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.

William D. Ostrand
Tracey Gotthardt
John M. Maniscalco
Lisa A. Joyal

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

April 1999

Seabird/Forage Fish Interactions Component
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. During 1998 we began an effort to model habitat selection by Pacific sand lance (*Ammondytes hexapterus*). In past years we have directed much of our time to the comparisons of hydroacoustic data and the distribution of seabirds. Due to concerns about target strength values of forage fish, we suspended work that involved the use of fish abundance data and focused our efforts on developing a habitat selection model for sand lance and preparing manuscripts on the behavioral interactions of seabirds at feeding flocks.

Abstract:
Our preliminary investigations of bottom typing software, conducted in 1998, determined substrates associated with sand lance were significantly different from locations selected randomly. Encouraged by these results we have preceded to develop a model of habitat selection by sand lance. During 1999 we have collected and processed bottom samples for the purpose of calibrating bottom typing software. We have also completed the analysis of bottom-typing the hydroacoustic data. We intend to continue this effort and ultimately will develop geographic information system coverages of bathymetry, bottom type, and the probability of encountering sand lance. Our behavioral studies determined that Marbled Murrelets (*Brachyramphus marmoratus*) initiated most feeding flocks that we observed and, at flocks, the rate at which Black-legged Kittiwakes (*Rissa tridactyla*) attempted to feed was inversely related to the abundance of Glaucous-winged Gulls (*Larus glaucescens*).

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

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

Citation: Ostrand, W. D., Tracey Gotthardt, John M. Maniscalco, and Lisa A. Joyal. 1999. 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 99163), Alaska Natural Heritage Program and Department of Biology, University of Alaska Anchorage, Anchorage, Alaska.

TABLE OF CONTENTS

INTRODUCTION

This report for component 99163B is composed of three chapters that represent two manuscripts and a work in progress. Chapter one is a manuscript on the initiation of feeding flocks in Prince William Sound that has been submitted to the journal *Waterbirds* for review. Chapter two is a manuscript on competative interactions between Black-legged Kittiwakes and Glaucous-winged Gulls that is under internal review. Chapter three presents the status of the developement of a habitat selection model for sand lance and bottom typing of our study areas. We antipate that our manuscripts will be accepted for publication this year and that the work described in Chapter 3 will be completed early in 2000.

17 March 1998

MARBLED MURRELETS AS INITIATORS OF FEEDING FLOCKS IN PRINCE WILLIAM SOUND, ALASKA

WILLIAM D. OSTRAND

U.S. Fish and Wildlife Service, 1011 E. Tudor Rd., Anchorage, AK 99503 e-mail: william_ostrand@mail.fws.gov

RH: Murrelets as Feeding Flock Initiators

Abstract. I sought to determine which seabird species initiated small, ephemeral, multispecies feeding flocks in Prince William Sound, AK (PWS), by observing the formation of flocks at sites known to have frequent feeding aggregations. I observed 43 feeding flocks at 5 sites during June 1996 and determined the initiating species at 34. All of the latter flocks were initiated by pursuit divers, of which 76.5 % were Marbled Murrelets (*Brachyramphus marmoratus*), the most abundant seabird in PWS. Formation of feeding flocks followed either of 2 scenarios: 1) larids were attracted to a feeding location by the presence or activity of Marbled Murrelets or 2) both larids and murrelets were present and flock feeding began after the murrelets dove from the surface. Of the observed flocks, 26.9 % and 50.0 % were initiated under scenarios 1 and 2, respectively. Other principal participants were Black-legged Kittiwakes (*Rissa tridactyla*) and Glaucous-winged Gulls (*Larus glaucescens*). I observed an apparent commensal relationship between murrelets and larids at feeding flocks with larids being the beneficiary.

Key words: *Black-legged Kittiwakes*, Brachyramphus marmoratus, *foraging*, *feeding flocks*, *Glaucous-winged Gulls*, Larus glaucescens, *Marbled Murrelets, Prince William Sound, AK,* Rissa tridactyla.

INTRODUCTION

Worldwide, seabirds commonly form mixed-species feeding flocks in pursuit of plankton or nekton (Hoffman et al. 1981, Duffy 1983), which may be a response to the aggregation of their prey (Ainley and Boekelheide 1990) and enhanced feeding success when participating in flocks (Götmark et al. 1986). In Prince William Sound, Alaska (PWS), Tufted Puffins (*Fratercula cirrhata*), Marbled Murrelets (*Brachyramphus marmoratus*) (Ostrand et al. 1996), and Black-legged Kittiwakes (*Rissa tridactyla*) (Irons 1998) feed more frequently as individuals or in pairs than in flocks. However, kittiwakes and Glaucous-winged Gulls (*Larus glaucescens*) have high foraging efficiency rates when feeding in flocks (Mansicalco and Ostrand 1997) and during years of lower food availability, they fed more frequently in flocks than during years of greater food abundance (D. B. Irons, R. M. Suryan, and W. D. Ostrand, U.S. Fish and Wildl. Serv., Anchorage, AK, unpubl. data). These findings suggest that although flock feeding is not the exclusive foraging strategy of seabirds in PWS, it does retain a great importance, particularly during times of food stress.

Hoffman et al. (1981) grouped seabird feeding flocks into three classes: Type I, ephemeral flocks associated with tightly aggregated prey; Type II, large and persistent flocks associated with dispersed prey; and Type III, flocks associated with prey concentrated by downwelling. Of these, Type I are the most common in PWS (Maniscalco and Ostrand 1997). Due to the short duration of these flocks, birds must frequently find new food sources by either locating their own prey or joining others. Hence, those species that function as flock initiators within PWS serve an important ecological function by locating available prey for themselves and in doing so, benefit other species.

Studies conducted in the North Pacific report equivocal findings as to which species initiate feeding flocks. Most of these indicate that larids are the principle initiators of feeding flocks (Sealy 1973, Hoffman et al. 1981, Porter and Sealy 1982). However, Chilton and Sealy (1987) reported that both alcids and larids initiated flocks and, in a more recent investigation, all the flocks observed were initiated by Marbled Murrelets (Mahon et al. 1992). This disparity in the literature results in an uncertainty concerning the ecological roles of seabirds and how they interact during foraging. Here, I report on my effort to determine which seabird species initiate Type I flocks within PWS.

STUDY AREA AND METHODS

I conducted this study in PWS, an embayment of ca.10,000 km^2, located on the southcentral coast of Alaska (Fig. 1). 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 4,000 m in elevation and numerous fjords and tidewater glaciers. The avia-fauna of PWS is diverse collection species with Marbled Murrelets the most abundant seabird (Agler and Kendall 1997).

I preselected seven locations where I and others had consistently observed feeding flocks (Fig. 1). At each location, observations were made from 7:00 to 19:00 h (Alaska standard time), between 14-29 June 1996, by 2 individuals who alternated 2-h watches. Two observation days were terminated early, at 14:40 and 11:10, to respond to a Mayday call and adverse weather; respectively. Data collected during shortened days were included in the analysis. The observations were made from the deck of a 7.3-m boat at sea level with the aid of 8 x 42 or 10 x 42 binoculars. Data were collected on flocks within 500 m of the boat. If flocks were forming >100 m away, we motored closer without disturbing feeding activities. We recorded the initiating species when possible and noted whether other seabird species were present (within 100 m) at the moment of initiation. A count of each species participating (actively feeding) in each flock was made at 10-min intervals begining at initiation. These counts were averaged to determine a representative value for each flock. I defined a flock as a mixed species feeding group of ≥3 individuals; mono-specific aggregations were not considered. Location, depth of water, and distance from shore were obtained for each flock using a commercial global positioning system device, fathometer, and radar, respectively.

At each of the observation sites, measurements of depth and distance to shore may have been spatially correlated and different flocks may have contained some of the same individual birds. Therefore, to avoid pseudoreplication, I used the observation site, rather than the flocks, as the sample unit in analyzing data. To determine mean values for each variable presented (Table 1), I determined the mean value for each location and then calculated the grand mean and standard error for all locations.

To quantify feeding flock participation for each species I converted the composition of each 10-min flock count to proportions. Next I averaged the 10-min proportions to determine participation composition of each flock. I then determined the mean proportions for each species at each observation site. Lastly I calculated grand means and standard errors for all observation sites. Because observation sites were not selected randomly, statistical inference was limited to the locations sampled.

RESULTS

I observed Type I flocks from initiation to dispersal at 5 of the 7 observation sites, 3 of which were located near Naked Island (Fig. 1). Of 43 flocks detected, I was able to determine the initiating species at 34. Pursuit divers initiated all of the observed flocks, primarily Marbled Murrelets (Table 1). Of the non-murrelet initiated flocks, one was initiated by Pacific Loons (*Gavia adamsii*), at Graveyard Point, one by a Red-throated Loon (*Gavia stellata*) at Cabin Bay, and Tufted Puffins (*Fratercula corniculata*) initiated 2 flocks observed at South Naked Island. The puffin-initiated flocks were located within 1 km of a Tufted Puffin colony.

The initiation of feeding flocks by murrelets generally followed either of 2 scenarios: 1) larids were attracted to a feeding location by the presence or activity of Marbled Murrelets or 2) both larids and murrelets were observed together, either both on the water or larids resting on rocks nearby, and flock feeding began after the murrelets dove from the surface. Of the observed flocks, 26.9 ± 11.0 % and 50.0 ± 15.6 % were initiated under scenarios 1 and 2, respectively.

The mean depth and distance to shore at flock locations was 15.1 ± 3.1 m and 161.7 ± 37.6 m, respectively. Twelve species were observed in feeding flocks; however, composition was dominated by 3 species, Marbled Murrelets, Glaucous-winged Gulls, and Black-legged Kittiwakes (Table 2).

DISCUSSION

The sites that I chose to observe feeding flocks were located near shore and over shallow water as were the feeding flocks sampled by Maniscalco and Ostrand (1997) on a systematic survey of PWS during the previous summer. These similarities suggest that our findings did not differ greatly from what could have been obtained from a systematic or random sample.

In their survey of feeding flocks in Alaskan waters, Hoffman et al. (1981) recorded much larger Type I feeding flocks than observed during this study, 88.1 vs 24.9 ± 8.8 birds. However, their observations of mixed species flocks containing the numerically dominant PWS species were similar in size to our overall mean value; 30.1, 26.0, and 24.5 individuals for their flocks containing Glaucous-winged Gulls, Black-legged Kittiwakes, and Tufted Puffins, respectively. These similarities suggest that Type I feeding flocks in PWS are comparable in size to those observed elsewhere in Alaskan waters.

My findings that pursuit divers initiated all of the observed Type I flocks differs from studies conducted in the North Pacific which reported larids as initiators (Sealy 1973, Hoffman et al. 1981, Porter and Sealy 1982, Chilton and Sealy 1987). Results consistent with mine have been reported by Mahon et al. (1992), who observed murrelets as initiators, and Grover and Olla (1983) who describe another pursuit diver, the Rhinoceros Auklet (*Cerorhinca monocerata*), as behaving as described in initiation scenario 2 (Table 3). These disparities may be the result of differences in the response of seabirds to local conditions. Hoffman et al. (1981) observed Marbled Murrelets in only one feeding flock, which may have been a consequence of conducting his study outside of areas where murrelets are abundant (Piatt and Ford 1993, Agler et al. 1998). In both Mahon et al.'s (1992) and my study area, Marbled Murrelets were a numerically dominant species (Piatt and Ford 1993) and in PWS there were few other alcids that could have competed with them for forage (Agler and Kendall 1997). These attributes may have facilitated the murrelets role in the formation of Type I flocks. Also, in the Galapagos Archipelago, Mills (1998) determined that pursuit-divers played an important role in prolonging the duration of feeding flocks in nearshore habitats where the mechanisms that keep prey near the surface and available to seabirds differed from those of flocks on the open ocean. It is possible that such differences also occur between inshore and offshore feeding flocks of northern latitudes. Ostrand et al. (1998) observed that Marbled Murrelets in PWS selected fish schools which occurred in shallow water, which suggests that murrelets would have a limited role in pelagic flocks and a greater role in shallow, nearshore, waters as was observed by Porter and Sealy (1981). Disparity may also have resulted from differences among study designs. Grover and Olla (1983), Chilton and Sealy (1987), and Mahon et al. (1992) had the specific objective to observe the initiation of feeding flocks. That Chilton and Sealy (1987) made their observations from land at distances up to 1 km and were not able to approach flocks may be problematic. During the collection of the data for this study I observed that murrelets on the water were difficult to detect >100 m distant and data collected at greater distances my be suspect.

My findings suggest a commensal relationship between larids and Marbled Murrelets of PWS, with larids being the benificiary species. Murrelets locate fish schools, then force schools into tight balls and drive them to the surface where they become available to larids (Mahon et al. 1992, Hunt 1995, Maniscalco and Ostrand 1997). I did not observe any benefits to murrelets that resulted from their roll in feeding flocks and there may be a negative effect due to kleptoparasitism by larids (Maniscalco and Ostrand 1997). However, Hunt (1995) speculated that the foraging activity of larids may aid murrelets by driving fish from their protective balls.

Mahon et al. (1992) and I have demonstrated that in at least two locations within their range, murrelets functioned as initiators of Type I feeding flocks. As such, murrelets may be viewed as a catalyst in the transfer of energy from the marine system to other avian predators within PWS. Elucidation of their role in seabird foraging ecology raises questions about the impacts of murrelet population declines on other species. Do murrelet population declines result in less forage available to other seabirds? To what extent have Marbled Murrelet declines within PWS (Klosiewski and Laing 1994) impacted other picivorous predators? Likewise, if Marbled Murrelets fill a similar roll throughout their range, then are their continuing population declines (Beissinger 1995) having broader impacts on other marine communities? These questions merit further discussion and investigation within the context of the management and conservation of seabirds of the North Pacific.

ACKNOWLEDGMENTS

The research described in this paper was supported by the *Exxon Valdez* Oil Spill Trustee Council and the U. S. Fish and Wildlife Service. However, the findings and conclusions presented are mine and do not necessarily reflect the views or position of the Trustee Council and the Service. I thank individuals who provided assistance throughout this study. J. M. Maniscalco assisted with data collection and study design. L L. McDonald and J. Kern of Western EcoSystems Technology, Inc. provided advice and assistance with statistical analysis. T. A. Gotthardt developed maps. The suggestions of D. G. Ainley, G. S. Drew, D. C. Duffy, T. A. Gotthardt, D. B. Irons, K. J. Kuletz, B. K. Lance, and R. M. Suryan significantly improved this paper.

LITERATURE CITED

Agler, B. A. and S. J. Kendall. 1997. Marine bird and sea otter population abundance of Prince William Sound, Alaska: trends following the T/V *Exxon Valdez* oil spill, 1989-1996. *Exxon Valdez* oil spill restoration final reports, Restoration Project 96159. U. S. Fish and Wildl. Serv., Anchorage AK.

Agler, B. A., S. J. Kendall, and D. B. Irons. 1998. Abundance and distribution of Marbled and Kittiltz's Murrelets in Southcentral and Southeast Alaska. Condor 100:254-265.

Ainley, D. G. and R. J. Boekelheide. 1990. Seabirds of the Farallon Islands: ecology, dynamics, and structure of an upwelling-system community. Stanford Univ. Press, Stanford, CA.

Beissinger, S. R. 1995. Population trends of the Marbled Murrelet projected from demographic analyses, p. 385-393. *In*: C. J. Ralph, G.L. Hunt, M. G. Raphael, and J. F. Piatt (eds.), Ecology and conservation of the Marbled Murrelet. Pacific Southwest Res. Sta. Albany, CA.

Chilton, G. and S. G. Sealy. 1987. Species roles in mixed-species feeding flocks of seabirds. J. Field Ornithol. 58:456-463.

Duffy, D. C. 1983. The foraging ecology of Peruvian Seabirds. Auk 100: 800-810.

Götmark, F., D. W. Winkler, and M. Andersson. 1986. Flock-feeding on fish schools increases individual success in gulls. Nature 310:589-591.

Grover, J. J. and B. L. Olla. 1983. The role of Rhinoceros Auklet (*Cerorhinca monocerata*) in mixed-species feeding assemblages of seabirds in the Strait of Juan de Fuca, Washington. Auk 100:979-982.

Hunt, G. L. Jr. 1995. Monspecific and mixed species foraging associations of Marbled Murrelets, p. 255-256. *In*: C. J. Ralph, G.L. Hunt, M. G. Raphael, and J. F. Piatt (eds.), Ecology and conservation of the Marbled Murrelet. Pacific Southwest Res. Sta. Albany, CA.

Hoffman, W. D., D. Heinemann, and J. A. Wiens. 1981. The ecology of seabird feeding flocks in Alaska. Auk 98:437-456.

Irons, D. B. 1998. Foraging area fidelity of individual seabirds in relation to tidal cycles and flock feeding. Ecology 79:647-655.

Klosiewski, S. P. and K. K. Laing. 1994. Marine bird populations of Prince William Sound, Alaska before and after the *Exxon Valdez* oil spill. NRDA Bird Study Number 2. Unpubl. Rep., U.S. Fish and Wildl. Serv., Anchorage, AK.

Mahon, T. E., G. W. Kaiser, and A. E. Burger. 1992. The role of Marbled Murrelets in mixed-species feeding flocks in British Columbia. Wilson Bull. 104:783-743.

Maniscalco, J. M. and W. D. Ostrand. 1997. Seabird behaviors at forage fish schools in Prince William Sound, Alaska. Proceedings - Forage Fishes in Marine Ecosystems, Alaska Sea Grant College Program, AK-SG-97-01, Anchorage, AK.

Mills, K. L. 1998. Multispecies seabird feeding flocks in the Galápagos Islands. Condor 100:277-285.

Ostrand, W. D., K. O. Coyle, G. S. Drew, J. M. Maniscalco, and D. B. Irons. 1998. Selection of forage-fish schools by murrelets and Tufted Puffins in Prince William Sound, Alaska. Condor 100:286-297.

Piatt, J. F. and R. G. Ford. 1993. Distribution and abundance of Marbled Murrelets in Alaska. Condor 95:662-669.

Porter, J. M. and S. G. Sealy. 1981. Dynamics of seabird multispecies feeding flocks: chronology of flocking in Barkley Sound, British Columbia, in 1979. Colonial Waterbirds 4:104-113.

Porter, J. M. and S. G. Sealy. 1982. Dynamics of seabird multispecies feeding flocks: age-related feeding behaviour. Behaviour 81:91-109.

Sealy, S. G. 1973. Interspecific feeding assemblages of marine birds off British Columbia. Auk 90:792-802.

Table 1. Mean values for feeding flocks observed at 5 sites in Prince William Sound, Alaska during June 1996.

Location	Duration of observations (d)	No. flocks observed	% initiated by murrelets	$\bar{x}$ flock size (bird no.)	$\bar{x}$ no. murrelets	$\bar{x}$ no. kittiwakes	$\bar{x}$ no. gulls	$\bar{x}$ flock duration (min.)
Graveyard Point	2.6	10	88.9	5.5	2.7	2.4	0.1	5.4
NW Naked Is.	2	2	100.0	14.2	6.5	0.6	11.5	18.0
Cabin Bay	1.4	21	93.8	13.9	4.8	4.6	3.7	19.9
Disk Is.	2	9	100.0	38.7	25.8	2.5	10.6	20.2
S Naked Is.	1	2	0.0	52.3	0.0	0.7	19.5	21.5
Mean ± SE	1.8 ± 0.3	8.8 ± 3.5	76.5 ± 19.2	24.9 ± 8.8	7.9 ± 4.6	2.2 ± 0.7	9.1 ± 3.4	17.0 ± 3.0

TABLE 2. The proportional composition of feeding flocks at 5 study sites by species. See text for method of calculation of mean values. Data were collected in Prince William Sound, Alaska during June 1996.

Species	Mean percentage for all locations
Marbled Murrelet	39.0 ± 8.7
Glaucous-winged Gull	34.9 ± 12.9
Black-legged Kittiwakes	17.8 ± 8.7
Tufted Puffin	9.6 ± 9.5
Horned Puffin	2.7 ± 2.7
Pacific Loon	2.2 ± 1.7
Pigeon Guillemot	0.9 ± 0.9
Mew Gull	0.4 ± 0.4
Pelagic Cormorant	0.2 ± 0.2
Red-throated Loon	< 0.1 ± 0.1
Common Murre	< 0.1 ± 0.1
Arctic Tern	< 0.1 ± 0.1

Table 1. Mean values for feeding flocks observed at 5 sites in Prince William Sound, Alaska during June 1996.

Location	Duration of observations (d)	No. flocks observed	% initiated by murrelets	$\bar{x}$ flock size (bird no.)	$\bar{x}$ no. murrelets	$\bar{x}$ no. kittiwakes	$\bar{x}$ no. gulls	$\bar{x}$ flock duration (min.)
Graveyard Point	2.6	10	88.9	5.5	2.7	2.4	0.1	5.4
NW Naked Is.	2	2	100.0	14.2	6.5	0.6	11.5	18.0
Cabin Bay	1.4	21	93.8	13.9	4.8	4.6	3.7	19.9
Disk Is.	2	9	100.0	38.7	25.8	2.5	10.6	20.2
S Naked Is.	1	2	0.0	52.3	0.0	0.7	19.5	21.5
Mean ± SE	1.8 ± 0.3	8.8 ± 3.5	76.5 ± 19.2	24.9 ± 8.8	7.9 ± 4.6	2.2 ± 0.7	9.1 ± 3.4	17.0 ± 3.0

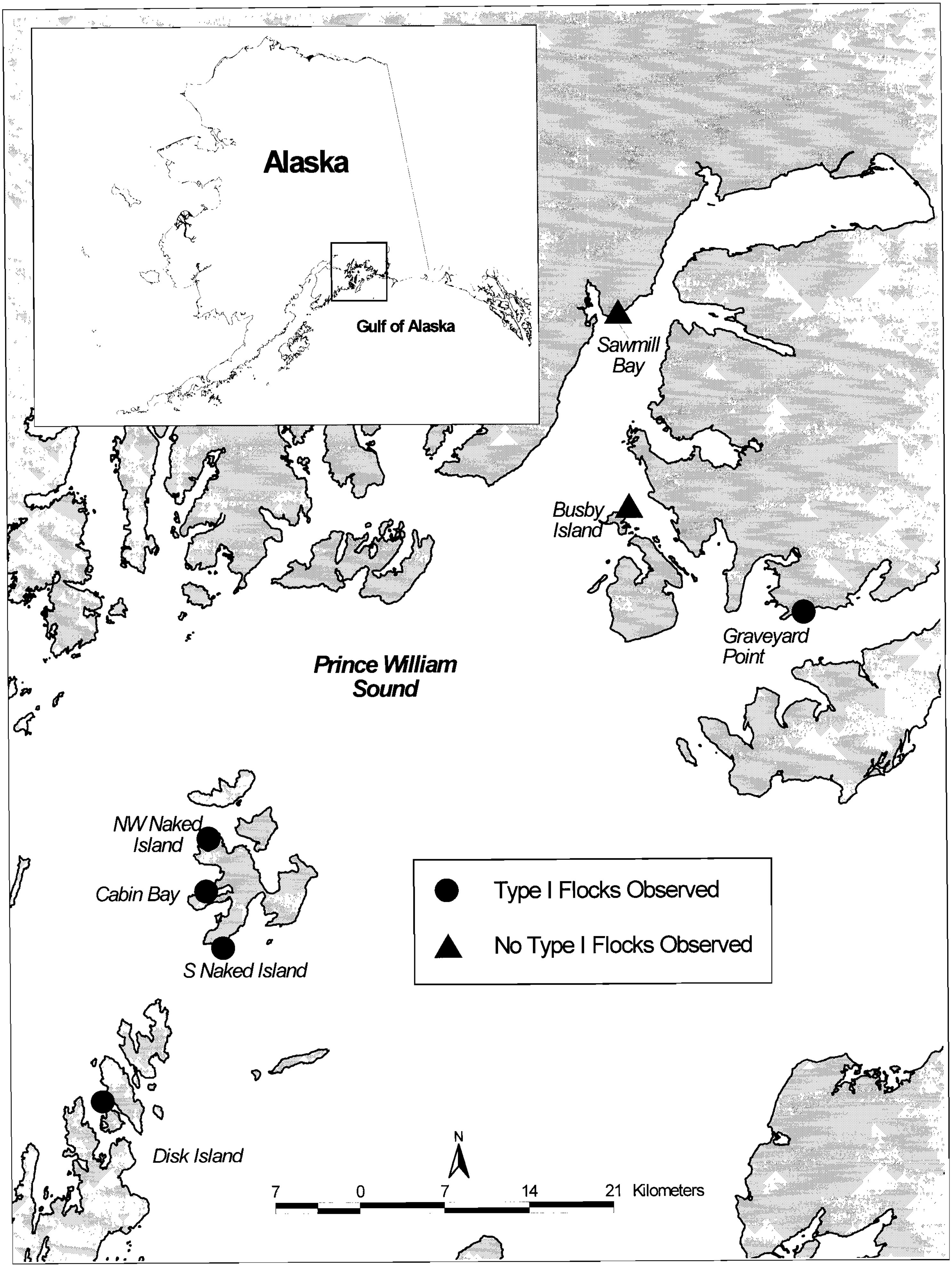
TABLE 3. Summary of the findings of studies conducted in the Northeast Pacific that report on initiators of seabird feeding flocks.

Study	Location	Initiators of feeding flocks
Sealy (1973)	Queen Charlotte Islands, British Columbia, Canada	72 % kittiwakes (surface-feeders) and 14 % alcids (pursuit-divers)
Hoffman et al. (1981)	Northern Gulf of Alaska and Destruction Is., Washington, USA	76% kittiwakes (surface-feeders) (Gulf of Alaska), 77 % gulls (surface-feeders) (Washington)
Porter and Sealy (1982)	Barkley Sound, Vancouver Is., British Columbia, Canada	96 % gulls (surface-feeders)
Grover and Olla (1983)	Strait of Juan de Fuca, Washington, USA	100 % Rhioceros Auklets (pursuit-divers)
Chilton and Sealy (1987)	Barkley Sound, Vancouver Is., British Columbia, Canada	57.1 % gulls (surface-feeders) and 39.7 % alcids (pursuit-divers)
Mahon et al. (1992)	Okeover Inlet, SW British Columbia, Canada	100 % murrelets (pursuit-divers)
Ostrand (this study)	Prince William Sound, Alaska, USA	100 % pursuit-divers, of which 76.5 % were murrelets

TABLE 3. Summary of the findings of studies conducted in the Northeast Pacific that report on initiators of seabird feeding flocks.

Study	Location	Initiators of feeding flocks
Sealy (1973)	Queen Charlotte Islands, British Columbia, Canada	72 % kittiwakes (surface-feeders) and 14 % alcids (pursuit-divers)
Hoffman et al. (1981)	Northern Gulf of Alaska and Destruction Is., Washington, USA	76% kittiwakes (surface-feeders) (Gulf of Alaska), 77 % gulls (surface-feeders) (Washington)
Porter and Sealy (1982)	Barkley Sound, Vancouver Is., British Columbia, Canada	96 % gulls (surface-feeders)
Grover and Olla (1983)	Strait of Juan de Fuca, Washington, USA	100 % Rhioceros Auklets (pursuit-divers)
Chilton and Sealy (1987)	Barkley Sound, Vancouver Is., British Columbia, Canada	57.1 % gulls (surface-feeders) and 39.7 % alcids (pursuit-divers)
Mahon et al. (1992)	Okeover Inlet, SW British Columbia, Canada	100 % murrelets (pursuit-divers)
Ostrand (this study)	Prince William Sound, Alaska, USA	100 % pursuit-divers, of which 76.5 % were murrelets

FIGURE 1. Map of the study area depicting observation sites where data were collected on the initiation of feeding flocks in Prince William Sound, Alaska, 14 June-29 June 1996


Alaska
Gulf of Alaska
Sawmill Bay
Busby Island
Graveyard Point
Prince William Sound
NW Naked Island
Cabin Bay
S Naked Island
Disk Island
Type I Flocks Observed
No Type I Flocks Observed
N
7 0 7 14 21 Kilometers

Passive Interference Competition of Black-legged Kittiwakes by Glaucous-winged Gulls in Prince William Sound, Alaska.

John M. Maniscalco, William D. Ostrand, Rob M. Suryan, and David B. Irons

U.S. Fish and Wildlife Service, Office of Migratory Bird Management

1011 East Tudor Rd.

Anchorage, Alaska 99503

Abstract – We studied mixed species feeding flocks during 1995 and 1996 and analyzed data from an independent radio-tracking study of Black-legged kittiwakes from 1997, both in Prince William Sound, Alaska. Our purpose was to determine if Glaucous-winged Gulls hinder prey capture by kittiwakes by examining their foraging and feeding behaviors. At tightly aggregated feeding flocks, gulls sat on the water directly over the prey source and maintained their position by making brief hop-plunges or surface-seizing. Kittiwakes, on the other hand, fed by looking for an open spot in the flock and plunging from the air. Data from both studies indicated that kittiwakes made significantly fewer feeding attempts in flocks that had greater numbers of gulls. However, kittiwakes were no more successful at feeding when gulls were absent. Kittiwakes were also more likely to join flocks that had fewer Glaucous-winged Gulls. Our findings are evidence of interference competition between these two species and suggest that increased populations of large gulls in PWS cause additional stress on Black-legged Kittiwakes especially when prey is scarce.

INTRODUCTION

Central place foraging theory attempts to predict which and how much of a particular food patch will be used by a predator dependent upon factors such as travel time and food density (Orians and Pearson 1979). Interference, which reduces the rate of food intake by the inferior competitor, is essentially the same as a decrease in food density for that competitor. Thus, increased interference by a superior competitor at a prey patch should result in a decrease in the optimal food load and an increase in search times for alternative patches by the inferior competitor (Ydenberg et al. 1986).

Interference competition is commonly divided into two major categories: active (Schoener 1983) and passive (Charnov et al. 1976). Passive interference competition in which one species obstructs the availability of a resource to another species by non-aggressive behaviors is often difficult to detect (Maurer 1984). However, in surface feeding seabirds it may be more readily observed due to their highly viewable habits of feeding on a nearly two-dimensional surface in localized areas. For example, Shealer and Burger (1993) have shown that Brown Noddies (Anous Stolidus) interfere with Roseate Terns (Sterna dougalli) by blocking access to prey and hence reducing the number of feeding attempts by terns. Also, in the feeding guild of dabbling ducks, evidence exists of the passive exclusion of Northern Shovelers (Anas clypeata) by Green-winged Teals (A. crecca; Poysa 1985).

The purpose of this study was to determine if passive interference exists among surface feeding seabirds in Prince William Sound (PWS), Alaska. We examined data from two different and independent studies in PWS with emphasis on the feeding strategies of Black-legged Kittiwakes (Rissa tridactyla) and Glaucous-winged Gulls (Larus glaucescens). Glaucous-winged Gulls are large (66 cm in length) compared to kittiwakes (43 cm) and recent changes in their relative abundance in PWS have been estimated (Data provided by Brian Lance, USFWS). In many cases, larger species outcompete smaller ones (Persson 1985) and thus can monopolize a greater proportion of resources as their numbers increase and/or food supply decreases. We briefly discuss the potential impact that interference competition might have on kittiwakes in PWS.

STUDY AREA AND METHODS

Prince William Sound is a large estuarine embayment of the northern Gulf of Alaska which provides important foraging and breeding habitat for many seabirds (Isleib and Kessel 1973, Irons et al. 1988). During the summers of 1995 and 1996 we examined the behaviors of seabirds at feeding flocks encountered along systematically run transects in PWS from vessels averaging 18 m in length using 7 x 40 and 10 x 42 binoculars. During 1995 we ran a combination of offshore and nearshore transects (See Ostrand et al. 1998 for details). However, in 1996, we concentrated our efforts on nearshore transects in randomly selected 12 x 1 km blocks (Haldorson et al. 1998) because feeding flocks were found to be close to shore (Maniscalco et al. 1999).

A feeding flock was defined as an aggregation of three or more seabirds actively feeding as observed by diving alcids surfacing with fish in their bills or larids plunging or dipping into the water. Flock types were loosely classified following Hoffman et al. (1981): (I) small, short duration flocks over tightly clumped prey; (II) large, persistent flocks over more broadly dispersed prey; and (III) flocks associated with sites where forage was concentrated by downwelling or other hydrophysical influence, determined by a subjective evaluation of oceanographic features. For this part of the study we concentrated our analyses on Type I flocks where gulls and kittiwakes fed in close proximity.

Upon encountering a feeding flock we noted species composition and their positions in the flock and quantified the frequencies and types of feeding strategies for Glaucous-winged Gulls and Black-legged Kittiwakes using a voice recorder or videotape. Feeding was categorized as plunge-diving, surface-seizing, piracy (Ashmole 1971) and hop-plunging (Hoffman et al. 1981) and compared between the two species with reference to their position in the flock. We did not record aborted dives or swoops because of uncertainty to their cause. We did record feeding frequency and success of kittiwakes when our position and the prey type facilitated those observations. We remained with each flock until it broke up naturally or became disturbed by our presence.

We also examined 1997 radio-tracking data of several kittiwakes from Shoup Bay, a large colony in Northeastern PWS (see Suryan et al. 1998 for methodology). Fish abundances in that region were low in 1997 compared to the previous year (Haldorson et al. 1998). Furthermore, Suryan et al. (1998) reported that kittiwakes foraged more often in flocks in 1997 as opposed to 1995 and 1996 although only the 1997 data were suitable for our analyses here. With those data we compare the species composition of flocks joined with those passed by using individual kittiwakes as the sample unit and averaging the data collected for each individual bird. We also examined the ratio of Glaucous-winged Gulls to kittiwakes in relation to the number of feeding attempts by kittiwakes and their success as averaged by flock. We did not use data from flocks formed by fish processors spewing offal into the waters because they were intermittent and artificial in nature.

Changes in the relative abundance of Glaucous-winged Gulls and Black-legged Kittiwakes are displayed graphically from data provided by U.S. Fish and Wildlife Service, Office of Migratory Bird Management, Anchorage, Alaska.

RESULTS

Feeding Flock as the Sampling Unit

The majority of feeding flocks encountered (14 of 22 in 1995 and 20 of 22 in 1996) were tightly aggregated Type I flocks. Sixteen of those flocks had both Black-legged Kittiwakes and Glaucous-winged Gulls participating. Other members of the Laridae, comprising less than 5% of the flocks, included Mew Gulls (Larus canus), Bonaparte's Gulls (L. philadelphia), Arctic Terns (Sterna paradisaea), and Parasitic (Stercorarius parasiticus) and Pomarine (S. pomarinus) Jaegers. Marbled Murrelets (Brachyramphus marmoratus), Tufted Puffins (Fratercula cirrhata), and Pigeon Guillemots (Cepphus columba) also commonly took part in the flocks.

At Type I feeding flocks, Glaucous-winged Gulls often sat on the water over the center of a concentrated prey source while kittiwakes typically circled or hovered above the flock. Glaucous-winged Gulls maintained their position in the flocks by hop-plunging and surface-seizing for their prey 86.9% of the time; they also plunge-dived 6.6%, and pirated 6.5% of the time. Conversely, kittiwakes hop-plunged and surface-seized 13.9%, plunge-dived 80.1%, and pirated 6.0% of the time. These feeding strategies were drastically different ($P^2 = 962.9$, df = 2, $P < 0.001$). Fish schools held in tight balls near the water surface by alcids (Maniscalco and Ostrand 1997) were easily monopolized by gulls on the water which virtually blocked access to plunge-diving kittiwakes. On two occasions kittiwakes were denied any feeding opportunities at flocks where several gulls were centralized over the prey.

In Type I flocks that contained both kittiwakes and Glaucous-winged gulls kittiwakes made more feeding attempts in flocks when there was a smaller ratio of gulls to kittiwakes (Spearman rank correlation, $r_s = 0.547$, df = 14, $P = 0.002$, Fig. 1a). There was not a significant difference in the feeding success of kittiwakes in flocks without Glaucous-winged Gulls (27/30.97 min) as opposed to those with (30/28.55 min, $P^2 = 0.496$, df = 1, $P = 0.479$).

Black-legged Kittiwake as the Sampling Unit

During 1997, we radio-tracked 20 Black-legged kittiwakes from Shoup Bay colony. Data from 16 of those birds contained enough information for our analysis here. Kittiwakes joined feeding flocks that had a mean of 4.7 (SE = 1.61, $n = 16$) Glaucous-winged Gulls as opposed to 9.8 (SE = 1.79, $n = 13$) gulls in flocks that were passed by ($P^2 = 10.462$, df = 1, $P = 0.001$).

In flocks that were joined, kittiwakes made fewer feeding attempts in the presence of greater ratios of Glaucous-winged Gulls to kittiwakes (Spearman rank correlation, $r_s = 0.332$, df = 15, $P = 0.019$, fig. 1b). There was no relationship between the feeding success of kittiwakes and the relative number of Glaucous-winged Gulls in the flock (Spearman rank correlation, $r_s = 0.002$, df = 22, $P = 0.824$). We did not examine the feeding methods during this portion of the study.

The relative abundance of Glaucous-winged Gulls to kittiwakes has increased steadily in PWS since 1991 (Figure 2). Data from 1989 and 1990 were available but not included due to possible biases from disturbances caused by the Exxon Valdez oil spill and clean-up operations.

DISCUSSION

Unlike active interference, which more likely occurs when resources are abundant and concentrated, passive interference may occur more often when resources are rare and concentrated (Maurer 1984). In the former situation the predator will gain enough energy for active resource defense. The prey availability of seabirds feeding in flocks, although at times abundant, may be quite ephemeral in nature due to rapid dispersion below the birds' diving ability. In that case it may be prudent for birds to devote more time to feeding and limit other activities. Therefore, passive interference would likely be the major aspect of competition at feeding flocks of seabirds. This is what we observed at the tightly aggregated Type I feeding flocks where Glaucous-winged Gulls maintained their position over the prey source by hop-plunging and surface-seizing. In doing so, the large gulls were able to block access to prey from kittiwakes by expending little or no extra energy.

In other studies (e.g. Duffy 1986, Shealer and Burger 1993) larger seabirds flew in circles or hovered close to the water between the prey and their smaller competitors and fed by plunge-diving or dipping. Those feeding methods are advantageous when prey is highly mobile and the dominant competitor must change its position frequently to track it. However, when prey is held in one location such as by feeding alcids (Hoffman et al. 1981, Mahon et al. 1992, Maniscalco and Ostrand 1997), it makes better economic sense for the superior competitor to sit over the patch and not make movements by which it could lose an advantageous position.

We posit that passive interference induced by Glaucous-winged Gulls' location in the flock and feeding behaviors resulted in the reduced number of feeding attempts by Black-legged Kittiwakes as evidenced here by two independent studies. Both studies also revealed no significant difference in the feeding success of kittiwakes with the presence of gulls indicating that reduced feeding rates also reduce overall capture rates by kittiwakes. Further, during 1997 kittiwakes joined flocks that had fewer gulls. The biomass of kittiwakes' favored prey in Northeastern PWS (age 1+ Pacific herring and sand lance) was greatly reduced in 1997 compared to 1996 (Haldorson et al. 1998) effecting an increase in predator aggregation where prey was available (Hassell and May 1974). Thus, kittiwakes were obligated to feed at flocks more often, but chose flocks that had fewer gulls because interference at those flocks was diminished. During 1996, when prey was more abundant and therefore easier to locate, kittiwakes frequently fed alone (Suryan et al. 1998).

The results presented here are similar to those found by Shealer and Burger (1993) who state that the effects of passive interference on Roseate Tern survival may be insignificant. Although active interference can have obvious and serious detrimental effects on the inferior species (e.g. Kennedy and White 1996), no such evidence exists in regard to passive interference, to our knowledge. At Shoup Bay colony in Northeastern PWS greatly reduced productivity of kittiwakes in 1997 compared to 1996 (Roby et al. 1998) may be attributed primarily to lower prey abundance. We could not ascertain potential negative effects on the survival of kittiwakes due to interference competition. However, our study indicates that the presence of large gulls may confer additional stresses on kittiwakes during times of food shortage.

Populations of Glaucous-winged Gulls may not be significantly increasing in PWS but data presented here suggests an increasing trend when taken in relation to kittiwake numbers. Additional growth in the relative abundance of large gulls may compound kittiwakes ability to obtain food with or without changes in prey abundance.

LITERATURE CITED

Ashmole, N. P. 1971. Sea bird ecology and the marine environment. Pp. 223-286 in D. S. Farner and J. R. King, eds. Avian Biology Vol. 1. Academic Press, New York.

Charnov, E. L., G. H. Orians, and K. Hyatt. 1976. Ecological implications of resource depression. Am. Nat. 110:247-259.

Duffy, D. C. 1986. Foraging at patches: interactions between common and roseate terns. Ornis Scand. 17:47-52.

Haldorson, L., T. Shirley, and K. Coyle. 1998. Forage species studies in Prince William Sound. Pp. A1-10 in D.C. Duffy, compiler. Exxon Valdez Oil Spill Restoration Project Annual Report. Restoration Project 97163 A-Q. Anchorage, AK.

Hassell, M. P. and R. M. May. 1974. Aggregations of predators and insect parasites and its bearing on stability. J. Anim. Ecol. 43:567-594.

Hoffman, W., D. Heinemann, and J. A. Wiens. 1981. The ecology of seabird feeding flocks in Alaska. Auk 98:437-456.

Kennedy, D. E., and D. W. White. 1996. Interference competition from house wrens as a factor in the decline of Bewick's wrens. Conserv. Biol. 10:281-284.

Mahon, T. E., G. W. Kaiser, and A. E. Burger. 1992. The role of marbled murrelets in mixed-species feeding flocks in British Columbia. Wilson Bull. 104:738-743.

Maniscalco, J. M. and W. D. Ostrand. 1997. Seabird behaviors at forage fish schools in Prince William Sound, Alaska. Pp. 175-189 in Forage fishes in marine ecosystems. Alaska Sea Grant College Program, AK-SG-97-01, University of Alaska Fairbanks.

Maniscalco, J. M., W. D. Ostrand, and K. O. Coyle. 1999. Selection of fish schools by flocking seabirds in Prince William Sound, Alaska. Col. Waterbirds in press.

Maurer, B. A. 1984. Interference and exploitation in bird communities. Wilson Bull. 96:380-395.

Orians, G. H., and N. E. Pearson. 1979. On the theory of central place foraging. Pp. 154-177, in D. J. Horn, R. D. Mitchell, and G. R. Stairs, eds. Analysis of ecological systems. Ohio State University Press, Columbus.

Ostrand, W. D., K. O. Coyle, G. S. Drew, J. M. Maniscalco, and D. B. Irons. 1998. Selection of forage-fish schools by murrelets and tufted puffins in Prince William Sound, Alaska. Condor 100:286-297.

Perrson, L. 1985. Asymmetrical competition: are larger animals competitively superior? Am. Nat. 126:261-266.

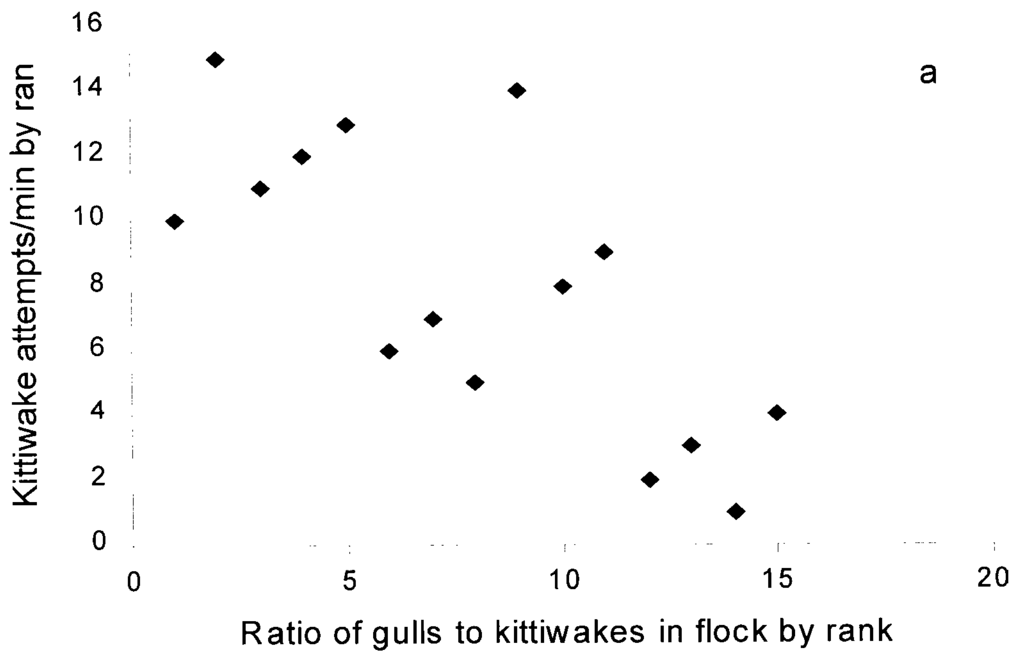
Poysa, H. 1985. Circumstantial evidence of foraging interference between two species of dabbling ducks. Wilson Bull. 97:541-543.

Roby, D. D., K. R. Turco, and J. A. Anthony. 1998. Diet composition, reproductive energetics, and productivity of seabirds damaged by the Exxon Valdez oil spill. Pp. G1-23 in D. C.

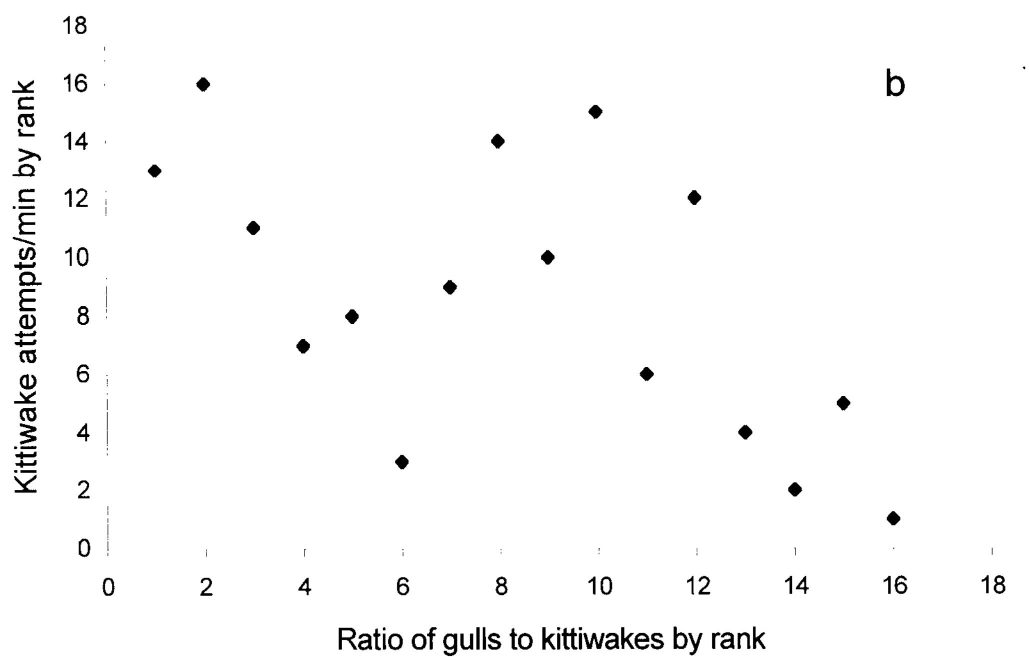
Duffy, compiler. Exxon Valdez Oil Spill Restoration Project Annual Report. Restoration Project 97163 A-Q. Anchorage, AK.
Schoener, T. W. 1983. Field experiments on interspecific competition. Am. Nat. 122:240-285.
Shealer, D. A., and J. Burger. 1993. Effects of interference competition on the foraging activity of tropical roseate terns. Condor. 95:322-329.
Suryan R. M., D. B. Irons, and J. E. Benson. 1998. Interannual variation in diet and foraging effort of kittiwakes in relation to prey abundnace. Pp. E1-15 in D. C. Duffy, compiler. Exxon Valdez Oil Spill Restoration Project Annual Report. Restoration Project 97163 A-Q. Anchorage, AK.
Ydenberg, R. C., L-A. Giraldeau, and D. L. Kramer. 1986. Interference competition, payoff asymmetries, and social relationships of central place foragers. Theor. Popul. Biol. 30:26-44.

Figure 1. Relationship between the number of feeding attempts by Black-legged Kittiwakes and the ratio of Glaucous-winged Gulls to kittiwakes in the feeding flock; a) feeding flocks as the sample unit (1995 and 96) and b) Black-legged Kittiwake as the sample unit (1997).

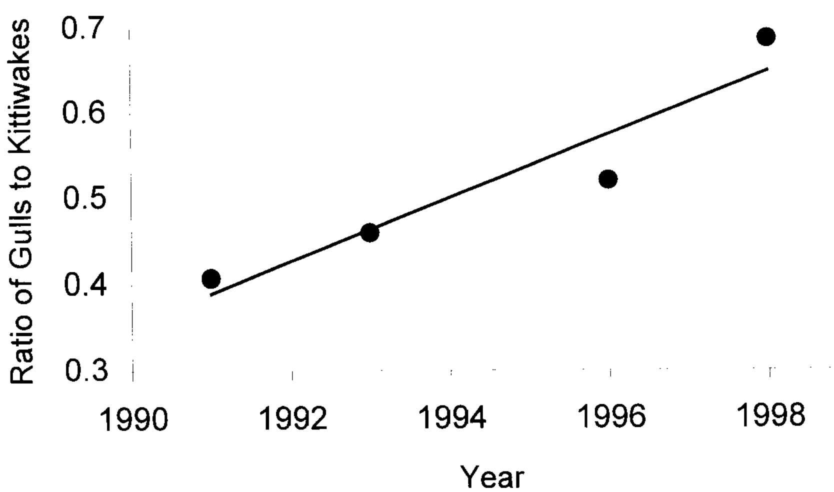
Figure 2. Relative abundances of Glaucous-winged Gulls to Black-legged Kittiwakes in PWS since 1991 with trend line.



a
Kittiwake attempts/min by ran
0
2
4
6
8
10
12
14
16
0
5
10
15
20
Ratio of gulls to kittiwakes in flock by rank



b
Kittiwake attempts/min by rank
0
2
4
6
8
10
12
14
16
18
0
2
4
6
8
10
12
14
16
18
Ratio of gulls to kittiwakes by rank



Ratio of Gulls to Kittiwakes
0.7
0.6
0.5
0.4
0.3
1990
1992
1994
1996
1998
Year

Sand Lance Habitat Determination Through Hydroacoustic Sampling

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

Pacific sand lance (*Ammodytes hexapterus*) play an important ecological role as energy-rich prey for seabirds, marine mammals, and predatory fishes in Prince William Sound, Alaska (PWS). However, due to lack in commercial interest, the biology and habitat requirements of this species are poorly understood (McGurk and Warburton 1992). Sand lance are commonly found in shallow nearshore habitats where they burrow in sandy substrates while not foraging, to avoid predation, and during overwintering, thereby linking this species distribution to habitats with distinct sediment grain sizes (Pinto et al. 1984). Sand lance are generally found in association with sandy bottoms, and avoid rocky, muddy, and coarse gravel bottoms (Reay 1970).

Sand lance population dynamics may play an important role in regulating apex predator populations and are a potential indicator of marine pollution in areas at risk to oil spills. For example, the reproductive success of at least 10 avian species has been correlated with sand lance availability, including: great skuas, parasitic jaegers, shags, black-legged kittiwakes, Arctic terns, common terns, Atlantic puffins tufted puffins, and rhinoceros auklets (Wilson et al., In prep.). In addition, the distribution of kittiwake breeding colonies has been shown to reflect sand lance distribution and abundance (Lock 1986 *in* Wilson et al., In prep.). The life history of sand lance, as both a schooling and a semi-demersal species, places them at risk to oil slicks, soluble toxins within the water column, and long term impacts due to sediment contamination. In planning development in marine environments and in identification of critical habitats to protect in the event of oil spills, we suggest that sand lance burrowing habitat should be of a primary concern.

Sand lance habitat may be broadly distributed (Penttila 1997), making the identification of critical habitat problematic. Dedicated surveys are expensive and time consuming. The development of accurate and inexpensive methods of identifying sand lance habitat are desirable both for research and environmental protection. Recently, software has been developed that can classify bottom type by interpreting narrow beam, quantitative hydroacoustic data. In other words, this software can determine the bottom type by interpreting data that may have been previously collected during fisheries (hydroacoustic) surveys. The use of acoustic methods to retrieve information from the acoustic bottom echo has advantages over other methods (i.e. geological cores) as being non-invasive, more cost effective, and faster (Lubniewski and Stepnowski 1997). Due to the strong linkage of sand lance to a narrow range of sediment types (Reay 1970), the classification of substrates through the use of bottom typing software is a potential tool in determining the distribution of sand lance burrowing habitat.

<u>Objectives</u>

1. Develop an inexpensive method to predict the distribution of sand lance burrowing habitat.

2. Develop GIS coverages that indicate the probability of encountering sand lance at all locations within our study areas using results derived from sand lance resource selection function.

Data collection and analysis completed and in progress:

During 17-27 July 1997 (in collaboration with the School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, Project 98163A) we hydroacoustically sampled nearshore transects in PWS arranged within 27 study blocks. Blocks followed the contour of 12 km of shoreline with a width of 1 km and contained 20 continuous, 1.2 km transects, that were laid out in a zigzag pattern for a total of 530 transects (Figure 1). Hydroacoustic data were collected with a single beam 120 kHz BioSonics DT4000 system that emitted a 6° beam.

To model forage fish habitat selection we have developed a set of sand lance locations that were collected by numerous APEX studies in PWS during 1997 and 1998 (Figure 2). Techniques used to determine the presence of sand lance included cast, dip, and seine nets; fish traps; under rocks and by stomping; visual identification; video cameras; and aerial surveys.

To calibrate bottom typing software, sediment samples were collected with a Ponar grab at 53 randomly selected locations within the APEX study area during the summer of 1998 . Due to the roughness and/or rockiness of the bottom substrate, successful samples (i.e. ≥ 50 g) were only obtained at 26 of 53 random sites (Figure 1). Samples were frozen and then oven dried (150^0 C for three hours) prior to laboratory analysis. Grain size analysis was performed on sediment samples using a sieve/hydrometer procedure (Day 1965) which determined percentage gravel, sand, silt, and clay for each sample following the USDA scale (Gee and Bauder 1986).

To model habitat selection by sand lance we began by performing cluster analysis, Ward's minimum variance method (SAS Institute Inc., 1996), of sediment sample data with the variables percent gravel, sand, and mud (silt/clay). Clusters were assigned a sediment code (gravel, sand, sandy mud, and mud) taken from Folk (1980) (Table 1; Figure 3). We added an unknown category to account for all substrate types that we did not sample.

Next, we analyzed hydroacoustic data collected during the 1997 forage fish survey with bottom typing software (VBT Seabed Classifier™, BioSonics, Inc., Seattle, WA). This process produced several variables that described the characteristics of the bottom signal. We adjusted the software to average the characteristics of the bottom and produce an output at 30-m intervals. We found the calibration feature of the software to be ineffective and are proceeding to develop our own methods to calibrate and categorize the programs output. First we will import the bottom typing output into GIS. A separate coverage will be developed for each variable of the output to which we will apply a krigging algorithm (surface interpolation function) to create a 1-km wide buffer along the survey routes (Figure 4). Next we will categorize sediments by comparing the characteristics of the bottom signal at locations at which grabs were taken to all locations through the use of compositional analysis (SAS Institute Inc., 1996). Each location within the buffers will be assigned the bottom type to which its bottom signal is most similar. We will also develop a krigged bathymetry coverage from the hydroacoustic data for the buffered survey lines. These coverages will be used to determine the depth, distance from shore, and bottom type at known sand lance and an equal number of randomly selected locations. We will utilize these data to develop a sand lance resource selection function, based upon logistic regression (Manly et al. 1993). Finally the resource selection function will be utilized to develop a GIS coverage that displays the probability of encountering sand lance along the buffered survey routes.

Literature Cited

Day, P. R. 1965. Particle fractionation and particle-size analysis, hydrometer method. *In* Methods of Soil Analysis, Part I. Agronomy 9:562-66. Amer. Soc. of Agron., Madison, Wis.

Folk, F. L. 1980. Petrology of sedimentary rocks. Hemphill Publishing Co., Austin, T., pp 182.

Gee, G. W. and J. W. Bauder. 1986. Particle-size analysis. Chapter 15 *in* Methods of Soil Analysis, Part I. Physical and Mineralogical Methods. Agronomy Monograph no. 9, pp. 383 – 411.

Lubniewski, Z. and A. Stepnowski. 1997. Sea bottom typing using fractal dimensions. Pages 12 – 16 *in* International Symposium on Hydroacoustics and Ultrasonics. Gdansk-Jurata, Poland.

Manly, B. F. J., L.L. McDonald, and D. L. Thomas. 1993. Resource selection by animals, statistical design analysis for field studies. Chapman and Hall, London.

McGurk, M. D. and H. D. Warburton. 1992. Pacific sand lance of the Port Moller estuary, southeastern Bering Sea: an estuarine-dependent early life history. Fisheries Oceanography 1(4):306-320.

Penttila, D. E. 1997. Investigations of intertidal spawning habitats of surf smelt and Pacific sand lance in Puget Sound, Washington. Pages 395 – 408 *in* Forage Fishes in Marine Ecosystems: Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program, AK-SG-97-01, Anchorage, AK.

Pinto, J M, W.H. Pearson and J. W. Anderson. 1984. Sediment preferences and oil contamination in the Pacific sand lance *Ammodytes hexapterus.* Marine Biology 83: 193-204.

SAS Institute Inc., 1996. SAS/STAT User's Guide: Volume 1, Version 6, Fourth Edition. SAS Institute Inc., Cary, N.C., pp. 535 – 536.

Wilson, M. F., R. H. Armstrong, M. D. Robards, and J. F. Piatt. In prep. Sand lance as cornerstone prey for predator populations. Res. Pap. PNW-RP-XXX, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest research Station, pp. 48.

Table 1. Results of cluster analysis of sediment types for 26 samples using four variables: gravel, sand, silt, and clay.

Cluster	1	2	3	4
Sediment	S	SM	G	M
N of Samples	4	11	7	3
min%S	0.8	0.38	0.05	0.13
max%S	0.92	0.62	0.31	0.39
min%M	0.06	0.01	0.05	0.49
max%M	0.2	0.47	0.29	0.55
Description	Sand	Sandy Mud	Gravel	Mud (Silt/Clay)
	>80%		>50%	>50%

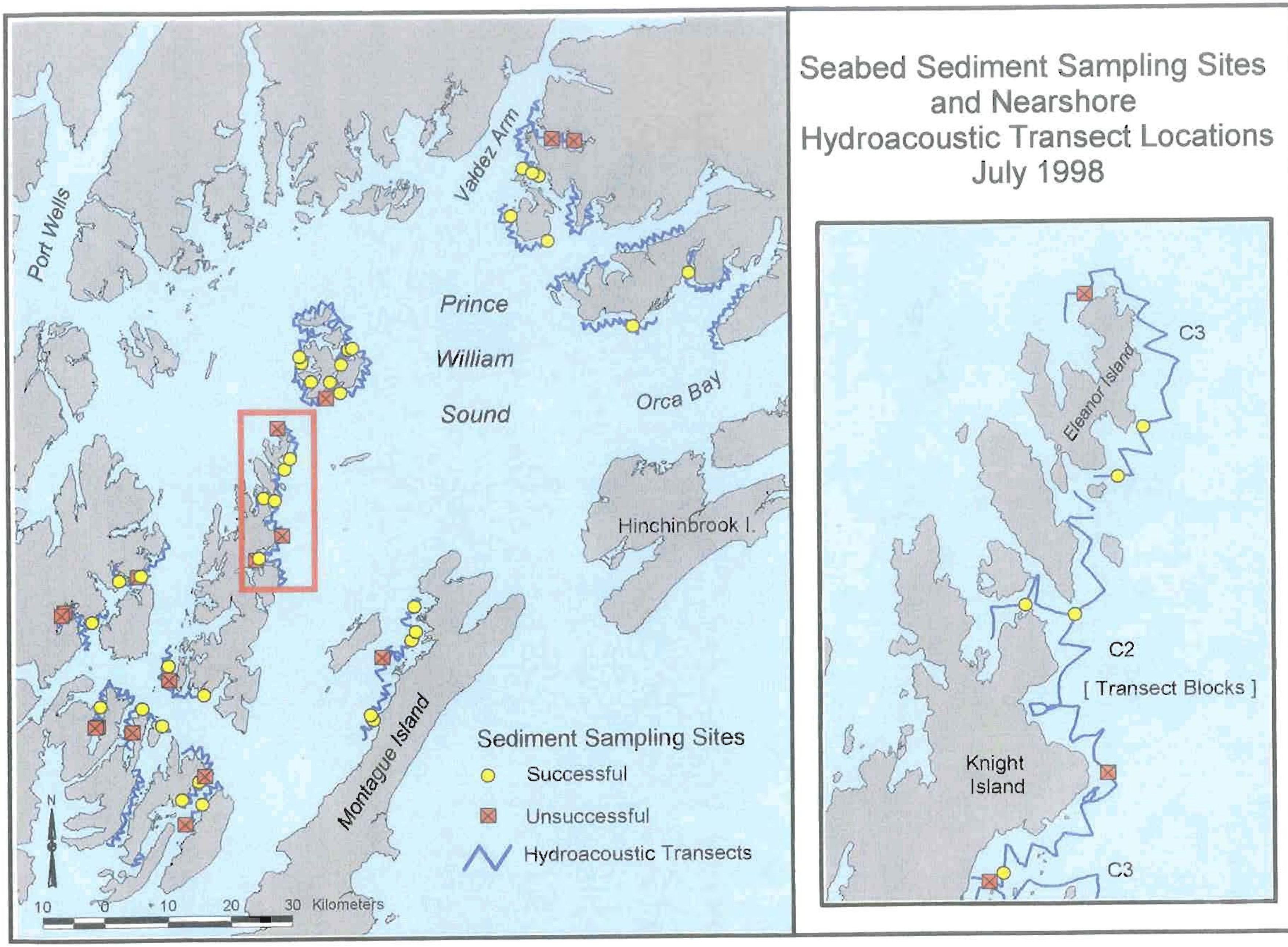
Figures

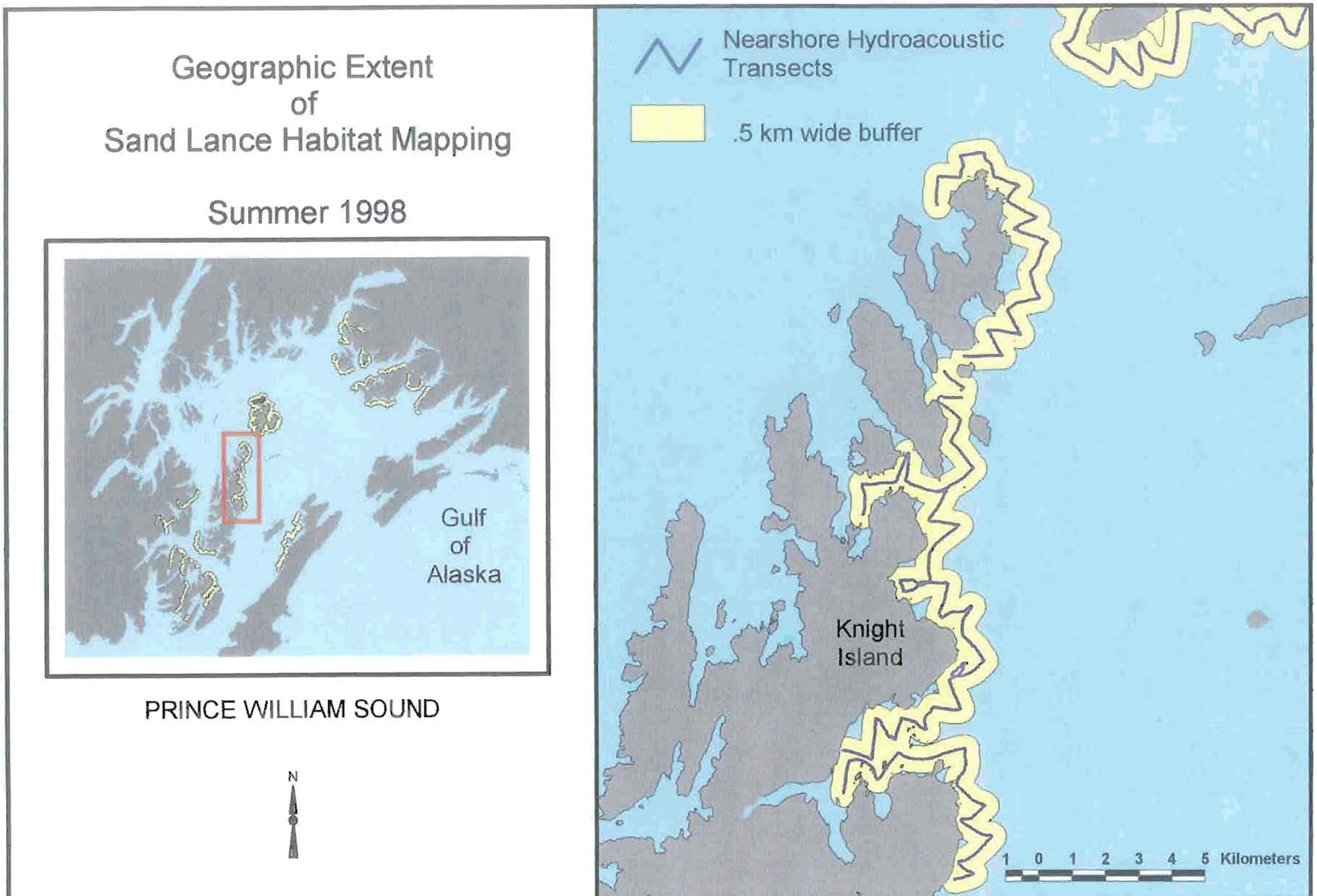
FIGURE 1. Location of nearshore hydroacoustic transects during summer 1997 and location of seabed sediment sampling sites during summer 1998.

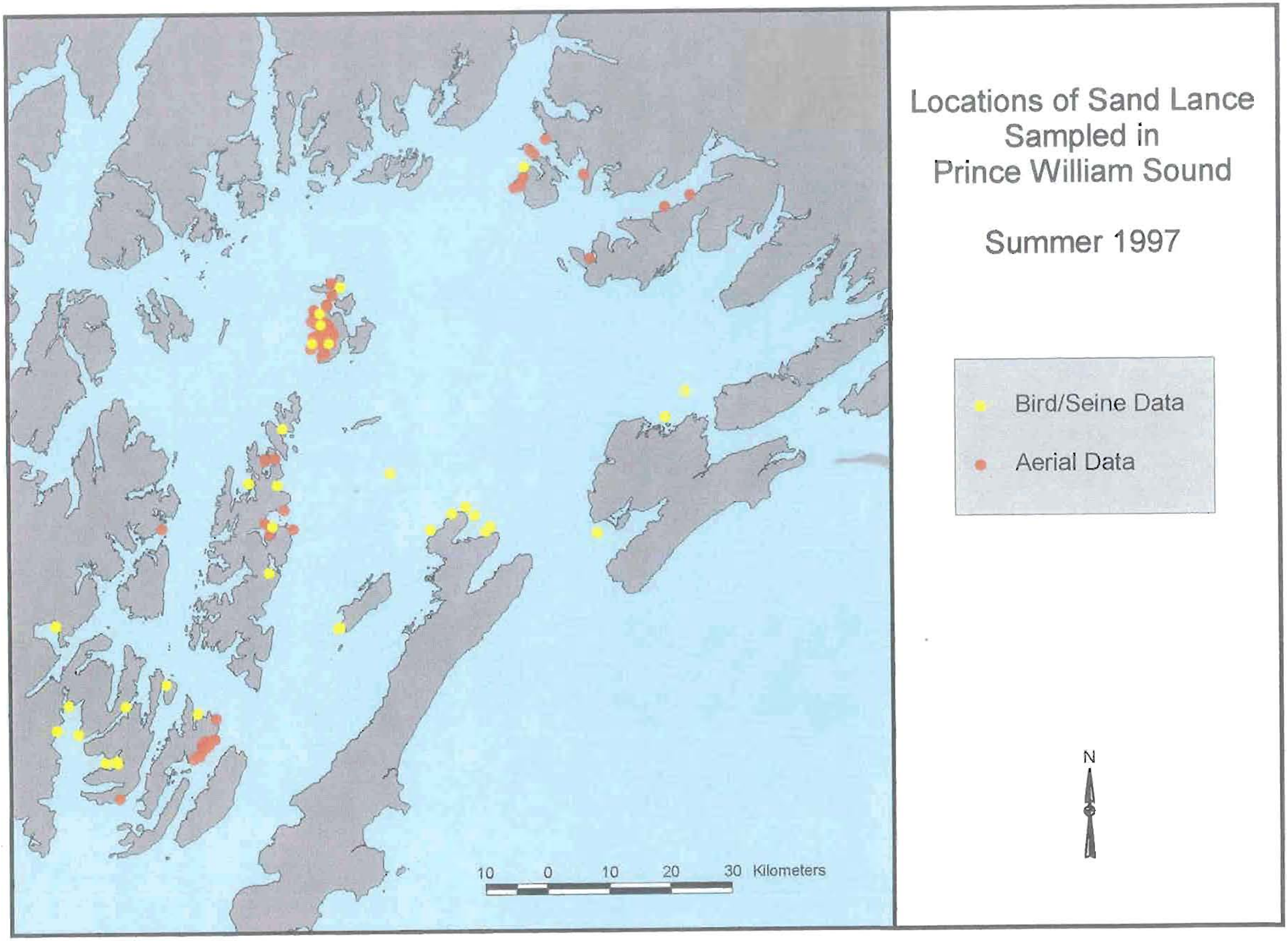
FIGURE 2. Locations where sand lance were observed during summer 1997.

FIGURE 3. Particle size analysis results for 26 sediment samples.

FIGURE 4. The geographic extent of sand lance habitat mapping. To determine this extent we generated a 1 km wide buffer around nearshore transects. Krigging analysis will be performed only within buffered areas.


Seabed Sediment Sampling Sites
and Nearshore
Hydroacoustic Transect Locations
July 1998
Port Wells
Valdez Arm
Prince
William
Sound
Orca Bay
Hinchinbrook I.
Montague Island
Sediment Sampling Sites
Successful
Unsuccessful
Hydroacoustic Transects
N
10 0 10 20 30 Kilometers
C3
Eleanor Island
C2
[Transect Blocks]
Knight
Island
C3


Geographic Extent
of
Sand Lance Habitat Mapping
Summer 1998
Gulf
of
Alaska
PRINCE WILLIAM SOUND
N
Nearshore Hydroacoustic
Transects
.5 km wide buffer
Knight
Island
1 0 1 2 3 4 5 Kilometers

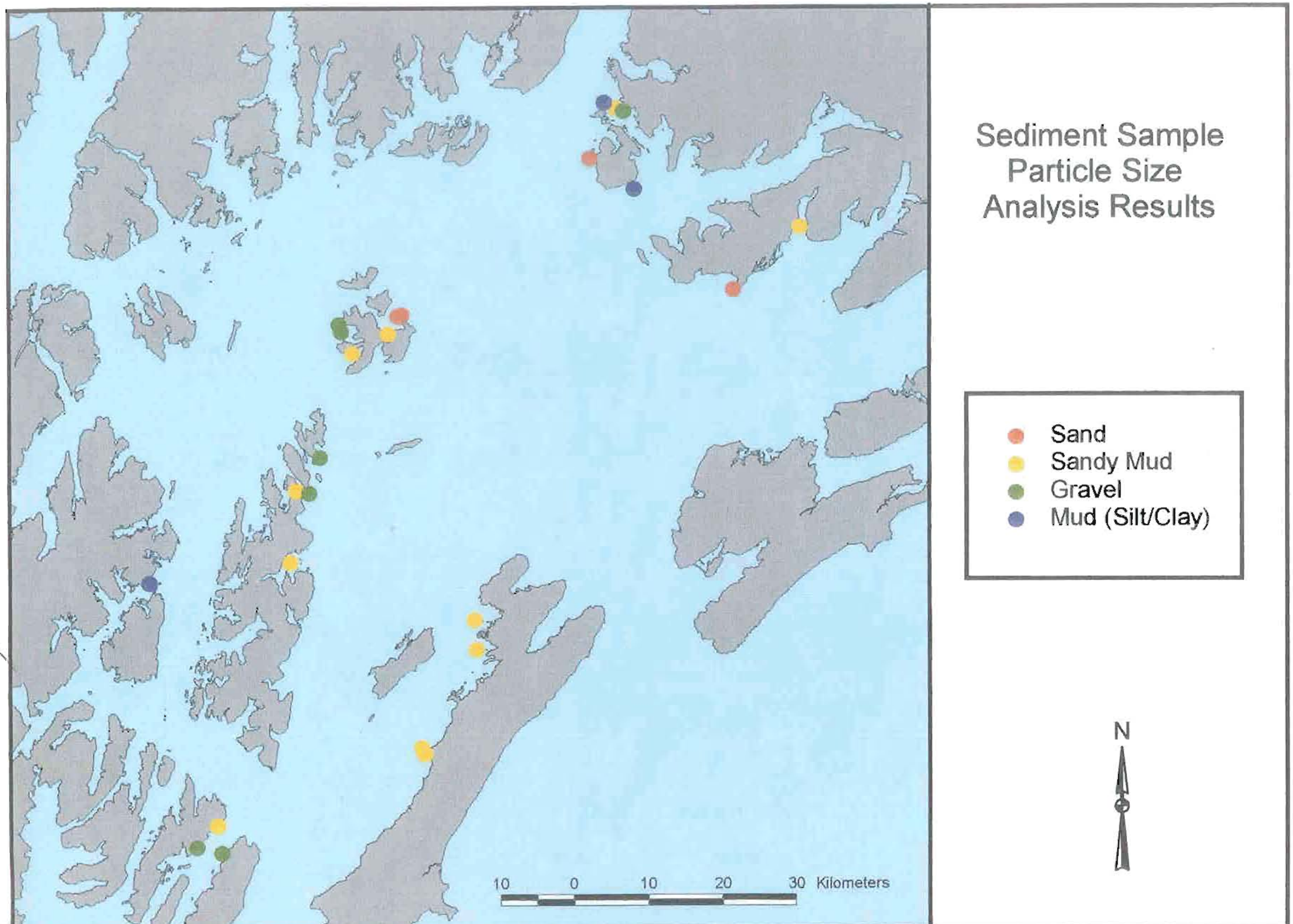

Locations of Sand Lance
Sampled in
Prince William Sound

Summer 1997

Bird/Seine Data
Aerial Data

10 0 10 20 30 Kilometers

N


Sediment Sample
Particle Size
Analysis Results
Sand
Sandy Mud
Gravel
Mud (Silt/Clay)
N
10 0 10 20 30 Kilometers