding chicks.

Opportunistic diet observations. -- We opportunistically observed adult murrelets feeding themselves during our surveys and while in transit between sites. Additionally, the behavior of birds and their association with forage flocks was recorded during the productivity surveys. We attempted to capture prey below feeding murrelets using a dip net. Prey samples were labeled with date, location and associated feeding activity, frozen within 6 h and transported to Kathy Turco (University of Alaska, Fairbanks) for identification and measurement.

Foraging behavior

The foraging patterns of birds was observed during land-based foraging watches (N = 46 watches, 2-3 h each), with sampling blocks as self and chick feeding periods at Jackpot and Naked. Chick-feeding periods were considered to be before 0900 and after 1700 h. Mid-day was considered to be primarily a self-feeding period. I will test for differences between groups in proportion of diving birds, group size, and diving times of birds.

Capture and marking of juveniles

As a pilot study, we attempted to capture murrelets using a dipnet and spotlights from a boat. This was primarily to gauge the effectiveness of the capture method for juveniles and to attach radio-tags. The goal was to determine the turnover rate of juveniles in the study sites, foraging patterns, and to obtain body measurements of juveniles. Radio tags were donated by the U.S. Forest Service (Juneau). Captured birds were measured, weighed to the nearest gram with pesola hand-held scales, and fitted with USFWS aluminum bands. We glued a 2 g radio tag (Holohill) to the back of the juvenile murrelets. Tracking was done opportunistically by boat on 16 days.

In 1997 we found that, although juveniles remain near shore until about 2300 h, they would swim offshore as darkness approached. At Naked Island, scattered adults and juveniles can be found about 3 km off shore of the west side of the island and north towards Storey Island. A crew of 4 (boat operator, 2 spotlighters, 1 dipnetter) cruised this area at approximately 2400-0330 on 7 nights between 29 July and 12 August.

Data analysis

The primary hypothesis we will test is that murrelet productivity will be higher in areas and in years when forage fish availability is relatively higher. Preliminary analysis from 1995-97 supported this hypothesis (Kuletz and Kendall 1998b)

We conducted preliminary analyses using juvenile murrelet densities. The juvenile:adult ratios will be examined in detail in the final report and manuscripts. For 1995 and 1997, we regressed the average fish biomass at a site in July (main chick rearing period) with the juvenile density at the site during the core fledging period (average of 5 core surveys, primarily early to mid-August). We also examined among-year trends in productivity and fish biomass at Naked Island with 3 years data. At this stage, we provide only descriptive comparisons of juvenile murrelet density vs. number of fish schools counted during aerial surveys, and murrelet diet among areas.

We regressed average juvenile density at a site during 5 core surveys to both average June adult density at a site (sequential surveys) and the average adult density in July-August (concurrent surveys). This was a continuation of a test of the hypothesis that, due to post-breeding dispersal of adults, June (incubation period) counts of adults should correlate better to July-August counts of juveniles than would concurrent counts of adults (see Kuletz and Kendall 1998a). If the relationship remains consistent, we will eventually compare slopes of the regression of the ratio index among sites and years.

RESULTS

During our surveys in 1998 we counted 158 juveniles at the 3 sites. We found most juveniles (89%) as solitary individuals, with no evidence of clumping, although we consistently found juveniles on certain transects. We observed juveniles an average of 61 m from shore in average water depth of 55 m. Most juveniles were in waters adjacent to cobble beaches (51%) or rocky shoreline (28%) or sandy beaches (11%), and in sheltered waters (67%) as opposed to exposed. Only 4% of juveniles were associated with kelp beds. These descriptive results agree with the detailed analyses of habitat associations for both adults and juveniles presented in the attached manuscript (Kuletz and Kendall ms). The final report will test the individual locations of juveniles in 1997-98 against the model derived from 1995 transect data. Analyses presented below are considered preliminary and final results will be subject to additional statistical analyses.

Murrelet productivity and fish abundance

Juvenile murrelet density at sites corresponded to the number of fish schools counted from the air in 1998, as it did in 1997 (Table 1). However, in 1998 the total surface area (m^2) of fish schools was highest per survey day at Jackpot, due to some dense schools of herring there in July. It was not clear if these herring were in the size range appropriate for murrelets. Aerial surveys indicated that Naked had more fish available in August, particularly sand lance. Pacific herring was the most common prey observed within 10 km of Galena and Jackpot, and Pacific sand lance was the primary species around Naked.

Murrelet abundance and chronology

Adult murrelet densities in 1998 were similar to those in 1994-96, leaving the very high numbers observed in 1997 an outlier (Table 2). Compared to previous years, juvenile densities remained high at Naked Island, ($1.53/km^2$). Jackpot ($0.49/km^2$) and Galena ($0.21/km^2$) were both lower than in 1997. Among sites, the relative abundance of juveniles (Naked \gg Jackpot $>$ Galena) was similar to that of previous years. For the third time (1995, 1997, 1998), we found a positive relation between June adult densities and juvenile densities among sites in July-August ($R = 0.98$, $P = 0.09$).

The pooled and standardized adult densities (Fig. 2) showed greater temporal variability than in previous years, with peak densities at Naked and Galena occurring in June rather than

July. However, adult murrelet densities again generally declined through August, with the exception of 2 spikes in attendance at Galena. The extreme fluctuations in the daily percentage of juveniles (Fig. 2) occurred despite standardization (to the highest density per site), due to the extreme differences in chronology between Naked and Jackpot. As in previous years, in 1998 juveniles appeared first and peaked earliest at Naked.

Murrelet nest initiation and fledging appeared to be about 1-2 weeks late relative to previous years. During June surveys, 3% of the 1,976 adults (where plumage was recorded). An additional 47% of the birds were in transitional plumages. The plumages indicated differences in chronology among sites. In June, the proportion of birds in basic plumage were 1% at Naked, 2% at Jackpot and 8% at Galena. The proportion of birds in transitional plumage were 40% at Naked, 49% at Jackpot and 61% at Galena. These numbers compare with previous June records of 0.03% in basic and 20-40% transitional.

Murrelet diet

As in 1997, the primary prey fed to chicks was Pacific herring and Pacific sand lance. However, whereas their total proportions were roughly equivalent in 1997, in 1998 total chick-feeding observations were 80% herring, 12% sand lance, 2% capelin and 6% other species. The high percentage of herring occurred because most of the observations of birds during diet cruises were at Jackpot (N = 296; 215 identified), where 88% of the fish were herring. Only 51 birds with fish were observed at Naked (24 identified) where 88% were sand lance.

Incidental observations of birds with fish (N = 61 identified) at all 3 sites showed 41% herring, 52% sand lance, 5% capelin and 2% gadids. Of these, most of the herring were observed at Jackpot (84%) and most of the sand lance (94%) were at Naked.

The 16 dipnetted fish samples we obtained opportunistically show both sand lance and herring at Naked and herring at Jackpot (Table 3). However, at Naked, most of the herring samples were 40-60 mm, while most sand lance were 60-90 mm, with the exception of 1 sample in the 40-50 mm range. Two of the sand lance samples at Naked were taken in the same dipnet sample that contained primarily herring. Only 1 sample, comprised of herring, was obtained at Jackpot and these fish were considerably larger (120-130 mm) than the herring at Naked. This sample was taken below birds feeding in central Jackpot Bay, where murrelets were frequently observed holding fish at night. Based on fish lengths estimated from murrelet bill-length, the fish in this sample were in the same range as the herring held for chicks.

In 1998 the mean number of murrelets holding fish in the evening at Naked was 2.71 (SE = 1.44, N = 25 cruises) per cruise, but was much higher at Jackpot ($x = 14.6$, SE = 12.91, N = 23). The proportion of birds holding fish jumped dramatically at Jackpot in late July, and continued to be high at our last diet cruise on 26 August. The peak number of birds holding fish (44) occurred on 30 July, and the continued fish-holding through August suggests that peak fledging could have occurred in early September.

Foraging observations

The results of the forage watches will be presented in a later paper. To determine if murrelets alter their foraging and other activities when feeding chicks, I will test for differences in proportion of diving birds, group size, and diving times of birds.

The behavior of individual birds observed during the boat-based productivity surveys will also be used to test for differences in foraging patterns between sites of low and high fish density. Preliminary examination indicates that birds foraging at Naked were more likely to be associated with feeding flocks (46% of 115 observations) than murrelets at Jackpot (22% of 88 observations). Because we surveyed each site repeatedly, often in conjunction with aerial fish surveys, it will also be possible to test the relation between murrelet distribution and the predictability as well as immediate distribution of forage fish. These relationships will be examined at various spatial scales.

Juvenile murrelet catch and tracking effort

At Naked Island we caught 5 adults and 4 juvenile murrelets over 7 nights, averaging 1.28 birds/night and catching 0-4 birds on a given night. The juveniles were caught on the 5 and 11 of August and averaged 136 g (SD = 17). Average weight for adults was 231 g (SD = 16). Radio-tags were glued to the juveniles and the birds were tracked by boat as time and weather allowed. The 2 juveniles caught on 5 August were last detected on 12 August (8 days). One bird tagged on 11 August was not detected after the night of release and the other was last detected on 14 August (4 days). Because a series of storms and our survey responsibilities interfered with tracking efforts, these should not be considered accurate estimates of turnover rates. We did make visual contact with 2 birds and obtained limited habitat use data.

DISCUSSION

In both 1997 and 1998, measures of murrelet productivity have generally been consistent with the relative counts of fish schools among these sites, although the large schools of herring at Jackpot in July 1998 is inconsistent with this pattern. Aerial surveys also support the pattern of sand lance availability at Naked, and the availability of both herring and sand lance later in summer at this site, compared to Jackpot and Galena. Late summer availability of forage fish may enhance murrelet productivity and/or juvenile survival at Naked.

It is unclear why large numbers of birds were observed holding fish for chicks in central Jackpot Bay, and yet few juveniles were observed in that entire study area. Additionally, the aerial surveys did not detect schools of herring at Jackpot in August. Because the murrelets were taking these fish in the late evening, perhaps vertical migration of the fish made them difficult to detect from the air. Carter (1984) suggested the murrelets in British Columbia switched, when chick-feeding, to smaller patches of large fish that rose to the surface at twilight. Rhinoceros auklets (*Cerorhinca monocerata*) display a similar shift in foraging technique when provisioning chicks (Davoren and Burger, in review).

At Naked, the exclusive use of sand lance to feed chicks could be related to size differences in the fish and not solely a species preference. The herring at Naked were below the size range used for murrelet chicks, whereas the sand lance were consistent with observations in other regions (review in Burkett 1995). Adults were clearly taking both herring and sand lance when self-feeding, but were feeding their chicks the larger sand lance. The late chick-rearing period at Jackpot may thus be a response not just to fish availability (since herring were observed there in July), but the length of time necessary for juvenile herring to reach adequate size for chicks. However, the herring held for chicks at Jackpot appeared to be near the size limit used by murrelets, and might have been too large for the smaller chicks. Large fish, including herring, have been known to choke the chicks of other birds in PWS (Golet, unpubl. data).

Whether murrelets foraging in the evening at Jackpot were from other areas or nesting locally, our results suggest that murrelets in the region would have been fledging chicks late in the summer, and possibly into mid-September. Our surveys could thus have underestimated productivity at Jackpot, since we could not survey beyond late August. If these chicks fledged successfully, they might have met with less than optimum conditions due to poor weather and possibly low fish availability nearshore. Both the timing and sizes of fish available are important, and any model of murrelet recruitment should incorporate the dual needs of adults foraging for themselves and those foraging for chicks (review in Ydenberg 1994).

Juvenile capture and measurements

The limited data we obtained in this pilot study, when combined with other data available on juvenile murrelets, suggest that juveniles are near the edge of survival when they fledge. Juveniles fledge at 57-70% of adult weight (Hamer and Nelson 1995; Kuletz unpubl. data). Three juveniles found dead in the water in August (1995-98) weighed 90-115 g., not much less than the 117 g chick weighed in the nest the day before fledging (Kuletz and Marks 1997). Two juveniles found in forests on Kodiak Island averaged 120 g (SD = 4; unpubl. data). In contrast, the 4 juveniles we caught at sea were 136 g (SD = 17) with the heaviest at 153 g. Although these data are anecdotal, they suggest that weight gain immediately after fledging is critical for early survival of juvenile murrelets. Juveniles have shorter dive times (Kuletz and Marks 1997, Kuletz et al. 1995) and prefer shallow, protected water close to shore (Kuletz and Kendall, ms) or within kelp beds (Kuletz and Piatt, in press). Their lower diving capabilities may require that fish of adequate size be available in these habitats during the first critical weeks of fledging.

Summary

Diet was again associated with murrelet nesting chronology. Both fish-holding and the appearance of juveniles indicated that murrelets at Naked initiated nests and fledged chicks 1-2 weeks earlier than murrelets at Jackpot or Galena. Fledging began and peaked earliest at Naked, where sand lance appeared to be available throughout the breeding season. At Naked, the single peak occurred late (10 August) compared to 1995-97. At Jackpot, where herring use predominated, most of the juveniles did not appear until mid to late August. The timing of fish availability may have been more important than differences in prey quality.

Although there were significant and consistent differences among sites in juvenile density, the variance within sites has been relatively low, or at least lacking in 'boom and bust' years characteristic of many seabirds. However, based on preliminary analyses using backscatter estimates of total fish biomass, the fluctuations in murrelet productivity that we observed have been sensitive to fluctuations in prey abundance within a fairly narrow range. At these sites, average fish biomass has ranged from 0.2 to 1.7 g/m², with the steepest change in juvenile density occurring between 0.4 and 1.7 g/m². This suggests that, although murrelets can be successful in a region with an average low fish biomass (compared to an area like Lower Cook Inlet), the PWS population might be negatively affected by even slight decreases in biomass beyond what has been recorded during APEX studies.

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FIGURES

- Figure 1. Marbled murrelet study sites in Prince William Sound, Alaska, in 1995 (6 sites) and 1997 - 1998 (Galena, Naked, Jackpot). Shoreline areas surveyed, and pelagic transects at Naked Island and Port Nellie Juan, are shown in black. The circles are the 10 km radius used to determine fish abundance.
- Figure 2. Standardized adult murrelet densities (bars) and the daily percentage of juveniles (line) for three study sites in PWS, Alaska, in 1998.

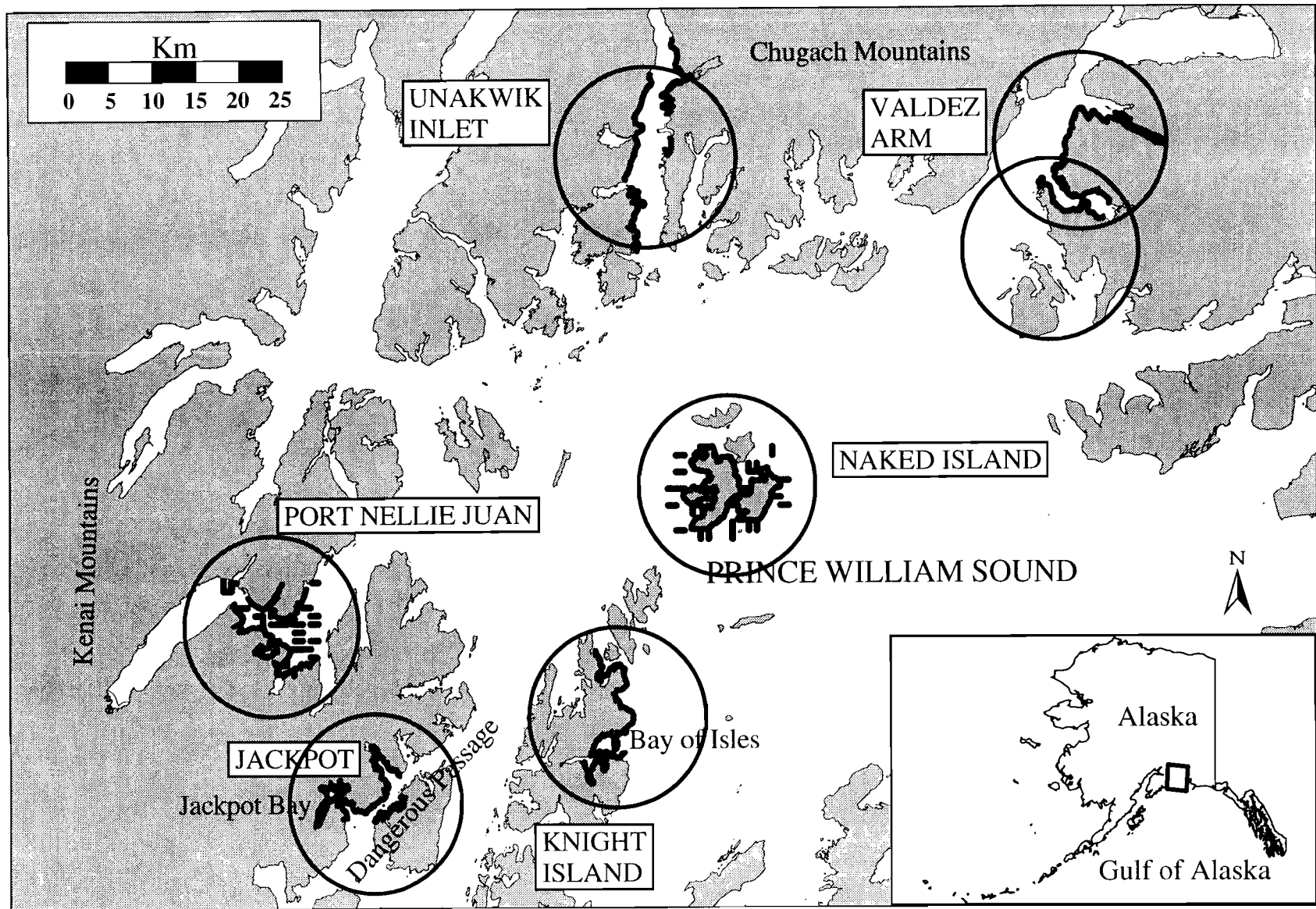


Figure 1

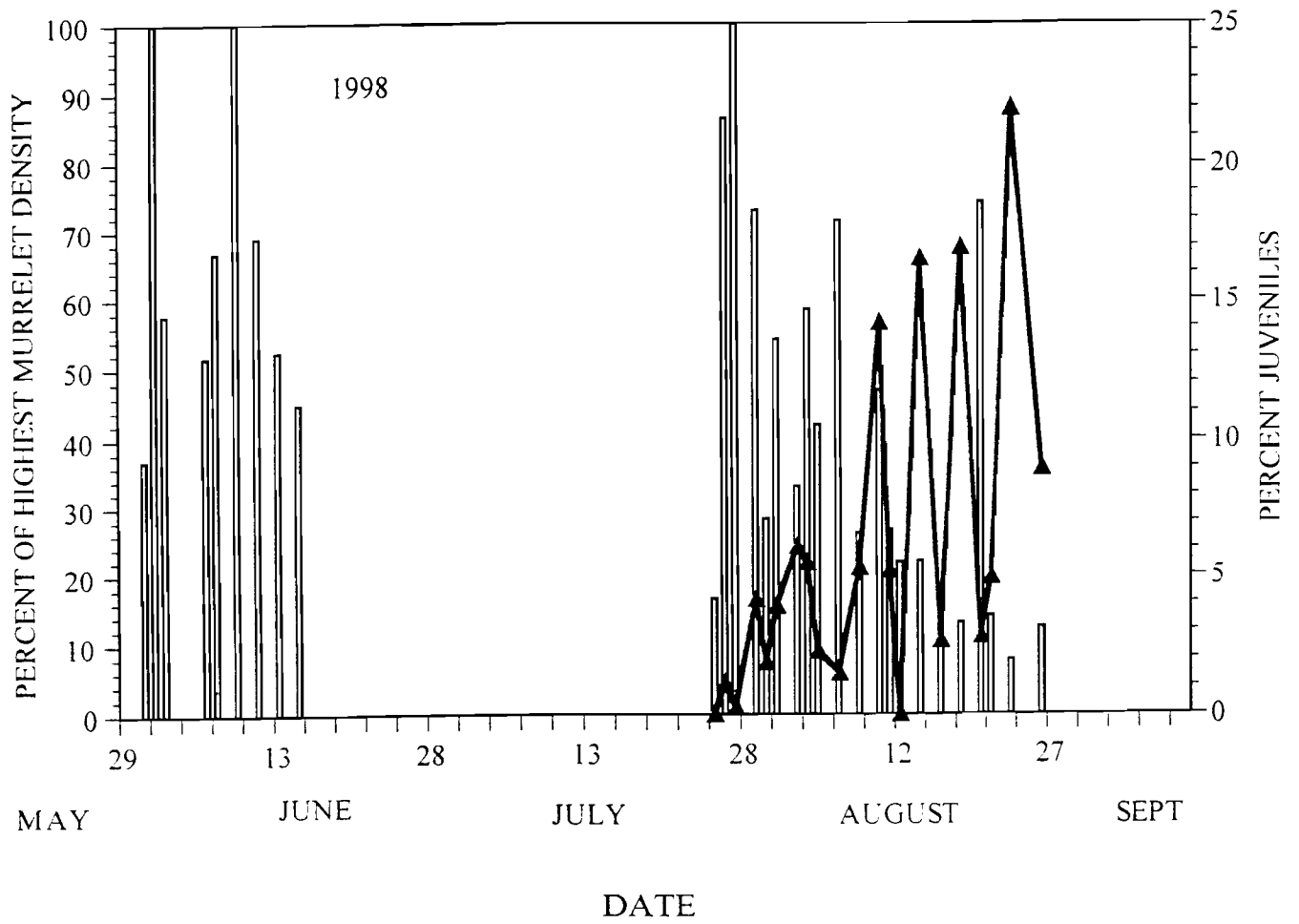


Table 4. Total numbers of key species sighted from the air by day, 1998.

Month	Day	Alcids	GW*	Kittiwakes	DP*	HS*	HW*	Orcas	Sea Lions	Sea Otters	Capelin	Eulachon	Herring	Sand Lance	Jellyfish
July	6	3	2	1062		1			7	2			43	2	67
	7	12	11	2119	4	4			161	26			96	26	88
	8			1617					13	35			65	35	40
	10	308		4013	2	51	10		39	34	10	5	41	34	7
	11	3		1698			5		5	36	18		16	36	14
	12	1723		4906		81	2		39	104	18		74	104	47
	13	100		5764	7		1	8	15	107	7	17	124	107	5
	14	17		522					4	5			11	5	11
	15			1552	2				9	17			104	17	52
	16	23		1401					218	16			56	16	45
	17	2		887			1		2	8			49	8	36
	18	224		2384		8	8		60	165		1	25	165	16
	19	164		2492			10		47	185			34	185	133
	20	16		393			1		1	11			2	11	3
	23	22	45	1364					18	11			41	11	8
	24	151	37	1550	4	3			224	12			21	12	11
	26	107		4759			7		208	151			9	151	3
	28	110		1267		1	2			157			39	157	42
	30	292	21	3385		2	7	2	135	125			156	125	25
	31	281	7	1552					30	8			11	8	22
	July Total		3558	123	44687	19	151	54	13	1235	1215	53	23	1017	1215
August	1	209	38	930					7	2			2	2	5
	3	122	1	1885			7		6	71			116	71	15
	4	257		2934		90	3	1	70	61			130	61	39
	5	202	4	2599		96	5		52	50			84	50	14
	7	136	2	1462					20	1			15	1	4
	8	175	4	1467					104				41		1
	9	105	5	1632					84	12			23	12	4
	10	401		612					19	4			17	4	
	11	58		156											13
	August Total		1665	54	13677		186	15	1	362	201			428	201
Grand Total		5223	177	58364	19	337	69	14	1597	1416	53	23	1445	1416	770

- GW = Glaucous-Winged Gulls, DP = Dahl Porpoise, HW = Humpback Whales, HS = Harbor Seals

**Environmental Factors and Marine Habitat Associations of Adult and Juvenile
Marbled Murrelets in Prince William Sound, Alaska :
Implications to Monitoring Murrelet Productivity**

Kathy Kuletz and Steve Kendall

E-mail: kathy_kuletz@fws.gov

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ABSTRACT

Monitoring the reproductive success of a non-colonial seabird poses special problems. For the marbled murrelet (*Brachyramphus marmoratus*), a threatened species along the eastern Pacific coast, productivity is measured by surveying juveniles at sea during the fledging period. Power to detect trends in juvenile murrelet densities are usually low, due to their low numbers and dispersal at sea. One way to reduce variance in counts would be to determine if juveniles exhibit habitat preferences, and if so, stratify survey effort by habitat. I examined the influence of habitat and survey conditions on juvenile murrelet densities at six study areas in Prince William Sound (PWS), Alaska. The areas, comprised of shoreline transect sections, were surveyed 7-10 times each in July and August 1995. I used stepwise multiple regression to model both adult and juvenile densities at the transect level. Based on the most parsimonious model, I used analysis of deviance tests on logistic regression models to select the best predictor of presence or absence of juveniles. In preliminary models, Area effect was an overwhelming factor, necessitating nested analyses. Weather-related, surface marine conditions, and tidal state did not significantly add to the models. The best model for juvenile density included shoreline type, exposure, and water depth. In PWS, juveniles are most likely to occur along rocky shoreline with moderate exposure and relatively shallow waters. Water depth was the only significant predictor variable for adults, once Area and date effects were controlled. The best habitat models explained 36% of the variance in juvenile numbers and 23% of adult numbers. Variability in counts of juveniles can probably be reduced by stratifying habitats for surveys, however, a large amount of variability was unexplained. Area effect was clearly important, suggesting that monitoring efforts should be built around a core of consistently productive sites. Further, Area could be incorporated as a stratifying factor in a monitoring scheme. Factors not included in these analyses, such as local inland nesting habitat and forage fish availability, likely are important to juvenile murrelet distribution.

INTRODUCTION

The conservation of threatened and endangered species requires adequate monitoring of population trends. For most seabird species, it is possible to study reproductive success because they nest in dense colonies (Wittenberger and Hunt 1985). Non-colonial species, such as the marbled murrelet (*Brachyramphus marmoratus*; Alcidae), however, pose a special problem.

This small diving seabird nests inland, typically in the branches of old-growth trees. Murrelets are noncolonial, widely dispersed, and they conduct much of their nesting activity in darkness or twilight. Once fledged, the chick is on its own, with no obvious parental association. These behaviors have hindered study of marbled murrelet reproduction (Nelson 1996, Ralph et al. 1995).

Currently, the most practical option for studying the reproductive performance of marbled murrelets is to count juveniles at sea during the fledging and early juvenile period (Kuletz and Kendall 1998, Ralph and Long 1995, Strong et al. 1995). Power to detect changes in juvenile murrelet abundance is generally low, unless multiple sites are surveyed within a region, or where adult murrelet abundance is high (approximately >10 birds/km²; Kuletz and Kendall 1998). Power to detect changes in juvenile densities would be most improved by reducing variance in juvenile counts during a 3 to 5-week core survey period (Kuletz and Kendall 1998).

Reduced variability in survey data can be achieved by standardizing protocol and by stratifying sampling effort. Counts of murrelets and other seabirds are potentially influenced by factors that affect observability, such as seas, rain, sun glare, and observer expertise. Seabird abundance is influenced by fluctuating or cyclic environmental conditions such as weather, daylight, tides, season, water temperature, salinity and clarity, and prey abundance (Carter and Sealy 1990, Hunt et al. 1993, Schneider and Piatt 1986). Seabirds may also be associated with stable habitat features, such as shoreline type, exposure, and water depth (Tyler et al. 1993, Vermeer et al. 1992). Adults and juveniles may exhibit different distribution patterns at sea (Gaston and Nettleship 1981), and juvenile murrelets in some areas appear to remain closer to shore than adults (Anderson and Beissinger 1995, Sealy 1975, Strachen et al. 1995), suggesting different habitat selection among age classes.

Many habitat and environmental factors may be correlated. For example, rough seas, which can affect seabird foraging (Furness and Monaghan 1987), are more typical along exposed coasts, and forage fish species may be associated with certain shoreline substrates (Robards et al., submitted). Identifying key habitat features associated with murrelets or their prey would allow stratification of sampling. Furthermore, knowledge of important effects on observability can lead to a more effective survey protocol. By reducing variance in murrelet counts we can reduce survey effort and improve our ability to make statistical comparisons. For murrelets, the ratio of juveniles to adults counted on the same surveys is often used as an index of productivity (Anderson and Beissinger 1995, Ralph and Long 1995, Strong et al. 1995). Because ratios would be sensitive to age-specific differences in habitat use, it is important to determine if adult and juvenile habitat use is similar during the survey period.

In this paper I examine at-sea counts of murrelets, particularly juveniles, to determine if environmental factors can be identified that might guide survey protocol or the stratification of habitats to reduce variance in counts. To do this I examined data I collected in 1995 in Prince William Sound, Alaska.

METHODS

Study Area. --The study was conducted in Prince William Sound (PWS), Alaska, a large embayment with approximately 3,000 km of shoreline, in the northern Gulf of Alaska. The area is characterized by deep, relatively protected waters, numerous islands, bays, and fjords, and glacial influence. Tree line is at 30-600 m elevation, and forests include Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and mountain hemlock (*T. mertensiana*). Unforested areas include bog meadows, willow and alder thickets, or barren rock. Study sites (Fig. 1) included stretches of shoreline at Unakwik Inlet (Unakwik), Valdez Arm (Valdez), Naked Island (Naked), Port Nellie Juan (PNJ), Knight Island (Knight), and Dangerous Passage-Jackpot Bay (Jackpot).

Each study site had between 45 and 60 km of shoreline, and included a variety of habitats. Unakwik, a mainland fjord, has a tidewater glacier at its terminus, and water depths to 350 m, but it is divided midway up its length by a 10 m deep sill. Valdez, a fjord on the northeastern mainland, includes 2 large bays off the main channel, which is 400 m deep. Naked and Knight are large islands in western PWS. Naked has 4 large bays and is surrounded by waters <100 m deep within 1 km of shore. The portion of Knight we surveyed has exposed shoreline with water 200 m deep within 1 km of shore but includes a narrow passage and the highly convoluted Bay of Isles with shallow, protected water. Port Nellie Juan, a fjord on the western mainland, is up to 700 m deep, bordered by steep mountains to 1,700-m elevation, with 1 tidewater and 7 hanging glaciers. Jackpot, in southwest PWS, includes 2 sheltered bays and shoreline along Dangerous Passage, which is 170 m deep.

Mean air temperature during our surveys ranged from 12.4 to 14.1°C, surface water temperature ranged from 8.9 to 13.0°C and surface salinity ranged from 9.5 to 25.2 ‰. Tidal range was approx 5 m at all sites, but the intensity of tidal flow varied greatly, depending on local topography and bathymetry (Burrell 1987).

We distributed study sites to sample from a variety of habitats and to minimize foraging overlap by marbled murrelets raising chicks. Site boundaries were ≥ 16 km apart (straight-line distance), the mean foraging range for radiotagged marbled murrelets in PWS (Kuletz et al. 1995), and greater than the distance a radiotagged juvenile moved over 2 weeks after fledging from its nest (Kuletz and Marks 1997).

Data Collection - Murrelet Densities

We surveyed each site 7-10 times between 18 July and 28 August. Each survey took a full day (0700 - 1600 h). Two crews, operating independently, surveyed from 7.5 m vessels traveling 100 m from shoreline. A boat operator and 2 observers recorded all birds 100 m either side of and ahead of the boat. We usually surveyed each site about every 3-4 days, with crews rotating among sites to minimize observer bias. Due to weather and logistic problems, we occasionally missed sites on a survey rotation, resulting in uneven sample sizes.

Juvenile marbled murrelets look similar to adults in winter plumage. When we encountered potential juvenile murrelets (in black-and-white plumage) we paused to identify the age class. I refer to hatching-year birds as 'juveniles', and after-hatch-year birds as 'adults', although the

latter category includes non-breeding and sub-adult birds that can not be distinguished visually (Sealy 1975).

I standardized marbled murrelet counts as densities (birds/km²) to compensate for differences in transect lengths or the occasional inability to complete sections of shoreline due to poor surveying conditions.

Data Sources for Environmental Conditions and Habitat Features

I examined the associations between murrelets and environmental or habitat features using data available for shoreline sections. Each Area (45-60 km of shoreline each) was divided into 9-18 transects ($x = 4.7$ km in length; range 1-9 km). These shoreline transects had been digitized to a geographic information system (GIS). Transect boundaries generally followed land forms, so boundaries were typically defined by prominent points, bays and shorelines with different exposures.

Prior to each transect we recorded time, sea state, swell height, wind speed and direction, precipitation, percentage cloud cover, sunglare, observer conditions, and sea surface temperature (SST). On each survey day we used a minimum of 4 stations to collect data on water clarity using a secchi disk (SECCHI) and sea surface salinity (SSS) with a digital conductivity meter. To derive time relative to sunrise or tidal state, I used the start time and date of each transect in Paradox scripts (Borland International 1992). The Paradox script calculated tide as hours from low tide. For analysis I used the 12-hour tide divisions to create 3 additional tide variables in 6-hour blocks (ebb vs flood), 3-hour blocks, and 2-hour blocks. Tide Range for the day was included as a separate variable, using a tide table for Cordova, PWS.

Because we did not take environmental measurements on every transect, for some analyses I used the day's average measure of salinity (xSSS) and water clarity (xSECCHI). Preliminary analyses indicated that these measurements did not vary significantly within an Area on the same day, with the exception of transects near tidewater glaciers in Unakwik and PNJ. For analyses that examined specifically the influence of SSS, SST and SECCHI on murrelet abundance at the transect level, I used only those transects with all measurements.

Static habitat features included water depth, shoreline type, and exposure. Water depth was obtained from GIS coverage of PWS given in 20 m increments from 0-120m depth, and increasingly larger increments from 120 to 450 m. Using GIS, S. Kendall (USFWS, unpubl. data) determined the area covered by each depth category from 0-200 m offshore of the transect, to provide a weighted depth (DEPTH) for each transect. I also used the maximum depth (MaxDepth) of the transect as a separate variable.

Shoreline type (SHORE) was obtained from GIS coverage resulting from surveys conducted by the Alaska Department of Natural Resources. The three categories of SHORE included 1) fine grain/sand beaches, 2) coarse grain/cobble beaches, and 3) rocky shore. Exposure (EXPOSURE) of transects (defined by D. Irons, USFWS, unpubl. data), was the perpendicular distance from transect midpoint to the nearest point of land beyond the transect shoreline, based on nautical charts. The three EXPOSURE categories were <1 km, 1-5 km, and >5 km from transect midpoint to nearest land.

Data Analyses

For statistical tests I used S-Plus (MathSoft 1997). I used the Spearman's correlation coefficient (r) to test for significant correlations between variables. Murrelet densities by transect were generally very low and highly skewed, particularly for juveniles (Fig. 2), therefore, I transformed murrelet densities ($\ln X + .01$) for multivariate analyses. Because the independent variables included categorical and continuous variables I used the general linear model (GLM). First, I used stepwise linear regression (SLR) to develop the best model from among all variables. Second, I tested the best predictors with logistic regression models, using GLM for a binomial distribution and analysis of deviance goodness of fit tests for significance. For all tests, $\alpha = 0.05$.

Selection of datasets for different models. -- Juvenile occurrence was rare during early surveys, and at some sites, juveniles did not appear until the second week, presumably due to differences in local chronology (see Kuletz and Kendall 1998). To minimize the effect of high numbers of zero values, I selected surveys (from 833 total) that occurred after at least one juvenile had been observed at all sites, so that $n = 474$ transects (dataset T474). Zero values for juveniles, however, remained high. I then eliminated all transect surveys where no juvenile was observed, resulting in a sample size of 242 (dataset NOZEROS). In the final SLR models, it was necessary to drop Knight transects if SHORE was included in nested analyses, because all Knight transects where juveniles occurred had the same SHORE type, resulting in inestimable effects; for this reduced set, $n = 221$ (dataset NOKNIGHT). I returned to the T474 dataset for logistic regression (predicting presence/absence of juveniles), because it contained transects with no juveniles.

RESULTS

Correlations between variables. -- Variables that could potentially affect observability during surveys, such as sea conditions, precipitation (included in observer conditions), and glare, showed little correlation with adult or juvenile densities (Table 1). Juvenile densities were not correlated with marine features such as tidal state, SST and SECCHI, although juveniles were weakly correlated with SSS. Adults were negatively correlated with SST and SECCHI. Sea surface variables were also correlated with date.

Among stable habitat features (Table 1), EXPOSURE tended to be associated with higher Seas, Swell height, and poor observer conditions (although this did not appear to result in significant affects on murrelet densities). Deeper waters tended to be found off rocky shores, with shallow waters in the inner bays with fine grained beaches. The lower SSS and SECCHI relationship to deeper waters is likely due to the glacial runoff in some deep fjords. Juvenile densities were significantly, but not strongly, correlated to adult densities at the transect level ($r=0.33$, $P < 0.001$).

Stepwise Linear Regression

Preliminary models. -- In preliminary models, Area explained most of the variance for both juvenile and adult densities, and the contribution of other variables could not be estimated. For

juveniles, one regression that loaded 13 unnested predictor variables appeared to make a good fit ($R^2 = 0.34$, $F_{7,60} = 4.45$, $P = 0.0004$), but the only significant predictors in the final model were Area ($F = 4.36$, $P = 0.002$) and MaxDepth ($F = 7.13$, $P = 0.01$), which was correlated with Area. Similarly for adults, a preliminary regression with all variables, and not including Area, was significant ($R^2 = 0.39$, $F_{3,64} = 14.4$, $P < 0.0001$), but the primary predictor was Date ($F = 31.5$, $P < 0.0001$). Adults leave PWS at a steady rate in late summer (Kuletz and Kendall 1998), so this exodus would overshadow habitat associations. A regression that omitted Date only explained 17% of the variance, and the best predictor was SST, which was significantly correlated with date. I could not account for nesting habitat, large scale oceanographic features, or prey availability at the study sites. Because my goal was to identify physical features associated with juveniles at a finer scale, while controlling for inherent productivity of an area, regressions were subsequently nested by Area, and Date was not included.

Best-fit models. -- Even when sea surface variables (SST, SSS, SECCHI) and tide were nested by Area, the model was a poor predictor of juvenile abundance ($R^2 = 0.16$, $F = 2.7$, $P = 0.03$), and only Area was significant in the final model. Similarly, variables that might affect observability (Glare, Seas, SunRise, Weather) and tide, when nested by Area, only explained 14% of the variance, and only Area was significant in the best fit ($F = 8.83$, $P < 0.0001$). Physical features nested by Area made a stronger model ($R^2 = 0.36$, $F = 5.75$, $P < 0.0001$), and the best fit included SHORE, EXPOSURE, and DEPTH nested in Area, all of which were significant contributors (Fig. 3). Results for adult densities were similar, but with lower predictive power; using the same dataset, and nesting SHORE, EXPOSURE and DEPTH in Area, $R^2 = 0.23$, $F = 3.02$, $P < 0.0001$. For adults, however, only DEPTH ($P = 0.006$) and Area ($P < 0.0001$) were significant contributors in the final model.

Logistic Regression

The Stepwise regression identified the best predictor variables as SHORE, EXPOSURE, and DEPTH, all nested in Area. For the nested analyses, it was necessary to remove all zero values for juveniles, and where SHORE was included, the Knight observations had to be removed because all juveniles there occurred on the same SHORE type. For a more robust test of these variables as predictors of juvenile presence or absence, I used the T474 dataset (which omitted very early surveys, but retained transects with no juveniles) for a series of logistic regressions. The results for juveniles (Table 2) indicate that SHORE contributed the most deviance, and thus higher Akaike's Information Criterion (AIC) scores when added to the models. DEPTH and EXPOSURE were fairly equal in contribution to the model with lower AIC. For adults (Table 3), DEPTH contributed lower deviance than the other variables, and SHORE and EXPOSURE were more equally weighted among models.

Predictor variables relative to juveniles. -- The relationship between juveniles and DEPTH was clear from scatterplots and previous analyses, with juvenile abundance decreasing with DEPTH. Scatterplots indicated that most juveniles were in waters < 25 m deep. For SHORE and EXPOSURE, it was not intuitive what the relationship was relative to juvenile abundance, and neither variable correlated with juveniles in paired comparisons. I used a boxplot to examine average juvenile density by transect for SHORE and EXPOSURE (Fig. 4). Both

variables show outliers that could have influenced regressions, although Area effect is not accounted for in these graphs. For SHORE, juvenile density is similar for coarse/cobble beach and rocky coast, and both categories have outliers that are strongly weighted against the low variance within the fine grain beach category. For EXPOSURE, the moderately exposed coast (1-5 Km) is only slightly higher in mean juvenile density than the more exposed coasts (>5 Km), and both have several outliers.

DISCUSSION

These results indicate that it is possible to identify key habitat associations for juvenile murrelets. The positive relation between juvenile occurrence and shallow, semi-protected waters off of rocky coasts, while not previously demonstrated in a rigorous analysis, was not unexpected. Murrelet adults typically forage in relatively shallow waters (Kuletz et al. 1995, Ostrand et al. 1998). Juvenile murrelets, in particular, may require shallow, protected waters, because of their relatively small size. Juvenile murrelets fledge at 58-70% of adult mass (Nelson and Hamer 1995, Kuletz and Marks 1997), and small body size is associated with weaker diving capacity (Watanuki et al. 1995). Diving times of juvenile murrelets are shorter, and more frequent, than those of adults (Strachen et al. 1995, Kuletz et al. 1995), suggesting their dives are not as deep as those of adults.

The significant loading factors for SHORE and EXPOSURE are possibly more equivocal, since no clear pattern emerged when these variables were examined independently against the average juvenile density for each transect. Results do indicate that extremely protected waters off of fine grained beaches, such as often occurs at the heads of long fjords with tidal flats, will be least likely to attract juvenile murrelets.

None of the sea surface features (SST, SSS, SECCHI) were incorporated into final models predicting murrelet occurrence. Large-scale effects from sea surface variables have been noted for seabirds (Hunt et al. 1993, in press; Tyler et al. 1992), including murrelets (Ainley et al. 1995), but they are usually secondary to the fronts and upwelling with which changes in these variables are often associated. Fine-scale interactions, if they do occur, are more difficult to detect (Hunt et al. in press, Schneider and Piatt 1986).

Juvenile and adult murrelets did not demonstrate strong differences in habitat selection, and the weak, but significant, correlation between their numbers suggests a generally congruous preference for habitats. Adults, being more ubiquitous in the region, did not have as strong an association as juveniles to specific Shore or Exposure types. Adults, however, decline steadily in late summer, which could both mask habitat associations and reduce the correlation with juveniles at the transect scale.

Factors that could affect counts by lowering observability of the birds did not appear to be significant in this study. These factors were already partly controlled for by a survey protocol that limits surveys to reasonable conditions (Kuletz 1996). Factors that could potentially be important locally, such as weather-related effects or tidal phase (Speckman 1996) were likely minimized by covering a large total area in a variety of habitats over the course of 5 weeks.

Management Implications. -- These results suggest that in PWS, monitoring efforts could be

improved for juveniles by focusing on, or creating a sampling strata for moderately protected, rocky coasts, particularly where water averages roughly < 25 m in depth < 200 m from shore. Even in regions where large kelp beds attract juvenile marbled murrelets (Kuletz and Piatt, in press), shallow water appears to be critical for juvenile murrelets. Recent improvements in bathymetric GIS coverages could be used to *a priori* identify water depth and exposure within study areas.

Clearly, however, a key finding of this study is that undefined variables, at the scale of approximately 50 km, make Area effects strong. Murrelet densities varied significantly among these study Areas (see Kuletz and Kendall 1998). Until we can identify and measure the additional biological and physical features that influence juvenile murrelet distribution, a monitoring program should locate specific areas that are consistent 'hot spots'. Similar suggestions have been made for monitoring juveniles in Kachemak Bay, Alaska (Kuletz and Piatt, in review) and adult murrelets in British Columbia (Rodway et al. 1995) and southeast Alaska (Speckman 1996). In Kachemak Bay, juvenile murrelets were more highly clumped and in more exposed habitat than found in this study, but were associated with large kelp beds. Results reported here indicate that stratification by habitat can also be applied in areas that lack large kelp beds.

In PWS, statistical power to detect trends in juvenile murrelet abundance were highest at sites with consistently high murrelet densities (Kuletz and Kendall 1998), as it was for adult murrelets at two sites in southeast Alaska (Speckman 1996). While statistical power is desirable in monitoring population trends, trends at sites with intermediate or low numbers of murrelets should not be ignored, as they may be the first to indicate declines in a regional population (Perrins et al. 1991). Thus, the optimum approach may be to maintain coverage of both high and low density sites within a region, but monitor and analyze them as separate strata.

In PWS, Naked Island is an example of a site with consistent and high juvenile murrelet abundance. Compared to other sites in 1994 (2 sites), 1995 (6 sites), and 1997-1998 (3 sites), Naked had the highest juvenile density. Additionally, productivity has been relatively consistent from 1994-1998, ranging from 1.46-1.52 juveniles/Km², which increases power to detect significant changes. Although a selection of habitats should be included in any monitoring plan, sites similar to Naked, once identified, could form a core study population.

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Figures

- Figure 1. The six study Areas (outlined in black) in Prince William Sound, Alaska, surveyed in July and August 1995.
- Figure 2. Frequency distribution of juvenile murrelet densities (in 1/Km² intervals) for transects that had at least one juvenile present during surveys conducted in Prince William Sound, Alaska, in July and August 1995 (n = 242 transects).
- Figure 3. Plots for the residual-fit spread (top) and fitted model (bottom) for juvenile murrelet density, with Area and Area-nested variables SHORE, EXPOSURE, and DEPTH. Data included only transects with at least one juvenile. The residuals show a good spread, suggesting they explain some variation in the data, however, the variability increases with increasing fitted values. In the final fitted model ($R^2 = 0.36$, $P < 0.0001$), all variables were significant (all $P_s < .002$).
- Figure 4. Boxplots showing the median, variance and outliers for average juvenile density on transects relative to (top) SHORE and (bottom) EXPOSURE. The average juvenile density was calculated for each transect (n = 40) surveyed (7-10 times each) in July and August 1995, in Prince William Sound, Alaska. Both variables show outliers that could have influenced regressions, although Area effect is not accounted for in these graphs.

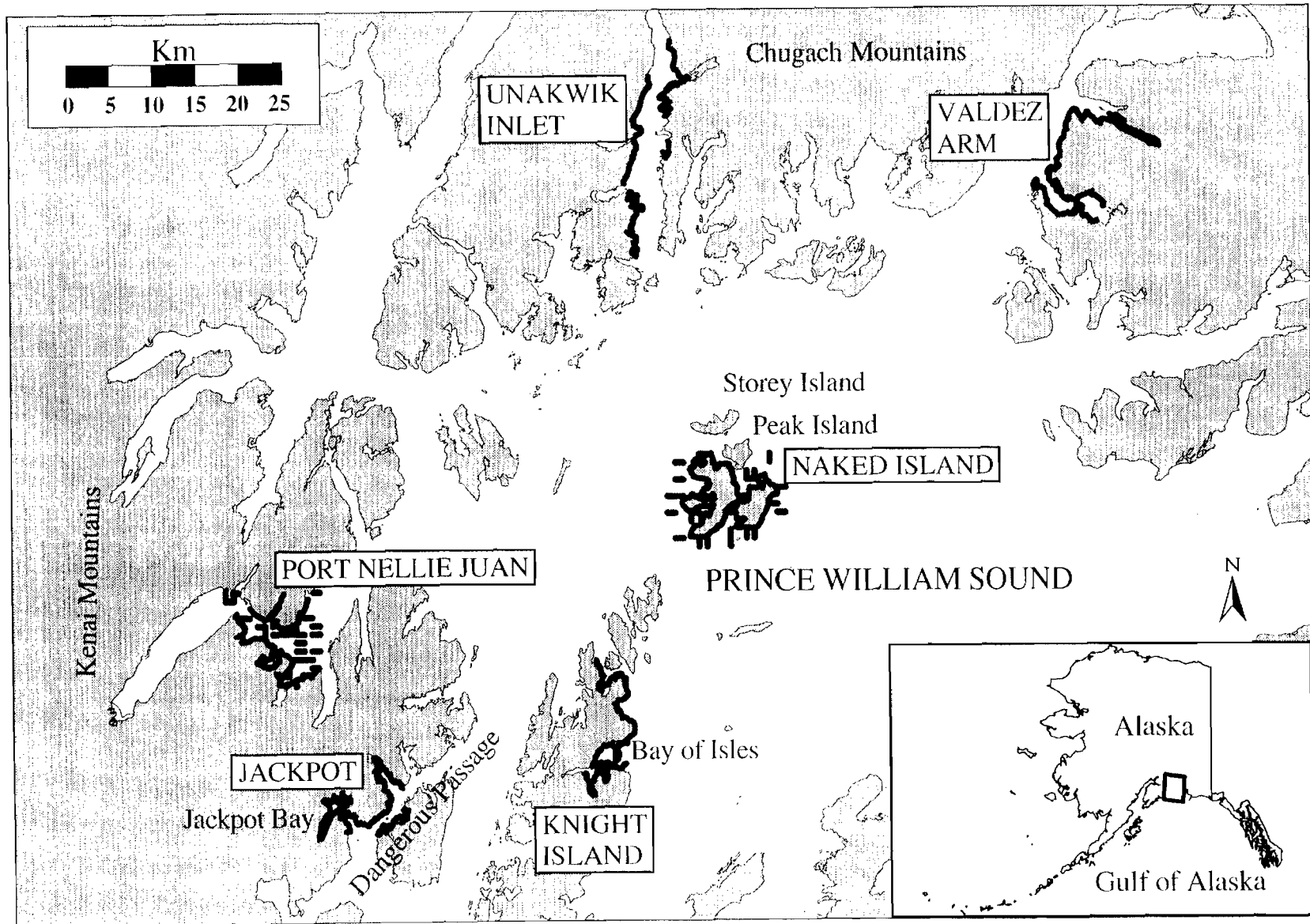


Fig 2

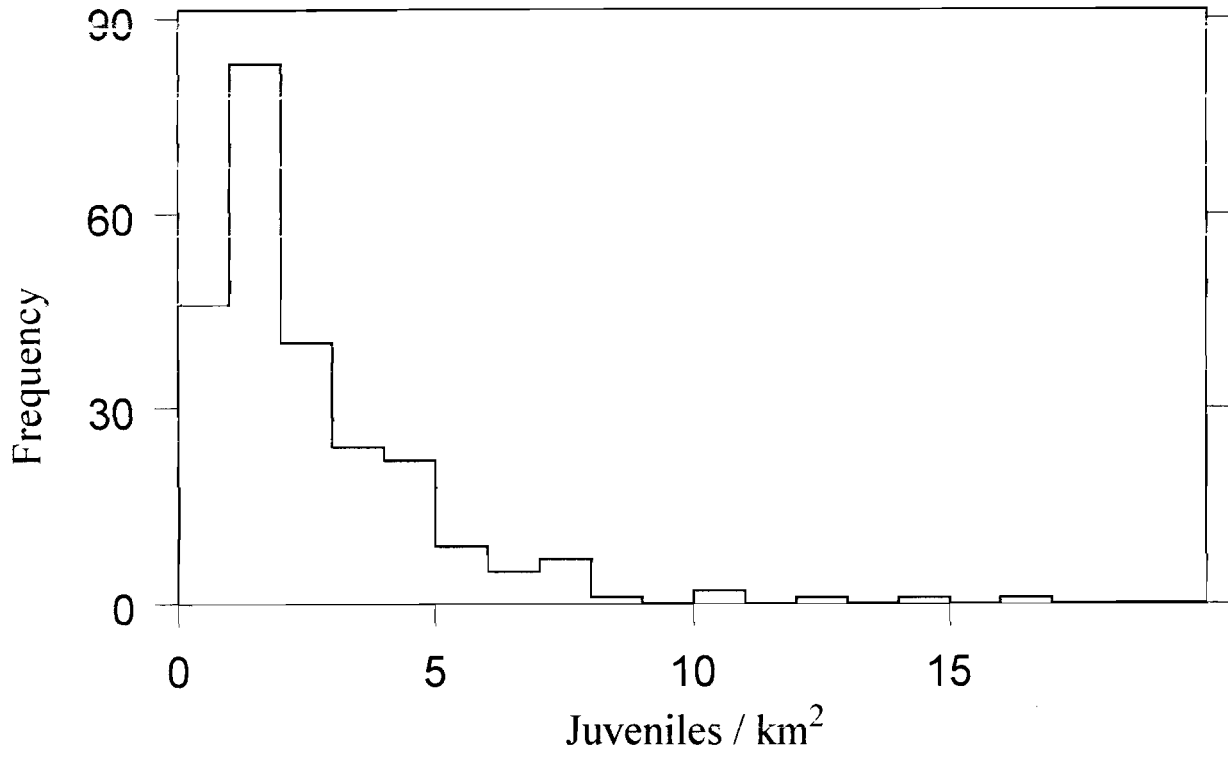


Fig 2

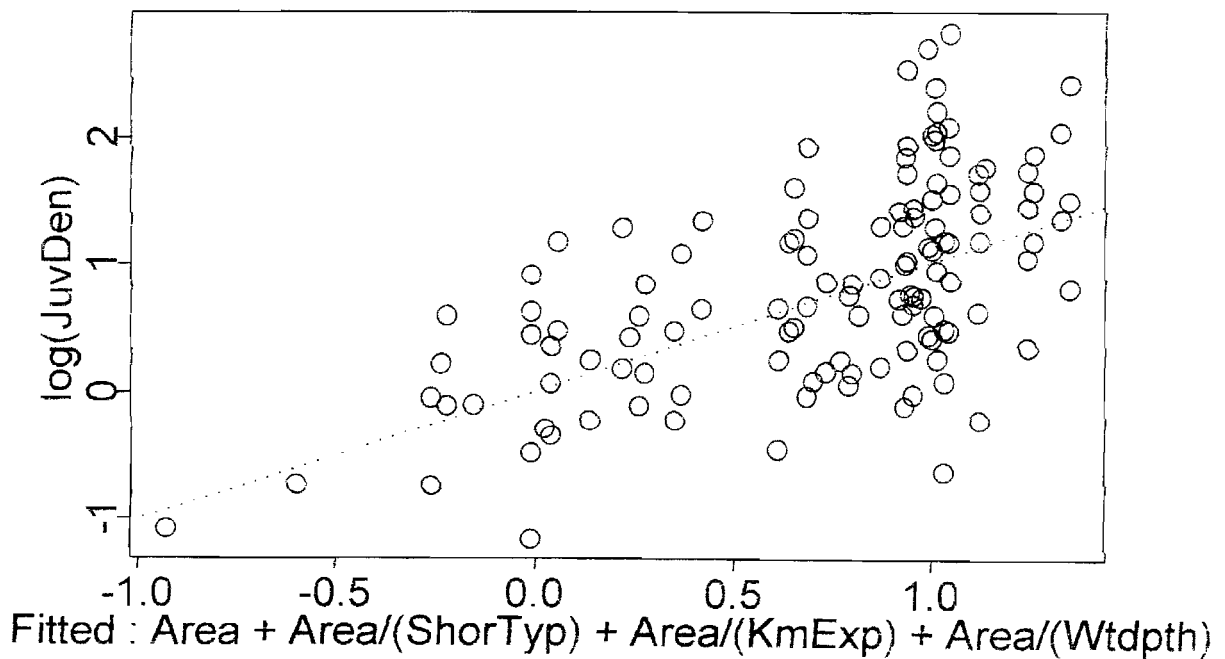
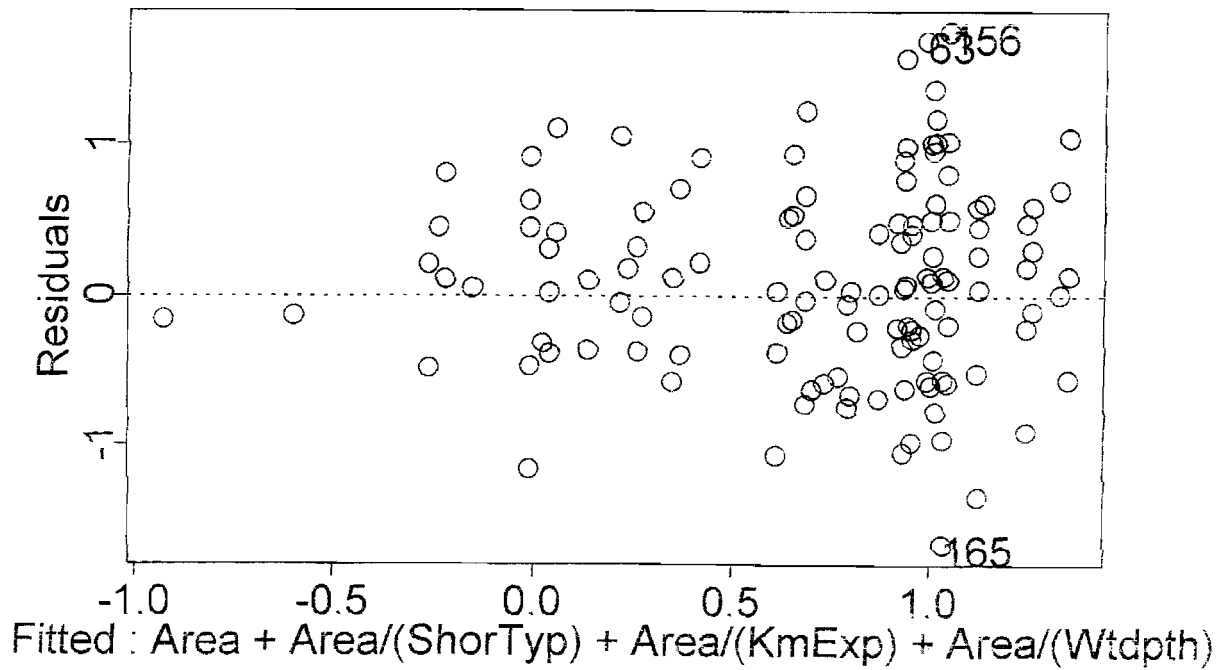


Figure 3. Plots for the residual-fit spread (top) and fitted model (bottom) for juvenile murrelet density, with Area and Area-nested variables Shore, Exposure, and Depth. Data included only transects with at least one juvenile. The residuals show a good spread, suggesting they explain some variation in the data, however, the variability increases with increasing fitted values. In the final fitted model ($R^2 = 0.36$, $P < 0.0001$), all variables were significant (all P s $< .002$).

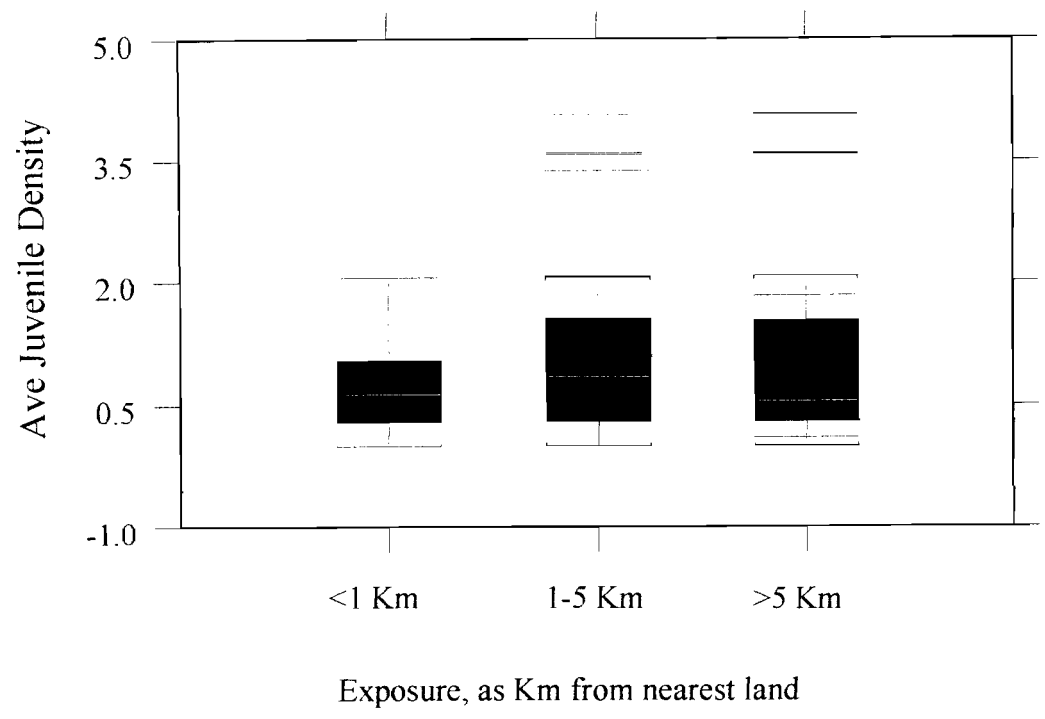
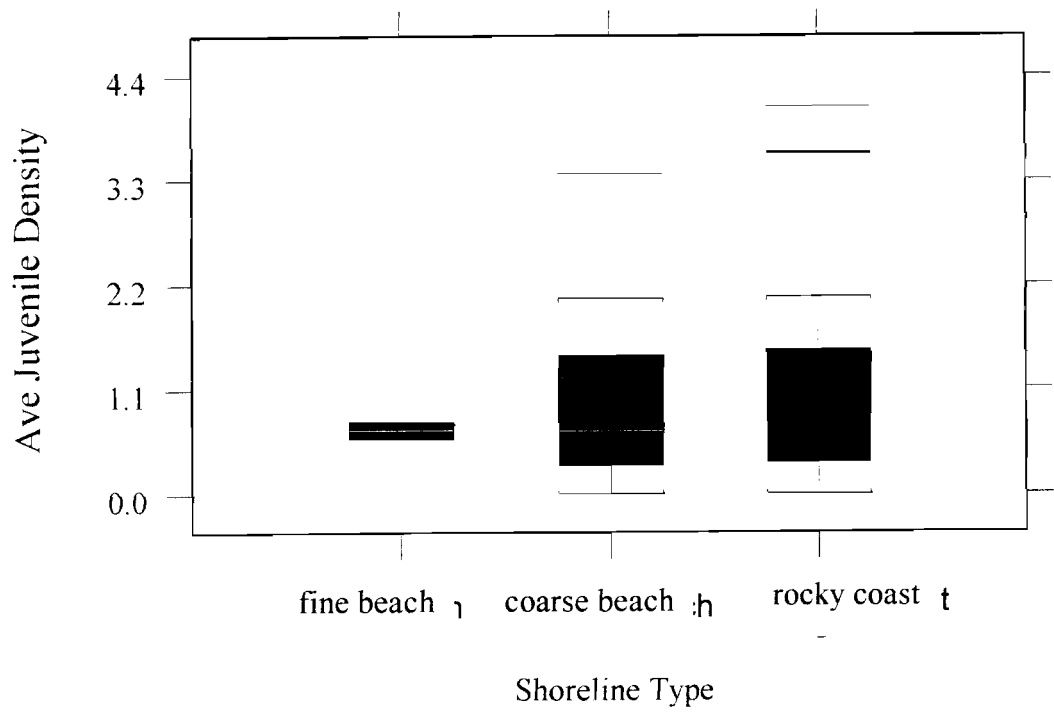


Fig. 4

Table 1. Spearman correlation coefficients for variables of 474 transect samples surveyed in Prince William Sound, Alaska, in July and August, 1995. Correlation coefficients >0.20 are highlighted. Adults = adult murrelet density, Juv = juvenile density, SST= sea surface salinity, Seas= wave conditions, Swell= swell height, xSecc=mean Secchi reading for the day, xSSS= mean sea surface salinity for the day, Cond=observer conditions, TideR= tidal range for the day, Shore= shoreline type, Expos= Exposure of coast, Depth= weighted water depth for the transect, MaxD= maximum depth for the transect. Not included in the table are variables Glare, three types of tidal phase, and hours from sunrise, since they had no significant correlations. Also not included were specific measurements of transect salinity and secchi, because they had many missing values and were highly correlated with daily averages.

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	Adults	Juv	SST	Seas	Swell	xSecc	xSSS	Cond	TideR	Shore	Expos	Depth
Adults	*											
Juv	.33	*										
SST	-.40	-.14	*									
Seas	-.02	-.04	.04	*								
Swell	-.05	-.04	.02	.54	*							
xSecc	-.40	-.19	.63	-.04	.00	*						
xSSS	-.11	.24	.14	.22	.33	.40	*					
Cond	-.04	-.06	-.00	.55	.52	-.05	.28	*				
TideR	.13	.01	.23	.12	.12	-.39	-.12	.12	*			
Shore	-.01	-.01	.09	-.04	-.15	-.00	-.28	-.16	-.00	*		
Expos	-.01	.01	-.01	.23	.32	.00	.15	.24	-.00	-.09	*	
Depth	.08	.12	-.15	-.07	-.19	-.23	-.37	-.14	.04	.21	-.02	*
MaxD	-.03	.05	-.01	-.09	-.21	-.24	-.55	-.19	.04	.42	-.14	.64

Table 2. Results of logistic regressions for predicting the presence or absence of juvenile marbled murrelets on transects surveyed in July and August, 1995, in Prince William Sound, Alaska. A general linear model was used, specifying a binomial distribution. Variables were added sequentially and start order rotated to test for analysis of deviance between models.

Fit	Terms	Resid. Df	Resid. Dev	Test	Df	Deviance	AIC	dif f in AIC
1	Area/(ShorTyp)	446	564.5801					
2	Area/(ShorTyp + KmExp)	440	550.1831	+KmExp %in% Area	6	14.39704	26.39	
3	Area/(ShorTyp + KmExp + Wtdpth)	434	543.1976	+Wtdpth %in% Area	6	6.98548	18.99	07.4
1	Area/(KmExp)	462	581.9756					
2	Area/(KmExp + ShorTyp)	440	550.1831	+ShorTyp %in% Area	22	31.79254	75.79	
3	Area/(KmExp + ShorTyp + Wtdpth)	434	543.1976	+Wtdpth %in% Area	6	6.98548	18.99	56.8
1	Area/(Wtdpth)	462	588.7912					
2	Area/(Wtdpth + ShorTyp)	440	558.6612	+ShorTyp %in% Area	22	30.13005	74.13	
3	Area/(Wtdpth + ShorTyp + KmExp)	434	543.1976	+KmExp %in% Area	6	15.46363	27.46	46.67
1	Area/(KmExp)	462	581.9756					
2	Area/(KmExp + Wtdpth)	456	575.0406	+Wtdpth %in% Area	6	6.93498	18.93	
3	Area/(KmExp + Wtdpth + ShorTyp)	434	543.1976	+ShorTyp %in% Area	22	31.84304	75.81	56.91

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Table 3. Results of logistic regressions for predicting the presence or absence of adult marbled murrelets on transects surveyed in July and August, 1995, in Prince William Sound, Alaska. A general linear model was used, specifying a binomial distribution. Variables were added sequentially and start order rotated to test for analysis of deviance between models.

Fit	Terms	Resid. Df	Resid. Dev	Test	Df	Deviance	AIC	diff in AIC	P
1	Area/(ShorTyp)	446	263.1860						
2	Area/(ShorTyp + KmExp)	440	253.4314	+KmExp %in% Area	6	9.75460	21.75		
3	Area/(ShorTyp + KmExp + Wtdpth)	434	242.9685	+Wtdpth %in% Area	6	10.46288	22.46	0.71	
1	Area/(KmExp)	462	270.4671						
2	Area/(KmExp + ShorTyp)	440	253.4314	+ShorTyp %in% Area	22	17.03575	61.04		
3	Area/(KmExp + ShorTyp + Wtdpth)	434	242.9685	+Wtdpth %in% Area	6	10.46288	22.46	38.58	
1	Area/(Wtdpth)	462	273.8960						
2	Area/(Wtdpth + ShorTyp)	440	257.4342	+ShorTyp %in% Area	22	16.46185	60.46		
3	Area/(Wtdpth + ShorTyp + KmExp)	434	242.9685	+KmExp %in% Area	6	14.46567	26.47	33.99	
1	Area/(KmExp)	462	270.4671						
2	Area/(KmExp + Wtdpth)	456	268.5295	+Wtdpth %in% Area	6	1.93767	13.94		
3	Area/(KmExp + Wtdpth + ShorTyp)	434	242.9685	+ShorTyp %in% Area	22	25.56096	69.56	55.62	