Exxon Valdez Oil Spill
Restoration Project Annual Report

Juvenile Herring Growth and Habitats

Restoration Project 97320T
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.

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April 1998

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Study history: Restoration Project 97320T is the core of the Herring Recruitment Dynamics Project, a multi-investigator ecosystem study and part of the Sound Ecosystem Assessment (SEA; PWSFERPG 1993) program in Prince William Sound (PWS). SEA was initiated because the lack of knowledge of the ecological processes affecting pink salmon and herring confounded the identification of damage caused by the *Exxon Valdez* oil spill. The PWS herring population crashed in 1993 possibly due to a viral infection (VHSV). This viral infection occurs more frequently in fish exposed to oil. Local residents, frustrated by the loss of valuable fisheries and the inability to accurately identify the causes, strongly voiced support for research. They formed a group, appealed to the EVOS Trustee Council, and as a result of their effort, SEA was created in 1994. Research on juvenile herring began in April 1995.

Abstract: The purpose of this project is to determine spatial distributions and habitats of age 0 to 2 year old Pacific herring (*Clupea pallasi*). In 1997 we completed 5 diel acoustic surveys, sampling Eaglek, Whale, Ziakof, and Simpson Bays in March, May, July, August and October. Aerial surveys were completed in June and July. As our field sampling effort decreased, our focus shifted to data analysis. The Prince William Sound Pacific herring population was made up of 3 size modes representing young of the year, juvenile (1-2 year old) and adult (sexually mature) herring. Herring of each size mode were contagiously distributed on different spatial scales. Cohorts (age/size) of herring were spatially segregated. Juvenile herring aggregated in Bays for the first 2 years of their life. Prey availability and herring prey selection varied spatially and temporally. These spatial distributions define the area where the physical and biological variables occur determining Pacific herring life history and population size in Prince William Sound.

Key Words: *Clupea pallasi*, Pacific herring, juvenile, habitat, Prince William Sound, distribution

Project Data: Spatial distribution (acoustic and aerial), length frequencies, zooplankton community structure, diet compositions and near shore ichthyofauna structure are part of the SEA data base (Project 97320-J Information Services and Modeling).

CITATION: Stokesbury, K.D.E., E.D. Brown, R.J. Foy, and B.L. Norcross. 1998. Juvenile Herring Growth and Habitats, *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 97320T), Institute of Marine Science, University of Alaska Fairbanks, Fairbanks, Alaska.

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Executive Summary

This project is a component of the Herring Recruitment group of SEA, initiated to provide information on the herring population in Prince William Sound and restoration measures required after the *Exxon Valdez* oil spill. The Herring Recruitment group is examining the physical and biological mechanisms affecting the survival of juvenile Pacific herring (*Clupea pallasi*) and providing indices of recruitment into the fishing stock. To do this a conceptual model addressing three objectives: 1.) overwintering survival model, 2.) summer habitat model, 3.) monitoring strategy, has been created. The Growth and Habitat project is determining: 1.) horizontal and vertical distributions of juvenile herring, using hydroacoustic and aerial surveys, and the underlying biological (predator distribution, prey distribution) and physical variables (oceanographic conditions, substrata) influencing these distributions, 2.) survival rate of juvenile herring based on densities and yearclass distribution, 3.) summer growth rates in different areas, 4.) habitat quality, based on oceanographic conditions, energetics, growth rates and prey availability, 5.) larval drift based on the SEA oceanographic model, 6.) an overwintering survival model.

In 1997 we completed 5 diel surveys, sampling Eaglek, Whale, Ziakof, and Simpson Bays in March, May, July, August and October. During all but the latter survey four or five vessels were employed: an acoustic vessel, a trawler, a seiner, a processing boat which also supported the inshore fry skiff, and an oceanographic vessel. Aerial surveys were completed in June and July. One vessel was used during the October survey and focused on developing a cost-effective monitoring strategy combining hydroacoustic, zooplankton and fish collections with oceanographic measurements. As our field sampling effort decreased, our focus shifted to data analysis. Presently, the majority of acoustic survey data has been combined with fish collection data to extrapolate estimates of spatial distributions for pollock and herring. Diet composition of juvenile herring and prey availability within the four bays has been determined for 1995 and 1996, and work continues on the 1997 data.

The Prince William Sound Pacific herring population was made up of 3 size modes representing young of the year, juvenile (1-2 year old) and adult (sexually mature) herring. Herring of each size mode were contagiously distributed on different spatial scales. Cohorts (age/size) of herring were spatially segregated. Juvenile herring aggregated in Bays for the first two years of their life. They congregated in surface waters during June and July. Prey availability and herring prey selection varied spatially and temporally.

These spatial distributions define the area where the physical and biological variables occur determining Pacific herring life history and population size in Prince William Sound. The lack of information of these variables confounded the identification of damage caused by the *Exxon Valdez* oil spill and estimates of the population's recovery time. Our future work will focus on determining these variables.

Introduction

The purpose of this project is to determine spatial distributions and habitats of age 0 to 2 year old Pacific herring (*Clupea pallasi*). It is linked to the Herring Recruitment Dynamic subgroup of SEA and provides data for the three objectives (1. overwintering survival model, 2. summer habitat model, 3. monitoring strategy) which will determine the physical and biological mechanisms influencing the recovery of Pacific herring. Pacific herring is listed as "not recovered" in the "Resources and Services Injured by the Spill" *Exxon Valdez* Oil Spill Restoration Plan.

The Herring Recruitment Model is being developed as the integration of several submodels, each of which focuses on a stage in the early life history of Pacific herring (*Clupea pallasi*). We hypothesize that, like other clupeoids, year-class strength of Pacific herring in Prince William Sound (PWS) is determined during its early life history. All field work, laboratory experiments, and data analysis for all components of SEA relate to one or more of these submodels. Two major SEA hypotheses are the focus of these submodels and will be linked within the overall Herring Recruitment Model (Figure 1). The first is the Herring Overwinter Hypothesis which states that survival of herring through their first winter is critical to year-class strength and is dependent upon their condition when they enter winter. We will test this hypothesis by examining distribution and condition of herring in the fall, winter and spring. We expect to see changes in condition indices related to the physical and biological variables of different geographic locations. A bioenergetic model, combining SEA field and laboratory observations together with energetic information from Atlantic herring studies, is being constructed to predict overwinter survival for recruiting herring. In support of the herring Overwinter Hypothesis we will examine how the Lake/River hypothesis applies to transport and distribution of herring at the larval stage. We will employ larval drift simulations, using the Circulation and Transport Models for PWS being formulated by Mooers and Wang as part of the Ocean Dynamics Model, to determine the expected drift of larval herring within PWS and determine how that affects the distribution of summer juvenile nursery areas. We expect to examine various drift patterns in response to simulated lake (i.e. retention), river (i.e. rapid movement through the sound), and combinations of varying amounts of "lake" and "river" in accordance with the recent evolution of the lake/river hypothesis. The larval drift synthesis is a tool, which will link the Summer Habitat Model, which examines location and characteristics of summer nurseries utilized by juvenile herring, with the Overwintering Survival Model. The Summer Habitat Model will determine the survival and growth rates of juvenile herring and the quality of nursery areas by examining changes in herring distribution, density, length, weight, energy (kJg^{-1}), interspecific biological variables (prey abundance, predation) and physical variables (oceanographic conditions, bathymetry). These data will define the conditions of herring entering into the Overwintering Survival Model.

This project is a component of the SEA project; Dr. T. Cooney chief scientist. Within SEA, coordination exists between projects linking physical and biological data. Multiple authors on proposed publications reflect this integration. In addition, this project coordinates with the APEX and NVP ecosystem projects via field logistics (vessels, equipment and samples), shared data (catch, aerial survey data, and acoustics results), and joint publications. Coordination with these groups increased during FY98 and we expect this to continue in FY99.

Objectives

The research objectives of this project are:

1. Develop an Overwinter Survival Model for juvenile herring.

2. Develop a Summer Habitat Model for juvenile herring.

3. Develop a Monitoring Strategy for juvenile herring.

For the Overwinter Survival Model:

Describe overwinter distribution, size, condition, energy needs, and relative abundance of juvenile herring, physical and biologic characteristics of herring nursery areas and overwintering bioenergetics.

Tasks:

1. Collect data on the whole body energy content of age 0 and 1 herring in the late fall and winter.

2. Determine changes in bioenergetics over the winter season using time sequence (monthly) sampling of juvenile herring from two or more index sites in 1996-97 and 1997-98.

3. Examine stomach contents of over-wintering recruits and make energetic estimates for consumption during the winter of 1996-97 and 1997-98.

4. Determine the energy need of fasting herring in the laboratory.

5. Develop a model to predict winter survivorship using field and laboratory measurements of over-winter energy needs and literature values for Atlantic herring.

6. Describe spring, pre-bloom biological and habitat conditions as an endpoint of Overwintering Survival Model and beginning of second year Summer Habitat Model.

7. Compile historic biological and physical data for the purpose of model verification

For Summer Habitat Model:

Describe summer and fall distribution, size, condition and relative abundance of juvenile herring (biological data), and physical and biological characteristics of herring nursery areas (habitat data) to evaluate quality of summer growth of herring and as initial conditions for the Overwintering Survival Model.

Tasks:

1. Use Circulation and Transport Models (Ocean Dynamics Model) to simulate drift of larval herring and distribution to summer nursery areas.

2. Determine distribution of juvenile herring during the spring, summer and fall using broad scale surveys that include simultaneous overflights, acoustics and net collections.

3. Determine physical (salinity, temperature, depth, currents, light levels, bathymetry) and biological (zooplankton, competitors) parameters which determine good vs. bad nursery areas measured by condition of herring (length, weight, age, growth rates, stomach contents, energetic condition and stable isotopes).

4. Develop maps of key habitats (nursery areas) for juvenile herring within PWS.

5. Describe the retention characteristics of herring nursery areas using information from the larval drift simulations, physical oceanographic measurements and biological data (spatial distributions, isotopes, and growth rates) indicating immigration or emigration.

6. Develop maps of possible retention areas with different historical spawning sites and transport conditions.

7. Compare historic distributions reported by local and traditional knowledge with distributions described by this study

For Monitoring Strategy:

Tasks:

1. Identify key index sites and develop monitoring techniques by relating aerial, acoustic and net sampling data during summer surveys to condition of juvenile herring.

Methods

To address the above objectives and tasks, we have formulated our approach into two component models, each with several subcomponents. These models and subcomponents are described in chronological order of herring life history (Figure 1).

The first subcomponent is embryo survival. This component is not a SEA program, but rather projects funded by EVOS outside of SEA. For the starting point of our Summer Habitat Model, we intend to combine the results of 1) the ADF&G spawn deposition survey, 2) the Haldorson, Quinn and Rooper egg loss model which predicts losses due to physical factors and predation, 3) estimates of baseline egg mortality, and 4) estimates of baseline levels of viable hatch (Hose et al. 1996; Kocan et al. 1996). From this we will know the location of spawning of herring, an estimate of the amount of spawn, and the expected percentage of viable larvae produced.

The output of that subcomponent is the input into the Larval Drift Model (Figure 1). We will examine the direction of transport without incorporating the population size component. We will run the Ocean Circulation and Transport Model with input at the locations of herring spawning and test observed distribution of particles. Distribution predicted by this subcomponent will be verified by the distribution of age-0 herring during the summer. We will compare the Larval Drift Model results to the transport and retention of larval Atlantic herring (*Clupea harengus*) in North Atlantic (Graham and Davis 1971, Graham and Townsend 1985, Sinclair and Iles 1985, Sinclair 1988). We will also use 1989 as a test case. By inputting location of spawning and physical conditions which we know occurred in 1989, we can test the model against the offshore distribution of larvae observed in May, June and July 1989 (Norcross and Frandsen 1996) and the nearshore distribution observed in May 1989 (McGurk 1990). We will also use spawning location information from 1995, 1996 and 1997 correlated with the distribution of larvae and the distribution of herring observed from the aerial and acoustic surveys. This simulation will be an iterative process.

The output of the larval drift simulation is the input for the Summer Habitat Model (Figure 1). From October 1995 to March 1998, acoustic and aerial surveys were conducted and these data will be processed, analyzed, interpreted and combined to determine herring nurseries. The broadscale distribution of age-0 herring was observed during October 1995, March and July 1996. These surveys covered most of PWS and adjacent waters to Resurrection Bay. The Sound is very large and resources were limited so the survey focused on regions where fishermen had observed juveniles and where earlier ADF&G surveys indicated high densities of herring (<1 km from shore). Sampling from the air provided approximately weekly estimates of horizontal distribution of herring across the Sound.

These broadscale surveys provided a preliminary estimate of oceanographic patterns and distribution of herring. However, the broadscale survey was a continuous transect along the coastline of Prince William Sound and there were several limitations associated with its design, for example, it was non-random, and it was a temporal point measurement while fish distribution and oceanographic conditions are strongly effected on a short temporal scale by the tidal cycle and the diel (day/night) cycle.

We have addressed these limitations by employing a factorial design, based on Green's (1979) principles of sampling to derive the survival rate of juvenile herring from density changes using a life table. Densities must be estimated precisely and accurately on both spatial and temporal scales. In this factorial design each spatial replicate (bay) has 3 temporal replicate samples within 24 hours, allowing us to estimate the variability in densities caused by tidal and diel cycles and allow accurate measurements of the oceanographic conditions of each bay (Gunderson, 1993) (Figure 2). This design allows an overall estimate of changes in survival rates of Prince William Sound juvenile herring and comparisons between and within bays on different spatial and temporal scales, i.e. 24 hours, monthly, annually. The four bays are, Eaglek, Whale, Ziakof and Simpson. These bays were selected because:

1. herring overwinter in bays

2. spatially segregated; North South, East and West.

3. located at a distinct position along the prevailing PWS current, relating directly to the lake/river hypothesis (Cooney 1995: Chapter 7 Fig. 11-17; and Chapter 9).

4. strong evidence that herring spawn/recruitment in each of these bays

Each bay was surveyed three times in a 24 hour period using sidescan sonar (Figure 2). Net collections of herring were coupled with acoustics estimates of horizontal and vertical distribution and abundance, and aerial estimates of horizontal distribution. These net collections are used to ground-truth both acoustic and aerial estimates for species size and composition. Subsamples of herring were retained and later evaluated for size, age, stomach contents, condition (energetics and standard fisheries age-weight-length (AWL)), and stable isotopes (trophic analysis). Simultaneous with net collections for fish were vertical plankton tows to estimate availability of food for planktivorous herring. Oceanographic parameters collected include salinity and temperature at depth (CTD), estimates of current structure (ADCP), light levels and bathymetry at location. The main effort in 1998 will be to process, analyze and interpret these data.

Results and Discussion

Larval Drift Model

The Ocean Circulation and Transport Model is being developed and the first results are being published in the manuscript:

Mooers, C.N.K. and J. Wang. 1998. On the development of a three-dimensional circulation model for Prince William Sound, Alaska. Continental Shelf Research 17:000-000 in press.

This model will be the basis for the Larval Drift Model, which is presently being developed.

Summer Habitat Model

In this component we are determining the biological and physical variables influencing the spatial and temporal distribution of Pacific herring (*Clupea pallasi*) in Prince William Sound. This is a combined effort with support for acoustics and oceanography from PWSSC and technical support from Alaska Department of Fish and Game in Cordova.

The first manuscripts from this work are:

Stokesbury, K. D. E., J. Kirsch, E. D. Brown, G. L. Thomas, B. L. Norcross. 1998. Seasonal variability in Pacific herring (*Clupea pallasi*) and walleye pollock (*Theragra chalcogramma*) spatial distributions in Prince William Sound, Alaska. **Appendix I**

Brown, E.D. , S. Vaughan, and B.L. Norcross. In prep. Annual and seasonal spatial variability of herring, other forage fish, and seabirds in relation to oceanographic regimes in Prince William Sound, Alaska *in* Ecosystem Considerations in Fisheries Management, Lowell-Wakefield Symposium. A preliminary look at data to be included in this publication is attached in **Appendix II**.

Brown, E.D., G.A. Borstad, and B.L. Norcross. In prep. Assessment of forage fish distribution, relative abundance, and ecology using aerial surveys: survey design and methodology. Ecological Applications draft. Chapter 11, Appendix I, SEA 1996 Annual Report. **Appendix III** is a progress report on this work.

Foy, R. J., and B. L. Norcross. 1998. Spatial and Temporal Differences in the Diet of Juvenile Pacific Herring (*Clupea pallasi*) in Prince William Sound, Alaska. **Appendix IV**

Overwintering Survival Model

The Overwintering Survival Model evaluates distribution and condition of age 0 and 1 herring as they enter, pass through, and complete the winter. The objective of this sampling is to determine change in condition of herring over the course of winter in concert with the hypothesis that herring which enter winter in poor condition due to "bad" nursery habitats will not survive winter, while those from "good" habitats will successfully survive winter.

Dr. A.J. Paul is leading this effort, he and his co-authors have submitted the following manuscripts:

Paul, A.J., J.M. Paul, and E.D. Brown. 1997. Fall and spring somatic energy content for Alaskan Pacific herring (*Clupea pallasi* Valenciennes 1847) relative to age, size and sex. Journal of Experimental Marine Biology and Ecology. 000:000-000 in press.

Paul A.J., and J. M. Paul. 1997) Comparisons of whole body energy content of captive fasting age zero Alaskan Pacific herring (*Clupea pallasi* Valenciennes) and cohorts over-wintering in nature. Journal of Experimental Marine Biology and Ecology. 000:000-000 in press.

Refer to Dr. Paul's sections in this Annual report for more details on these manuscripts.

Alaska Predator Ecosystem Experiment (APEX) Project Support

Juvenile herring were determined to be an important forage fish in PWS (Haldorson et al. 1996). Thus there is considerable overlap between research conducted by SEA and APEX. In 1997, SEA herring researchers were requested to cooperate and share data with researchers within APEX. Overflights were coordinated with APEX acoustic surveys and ongoing sea bird research. The aerial database was shared with APEX to enhance modeling efforts linking fish distribution to bird foraging behavior and reproductive effort. In addition, SEA aerial and net catch data concerning jellyfish was shared with the APEX project for analysis and publication. We expect these cooperative efforts to continue as both programs move toward synthesis.

Historic Data Summary

An effort to capture local knowledge about herring and other forage fish continued, for its second year, as a supplement to this project. Presently thirty-nine individuals have been interviewed. Several observations were consistent among interviewees: juvenile herring are most abundance at the heads of bays in the summer, juvenile herring have a different distribution than adults, juvenile herring schools are smaller but more abundant that adult schools. These anecdotal observations are in general agreement with the results of this study. A separate annual report has been prepared for 97320T supplement **Appendix V**.

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Norcross, B.L. and M. Frandsen. 1996. Distribution and abundance of larval fishes in Prince William Sound, Alaska during 1989 after the *Exxon Valdez* oil spill. *In* S.D. Rice, R.B. Spies, D.A. Wolfe and B.A. Wright (eds.). *Exxon Valdez* Oil Spill Symposium Proceedings. *Am. Fish. Soc. Symp.*

Sinclair, M. 1988. Marine Populations. Washing Sea Grant Program, Seattle, WA, 252p.

Sinclair, M. and T.D. Iles. 1985. Atlantic herring (*Clupea harengus*) distributions in the Gulf of Maine-Scotian Shelf area in relation to oceanographic features. Can. J. Fish. Aquat. Sci. 41:1055-1065.

Table 1. List of researchers we collected samples for during the SEA Herring cruises.

1. Kathy Frost, ADF&G Fairbanks, AK.; Marine Mammal Ecosystem. Needed various size fish of any species.

2. Jeff Short, Auke Bay, Juneau AK.; Needed herring and pollock.

3. Molly Sturdavent, Auke Bay, Juneau AK.; Needed capelin, sandlance, eulachon and pollock.

4. Tom Kline, PWSSC, Cordova AK.; Isotopes

5. John Piatt, NBS, Anchorage AK.; Needed juvenile herring and pollock

6. A.J. Paul, Seward Marine Center, Energetics, herring and pollock.

7. James Raymond, Univ. of Nevada; Needed blood and liver samples from herring in the Gravina or Montague area.

8. Steve Moffitt and John Wilcox, ADF&G Cordova. Herring AWL.

9. Richard Kocan, UW; Disease; 60 juvenile herring from 5 sites, would like heart, liver and spleen removed, put in tubes, and kept cool.

10. Gary Marty, UC-Davis; Disease; Looking at herring from the Montague Is. area

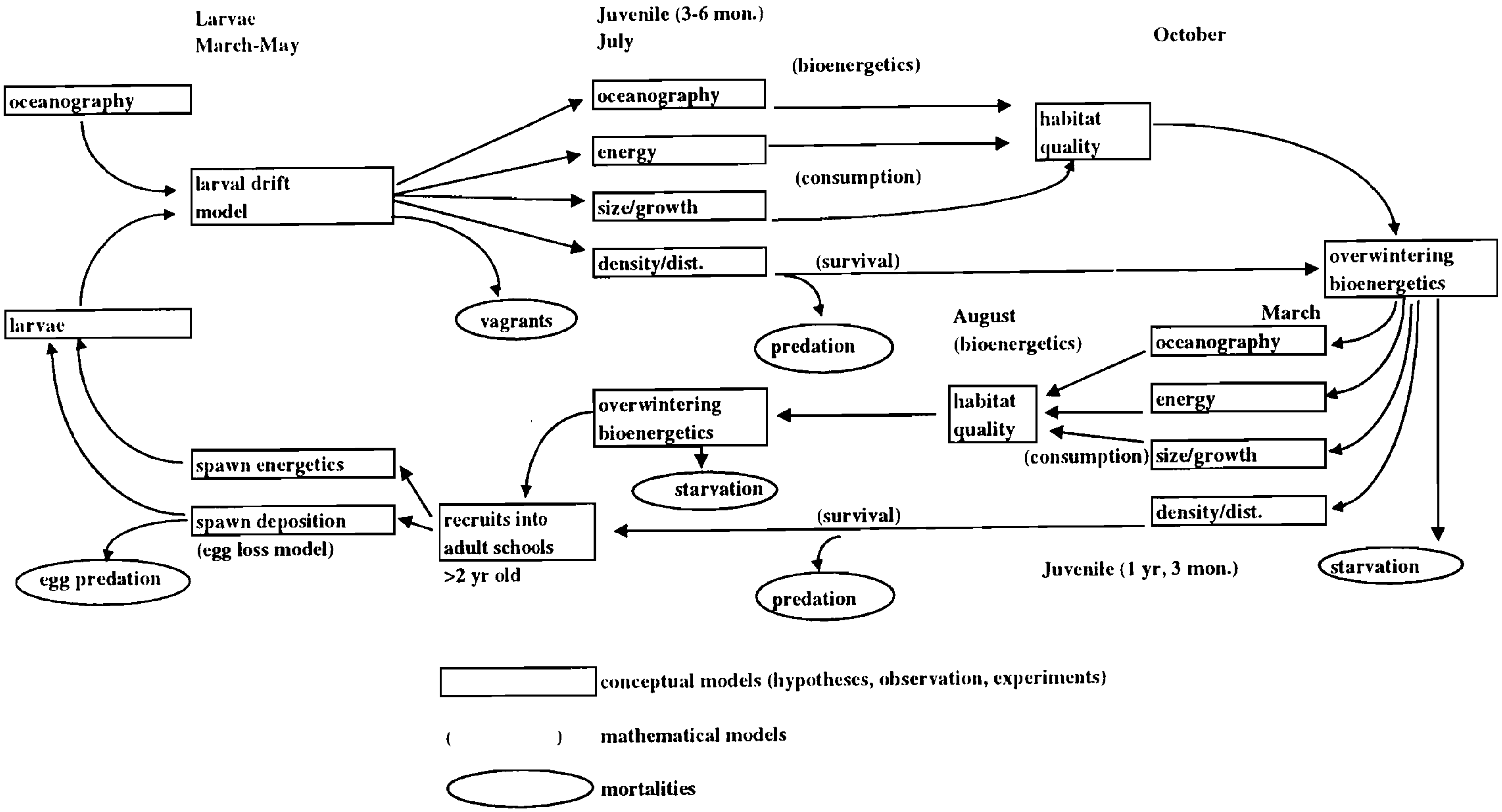

Figure 1. Herring Recruitment Model

SEA Herring Survival-Growth Sampling Design

7 day survey of Prince William Sound

Oct. 95 to Mar 98

	800	1600	2400	
Eaglek Bay				AWL, energetics, aerial survey
Whale Bay				AWL, energetics, aerial survey
Zaikof Bay				AWL, energetics, aerial survey
Simpson Bay				AWL, energetics, aerial survey

Sample Unit

Biological Factors		Environmental factors	
Y1	YOY herring	X1	Simpson/Hunter parameter
Y2	age 1 herring	X2	salinity
Y3	age 2 herring	X3	temperature
Y4	mature herring	X4	bathymetry
Y5	larval herring	X5	light intensity
Y5	juvenile pollock	X6	freshwater input
Y6	adult pollock	X7	tidal cycle
Y7	other species	X8	light
Y8	zooplankton		
Y9	jellyfish		
Y10	predators		

Y = dependent or independent variable
X = independent variable

Figure 2. 4-bay diel sampling design.

Appendix I

Stokesbury, K. D. E., J. Kirsch, E. D. Brown, G. L. Thomas, B. L. Norcross. 1998. Seasonal variability in Pacific herring (*Clupea pallasi*) and walleye pollock (*Theragra chalcogramma*) spatial distributions in Prince William Sound, Alaska. For submittion to Marine Ecology Progress Series.

Seasonal variability in Pacific herring (Clupea pallasi) and walleye pollock (Theragra chalcogramma) spatial distributions in Prince William Sound, Alaska.

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ABSTRACT: Pacific herring, Clupea pallasi, and walleye pollock, Theragra chalcogramma, spatial distributions were determined using acoustic surveys, with supporting net collections, in October 1995, March and July 1996 in Prince William Sound, Alaska. Of the 97 species of fish and macroinvertebrates collected, Pacific herring (65.0%) dominated the nearshore ichthyofauna, followed by walleye pollock (19.2%), Pacific sand lance (Ammodytes hexapterus; 2.6%), and capelin (Mallotus villosus; 1.9%). The Pacific herring population size structure was trimodal representing age 0, 1 to 2 year old, and adult fishes. The walleye pollock population size structure was bimodal representing age 0 and adult fishes. Large scale distributions of Pacific herring and walleye pollock were contagious, with aggregations occurring in the east-northeast and the west-southwest areas of the Sound. Pacific herring occupied the upper 30 m of the water column while walleye pollock were usually located near the bottom. Bays appeared to be nursery areas as age 0 and 1 to 2 Pacific herring were aggregated within them during all surveys. After their second winter juvenile herring joined the adult schools, leaving the bays at approximately the same time that new recruits enter the bays. Adult Pacific herring migrated seasonally, overwintering in Zaikof Bay and spending the summer in the west-southwest portion of the Sound.

Key words: Pacific herring, Clupea pallasi, walleye pollock, Theragra chalcogramma, acoustics, spatial distribution, nursery area, migration, size distribution, oil spill

Introduction

An organism's life history is it's response to physical and biological variables allowing it to persist in a specific geographic area over time (Sinclair 1988). In Prince William Sound, Alaska, the Pacific herring (Clupea pallasi Valenciennes, 1847) population crashed in 1993 (Funk 1994, Paine et al. 1996). Prince William Sound contains a biologically rich, high latitude ecosystem and little is known of the physical and biological variables influencing Pacific herring life history (Paine et al. 1996). This lack of information confounded the identification of damage caused by the 24 March 1989 Exxon Valdez oil spill (36,000 metric tons of north Slope crude oil effecting 900 km of coast line in PWS), commercial fisheries (bait, sac-roe, and roe on kelp) and estimates of the population's recovery time (Paine et al. 1996, Spies et al. 1996). This is the second pulse perturbation effecting Prince William Sound's marine community in 34 years, the 27 March 1964 earthquake raised sections of the coast line by as much as 3 m (Hansen & Eckel 1971). A third pulse perturbation may be occurring with this year's large El Nino. Fish communities in other highly perturbed systems have shifted their species composition and abundance to new equilibrium levels, for example large sand eel, pollock and eel pout populations replaced herring and mackerel populations in the North Sea due to high fishing mortality on the latter species (Andersen & Ursin 1978, Auster 1988). Walleye pollock (Theragra chalcogramma Pallas, 1814) may be a competitor and predator of Pacific herring and may have filled the vacancy in the nearshore ecosystem that occurred due to the decrease in herring density (Willette et al. 1997).

Pacific herring usually begin to spawn in their third year when they have reached a size of about 185 mm and a weight of 95 g (Robinson 1988). Females can produce as many as 40,000 eggs each year until they reach an age of about 15 years (Robinson 1988). Pacific herring deposit their eggs in mid-April in the nearshore low intertidal or subtidal zone, primarily on marine vegetation (Wespestad & Moksness 1990, Brown et al. 1996). In early May, after approximately 2 weeks, the eggs hatch into larval herring. They metamorphose from the larval to juvenile form when they reach a size of 25 mm to 30 mm, which can take from 4 to 10 weeks (Wespestad & Moksness 1990). During this time larvae are transported away from the spawning areas, although studies in British Columbia, Canada, have found significant densities remaining nearshore (Robinson 1988).

Walleye pollock, (Theragra chalcogramma) are an important commercial species in Alaskan waters and a primary forage fish for sea birds, marine mammals and fish (Clausen 1983, Hatch & Sanger 1992, Livingston 1993). Walleye pollock congregate and spawn in deep water in late March and April and the larvae occupy the upper 50 m of the water column in late May (Hinckley et al. 1991, Kendall et al. 1996). Walleye pollock metamorphose into juveniles in August and September (Hinckley et al. 1991, Kendall et al. 1996).

Acoustic estimates of fish abundance are frequently used for stock assessment and fisheries management but infrequently for ecological and life history studies (Thorne 1983a, Thorne 1983b, MacLennan & Simmonds 1991, Thomas 1992, Gunderson 1993, Misund 1997). Acoustic surveys estimating Pacific herring fishing stocks have been conducted from Alaska to California. but relatively few have been conducted in Prince William Sound (Thorne 1977a, Thorne 1977b, Trumble et al. 1982, Thorne et al. 1983, Thorne & Thomas 1990).

We examined seasonal variability in Pacific herring, Clupea pallasi, and walleye pollock, Theragra chalcogramma, spatial distributions in Prince William Sound, Alaska. We hypothesized that: 1. Pacific herring and walleye pollock were contagiously distributed and this distribution varied seasonally; 2. Pacific herring and walleye pollock occurred in different areas of the water column; 3. cohorts (age/size) of Pacific herring were spatially segregated; 4. juvenile Pacific herring aggregated in bays rather than passages or along open coastline. To test these hypotheses we determined the spatial distributions of Pacific herring age cohorts and walleye pollock observed during three acoustic surveys of the Prince William Sound coastline in October 1995, March and July 1996.

Material and Methods.

Prince William Sound is a large body of water separated from the Gulf of Alaska by a series of mountainous islands and deep passages (Fig. 1). The rocky coastline is highly irregular with numerous islands, passages, bays and deep fjords. The Sound has a semi-diurnal tide with a maximum range 4.4 m during this study.

The Prince William Sound coastline was acoustically surveyed in October 1995, March and July 1996 (Fig. 1). Five vessels were used during each 10 day survey (12 hours per day); three commercial fishing vessels (≈16.8 m) which deployed the acoustic and oceanographic equipment and fished the seines, a trawler (Alaska Department of Fish and Game R/V Pandalus, ≈20 m trawler), a cruise vessel (≈25 m) where the samples were processed. Surveys were conducted during the night (2000 to 0800 h) in October 1995 and March 1996 and in daylight (0800 to 2000 h) during July 1996.

The acoustic vessel followed a zig-zag pattern along the shore to a distances of ≈1 km at a speed of 14 to 17 km h^{-1}. The vessels sonar (50 KHz, 46°) was used to locate schools along the transect. When a school of fish was encountered the acoustic vessel slowed to 9 to 11 km h^{-1} and completed a series of parallel transects perpendicular to shore using a 120 kHz BioSonics 101 echosounder with a preamplifier dual-beam transducer. The transducer was mounted on a BioSonics 1.2 m BioFin and towed ≈1 m under the water surface. The acoustic signals were processed in real-time using the BioSonics ESP 221 Echo square integration software and ESP 281 Dual beam software, and stored on digital audio tape (Thorne 1983a, Thorne 1983b, MacLennan & Simmonds 1991). The acoustic system was calibrated both with a hydrophone and a standard target. Parameters of the acoustic system during the surveys were: source level = +225.023 dB; receiver gain = -159.28 dB; transducer directivity = 0.00107 and pulse duration = 0.4 ms. The signal to noise ratio exceeded that required to estimate the minium fish densities. The acoustic survey vessel used a GPS navigational system, and coordinates were imported by the ESP software and C-MAP software to plot the survey tracks.

Once the acoustic vessel surveyed a fish school, one of three fishing vessel sampled it to determine species composition and size structure. Fish were sampled using a modified bottom trawl for deep water targets (1.52 x 2.13 m Nor'Eastern Astoria V trawl doors, head rope 21.3 m, foot rope 29.0 m, estimated 3 x 20.0 m mouth, 10.2 cm mesh wings, 8.9 cm middle and a 32.0 mm cod end liner), an anchovy seine for surface schools (250.0 x 34.0 m and 20.0 m, 25.0 mm stretch mesh) or, in shallow water, a small salmon fry seine (50.0 x 8.0 m, 3.0 mm stretch mesh deployed from a 6m skiff equipped with a 70 horsepower engine). Each collection was speciated and 1000 herring, or other dominant fish species in the catch, were randomly subsampled. Fork length (mm) and weight (g) were recorded from 450 herring and remaining fish were measured to fork length. Seine collections were often very large, therefore once the subsample had been collected the remaining fish were released unharmed.

A length dependent scaling constant was used to convert the reflected acoustic energy into a biomass estimate:

TS re:w (dB re:kg) = -6.0 logx - 24.2 dB

where x is the mean fork length (cm) of the fish caught in the area (Thorne 1977b, Thorne 1983a, Thorne 1983b, Thorne& Thomas 1990). This equation differs from the more standard regression equation calculated by Foote (1987) as it derives the target strength as a proportion of weight. It was developed for echo integration primarily using Pacific herring surveys from Alaska and Puget Sound (Thorne 1983a). However, Thorne's equation was unsuitable for estimating walleye pollock target strength, due to the fish's morphology, therefore the more standard equation:

TS = 20 logx - 66.0 dB

was used (Foote & Traynor 1988, MacLennan & Simmonds 1991).

Echo integration measurements were converted into data cells with 120 to 40 m, 40 m or 20 m lengths (estimated from 2 ping s^{-1} with a surveying speed of 2.5 to 3.0 m s^{-1} equals 60 or 32, 32, 16 pings $cell^{-1}$ respectively) and 1 m widths and depths, during the October 1995, March 1996, and July 1996 surveys, respectively. Latitude and longitude were recorded simultaneously with each data cell from the GPS. The acoustic files were transferred to a UNIX work station for batch processing. Software created in the Interactive Data Language (IDL) was used to apply the acoustic calibrations and enabled interactive image editing to remove untracted bottom and other non-biological scatter.

Species proportion and size modes per species were determined from the fish collections. The species proportions, based on the number individuals per fish species in the random subsample, were converted to biomass using length/weight regressions. Using these proportions the echo integration densities (kg m^{-3}) were converted into number of Pacific herring per size mode, or number of Walleye pollock. Walleye pollock were not divided into size modes because the standard deviations of the mean fork lengths for individual collections indicated that aggregations were primarily a single size mode. Based on frequency distributions of the data we assumed that cells containing the equivalent of <0.5 fish m^{-3} were probably zooplankton, so they were removed from the data set (MacLennan & Simmonds 1991, Gunderson 1993). Fish located near the bottom were difficult to distinguish acoustically, so if the signal appeared to be corrupted the bottom 5 m were removed. Visual examination of the echograms and fish collections agreed with these assumptions.

The hypotheses that Pacific herring and walleye pollock were contagiously distributed, were spatially segregated, and that Pacific herring cohorts (age/size) were spatially segregated were tested by determining the large scale spatial distributions of herring size modes, calculated from fork length frequencies, using circular statistics (Batschelet 1981). The angle (0° = true north) for each data cell, within each herring size mode, was determined from an origin in the center of Prince William Sound (60° 60.00', 146° 90.00'; Fig. 1). These angles represent distributions along the transect line and are influenced by inequalities in shore line distance and sampling bias. These angle frequency distributions were compared to random distributions and to the distributions of other herring size modes along the same transect using a chi-squared test at the 5 % levels of significance (Batschelet 1981). Expected values were grouped according to Cochran's rule, which states that <20% of the expected frequencies should have a value <5 (Sokal & Rohlf 1981).

The hypothesis that juvenile herring aggregated within bays was tested by examining the relationship between the spatial distributions of herring and distances from shore. A group of data cells was considered to be a fish school if the sum of the differences between latitudes and longitudes of adjacent cells was >0.009°. Visual examination of the echograms and plots of cells along transects supported this assumption. Bays were statistically defined from passages or open coast line by creating a parameter that is the sum of the three nearest shore distances (Σ3NSD), each separated by 90°. This measurement was calculated at 12 bays and along 2 passages, 26 inside bays and 17 outside bays, to verify that it accurately defined bays, passages, and open coast line. The Σ3NSD for each herring school within each size mode was calculated and compared to the same measurements from randomly selected points along the transect for the three surveys using a chi-squared test. Expected values were grouped according to Cochran's rule (Sokal & Rohlf 1981). This technique corrected sampling and shoreline structure biases, for example 80 % of the shoreline may have been in bays or we may have surveyed bays more than open coastline or passages. Further to determine if there were physical differences in water mass and larval fish community structure at these locations vertical water profiles measuring temperature and salinity at 1 m intervals, using a SeaBird instrument, and two tucker trawl samples (1 m^2 mouth, 505μ mesh nets) were collected at each of these sites. Tucker trawl samples were preserved in 10% formalin for >48 h, then transferred to 50% isopropyl acholol and sorted to species and measured in the laboratory.

Results.

Ninety-seven species of fish and macroinvertebrates were collected during October 1995, March and July 1996 surveys. Pacific herring (Clupea pallasi; 65.0%) dominated the ichthyofauna; followed by walleye pollock (Theragra chalcogramma; 19.2%), Pacific sand lance (Ammodytes hexapterus Pallas, 1814; 2.6%), and capelin (Mallotus villosus Muller 1776; 2.0%) (Table 1). Pacific herring and walleye pollock were collected in all fishing gear during each survey while the majority of capelin and Pacific sand lance were collected in seines during March and July 1996, respectively (Table 1).

The Pacific herring population consisted of three size modes representing age 0, 1 - 2 year old, and adult fishes (Fig. 2). In October 1995 the first mode (0-110 mm) were the 5 months old 1995 cohort, the second mode (111 - 180 mm) were the 1 year 5 month old 1994 cohort and the third mode are mature adults. The March 1996 the first mode (0-120 mm) were the 10 months old 1995, the second mode (121 - 180 mm) were the 1 year 2 month old 1994 cohort and the third mode are mature adults. In July 1996 the first mode (0-80 mm) were the 3 months old 1996 cohort, the second mode (81 - 160 mm) were the 1 year 3 month old 1995 cohort and the 1994 cohort moved into the adult mode. The walleye pollock population was bimodal representing age 0 and adult fishes, in October 1995 and March 1996 while only age 0 fish were collected during July 1996 (Fig. 3).

Pacific herring and walleye pollock were contagiously distributed within Prince William Sound (Fig. 4). The general distribution of both species was bimodal with aggregations occurring in the east-northeast and the west-southwest (Fig. 1 and 4).

Location of age 0 and 1 - 2 herring and walleye pollock aggregations were relatively similar within this bimodal distribution during each survey (Fig. 4). Adult herring appeared to be aggregated in the southwest (210°-240°) in October 1995, in the south (180°) and east (90°) in March 1996, and west (240°-270°) in July 1996 (Fig. 4).

The distributions of the three size modes of Pacific herring differed from each other and from walleye pollock in October 1995, March, and July 1996 (Table 2; Fig. 4). Age 0 herring had a similar distribution to age 1 - 2 herring in October 1995 but differed in March and July 1996 (Table 2; Fig. 4). Age 0 herring distribution always differed from adult distribution (Table 2; Fig. 4). Age 1 - 2 and adult herring distributions were similar in March 1996 but differed during the other two surveys (Table 2; Fig. 4). Walleye pollock distribution differed from all three herring size mode distributions combined and from each size mode except for Age 0 herring in March 1996 (Table 2; Fig. 4).

Pacific herring schools had the lowest densities for all size modes in March 1996 and the highest densities in July 1996 (Table 3). Pacific herring schools had the highest average number of data cells in March 1996 (Table 3). Walleye pollock schools had low densities in October 1995 and March 1996 compared to very dense schools in July 1996 (Table 3).

Pacific herring were primarily distributed top half of the water column. Pacific herring were deeper in the water column in March 1996 (27.0 - 28.9 m) than in October 1995 (15.0 - 20.2 m) and July 1996 (14.1 - 16.7 m) which were similar (Table 4). Walleye pollock were distributed near the bottom during all three surveys (Table 4). There appeared to be little vertical overlap between Pacific herring and walleye pollock as the mean depths were separated by >29 m of water during all surveys (Table 4).

The proportion of herring schools consisting of a single size cohort varied among seasons. In October 1995, 49.0% of the herring schools sampled with the nets consisted of a single size class, primarily age 0 (21 schools of the 55 schools sampled). In March 1996, 38.9% of the herring schools sampled with the nets consisted of a single size, primarily age 1 - 2 (14 schools of the 72 schools sampled). In July 1996, 83.3% of the herring schools sampled with the nets consisted of a single size, primarily age 1-2 (21 schools of the 30 schools sampled).

The 26 sites located within the 12 bays had a mean Σ3NSD value of 3.8 km (SD = 2.45) which was significantly smaller than 9.8 km (SD = 6.69) for the 17 sites located in passages and along open coast line (t-test = -3.61, df = 41, $p<0.001$, log transformed). The water conditions within bays generally differed from conditions in passages and along open coastlines (Table 5). The surface water temperatures (0 - 30 m) were colder inside than outside the bays by 0.32 °C and 0.20 °C in October 1995 and July 1996, respectively. The surface water inside the bays was also more saline in October 95 (0.52 ‰) but were similar inside and outside the bays in deeper water (31-60 m) and throughout the water columns in July 1996 (Table 5). Conversely, the water columns inside the bays were warmer than outside the bays by 0.08 °C (0 - 30 m) and 0.28 °C (31 - 60 m) in March 1996. Surface water salinities were similar but deeper waters (31-60 m) had higher salinities inside bays (0.284 ‰) in March 1996.

Greater numbers of Pacific herring larvae were collected inside the bays (CPUE 1 minute tow mean = 3.2, SD = 11. 39) than in passages or along open coastline (mean = 0.21, SD = 0.68), (Mann-Whitney rank sum test T = 980, $p = 0.01$). Pacific herring larvae were similar in length, with a mean of 13.6 mm (SD = 4.52) inside the bays and a mean of 13.4 mm (SD = 3.04) in passages and open coastline ($T = 1103$, $p = 0.66$).

Pacific herring and walleye pollock $\sum$3NSD distributions differed from randomly calculated $\sum$3NSD distributions during all three surveys. In October 1995, age 0 and 1 herring aggregated at the heads of bays with $\sum$3NSD values (<3 km) below the mean bay value (3.8 km). Adult herring were aggregated in passages or along open coastline with $\sum$3NSD values (>11 km) above the mean value calculated from sites outside of the bays (9.8 km; Table 6). Walleye pollock distribution was also significantly aggregated within bays but not as tightly as age 0 and 1 herring (Table 6). In March 1996, all size modes of Pacific herring and walleye pollock had greater than expected $\sum$3NSD values ranging between 4 and 10 km (Table 7). In July 1996, age 0 herring aggregated tightly into the heads of bays (57.1% of $\sum$3NSD < 1 km). Age 1 herring were also aggregated at the head of bays (<2 km). Adult herring were aggregated within bays (< 2 km) but also more than expected had $\sum$3NSD values of 6 to 7 km. Walleye pollock were tightly aggregated within bays with the majority of $\sum$3NSD values < 3 km (Table 8).

Discussion.

The near shore ichthyofauna structure of Prince William Sound consisted of a few common species and a large number of relatively rare species. Pacific herring, Clupea pallasi, was the most abundant annual resident followed by walleye pollock, Theragra chalcogramma.

The size distribution of Pacific herring in Prince William Sound was trimodal with a strong annual mode during the juvenile phase, similar to Atlantic herring distributions. Atlantic herring complete 75 % of their somatic growth by the time they reach first maturity (Cushing 1967). Walleye pollock distribution was bimodal indicating a speration between the young of the year and mature fish. Walleye pollock feed year round and continue to grow after reaching sexual maturity (Clausen 1983, Livingston 1993).

Pacific herring and walleye pollock were aggregated in the east-northeast and west southwest areas of Prince William Sound. The cause of this distribution is unclear. This distribution may partially be explained by sampling bias. The southeast area were only surveyed during the July 1996 cruise. However the northwest area was thoroughly surveyed during all three cruises. Age 0 and 1-2 Pacific herring aggregations remained relatively constant within the bimodal distribution during all three surveys. Adult Pacific herring distribution appeared to shift seasonally from the east in March to the west in July.

The largest aggregations of walleye pollock occurred in the southern portion of Prince William Sound. This school partially dispersed in March when pollock were more evenly distributed throughout the Sound. The majority of age 0 pollock were collected in the east and in the south west in July 1996 and appeared to be spatially and temporally segregated from adult pollock. This segregation probably results from the strong cannabilistic behaviour of adult walleye pollock preying on age 0 pollock (Livingston 1993).

Our estimates of Pacific herring and walleye pollock school densities are dependent on the applied target strength equations. This is a limitation of acoustic surveys as many physical and biological variables effect target strength including, fish orientation, depth, fat content, gonadal development, vertical avoidance reaction, and morphology of the fish

(Thorne 1983b, Foote 1987, Rose & Leggett 1988, Thorne & Thomas 1990, MacLennan & Simmonds 1991, Misund et al. 1995, Huse & Ona 1996, McClatchie et al. 1996, Ona & Mitson 1996, Misund 1997).

Thorne's target strength equation differs from equations calculated for Atlantic herring (MacLennan & Simmonds 1991), however, our estimates of Pacific herring density (means ranging from 0.51 to 9.15 fish m^{-3}) were similar to many herring density estimates measured using similar techniques, for example Atlantic herring densities in a fjord in northern Norway ranging from 0.3 to 5.0 fish m^{-3} (Misund & Floen 1993) and in the North Sea from 2.94 to 6.68 fish m^{-3} (Misund et al. 1995). Our density estimates do not agree well with the theoretical density of schooling fish (volume = 0.7 herring body length^{-3}) (Pitcher & Partridge 1979, Pitcher & Parrish 1993). However, in the wild large variations in herring density occur within schools (Misund & Floen 1993) and between schools (Blaxter & Hunter 1982).

The number, density, age and depth of schools of Pacific herring varied seasonally. Pacific herring were tightly aggregated forming fewer, denser schools of a single size cohort near the surface in July. This pattern began to deteriorate in October when schools were slightly less cohesive, and at approximately the same depth. However, the number of schools increased, the number of data cells making up each school decreased and the majority of schools were made up of mixed age cohorts. Pacific herring formed many schools with low densities, and mixed size cohorts, in deeper water (<1 fish m^3 for herring), in March. The October and March surveys were conducted during the night while the July survey was conducted during daylight. Clupeid distribution is strongly effected on a short temporal scale by the diel (day/night) cycle (Blaxter& Hunter 1982, Scott & Scott 1988, Stokesbury & Dadswell 1989, Huse& Ona 1996). However, these observation appear to reflect the conditions in the natural habitat and are therefore comparable to each other because in this northern latitude there is very little daylight in March and practically no darkness during July.

The seasonal difference in the structure of herring schools may result from the availability of food, the physical condition of the fish, and the threat of predation. The inter-fish distance within schools increases with hunger, reducing cohesion, and causing lower mean densities (Robinson 1995). Competition within schools for food is reduced with independent and segregated behavior (Robinson & Pitcher 1989). Fish also increase their chance of encountering food by breaking into small groups or by reducing shoal compactness, thereby increasing the schools foraging area (Robinson 1995). in March herring appeared to be spreating out forming low density aggregations covering large areas. These herring have just survived the winter when prey abundance is minimal and the risk of starvation is high (Paul & Paul 1997, Paul et al. 1997).

The number, density and depths of schools of walleye pollock varied seasonally. Walleye pollock were highly aggregated forming fewer, very dense schools in July and many, low density schools in October and March. Walleye pollock schools were always deep in the water column, near the bottom, and probably less influenced by light conditions. This seasonal variation maybe related to different phases of the life cycle. The walleye pollock collected in July were age 0 and their dense schools seemed to be associated with large jellyfish, Aurelia aurita, aggregations. Large jelly fish, Cyanea capillata, were also frequently seen with several gadids, possibly walleye pollock, continuously associated with them. The October and March pollock collections were larger juveniles or adult fish, were not associated with jelly fish, and seemed to be pre and post spawning aggregations, respectively.

Pacific herring and walleye pollock distributions were roughly similar, both were bimodal with high concentrations occurring in the northeast and southwest. However, there appeared to be little overlap as they occupied different portions of the water column, Pacific herring in surface waters and walleye pollock near the bottom. Further their morphologies and behavior are different. Therefore competition for prey between these species seems unlikely.

Bays in Prince William Sound appeared to be nursery areas for age 0 and 1 Pacific herring. Larval Pacific herring aggregated within bays in July just prior to metamorphosing into juveniles. Larval herring depend on their transparency to escape detection and capture by visual predators (Batty 1989, Gallego & Heath 1994). The ontogenetic changes from the larval to juvenile body morph (body length 31 - 38 mm) require switching to a different antipredator strategy and this is a critical period in terms of vulnerability to predation (Gallego & Heath 1994). As juvenile herring develops its camouflage of guanine reflecting platelets under the scales and black dorsum they also fill their swim bladder and bullae with air (Blaxter 1985). The coupling of the bullae and head lateral line allows herring to detect range as well as direction of sound source and is indispensable to forming and maintaining the schools (Blaxter et al. 1981, Blaxter 1985, Gallego & Heath 1994). Schooling becomes the herring's primary defense against predation for the remaining portion of its life cycle (Blaxter & Hunter 1982).

Age 0 herring were very tightly aggregated near the shore in shallow water at the heads of bays in July. This distribution continued through October but in March the schools had moved away from the shores, into deeper water, however they still remained within the bays. The age 1 herring were also aggregated into tight schools in shallow water near the heads of bays during July and October and dispersed into a scattered layer in March. After their second winter within these bays the juvenile herring appear to join the adult schools leaving the bays at approximately the same time as the new recruits enter the bays (in June-August).

There appears to be a physical difference in the water conditions within bays compared to the open Sound. In October 1995 and July 1996 water temperatures in the upper 30 m were cooler inside these bays than in the open Sound. In March this pattern was reversed and waters were warmer within the bays. What effect this has on juvenile herring metabolic rate is unclear. Juvenile herring require a critical amount of energy to survive the winter (Paul & Paul 1997, Paul et al. 1997) and there may be an advantage to overwintering in cooler waters. The effect these water conditions have on zooplankton production is also unclear. Juvenile herring tightly aggregating near the shore may be feeding on prey associated with the nearshore algae or using the algae as a shelter from predation. Other juvenile species utilize near shore algae in a similar manor (Rangeley & Kramer 1995a, Rangeley & Kramer 1995b). The shift to deeper water away from the shore in March may result from increased food supply being transported into these bays. Adult Pacific herring appear to seasonally migrate within Prince William Sound. A large school of adult herring was observed in Zaikof Bay in March 1996. Large adult schools have traditionally been observed and fished in this bay and a similar large school was observed here in 1997 (author's unpublished data). These adults moved out of Zaikof Bay and spawned in the Green Island - Stockdale harbor area in April (John Wilcox, personal communitication; Alaska Department of Fish and Game, Cordova). We observed them during the summer months feeding from the lower part of Green Island to the southern part of the Sound, in Latouche and Elrington Passages. There appears to be a great deal of food in this region as the waters leaving Prince William Sound mix with the Gulf of Alaska current. Large schools of Pacific sand lance, large flocks of foraging sea birds and many marine mammals were also observed here during July 1996. The adult herring then migrate back towards Zaikof and are in the Green Island area in late October, as we observed in 1995. The bait fishery traditionally occurs in this area in late October-early November, and occurred in 1996 and 1997 (John Wilcox, personal communitication; Alaska Department of Fish and Game, Cordova).

The predictability in temporal and spatial distributions of herring populations in tidally energetic systems has contributed to overfishing (Sinclair et al. 1985). Further, herring do not exhibit the classic signs of overfishing, i.e. a decline in the catch per unit effort and a loss of larger fish. The dual characteristics of homing to natal spawning areas and larval retention severely restrict the ability of one spawning population to repopulate neighboring spawning areas that have been disrupted by overfishing or a major perturbation (Iles & Sinclair 1982, Sinclair et al. 1985, Sinclair 1988). It is therefore critical to determine the seasonal variability in spatial distributions of each phase of the Pacific herring life cycle in Prince William Sound to determine the potential for recovery of the population and it's role in the ecosystem and effective future management.

Acknowledgments We thank R. Foy, M. McEwen, S. Gay and L. Tuttle for assistance with field collections. N. Peters and G. Steinhart assisted in collecting and processing the acoustic data. M. Frandsen assisted with larval fish identification. S. Moreland and M. Vallerino assisted with data analyses. We also thank the captains and crews of the F/V Temptation, F/V Miss Kayley, F/V Kyle David, M/V Pacific Star, F/V Pagan, R/V Pandalus and the Alaska Department of Fish and Game, Cordova, for their help and insights on Prince William Sound. This project was funded by the Exxon Valdez Oil Spill Trustee Council through the Sound Ecosystem Assessment (SEA) project. However the findings presented by the authors are their own and not necessarily the Trustee Council position.

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Table 1. Numbers of dominant fish species collected in Prince William Sound, Alaska in 1995 and 1996. The number of fish measured from seine collections are random subsamples (1000 individuals) of the total catch therefore the % reflect the subsample maximum.

		October 1995		March 1996		July 1996	
		trawl	seine	trawl	seine	seine	
scientific name	common name	74	72	67	59	60	%
Clupea pallasi	Pacific herring	1421	47803	11535	40588	22639	65.0
Theragra chalcogramma	walleye pollock	3308	13994	7319	3950	7929	19.2
Ammodytes hexapterus	Pacific sandlance		1		1	5000	2.6
Mallotus villosus	capelin		68	266	3406		2.0

Table 2. Clupea pallasi and Theragra chalcogramma. Chi-squared tests examining the polar angle distributions of the three size modes of Pacific herring and walleye pollock during three acoustic surveys of Prince William Sound, Alaska in 1995 and 1996; NS = no significant difference, p>0.05.

	October 1995			March 1996			July 1996		
	df	χ^2	p =	df	χ^2	p =	df	χ^2	p =
herring age 0, 1 and adults	8	109	0.01	7	41.5	0.01	6	87.7	0.01
herring age 0 and 1	8	0.9	NS	7	20.9	0.01	6	18.2	0.05
herring age 0 and adults	8	85.0	0.01	7	40.1	0.01	6	87.9	0.01
herring age 1 and adults	8	80.8	0.01	7	9.7	NS	6	43.4	0.01
herring and pollock	8	227	0.01	7	65.8	0.01	6	240	0.01
herring age 0 and pollock	8	117	0.01	7	9.0	NS	4	90.2	0.01
herring age 1 and pollock	8	114	0.01	7	23.2	0.01	4	62.2	0.01
herring adults and pollock	7	29.6	0.01	7	31.7	0.01	6	67.1	0.01

Table 3 Clupea pallasi and Theragra chalcogramma. Estimated means and standard deviations (SD) of densities (fish m^{-3}) and number of data cells for the three size modes of Pacific herring and walleye pollock aggregations observed during three acoustic surveys of Prince William Sound, Alaska in 1995 and 1996 (n = count).

	October 1995 fish m^{-3}			March 1996 fish m^{-3}			July 1996 fish m^{-3}		
herring	n	mean	SD	n	mean	SD	n	mean	SD
age 0	137	2.52	8.36	179	0.91	2.84	8	2.67	5.46
age 1	126	0.51	1.10	223	0.81	0.95	42	9.15	15.75
adult	54	1.35	3.21	147	0.51	0.95	32	3.62	0.86
pollock	119	3.14	8.68	148	4.20	14.59	31	267.87	72.05
herring	cells (40-120 x 1m)			cells (40 x 1m)			cells (20 x 1m)		
age 0	137	15.55	39.58	179	22.50	65.11	8	98.25	155.28
age 1	126	13.77	37.42	223	25.00	82.82	42	31.55	85.97
adult	54	9.63	14.04	147	28.36	96.88	32	21.00	56.98
pollock	119	8.05	11.07	148	13.12	44.73	31	300.16	72.05

Table 4 Clupea pallasi and Theragra chalcogramma. Estimated means and standard deviations (SD) of three size modes of Pacific herring and walleye pollock depth in the water column and sea bed depth during three acoustic surveys of Prince William Sound, Alaska in 1995 and 1996 (n = count).

	depth of fish (m)								
	October 1995			March 1996			July 1996		
herring	n	mean	SD	n	mean	SD	n	mean	SD
age 0	2131	15.02	6.51	3675	27.48	15.82	780	14.14	9.38
age 1	1819	15.48	6.65	5463	27.04	13.83	1325	15.18	10.42
adult	520	20.24	7.72	4180	28.86	13.66	633	16.65	10.58
pollock	958	64.44	26.42	1942	57.88	25.27	6301	63.75	34.65
herring	bottom depth (m)								
age 0	2131	47.87	26.01	3420	47.08	20.69	723	34.49	21.62
age 1	1819	45.62	26.10	5016	47.46	19.46	1242	34.96	18.28
adult	520	45.96	24.95	4026	46.43	16.76	583	47.42	38.35
pollock	958	68.7	30.96	1872	63.09	22.46	5612	86.99	34.65

Table 5 Mean and standard deviations (SD) of water columns inside bays and outside bays in passages and along open coastline during three surveys of Prince William Sound, Alaska in 1995 and 1996 (n = count). The Mann-Whitney rank sum test was used to determine differences between mean values (T).

water depth (m)		n	temperature (oC) mean	SD		salinity (o/oo) mean	SD	
October 1995								
0-30	inside	146	9.34	0.626	T=16135	28.77	1.111	T=18583
0-30	outside	180	9.66	0.821	p<0.001	29.29	1.063	p<0.001
31-60	inside	71	7.95	2.06	T=4212	30.62	0.749	T=8610
31-60	outside	186	9.87	0.393	p<0.001	30.36	0.21	p=0.303
March 1996								
0-30	inside	667	4.14	0.437	T=281130	31.65	0.225	T=305280
0-30	outside	509	4.06	0.357	p<0.001	31.66	0.219	p=0.320
31-60	inside	416	4.53	0.521	T=228192	31.83	0.106	T=209925
31-60	outside	512	4.25	0.344	p<0.001	31.80	0.106	p<0.001
July 1996								
0-30	inside	688	10.93	1.984	T=291730	28.98	1.772	T=287935
0-30	outside	480	11.10	1.569	p=0.049	29.09	1.642	p=0.194
31-60	inside	453	6.45	1.084	T=192162	31.02	0.479	T=213780
31-60	outside	492	6.94	1.238	p<0.001	31.08	0.265	p=0.911

Table 6. Clupea pallasi and Theragra chalcogramma. Chi-squared analysis comparing the percent frequency distributions of observed sum of the three near shore distances (Σ3NSD) for Pacific herring and walleye pollock aggregations to values generated from a random distribution, during the October 1995 acoustic survey in Prince William Sound, Alaska; * $p<0.05$, ** $p<0.01$.

	Pacific herring (%)			walleye	
Σ3NSD (km)	age 0	age 1+	adult	pollock (%)	random (%)
1, 2	35.38	32.77	4.08	19.82	15.59
3	12.31	13.45	12.24	18.92	10.22
4	5.38	5.04	4.08	10.81	9.14
5	3.08	3.36	2.04	10.81	5.91
6	4.62	4.20	0.00	3.60	9.14
7, 8	3.08	3.36	2.04	1.80	9.14
9, 10, 11	3.85	4.20	6.12	7.21	6.45
12, 13, 14	14.62	15.13	26.53	3.60	5.91
15 - 18	3.08	2.52	6.12	3.60	6.99
19 - 23	6.92	7.56	16.33	4.50	5.91
24 - 28	3.08	3.36	8.16	5.41	5.38
29 - 35	1.54	1.68	4.08	5.41	5.38
>36	3.08	3.36	8.16	4.50	4.84
χ^2=	55.30**	51.41**	123.26**	25.16*	
df=	12	12	12	12	

Table 7. Clupea pallasi and Theragra chalcogramma. Chi-squared analysis comparing the percent frequency distributions of observed sum of the three near shore distances ($\sum$3NSD) for Pacific herring and walleye pollock aggregations to values generated from a random distribution, during the March 1996 acoustic survey in Prince William Sound, Alaska; * p<0.05, ** p <0.01.

	Pacific herring (%)			walleye	
$\sum$3NSD (km)	age 0	age 1+	adult	pollock (%)	random (%)
1	7.74	8.00	3.10	3.13	11.18
2	22.58	20.00	17.83	15.63	26.71
3	18.71	18.86	17.83	21.09	18.01
4	14.84	15.43	16.28	14.06	9.32
5, 6	16.13	15.43	18.60	14.84	6.21
7 to 10	15.48	17.14	19.38	18.75	5.59
11,12,13	0.65	1.71	2.33	6.25	6.21
14 to 17	2.58	2.29	3.10	3.13	6.21
18 to 29	1.29	1.14	1.55	3.13	6.83
>30	0.00	0.00	0.00	0.00	3.73
χ^2=	53.68**	58.40**	84.55**	63.60**	
df=	9	9	9	9	

Table 8 Clupea pallasi and Theragra chalcogramma. Chi-squared analysis comparing the percent frequency distributions of observed sum of the three near shore distances (Σ3NSD) for Pacific herring and walleye pollock aggregations to values generated from a random distribution, during the July 1996 acoustic survey in Prince William Sound, Alaska; * p<0.05, ** p <0.01.

	Pacific herring			walleye	
3NSD (km)	age 0	age 1+	adult	pollock (%)	random (%)
1	57.14	41.67	38.46	26.67	16.58
2	14.29	27.78	26.92	26.67	22.99
3	0.00	8.33	7.69	33.33	13.37
4	28.57	11.11	7.69	6.67	10.70
5	0.00	2.78	3.85	0.00	10.70
6,7	0.00	2.78	11.54	3.33	7.49
8,9,10	0.00	2.78	0.00	3.33	5.88
11 to 15	0.00	0.00	0.00	0.00	5.88
>16	0.00	2.78	3.85	0.00	6.42
χ^2=	182.17**	59.29**	52.18**	64.46**	
df=	8	8	8	8	

List of Figures.

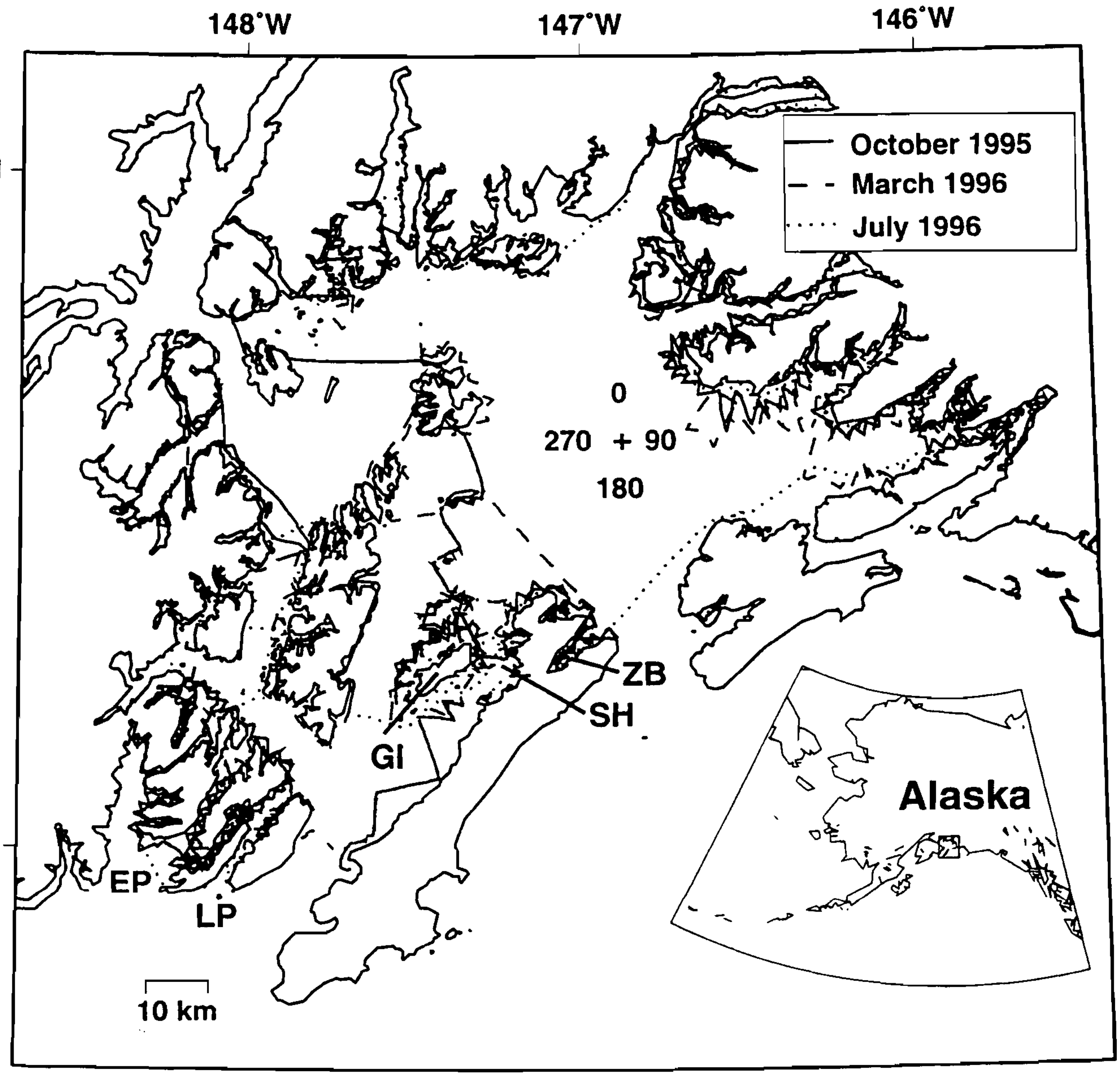


Fig. 1. Stokesbury et al.

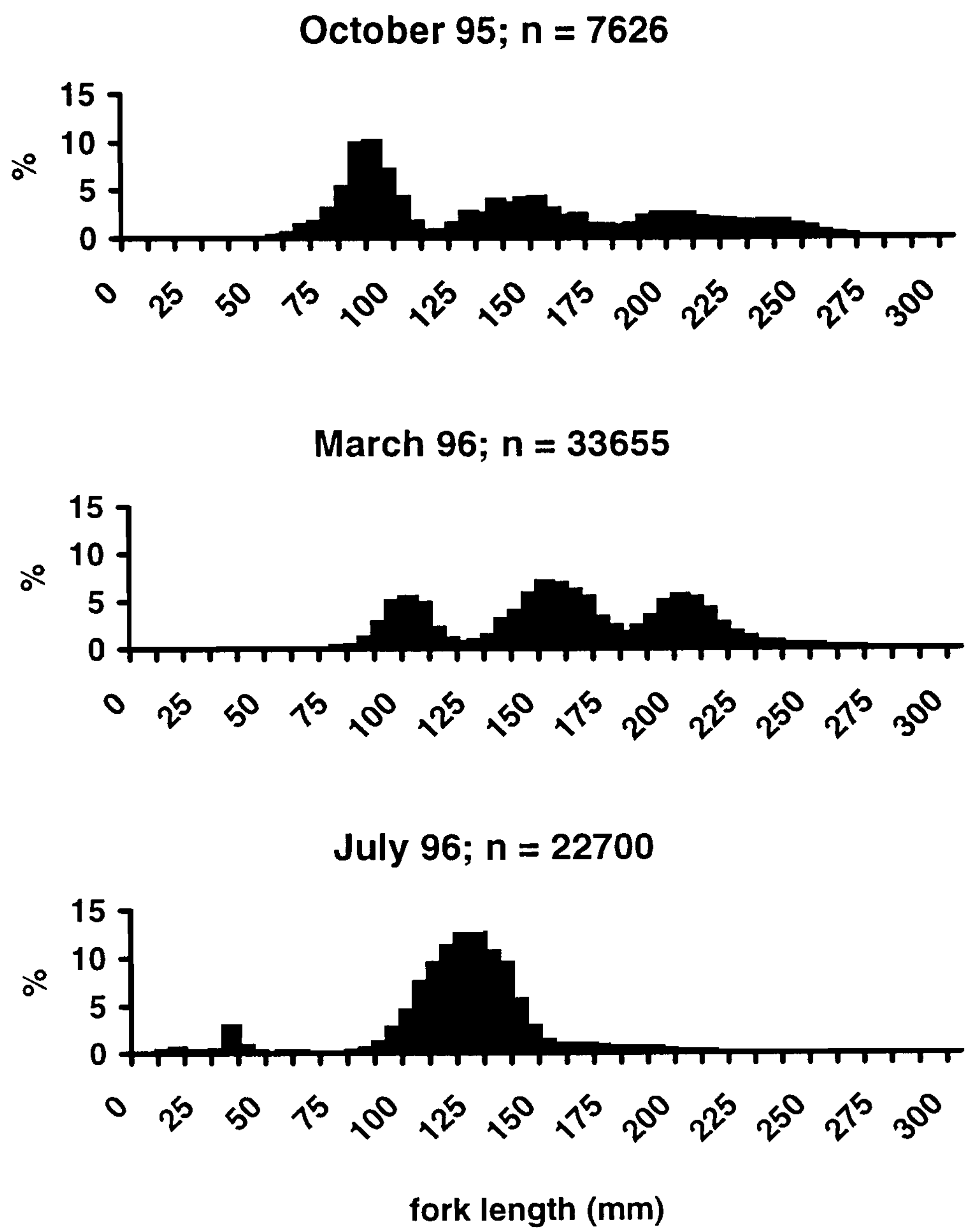


Fig. 2 Stokesbury et al.

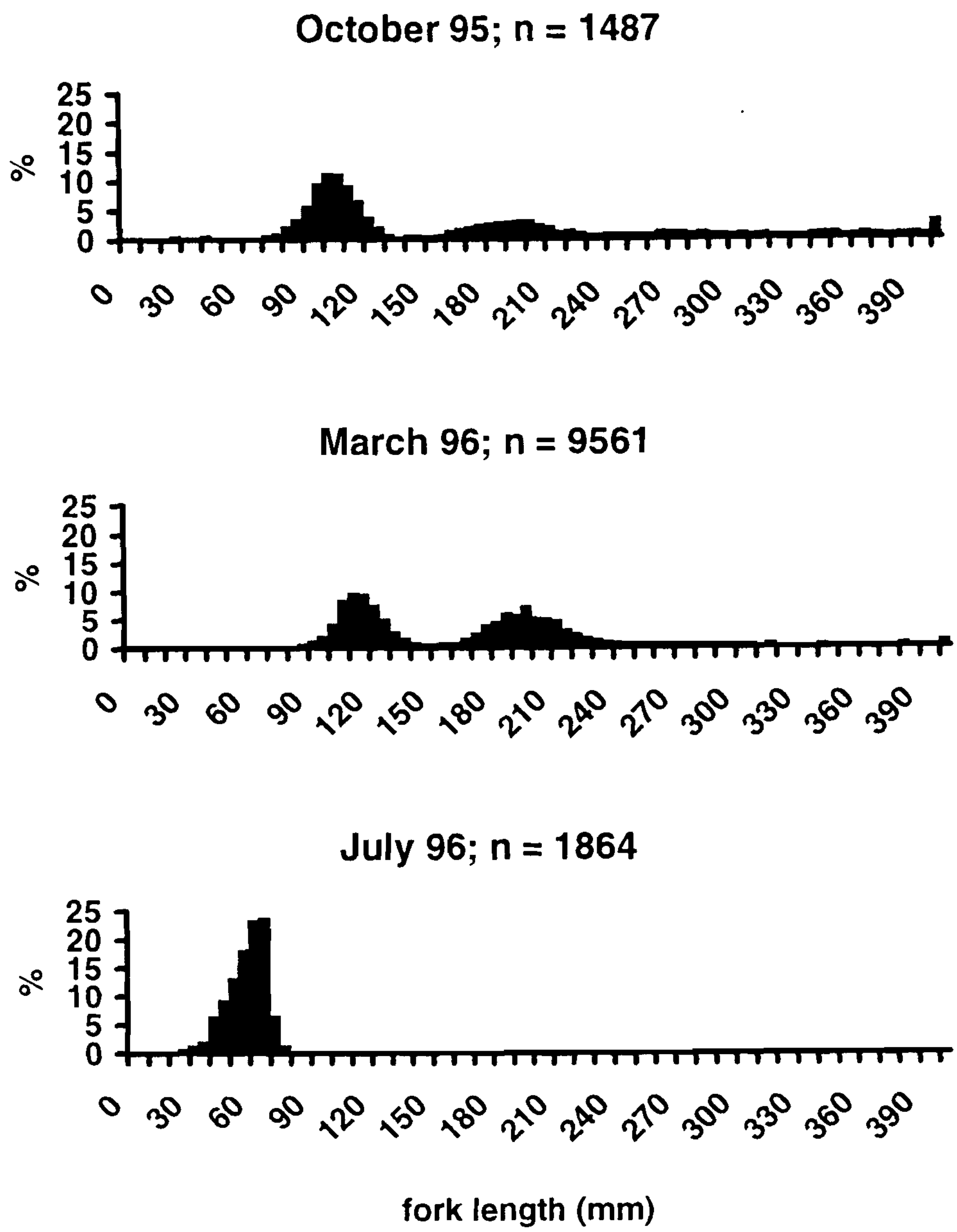


Fig. 3 Stokesbury et al.

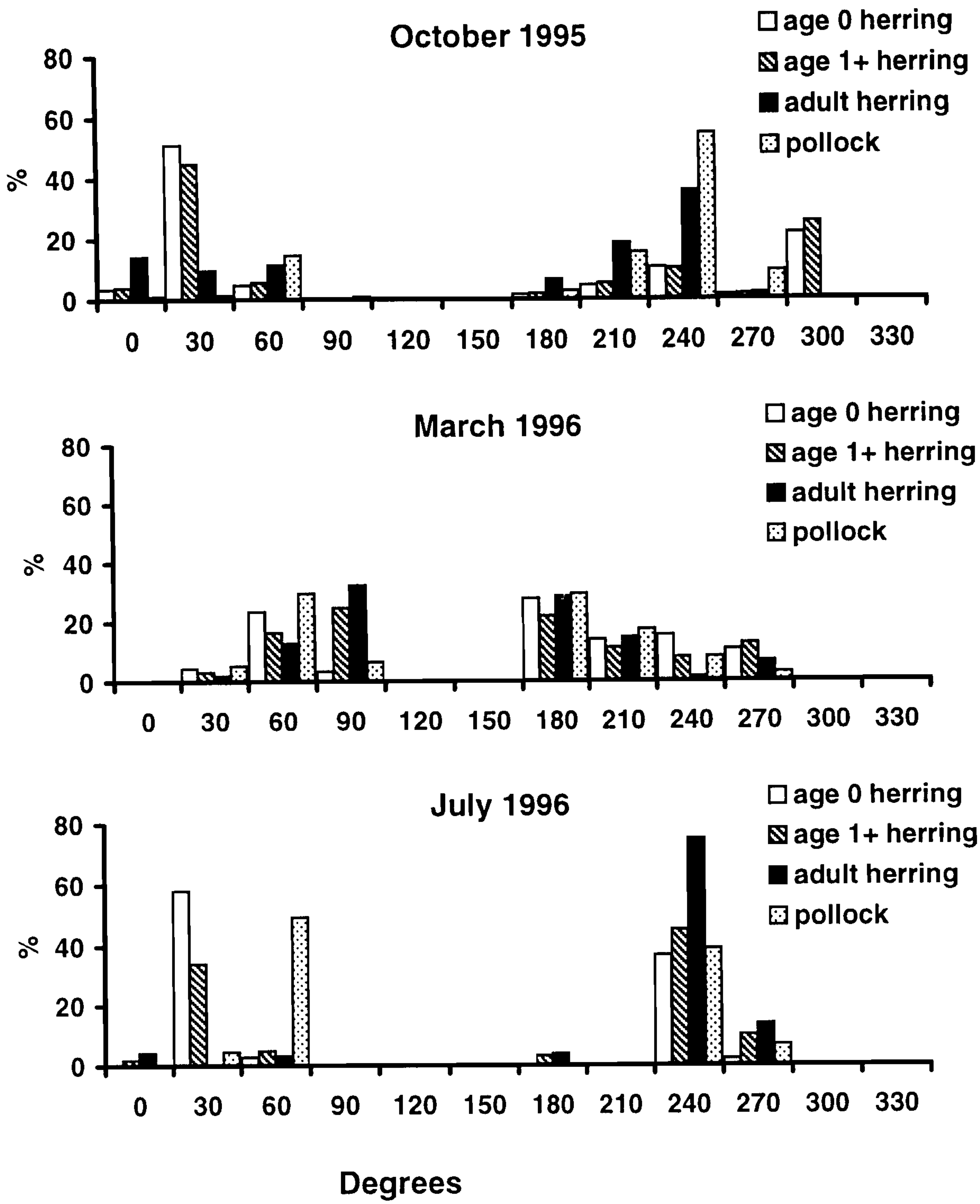


Fig. 4 Stokesbury et al.

Appendix II

Preliminary Documentation of Temporal and Spatial Variability of Pacific Herring, Other Forage Fish, and Seabirds in Prince William Sound, Alaska

Evelyn D. Brown
April 7, 1998

Appendix II. Preliminary Documentation of Temporal and Spatial Variability of Pacific Herring, Other Forage Fish, and Seabirds in Prince William Sound, Alaska

Evelyn D. Brown

Introduction

This report covers preliminary aerial survey data presented at the annual science reviews for both the Sound Ecosystem Assessment (SEA) and Alaska Predator Ecosystem Experiment (APEX) projects funded by the *Exxon Valdez* Oil Spill Trustee Council (EVOS TC). From 1995 through 1997, monthly broadscale aerial surveys were flown in Prince William Sound (PWS) and the Outer Kenai (OK) over a 5-7 day period during May through August (see Appendix III and Stokesbury et al., 1997). Peak counts of fish schools were recorded in June and July. Less schools were observed in May and August. Increased counts observed in June and July were probably due to a change in fish distribution to shallow surface waters (see Stokesbury et. al., Appendix I this report) as the aerial survey is limited to observations of surface schooling fishes. Also, by July metamorphosis of larval Pacific herring (*Clupea pallasi*; Stokesbury et al., Appendix I) and sandlance (*Ammodytes hexapterus*) occurs and schooling behavior begins (evidenced by reductions in larval abundance, Norcross et al. 1996 and observations of large numbers of age-0 juvenile sandlance in the nearshore, APEX, unpublished data). Finally, pre-spawning capelin (*Mallotus villosus*) and post-spawning eulachon (*Thaleichthys pacificus*) form large visible schools in June in PWS and adjacent waters of the Gulf of Alaska (E. Brown, unpublished data).

I will present here the graphic results of the broadscale surveys during the months of June and July for PWS.

Methods

Methodology for the aerial survey technique is documented by Brown and Norcross (in prep) and in Appendix III of this report. For this report, the aerial survey database was queried for the broadscale survey data from June and July. Repeat surveys over herring nursery bays of interest to the SEA project were left out of the query. The data therefore represents a single pass over the entire area over the course of a week. The only shorelines not sampled were in the fiords of the extreme northwest corner of PWS (Port Wells, not labeled on the maps). Surface areas were estimated for all schools and total surface area estimates were plotted for each unique latitude and longitude by species (there were often several schools at a given location). The results were plotted using the GMT mapping software and the key for the shade-by-value school plots is given in Figure 1.

Seabird behavior codes are recorded easily from the air including plunging, milling tightly aggregated on the water, resting on the water (loose aggregation), resting on shore, broad-area search, and travelling. Therefore, a determination of the numbers of birds foraging (plunging, milling, tightly aggregated on the water) versus searching or other behaviors can be made. I can determine not only the degree to which birds are associated with surface schools, but also what their behaviors are in association with schools. Therefore, the degree of spatial and temporal variability in foraging and school association can be determined.

The aerial database includes mainly white gulls (black-legged kittiwakes, mew gulls, and gloucous-winged gulls) which are easy to sight from the air. They also do not spend any time under the surface. Diving ducks and other seabirds are difficult to sight from the air. Therefore, the seabirds represented are gull species.

Results and Discussion

All forage species and seabirds or gulls were plotted by month and year (Figures 2-7). The notable features are discussed. The existence of large numbers of pre-spawning capelin schools were observed in June of 1995, but not in subsequent years (Figures 2-4). These sightings were validated by targeted catches on pre-spawning capelin sighted from the air. In June of 1997, following reports of excessive interceptions of spawning eulachon by Copper River drift net salmon fishermen (Copper River Fishermen's United, Cordova, Alaska, personal communication), large numbers of huge eulachon schools (about 1000 m^2) were sighted mainly off Montague Island (Figure 4). These sightings were validated by examinations of stomach contents of predatory fish caught near the school groups and by interceptions of eulachon by salmon fishermen. No eulachon were observed in June of 1995 and 1996. Large numbers of juvenile herring schools were sighted all three years in June representing mainly age-1 herring (see Appendix III). However, interannual variability in abundance was evident with peak surface area estimates occurring in 1996 (Figures 2-4). This could represent differences in overall year-class strength. Only in June of 1997 were sandlance schools observed in significant numbers. Surface water temperatures were abnormally high in 1997 (SEA, unpublished data) and the anomalous numbers of sandlance sighted in June could represent early recruitment of post-metamorphic sandlance to nearshore beaches.

In June, broadscale seabird foraging activities were focused on the pre-spawning capelin and in eastern PWS in 1995 (Figure 2) and post-spawning eulachon in 1997 (Figure 4). In general, more foraging activity was observed in 1997 over the two previous years. In 1996, bird foraging activities were more numerous at nearshore beaches on outer Montague and western and northern Hinchinbrook Island. There was also large number of foraging flocks in northwestern PWS near the village of Tatitlek and associated with juvenile herring schools.

The notable features in July of each year were the absence of capelin and eulachon and peak annual counts of both juvenile herring and sandlance (except in 1995 when peak herring counts occurred in June) (Figures 5-7). The variability of herring counts in July probably represents changes in year-class strength for both age-1 and age-0 herring. However, changes in the depth distribution of juvenile herring as well as early departure of age-1+ herring from nursery bays could also explain the variability observed (see Stokesbury et al., Appendix I). Comparisons of acoustic and aerial data, planned for later this spring, will document variability in distribution by depth, which will aide in correct interpretation of the aerial results (see Appendix III). No such comparisons are available for sandlance since they generally occur in waters too shallow for acoustic measurements (Appendix III). However, because of that characteristic, aerial counts are probably more conclusive for sandlance than for juvenile herring at this time. Sandlance appear to be in a state of population building as increasingly higher numbers of schools were observed from 1995 to 1997 (Figures 5-7).

Although there was considerably bird foraging activity associated with schools sighted from the air in July, flock size appeared to have decreased from June to July (compare the size of the triangles from Figures 2-4 to 5-7). There appears to be a species preference by the foraging seabirds for juvenile herring over sandlance. In 1996 and 1997, 35.7% (n=226) and 43.6% (n=326) respectively of the herrings schools were associated with seabirds. This compares to 18.3% (n=71) and 11.1% (n=180) of the sandlance schools in 1996 and 1997 respectively. There did not appear to be a preference for school size as the frequency distribution of school size was identical for schools with or without birds.

In all three years, the majority of the seabirds sighted from the air were involved in active foraging behaviors (41.0%) or search activities (27.0%). The remainder were either resting or travelling (15.7%) including counts at seabird colonies (mainly kittiwakes).

It appears from preliminary results of APEX chick diet studies, that PWS seabirds feeding primarily on pelagic fishes are targeting juvenile herring and sandlance. Since sandlance and juvenile herring are the most abundance surface schooling fishes observed in PWS, the birds appear to be feeding on what is available. I produced plots to show interannual variability of juvenile herring and sandlance in the months of June and July. The peak abundance estimates (total school surface areas) of juvenile herring (probably age-1) in June of 1996 are obvious in Figure 8. For sandlance, the 1997 peak June count is obvious (Figure 9). In July, both peak school counts and surface area estimates in 1996 and 1997 exceeded those in 1995 (Figure 10). There is also evidence of slight changes in distribution from year to year. In 1997, more herring schools were observed in waters outside bays than in 1996. I have no explanation for this. The population increase in sandlance is obvious in Figure 11 with an accompanying increase in spatial distribution from 1995 to 1997.

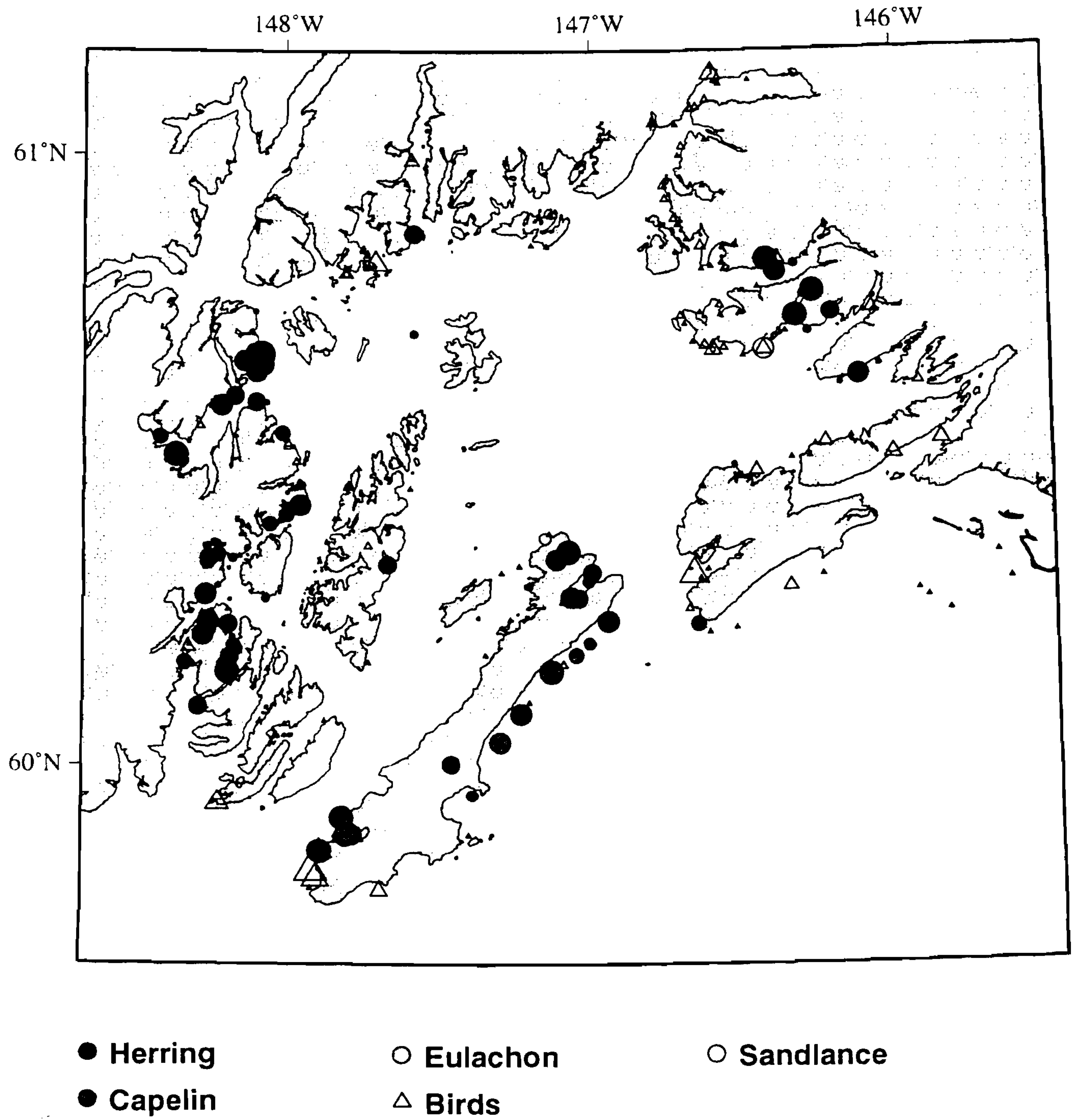
Now that the documentation of fish distribution is complete, I can proceed with ecological evaluations of those distributions. I can compare the distributions to oceanographic conditions and regimes occurring within and outside of PWS. I can compare the trends in abundance of the juvenile herring to resulting changes in the adult population size and distribution. I can examine regional and temporal changes in seabird or gull foraging activity as well as interannual fluctuations in colony size (on a broadscale). In short, the potential for use is broad-based. There are obvious monitoring advantages in the continuation of this data set over a longer period of time.

Literature Cited

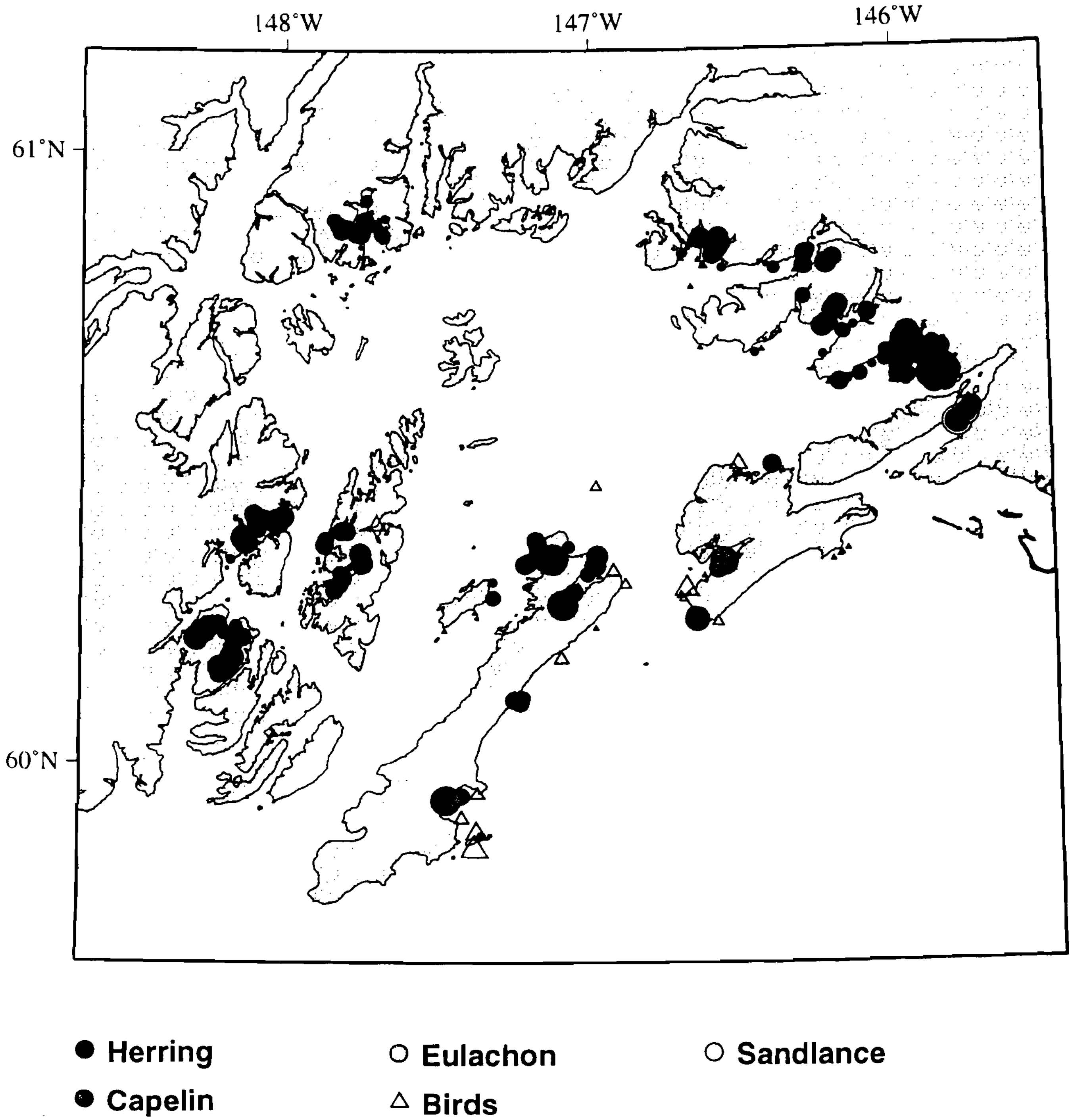
Brown, E.D. and B.L Norcross. In prep. Assessment of forage fish distribution and abundance using aerial surveys: survey design and methodology. To be submitted to Ecological Applications.

Appendix II Figure 1. Key for following figures.

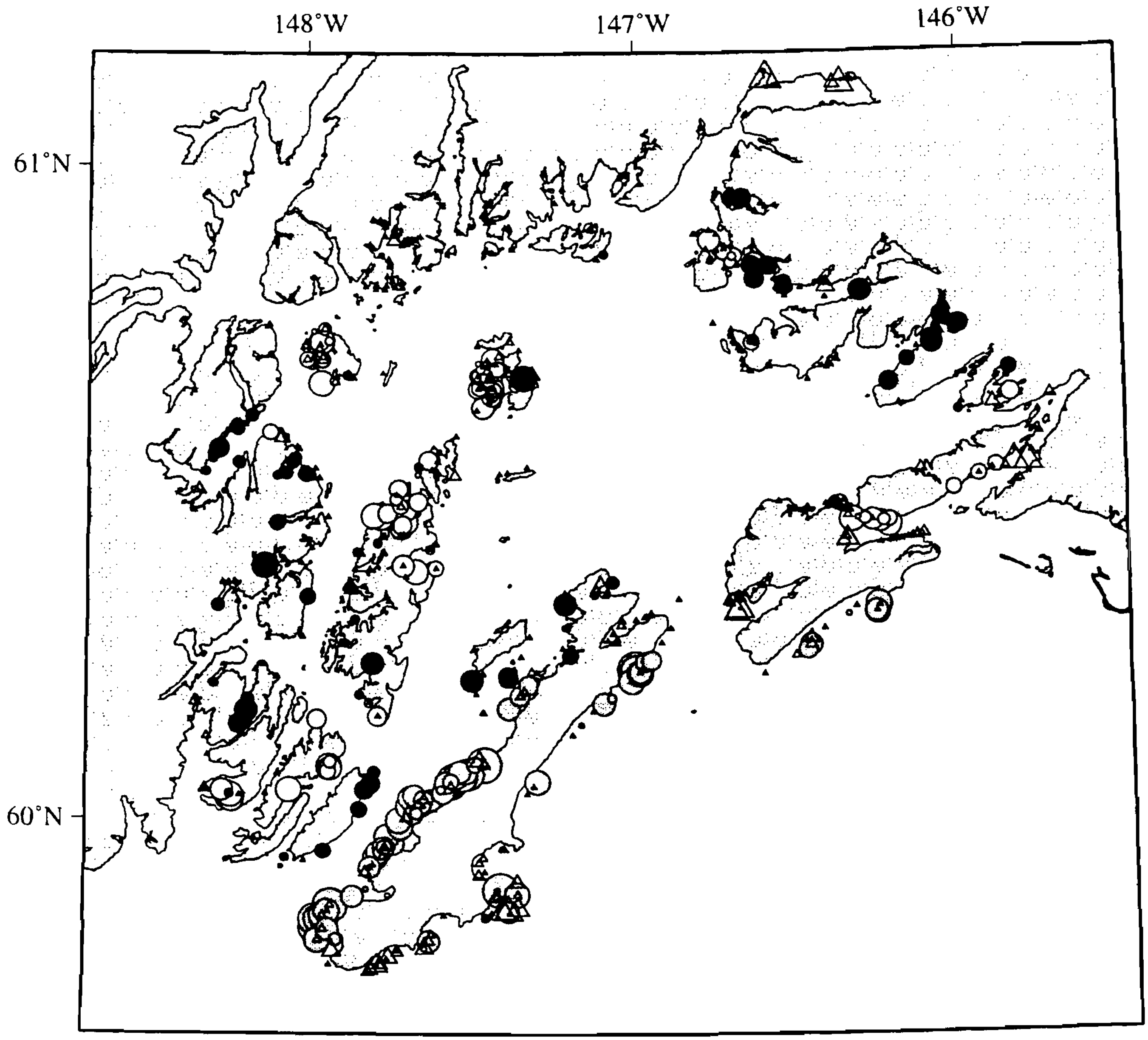
Shade by value of fish schools at a given location, species by color	Total no. birds at a given location
○ 1-10	
○ 11-20	△ 1-25
○ 21-30	△ 26-50
○ 31-50	△ 51-100
○ 51-100	△ 101-200
○ 101-200	△ 201-500
○ 201-500	△ 501-1000
○ 501-1000	△ 1001-5000
○ >1000	△ >5001



Appendix II Fig. 2. Distribution of Seabird and Forage Fish. in Prince William Sound. Alaska, June 1995. No eulachon were sighted.

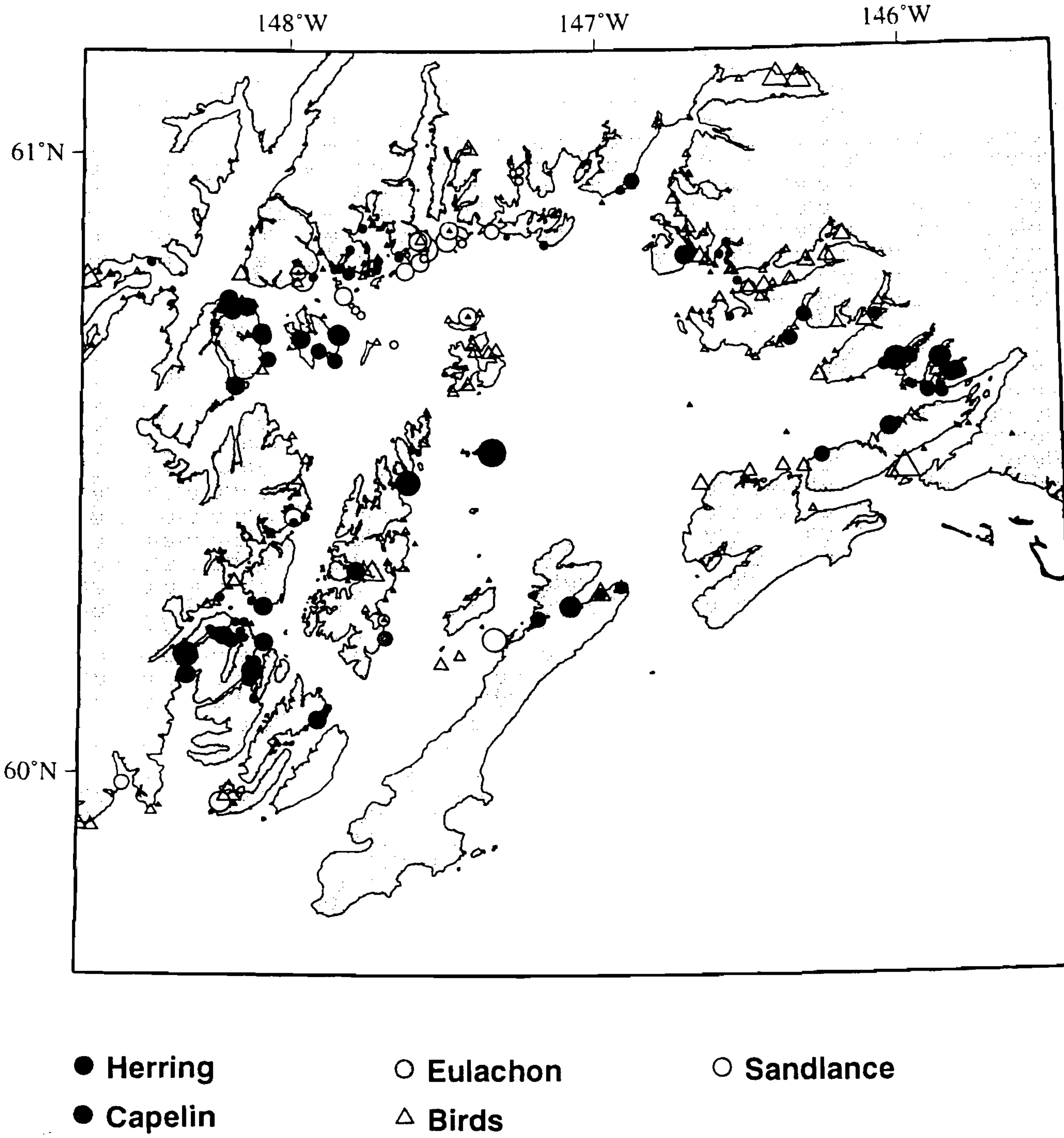


Appendix II Fig. 3. Distribution of Seabird and Forage Fish, in Prince William Sound, Alaska, June 1996. No eulachon were sighted.

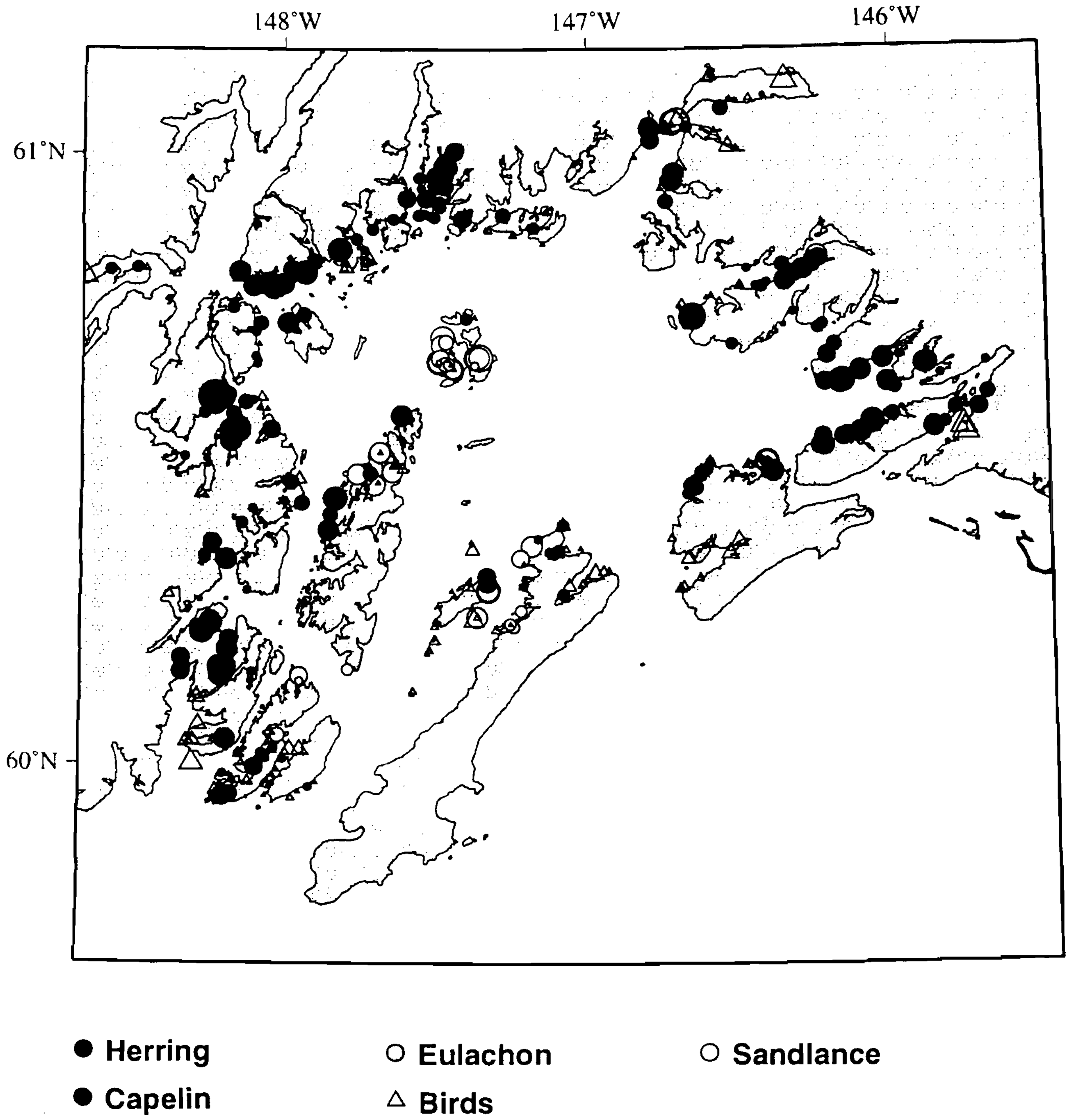


● Herring ○ Eulachon ○ Sandlance
● Capelin △ Birds

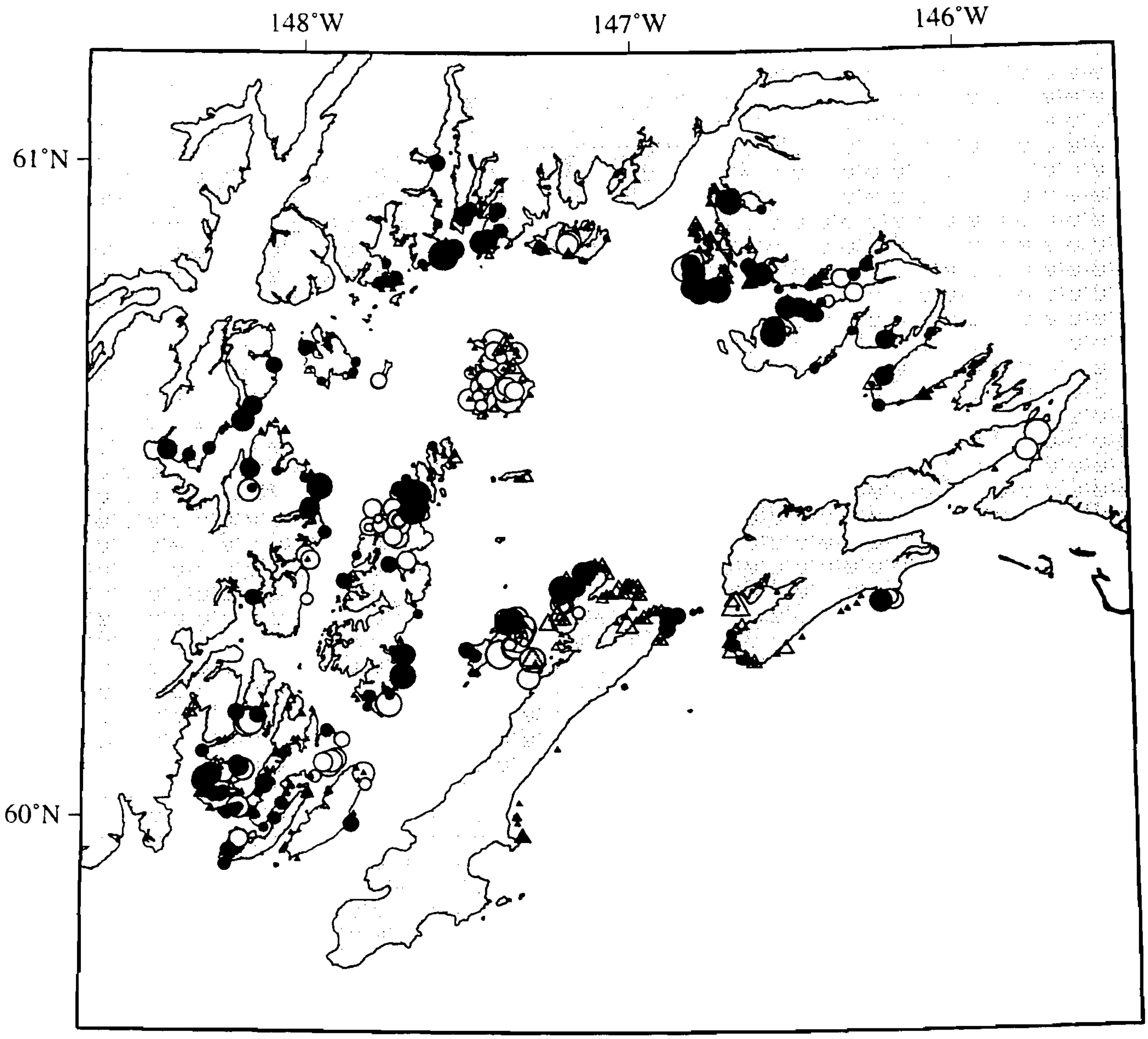
Appendix II Fig. 4. Distribution of Seabird and Forage Fish, in Prince William Sound. Alaska. June 1997. No capelin were sighted.



Appendix II Fig. 5. Distribution of Seabird and Forage Fish, in Prince William Sound, Alaska, July 1995. No eulachon were sighted.

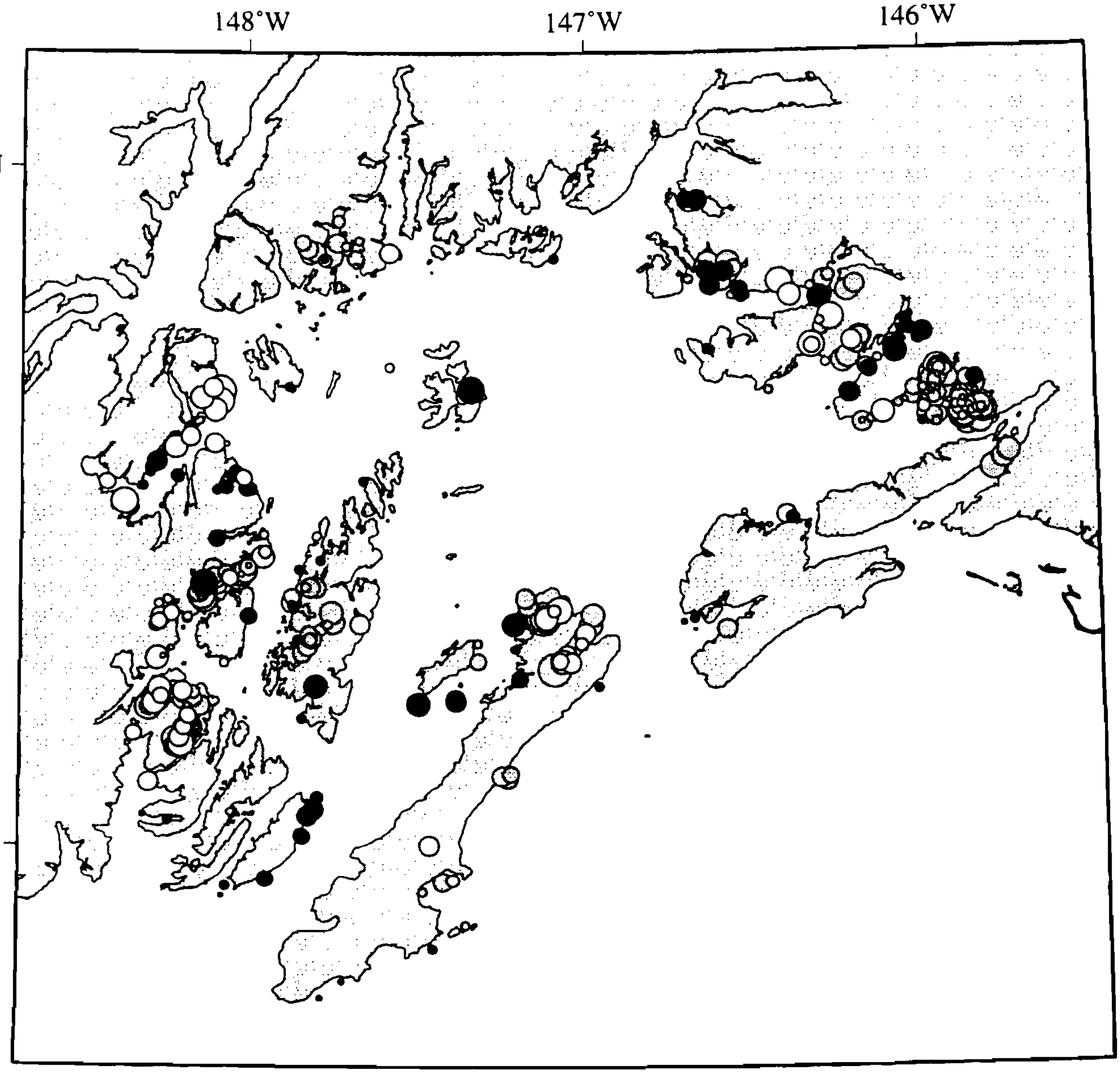


Appendix II Fig. 6. Distribution of Seabird and Forage Fish, in Prince William Sound, Alaska, July 1996. No capelin, or eulachon were sighted.



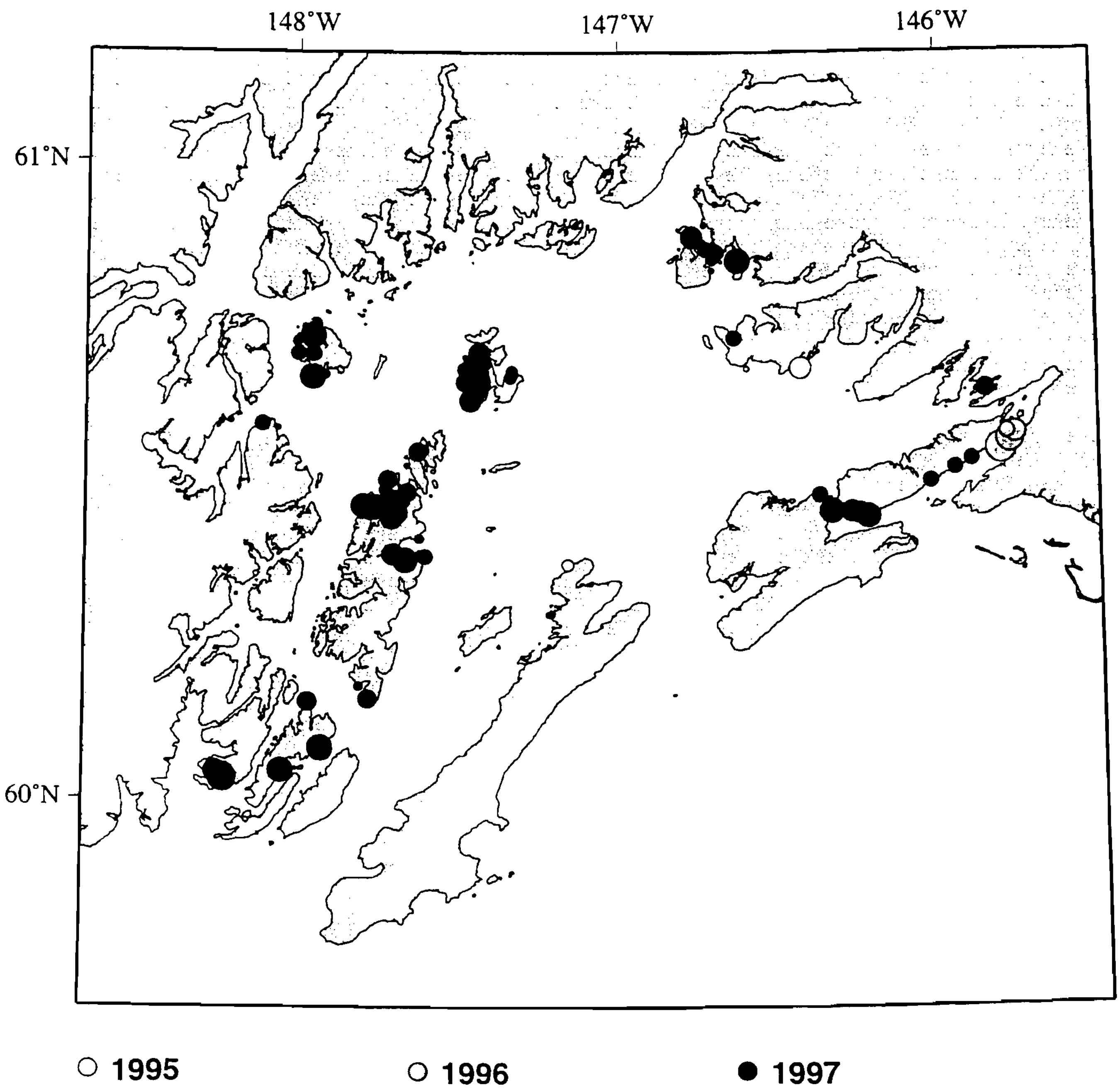
● Herring ○ Eulachon ○ Sandlance
● Capelin △ Birds

Appendix II Fig. 7. Distribution of Seabird and Forage Fish, in Prince William Sound, Alaska, July 1997. No capelin were sighted.

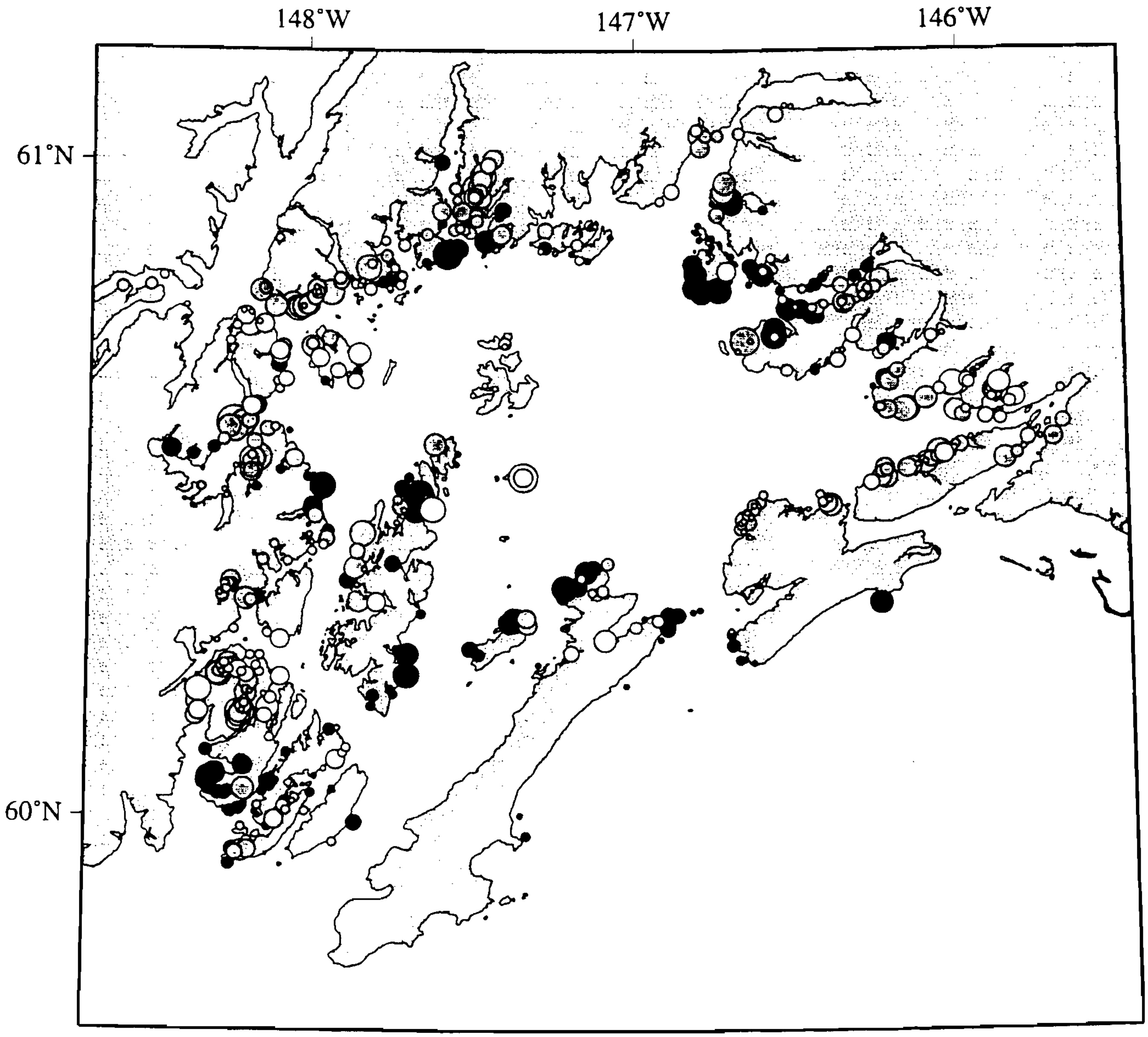


○ 1995 ○ 1996 ● 1997

Appendix II Fig. 8. Interannual Variation in the Distribution of Herring, in Prince William Sound, Alaska, June 1995-1997.

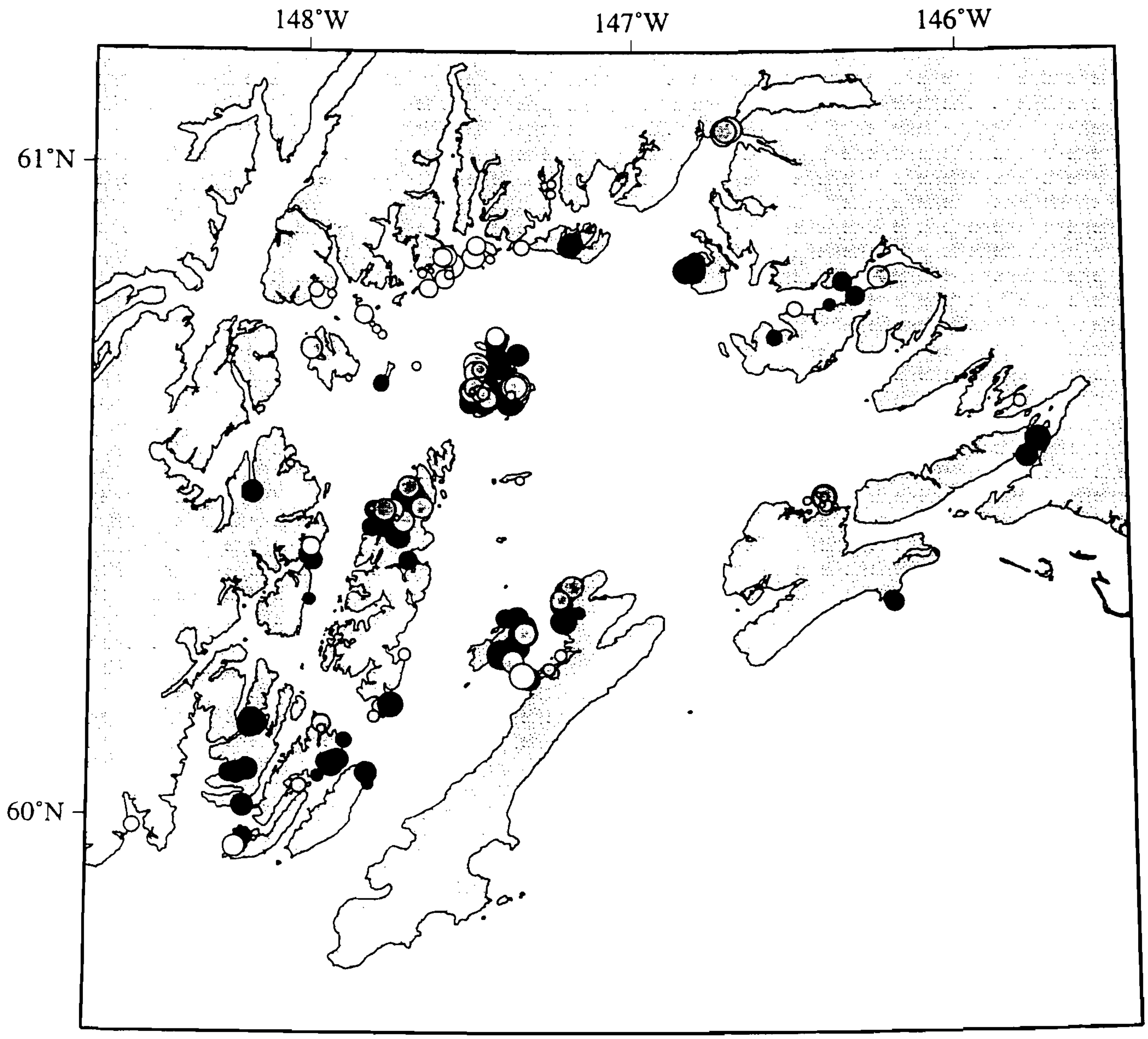


Appendix II Fig. 9. Interannual Variation in the Distribution of Sandlance, in Prince William Sound, Alaska, June 1995-1997.



○ **1995** ○ **1996** ● **1997**

Appendix II Fig. 10. Interannual Variation in the Distribution of Herring, in Prince William Sound, Alaska, July 1995-1997.



○ **1995** ○ **1996** ● **1997**

Appendix II Fig. 11. Interannual Variation in the Distribution of Sandlance, in Prince William Sound, Alaska, July 1995-1997.

Appendix III

Progress Report on Aerial Survey Development

Evelyn D. Brown and Gary A. Borstad
April 7, 1998

Appendix III. Progress Report on Aerial Survey Development

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Introduction

This section of the SEA annual report (97320T) is an update on the development of aerial survey methodology used by the SEA project for the last three years. The original objective of aerial surveys was to provide an economic method of documenting broadscale distributions of juvenile herring. Because of the way surveys were conducted, a considerable amount of incidental data was collected that has now become pivotal for other EVOS projects. Information on the distribution of pre-spawning capelin (*Mallotus villosus*), juvenile and adult sandlance (*Ammodytes hexapterus*), eulachon (*Thaleichthys pacificus*), jellyfish aggregations, foraging gull distributions and behavior, and marine mammals (humpback whales, killer whales, sea lions, sea otters, and harbor seals) is included in the three-year database. Much of this incidental information has been shared with other EVOS projects and included in recent publications (Irons, Ostrand, Purcell, and Gotthardt from the APEX project). It is now clear, that this methodology is useful for a multiple array of research objectives and is cost effective.

We can now more clearly define research questions that can be answered with the aerial survey data in concert with other physical or biological data:

What is the distribution of juvenile herring, sandlance, capelin and other schooling forage fishes, and jellyfish aggregations?

How do those distributions relate interspecifically, to ocean conditions, and to distributions of predators?

What is the temporal and spatial variation of those distributions?

Current research objectives are also more clearly defined:

1) Measure the species-specific distribution and abundance of forage fish schools

2) Determine the precision, validity and accuracy of those measurements

3) Determine how those results relate to oceanic conditions or regimes and to the distributions of avian and mammalian predators.

In Appendix II of this report chapter, we document the distributions of all forage fish species observed in the last three years (objective 1). In this report section, we will focus on the progress toward measurement of error associated with the aerial survey methodology (objective 2).

Measurement of error falls into one of three categories: precision, validity and accuracy. Precision or variability of data introduced by the technique is determined via repeated measures, double counts, and comparison to independent measurements. Validity of aerial sightings is accomplished by species identification from net catches, ground identifications, or underwater videos of individual schools identified from the air. Accuracy or bias is measured by comparison of aerial survey results to independent measures such as acoustics and compact airborne spectrographic imager (CASI).

Finally, we will outline tasks yet to be accomplished for completion of the aerial survey methods publication (SEA Annual Report Chapter 11, Appendix I) and make recommendations for research direction in the future.

Methods

A detailed description of the methods was included in a chapter of the SEA 1996 Annual Report (Stokesbury et al., 1997), so this section will serve as a brief review.

For these methods a sighting tube is used which consists of a PVC tube with a mylar grid attached to the end. School diameters or dimensions were measured through the tube and converted to meters using a simple proportional equation (Brady 1987; Lebida and Whitmore, 1985):

$$X = A (L / F);$$ A=altitude, L=tube tick measurement, F=tube focal length.

A preferred altitude range of 275-365 m (900-1200 ft) was established based on school size. Since many of the schools were smaller than 5 m^2, the altitude range selected is lower than for many other established aerial surveys that are looking at much larger, pre-spawning adult aggregations (Carscadden et al. 1994; Funk et al. 1995)

The survey design is a "narrow-strip" line transect within which uniform detection is assumed (Thompson 1992). The visual swath is equivalent to the area perpendicular to the transect where uniform detection occurs and is a function of altitude. The dimensions of the visual swath were developed by flying over a fixed object of known distance and area (an airport runway and helipad) within the range of altitudes used for data collection. The distance to a maximum sighting tube angle of 30 degrees (to the vertical), and within which the smallest detectable object (a single gull) could be discriminated, was identified as the edge of the swath.

In order to eliminate survey condition bias, introduced by variable meteorological conditions or aircraft, minimum criteria were established. We did not fly if the winds were over 25 knots (creating a sea state of over 1 beaufort scale or 1 m wave heights), if the average ceiling (cloud cover) was below 200m, or on rainy days. We also used the same type of aircraft (Cessna 185) for each survey. Finally, where possible, we flew during the same tide stage and time of day.

In order to estimate the precision of the survey data produced, we used double counts (Rivest and Potvin, 1995). Two surveyors were independently counting and measuring schools simultaneously from the same side of the aircraft. For each map, bay, transect or survey day, counts were compared between the two. The residual distances represent an estimate of surveyor bias.

In order to measure repeatability of the survey results, we flew over the same bay several times within a 24-48 hr time period. The unit of measurement was a single bay or nursery site for juvenile herring (refer to the main body of this report).

Validation of schools was accomplished in several ways. The best validations were obtained when vessels or skiffs capable of catching fish or with divers were directed to specific schools spotted from the air. We also obtained validations by directing skiffs with underwater videos, although avoidance was a problem with this method. A priority for scheduling aerial surveys was to overfly acoustic vessel surveys whenever possible (for both APEX and SEA). Geocoded net catches were then matched to aerial sightings occurring during the same day and location. Finally, we landed at vessels where research diving activities were taking place (Steve Jewett, Nearshore Vertebrate Predator or NVP project, personal communication) and conferred with them about the identification of schools seen underwater that matched our school locations. In this case, latitudes and longitudes were also matched within a 24 hr time scale.

Validation of schools will be taken a step further in a modeling exercise. Species discrimination parameters were identified and measured for over 400 samples. The identification parameters will be used in a discriminate function analysis to separate species and age classes by their distinct characteristics.

For estimating the accuracy of the aerial survey results, we used both CASI and acoustic survey results. We only briefly discuss acoustic comparisons here (work in progress); see the body of this report and Appendix I of this annual report for more detail on acoustic methodology. For comparisons to CASI, two aircraft were used. We flew the visual surveys in the Cessna 185 as usual. The CASI equipment was mounted in a Dehavilland Beaver 216GB aircraft on floats with a hole cut in the bottom of the plane for the sensor array. The surveyors in the 185 performed a reconnaissance survey setting up straight line transect passes for the CASI. Then the two aircraft lined up and flew each transect simultaneously with the visual surveyors counting schools underneath the Beaver. The two aircraft were not always lined up perfectly in space or time, but exact school locations could be obtained later and compared within a defined geographic region rather than for each transect.

The CASI system acquired digital multispectral imagery of fish schools (Borstad et al. 1992). The resulting images were radiometrically calibrated (Borstad Associates. Program

CVTD3_3), corrected for aircraft roll, and scaled uniformly. Because the herring schools were small, the CASI instrument was configured to acquire data with the highest spatial resolution (small pixels) possible. The along-track pixel length was determined by the number of spectral channels and the aircraft speed. Only three channels were used (Table 1) allowing a 30 msec integration time. Wide spectral bands were defined, which gathered as much light as possible while still differentiating the schools from their surroundings. On some lines, the fore optics fstop were changed to f4 from 4 to 5.6 in order to further increase the signal levels.

Table 1. The Configuration File Bandset

CASI band #	Wavelengths (nm)
1	405 – 455
2	460 – 590
3	600 - 675

The settings resulted in single pixel dimensions of .3-.5 m wide and 1-2 m long. With these setting only a tiny school would be represented by a single pixel (as were gulls). For the vast majority of schools measured, the settings provided in excess of 10 pixels per school. The altitude flown affected the image swath, but generally at 305 m the CASI image was 200 m wide. In order to prevent the images from becoming too large to handle on the computer, transects were restricted to less than 10 km and preferably between 4-6 km long.

During post-processing, the 8 bit unsigned images were examined and the area for each school calculated. School dimensions and statistics were obtained using a custom program designed for the CASI on a Sun-Sparc5 Unix system. A full 512X1900 resolution window was used to process the images. Statistics were first recorded by transect line and checked for errors. Later, sections with concentrations of schools were extracted and geocoded so they could be linked in space with the visual sightings, since the two aircraft were not always lined up perfectly to record the same features at exactly the same time.

Results

In 1996-1997, 87 double counted surveys were conducted. Error was estimated for both total school counts and for surface area estimates within a given area (Figure 1a and 1b). The outliers in this relationship have not been checked; there is missing data that needs to be included. Once the corrections have been made, we expect the estimated surveyor bias to decrease. There is more error associated with making school surface area estimates than school counts. However, both relationships are currently close to one-to-one counts (slopes approximately equal to 1.0) with high correlation coefficients indicating that surveyor bias is a minor contributor to the total variability found in the data.

In 1996-1997, 11 repeat counts were conducted over individual juvenile herring nursery bays within a 24-48 hr time period (Figure 2). Residual analysis of this relationship indicates that normality may be a problem with increasing variability occurring when the delay between the repeat counts is increased. Despite that problem, the correlation coefficient (0.707) is relatively high and significant indicating that there is constancy in the number of surface herring schools observed in a given bay. The preliminary conclusion from this initial look at the data is that variability in school distribution over a 24-48 hr time period is probably not a significant contributor to overall variability in survey results.

During 1996-1997 over 350 validations of aerial survey observations were completed. Validations were collected from net catches, diver observations, and underwater videos of schools sighted from the air. Of the 309 herring schools identified on the ground (Figure 3), 96.1% were correctly identified as herring from the air. All of the misidentifications involved age-0 sandlance recorded as herring from the air. In addition, the vast majority (over 90%) of the validated herring schools were age 0-1. Of the 47 sandlance schools identified on the ground, 80.4% were correctly identified from the air. As with herring, all of the errors involved age-0 sandlance recorded as herring. Also, the vast majority (over 90%) of the validated sandlance schools were juveniles.

Ability to discriminate forage fish species from the air is an important objective for this project. In the initial definition of discrimination parameters, distance from shore, school shape, and school size are useful in separating herring and sandlance schools. Juvenile herring schools occur 31.8 m $\pm$ 2.26 m (95% confidence) from shore in contrast to sandlance which occur 10.2 m $\pm$ 1.23 m. The vast majority of juvenile herring schools observed from the air in the summer are round (Figures 3 and 5) while the vast majority of sandlance schools are oval or irregular (Figures 4 and 5). Juvenile herring schools average 24 m^2 $\pm$ 3.64 m^2 in surface area while juvenile sandlance schools average 55.8 m^2 $\pm$ 7.23 m^2. Sample means of both distance from shore and school size between the two species are significantly different from one another (p=0.000).

In early July, we completed a series of 37 transects with visual and CASI counts performed simultaneously using two aircraft (25 transects shown in Figures 6-9). A single CASI image was obtained for each transect covering a surface area of 200m by up to 10 km (length of transect varied). Portions of the image with fish schools were saved as bitmaps (examples in Figure 5). We initially compared the visual counts and estimated of surface area with similar estimates derived from CASI images per transect (n=33). We found relatively good agreement with a regression analysis of ln transformed school (r^2 = 0.730; slope = 0.75; d.f. = 36; p = 0.0000) (Figure 10). We had predicted that the visual method would result in undercounts and therefore expected a slope of less than one. However, when we examined the outliers, we found that geographic mis-alignment may have been responsible for some of the error (visual surveyor and CASI image not recorded the same area). The analysis of CASI versus visual counts is therefore incomplete at this time.

For an initial comparison of acoustic to aerial survey results, we compared the first available acoustic data set for July, 1996 (Figure 11). This was the date of the third and final broadscale acoustic survey of herring nursery areas in Prince William Sound (see Appendix I). Although there was general agreement in the breadth of distribution and the association with the shore, the number of schools documented by acoustics was significantly less. The analysis of the aerial visual counts versus acoustic estimates is incomplete at this time.

Discussion

There are some tasks remaining before the total variability due to survey technique can be quantified (accuracy and precision). Outliers occurring in the double count relationship need to be examined. There are more repeat counts that have not been processed and we plan to explore the relationship between variability and time. If the sample size is high enough, we will also examine the effect of tide stage on the counts.

For validation, we have more ground identifications to add since underwater video processing is incomplete. The analysis will be finalized at that point. The discriminate function analysis used to identify species in the aerial database without bias is incomplete. We are adding depth to the discrimination parameters of distance from shore, school shape, and school size and have recently acquired that data.

In order to correct the geographic discrepancies between the visual and CASI data, we completed additional processing of the CASI data to include latitudes and longitudes for fish schools identified in the image. The geocoded CASI data was available in January of this year. We plan to revisit the regression analysis of visual to CASI measurements using a number of geographic queries and comparing the counts within a defined geographic region. We will also compare surface area estimates from the two techniques. By comparing both school counts and surface area estimates, we will be able to calculate error in visual aerial assessments of fish relative abundance.

In our initial comparisons of acoustic and aerial survey data, we found a large discrepancy in the relative abundance estimates (Figure 11). The difference in measurement scale is obvious. The sonar beam is 6 degrees and directed at a 90 degrees to the water surface. If fish schools are relatively shallow (in this case, 15 m or less; Appendix I), than schools are being counted with the narrowest part of the beam. The width of the area measured is a few meters. Because of budget limitations, we had to limit the broadscale survey to approximately 10 days allowing a single pass through each area surveyed. The transect width of aerial measurements exceeds 200m and several passes can be made over an area to cover the entire surface area of the water. This results in approaching 100% coverage of the areas of interest (in this case nearshore waters of PWS and the Outer Kenai). The broadscale acoustic survey was accomplished for approximately $60,000 in vessel charter while the broadscale aerial survey covering an extended area (including all waters surveyed by boat) for approximately $7,500 in aircraft charter. The advantage is obvious. Our recommendation is to use acoustics and net sampling in a random stratified design to subsample areas covered by air. This would maximize the utility of both techniques.

Acoustics will be an important source of data elucidating the relationship between variability in the three dimensional distribution of fish schools over a 24 hr to monthly time period and fish schools observed from the air during the same time periods. Acoustic data needed to complete this task have recently become available. This will add confidence to the aerial survey results, enable interpretation of aerial survey abundance estimates, and allow us to convert aerial estimates to biomass. We expect the comparison of aerial results to acoustics to be included in a separate publication.

We expect to complete these tasks and finalize the publication by May of 1998. This is a critical step in assimilating the aerial data for use by other projects and studies. Although the aerial data has been analyzed in relation to gull foraging activities (APEX review, 1998), our ability to publish the distributions hinges on documentation of the methodology. However, preliminary forage fish distributions have been presented in **Appendix II** of this SEA report chapter.

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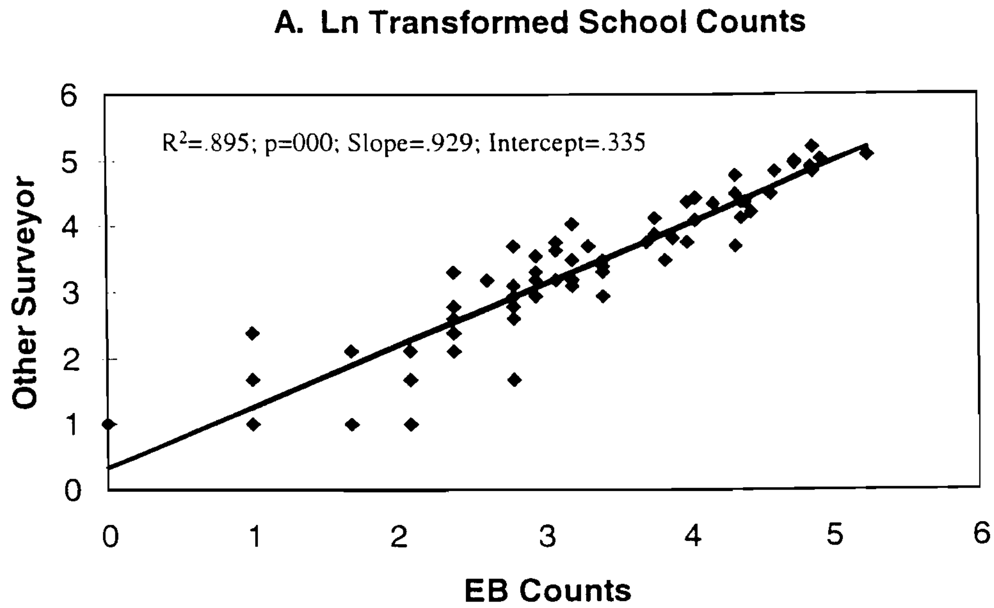


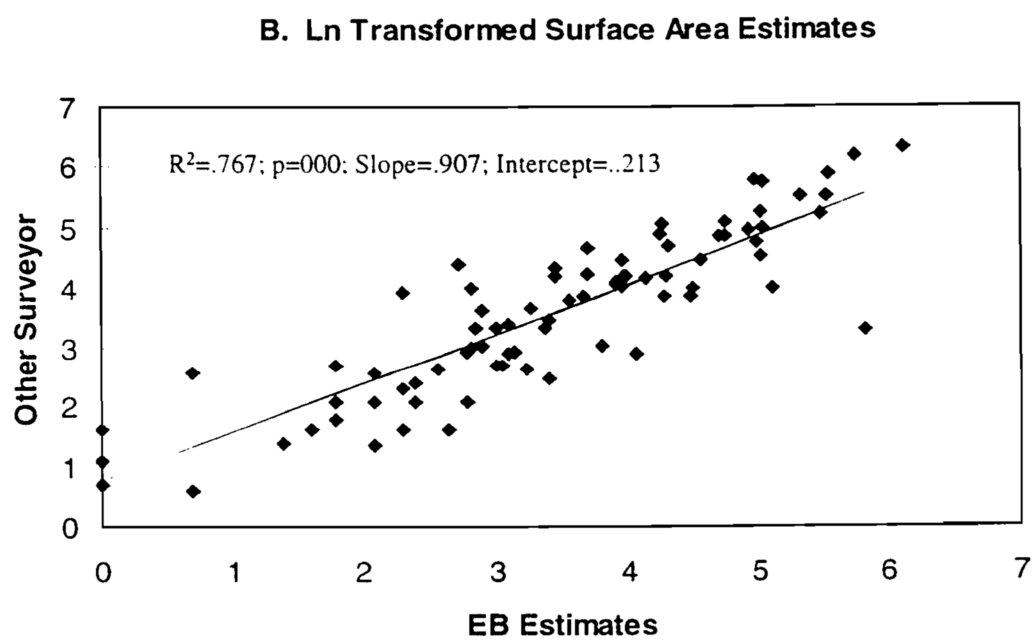


Figure 1. A. The regression between ln transformed simultaneous school counts for two surveyors. B. The regression between ln transformed simultaneous school surface area estimates for two surveyors.

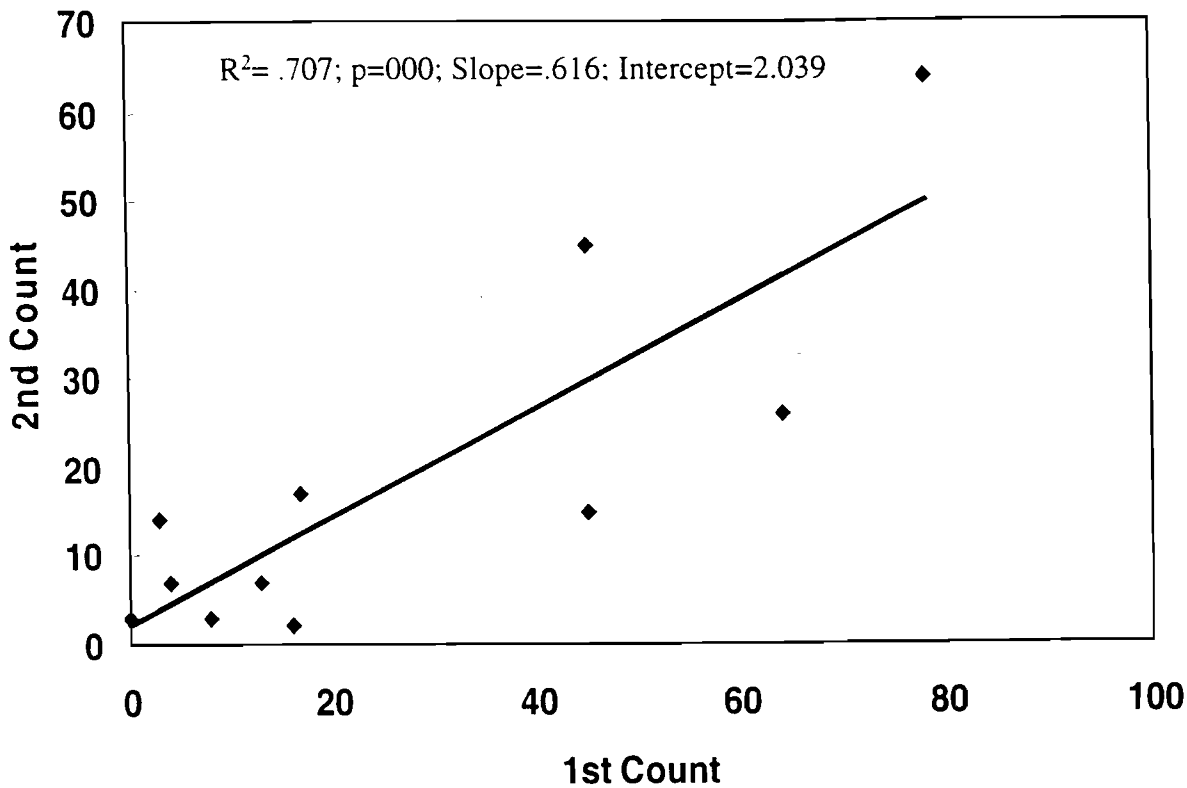


Figure 2. Repeat school counts conducted over a given bay between 24-48 hrs time difference.

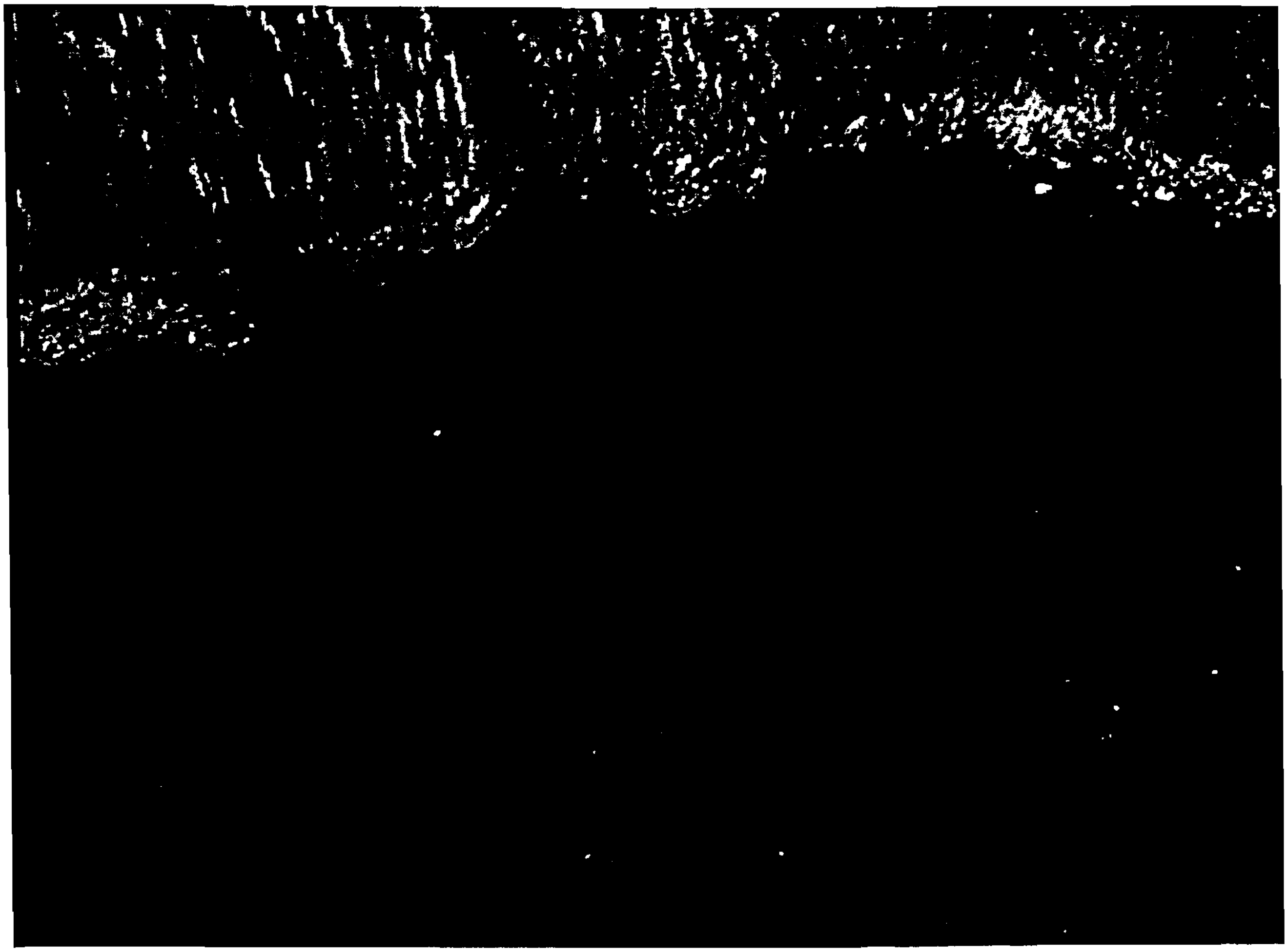


Figure 3. Two age-1 herring schools in southwestern Prince William Sound (validated with net catches).

Figure 4. Age-0 sandlance school in shallow water in northeastern Prince William Sound (validated with underwater video mounted on R/V Predator).

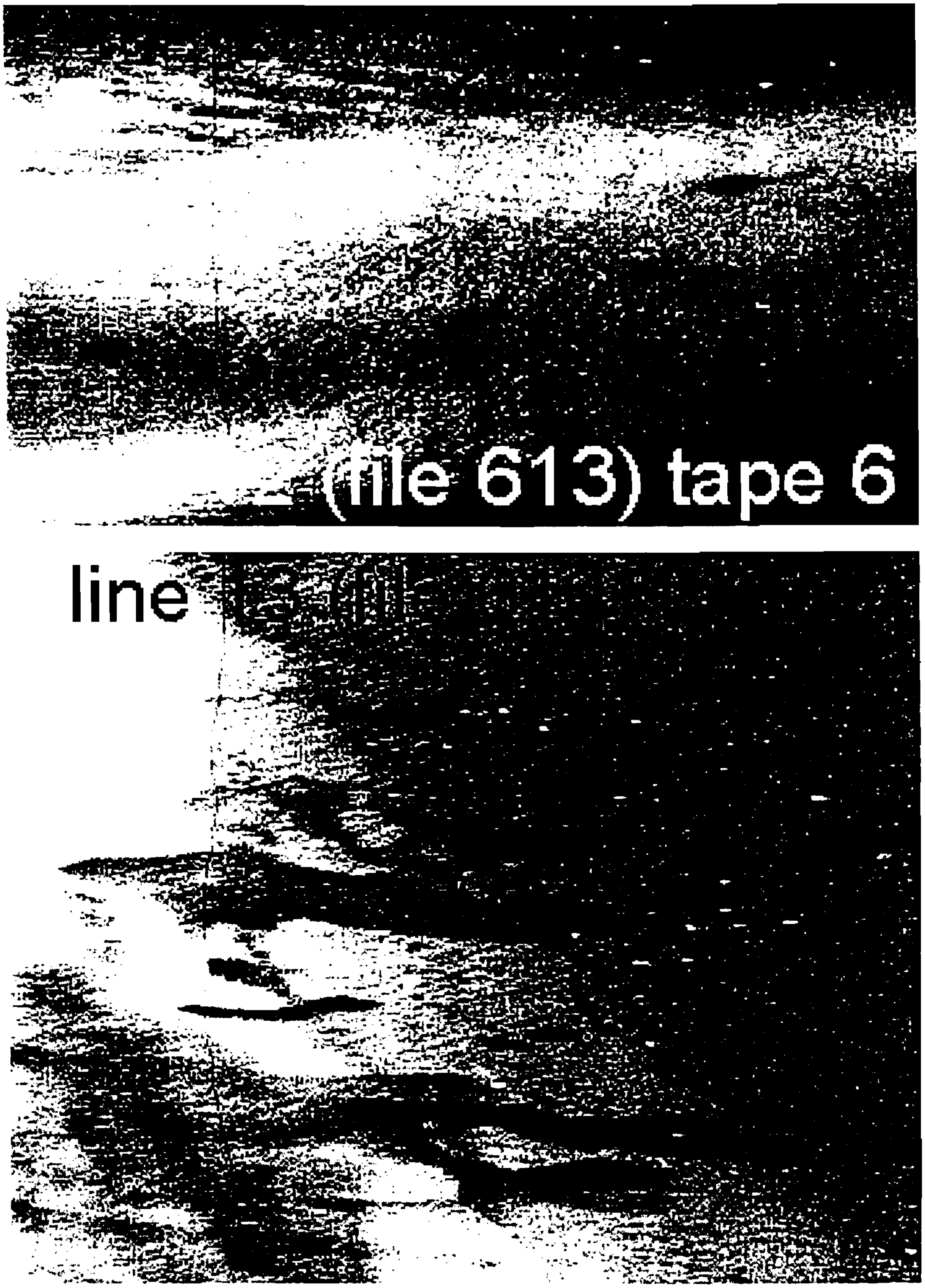
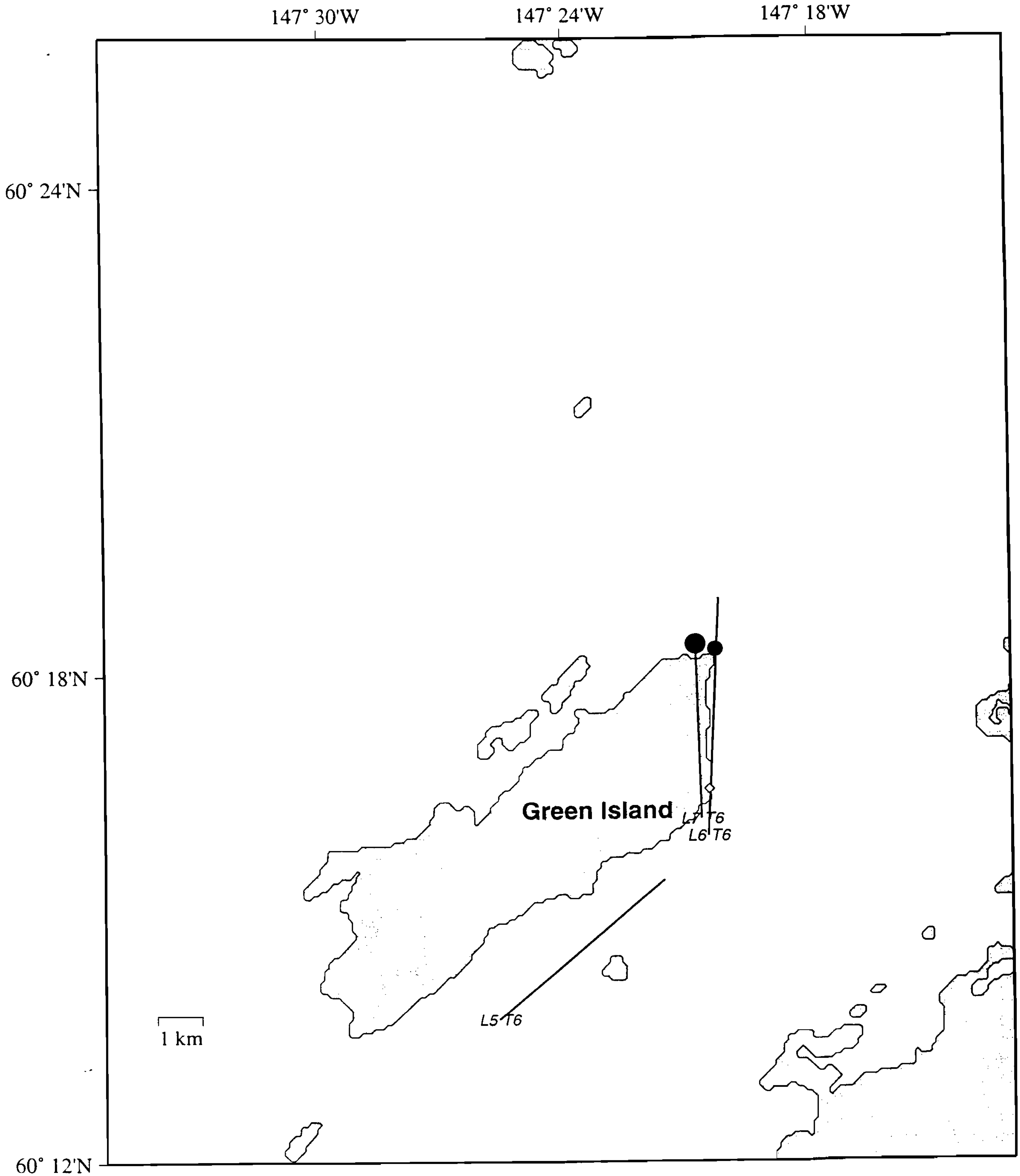


Figure 5. Images from the CASI system. The images have not been corrected for pixel distortion and appear compressed laterally as a result. The top image is herring schools on the northwestern shore of Hinchinbrook Island (eastern Prince William Sound). The bottom image is sandlance schools on the northeastern shoreof Hinchinbrook Island. The white spots are individual gulls.

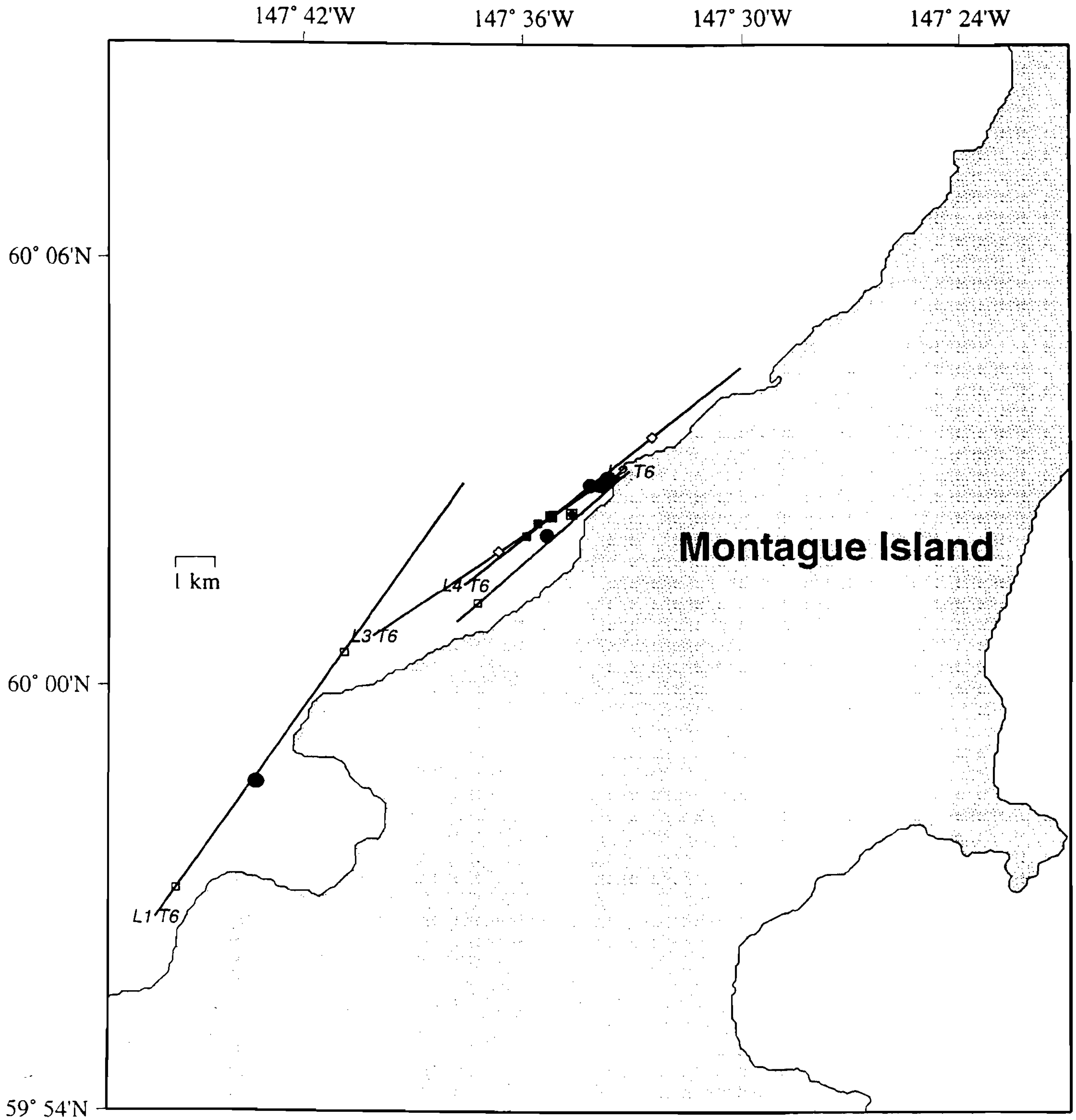
Appendix III Figure 6. Key for following figures.

Shade by value (m^2 surface area) of fish schools at a given location.	Total no. birds at a given location	Marine mammal(s) at a given location
1-10		
11-20	1-25	1-3
21-30	26-50	>4
31-50	51-100	
51-100	101-200	
101-200	201-500	
201-500	501-1000	
501-1000	1001-5000	
>1000	>5001	

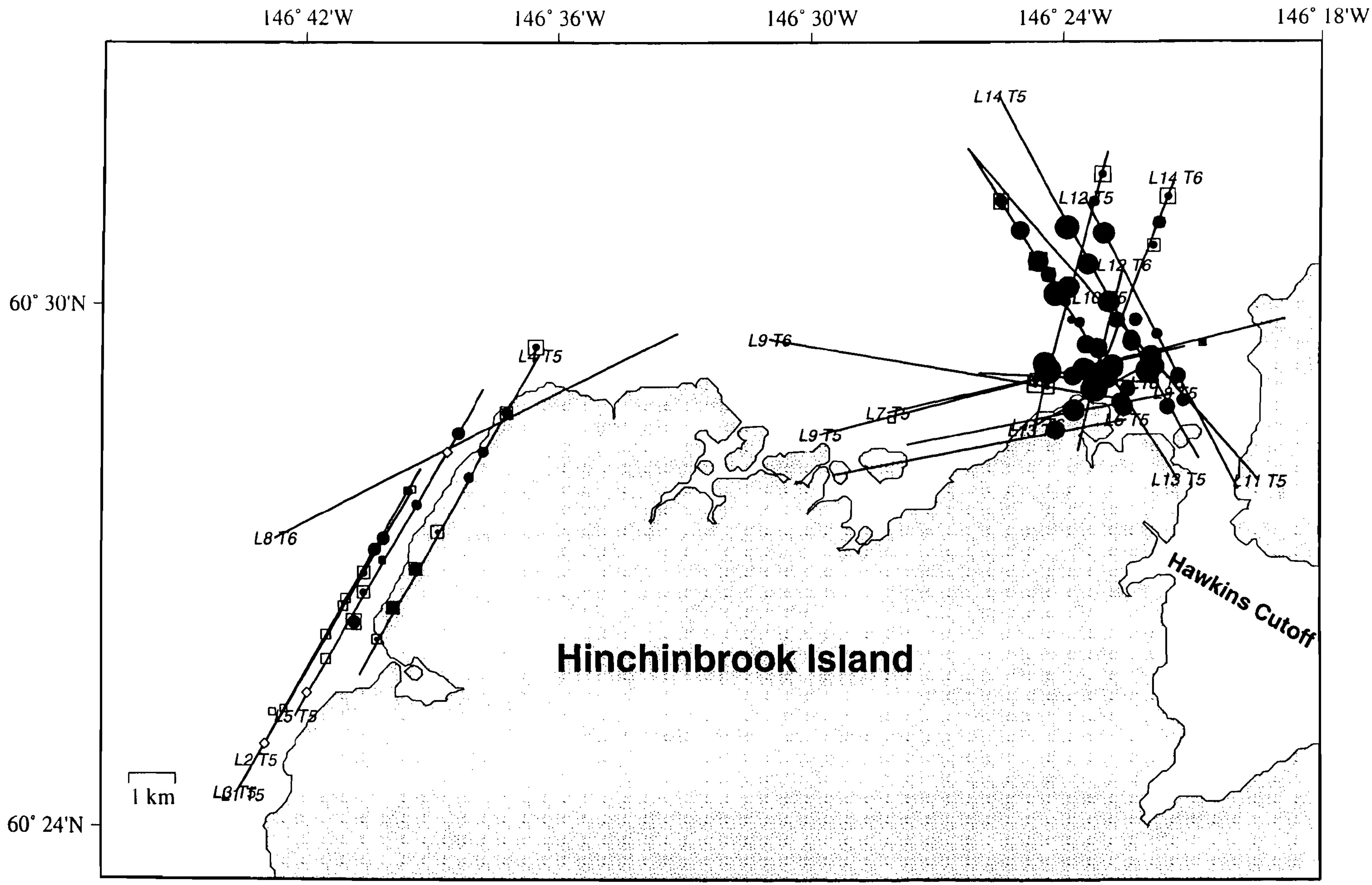
Appendix III Figure 7. CASI surveys at Green Island (low density).

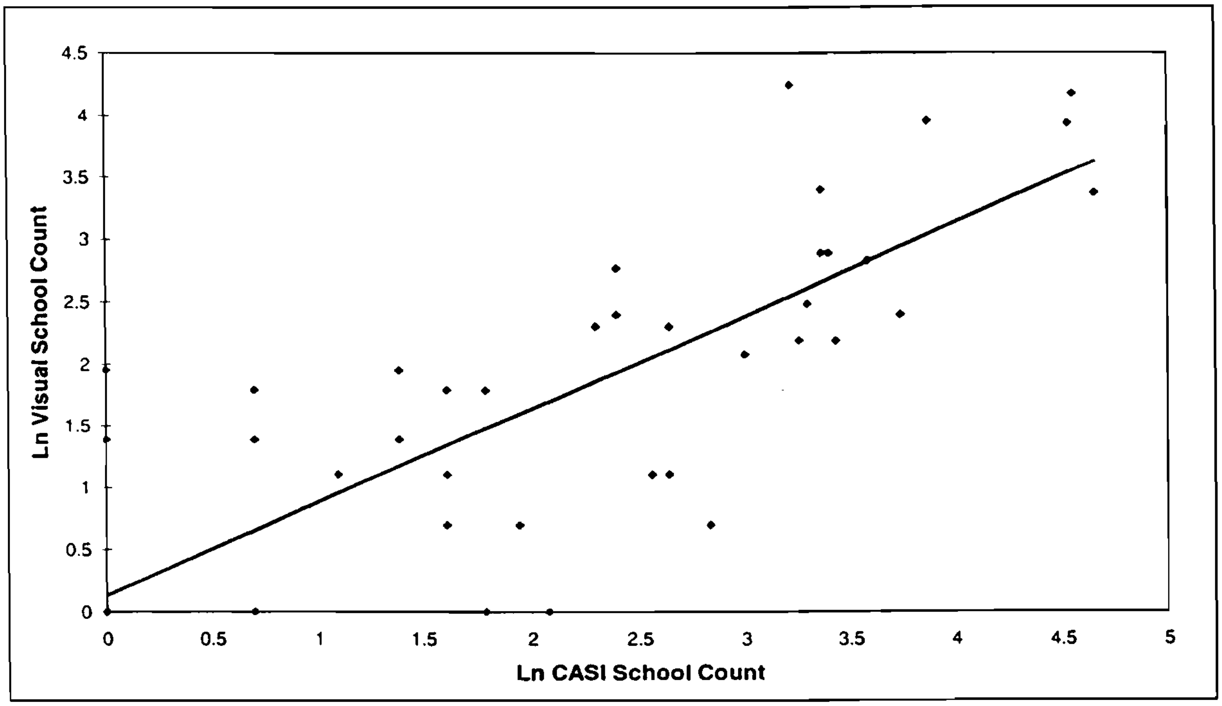


Appendix III Figure 8. CASI surveys at Montague Island (low density).



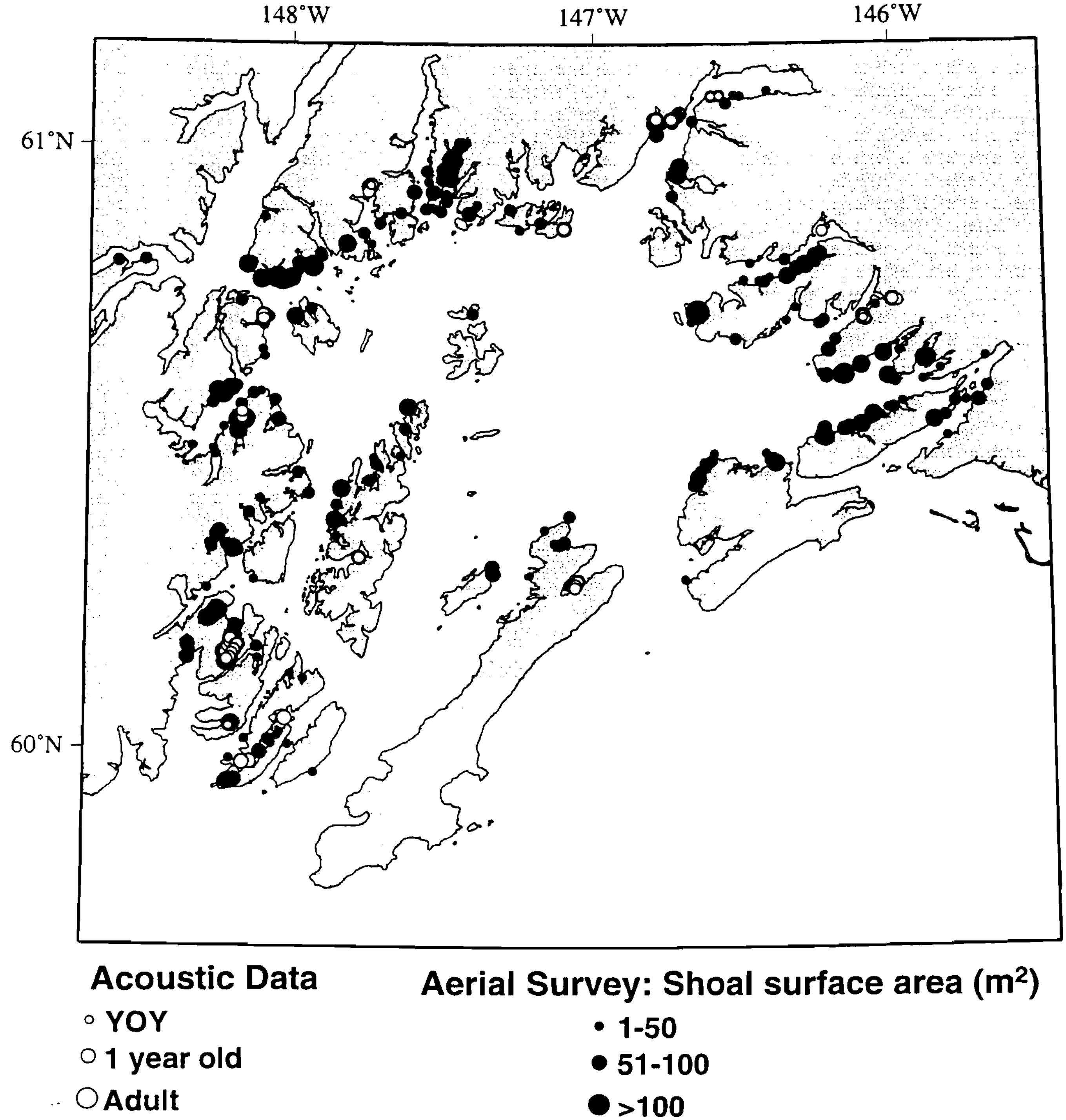
Appendix III Figure 9. CASI surveys at Hinchinbrook Island (medium and high densities).





R^2=0.730; p=0.0000; d.f.=36 (transects); slope=0.75

Figure 10. Regression analysis of ln transformed visual school counts versus CASI school countsby transect.



Appendix III Figure 11. Comparison of broadscale aerial survey results to broadscale acoustic measurements.

Appendix IV

Foy, R. J., and B. L. Norcross. 1998. Spatial and temporal differences in the diet of juvenile Pacific herring (*Clupea pallasi*) in Prince William Sound, Alaska.

Spatial and Temporal Differences in the Diet of Juvenile Pacific Herring (Clupea pallasi) in Prince William Sound, Alaska

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Abstract

The diet of juvenile Pacific herring, Clupea pallasi, from four bays in Prince William Sound, Alaska, differed spatially and seasonally. The stomach fullness and diversity indices of juvenile herring were significantly larger in May and declined through the following winter. Spatial and temporal trends were found among the most important prey species in the diet of juvenile herring. In March, fish eggs, Cirripedia nauplii, small Calanoida, and large Calanoida were the dominant prey in Eaglek, Simpson, Whale, and Zaikof Bay, respectively. In October, Oikopleura species of Larvacea were dominant in all bays sampled. In Zaikof Bay, large Calanoida dominated the prey taxa in May of 1995 and March of 1996. Small Calanoida and Larvacea were the highest prey biomass in summer and fall, respectively.

Introduction

Pacific herring, Clupea pallasi Valenciennes (1847), are distributed along the Asiatic and North American continental shelves in the Pacific Ocean. In Prince William Sound, Alaska, herring are a commercially important fishery. Reduced abundance, resulting in the closure of the commercial fishery in 1993, have led to questions about the recruitment processes in Prince William Sound. When studying recruitment it is important to understand mechanisms that create variation at particular stages in the fish's development (Houde 1987; Miller et al. 1991). For example, starvation or slow growth rates can lead to high mortality and decreased recruitment. Water temperature has been correlated to the density of zooplankton and subsequent abundant classes of herring (Maksimenkov 1982). An important aspect of herring recruitment variation, therefore, is that associated with the feeding behavior and success of larvae and juveniles prior to recruitment.

Most feeding studies and subsequent hypotheses regarding herring recruitment focus on larval stages and first feeding (Cushing 1975; Iles and Sinclair 1982; Sinclair and Tremblay 1984; Cushing 1990). However, recruitment may also be regulated during the juvenile stage of development (Houde 1987; Bollens et al. 1992). We hypothesize that the juvenile stage of Prince William Sound herring development incurs a significant amount of variation in mortality and therefore recruitment to older stages. This variation may be explained through the understanding the juvenile feeding ecology.

The spatial and temporal characteristics of the juvenile herring feeding ecology in Prince William Sound are poorly understood. Atlantic herring (Clupea harengus) are capable of filter and particulate feeding, depending on the size and concentrations of potential prey (Gibson and Ezzi 1985). Size dependent predation (Hrbáček et al. 1961; Brooks and Dodson 1965) suggests that herring would preferentially prey on the larger zooplankton. Densities of smaller zooplankton would then become greater due to decreased grazing pressure from larger zooplankton and, therefore, would become an available prey source to small fish such as juvenile herring. The prey of Baltic herring (Clupea harengus) increase in size with sampling date and fish size (Arrhenius 1996). Age 0+ Baltic herring feed on smaller zooplankton such as small copepods and cladocerans (Raid 1985; Rudstam et al. 1992; Mehner 1993; Arrhenius 1996) whereas larger juvenile herring prey on larger calanoid species when available (Pearcy et al. 1979; Sandstrom 1980). Cannibalism on larval herring by juveniles in the North Pacific has been found to occur (Hourston et al. 1981). Adult herring feed on euphausiids and larger copepod species (Pearcy et al. 1979), reproducing copepod and cladoceran species (Flinkman et al. 1991), and occasionally on pink salmon fry (Thorsteinson 1962) and chinook salmon fry (Ito and Parker 1971). Alternative fish feeding theories, which suggest the importance of the profitability of prey, take into account searching and handling time (optimal foraging) which may not favor the larger prey species (Werner and Hall 1974; Bence and Murdoch 1986). Selective feeding by Atlantic herring has been hypothesized to be dependent on prey escape capability, visibility, and possibly nutritional value (Checkley 1982).

Identification of seasonal prey species in herring diet is an important first step to understanding the trophic interactions of herring and its prey. We hypothesize that the diet of juvenile herring in Prince William Sound will temporally and spatially vary according to the abundance and species composition of available prey. Therefore, the objective of this study is to describe the relative importance of prey categories in the diet of juvenile herring from four bays within Prince William Sound during the spring, summer, and fall.

Materials and Methods

Sample Collection

Prince William Sound is a coastal estuarine system located along the southern coast of Alaska. Four bays were chosen as study sites within the sound (Fig. 1). Eaglek and Whale Bays are deep fjords whereas Simpson and Zaikof Bays are relatively shallow estuaries. A total of 38 herring schools were sampled in May, June, and October 1995 and March 1996. Juvenile herring schools were targeted and caught using a purse seine vessel with a 250 m x 34 m or 250 m x 20 m, 150 mm stretch mesh anchovy net or a trawl vessel with a 40 m x 28 m, 150 mm mesh mid-water wing trawl net. From each catch, 15 fish were randomly sampled. Fish were measured (fork length mm) and preserved in a 10 % buffered formaldehyde solution. After 24 hours, samples were transferred to 50 % isopropanol for diet analysis.

Average weights of preserved zooplankton (Appendix 1) for prey biomass estimates were obtained from a database generated at the Institute of Marine Science at the University of Alaska Fairbanks. Seasonal zooplankton samples have been obtained from multiple sites in Prince William Sound and the upper North Pacific Ocean via 20 m vertical tows with a 333 um mesh net since 1987. Average weights of taxa are updated annually by weighing formalin preserved individuals (at least 15) until a representative weight distribution has been obtained and added to the database.

Diet analysis

Each fish was blotted dry, weighed to the nearest 0.01 g, and measured (fork and standard length) to the nearest 1.0 mm. The stomach was removed and weighed to the nearest 0.001 g. Stomach contents were removed and the empty stomach was reweighed to determine stomach content weight. Stomach fullness indices were calculated by dividing the stomach content weight by the total fish weight and were used to compare the temporal and spatial feeding activity of juvenile herring.

Prey in the stomach were enumerated and identified to the lowest possible taxonomic level. In some cases, due to digestion, it was only possible to identify prey to a broad taxonomic grouping (i.e. Calanoida > 2.5 mm). Prey biomass in the stomach was calculated by multiplying the database value of mean weight by the total stomach content number for each prey species. The distribution of prey biomass was compared to a logarithmic function in order to determine if a logarithmic series would be an appropriate measure of heterogeneity of prey found in the diet of herring. A logarithmic index of species diversity (α) of prey biomass in the stomach content was calculated for each site within each month (Fisher et al. 1943; Anscombe 1950; Krebs 1989). The logarithmic index of diversity is a function of the number of species in a sample and the number of individuals in a sample. For this study, however, the total biomass of a taxon was used instead of the number of individuals in a taxon. Spatial and temporal comparisons described the dominant prey taxa seasonally within each bay.

The percentage of stomach content number (% N), percentage of stomach content weight (% W), and percent frequency of occurrence among fish (% FO) was determined for each prey species in the stomach contents. The percent index of relative importance (% IRI

= (% N + % W) * % FO; Pinkas et al. 1971) was calculated separately by site and by month and used to compare the relative importance of prey species taking into account the number of times a prey species was actually encountered in the diet of the herring sampled. Only IRI values above five percent are reported here to focus on the most important prey species.

Statistical analysis

Spatial analyses were conducted among all four sites from March, and among Zaikof Bay, Simpson Bay, and Whale Bay from October. Temporal analyses were conducted among the four months on samples from Zaikof Bay. Stomach fullness indices were arcsine transformed to satisfy the assumptions of normality by a Shapiro-Wilks' W test of normality prior to analysis. Mean stomach fullness indices were compared among sites and months using one-way analyses of variance. Significant differences between groups were analysed post hoc using an extended Tukey method when cases have unequal sample sizes (Spjotvoll and Stoline 1973). Prey biomass distributions were compared to logarithmic functions using the coefficients of determination from the fitted equation.

Results

Sample sizes of herring used in the diet analysis within bays ranged from 12 to 146 fish (Table 1). Standard lengths of herring averaged 107 mm and ranged from 42 to 230 mm. The number of stomachs that contained prey items ranged from 12 to 114 fish.

Herring stomach fullness indices were significantly different among sites in October ($F=12.28$ $P<0.01$ $DF=2$) and March ($F=14.59$ $P<0.01$ $DF=3$). In October, stomach fullness indices from herring in Whale Bay were not significantly different from those in Zaikof Bay. In March, stomach fullness indices of herring from Simpson Bay were not significantly different from those in Zaikof Bay and Eaglek Bay (Table 1).

Stomach fullness indices from herring sampled for temporal analysis from Zaikof Bay were significantly different among months ($F=91.90$ $P<0.01$ $DF=3$), however, there was no significant difference in stomach content indices between October and March.

The logarithmic distribution described the distributions of prey species biomass described from the herring stomach contents in all months and sites; coefficients of determination ranged from 0.43 to 0.88 (Table 2). The logarithmic distribution also described the distributions of total biomass in October and March with coefficients of determination of 0.95 and 0.79, respectively (Figs. 2 and 3). In October, the five highest contributors to prey biomass were Oikopleura sp., Euphausia sp., Calanoida (<2.5 mm), Malacostraca, and Metridia ochotensis, respectively (Fig. 2). The five highest contributors to prey biomass in March were fish eggs, Calanoida (> 2.5 mm), Cirripedia nauplii, Calanoida (<2.5 mm), and Decapoda zoea, respectively (Fig. 3). The logarithmic indices of species diversity (α) ranged from 1.3 to 7.1 and had variances ranging from 0.18 to 2.20 (Table 2).

Indices of relative importance were calculated to determine spatial trends in the frequency of prey taxa in the diet of herring. In October, Oikopleura sp. of Larvacea was the dominant prey species in all three bays. In March, there were notable spatial differences in dominant prey taxa among the four bays (Fig. 4). Fish eggs were dominant in Eaglek Bay and were the second most important prey taxa in Simpson and Zaikof Bays. Cirripedia nauplii were the dominant prey taxa in Simpson Bay. As in March, Calanoida (< 2.5 mm) were the dominant prey in Whale Bay whereas Calanoida (> 2.5 mm) were dominant in Zaikof Bay.

Indices of Relative Importance were also calculated to determine temporal differences in the dominant prey taxa in Zaikof Bay (Figs. 4 and 5). Calanoida (> 2.5 mm) were dominant in May. The June diet consisted of more species above an importance index of 5 % than any other period and Calanoida (< 2.5 mm) was the dominant taxa.

Discussion

Stomach fullness indices are applied to biomass data because we wanted to analyze both the number and weight of prey in each taxa identified. For instance, in October and March, herring from Whale Bay have significantly larger biomass of prey than any other site. In October, this is due to greater weights of prey species whereas the number of prey per fish is greater in March.

In Zaikof Bay, significantly larger prey biomass in May diets than later in the fall and the following spring is explained by the higher biomass of zooplankton common to Prince William Sound in April and May after the period of high productivity (Goering et al. 1973). The availability of prey after the high spring productivity is, therefore, limiting to the amount of food ingested by the herring sampled in this study. This assumes a positive linear relationship between the stomach capacity and weight of the fish, which has been found to be exponential for other species of fish (Knight and Margraf 1982).

The spatial and temporal variability observed in the stomach fullness indices suggests that the consumption rates in Prince William Sound may be variable. Trophodynamic models based on empirical models of copepod biomass estimate that juvenile herring on the southern British Columbia continental shelf need to ingest 3 % of their body weight of copepods per day (Robinson and Ware 1994). Consumption rates for Baltic herring are 10-20 % body weight per day for 0+ fish, 7-13 % for juvenile fish and 5 % for older fish (Rudstam et al. 1992). A 1.3 % body weight consumption rate for 0+ southern Baltic herring in May has been estimated (Mehner and Heerkloss 1994). In a controlled experiment, Atlantic herring are estimated to consume 5 % body weight at 6.5 °C, and 11 % body weight at 11 °C (DeSilva and Balbontin 1974). Consumption of 9.2 % per day is estimated for juvenile herring in the Baltic (Rudstam 1988). Much of the variation in these estimates may be due to the temperature and/or relative energetic value of the prey items encountered.

Fifty-three percent of the stomachs in Zaikof Bay in March were empty. The occurrence of empty stomachs was never higher than 27 % in any other bay in any month. Low consumption rates in Zaikof Bay during the winter suggests a potential effect on the survival of juveniles through the winter in this bay. Future studies of juvenile herring feeding in Prince William Sound should focus on annual consumption rates around the sound in order to compare seasonal growth with respect to survival prior to recruitment.

Diversity indices are a means of describing the species composition of a community (Krebs 1989). In this study, the logarithmic diversity index is used to compare the seasonal variation in prey species biomass found in the stomach contents of juvenile herring from the four bays. The biomass of prey from Eaglek Bay in March does not fit a logarithmic distribution due to the dominance of fish eggs in the herring diets; however, this does not significantly affect the value of the index of diversity.

The diversity of prey species in Zaikof Bay is largest in May followed by June due to the availability of different prey associated with the spring plankton bloom. Herring from Whale Bay, which have significantly higher stomach fullness indices, have lower prey diversity indices suggesting that juvenile herring can feed more when there is an increased biomass of fewer available prey taxa. Feeding more, however, does not mean an energetically better diet. It is possible that selective feeding during periods of low prey diversity and high density provides energetically "better" prey than feeding at times of high prey diversity and low density regardless of the level of stomach fullness achieved.

Comparisons of dominant prey species in the stomach content of juvenile herring account for the relative frequency of prey taxa occurrence with the index of relative importance. The spatial and temporal differences of the stomach fullness indices and diversity indices are exemplified by the distribution of most important prey species. Temporal differences are apparent in Zaikof Bay, indicating the seasonal importance of feeding to juvenile herring. In October, the dominant prey species in the diet was Oikopleura sp. in all three bays, which emphasizes the feeding strategy of herring when there is low prey diversity. A low diversity diet consisting of Copepoda, especially Eurytemora/Temora, dominates 0+ Baltic herring diet in October (Rudstam et al. 1992). The availability and energy density of prey may very well dictate which fish have enough energetic reserves to survive the winter, especially in the first year (Paul et al. ??).

Spatial differences in dominant prey taxa are especially evident in the spring. In March, when primary productivity is beginning to increase, the dominant prey species in the juvenile herring diet is different in each bay. This may represent a difference in prey composition or different herring feeding behavior. Variation among bays is controlled by the ecosystem response to the spring bloom oceanographic factors such as temperature, salinity, and nutrient availability as well as biological factors such as predation and competition among zooplankters.

Temporal differences of copepod presence in herring diets from this study are similar to variations in copepod abundance on the shelf near Kodiak Island, Alaska (Vogel and McMurray 1982) and the Gulf of Alaska (Cooney 1988). The diet of 0+ Baltic herring in the summer reflects the zooplankton availability, which consists mostly of Cladocera in the summer (Rudstam et al. 1992). In the fall of 1975, the dominant taxa of zooplankton in Prince William Sound were Copepoda, Amphipoda, and Euphausiacea (Damkaer 1977). Of the copepods, Acartia longiremis, Oithona similis, and Pseudocalanus sp. were the most abundant living in the upper waters. These species were present in low abundance in the herring diets in the fall of 1996. It is interesting to note that Larvacea were only in small abundance among the zooplankton in 1975, whereas in this study, they dominate the juvenile herring diet. Future analysis of the current zooplankton densities and composition in Prince William Sound will augment juvenile herring diet information with measures of prey availability.

Behavioral characteristics also have effects on the diet composition depending on whether the fish are filter or particulate feeding. Selective feeding by herring occurs in many locations. The size and abundance of prey of age-0 Baltic herring from 1978-1982 depend on the body size of the fish in the Gulf of Finland feeding mostly on Eurytemora sp. and Cladocera including Podon polyphemoides (Raid 1985). Baltic herring (150-220 mm) in Bothinian Bay select for the largest prey available which is (Limnocalanus grimaldi) in the early summer and switch to Eurytemora sp. and Cladocera after the L. grimaldi are gone (Sandstrom 1980). Similarly, in Zaikof Bay, the juvenile herring diets are dominated by large copepods available in the spring and then a mixture of other prey later in the season. The other three bays did not exhibit this trend, possibly due to the lack of availability of the larger zooplankton or to selection of different prey species. This is consistent 0+ Baltic herring which in April through June 1990 and 1991 consume Eurytemora affinis adults, nauplii, and eggs and to a small extent Harpacticoida in a bay in the southern Baltic Sea (Mehner 1993) and in the summer and fall 1992 and 1993 consume Acartia sp., Eurytemora sp., and Pseudocalanus sp. of Copepoda and Bosmina sp. and Pleopsis sp. of Cladocera (Arrhenius 1996). Bering Sea larval herring feed on smaller prey such as bivalve larvae and barnacle nauplii (Maksimenkov 1982), consistent with the juvenile herring diets from Simpson and Whale Bay in this study.

Diet composition will also be affected by the diel vertical migration of herring. For instance, the relatively small number of benthic and epibenthic invertebrate species found in the diet of herring in this study most likely represent feeding near the bottom during the day when feeding is at a minimum. Baltic herring prey on increased numbers of zoobenthic prey species, corresponding to the depth of capture (Ostrowski and Mackiewicz 1992). They hypothesize that this was due to the unavailability of preferred macro and mesozooplankton. It will be the goal of future work to elucidate such diel and ontogenetic shifts in juvenile herring feeding behavior.

Acknowledgments

We thank P. Lovely and C. Stark for sample sorting. Thanks to K. D. E. Stokesbury and A. Blanchard for advise with data analysis. This project was funded by the Exxon Valdez Oil Spill Trustee Council through the Sound Ecosystem Assessment (SEA) project. However, the findings presented by the authors are their own and not necessarily the Trustee Council position.

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Table 1. Spatial and temporal distribution of juvenile herring lengths, the number (percent) of stomachs with prey, and stomach fullness indices of herring from Prince William Sound.

month	site	n	stomachs with prey (%)	standard length (mm)			fullness index	
				mean	SD	range	mean	SD
May	Zaikof Bay	12	12 (100)	101	3.3	95-107	0.30	0.027
June	Zaikof Bay	60	54 (90)	101	6.9	78-122	0.11	0.063
October	Simpson Bay	106	83 (78)	76	15.9	78-115	0.07	0.048
	Whale Bay	30	30 (100)	89	8.0	42-140	0.11	0.037
	Zaikof Bay	31	30 (97)	70	10.2	58-97	0.10	0.047
March	Eaglek Bay	146	114 (78)	133	26.8	84-191	0.10	0.075
	Simpson Bay	29	27 (93)	116	16.6	91-142	0.07	0.029
	Whale Bay	60	44 (73)	109	24.8	79-157	0.15	0.089
	Zaikof Bay	100	47 (100)	164	29.4	88-230	0.05	0.029

Table 2. Spatial and temporal distribution of juvenile herring prey diversity as well as coefficients of determination for fitting the data to logarithmic series.

Month	Bay	fish n	prey taxa n	r^2	diversity (□)	□ variance
May	Zaikof	12	23	0.52	7.10	2.19
June	Zaikof	54	33	0.71	5.24	0.83
October	Simpson	83	26	0.56	4.21	0.68
	Whale	30	24	0.78	3.35	0.47
	Zaikof	30	15	0.82	2.10	0.29
March	Eaglek	114	29	0.43	4.38	0.66
	Simpson	27	10	0.75	1.33	0.18
	Whale	44	20	0.88	2.32	0.27
	Zaikof	47	27	0.61	4.18	0.65
Totals	March	232	41	0.79	5.44	0.72
	October	143	30	0.96	3.87	0.50

Figure captions

Fig. 1. Location of four bays sampled in Prince William Sound, Alaska.

Fig. 2. Distribution of juvenile herring prey biomass (g) fit to a logarithmic series from three bays in Prince William Sound in October 1995.

Fig. 3. Distribution of juvenile herring prey biomass (g) fit to a logarithmic series from four bays in Prince William Sound in March 1996.

Fig. 4. Spatial comparison of Indices of Relative Importance of juvenile herring prey in October and March.

Fig. 5. Temporal comparison of Indices of Relative Importance of juvenile herring prey in Zaikof Bay.

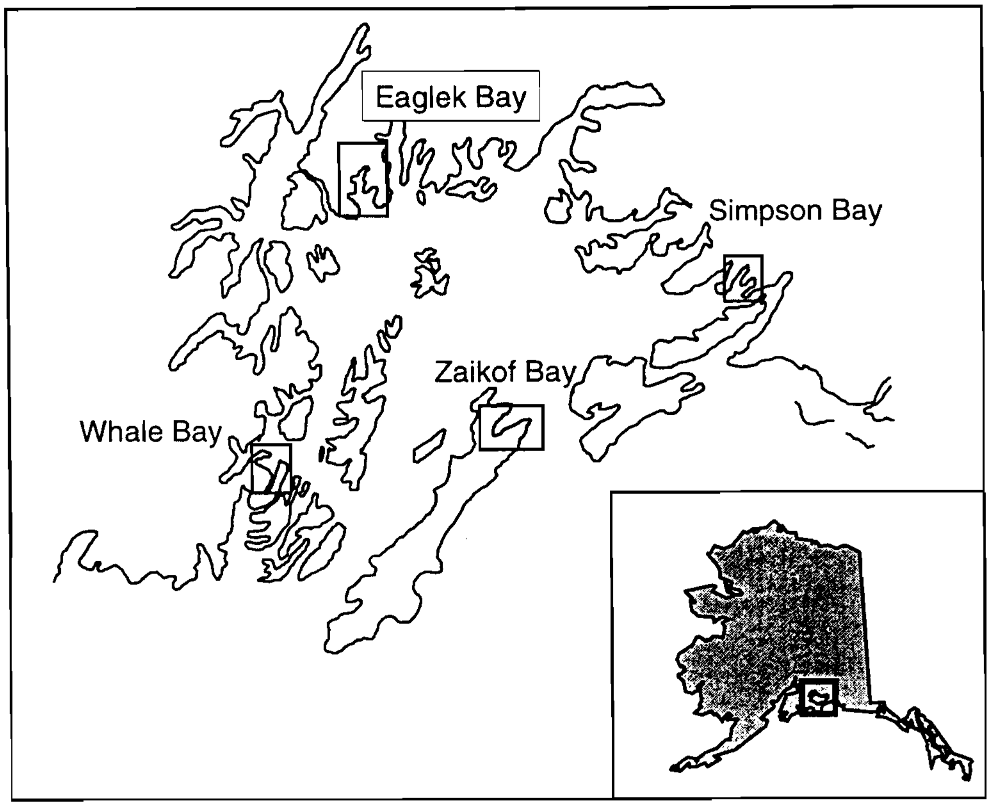


Fig. 1

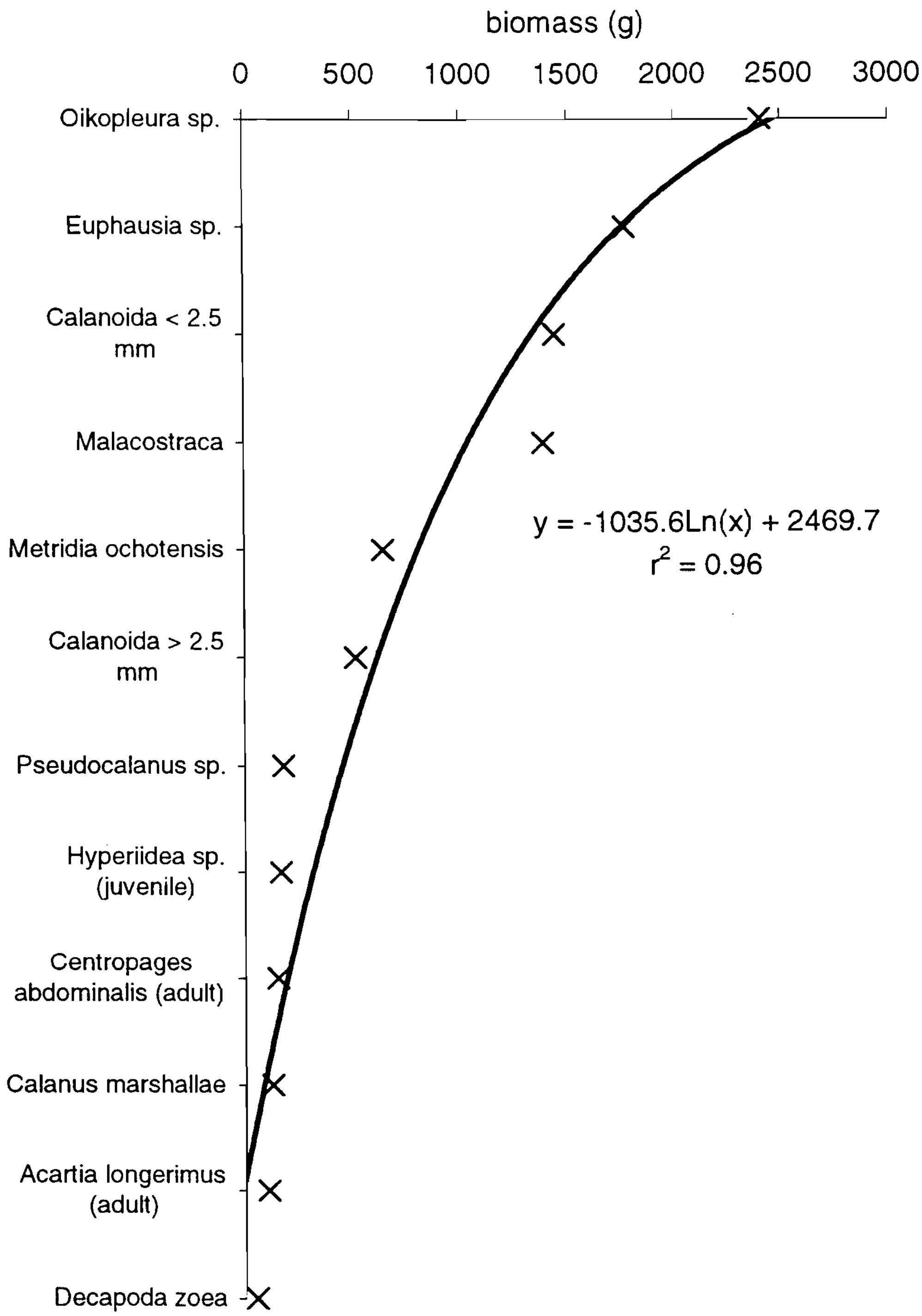
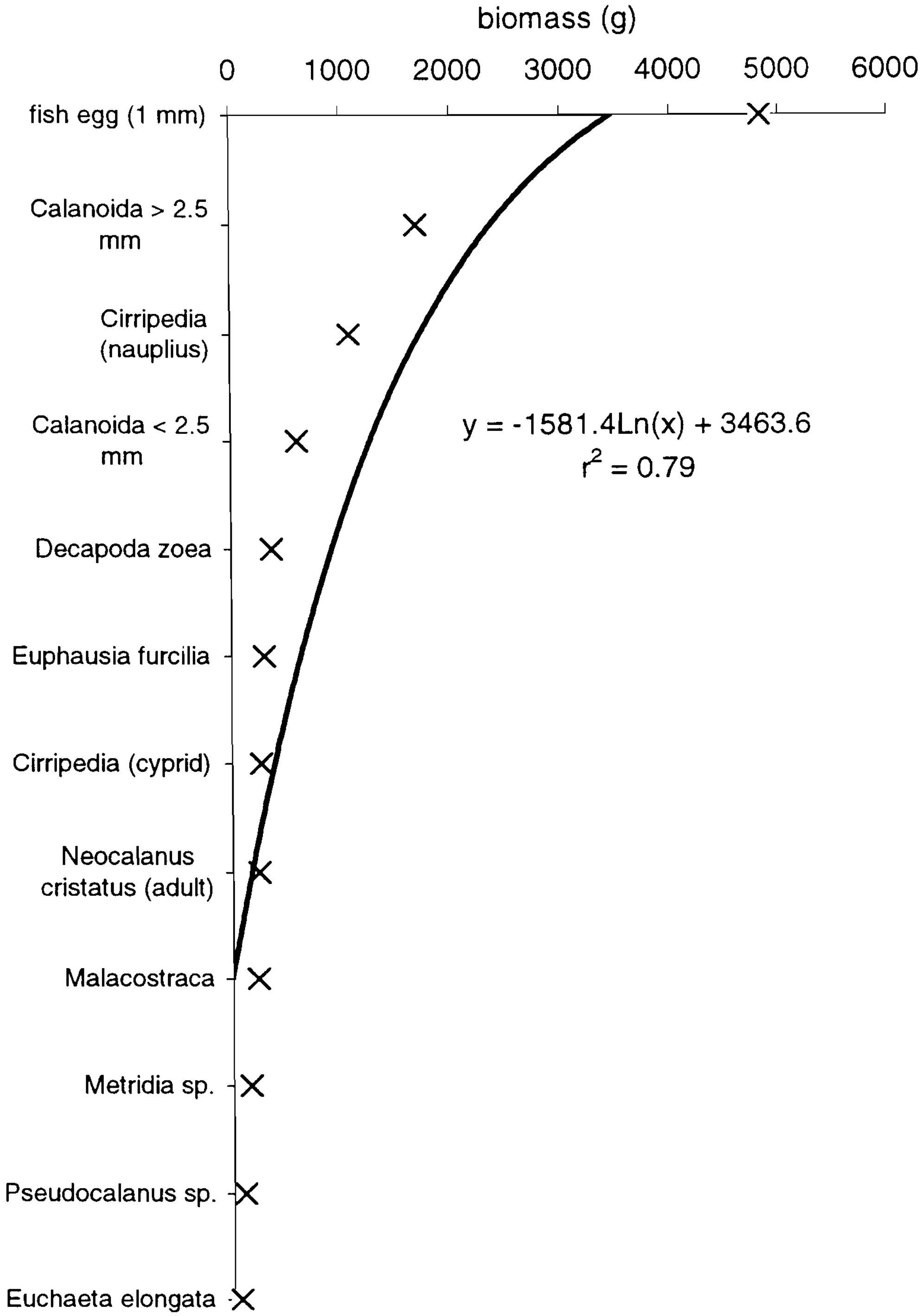

biomass (g)
0
500
1000
1500
2000
2500
3000
Oikopleura sp.
Euphausia sp.
Calanoida < 2.5 mm
Malacostraca
Metridia ochotensis
Calanoida > 2.5 mm
Pseudocalanus sp.
Hyperiidea sp. (juvenile)
Centropages abdominalis (adult)
Calanus marshallae
Acartia longerimus (adult)
Decapoda zoea
y = -1035.6Ln(x) + 2469.7
r2 = 0.96

Fig. 2



biomass (g)
0
1000
2000
3000
4000
5000
6000
fish egg (1 mm)
Calanoida > 2.5 mm
Cirripedia (nauplius)
Calanoida < 2.5 mm
Decapoda zoea
Euphausia furcilia
Cirripedia (cyprid)
Neocalanus cristatus (adult)
Malacostraca
Metridia sp.
Pseudocalanus sp.
Euchaeta elongata
y = -1581.4Ln(x) + 3463.6
r2 = 0.79

Fig. 3

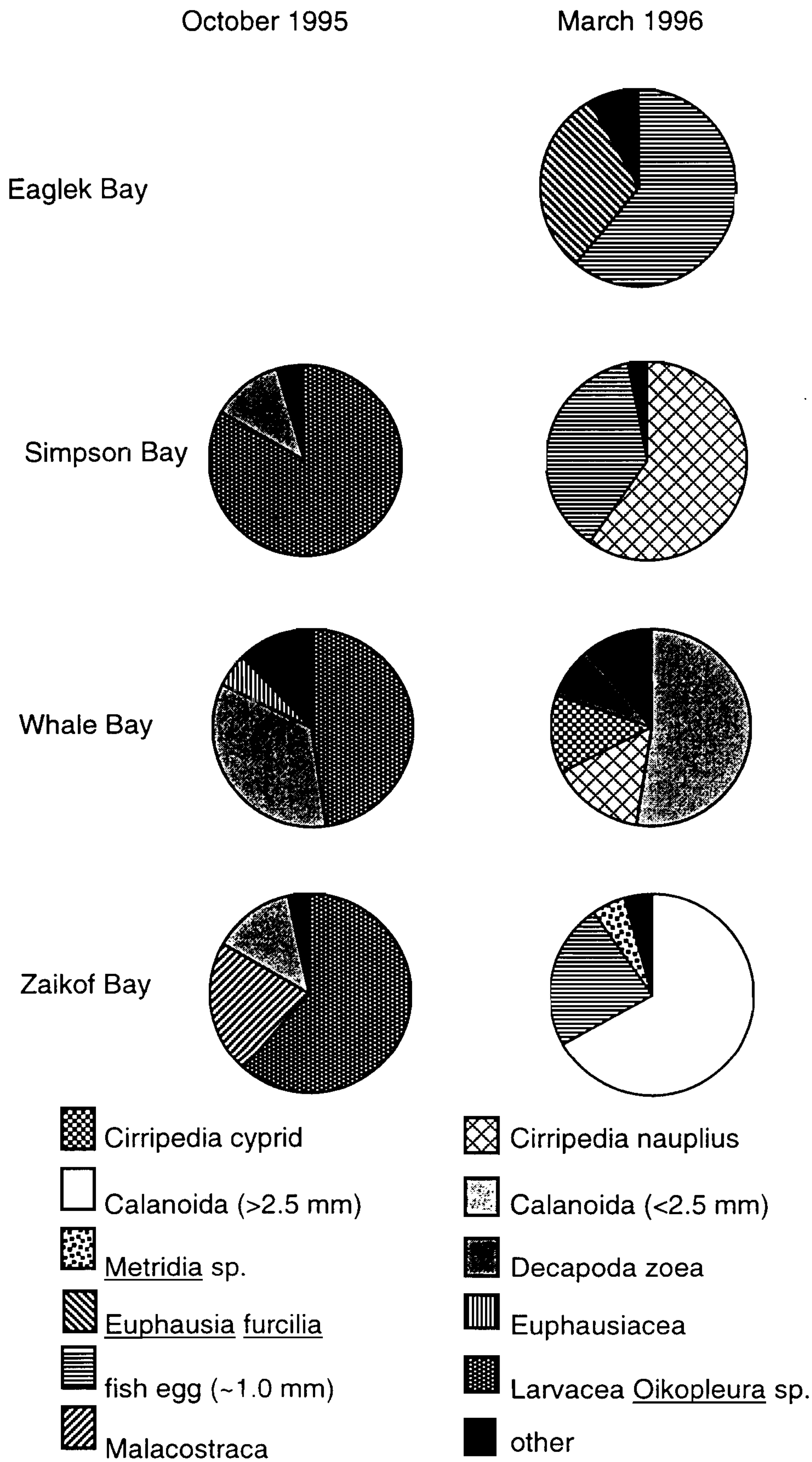
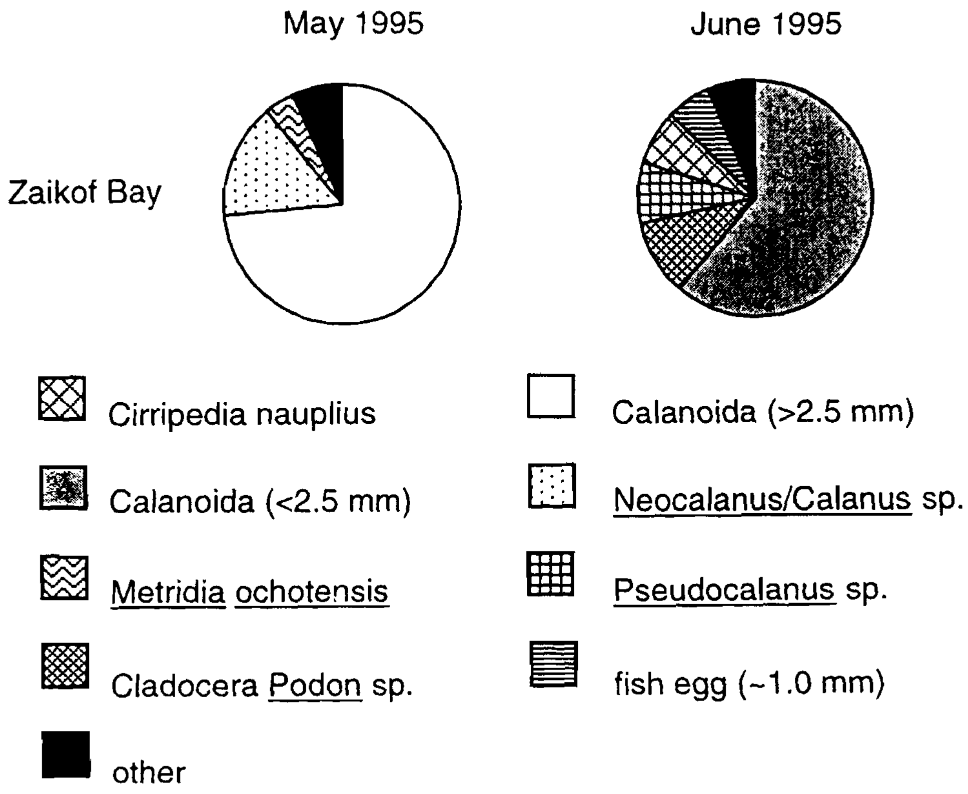

October 1995
March 1996
Eaglek Bay
Simpson Bay
Whale Bay
Zaikof Bay
Cirripedia cyprid
Calanoida (>2.5 mm)
Metridia sp.
Euphausia furcilia
fish egg (~1.0 mm)
Malacostraca
Cirripedia nauplius
Calanoida (<2.5 mm)
Decapoda zoea
Euphausiacea
Larvacea Oikopleura sp.
other

Fig. 4



May 1995
June 1995
Zaikof Bay
Cirripedia nauplius
Calanoida (<2.5 mm)
Metridia ochotensis
Cladocera Podon sp.
other
Calanoida (>2.5 mm)
Neocalanus/Calanus sp.
Pseudocalanus sp.
fish egg (~1.0 mm)

Fig. 5

Appendix 1. Average weights (mg) of invertebrate taxa from Prince William Sound used for biomass estimates.

taxon	wt (mg)	taxon	wt (mg)
Acartia longiremus adult	0.052	Euphausia calyptopis	0.165
Acartia sp.	0.028	fish egg (~1.0 mm)	6.590
Amphipoda Gammaridea	0.650	fish larvae	50.000
Amphipoda Hyperiidea (juvenile)	7.860	fish scales	0.001
Bivalvia (larvae)	0.005	Gadius variabilis	1.610
Brachyura zoea	2.620	Gammaridea Ischyocerus sp.	1.340
Bryozoa cyphonautes larva	0.020	Gastropoda (juvenile)	0.160
Calanoida (<2.5 mm)	0.075	Harpacticoida	0.090
Calanoida (>2.5 mm)	2.262	Hyperiidea Primno macropa	3.990
Calanoida Metridia ochotensis	1.480	invertebrate egg <0.2mm	0.000
Calanoida Metridia pacifica (adult female)	0.789	Isopoda	2.740
Calanus marshallae	1.430	Isopoda Epicaridea larva	0.190
Calanus pacificus	0.487	Limacina helicina (juvenile)	0.043
Candacia columbiae	2.150	Malacostraca	12.060
Centropages abdominalis (adult)	0.144	Metridia ochotensis (adult female)	1.883
Chaetognatha	0.440	Metridia pacifica	0.489
Chaetognatha Sagitta sp.	0.440	Metridia sp.	0.717
Cirripedia cyprid	0.288	Neocalanus cristatus adult	12.200
Cirripedia nauplius	0.190	Neocalanus/Calanus sp.	2.262
Cladocera	0.039	Oncea sp.	0.012
Cladocera Evadne sp.	0.039	Oikopleura sp.	0.033
Cladocera Podon sp.	0.039	Ostracod Conchoecia sp.	1.175
Cyclopoida Oithona similis	0.012	Paguridae zoea	1.590
Decapoda zoea	2.739	Pisinae zoea	0.330
diatom	0.000	Polychaeta (juvenile)	0.087
Epilabidocera longipedata	1.800	Pseudocalanus (adult male)	0.066
Euchaeta elongata	3.850	Pseudocalanus sp.	0.142
Euphausia furcilia	0.390	unknown egg mass	0.021
Euphausiacea	10.65	unknown nauplius	0.011
Euphausiacea egg	0.002		

Appendix V

Exxon Valdez Oil Spill
Restoration Project Interim Report

Distribution of Herring and Other Forage Fish as Observed by Resource Users

Restoration Project 98320T supplement
Annual Report

This annual report has been prepared for the Exxon Valdez Oil Spill Trustee Council.

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March 1998

Distribution of Herring and Other Forage Fish as Observed by Resource Users
Restoration Project 97320T Supplement
Annual Report

Study History: The project was initiated in 1997. The project was designed to document the historical distribution of forage fish such as juvenile herring, sandlance, capelin, and eulachon through qualitative interviews with key respondents in several communities. The information will be mapped and indexed by subject and provided to researchers with the Alaska Predator Ecosystem Experiment (APEX) and Sound Ecosystem Assessment (SEA). It is designed to provide researchers with population and habitat use information over a longer period and broader area than can be known through existing records and current data collection efforts.

Abstract: The researchers used a combination of key respondent interviews and mapping to document the locations of juvenile herring, herring of unknown age (unknown herring), mixed adult and juvenile herring (mixed herring), herring spawn, unidentified small fish (small fish), capelin, sand lance, eulachon and pollock. Researchers concentrated on recording information about juvenile herring and small fishes other than juvenile herring, such as sand lance and capelin. A total of thirty-nine respondents were interviewed in thirty-seven interviews (two couples were interviewed jointly). Ten interviews were carried out in Homer; twenty-six interviews were conducted in Cordova; and three interviews were carried out in Tatitlek. Most interviews were tape recorded. Respondents and researchers marked locations of fish schools on charts overlaid with mylar. Fish schools were color-coded by species for later reference. Maps of juvenile herring distribution in Prince William Sound were produced using the computer software mapping programs GMT for this report.

Key Words: *Exxon Valdez*, nursery areas, juvenile herring, forage fish, small fish, sand lance, capelin, traditional ecological knowledge, local knowledge, distribution.

Introduction

The Prince William Sound ecosystem, on the northern rim of the Gulf of Alaska, supports many ecologically important species, several of which are listed as threatened or endangered. Salmon and herring are two of the most important resources in the region, supporting both commercials fishing communities and wildlife populations. The 1989 Exxon Valdez oil spill occurred in the Sound at the most productive season of the year, early spring. Herring were returning to spawn, in record numbers.

Brown et al. (1996) reported that about half of the egg biomass was deposited within the oil trajectory, and an estimated 40 to 50 percent sustained oil exposure during early development. The 1989 year class was a minority of the 1993 spawning population, one of the smallest cohorts observed in the Sound. In 1993, only one third of the herring population expected to spawn were observed (Meyers et al. 1994). Viral hemorrhagic septicemia virus was identified in the population and later determined to be the primary disease related reason for the population crash.

In 1994, as part of a larger effort to understand the productivity of pink salmon and herring within the Prince William Sound ecosystem, fisheries oceanographers began a project to understand the factors contributing to the survival of juvenile herring. A focus of that project was an effort to learn more about the habitats of herring early life history stages from hatch up until the time they recruit to the adult population.

Locations of herring nursery areas have never been the subject of research in Prince William Sound prior to this effort. Herring research concerning distribution has primarily consisted of documentation of spawning areas, adult spawning aggregations, and concentrations of overwintering adult herring. This research has been focused in support of commercial fishing activities in early spring, fall and winter. Juvenile herring were sometimes caught with adult herring, but there did not seem to be complete overlap and catch-age sampling targeted adults. On the other hand, there seemed to be a large amount of anecdotal information available about distribution of small schooling fishes during times and places in Prince William Sound outside of commercial herring fishing seasons and areas.

The human presence in Prince William Sound dates back thousands of years. There are still people living in the sound who have lived in areas or who worked in areas of the sound which are no longer occupied. There are still people alive who remember and participated in the reduction fisheries and who sampled the herring in the catch for scientific analyses. Then, and more recently residents have had the opportunity to observe herring in the course of a variety of activities, including: subsistence hunting and fishing, aerial surveys of resource populations, herring or salmon spotting, fishing for bait herring or crab, or even delivering the mail by boat. Compiling and summarizing the large body of human knowledge about small herring and other schooling fishes provide researchers invaluable and often the only clues to past trends.

The goal of this project is to document historic knowledge about herring, especially during life stages and seasons when little other information is available. Since information about other schooling forage fishes can be readily obtained as well for no extra cost, the goal was expanded to include documentation of historic knowledge about all small schooling fishes. Specific objectives included the development of an appropriate interview guide, development of a historic knowledge data base, mapping and analyzing historic trends and providing this information in a format that is readily accessible to researchers. Finally, recommendations are provided in this report concerning the direction and continuation of this project.

Objectives

1. Develop an appropriate method for collection of historical and contemporary ecological knowledge about herring and other forage fish held by residents of the region.
2. Collect, organize, and map these data.
3. Disseminate these data.

Methods

TEK Protocol: The project followed the Traditional Ecological Knowledge protocols as outlined by the *Exxon Valdez* Oil Spill Trustee Council TEK advisory group. In Cordova, letters were written to the Traditional Village of Eyak and Cordova District Fishermen United was contacted regarding the project.

The first contacts were initiated from a list of potential respondents created by 97320T Project Leader, Evelyn Brown. CDFU contributed a list of potential participants. Following the first interview, other respondents were contacted through chain referral. Letters and project descriptions were sent to potential respondents. Written requests for permission to carry out the project were submitted to the IRA councils of Chenega Bay and Tatitlek. The Valdez Native Association was contacted by letter and by phone. In Homer individual respondents were recommended by chain referral and were contacted by phone, letter, and in person. An example of the interview guide is attached (Appendix A).

<u>Community Approval:</u>
The project leader sought approval by the IRA Councils of Chenega Bay and Tatitlek. Tatitlek approved the project May 10, 1997. The Tatitlek IRA Council recommended several elders. Two older men and a couple were interviewed.

Due to May weather, followed by summer activities; Chenega Bay's annual meeting was postponed until August. I was given approval to conduct the study in Chenega Bay on September 30, 1997.

<u>Interview method:</u>
All participants were given project descriptions and asked to read and sign a statement regarding the anonymity of their information, which the interviewer also signed. The statement assures the respondent that their information will be presented as part of compiled responses in a manner that protects their identity.

The interviews were carried out following Ives (1980) and Weiss (1994). All respondents were asked for permission to record the interview. Most of the interviews were tape-recorded. The interview guide was developed with the assistance of the herring researchers and was adapted over several interviews. I also referred to the interview design used by Ames and Watson in their study of cod and haddock spawning areas in the Gulf of Maine Ames (1966, unpublished manuscript). In the initial seven interviews I asked for detailed information on the respondent's use of the Sound. The interview guide was revised after the seventh interview.

The revised interview asked less detail about respondents' use of the sound and got right to the questions about juvenile herring and forage fish. I maintained questions on commercial fishing history, and for pilots, their flight path. When these are combined with a review of ADF&G's commercial fishing seasons and history should provide much of the relevant information about patterns of use of the sound.

Responses for all interviews were recorded on a data sheet and on a chart overlaid with mylar. Following the interviews, the tapes were later reviewed, and used to check the datasheets and charts. The notes from the interviews have yet to be entered into the notes database.

Data was entered into Excel spreadsheets and digitized using a mapping software designed as a cruise planner for SEA by Charles Falkenberg, Prince William Sound Science Center, Cordova. The Homer and Seward data will be digitized using NavMaster software, since the Planner does not cover the outer Kenai Peninsula. GMT software was used to create the maps for this report.

Participants were asked to record where they had seen juvenile herring – herring less than four inches long. They were asked the year, or time frame, during which they had seen the fish schools, and asked to use colored pens to mark these schools on a chart covered with mylar. If they could not recall the exact year, they were asked to recall the range of years when they were in the area and how they saw the fish, whether they were caught, or "seen" on a sonar, or seen on the surface of the water. If respondents could not recall seeing juvenile herring they were asked to recall seeing herring in general, or small fish, at different times of the year. Information was also sought on sand lance, capelin, and eulachon, under the general category of small fish other than herring.

Respondents were asked to judge how often they saw juvenile herring in the places they had seen them, especially if they had seen them over the course of a season, or a range of years. They were asked to judge if they had seen them consistently, occasionally, or rarely.

C - CONSISTENTLY - "I'd see them almost every time I went there this time of year.

O - OCCASIONALLY - "I'd see them once in a while this time of year."

R - RARELY - "I remember them showing up there once or twice."

We also sought information about the presence of animals associated with the fish schools, but found it difficult to record much about their presence or absence over multiple years.

The Data

The Prince William Sound mapped database consists of data from interviews with twenty-five Cordova residents, four Tatitlek residents, and eight Homer residents who fished along the outer Kenai Peninsula and Prince William Sound. The notes database comprises these interviews and additional phone conversations and interviews where no observations were actually mapped. The observations are from 1938 to 1997. The Chenega Bay and Seward data has not been entered yet.

Ten Homer residents contributed observations to the database on the outer Kenai Peninsula. The observations of fishes in the bays and coastal areas of the Kenai Peninsula are from 1952 to 1997.

The Maps

The maps of juvenile herring observations in Prince William Sound were created using GMT software at the University of Alaska Fairbanks, Institute of Marine Science. Maps of juvenile herring observations in Prince William Sound for 1970, 1980, and 1990 are enclosed.

These maps group observations from a range of years into the decades which they overlap. For example, if someone saw juvenile herring in Eaglek Bay from 1970 through 1985, their observations would be represented in both the 1970s and in the 1980s. The same process was followed for observations on the outer Kenai. If a respondent had one observation in one decade, it was lumped into that decade for the purposes of this series of maps.

Notes

An additional source of information about the observations is the notes database, in preparation. Notes are being indexed using ASKSAM, which is compatible with ADF&G's marine mammal notes database. The notes concern a variety of topics: how respondents saw the fish; how they identified the fish; where the fish were in relation to the shore, or to depth; adult herring migrations; abnormal events – such as a large number of dead juveniles; and respondent's theories about herring.

Here is an example of the response to a question about how the respondent recognized juvenile herring. The notes database has not been completed. This is only an example.

> To tell schools of fish in the summer, he notes that herring have, generally speaking, round schools. The schools of juveniles have soft edges. They are hard to tell from bait fish or needle fish (sandlance) in cloudy conditions with flat light. With enough light you can see the fish "flash". The herring flash is bright silver, but the bait fish looks brown and gold. The herring flash is much larger than the bait fish.

"Juveniles and bait fish are out there eating and growing. They are schooled up in round schools, for protection. They stay off the beach, and can be found on top of a cone of adults. They will be usually one to three fathoms from the surface and rarely against a beach. They like calm water with low currents, such as the backwaters of bays. If he were looking for juveniles while out flying he'd fly transects across the bays. However, he mainly looks for salmon. Their fry go into shallow water.

Sac roe fish are adults that have a mission. They are traveling and will be seen as a ball with a tail coming out ahead of it."

One year he saw a lot of juvenile herring around Naked Island and Perry Island.

Describe for me, if you could, what it looked like to see a lot of fish:
"In terms of thousands of tons, we're not talking about tens of thousands of tons, but you've got to remember -we're not looking for herring. We're looking for salmon, and you're flying along the beaches.

The schools typically were 10 to 30 ton schools and if they were less than 10 tons, you'd have to be careful about calling them bait or herring. You'd have to have some light, because a lot of the bait fish were in little 2 to 5 ton schools. In terms of numbers, putting a number on it as far as of biomass, I don't know if I could do that.

Eaglek's always been a good producer of juveniles. And if you flew around in there you'd see 15 schools, 20 schools at a peak, and at a lull you might see one."

Results

Respondents

Respondents included 28 salmon fishermen, of whom 21 were also herring fishermen and eight of whom were also pilots and had spotted salmon. Five individuals had had other occupations as professional biologists, cannery watchmen, and mail carriers. The average age of respondents was 54 years, the youngest was 34 and the oldest person interviewed was 86 years old. They ranged in years of commercial fishing experience from one year to sixty-eight years, with an average of 30 years of experience.

Herring spotter pilots ranged in experience from eight to thirty-six years, with an average of thirteen years experience. Several of the respondents were pilots by occupation. Several had worked both in the fishing industry and as charter pilots. Professional and non-professional pilots had a range of experience from four to 36 years, and averaged eighteen years of experience. The averaged experience of persons in other occupations was twenty years.

Maps and Tables

The enclosed tables present some of the data upon which the maps are based. They list the places where observations occurred, and the range of years and number of respondents who saw fish in a group of neighboring areas or in one place. These tables show the overlap in time, and number of people making the observations.

The dots plotted on these maps are merely coordinates along the lines, points and polygons marked by respondents. We were restricted by our software and hardware to these size maps, and unless the coordinates are adjusted, lines cannot be plotted on top of each other and still be distinguished. Therefore, all the areas marked are represented by dots on these larger scale maps. To see if we could produce better representations of the lines, points, and polygons marked by respondents we produced regional maps of the sound as well (Figures A-C for all maps). The sound was divided into eastern, northern and southwestern regions, and areas with observations were represented as lines or polygons. The technician was unable to shade the polygons.

The locations where juvenile herring were seen in the spring (March, April, or May) during the 1970s, 80s, and 90s were listed (Table 1) and mapped (Figure 1). The number of respondents was listed below each decade. In the seventies observations from four respondents were concentrated along the northern shore, Valdez Arm - Galena Bay, Port Fidalgo, and the head of Port Gravina.

In several areas respondents saw herring over a range of several years (Table 1). In order to maintain the anonymity of respondents' information, the tables include the range of years and number of different observers for each area, but no way to attach individual respondents to to the information. For example, four respondents saw juvenile herring in Eaglek Bay during the 1980s and 1990s.

Eight respondents' observations from spring of the 1980s were concentrated along the northern shore, the eastern side of the sound, and the northern end of Montague Island.

In the 1990s, four respondents observed juvenile herring in all of the above areas and along the western shore and the southeastern end of Montague Island. For somewhat finer scale views of these observations, please see the regional illustrations.

The number of observers and locations juvenile herring were seen in summer was mapped (Figure 2), and the range of years in which they were seen was listed by each place (Table 2). Over the seventies and eighties three respondents saw juveniles at Culross Island. More respondents saw juveniles in the summer than at any other time of year.

Seven respondents saw juvenile herring in Eaglek Bay between 1970 and 1997 -- two observers in the seventies, five in the eighties, and three in the nineties. Two respondents saw juvenile herring in Landlocked Bay in the summer in the seventies. During the eighties and nineties four observers saw summer juvenile herring in St. Mathew's Bay, Port Gravina, and Sheep Bay and Landlocked Bay. Fairmount Island is another place were juveniles were often seen in summer -one observer in the seventies is followed by three observers in the eighties, and two in the nineties. Polygons encircling Perry and Naked Islands are correctly represented. The respondent saw huge schools of juveniles around both islands in the late 80s.

In both spring and summer juvenile herring were observed near Fairmount Island, in Port Fidalgo, Port Gravina, Montague, Sheep and Simpson Bays (Tables 1 and 2; Figures 1 and 2).

Figures 3 and 4 illustrate the information gathered for fall and winter. The fall and winter information reflects the exploration in the early 70s of the sound for the bait fishery. Fishermen had taken some fish for bait all through the 1960s. It is said that the harvests were small, and not reported to the ADF&G.

In the early 70s local Cordova fishermen experimented with fishing for bait, and searched the sound for herring. Reported harvests were small until fishermen figured out how to catch the herring more efficiently, using a pair trawl and deep seines. In 1977, the Northern District and Montague Districts were established for the sac roe fishery. The Eastern District, consisting of Port Gravina and Orca Bay was established in 1980. After the sac roe districts were established, bait fishing was not allowed within them.

From 1978 until 1981 pair trawling and seiners were used to harvest bait outside the sac roe districts. The pair trawl users reported that they "got so they wouldn't go up into the bays, because they didn't want to run into juvenile herring." Table 3 reports juvenile herring that were caught with shrimp trawls and smelt nets in Simpson Bay. Table 4 reports in the notes for Simpson Bay, they "plugged the trawl." The respondents reported they spent hours scraping juvenile herring out of the trawl with flat-bladed snow shovels. They made the mistake a couple of times and didn't investigate the heads of bays again.

Although some information gathered about small fish, capelin and sand lance has been mapped (Figure 5) the tables for these figures have not been prepared yet.

The differences in the distribution of juvenile herring observations between the years can not be solely explained by respondents' participation in commercial fishing. The majority of the respondents who fish (18 out of 28) began fishing prior to 1970, only five of the fishermen interviewed were no longer fishing in the 1990s. Nine herring spotter pilots' experience bridges all three decades.

Experience spotting salmon is difficult to assess. Fishermen charter planes together to fly the sound looking for schools of fish. The pilots fly the plane, the fishermen look for fish.

This practice was made illegal in 1994, and prior to that it's difficult to say how many fishermen participated in this. However, at that time of year, the juvenile herring would have been most visible to people engaged in this type of activity.

Summary

This report was prepared after the first round of data was entered into the computer and is the first representation of the information. More interviews have been completed since then. The final report will be greatly refined.

The interview schedule for Valdez has been slightly delayed. We expect to finish interviewing respondents by the end of April.

Due to the short cycle of the grant and administrative procedures, hiring of a data entry technician was delayed by four months in FY97. This seriously compromised our ability to get other work done on the project. We are now caught up with data entry, but behind in other areas – such as interviews in Valdez, and notes transcription. We are in the process now of hiring another person to help with data analysis and GIS.

The mapping software which will be used to complete the project is ARC INFO, rather than GMT. This program is a relational database and has much more power to assist researchers in geographic analysis of the data than GMT.

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PLACE	AREA	RANGE	n=12	FREQ	ID	NOTES
Bainbridge Passage	614	1994-1996	1	n.d.	y	< 20 feet deep, within 20 meters of shore
Blackstone Bay	560	1987-1988	1	once	y	
Cochrane Bay	558	1987-1988	1	once	y	
Columbia Bay	554	1978	2	n.d.	Y	
Columbia Bay, Granite Cove	554	1975		once	y	50-100 grams, not quite gilling in the net
Dangerous Passage, Paddy Bay	610	1994	1	occs	y	
Dangerous Passage, Paddy Bay	610	1995		occs	y	
Dangerous Passage, Paddy Bay	610	1996		occs	y	
Eaglek Bay	584	1981-1987	4	n.d.	n	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
Eaglek Bay	584	1987-1988		once	y	
Eaglek Bay	584	1987-1988		n.d.	n	
Eaglek Bay	584	1989-1996		cons	n	< 20 feet deep, within 20 meters of shore
Eaglek Bay	584	1990		n.d.	n	
Eleanor Island	537	1972	1	n.d.	y	
Eleanor Island, Ingot Island	537	1972		n.d.	y	
Esther Bay	502	1987-1988	2	once	y	
Esther Island, Point Esther	501	1987-1988		once	y	
Esther Island, Quillion/Lake Bays	526	1987-1988		once	y	
Esther Island, west side	525	1987-1988		once	y	
Esther Passage	499	1987-1988		once	y	
Esther Passage	499	1989-1996		occs	n	< 20 feet deep, within 20 meters of shore
Fairmount Island	545	1981-1987	2	n.d.	n	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
Fairmount Island	545	1987-1988		n.d.	n	
Fairmount Island	545	1990		n.d.	n	
Glacier Island	629	1970-1973	3	n.d.	y	
Glacier Island	629	1978		n.d.	y	
Glacier Island	629	1985		once	y	
Glacier Island, Growler Bay	629	1979		n.d.	y	some sets on shrimp

PLACE	AREA	RANGE	n=12	FREQ	ID	NOTES
Green Island	630	1989-1996	1	occs	n	< 20 feet deep, within 20 meters of shore
Icy Bay	652	1994-1996	1	cons	y	< 20 feet deep, within 20 meters of shore
Jackpot Bay	671	1994-1996	1	cons	y	< 20 feet deep, within 20 meters of shore
Kiniklik	587	1987-1988	2	once	y	
Kiniklik	587	1989-1996		occs	n	< 20 feet deep, within 20 meters of shore
Knight Island, east side	556	-1989	1	once	y	during oil spill
Long Bay	553	1978-1979	1	n.d.	y	
Montague Island, Jeanie Cove	541	1994-1996	1	occs	n	< 20 feet deep, within 20 meters of shore
Montague Island, Patton Bay	540	1994-1996		occs	n	< 20 feet deep, within 20 meters of shore
Montague Island, Port Chalmers	529	1989-1993	3	cons	n	< 20 feet deep, within 20 meters of shore
Montague Island, Port Chalmers	529	1993		rare	y	pollock had adult herring in their stomachs
Montague Island, Port Chalmers	529	1994-1996		cons	y	< 20 feet deep, within 20 meters of shore
Montague Island, Rocky Bay	583	1989-1993		occs	n	< 20 feet deep, within 20 meters of shore
Montague Island, Rocky Bay	583	1990		rare	y	pollock had adult herring in their stomachs
Montague Island, Rocky Bay	583	1994-1996		occs	y	< 20 feet deep, within 20 meters of shore
Montague Island, Graveyard Point	631	1993		rare	y	pollock had adult herring in their stomachs
Montague Island, Stockdale Harbor	631	1983		n.d.	y	
Montague Island, Stockdale Harbor	631	1989-1993		cons	n	< 20 feet deep, within 20 meters of shore
Montague Island, Stockdale Harbor	631	1994-1996		cons	y	< 20 feet deep, within 20 meters of shore
Montague Island, Zaikof Bay	521	1989-1993		occs	n	< 20 feet deep, within 20 meters of shore
Montague Island, Zaikof Bay	521	1994-1996		occs	y	< 20 feet deep, within 20 meters of shore
Naked Island	520	1989-1996	2	occs	n	< 20 feet deep, within 20 meters of shore
Naked Island, Cabin Bay	520	1989-1996		occs	n	< 20 feet deep, within 20 meters of shore
Naked Island, north shore	520	1987-1988		n.d.	n	
Naked Island, north shore	520	1990		n.d.	n	
Olsen Island	586	1989-1996	1	occs	n	< 20 feet deep, within 20 meters of shore
Port Fidalgo	544	1978-1991	3	cons	n	juv like these places, Deep Bays with shallow estuaries at the back of the bay
Port Fidalgo, Fish Bay	585	1987-1988		occ	n	

PLACE	AREA	RANGE	n=12	FREQ	ID	NOTES
Port Fidalgo, Fish Bay	585	1990		occ	n	
Port Fidalgo, Irish Cove	585	1981-1992		n.d.	n	
Port Fidalgo, Landlocked Bay	625	1987-1988		n.d.	n	
Port Fidalgo, Landlocked Bay	625	1990		n.d.	n	
Port Fidalgo, Snug Corner Cove	603	1987-1988		n.d.	n	
Port Fidalgo, Snug Corner Cove	603	1990		n.d.	n	
Port Gravina	621	1978-1991	3	cons	n	juv like these places, Deep Bays with shallow estuaries at the back of the bay
Port Gravina, Red Head	628	1989-1996		occs	n	< 20 feet deep, within 20 meters of shore
Port Gravina, Hell's Hole	518	1989-1996		occs	n	< 20 feet deep, within 20 meters of shore
Port Gravina, Olsen Bay	586	1989-1993		occs	n	
Port Gravina, Olsen Bay	586	1994-1996		occs	y	
Port Gravina, St. Mathew's Bay	528	1989-1993		occs	n	< 20 feet deep, within 20 meters of shore
Port Gravina, St. Mathew's Bay	528	1994-1996		occs	y	< 20 feet deep, within 20 meters of shore
Port Gravina, St. Matthew's Bay	528	1981		n.d.	y	
Port Nellie Juan, Kings Bay	655	1970-1972	1	n.d.	y	
Port Wells, Coghill Bay	656	1973	1	n.d.	y	3-4 inch long, < 100 grams
Sheep Bay	611	1987-1988	3	n.d.	n	
Sheep Bay	611	1987-1989		cons	n	0-2, some spot spawn
Sheep Bay	611	1989-1993		occs	n	
Sheep Bay	611	1990		n.d.	n	
Sheep Bay	611	1994-1996		occs	y	
Simpson Bay	601	1987-1988	2	n.d.	n	
Simpson Bay	601	1989-1993		occs	n	
Simpson Bay	601	1990		n.d.	n	
Simpson Bay	601	1994-1996		occs	y	
Storey Island	532	1987-1988	1	n.d.	n	
Storey Island	532	1990		n.d.	n	
Tatitlek Narrows	623	1997	2	once	y	
Tatitlek Narrows Black Point	623	1979		cons	y	

PLACE	AREA	RANGE	n=12	FREQ	ID	NOTES
Valdez Arm, Galena Bay	624	1978-1991	4	cons	n	juv like these places, Deep Bays with shallow estuaries at the back of the bay
Valdez Arm, Galena Bay	624	1986-1988		once	y	while pounding
Valdez Arm, Galena Bay	624	1987-1988		n.d.	n	
Valdez Arm, Galena Bay	624	1987-1989		cons	n	too small to market 0-2 yr olds
Valdez Arm, Galena Bay	624	1990		n.d.	n	
Valdez Arm, Jack Bay	604	1978-1991	1	cons	n	juv like these places, Deep Bays with shallow estuaries at the back of the bay
Wells Bay	626	1978-1991	3	cons	n	juv like these places, Deep Bays with shallow estuaries at the back of the bay
Wells Bay	626	1987-1988		n.d.	n	
Wells Bay	626	1990		n.d.	n	
Wells Passage	559	1987-1988		once	y	
Whale Bay	602	1994-1996	1	occs	y	

PLACE	AREA	R/YR	RANGE	n=17	ID	FREQ	NOTES
Bainbridge Passage	614	y	1994-1996	2	y	occs	< 20 feet deep, within 20 meters of shore
Bainbridge Point	511	r	1970-1985		n.d.	cons	
Chenega Island, east side	510	r	1970-1985	2	n	cons	
Chenega Island, east side	510	r	1985-1991		n	cons	Balls and schools
Chenega Island, south side	539	r	1970-1985		n	cons	
Cochrane Bay	558	y	1985		y	n.d.	
Crafton Island	507	r	1967-1975	2	y	cons	age zeros moving south, saw them when he was set netting
Crafton Island	507	r	1970-1985		n	cons	
Culross Island	504	r	1970-1985	4	n	cons	
Culross Island	505	r	1970-1985		n	cons	
Culross Island	505	y	1982		n	once	
Culross Passage	605	y	1985		y	n.d.	
Culross Point	504	y	1982		n	once	lots of juveniles here
Dangerous Passage, Paddy Bay	610	y	1994-1996	1	y	cons	
Eaglek Bay	584	r	1970-1985	7	n	cons	
Eaglek Bay	584	r	1972-1978		n	occ	
Eaglek Bay	584	r	1981-1987		n	cons	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
Eaglek Bay	584	y	1982		n	once	
Eaglek Bay	584	r	1982-1996		n.d.	occ	
Eaglek Bay	584	y	1987-1988		n	n.d.	
Eaglek Bay	584	y	1989-1996		n	cons	< 20 feet deep, within 20 meters of shore
Eaglek Bay	584	y	1990		n	n.d.	
Eaglek Bay	584	y	1994-1996		y	cons	< 20 feet deep, within 20 meters of shore
Eleanor Island	537	r	1970-1985	2	n.d.	cons	
Eleanor Island, Point Eleanor	537	r	1974-1987		no	cons	
Elrington Island, Bettles Island	516	r	1970-1985	2	y	cons	
Elrington Passage	516	r	1971-1991		y	occ	
Elrington Passage	616	r	1971-1991		y	occ	
Eshamy Bay	617	r	1967-1975	2	y	cons	age zeros moving south, saw them when he was set netting
Eshamy Bay	617	r	1970-1985		n	cons	

Esther Bay	502	y	1982	3	n	once	
Esther Passage	499	r	1972-1978		n	occ	
Esther Passage	499	y	1982		n	once	
Esther Passage	499	y	1989-1993		n	cons	< 20 feet deep, within 20 meters of shore
Esther Passage	499	y	1994-1996		y	cons	< 20 feet deep, within 20 meters of shore
Prince of Wales Passage, Aluklik Ba	513	r	1970-1985		y	cons	
Evans Island, northwest side	512	r	1970-1985	2	y	cons	
Evans Island, Shelter Bay	512	y	1990		y	once	a lot of jh tight on beach, 10 to 20 feet off beach <10 m deep
Fairmount Island	545	r	1970-1985	4	n	cons	
Fairmount Island	545	r	1981-1987		n	cons	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
Fairmount Island	545	r	1982-1996		n.d.	cons	
Fairmount Island	545	y	1987-1988		n	n.d.	
Fairmount Island	545	y	1990		n	n.d.	
Glacier Island	629	r	1982-1996	1	n.d.	occ	
Green Island	630	y	1989-1996	2	n	cons	< 20 feet deep, within 20 meters of shore
Green Island, north west side	630	r	1982-1996		n.d.	occ	
Hawkins Island, Canoe Pass, Windy	548	y	1987-1988	2	n	n.d.	
Hawkins Island, north side	548	r	1970-1985		n	cons	
Hawkins Island, Windy Bay	548	y	1990		n	n.d.	
Hinchinbrook Island, north side	527	r	1970-1985		n	cons	
Icy Bay	652	y	1994-1996	1	y	cons	< 20 feet deep, within 20 meters of shore
Jackpot Bay	671	y	1994-1996	1	y	cons	< 20 feet deep, within 20 meters of shore
Kiniklik	587	r	1970-1985	3	n	cons	
Kiniklik	587	y	1982		n	once	
Kiniklik	587	y	1989-1993		n	cons	< 20 feet deep, within 20 meters of shore
Kiniklik	587	y	1994-1996		y	cons	< 20 feet deep, within 20 meters of shore
Knight Island, Drier Bay	622	r	1970-1985	3	n	cons	
Knight Island, Drier Bay	622	r	1980-1983		n	cons	
Knight Island, Drier Bay	622	r	1985-1991		n	cons	Balls and schools

Knight Island, Herring Bay	609	r	1970-1985	3	n.d.	cons	
Knight Island, Herring Bay	609	r	1974-1987		no	cons	
Knight Island, Herring Point	509	r	1970-1985		n.d.	cons	
Knight Island, Herring Point	509	r	1985-1991		n	cons	Balls and schools
Knight Island, Lower Herring and Jol	612	r	1985-1991	2	n	cons	Balls and schools
Knight Island, Lower Herring Bay	612	r	1970-1985		n.d.	cons	
Knight Island, west	555	r	1970-1985		n	cons	
Knight Island, Squire Island	522	r	1970-1985	3	n	cons	
Knight Island, Squire Island	522	r	1985-1988		y	once	scattered rocks among the rocks < 10 m deep
Knight Island, Squire Island	522	r	1985-1991		n	cons	Balls and schools
Knight Island, Snug Harbor to Point	555	r	1974-1987	1	no	cons	
Latouche Island, east side	619	y	1994	2	y	once	large concentration of herring
Latouche Passage, northwest	581	r	1970-1985		y	cons	
Latouche Passage, south	619	r	1970-1985		y	cons	
Long Bay	553	r	1970-1985	2	n	cons	
Long Bay	553	r	1982-1996		n.d.	occ	
Main Bay	608	r	1967-1975	2	y	cons	age zeros moving south, saw them when he was set netting
Main Bay	608	r	1970-1985		n	cons	
Montague Island, Graveyard Point t	631	r	1980-1983	2	y	cons	
Montague Island, Jeanie Cove	541	y	1994-1996		n	cons	< 20 feet deep, within 20 meters of shore
Montague Island, middle west side	566	r	1980-1983		y	cons	
Montague Island, Patton Bay	540	y	1994-1996	1	n	cons	< 20 feet deep, within 20 meters of shore
Montague Island, Port Chalmers	529	y	1989-1996	3	n	cons	< 20 feet deep, within 20 meters of shore
Montague Island, Port Chalmers	529	y	1994-1996		y	cons	< 20 feet deep, within 20 meters of shore
Montague Island, Port Chalmers	529	r	1980-1983		y	cons	
Montague Island, Port Chalmers	529	r	1981-1987		n	cons	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
Montague Island, Port Chalmers	529	y	1991-1992		n	cons	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
Montague Island, Rocky Bay	583	r	1980-1983	3	y	cons	

Montague Island, Rocky Bay	583	r	1982-1996		n.d.	cons	
Montague Island, Rocky Bay	583	y	1989-1993		n	cons	< 20 feet deep, within 20 meters of shore
Montague Island, Rocky Bay	583	y	1994-1996		y	cons	< 20 feet deep, within 20 meters of shore
Montague Island, Stockdale Harbor	631	r	1981-1987	3	n	cons	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
Montague Island, Stockdale Harbor	631	r	1982-1996		n.d.	occ	
Montague Island, Stockdale Harbor	631	y	1989-1993		n	cons	< 20 feet deep, within 20 meters of shore
Montague Island, Stockdale Harbor	631	y	1994-1996		y	cons	< 20 feet deep, within 20 meters of shore
Montague Island, Zaikof Bay	521	r	1980-1983	3	y	cons	
Montague Island, Zaikof Bay	521	r	1982-1996		n.d.	cons	
Montague Island, Zaikof Bay	521	y	1989-1993		n	cons	< 20 feet deep, within 20 meters of shore
Montague Island, Zaikof Bay	521	y	1994-1996		y	cons	< 20 feet deep, within 20 meters of shore
Montague Strait, west lower	530	r	1970-1985	2	y	cons	
Montague Trench	566	r	1982-1996		n.d.	occ	
Montague Trench	653	r	1982-1996		n.d.	occ	
Naked Island	520	r	1982-1996	3	n.d.	occ	
Naked Island	546	r	1987-1989		n	once	once in late 1980s
Naked Island	520	y	1989-1996		n	cons	< 20 feet deep, within 20 meters of shore
Naked Island, north shore	520	y	1987-1988		n	n.d.	
Naked Island, north shore	520	y	1990		n	n.d.	
Olsen Island	586	r	1972-1978	2	n	occ	
Olsen Island	586	y	1989-1993		n	cons	< 20 feet deep, within 20 meters of shore
Olsen Island	586	y	1994-1996		y	cons	< 20 feet deep, within 20 meters of shore
Orca Bay	563	r	1972-1978	2	n	cons	one years in 1970s saw bay loaded with juv
Orca Inlet, Cordova Harbor	517	n.d.	n.d.		y	cons	
Perry Island	547	r	1987-1989	1	n	once	once in late 1980s
Port Fidalgo, Fish Bay	585	r	1972-1978	3	n	cons	
Port Fidalgo, Fish Bay	585	r	1972-1978		y	cons	
Port Fidalgo, Fish Bay	585	r	1981-1987		n	occ	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
Port Fidalgo, Fish Bay	585	y	1987-1988		n	occ	
Port Fidalgo, Fish Bay	585	y	1990		n	occ	
Port Fidalgo, head	544	r	1970-1985	2	n	cons	
Port Fidalgo, head	544	r	1981-1987		n	cons	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet

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Port Fidalgo, head	544	r	1981-1987		n	occ	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
Port Fidalgo, Irish Cove	585	r	1970-1985		n	cons	
Port Fidalgo, Landlocked Bay	625	r	1972-1978	4	n	cons	
Port Fidalgo, Landlocked Bay	625	r	1982-1996		n.d.	occ	
Port Fidalgo, Landlocked Bay	625	y	1987-1988		n	n.d.	
Port Fidalgo, Landlocked Bay	625	y	1990		n	n.d.	
Port Fidalgo, Landlocked Bay	625	r	1970-1985		n	cons	
Port Fidalgo, Snug Corner Cove	603	r	1970-1985	4	n	cons	
Port Fidalgo, Snug Corner Cove	603	y	1987-1988		n	n.d.	
Port Fidalgo, Snug Corner Cove	603	y	1990		n	n.d.	
Port Fidalgo, Two Moon Bay	603	r	1972-1978		y	cons	
Port Fidalgo, Two Moon Bay	603	r	1982-1996		n.d.	occ	
Port Fidalgo, Whalen Bay	544	r	1972-1978		y	cons	
Port Gravina, Gravina Rocks	562	r	1970-1985	1	n	cons	
Port Gravina, head	621	r	1970-1985	1	n	cons	
Port Gravina, Hell's Hole	518	r	1970-1985	3	n	cons	
Port Gravina, Hell's Hole	518	r	1982-1996		n.d.	occ	
Port Gravina, Hell's Hole	518	y	1989-1993		n	cons	< 20 feet deep, within 20 meters of shore
Port Gravina, Hell's Hole	518	y	1994-1996		y	cons	< 20 feet deep, within 20 meters of shore
Port Gravina, Olsen Bay	621	r	1982-1996	2	n.d.	occ	
Port Gravina, Olsen Bay	586	y	1989-1993		n	cons	
Port Gravina, Olsen Bay	586	y	1994-1996		y	cons	
Port Gravina, Knowles Head	632	r	1970-1985	3	n	cons	
Port Gravina, Knowles Head to Red	628	r	1982-1996		n.d.	occ	
Port Gravina, Red Head	628	r	1970-1985		n	cons	
Port Gravina, Red Head	628	y	1989-1993		n	cons	< 20 feet deep, within 20 meters of shore
Port Gravina, Red Head	628	y	1994-1996		y	cons	< 20 feet deep, within 20 meters of shore
Port Gravina, St. Mathew's Bay	528	r	1970-1985	5	n	cons	
Port Gravina, St. Mathew's Bay	528	r	1981-1987		n	occ	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
Port Gravina, St. Mathew's Bay	528	r	1982-1996		n.d.	occ	
Port Gravina, St. Mathew's Bay	528	y	1989-1993		n	cons	< 20 feet deep, within 20 meters of shore
Port Gravina, St. Mathew's Bay	528	y	1994-1996		y	cons	< 20 feet deep, within 20 meters of shore
Port Gravina, St. Matthews Bay	628	r	n.d.		y	n.d.	

Port Nellie Juan, Kings Bay	655	r	1970-1972	1	y	n.d.	
Port Wells, middle	565	r	1938-1988	2	y	cons	n.d.
Port Wells, middle	565	r	1972-1978		n	occ	
Port Wells, south	564	r	1938-1988		y	cons	n.d.
Port Wells, south	564	r	1970-1978		n	occ	
Port Wells, south	564	r	1972-1978		n	occ	
Prince of Wales Pass	615	r	1970-1985	1	y	cons	
Prince of Wales Passage, Aluklik Ba	513	r	1970-1985		y	cons	
Sheep Bay	611	r	1970-1985	4	n	cons	
Sheep Bay	611	r	1982-1996		n.d.	occ	
Sheep Bay	611	y	1987-1988		n	n.d.	
Sheep Bay	611	y	1989-1993		n	cons	
Sheep Bay	611	y	1994-1996		y	cons	
Simpson Bay	601	r	1970-1985	3	n	cons	
Simpson Bay	601	y	1987-1988		n	n.d.	
Simpson Bay	601	y	1989-1993		n	cons	
Simpson Bay	601	y	1994-1996		y	cons	
Squaw Bay	498	r	1970-1985	2	n	cons	
Squaw Bay	498	y	1982		n	once	
Storey Island	532	y	1987-1988	1	n	n.d.	
Storey Island	532	y	1990		n	n.d.	
Tatitlek Narrows	623	r	1934-1996	3	y	cons	
Tatitlek Narrows, Boulder Bay	623	r	1967-1975		y	cons	
Tatitlek Narrows, Boulder Bay	623	r	1982-1996		n.d.	occ	
Valdez Arm	534	r	1980-1983	2	y	once	one time
Valdez Arm	523	r	1982-1996		n.d.	occ	
Valdez Arm, Galena Bay	624	r	1967-1975	4	y	cons	75% of the time not uncommon
Valdez Arm, Galena Bay	624	r	1970-1988		y	once	little balls of 1 years
Valdez Arm, Galena Bay	624	r	1972-1978		n	occs	
Valdez Arm, Galena Bay	624	y	1987-1988		n	n.d.	
Valdez Arm, Galena Bay	624	y	1990		n	n.d.	

Valdez Arm, Jack Bay	604	r	1970-1973	2	y	n.d.	saw balls of fish
Valdez Arm, Jack Bay	604	r	1982-1996		n.d.	occ	
Wells Bay, Cedar Bay	626	r	1982-1996	4	n.d.	cons	
Wells Bay	626	r	1970-1985		n	cons	
Wells Bay	626	r	1972-1978		n	occ	
Wells Bay	626	y	1987-1988		n	n.d.	
Wells Bay	626	y	1990		n	n.d.	
Wells Bay, Granite Bay	508	r	1970-1985		n	cons	
Whale Bay	602	y	1994-1996	2	y	cons	
Whale Bay, mouth	602	r	1970-1985		y	cons	

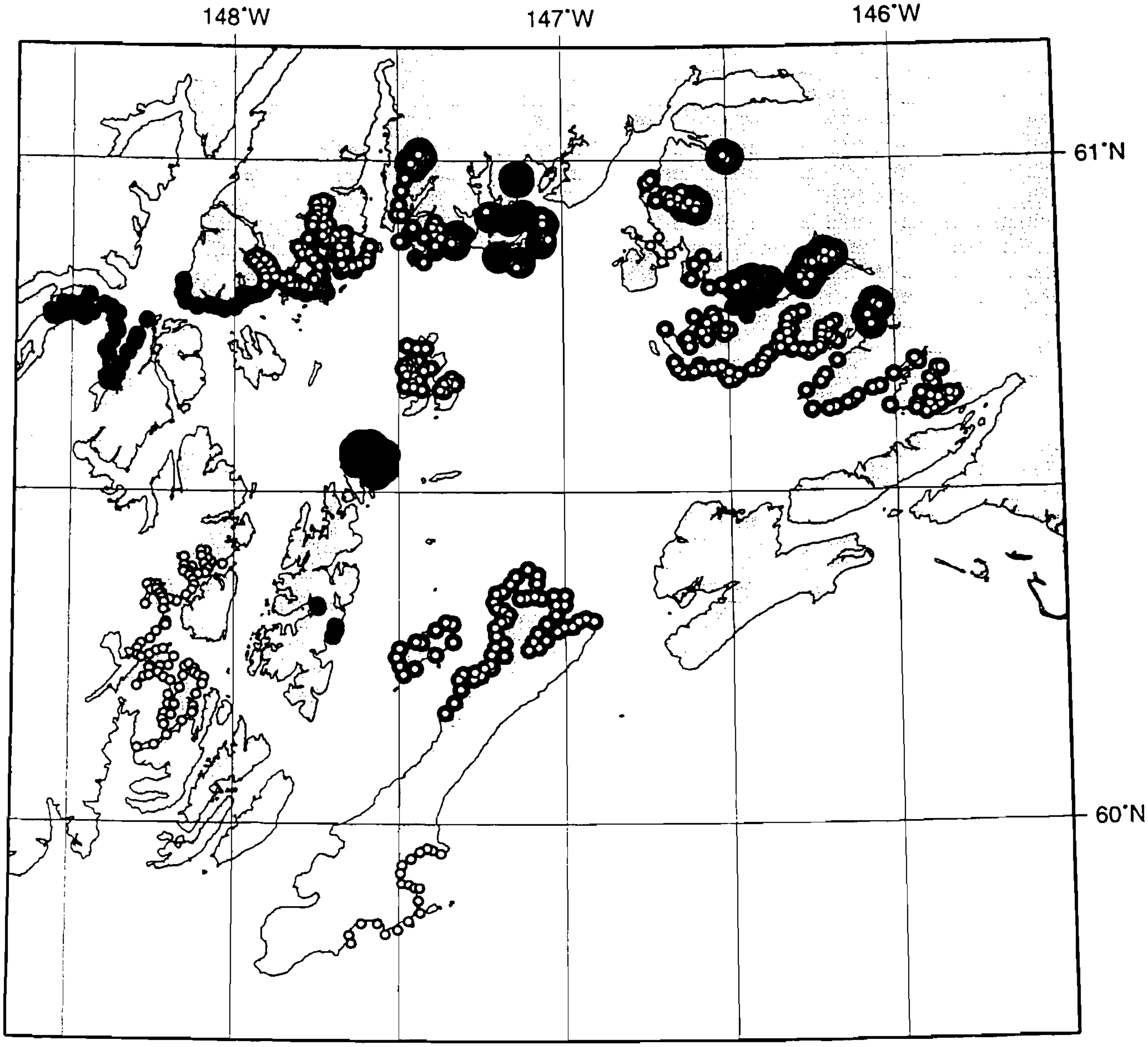
REGION	PLACE	AREA	RANGE	COUNT	
1	Esther Passage	499	1989-1996	2	
1	Eaglek Bay	584	1989-1996		
1	Kiniklik	587	1989-1996		
1	Olsen Island	586	1989-1996		
1	Wells Bay, Granite Bay	626	1996		
1	Naked Island	520	1989-1996	1	< 20 feet deep, within 20 meters of shore
2	Nelson Bay	517	1985-1995	2	caught with smelt nets, herring where 4" to 5" long
2	Orca Inlet	517	n.d.		
2	Orca Inlet	517	n.d.		
2	Port Fidalgo	542	n.d.	2	
2	Port Fidalgo, Fish Bay	585	1992		went trapping, could see from boat lights while anchored
2	Port Gravina, Beartrap Bay	621	1977-1981	3	5-20 fathoms on sonar
2	Port Gravina, Red Head	628	1989-1996		
2	Port Gravina, Hell's Hole	518	1989-1996		
2	Port Gravina, Olsen Bay	586	1989-1996		
2	Port Gravina, St Mathews Bay	528	1989-1996		
2	Port Gravina	621	1992		
2	Sheep Bay	611	1989-1996	1	
2	Simpson Bay	601	1977-1981	5	5-20 fathoms on sonar
2	Simpson Bay, head	601	1978-1981		midchannel
2	Simpson Bay	601	1985-1989		saw one time 1985-1989, on sonar
2	Simpson Bay	601	1985-1995		dragging for shrimp in '94; in '95 caught 4-5" herring with smelt nets
2	Simpson Bay	601	1989-1996		
3	Dangerous Passage, Paddy Bay	610	1994-1996	1	
3	Jackpot Bay	671	1994-1996	1	
3	Icy Bay	652	1994-1996	1	
3	Bainbridge Point	511	1970-1985	2	
3	Bainbridge Passage	614	1994-1996		
3	Prince of Wales Passage, Aluklik Bay	513	1970-1985	1	
3	Prince of Wales Passage	615	1970-1985		
3	Evans Island, northwest side	512	1970-1985	1	

REGION	PLACE	AREA	RANGE	COUNT	
3	Elrington Island, Bettles Island	516	1970-1985	1	
3	Latouche Passage, northwest	581	1970-1985	1	
3	Latouche Passage, south	619	1970-1985		
3	Knight Island, Mummy/Little Bays to Point Helen	613	1985-1991	1	Thin Bands
3	Green Island	630	1989-1996	1	
3	Montague Island, Port Chalmers	529	1981-1987	3	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
3	Montague Island, Port Chalmers	529	1981-1987.		called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
3	Montague Island, Port Chalmers	529	1985-1991		
3	Montague Island, Port Chalmers	529	1989-1996		< 20 feet deep, within 20 meters of shore
3	Montague Island, Port Chalmers	529	1991-1992		called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
3	Montague Island, Gilmour Point	529	1991-1992		called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
3	Montague Island, Stockdale Harbor	631	1981-1987	4	called juveniles because wouldn't set a seine on them, estimated depth 1 to 3 feet
3	Montague Island, Stockdale Harbor	631	1989-1996		
3	Montague Island, Stockdale Harbor	631	1991-1992		
3	Montague Island, Stockdale Harbor	631	1992		tide went out, found a lot of juv herring dead on shore
3	Montague Island, Graveyard Point	631	1989		1/4 mesh by 5.6 fathoms deep net
3	Montague Point	583	1989	2	1/4 mesh by 5.6 fathoms deep net
3	Montague Island, Rocky Bay	583	1989-1996		< 20 feet deep, within 20 meters of shore
3	Montague Island, Zaikof Bay	521	1989-1996	2	< 20 feet deep, within 20 meters of shore
3	Montague Island, Zaikof Point	521	1993		50 gram fish
3	Whale Bay	602	1994-1996	1	

PLACE	AREA .	RANGE	n=4	FREQ	ID	NOTES
Bainbridge Point	614	1971-1972	1	cons	n	
Chenega Island	510	1971-1972	1	cons	n	
Chenega Point	539	1971-1972		cons	n	
Crafton Island	507	1971-1972	1	cons	n	
Dangerous Passage, Ewan Bay	610	1971-1972	1	cons	n	
Elrington Passage	516	1971-1972	1	cons	n	
Eshamy Bay	617	1971-1972	1	cons	n	
Evans Island	616	1971-1972	1	cons	n	
Evans Island, Shelter Bay	512	1971-1972		cons	n	
Flemming Island	511	1971-1972	1	cons	n	
Knight Island, Herring Bay	609	1971-1972	1	cons	n	
Latouche Passage	619	1971-1972	1	cons	n	
Main Bay	608	1971-1972	1	cons	n	
Orca Inlet	517	n.d.	3	n.d.	n.d.	
Orca Inlet, Cordova Harbor	517	-1989		rare	y	sometime before oil spill
Orca Inlet, Cordova Harbor	517	n.d.		cons	y	
Orca Inlet, Mud Bay	517	-1989		rare	n	sometime before oil spill
Orca Inlet, Salmo Point	517	-1989		rare	n	sometime before oil spill
Port Gravina	562	1978-1981	1	cons	y	that's where they grow
Port Gravina, head	621	1978-1981		cons	y	plugged the trawl
Port Gravina, Hell's Hole	518	1978-1981		cons	y	
Port Gravina, St. Mathew's Bay	528	1978-1981		cons	y	

PLACE	AREA .	RANGE	n=4	FREQ	ID	NOTES
Port Nellie Juan, mouth	654	1971-1972	1	cons	n	
Sheep Bay, head	611	1978-1981	1	cons	y	midchannel
Wells Bay, Granite Bay	508	1971-1972	1	cons	n	
Whale Bay, mouth	672	1971-1972	1	cons	n	

PRINCE WILLIAM SOUND

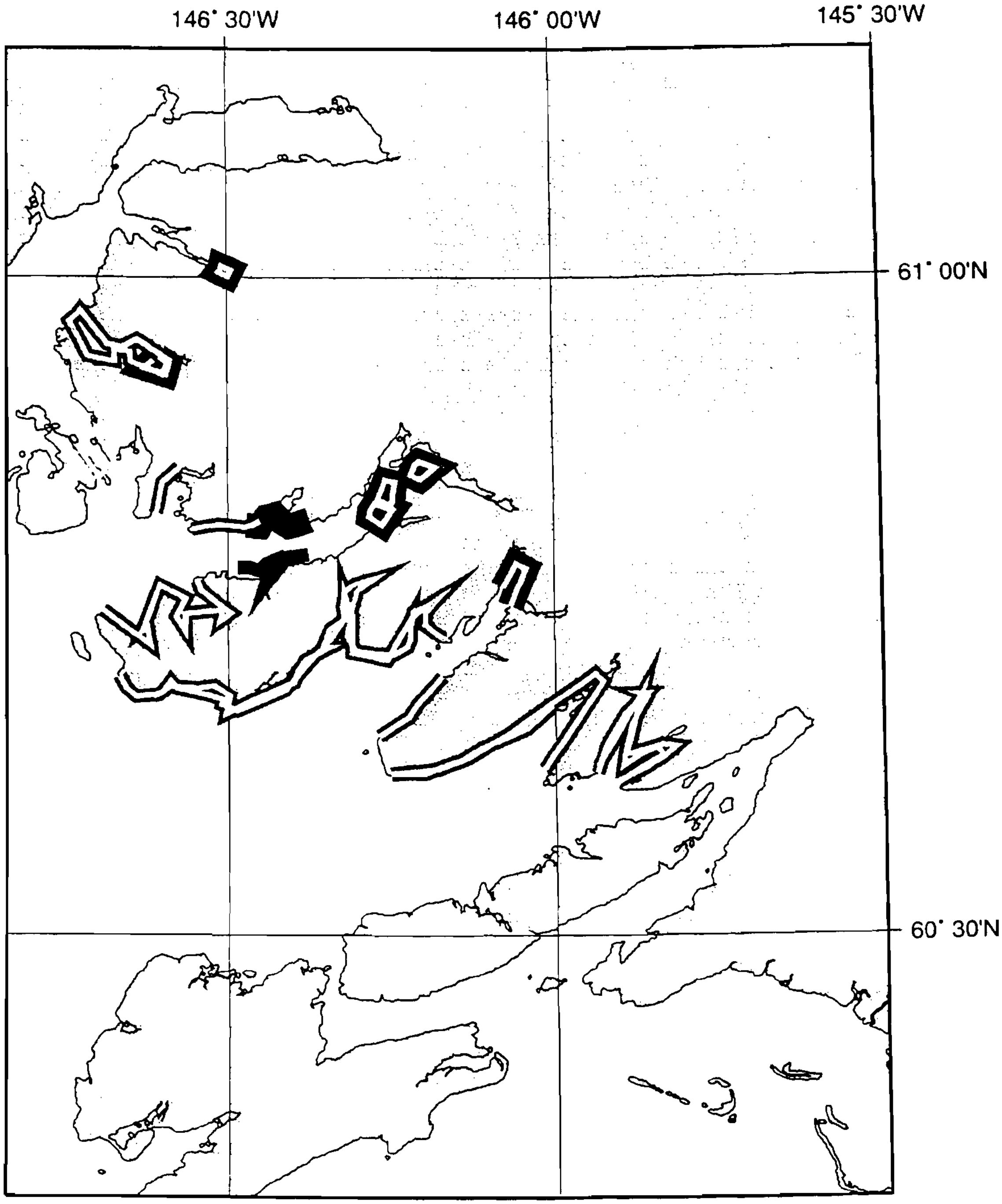


JUVENILE HERRING DISTRIBUTION: SPRING

● 1970s n = 4 ● 1980s n = 8 ○ 1990s n = 4

Figure 1.

PRINCE WILLIAM SOUND

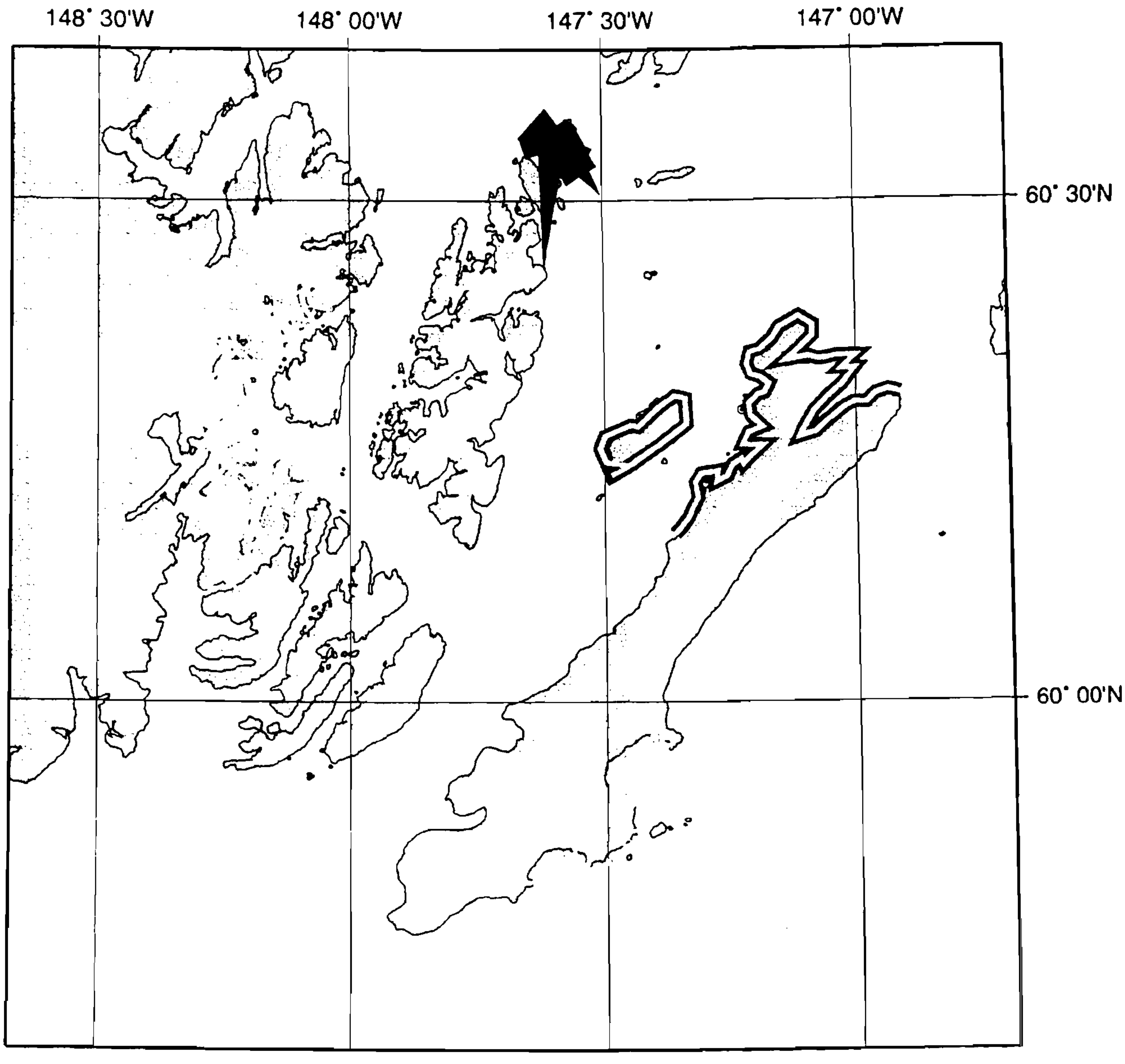


JUVENILE HERRING DISTRIBUTION: SPRING

● 1970s ● 1980s ○ 1990s

Figure 1A.

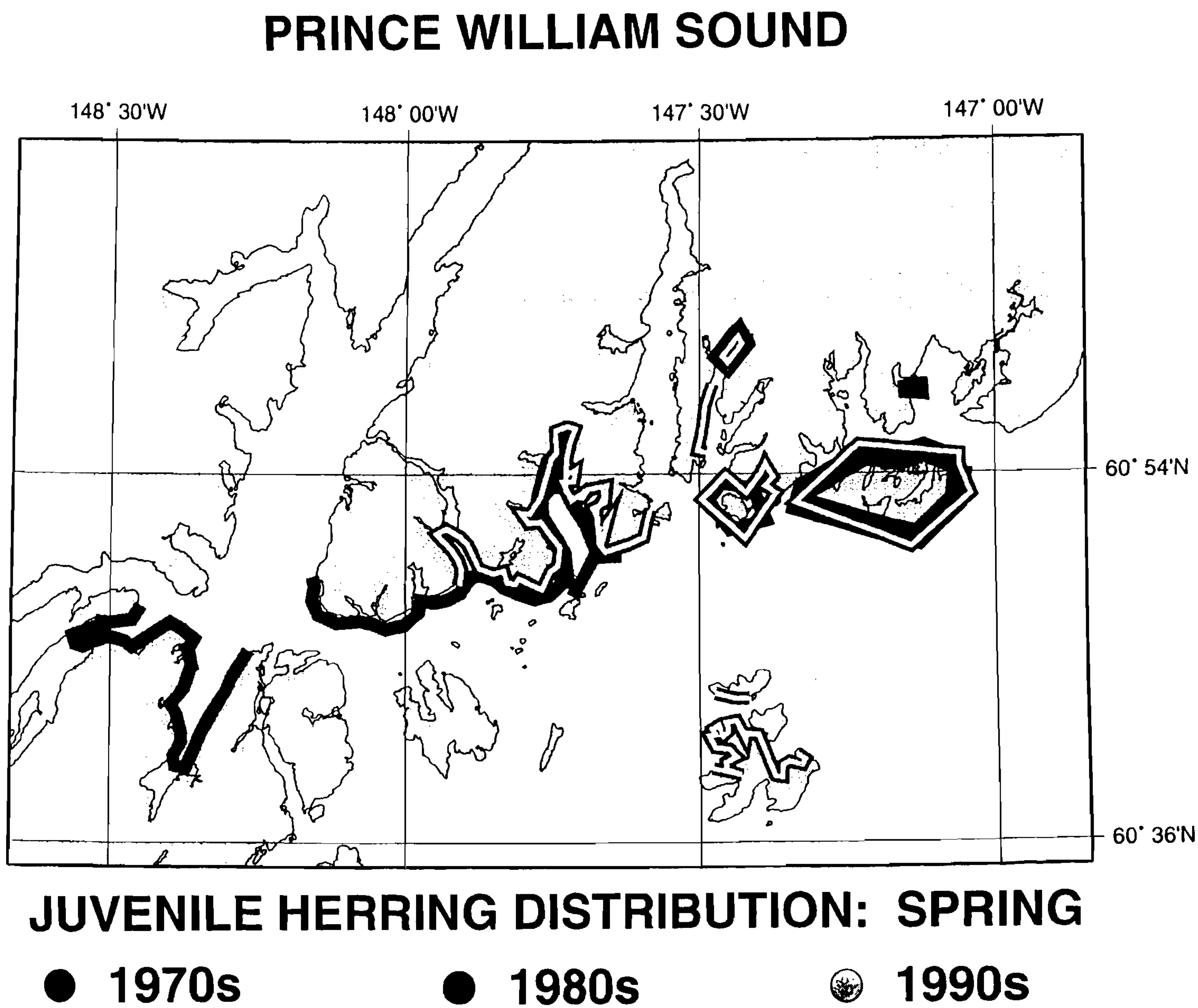
PRINCE WILLIAM SOUND



JUVENILE HERRING DISTRIBUTION: SPRING

● 1970s ● 1980s ○ 1990s

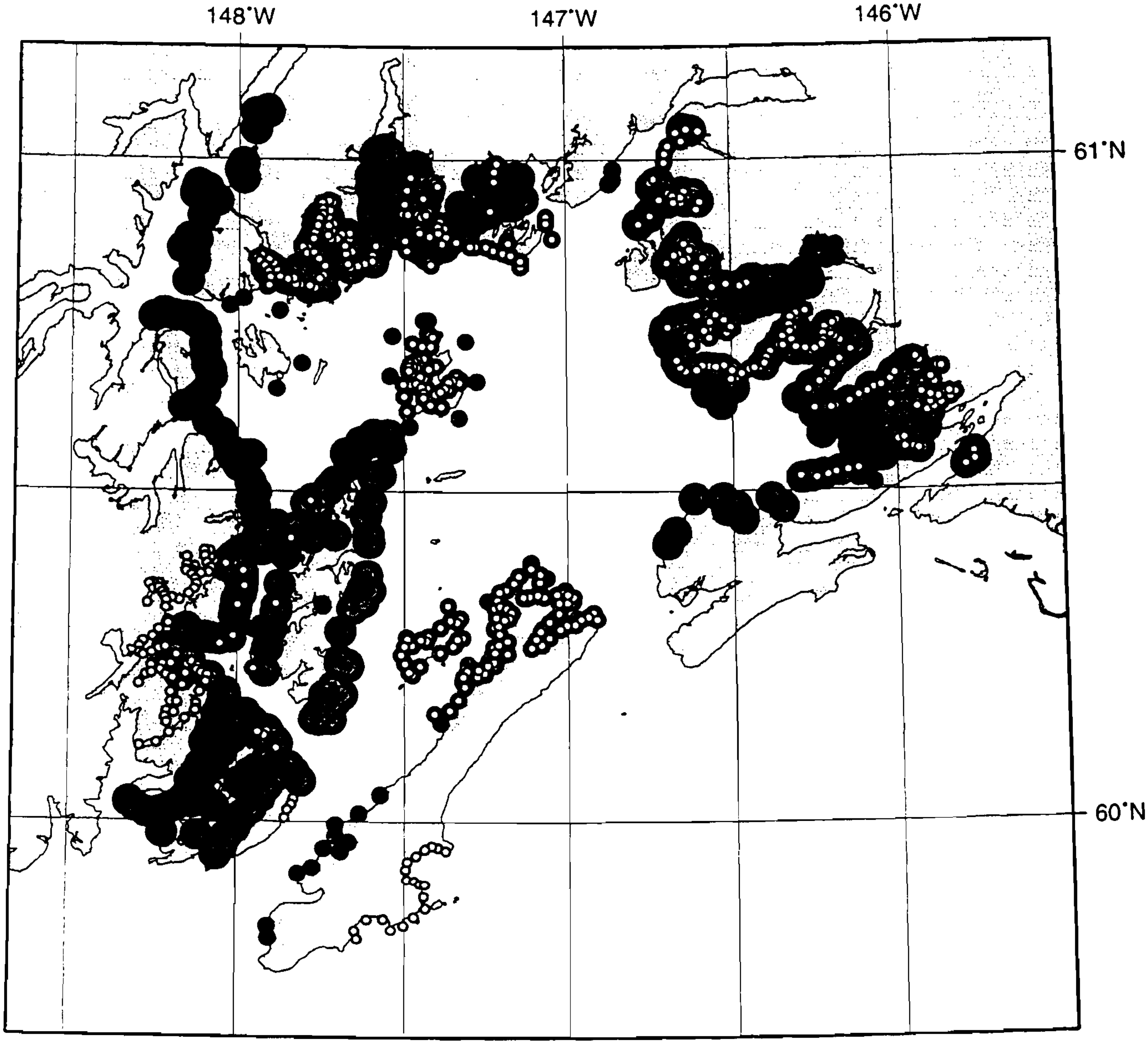
Figure 1B.



PRINCE WILLIAM SOUND
148° 30'W
148° 00'W
147° 30'W
147° 00'W
60° 54'N
60° 36'N
JUVENILE HERRING DISTRIBUTION: SPRING
1970s
1980s
1990s

Figure 1C.

PRINCE WILLIAM SOUND

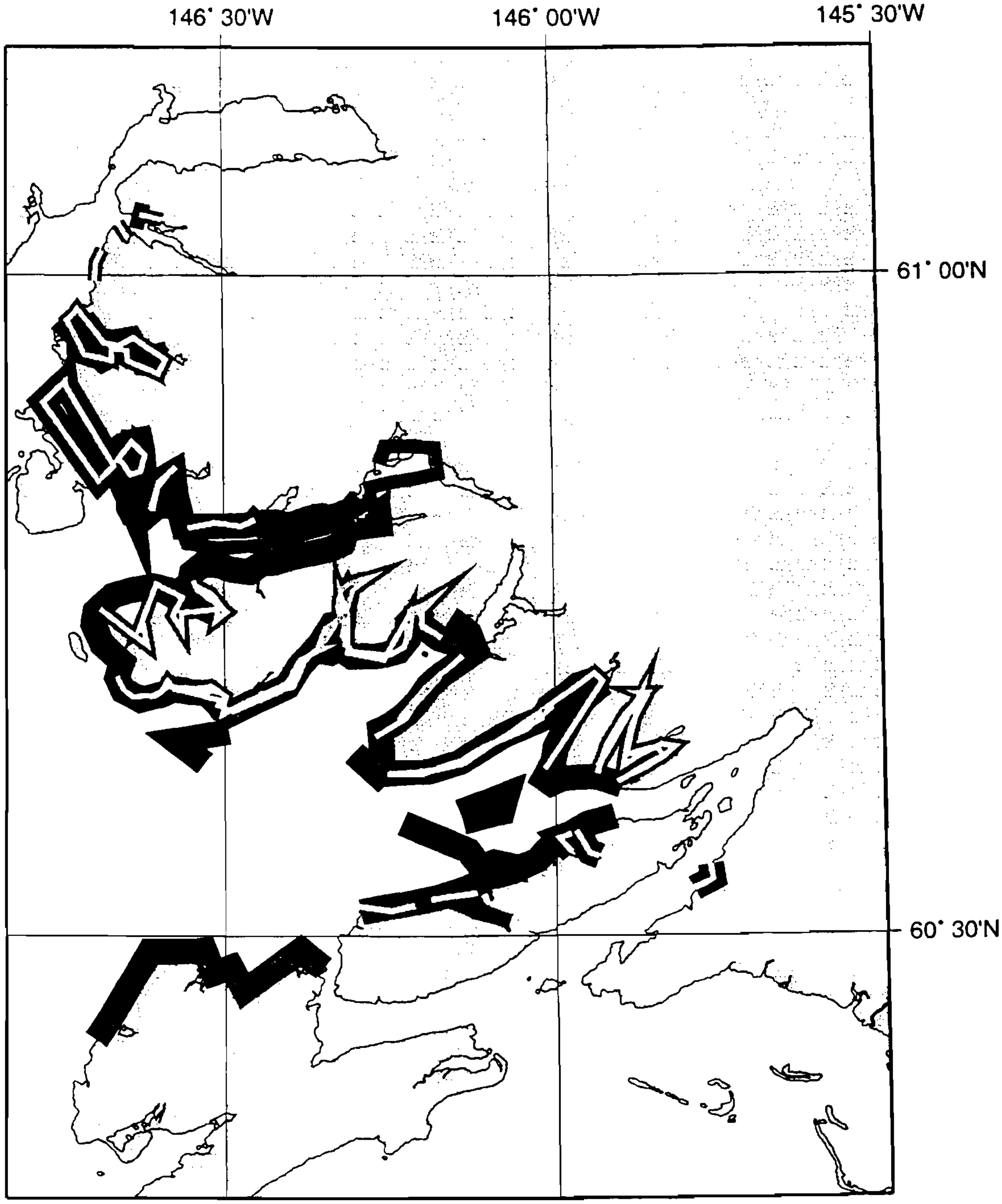


JUVENILE HERRING DISTRIBUTION: SUMMER

● 1970s n = 10 ● 1980s n = 15 ○ 1990s n = 10

Figure 2.

PRINCE WILLIAM SOUND

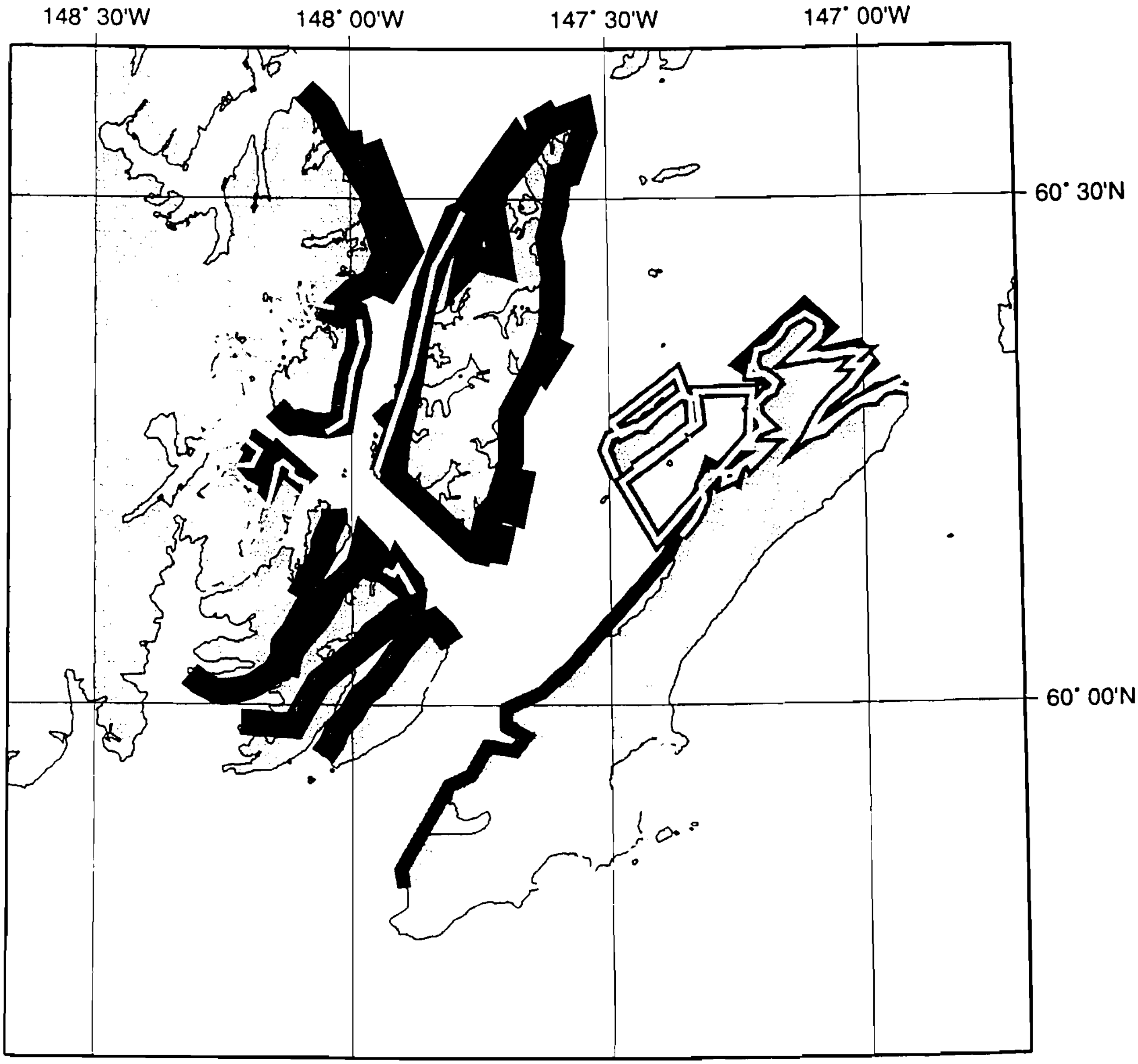


JUVENILE HERRING DISTRIBUTION: SUMMER

● 1970s ● 1980s ○ 1990s

Figure 2A.

PRINCE WILLIAM SOUND

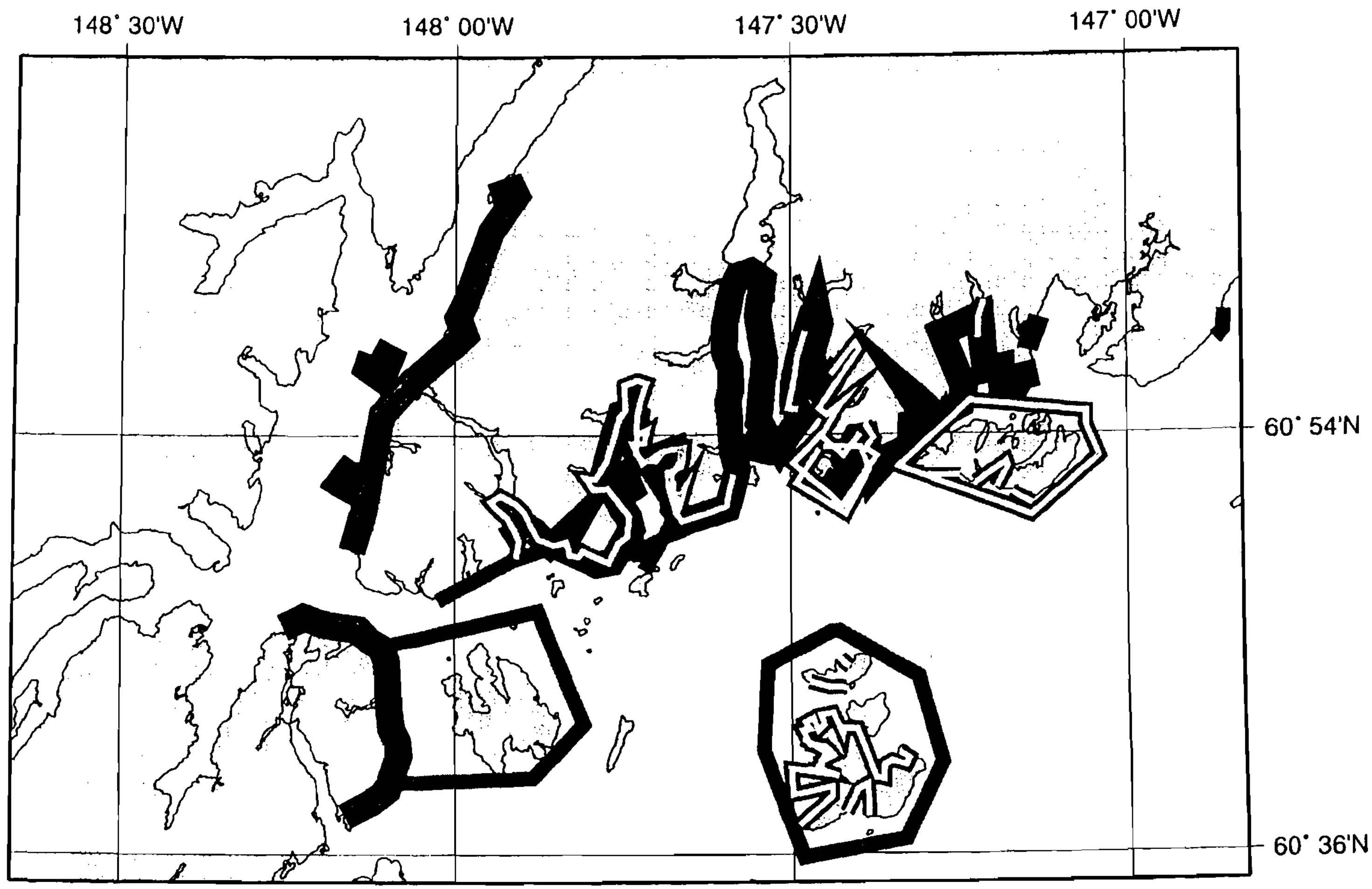


JUVENILE HERRING DISTRIBUTION: SUMMER

● 1970s ● 1980s ○ 1990s

Figure 2B.

PRINCE WILLIAM SOUND

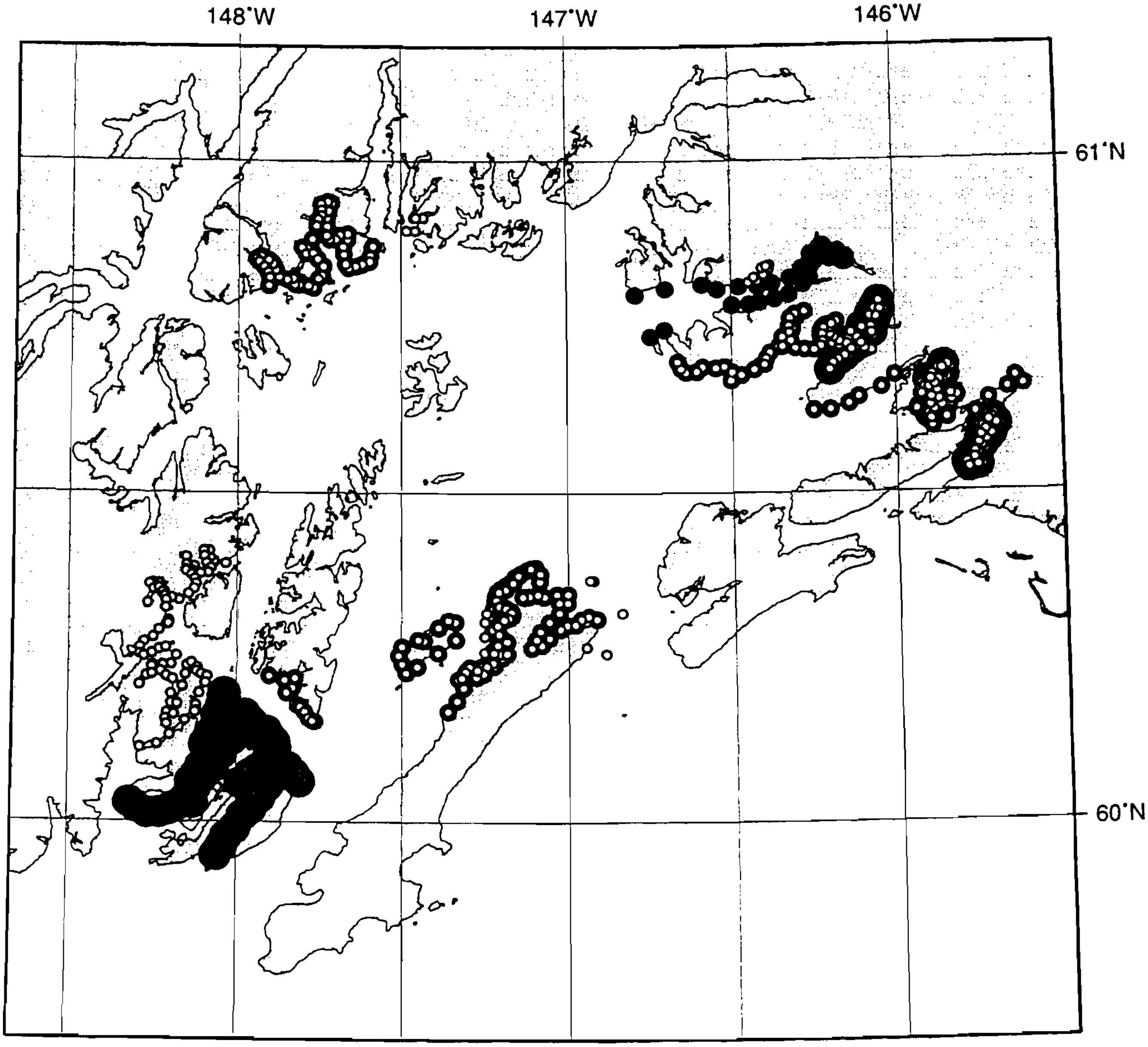


JUVENILE HERRING DISTRIBUTION: SUMMER

● 1970s ● 1980s ◌ 1990s

Figure 2C.

PRINCE WILLIAM SOUND



JUVENILE HERRING DISTRIBUTION: AUTUMN

● 1970s n = 6 ● 1980s n = 9 ○ 1990s n = 8

Figure 3.

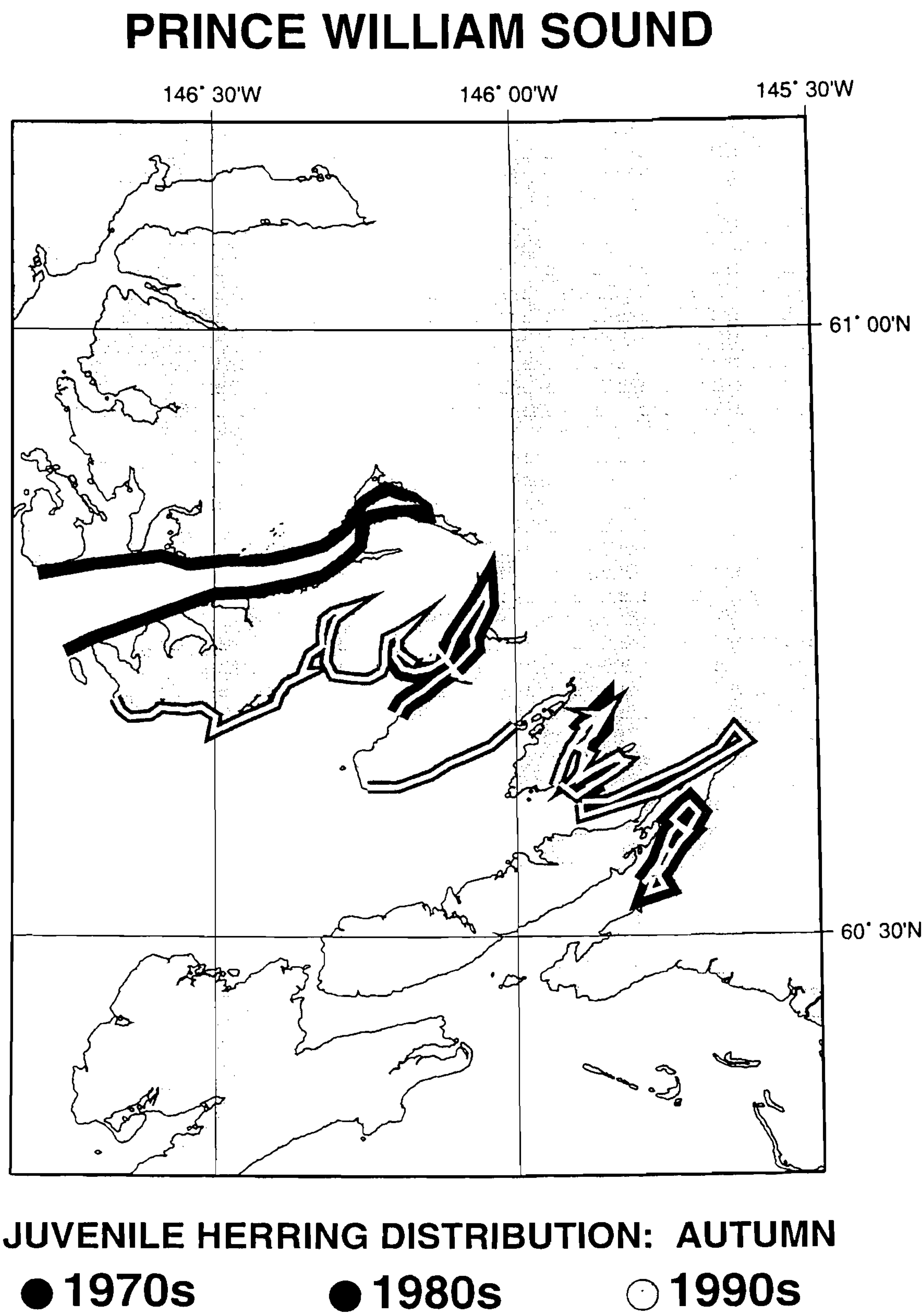
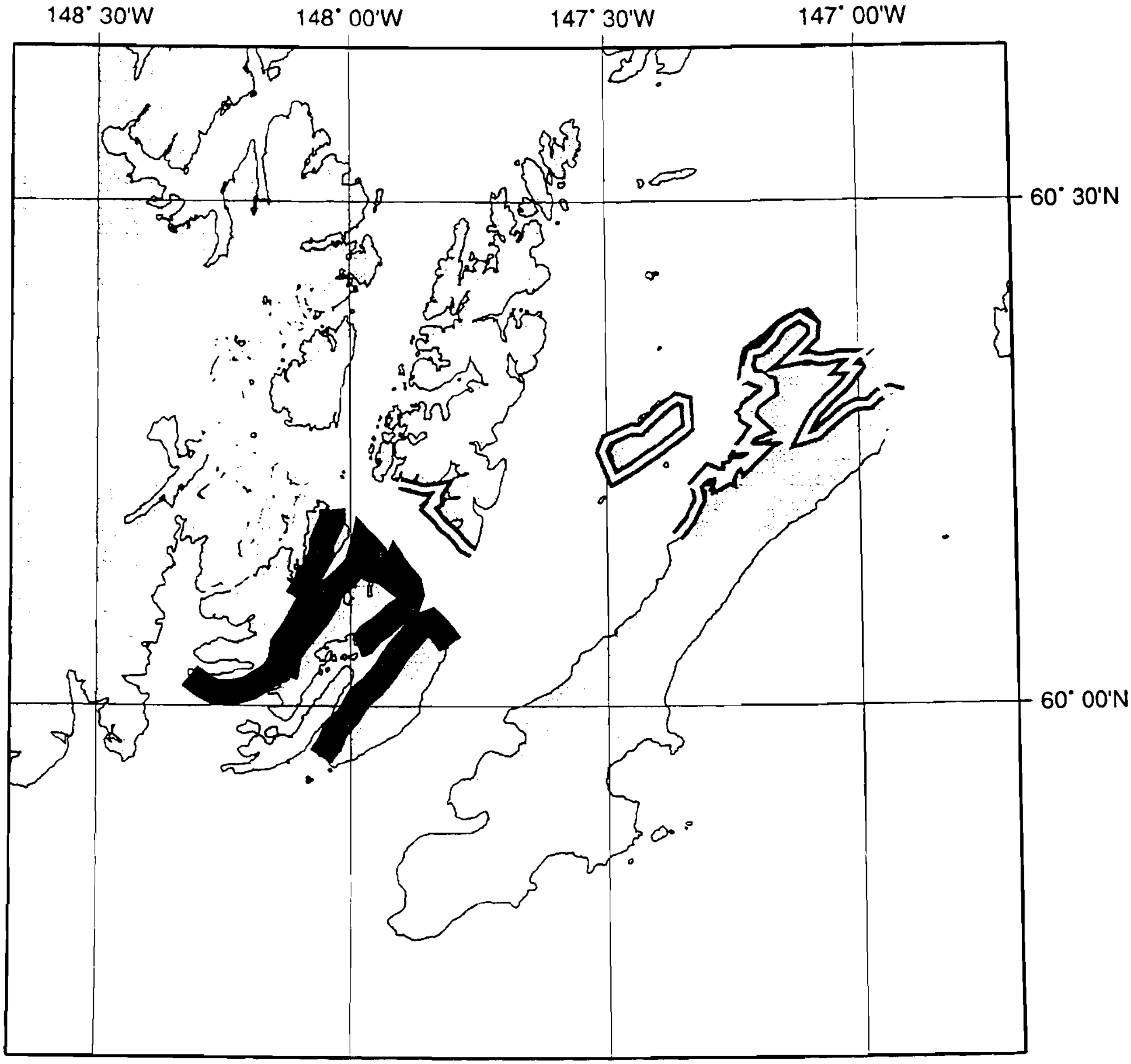

PRINCE WILLIAM SOUND
146° 30'W
146° 00'W
145° 30'W
61° 00'N
60° 30'N
JUVENILE HERRING DISTRIBUTION: AUTUMN
● 1970s
● 1980s
○ 1990s

Figure 3A.

PRINCE WILLIAM SOUND



JUVENILE HERRING DISTRIBUTION: AUTUMN

● 1970s ● 1980s ○ 1990s

Figure 3B.

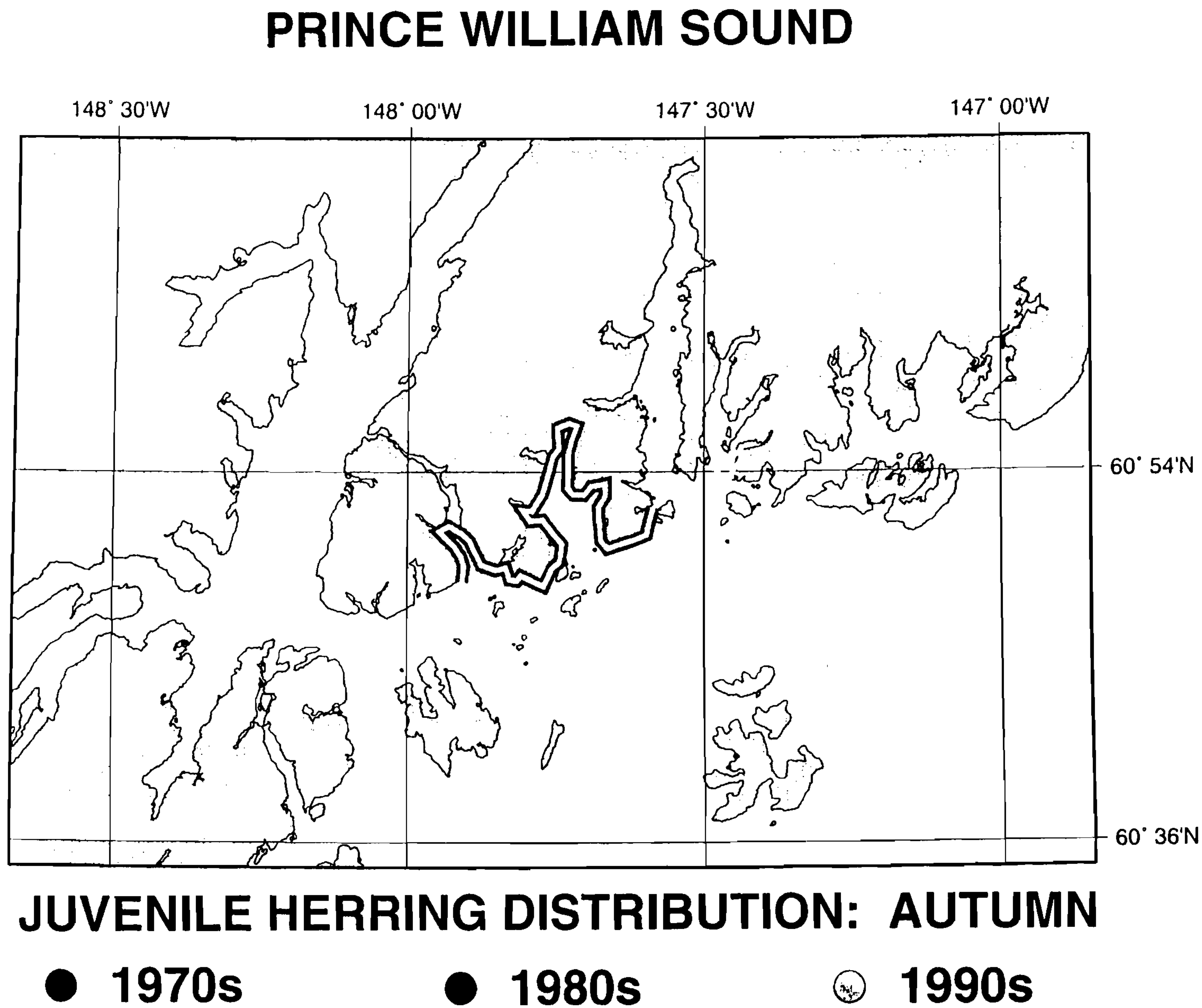
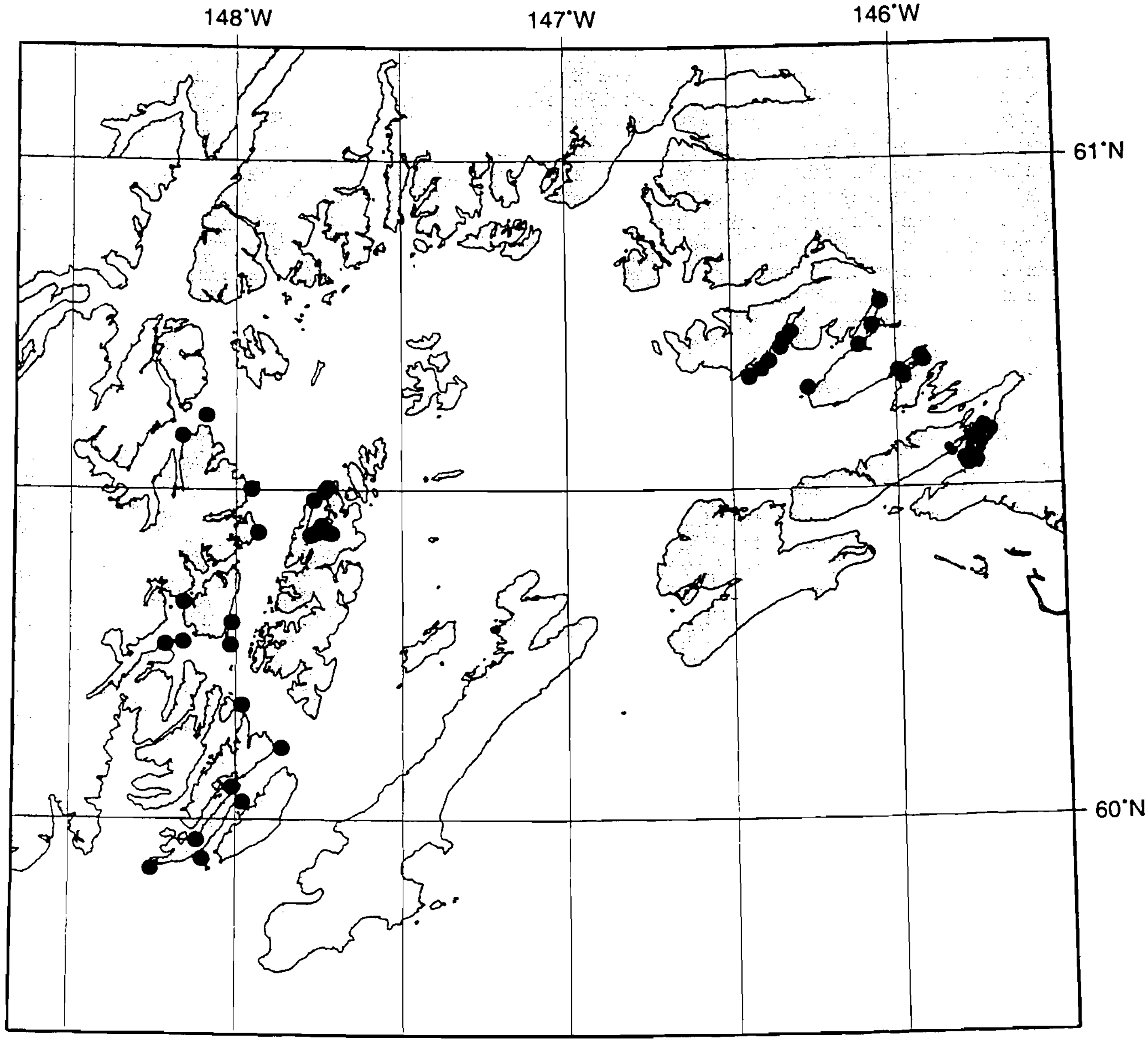

PRINCE WILLIAM SOUND
148° 30'W
148° 00'W
147° 30'W
147° 00'W
60° 54'N
60° 36'N
JUVENILE HERRING DISTRIBUTION: AUTUMN
1970s
1980s
1990s

Figure 3C.

PRINCE WILLIAM SOUND



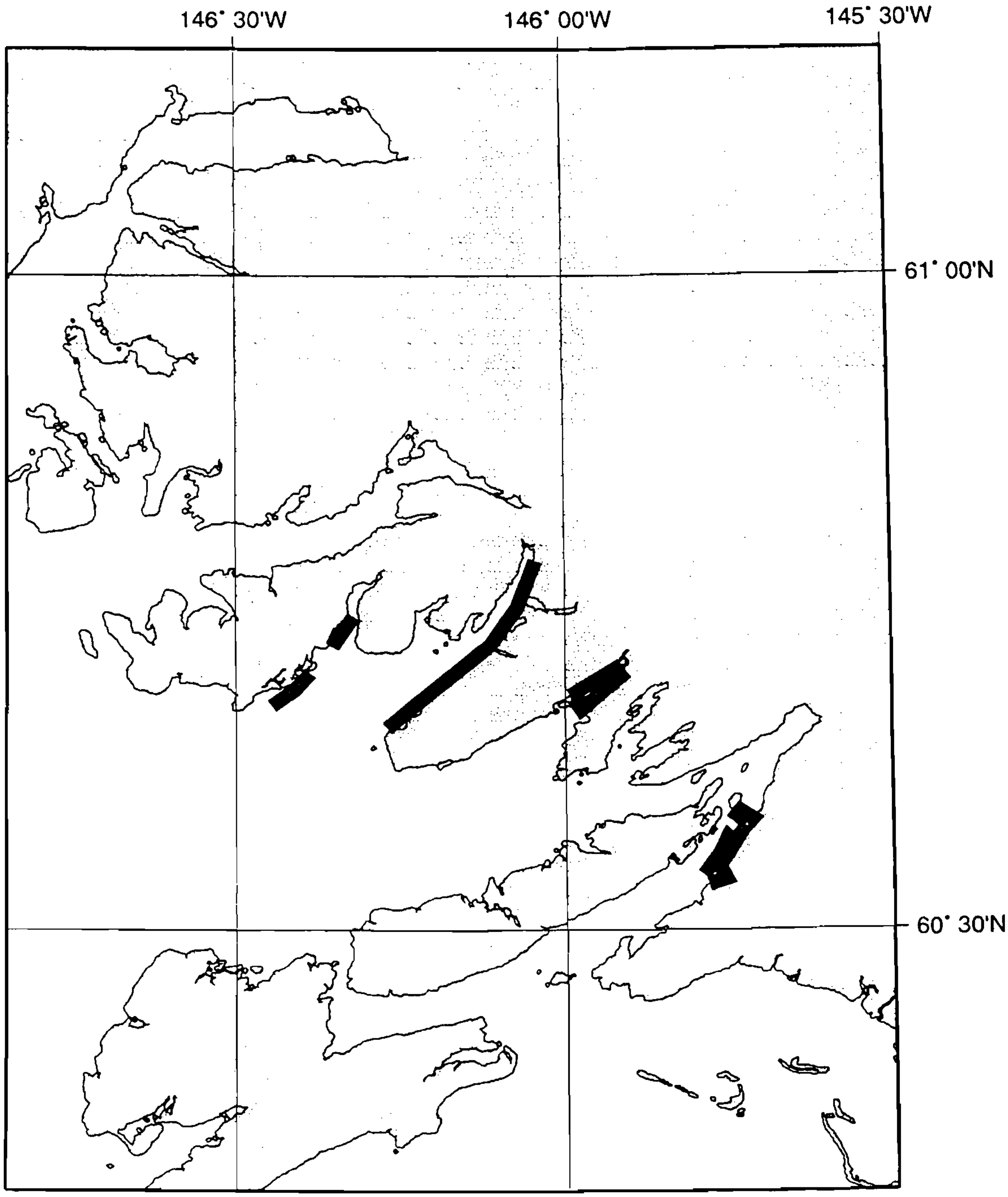
JUVENILE HERRING DISTRIBUTION: WINTER

● 1970s n = 2

● 1980s n = 3

Figure 4.

PRINCE WILLIAM SOUND

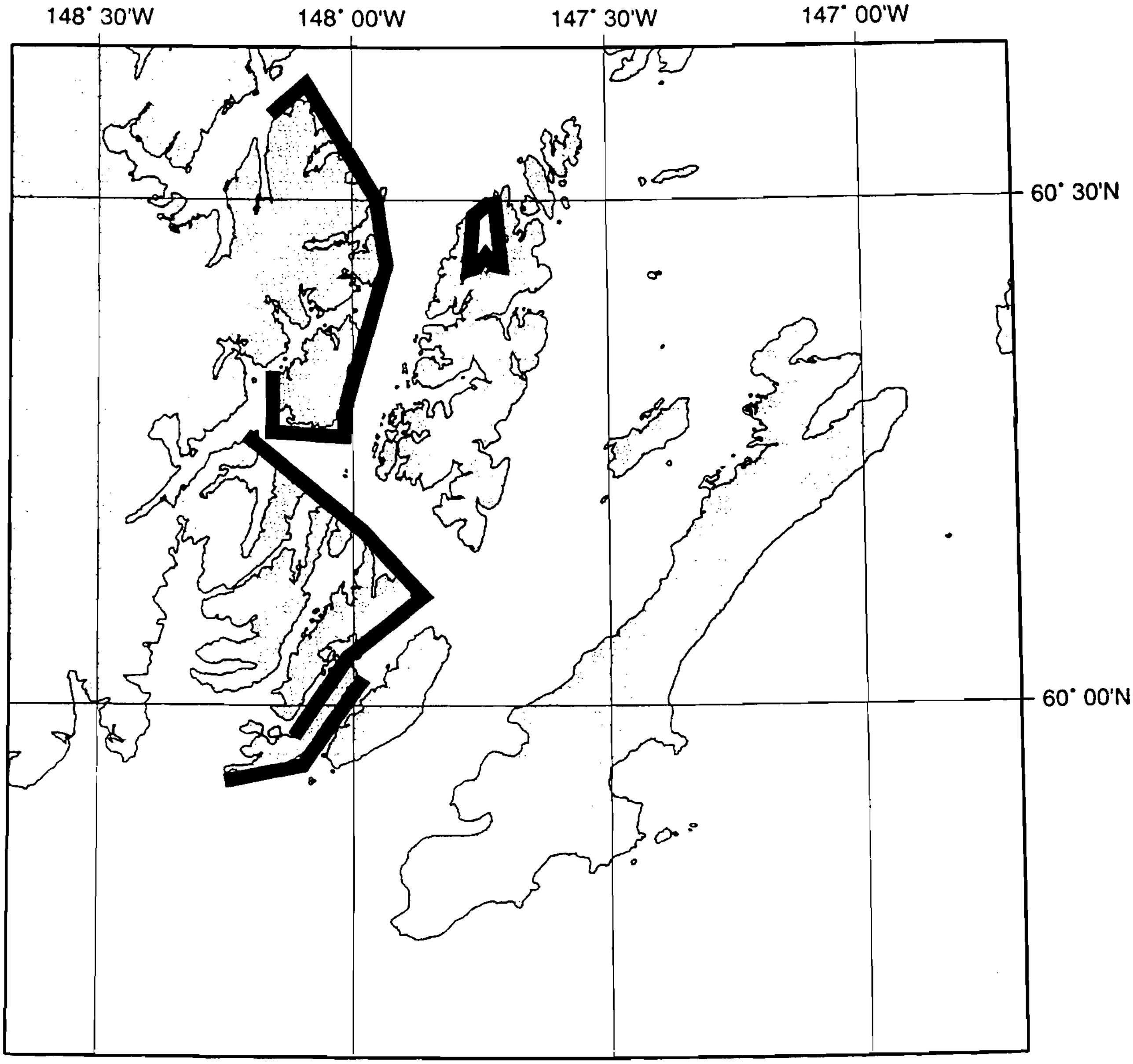


JUVENILE HERRING DISTRIBUTION: WINTER

● 1970s ● 1980s

Figure 4A.

PRINCE WILLIAM SOUND

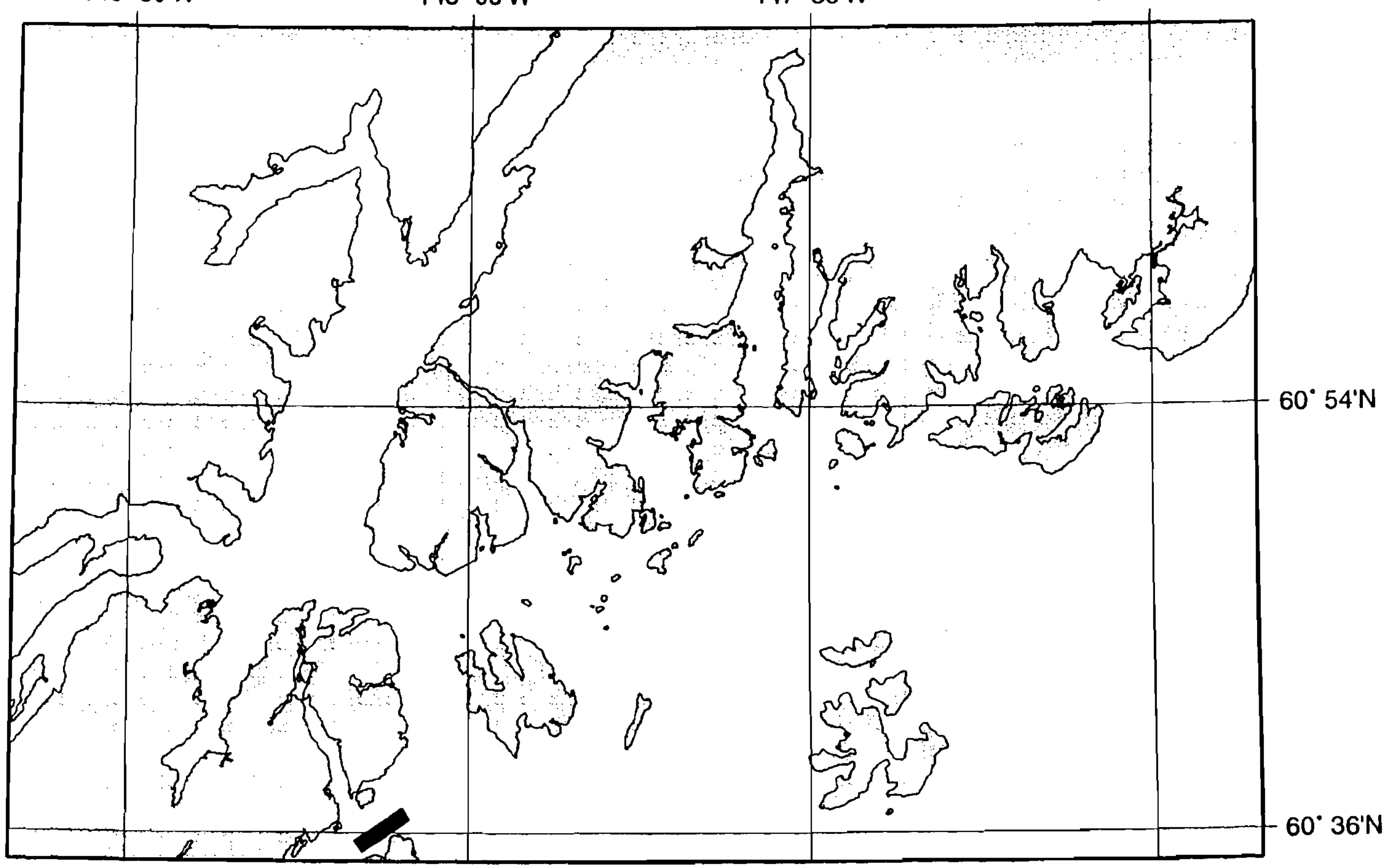


JUVENILE HERRING DISTRIBUTION: WINTER

● 1970s ● 1980s

Figure 4B.

PRINCE WILLIAM SOUND

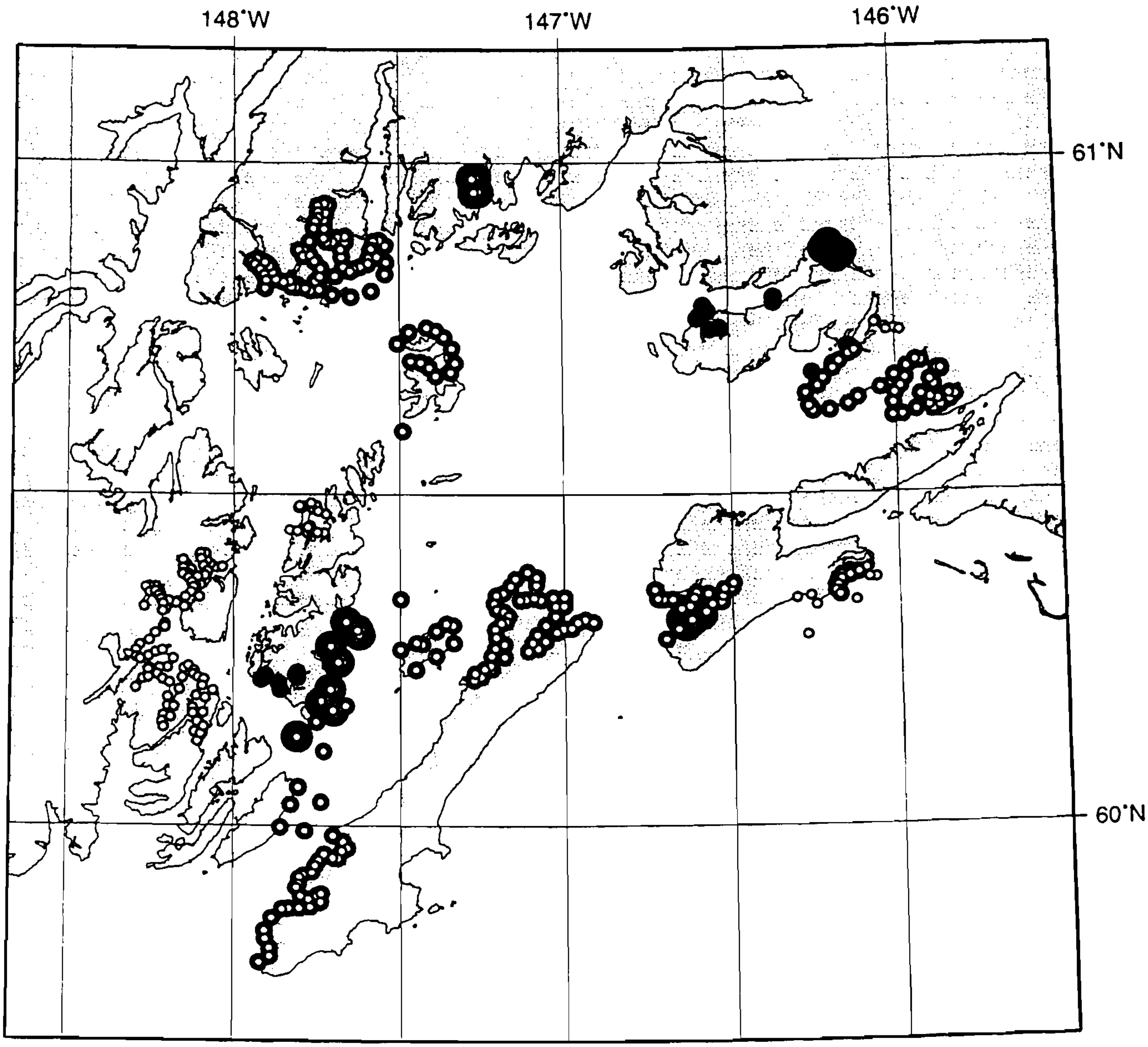


JUVENILE HERRING DISTRIBUTION: WINTER

● 1970s ● 1980s

Figure 4C.

PRINCE WILLIAM SOUND

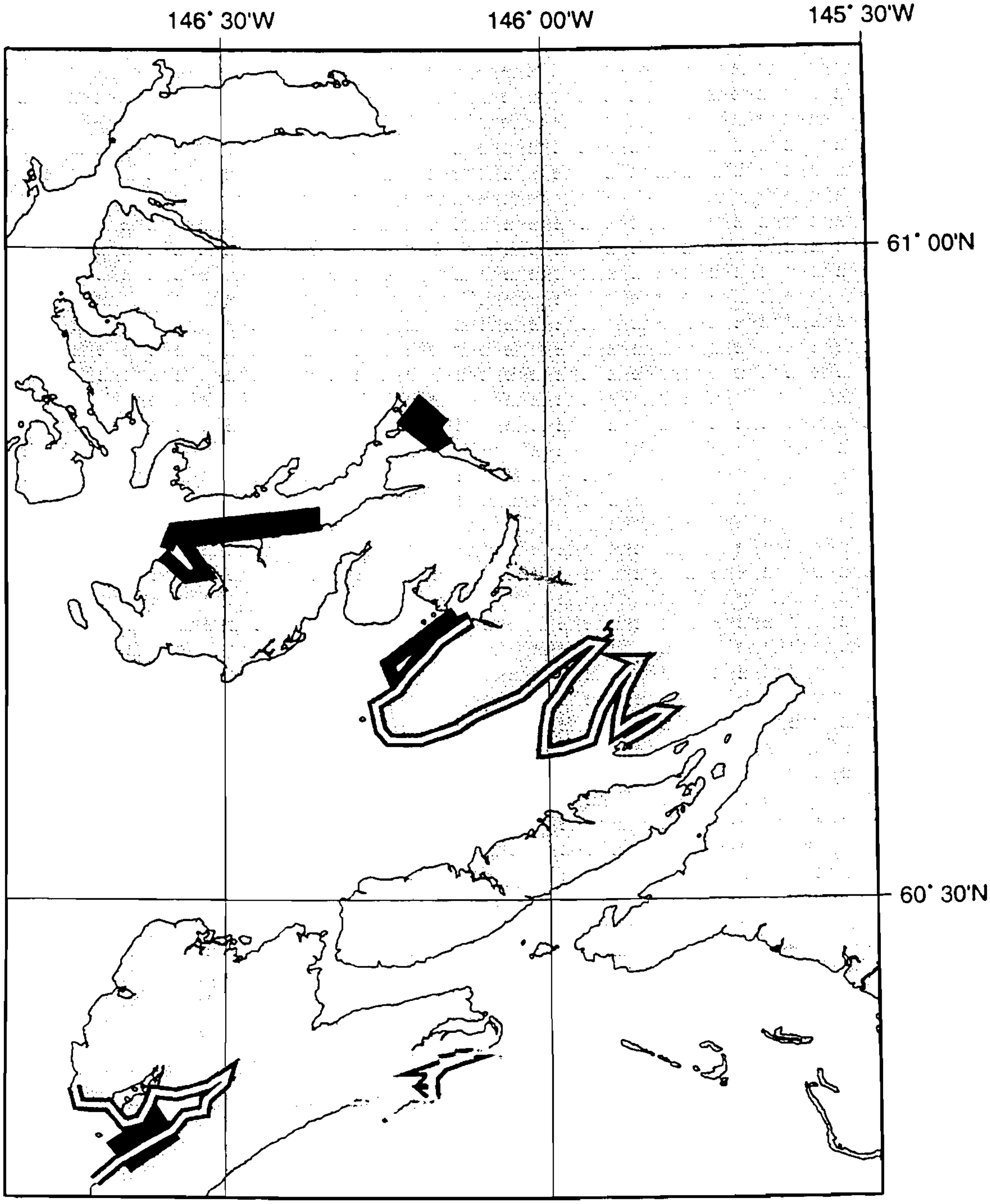


SMALL FISH, CAPELIN, & SANDLANCE DISTRIBUTION: SUMMER

● 1970s	● 1980s	○ 1990s
n = 2	n = 7	n = 7

Figure 5.

PRINCE WILLIAM SOUND

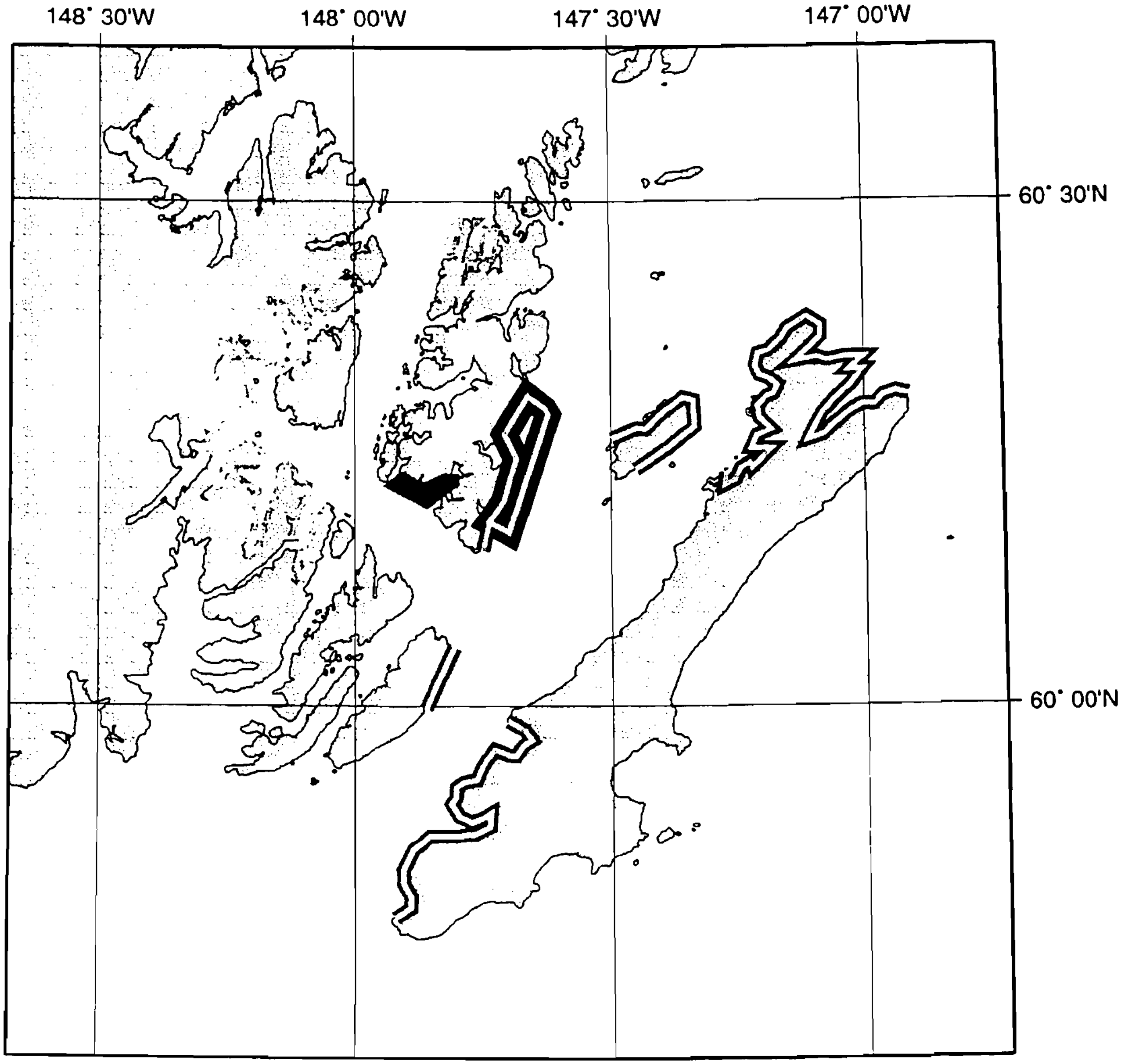


SMALL FISH, CAPELIN, & SANDLANCE DISTRIBUTION: SUMMER

● **1970s** ● **1980s** ○ **1990s**

Figure 5A.

PRINCE WILLIAM SOUND

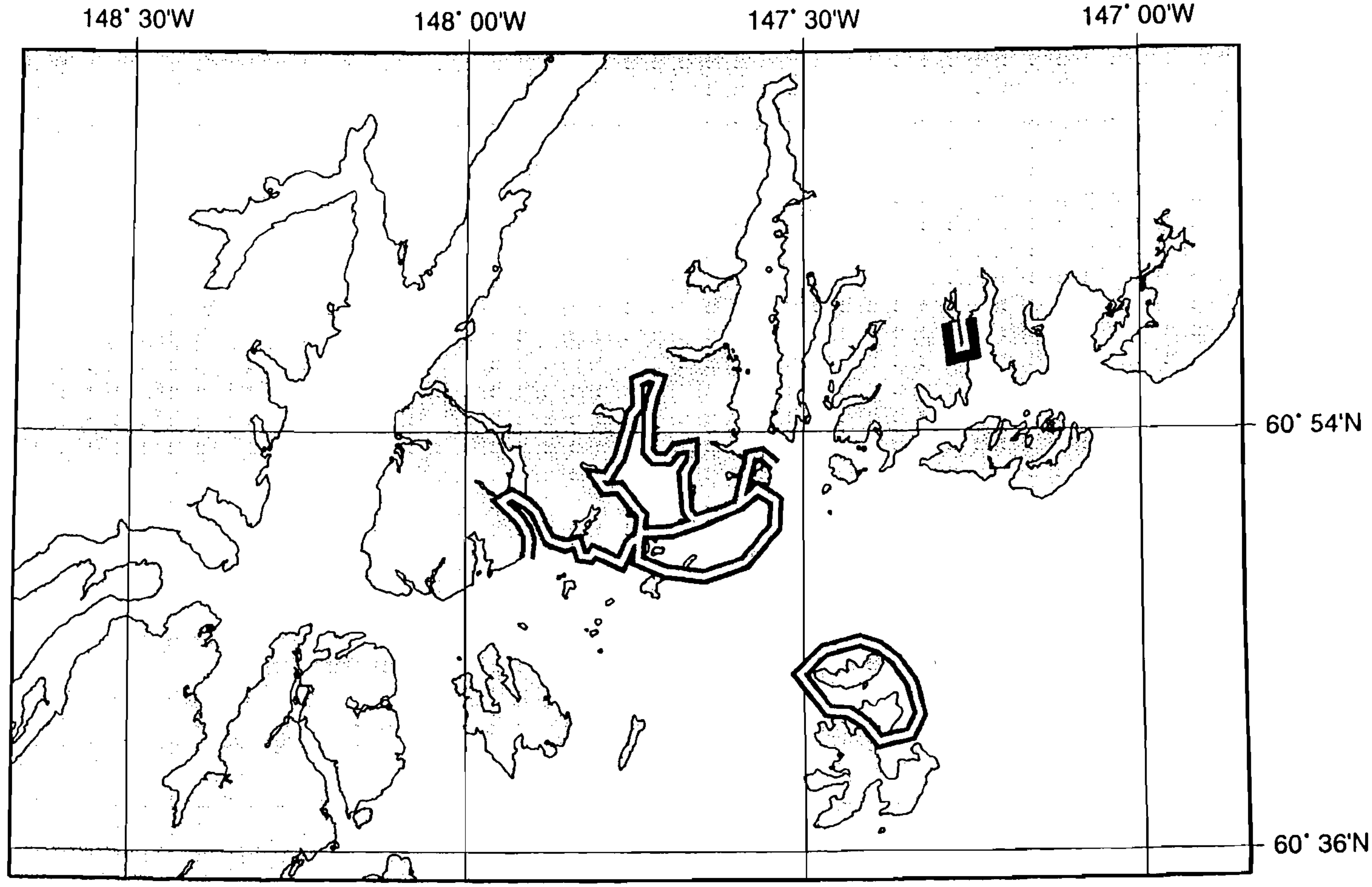


SMALL FISH, CAPELIN, & SANDLANCE DISTRIBUTION: SUMMER

● 1970s ● 1980s ○ 1990s

Figure 5B.

PRINCE WILLIAM SOUND



SMALL FISH, CAPELIN, & SANDLANCE DISTRIBUTION: SUMMER

● 1970s ● 1980s ● 1990s

Figure 5C.

Appendix A: Interview Guide

ID
DATE

BIRTHDATE
COMMUNITY

1. What year did you begin working in the Sound?
2. Please describe what your work was like:

3. Which fisheries were you involved in, in PWS?
    a) what time of year?
    b) Which years?

i)	salmon seine	______to _____	summer
ii)	salmon gillnet	______to _____	summer-fall
iii)	herring pound	______to_____	spring
iv)	herring seine	______to_____	spring
v)	herring gillnet	______to_____	spring
vi)	dive	______to_____	__________
vii)	handpick	______to_____	__________
ix)	shrimp pot	______to_____	__________
x)	bottomfish	______to_____	__________
xi)	bait herring	______to_____	__________

4. Were you ever a spotter for fisheries
    a). Which fisheries?
    b). Which years?
        i). Salmon seine _____ to______
        ii). Herring pound ______to______
        iii). Herring seine ______to______
        iv). Other______________________

5. How did the amount of time you spend in the Sound change since you began working here?

6. What activities take you out in the Sound now?

7. What months are you usually out in the Sound?

8. During those months, how frequently do you go out?

9. SHOW ON THE CHART THE GENERAL AREA OF THE SOUND YOU USE.
10. During what years were you out in the Sound the most?
    a. DRAW CIRCLES AROUND THE PLACES YOU USE MOST INTENSIVELY.
    b. Describe your activities there/ frequency duration

JUVENILE HERRING

11. Are there places you think are particularly important for juvenile herring?
    a) Which places?

    b) Why?

12. Where do you think juvenile herring (age 0-2, about 4 inches long) winter?

13. CIRCLE THE AREAS YOU'VE SEEN JUVENILE HERRING IN ORANGE.
    i) What years did you see them there?
    ii) What season/time of year did you see them?
    iii) Did you identify them? How?

iv) Describe where you saw them – nearshore/offshore, surface/deep,
v) Can you recall how much you observed?

14. How often did you see juveniles there: For each observation, mark frequency on the chart or table.

C – CONSISTENTLY – "I'd see them almost everyt ime I went there this time of year."
O – OCCASIONALLY – " I'd see them once in a while this time of year."
R – RARELY – "I remember them showing up there once or twice."

15. Do you remember seeing concentrations of animals feeding on the herring?

16. Tell me about the changes you've seen in abundance of herring in the Sound.

ADULT HERRING - RED
17. Where have you seen schools of adult herring in spring and fall aside from Northern Montague Island, Port Gravina, Port Fidalgo, Tatitlek Narrows, and Green Island?
18. How did you know they were herring?

19. How often have you seen them there?
20. At each place describe where you saw them - nearshore/offshore, surface/deep.

21. What other animals do/did you see with them?
22. Where do you find adult herring in winter?

23. Has the distribution of adult herring changed over the years you've been working in the Sound? Tell me about the changes you've noticed.

24. Did you fish for herring for home use or gather spawn on kelp this year?
25. Did you notice any signs of disease?

26. Had you ever seen disease in herring before 1993?

OTHER FORAGE FISHES - GREEN
27. Did you ever see or catch other forage fish such as sandlance or capelin while out in the Sound?
   a) Describe what you saw or caught.
   b) Could you identify them? How?
   c) When - year, season?
   d) Where – place, surface, deep
28. Have you seen them there before?

29. How frequently?
30. Have you noticed a change in abundance of these fish?

31. What other animals do you remember commonly associated with these schools of fish?
POLLOCK
32. Describe any changes you've noticed in pollock abundance and distribution since you began fishing/working in the Sound.
33. Where, what time of year, which years?
34. How often have you seen them there?
35. How does weather or ocean state on pollock abundance.
36. Did fish ever disappear completely from an area that you fished /hunted/used?
   a). why do you think they disappeared?