Exxon Valdez Oil Spill
Restoration Project Annual Report

Seabird/Forage Fish Interactions Component
APEX

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.

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April 1998

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APEX

Restoration Project Component 97163B
Annual Report

Study History: This is an ongoing study which began with a pilot effort in 1994 to test field methods. In 1995, the study was expanded to look at seabird foraging in several habitats in 3 study sites within Prince William Sound. Data collected in 1994 and 1995 indicated that seabird activity was concentrated in shallow water nearshore. In response to these findings, data collection in 1996 and 1997 was focused on nearshore habitats. In 1997 efforts were directed towards habitat selection by birds and fish, and to contributing to mass balance modeling of Prince William Sound.

Abstract:
We sought to develop statistical models that would describe habitat selection by birds and fish within the near shore margin of Prince William Sound, Alaska (PWS). We also investigated the utility of bottom typing hydroacoustic software in determining Pacific Sand Lance (*Ammodytes hexapterus*) habitat. Lastly, we contributed to mass balance modeling of the PWS food web, a project sponsored *Exxon Valdez* Oil Spill Trustee Council. Marbled Murrelets (*Brachyramphus marmoratus*), seabirds collectively, and forage fish were associated with shallow water, near shore in 1997 but not in 1998. We viewed this as a natural experiment that allowed us to examine the mechanism of habitat selection by birds. We suggested that murrelets and seabirds foraged where there was the greatest probability of locating suitable prey. Our preliminary investigations of bottom typing software determined substrates associated with sand lance were significantly different from locations selected randomly. Bottom typing from hydroacoustic data is preliminary and will require ground truthing prior to PWS wide analysis. Preliminary calculations of total seabird biomass and food consumption were made for the mass balance modeling project.

Key Words: *Ammodytes*, *Brachyramphus*, *Clupea*, forage fish, foraging, habitat selection, marbled murrelets, Prince William Sound, seabirds.

Project Data: (will be addressed in the final report)

Citation: Ostrand, W. D. and L. A. Joyal. 1998. Seabird/forage fish interactions. Appendix B *in* D. C. Duffy, compiler. APEX Project: Alaska Predator Ecosystem Experiment in Prince William Sound and the Gulf of Alaska. *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 97163), Alaska Natural Heritage Program and Department of biology, University of Alaska Anchorage, Anchorage, Alaska.

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INTRODUCTION

This report for component 97163B is composed of 3 chapters that represent work in progress. Chapter one is a draft manuscript that will be revised upon receiving final data from component 97163A and then submitted for review. Chapter two presents preliminary work on the use of hydroacoustic bottom typing software to identify potential Pacific Sand Lance (*Ammondytes hexapterus*) habitat. If funding is made available in 1998, this project will be continued and expanded. Chapter 3 is a draft "mini" manuscript that was written for a mass balance modeling project sponsored by the *Exxon Valdez* Oil Spill Trustees. This document will be further revised and will ultimately be a component of the mass balance model.

15 March 1998
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MURRELET AND SEABIRD FORAGING HABITAT IN PRINCE WILLIAM SOUND, ALASKA

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RH: Murrelet and seabird foraging habitat

Abstract: APEX has been examining the relationship between seabirds and forage fish since 1994. These studies have consistently found a relationship between bird distribution and depth. We have suggested that this association is due to seabirds selecting habitats where the probability of encountering prey is the greatest. Here we report on studies conducted in 1996 and 1997 in nearshore habitats of Prince Willam Sound, Alaska (PWS). The distribution of forage fish changed in 1997 generating a natural experiment that allowed us to examine factors influencing foraging habitat selection by murrelets and piscivorous seabirds collectively. We determined that forage fish, murrelet, and seabird distribution was associated with depth in 1996 and but not in 1997 and each of these groupings was associated with deeper water in 1997. These findings support our speculation on the mechanism of foraging habitat selection and indicate that murrelets and seabirds of PWS are not limited to shallow foraging habitat.

Key words: Brachyramphus marmoratus, *foraging*, *Marbled Murrelets*, *Prince William Sound, Alaska*.

Previous studies have linked the foraging activities of seabirds to habitats of quantifiable physical character where preferred food resources are consistently available (Bran and Gaskin 1982, Cairns and Schneider 1990). Similarly, within PWS, murrelets (Kuletz et al. 1994), seabirds (inclusive of all piscivorous species present in PWS) (Ostrand and Flint 1995, Ostrand and Maniscalco 1996), and feeding flocks (Maniscalco 1997) were associated with the same distinctive habitat, shallow depths near shore. Additionally, Ostrand et al. (1998) observed that fish schools associated with Marbled Murrelets (*Brachyramphus marmoratus*) were smaller, denser, and in shallower water then those available. They speculated that murrelets selected shallow, habitats and then searched within them for suitable prey. Hunt (1988) has observed that seabirds do not have complete knowledge of the distribution and abundance of prey and are able only to locate general areas of improved foraging potential. Hence, in PWS shallow depths should be associated with the greatest probability of encountering prey. Therefore, we expect that if the distribution of prey changed, murrelets and seabirds would response by changing their habitat preference.

Here we report on a study of the distribution of both Marbled Murrelets (*Brachyramphus marmoratus*), collective piscivorous seabirds, and schooling forage fish in PWS. Murrelets are the most abundant species within PWS and provided the largest samples for examining foraging behavior of an individual species. Previous studies have determined that the distribution of collective piscivorous seabirds have followed consistent patterns within PWS (Ostrand and Flint 1995, Ostrand and Maniscalco 1996); therefore, we included this grouping in our analysis. During the course of the study we observed a shift in forage fish distribution which provided us with a natural experiment that allowed us to examine the association among predator, prey, and habitat.

METHODS

DATA COLLECTION

We conducted this study in PWS, an embayment of about 10,000 km^2, located on the southern coast of Alaska. The climate is maritime with a mean annual precipitation of 1.6 m and moderate temperatures for the subarctic. The coastline of PWS is rugged, with mountains up to 4-km in elevation and numerous fjords and tidewater glaciers. Nearshore bathymetry is characterized by both shallow water shelves and steeply sloping bottoms. Three study sites were selected for sampling: (1) the northern study area, which included Valdez Arm and Port Valdez, (2) the central study area, which included waters near Naked and Knight Islands, and (3) the southern study area, which included Icy and Jackpot Bays. In a study conducted in conjunction with ours, Haldorson et al. (1997) determined that during our study the water structure was consistently stratified, with synchronous thermo- and pycnoclines, throughout our three study areas and speculated that it was due to freshwater input from rainfall and glacier melt.

We collected hydroacoustic and bird-location data simultaneously while traveling systematically arranged transects (Anderson et al. 1979, Litvaitis et al. 1994). We used the F/V *Miss Kaylee*, to conduct hydroacoustic/bird transect during 15-27 July 1996 and 17-27 July 1997. Study blocks were located systematically within three major study areas within PWS (Fig. 1).

Blocks followed the contour of 12 km of shoreline with a width of 1 km. We laid out 26, 8, and 21 contiguous blocks in the northern, central, and southern study areas, respectively. In the northern and southern study areas alternate blocks and one additional randomly selected block were deleted from the sample group. Following removals, 9 blocks remained in the North and 8 in both the Central and South. After the 1996 field season, computer files for blocks 5 and 6 of the central area were damaged and rendered unavailable, hence these data were not analyzed. In 1997 two blocks were added along the Northwest shore of Montague Island. Within each block, 20 continuous, 1.2 km transects were laid out in a zig-zag pattern (Fig. 1 - 7). The nearshore apexes of transects were located as close to shore as possible, cognizant of safety concerns for the survey vessel.

In 1996 we collected hydroacoustic data with a 130 kHz BioSonics DT6000 system with a 6° beam angle. Returns were processed as single beam data. This system failed on the final day of surveying and data for blocks 1, 3, 5, and 1/2 of 7 in the northern study area were collected with a 120 kHz BioSonics model 101 Scientific Echosounder and signal processing was accomplished with a BioSonics Model 221 ESP Echo Integrator. During 1997 we collected hydroacoustic data with a single beam 120 kHz BioSonics DT4000 system with a 6° beam angle. Transects were run at 6 knots with the transducer towed beside the vessel. The effective range of the equipment was 117 m from the transducer. Data obtained from a "military" Rockwell Global Positioning System (GPS) were written to each record.

Selected acoustic targets found by the hydroacoustic survey were sampled from a separate vessel, the F/V *Pagan*, during both surveys. Sampling was conducted using a 200 m long by 20 m deep with 25 mm stretched mesh, purse seine; dip nets; cast nets; or underwater video. We selected schools for sampling which had the greatest uncertainty regarding species and/or age-class composition.

DATA ANALYSIS

We determined biomass estimates by scaling acoustic data based on the length distributions of the dominant fish species collected in each study area. We collected data using a default target strength of -42.2 dB. Estimates of the number of individual fish m^{-3} were determined by the following equations that related acoustic target strength to fish length:

herring TS = 20 log10 L - 68 (Thorne et al. 1983)
pollock TS = 20 log10 L - 66 (MacLennan and Simmonds 1992)
rockfish TS = 20 log10 L - 67.1 (MacLennan and Simmonds 1995)

where TS is the calculated target strength in dB and L is the length of the fish in cm. Target strength length relationships for were not available for salmon sharks and sandlance at 120 kHz; therefore, we used the default target strength for these species. The estimates of fish densities were converted to biomass ($gm*m^{-3}$) using the following length-weight relationships for the dominant species, where W = weight in grams and L = length in mm:

herring	$W = (5.007 \times 10^{-6})\, L^{3.196}$
pollock	$W = (1.890 \times 10^{-6})\, L^{3.272}$
rockfish	$W = (7.500 \times 10^{-3})\, L^{3.200}$

The above regressions were determined from catch data except where noted. Biomass per cubic meter estimates were converted to biomass per square meter of surface by integrating the results over the depth of the sampled water column. We estimated the biomass for each nearshore block by calculating the mean for each block's individual transects separately and then determined an overall estimate by averaging the transect values.

Average depths for blocks were determined from hydroacoustic data. We averaged depth soundings obtained from each ping within each transect and then determined an overall estimate by averaging the transect values within each block. Depth values were determined for each block both years to account for possible differences in the execution of the surveys.

We used linear regression to determine the relationship between Marbled Murrelets abundance and fish biomass, seabird abundance and fish biomass, Marbled Murrelets abundance and depth, seabird abundance and depth, and fish biomass and depth (Zar 1984). Dependent variables were ln-transformed to improve normality. We compared Marbled Murrelet abundance, Seabird abundance, and fish biomass between years, using blocks as the sample unit, with chi-square, goodness of fit tests (Zar 1984). We applied two-tailed *t*-test of paired samples to make between year comparisons of means of per transect, using blocks as the comparison unit, for murrelets numbers, seabird numbers, and fish biomass (Zar 1984). Only blocks sampled in both years were included in both chi-square and *t*-test comparisons.

To determine if forage fish distribution changed relative to depth between years we first subtracted the mean biomass value for each block sampled in 1996 from the corresponding 1997 value. Then, linear regression was conducted with biomass differences as the dependent and 97 depth values as the independent variables. Significant positive slope indicated that fish were at greater depth in 1997 than 1996 and a negative slope indicate that they were at shallower depth in 1997.

To determine if murrelets and seabirds were located over water of greater or lesser depth in 1997 compared to 1996, we assigned each bird observation the mean depth of the block in which it was observed. Bird depths were then compared between years using a two-tailed *z*-test. We considered $P \leq 0.05$ to indicate statistical significance for all tests.

RESULTS

Depth was a significant predictor of fish biomass ($r^2 = 0.38$, $P = 0.002$), murrelets ($r^2 = 0.25$, $P = 0.02$), and collective seabird numbers ($r^2 = 0.37$, $P = 0.01$) for 1996 data (Fig. 8). These same depth relationships were not significant for 1997 ($r^2 = 0.03$, $P = 0.43$; $r^2 = 0.04$, $P = 0.32$; and $r^2 = 0.07$, $P = 0.19$, respectively). We did not detect a significant relationship between fish biomass and the number of murrelets or collective seabirds for either 1996 or 1997. The distribution of murrelets, seabirds, and fish biomass differed significantly between years, ($\chi^2_{21} = 1107.8$, $\chi^2_{21} = 2366.1$, $\chi^2_{21} = 62.1$, respectively; $P = 0.001$ for all tests). More murrelets and seabirds, and less fish biomass were observed in 1997 than 1996 (Table 1); however these differences were not significant ($t_{21} = -1.02$, $P = 0.32$; $t_{21} = -1.13$, $P = 0.27$; $t_{21} = -1.90$, $P = 0.07$; respectively).

In 1997 more fish were found in deeper blocks compared to 1996 ($r^2 = 0.42$, $P = 0.002$). Both murrelets and seabirds were observed over water of greater depth in 1997 than 1996 ($\bar{x}$ 1996 = 51.3m n = 1294, $\bar{x}$ 1997 = 60.9m n = 2177, $z = 11.3$, $P < 0.001$ and $\bar{x}$ 1996 = 50.1m n = 1925, $\bar{x}$ 1997 = 63.9m n = 4298, $z = 20.7$, $P < 0.001$ for murrelets and seabirds respectively).

Forage fish data for nearshore blocks have not been finalized, therefore results presented that include biomass should be considered preliminary.

DISCUSSION

The distribution of Marbled Murrelets, seabirds, and forage fish was related to nearshore depth in 1996; however, these relationships were not apparent in 1997 when all groupings were associated with water of greater depth. The distribution of both birds and forage also differed among years. In neither year was there a relationship between forage fish biomass and murrelet or seabird abundance.

Previous studies that have found a scale dependent relationship between the distribution of seabirds and forage fish (Hunt 1990). Our results suggest that we may have examined the inappropriate scale to identify a relationship between these trophic levels.

Worldwide, seabirds adapt different tactics to sample their environment in order to locate prey (Hunt et al. 1991). Our results suggest that murrelets and seabirds of PWS may have changed their foraging strategy in response to a change in the distribution of prey. In 1996 forage was more abundant in shallow water and murrelets and seabirds increased their probability of encountering prey by searching in shallow water habitats. In 1997 the forage fish were in water of greater depth and murrelets and seabirds responded to the shift by altering their foraging pattern. These findings further suggest that murrelets and seabirds of PWS are not limited to a particular habitat but are capable of altering foraging patterns to respond to environmental change. Our findings support our proposal that seabirds of PWS select foraging habitat associated with the highest probability of encountering prey.

Because previous studies conducted within PWS on murrelets (Kuletz et al. 1994, Ostrand et al. 1998) seabirds (Ostrand and Flint 1995, Ostrand and Maniscalco 1996) and feeding flocks (Maniscalco 1997) determined that these groups selected shallower depths in comparison to availability, we considered 1997 to be anomalous and the causes of the change merited speculation. We observed two possible environmental changes that occurred during 1997 that may have altered the distribution of forage fish: (1) An increase in sea temperatures at shallow depths (observed by component APEX 97163A) may have resulted in unsuitable conditions for either fish or their prey in shallow habitats and they responded by seeking cooler water. Direct evidence of the affect of temperature change on fish distribution is not yet available from PWS; however, Maravelias and Reid (1995) observed an indirect relationship between temperature, salinity and the distribution of herring. (2) Poor recruitment of age 1+ of Pacific herring (*Clupea harengus*) resulted in a shift in the age structure of herring population (pers. comm. Evelyn Brown, Univ. of Alaska). Further evidence of an age class failure was indicated by near absence of 1+ herring in Black-legged Kittiwake (Rissa tridactyla) chick diets (observed by APEX component 97163E) which had been a major food item in previous years. Previously 1+ herring had been a major component of the nearshore fish biomass (Haldorson et al. 1997) and their absence may have resulted in the observed fish distribution. Further explanation of the distribution of forage fish is beyond the scope of this component and will be reviewed in greater detail by study 95320T.

ACKNOWLEDGMENTS

This research was supported by the *Exxon Valdez* Oil Spill Trustee Council. However, the findings and conclusions presented are ours and do not necessarily reflect the views or position of the Trustee Council. We thank individuals who provided assistance throughout this study. The F/V *Miss Kaylee* and F/V *Pagan* served as a platforms for sampling and we are grateful to the captains and crews for their assistance. J. Kern and L. McDonald of Western EcoSystems Technology, Inc. provided advice and assistance with statistical analysis. L. Haldorson and T. Shirley directed research cruise activities including net sampling. J. M Maniscalco assisted in data collection in 1996. G. S. Drew provided advise with GIS and editorial comment.

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Table 1. Summary statistics on bird observations and forage fish biomass obtained during surveys conducted in Prince William Sound, Alaska in July of 1996 and 1997.

	1996 Mean ± SE (*n* = 22)	Minimum value	Maximum value	1997 Mean ± SE (*n* = 27)	Minimum value	Maximum value
murrelets[a]	3.0 ± 0.8	0.1	12.4	4.0 ± 0.8	0.1	11.8
seabirds[a]	4.7 ± 1.1	0.2	17.6	8.3 ± 2.7	0.1	74.0
forage fish biomass[b]	3.3 ± 1.4	0.01	28.0	0.9 ± 0.4[c]	0.01	7.9

[a]Mean of mean of number of birds observed transect^{-1} (n = 20) within 1 x 12 m nearshore blocks. Blocks are the sample unit.
[b]Mean of mean biomass (gm m^{-2}) determined transect^{-1} (n = 20) within 1 x 12 m nearshore blocks. Blocks are the sample unit.
[c]n = 25.

FIGURES 1-7. The locations of near shore study blocks sampled in hydroacoustic and seabird surveys in Prince William Sound, Alaska during July 1996 and 1997. 1996 Data from block C4 and C5 was not available for analysis. Blocks M1 and M2, the Montague study area, were added to the survey in 1997.

FIGURE 8. Scatter diagrams showing the 1996 relationships between depth and forage fish biomass, murrelet abundance, and the abundance of seabirds on the water.

Sand Lance in Relation to Bottom Type in Prince William Sound, Alaska.

Joyal, L. A., and W. Ostrand. Migratory Bird Management, U.S. Fish and Wildlife Service, Anchorage, AK.

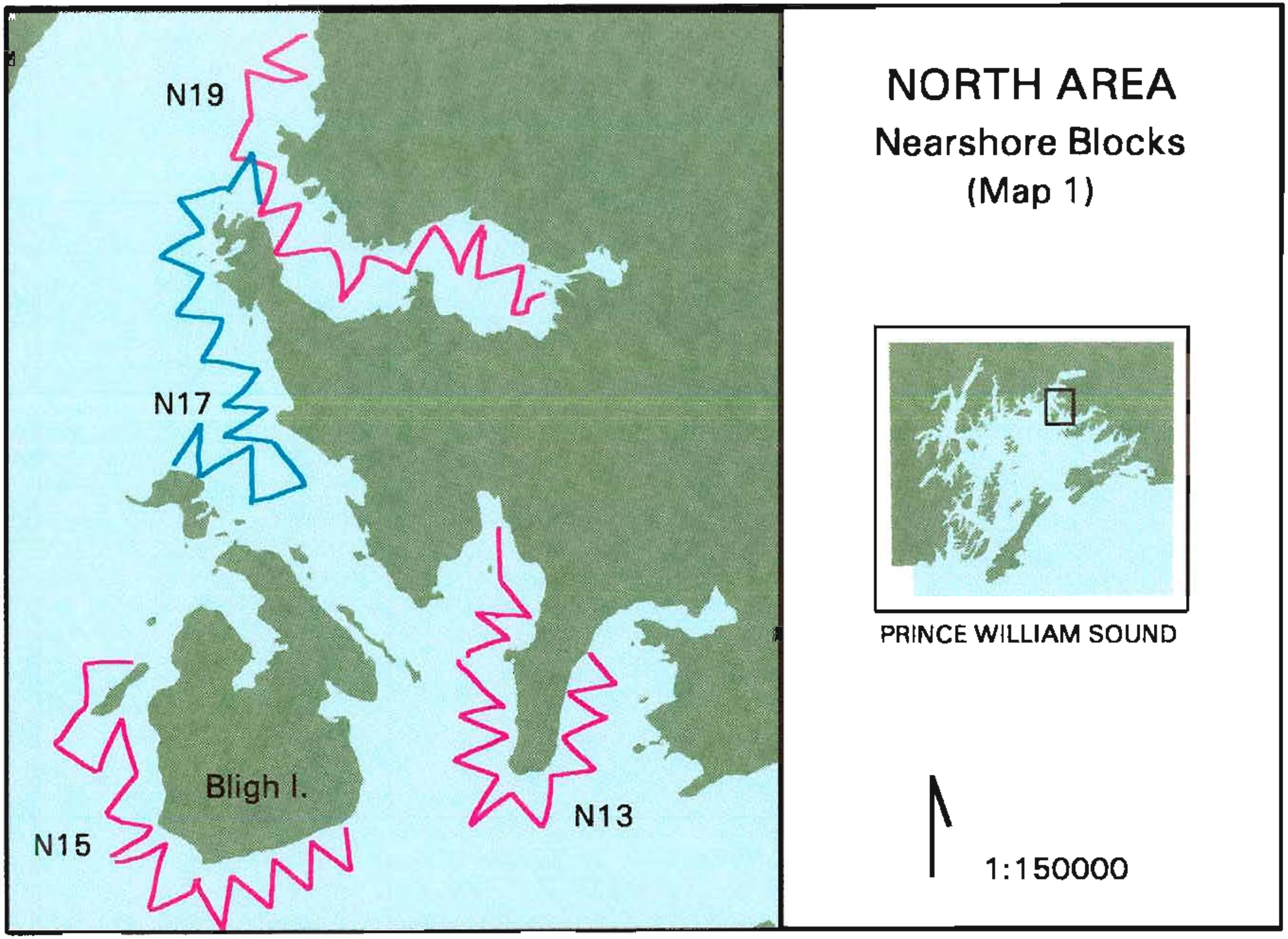
Pacific Sand Lance (*Ammodytes hexapterus*) plays an important ecological role as prey for marine mammals and seabirds in Prince William Sound, Alaska (PWS) (Kuletz et al. 1997). However, because of a lack of commercial interest in the United States, the biology and habitat requirements of this species are poorly known (McGurk and Warburton 1992). Sand lance are commonly found in shallow nearshore habitats where they feed in the water column during the day and burrow into sand or gravel substrates at night (Wilimovsky et al. 1988). Sand lance also deposit their eggs on sand and fine gravel (McGurk and Warburton 1992).

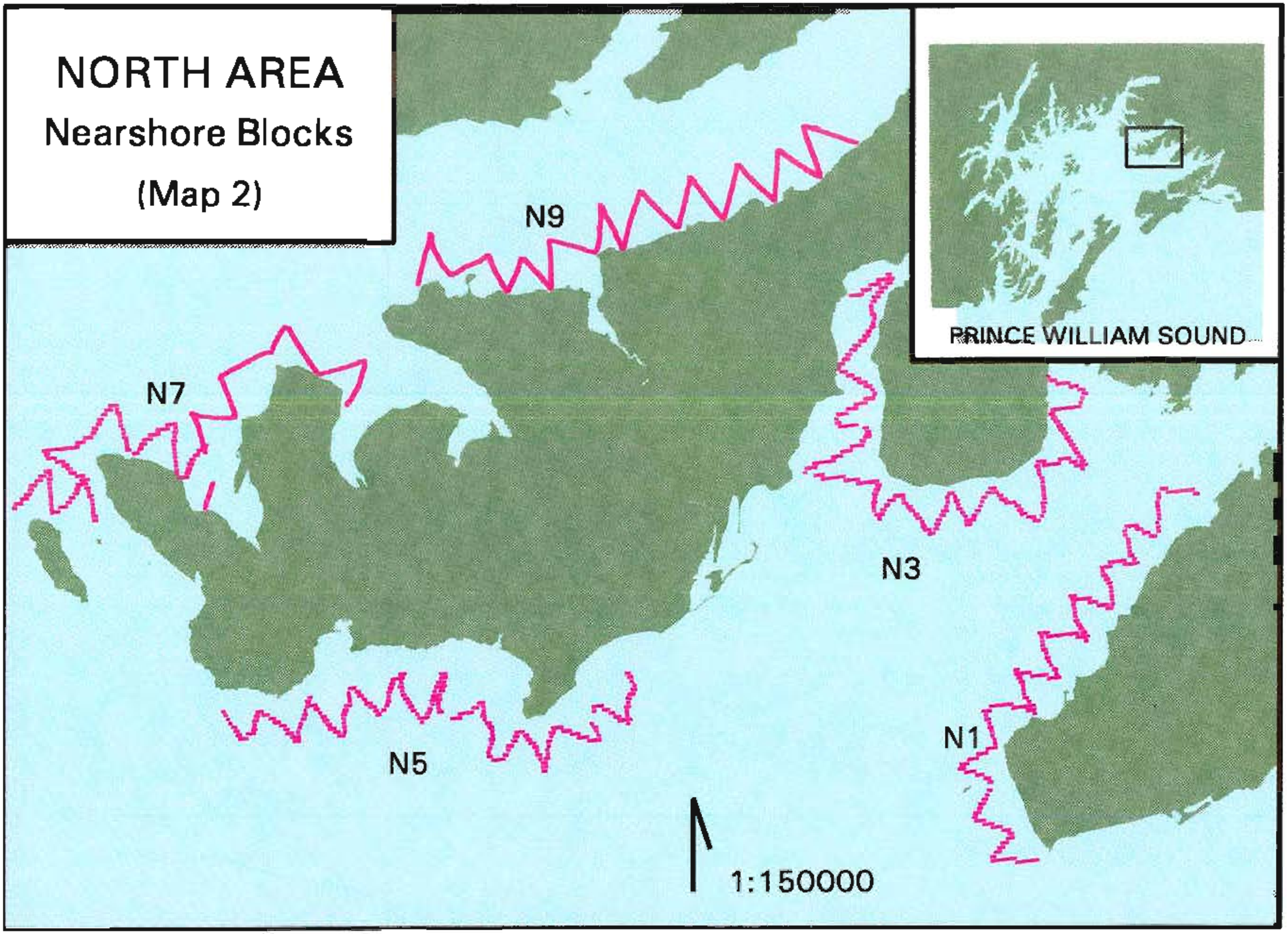
Hydroacoustic data are often collected during fisheries studies and these data are now being used not only to locate fish and estimate fish biomass, but also to characterize bottom types (Visual Bottom Typer, BioSonics, Inc.). The purpose of this study was to determine if Visual Bottom Typer software could differentiate substrates in PWS and, if so, to investigate the relationship between bottom type and sand lance locations.

During late July 1997 (in collaboration with the School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, project 97163A), we hydroacoustically sampled 545 nearshore transects in PWS. Each transect was approximately 1 km in length. A subset of the fish schools located hydroacoustically were physically sampled and identified to species. We also incorporated sand lance school locations that were made by other APEX components ($n = 72$). Of these locations, 32 also had associated hydroacoustic data. We also selected 21 random locations along the hydroacoustic transects and entered all locations into a geographic information system (GIS).

Each hydroacoustic transect was partitioned into 50 ping segments. We used the Visual Bottom Typer software to characterize the bottom of each segment. Using the First Echo Division (Visual Bottom Typer Manual, BioSonics, Inc.), the bottom was classified into one of three categories (soft mud, soft sand, or sand) based on differing ratios of bottom hardness to bottom roughness. Bottom types that did not fall into one of the three categories were designated as "unknown". Using GIS we determined the distance from the center of each segment to the nearest sand lance location and the nearest random location. We used a Log-likelihood Ratio analysis to test for differences in bottom types between segments within 500 m of a sand lance location and segments within 500 m of a random location. We then repeated the analysis using 1000 m instead of 500 m.

The proportion of segments in each bottom type differed significantly between segments associated with sand lance locations and segments associated with random locations (G test: $P < 0.005$ for 1000 m, $P < 0.001$ for 500 m; Fig. 1). Segments associated with sand lance were more likely to be classified as soft sand and less likely to classified as mud than expected.


NORTH AREA
Nearshore Blocks
(Map 1)
N19
N17
N15
N13
Bligh I.
PRINCE WILLIAM SOUND
1:150000

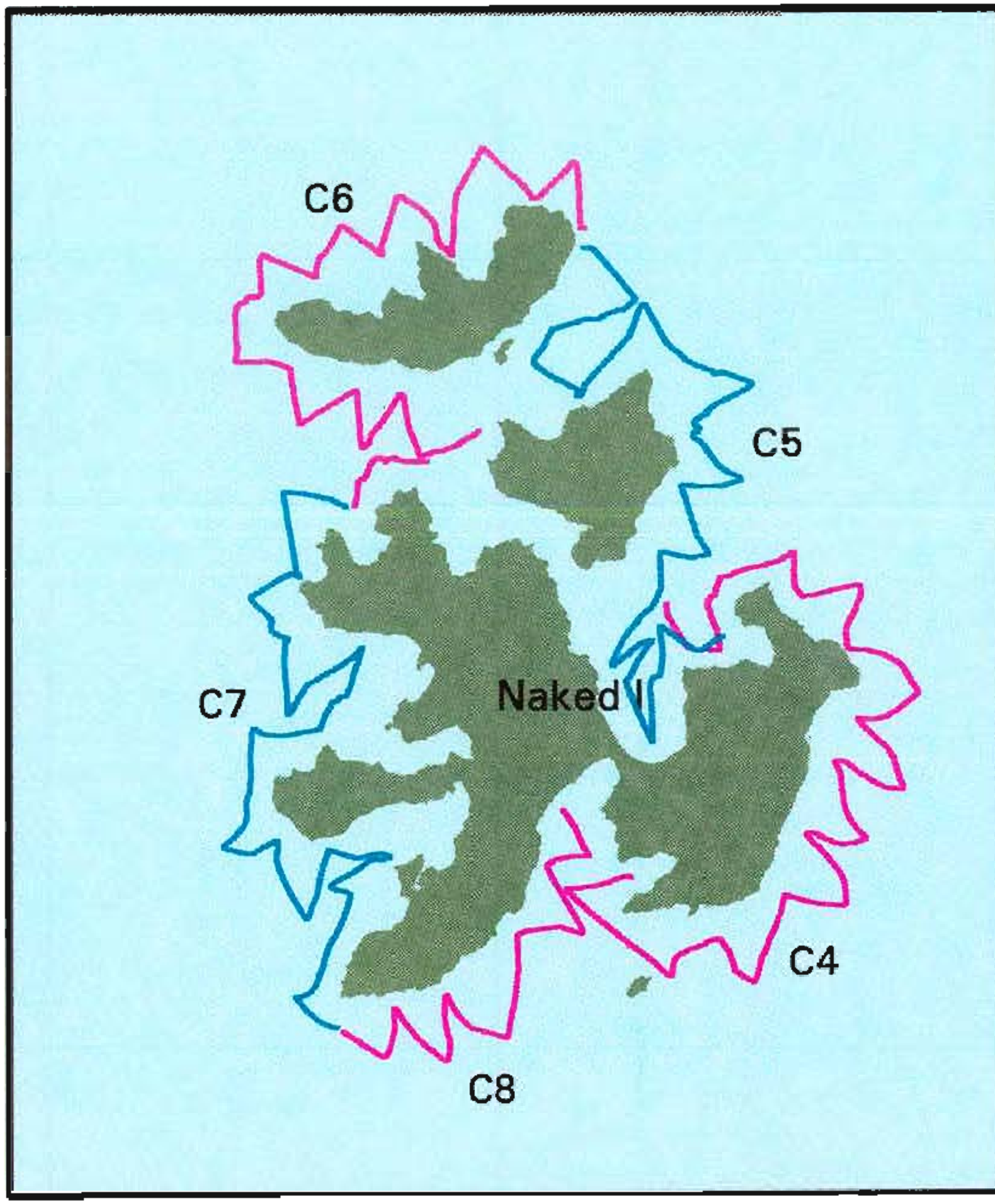

NORTH AREA
Nearshore Blocks
(Map 2)
PRINCE WILLIAM SOUND
N9
N7
N5
N3
N1
1:150000

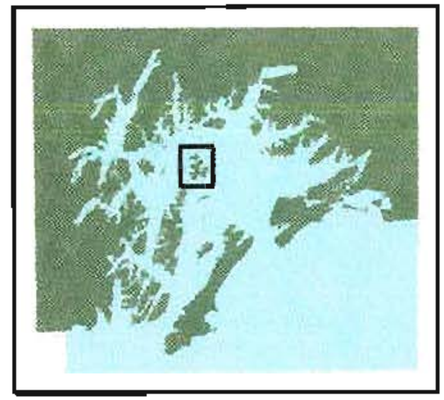
CENTRAL AREA

Nearshore Blocks

1997 Routes

(Map 1)





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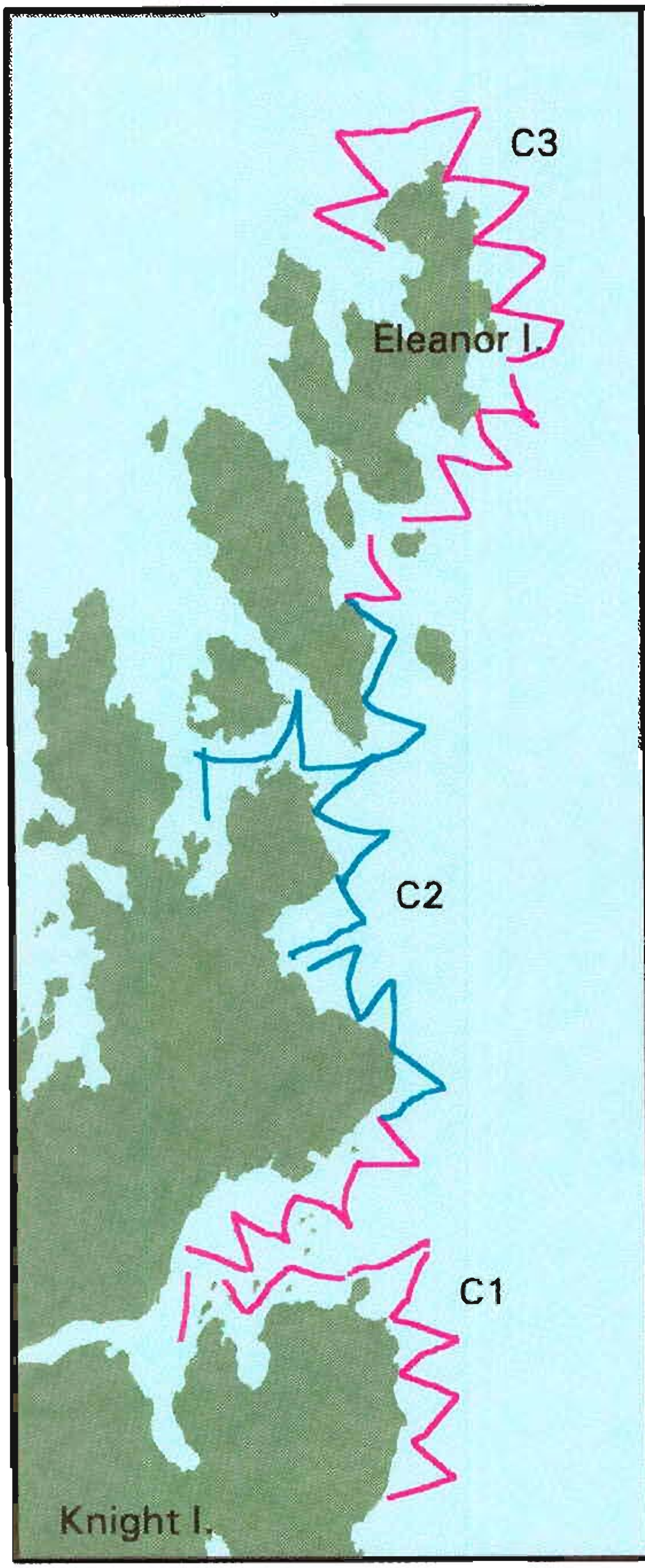
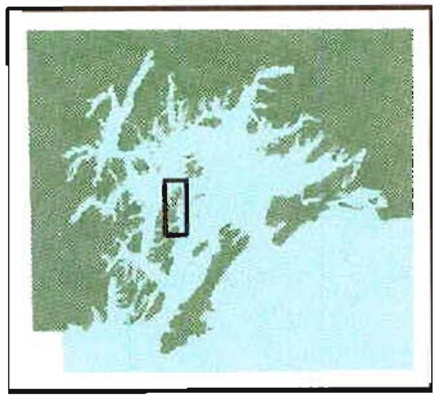


CENTRAL AREA

Nearshore Blocks

(Map 2)



PRINCE WILLIAM SOUND

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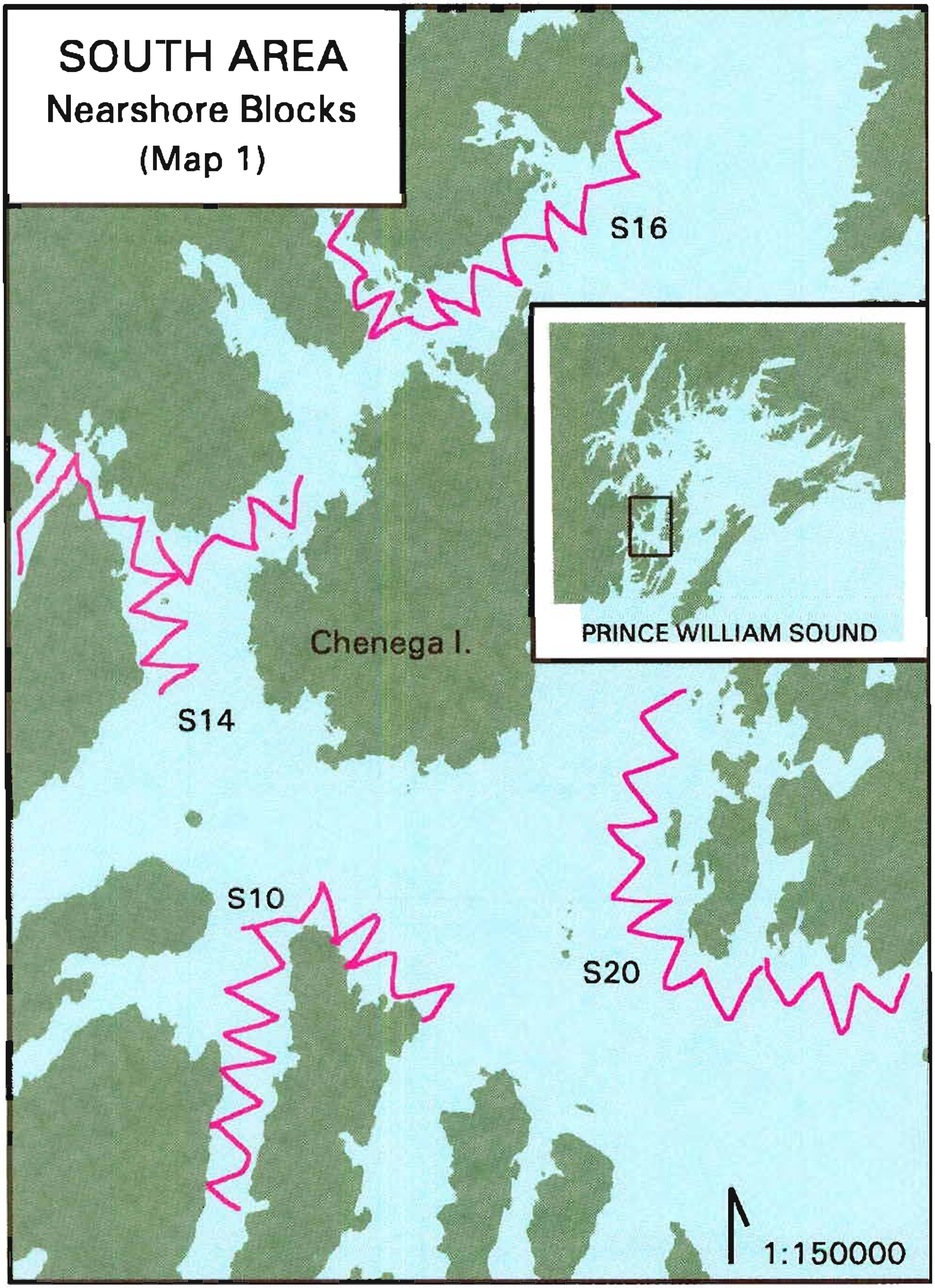
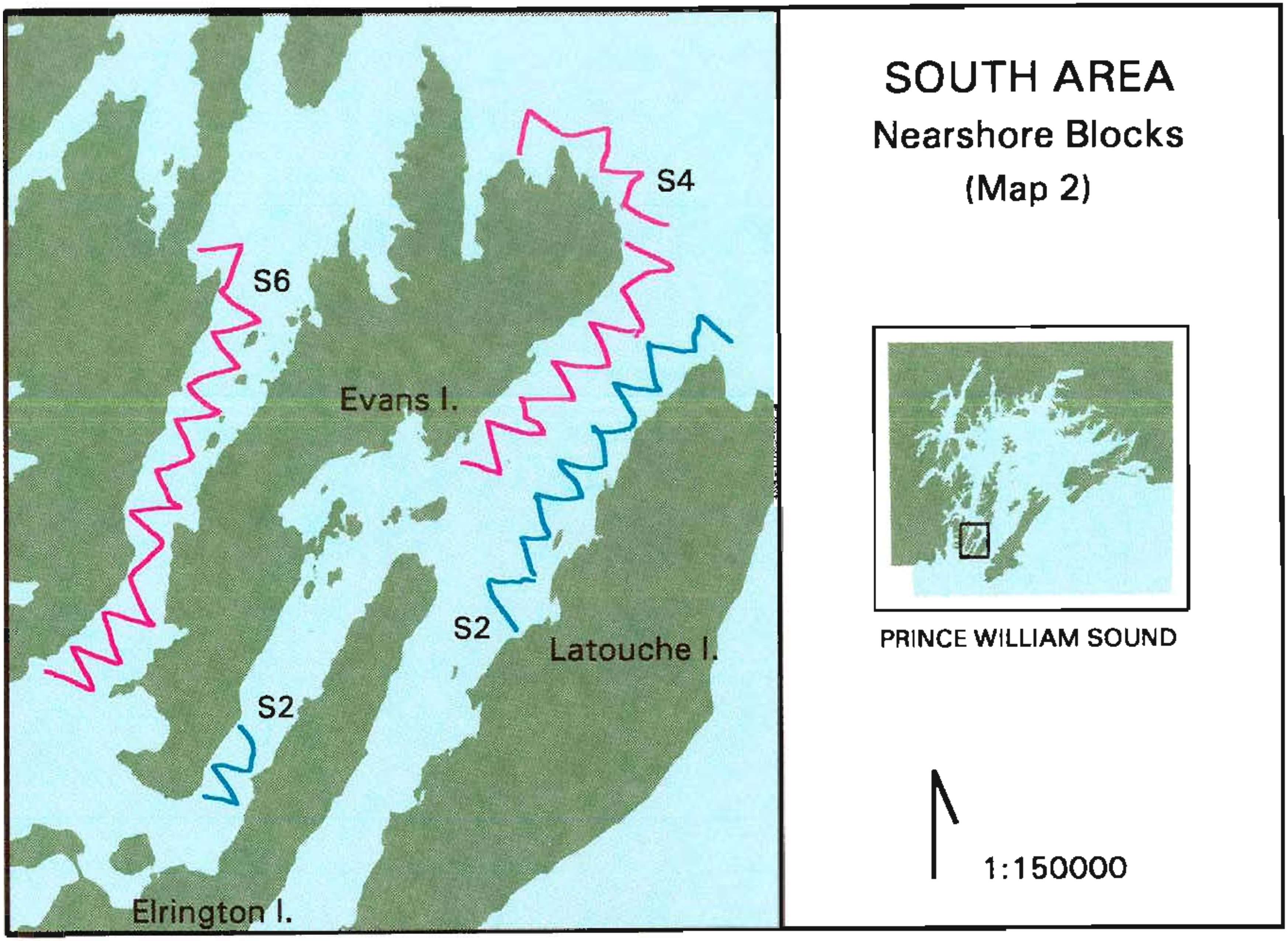
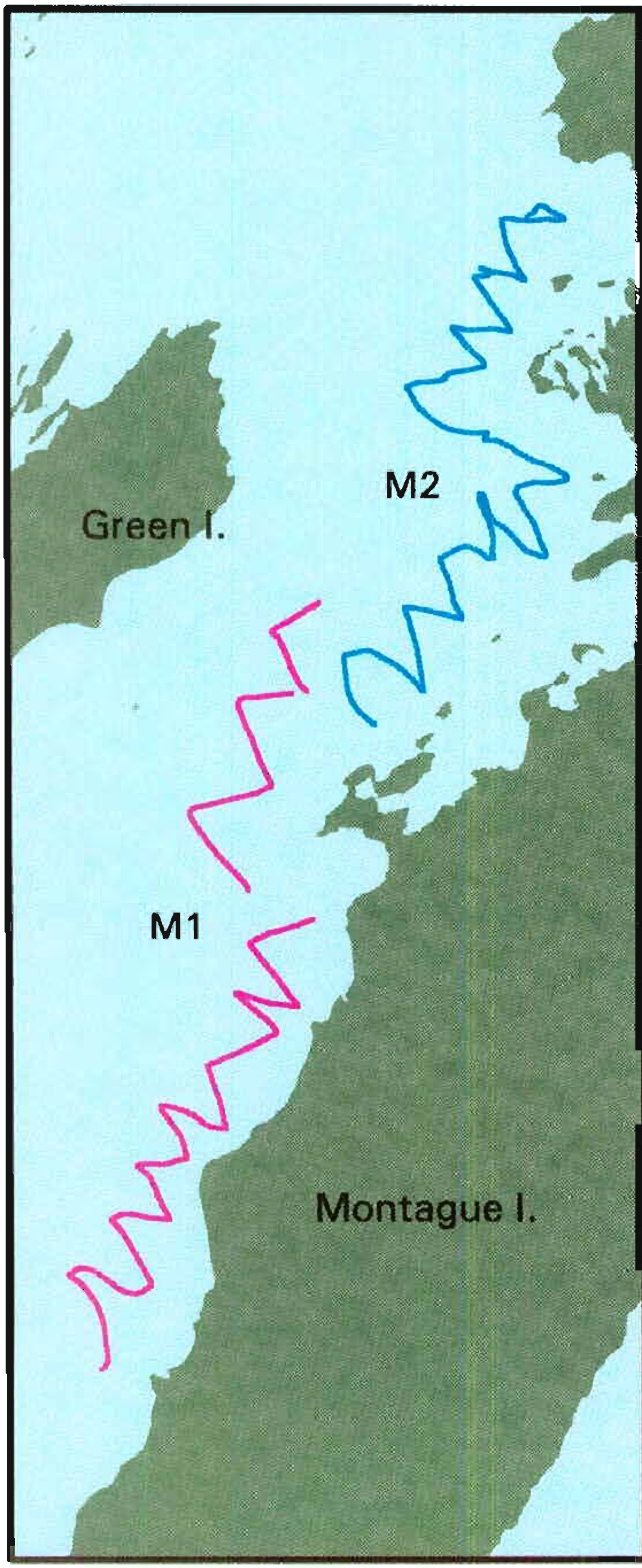

SOUTH AREA
Nearshore Blocks
(Map 1)
S16
PRINCE WILLIAM SOUND
Chenega I.
S14
S10
S20
1:150000

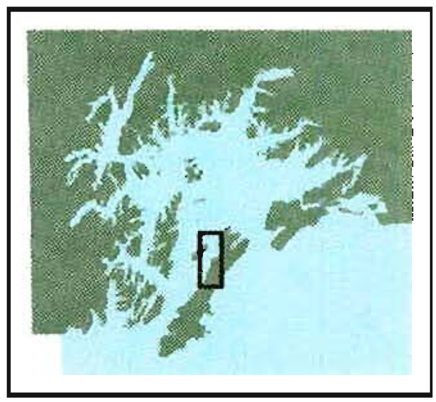

SOUTH AREA
Nearshore Blocks
(Map 2)
S4
S6
Evans I.
S2
Latouche I.
S2
Elrington I.
PRINCE WILLIAM SOUND
1:150000



MONTAGUE AREA

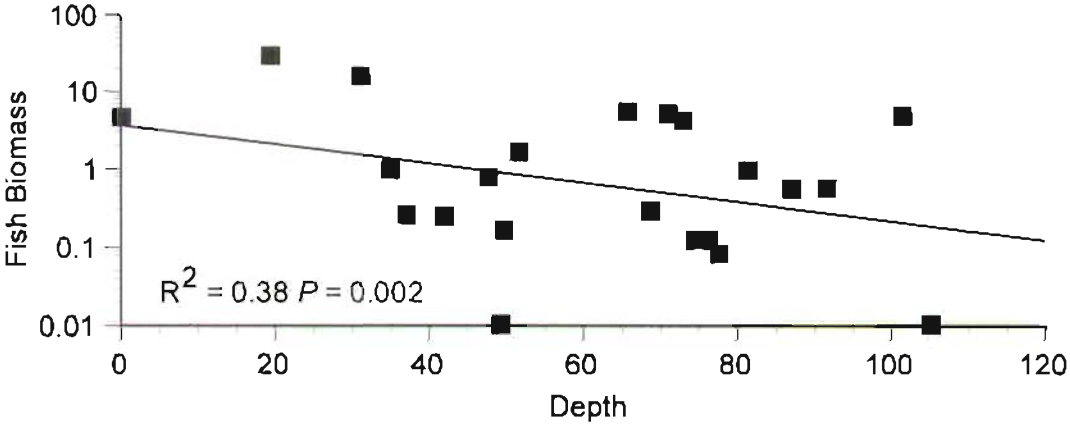
Nearshore Blocks

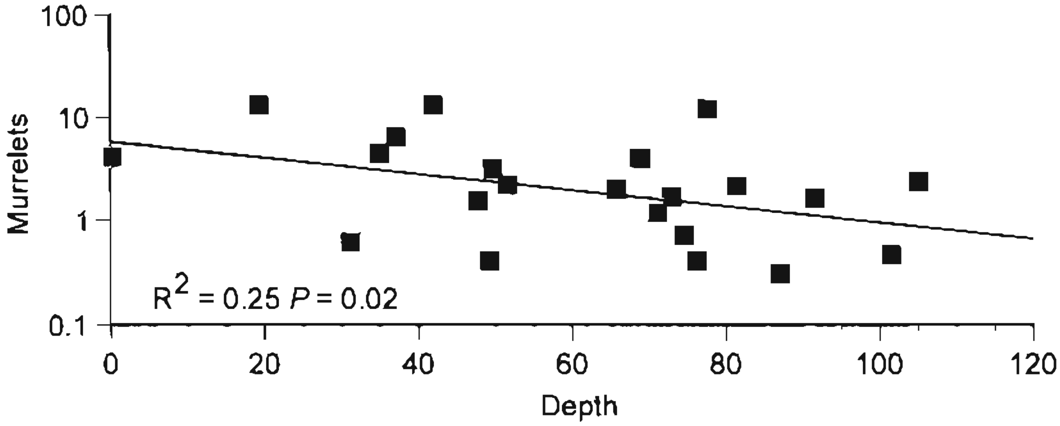
1997 Routes

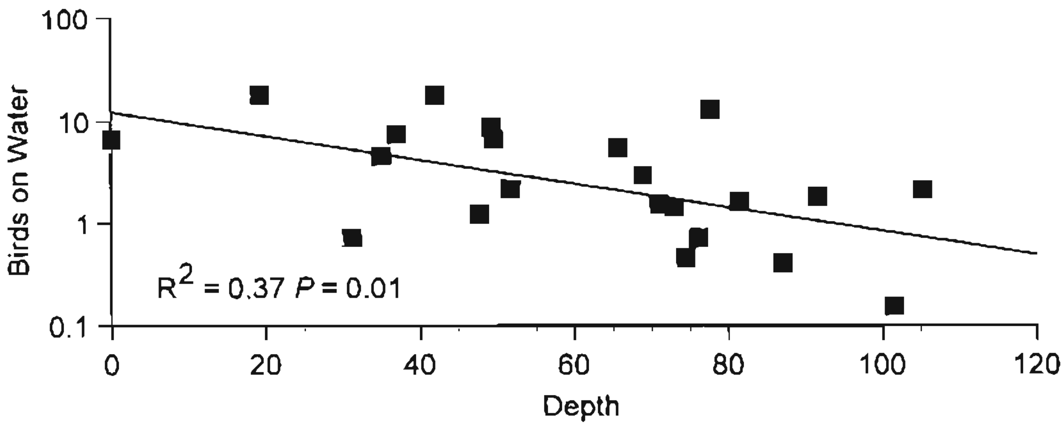


PRINCE WILLIAM SOUND

1:130000


Fish Biomass
Depth
$R^2 = 0.38$ $P = 0.002$


Murrelets
Depth
$R^2 = 0.25$ $P = 0.02$


Birds on Water
Depth
$R^2 = 0.37$ $P = 0.01$

Although we do not know if the these bottom classifications correspond directly to the actual bottom types, they should depict a real continuum from fine grain to course grain sediment. Approximately 40% of our segments were classified as "unknown". This underscores the fact that these results are preliminary; the bottom types need to be ground truthed in PWS. Physical core samples of different types of bottoms need to be collected in order to calibrate the software for this area.

The significance of the statistical analyses was slightly lower at 1000 m. One would expect that at some distance a difference would no longer be discernible. Doing repeated tests at incremental distances could provide information regarding the scale at which sand lance select their habitat.

The sand lance locations that aligned with hydroacoustic transects were a clustered subsample (32 of 72) of all the sand lance locations (Fig. 2). This exercise was an exploratory examination of data collected by other studies; it suggests that a study specifically designed to test a relationship between sand lance and bottom type may prove productive.

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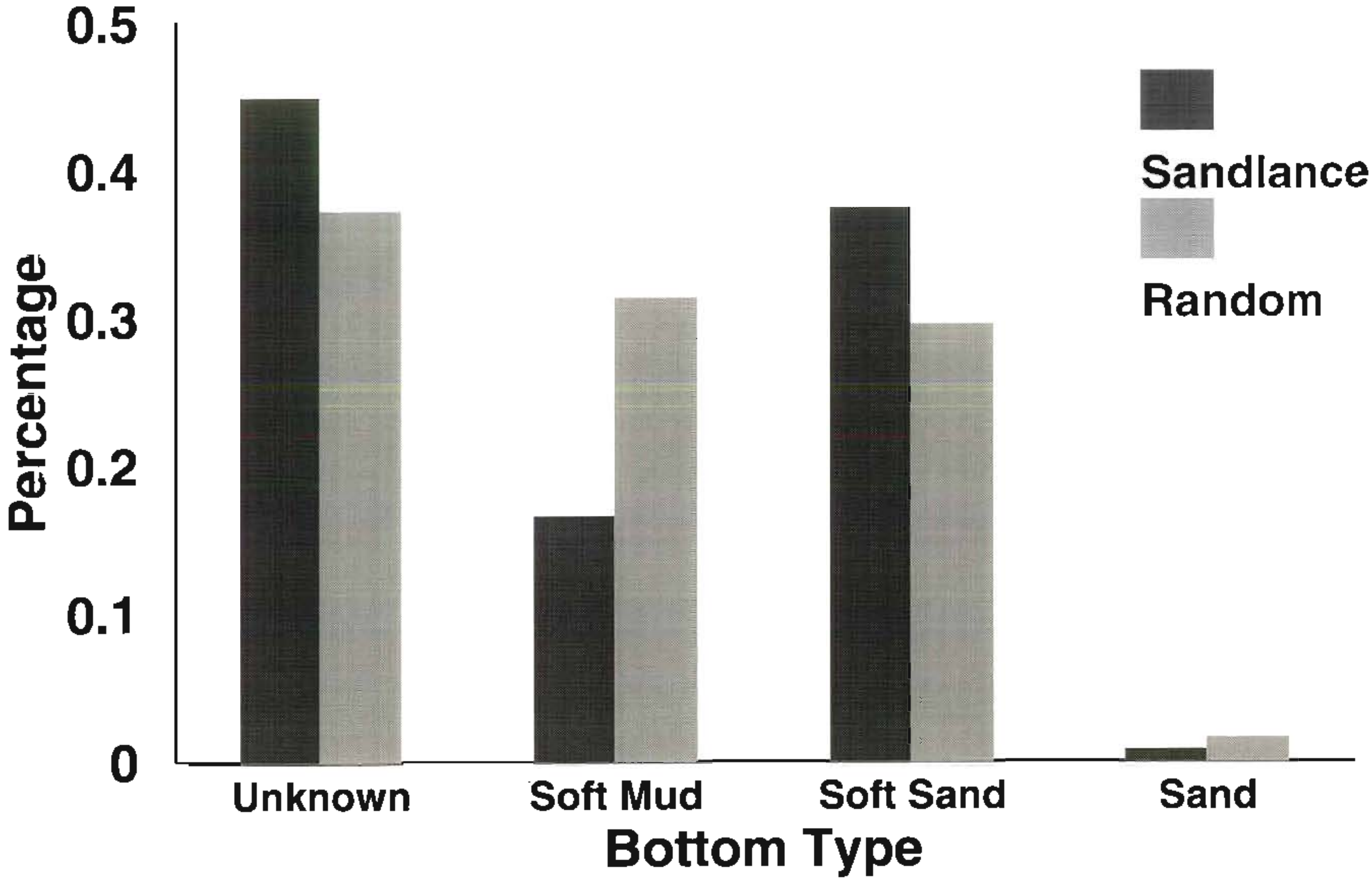
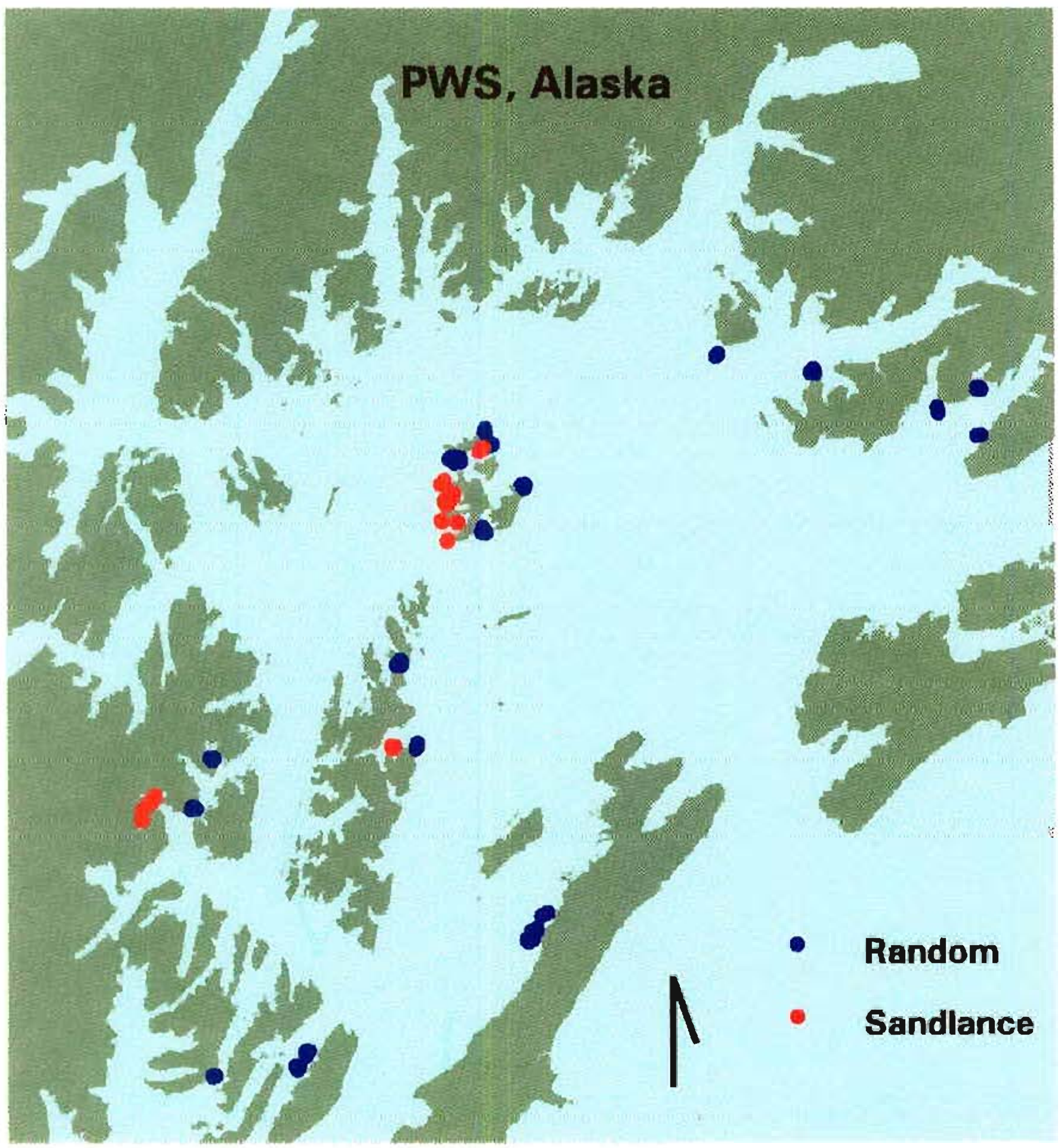
FIGURE 1. The proportions of bottom types of transect segments associated with sand lance and randomly selected locations.

FIGURE 2. Randomly selected locations and locations where Pacific Sand Lance were observed during the summer of 1997. These locacions were used to test the effectiveness of hydroacoustic bottom typing software in identifying sand lance habitat.



Loglikelihood Ratio   P < 0.001


PWS, Alaska
Random
Sandlance

PWS Mass Balance Model: Seabirds

W. D. Ostrand and D. B. Irons

Although the seabird population of Prince William Sound is a rich and diverse collection of species with differing foraging strategies (Dwyer et al. 1976), their distribution is consistent across taxa, with most bird observations occurring within 1 km of the shoreline (Ostrand and Maniscalco 1996). Within the near shore zone seabirds have associated with shallow water habitats, however this relationship was not apparent during 1997 (Ostrand, unpubl. data).

Population estimates are from 1996 U.S. Fish and Wildlife Service surveys (Agler and Kendall 1997). The survey will be replicated in 1998; hence, numbers can be updated. Population estimates on several species are included for general information on the attached spreadsheet and mass balance data is provided on the principle seabirds. The summer population and biomass is dominated (>20,000 individuals of each species) by Glaucous-winged Gulls (*Larus glaucescens*), Black-legged Kittiwakes (*Rissa tridactyla*), and Brachyrampus murrelets [Marbled Murrelet (*Brachyrampus marmoratus*) and Kittlitz's Murrelet (*Brachyrampus brevirostris*)]. The winter population and biomass differs and is dominated by Mew Gulls (*Larus canus*), murres [mostly Common Murre (*Uria aalge*)], and Brachyrampus murrelets. In addition, Bald Eagles (*Haliaeetus leucocephalus*) are a major contributors to avian biomass (>1.5 kg km^{-2}) during both seasons.

Bird body mass estimates for Alcids were taken from De Santo and Nelson (1995) and all other species from Dunning (1993). Daily food consumption estimates for Black-legged Kittiwakes and Pigeon Guillemot (*Cepphus columba*) were obtain from studies conducted in Prince William Sound (Greg Golet, U.S. Fish & Wildl. Serv., Anchorage, unpubl. data). Bald Eagle consumption estimate was obtained from Stalmaster and Gessaman (1984). For all other species daily food consumption was calculated using the following formula (Birt-Friesen et al. 1989):

$$\log_{10}(\text{daily energy}) = 3.08 + 0.667 \log_{10}(\text{body mass})$$

where energy is expressed in kJ and body mass in Kg. We assumed a 75% efficiency in converting energy consumed and a local energy content of 4.5 kJ gm^{-1} of forage fish (D. Roby, Oregon State Univ, Corvallis, pers. comm.). Hence, we divided daily energy by .75 and then divided that product by 4.5 kJ gm^{-1} to obtain a daily mass.

Food habits for Pigeon Guillemot ware obtained from local studies (Greg Golet, U.S. Fish & Wildl. Serv., Anchorage, unpubl. data). Bald Eagle food habits were taken from Cash et al. (1985). All other food habits data were obtained from Sanger (1987).

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Species	Summer (May-Sep) Numbers	Winter (Oct-Apr) Numbers	Body Mass(g)	Summer Biomass (kg/km^2)	Winter Biomass (kg/km^2)	Annual Mortality	Prey Mass (G/Day)	Q/B	Food Consumption (kg/km^2/year)
Planktivours birds									
Fork-tailed Storm-petrel	15800	0	43.0	0.1	0.0		43.7	1.0	14.3
Red-necked Phalarope	8000	0							
Terns									
All Terns	5400	0	110.0	0.1	0.0		81.7	0.7	9.1
	29200	0		0.1					23.4
Benth. Piscivorous birds									
Cormorants									
All Species	1400	13400	2000.0	0.3	3.0		565.6	0.3	174.0
Pigeon Guillemot	3000	2500	487.0	0.2	0.1	0.8	220.4	0.5	25.1
total	4400	15900		0.5	3.2				199.1
Pelagic Piscivorous birds									
Fulmars & Shearwaters									
All Species	2000	0	810.0	0.2	0.0		309.5	0.4	12.8
Gulls									
Bonapart's Gull	1600	0	212.0	0.0	0.0		126.6	0.6	4.2
Mew Gull	14200	20300	400.0	0.6	0.9		193.3	0.5	138.4
Herring Gull	100	100	1100.0	0.0	0.0		379.6	0.3	1.6
Glaucous-winged Gull	25100	13900	1010.0	2.9	1.6		358.6	0.4	289.8
Black-legged Kittiwake	48800	6700	390.0	2.2	0.3		190.1	0.5	218.3
Alcids									
All Murres	3300	46100	1004.0	0.4	5.3	11.0	357.2	0.4	366.8
Brachyramphus murrelet	82200	44300	221.0	2.1	1.1		130.1	0.6	341.2
Ancient Murrelet	200	0	206.0	0.0	0.0		124.2	0.6	0.5
Parakeet Auklet	800	0	297.0	0.0	0.0		158.5	0.5	2.6
Tufted Puffin	5000	0	773.0	0.4	0.0		300.0	0.4	31.0
Horned Puffin	500	0	612.0	0.0	0.0		256.7	0.4	2.7
Totals	183800	131400		8.9	9.2				1409.9
Prey on birds									
Bald Eagles	3000	3900	4700.0	1.6	2.1		489.0	0.1	70.0
NW Crow	2600	7100							
Common Raven	100	300							
Totals	5700	11300							
All Merganser	3100	6500							
Shorebirds									
Black Oystercatcher	800	0							
Wandering Tattler	100	0							
Whimbrel	100	0							
Ruddy Turnstone	100	0							
Surfbird	1600	700							
Jaegers									
All Jaegers	500	0							
Mammals									
Dall Porpoise	1100	1700							
Sea Otter	10800	8100							
River Otter	100	100							
Sealion	1000	2000							
Harbor Seal	1200	1000							
TOTAL	260900	276400		11.1	14.5				1702.4

Species	L.Pel	S. Pel	Demersal Fish	Decapods	Crust.	Ceph.	Cop.	Euph.	Non-marine
Sooty Shearwater		67.0		30.0				3.0	
Pelagic Cormorant		88.0	10.0		2.0				
Glaucous-winged Gull		95.0						2.0	3.0
Black-legged Kittiwake		95.0						5.0	
Arctic Tern		3.0						97.0	
Common Murre		88.0			2.0			10.0	
Pigeon Guillemots		30.0	70.0						
Marbled Murrelet		80.0						20.0	
Ancient Murrelet		20.0		2.0				78.0	
Tufted Puffin		78.0		10.0				12.0	
Bald Eagle	50		10						40