Chapter 11.

Juvenile Herring Growth and Habitats (96320T)

Exxon Valdez Oil Spill
Restoration Project Annual Report

Juvenile Herring Growth and Habitats

Restoration Project 95320T
Annual Report

Kevin D.E. Stokesbury
Evelyn D. Brown
Robert J. Foy
Brenda L. Norcross

Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, Alaska
99775-7220

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STUDY HISTORY: Restoration Project 95320T was initiated as the core project of the Herring Recruitment Dynamics Project, a multi-investigator ecosystems 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*). It is linked to the Herring Recruitment subgroup of SEA and provides data for the three objectives (1. Overwintering Survival model, 2. Summer Habitat Model, 3. Monitoring Strategy). In 1996 we completed 2 acoustic and 4 aerial broadscale surveys; 4 diel summer surveys, sampling Eaglek, Whale, Ziakof, and Simpson Bays; and 4 winter surveys sampling Whale, Ziakof and Simpson Bays. Aerial survey techniques appear to provide an accurate means of estimating juvenile herring densities and distributions. Preliminary results suggest that adult and juvenile herring distributions differ. Adult herring were found in large schools in Zaikof Bay in March and in the Latouche Passage area in July. Juvenile herring recruited into the bays throughout the Sound (fork length 15 to 74 mm). Each bay supported juvenile herring from August throughout the fall. These bays appear to be nursery areas for juvenile herring until they near maturity (age $1^1/2$ to 2). Further, it appears that juvenile herring grow faster in some bays than in others. The relative importance of prey appears to vary spatially and seasonally.

KEY WORDS: *Clupea pallasi*, Pacific herring, juvenile, habitat, Prince William Sound, distribution

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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 submodels, each of which focuses on a stage in the early life history of Pacific herring (*Clupea pallasi*). We hypothesize that, like other clupeids, 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 involved 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 key focus of the effort 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, throughout the winter and again in the 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 the likelihood of 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 initial 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 reflects that 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. We anticipate that coordination with these groups will increase during FY98 for the purpose of planning the monitoring of key species (i.e. herring) in the ecosystem that directly or indirectly impact oil-spill injured species (fish, birds, mammals) and resources (commercial and subsistence fisheries).

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. This information will be collected for the 1995, 1996, and 1997 year classes.
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. In the laboratory determine the energy need of fasting herring.
5. Using field and laboratory measurements of over-winter energy needs, and literature values for Atlantic herring develop a model to predict winter survivorship.

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 biolgocial 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 which 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, 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 hypotheses, 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 (Brown et al. in prep), and 4) estimates of baseline levels of viable hatch (Hose et al. in press; Kocan et al. in press). 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 (Figure 2).

The output of that subcomponent is the input into the Larval Drift Model (Figure 1). We will initially 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; McGurk and Brown 1996). We will also use spawning location information from 1995, 1996 and 1997 and correlated with the distribution of larvae to 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 August 1997 acoustic and aerial surveys were conducted and these data will be processed, analyzed, interpreted and combined in 1998 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; Figure 3). Sampling from the air provided approximately weekly estimates of horizontal distribution of herring across the Sound.

The broad scale survey was conducted for 12 hours each day. Five vessels were used during the 10 day survey: an acoustic vessel (refer to the Acoustic chapter for details on equipment and processing), a trawler (1.52 x 2.13 Nor'Eastern Astoria trawl doors, head rope 21.34 m, foot rope 28.96 m, estimated 3 x 20. 0 m mouth, 10.16 cm mesh wings, 8.89 cm middle and a 32 mm cod end liner; 1000 µm Tucker trawl), a seiner (250 x 34 m and 20 m, 25 mm stretch mesh), a processing boat which also supported the inshore frye skiff, and an oceanographic vessel (CTD, ADCP Doppler). The acoustic vessel cruised at 8-9 knots along a zig-zag pattern <1 km from shore with observations continuously recorded from the ship's sonar. When a school of fish was encountered the acoustic vessel slowed to 5-6 knots and surveyed the school with the acoustic sonar equipment (as well as the observer's comments of the ships sonar). The seine, trawler or frye skiff (50 x 8 m, 3 mm stretch mesh) then sampled the fish school. Oceanographic data, zooplankton and icthyoplankton data were also collected at the mouth, middle and head of 13 Bays. The net collections were used to verify acoustic targets and life-history data. We speciated each catch and randomly sampled 1000 herring for length frequencies. From each area we collected 450 herring for Age-Weight-Length analysis, 15 herring for stomach content analysis, 100 herring for energetics. When a different species dominated the catch we randomly sampled 1000 and measured their fork length. We removed the stomachs of predator species and determined the presents or absents of herring, fish, or invertebrates. We also collected numerous samples for other researchers (Table 1).

We are now processing the acoustic data from these cruises. Jay Kirsch's group at the PWSSC collects the data in the field with us and performs the preliminary crunch, removing all the nonbiological signals, such as the bottom. This data is converted into kg/m^{-3} units per 40 x 1 cell, with the lat.'s and long.'s and transported to our laboratory at UAF. We examine the echograms and catch data and determine the species proportion and size modes. We convert the kg/m^{-3} to numbers of individual fish per species, per size mode for each cell. We remove all signals smaller than 1 juvenile herring per 100 m^3. This agrees with the echogram signal and follows a similar sorting pattern to (MacLennan and Simmonds 1991) and (Gunderson 1993). This gives us measurements for the larger schools when we used the biosonic acoustics, we then use this data to calibrate our ship board observations for the less dense areas. This will give us a series of measurements that we can use in parametric (acoustic) and non-paramentric (ship board observations) tests.

These broadscale surveys provided a preliminary estimate of oceanographic patterns and distribution of herring. However, the broadscale survey is a continuous transect along the coastline of Prince William Sound. There are 3 major limitations of this design:

1. It is not a random sample and estimates represent only the densities of fish within the transect strip and cannot be extrapolated to the surrounding area (Krebs 1989; Gunderson 1993). One approach is to randomize the cells and we are examining this

possibility, plus the problems of autocorrelation and extremely skewed distributions. Systematic acoustic surveys may be superior to a random survey designs, stratified random surveys are by far the best design as they address both biological sampling problems and ensure strong statistical power because they conform to the assumptions of most models (Sokal and Rohlf 1981; Krebs 1989; Simmonds and Fryer 1996).

2. It is a temporal point measurement, areas were only surveyed during a single point in time. Clupeid distributions are strongly effected on a short temporal scale by the tidal cycle and the diel (day/night) cycle (Scott and Scott 1988; Stokesbury and Dadswell 1989; Stokesbury and Dadswell 1991).

3. Oceanographic data collect during the broadscale are point measures, i.e. the salinity, temperature, current, when a particular school was sampled. If there is any delay between vessels these results will be confounded by changes in the tidal cycle and light intensity. It is impossible to determine the underlying patterns of distribution or responses to environmental factors with single point measurements (Green 1979).

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 (Begon and Mortimer 1982). Densities must be estimated precisely and accurately on both spatial and temporal scales. This design will provide all the parameters required for the ALEWIFE Fish Model (Cooney 1995 ; Chapter 7; Fig. 19). In this factoral 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 4). 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 4). 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. Evaluation of these parameters will be used as estimates of the health of the population at each location.

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. 1997. On the development of a three-dimensional circulation model for Prince William Sound, Alaska. Continental Shelf Research. submitted Dec. 1996.

This model will be the bases 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 Cordova Fish and Game.

The first manuscripts from this work are:

Brown and Norcross 1997. Assessment of forage fish distribution and relative abundance using aerial surveys. Fisheries Research. draft. Appendix I

Foy, R. J., B. L. Norcross, A. Blanchard. 1997. Spatial and Temporal Differences in the Diet of Herring (Clupea pallasi) in Prince William Sound, Alaska. Appendix II

Summer Growth and Survival

We are testing 2 main hypotheses:

1. Bays in Prince William Sound are nursery areas for juvenile herring.

2. Biological and physical variables in these Bays determine the survival and growth of juvenile Pacific herring and dictate cohort strength.

Pacific herring (*Clupea pallasi*) usually begin to spawn in their third year when they have reached a size of about 185 mm and a weight of 95 g. 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 (Brown et al. 1996). The knowledge of herring distribution in PWS is largely dictated by the distribution of the fishing effort. Little is know about the location of the juveniles. Therefore our first task was to search the Sound for juvenile herring and determine where they metamorphose, spend their summers and overwinter.

We surveyed and collected 67 trawl and 59 seine collections from 7 to 31 March 1996. The 1995 year class are about 11 months old and have grown to a size between 60 and 120 mm (Figure 5). These fish just survived their first winter. The second mode are juvenile herring which have just survived their second winter. The third mode are mature adults that will spawn in April (Figure 5). It therefore appears that juvenile herring overwinter in these nearshore areas within the Bays (Figure 6). The majority of adults were congregated in a very large school within Ziakof Bay (24,200 - 29,100 metric tons of herring; J. Kirsch pers. comm. based on our March 96 survey) although a few smaller schools were sampled within the Sound.

In early May, after approximately three weeks at 8° C water temperature, the herring eggs hatch into larval herring. They are about 8 mm long and have a yolk sac which is absorbed within 6 days. They metamorphosis 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. During this time larval are transported away from the spawning areas, although studies in British Columbia have found significant densities remaining nearshore (Robinson 1988). Post-larval fish were collected with a box trawl designed to sample larval and juvenile fish, and with small shore seines on loan from APEX. The first size mode represents 3 month old herring, these herring just metamorphosed from larval to juveniles (Figure 7). We collected these juveniles in the nearshore bays of PWS (Figure 8). Each of the 4 bays we are focusing on had very high densities of post-larval herring. We are presently analyzing sample to determine if larval herring were present within these Bays in May and June or if they were transported in from other areas via currents. After spawning the adult herring resume feeding in the near shore area and then migrate out to their offshore feeding grounds. The juveniles appear to remain in these bays. We successfully collected them there in October 1996.

There is a great deal of debate over the relationship between herring and pollock populations in PWS. In March of the 59 seine collections only 3 were 100% pollock (2 Eaglek, 1 Aialek Bay) and these species rarely mixed (4 sets: 3 in Eaglek, 1 in Sawmill). The trawl data indicates that the passages were the primary location where both herring and pollock were collected but generally there was little spatial overlap between these species (12 areas >80% herring, 8 areas > 80% pollock; 4 with 50/50).

The density data is the driving force of the life table from which juvenile survival will be estimated. Site fidelity is a key assumption if survival is going to be estimated for each Bay (for Prince William Sound this estimate will be derived with 3 degrees of freedom). To examine site fidelity we will examine growth and spatial distribution of juvenile herring in each bay. Movement is a problem as we will not know if density shifts in a bay are caused by mortality or emigration. However, we will assume that these fish do not leave Prince William Sound and therefore these four bays are representative of PWS herring population densities. The preliminary data suggests that there may be site fidelity of the 0-1 herring and possibly until sexual maturity in these bays.

By following the temporal shifts in density and age structure we intend to estimate life tables for 3 cohorts of juvenile herring, 1995, 1996 and 1997. This work will complement ADF&G's present research as they use life tables to determine adult stocks, thus our information is readily available and interpretable for their managers.

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*) relative to age, size and sex. Journal of Experimental Biology and Ecology. submitted.

Paul, A.J., J.M. Paul, and E.D. Brown. 1997. Ovarian energy content of Pacific herring from Prince William Sound, Alaska. Alaska Fishery Research Bulletin. submitted

Kline, T.C.Jr., and A.J. Paul. Isotopic signature and somatic energy content of young of the year Pacific herring at two sites in Prince William Sound Alaska: implications for tropic studies. Canadian Journal of Fisheries and Aquatic Sciences. submitted.

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

The difficulty of sampling during the winter months in Prince William Sound hampered our time-sequence collections of juvenile herring from the four bays. We were able to collect herring and oceanographic data during November, December and February from Simpson Bay as well as several collections in Zaikof and Whale during these months. In 1998, the

1996-97 data will be analyzed, an additional Oct.-March sample will be collected, and this model will be linked to the Ocean Dynamics Model to determine the effect of the timing of the phytoplankton bloom on successful herring recruitment.

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

1. Ken Bouwens, UAF; arrowtooth flounder, all sizes.
2. Kathy Frost, ADF&G Fairbanks, AK.; Marine Mammal Ecosystem. Needed various size fish of any species.
3. Jeff Short, Auke Bay, Juneau AK.; Needed herring and pollock.
4. Molly Sturdavent, Auke Bay, Juneau AK.; Needed capelin, sandlance, eulachon and pollock.
5. Tom Kline, PWSSC, Cordova AK.; Isotopes
6. John Piatt, NBS, Anchorage AK.; Needed juvenile herring and pollock
7. A.J. Paul, Seward Marine Center, Energetics, herring and pollock.
8. James Raymond, Univ. of Nevada; Needed blood and liver samples from herring in the Gravina or Montague area.
9. Steve Moffitt, ADF&G Cordova. Herring AWL.
10. Richard Kocan, UW; Disease; 60 juvenile herring from 5 sites, would like heart, liver and spleen removed, put in tubes, and kept cool.
11. Gary Marty, UC-Davis; Disease; Looking at herring from the Montague Is. area

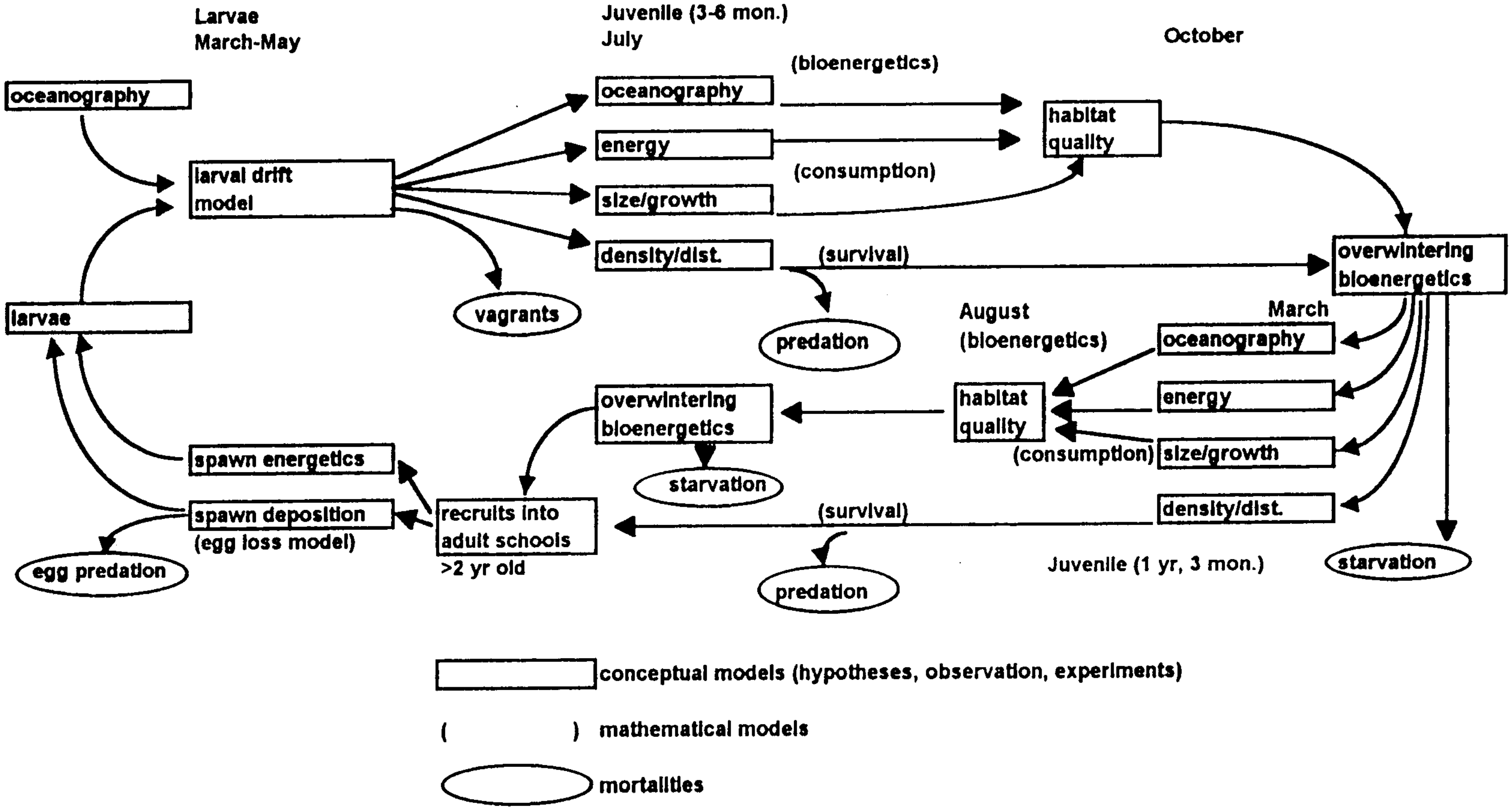
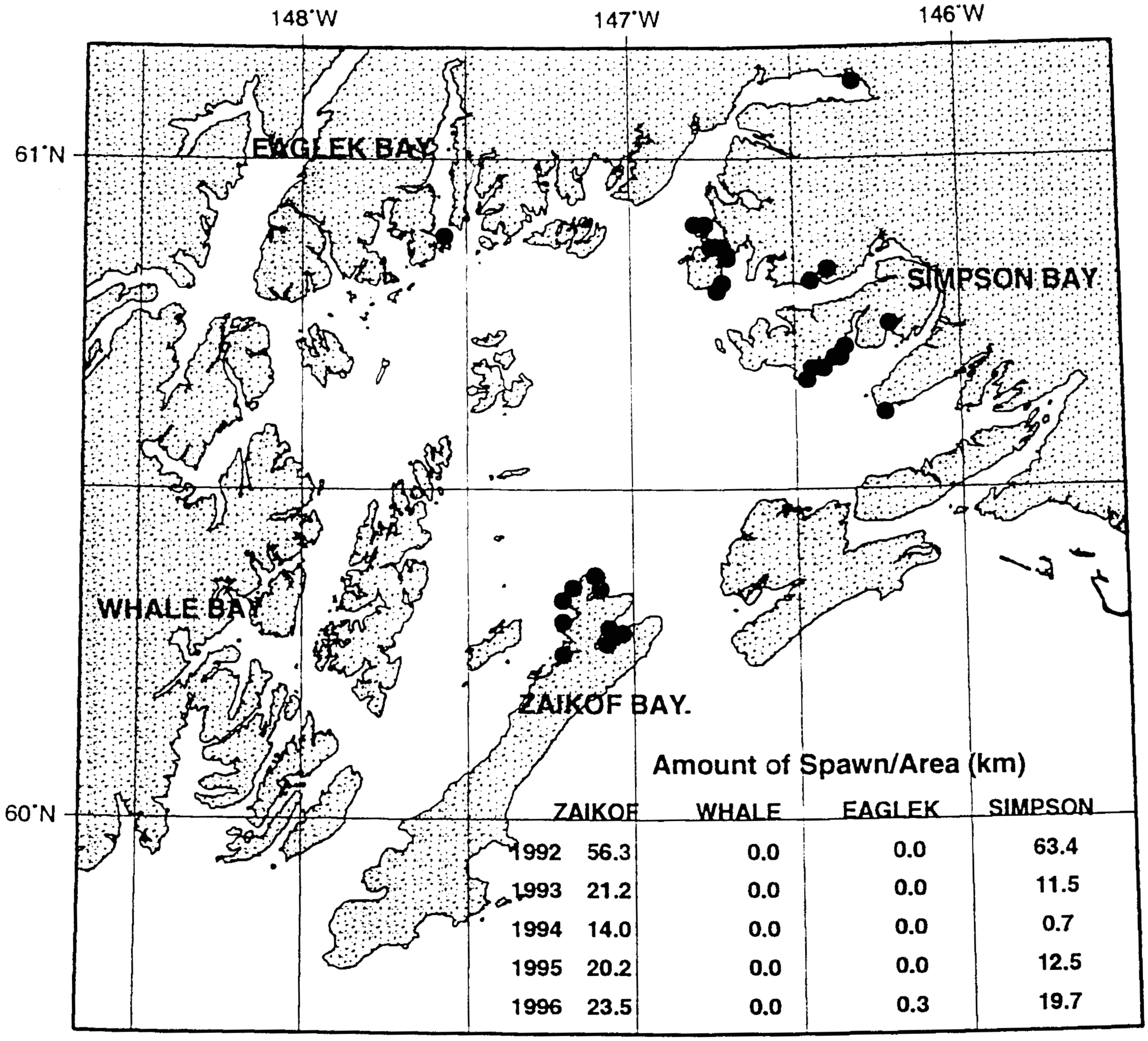


Figure 1. Herring Recruitment Model



Amount of Spawn/Area (km)

	ZAIKOF	WHALE	EAGLEK	SIMPSON
1992	56.3	0.0	0.0	63.4
1993	21.2	0.0	0.0	11.5
1994	14.0	0.0	0.0	0.7
1995	20.2	0.0	0.0	12.5
1996	23.5	0.0	0.3	19.7

Figure 2. Pacific herring spawning locations from 1990-1996. These data are summarized from reports produced by Alaska Fish & Game, Cordova. The dots represent the areas where spawning was observed and the distance of coast line is indicated in the table.

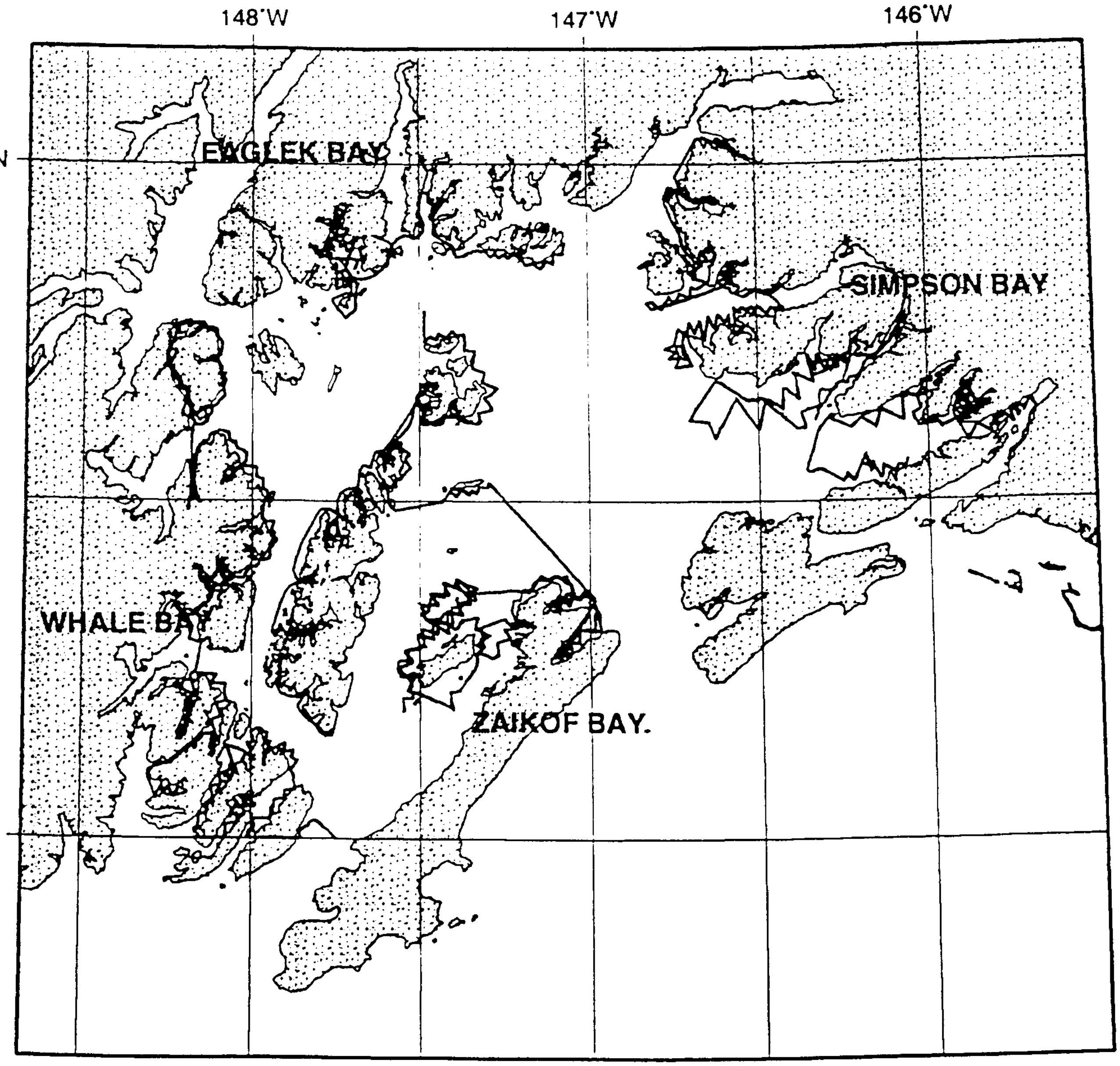


Fig 3. March 1996 survey area in Prince William Sound.

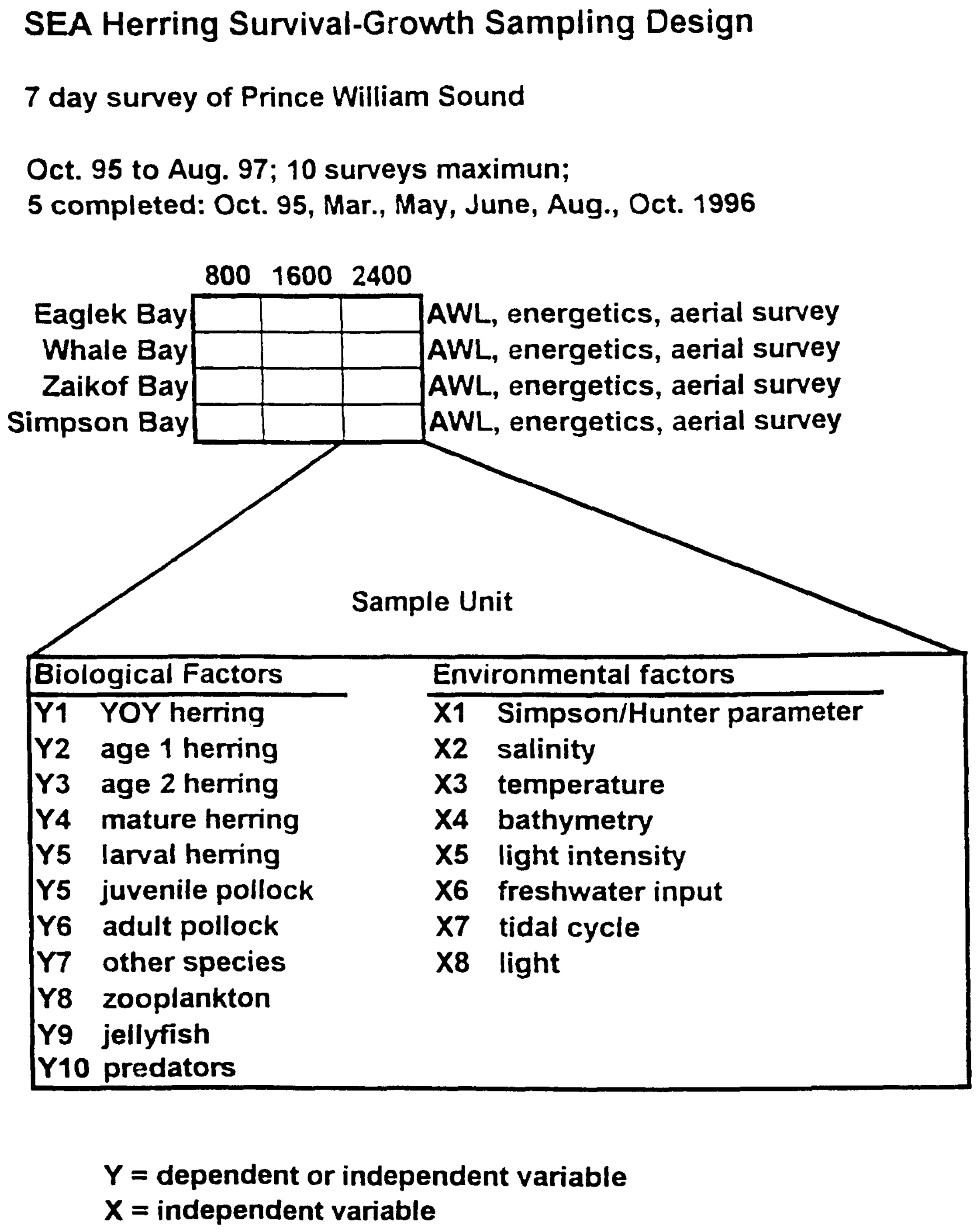


Figure 4. 4-bay diel sampling design.

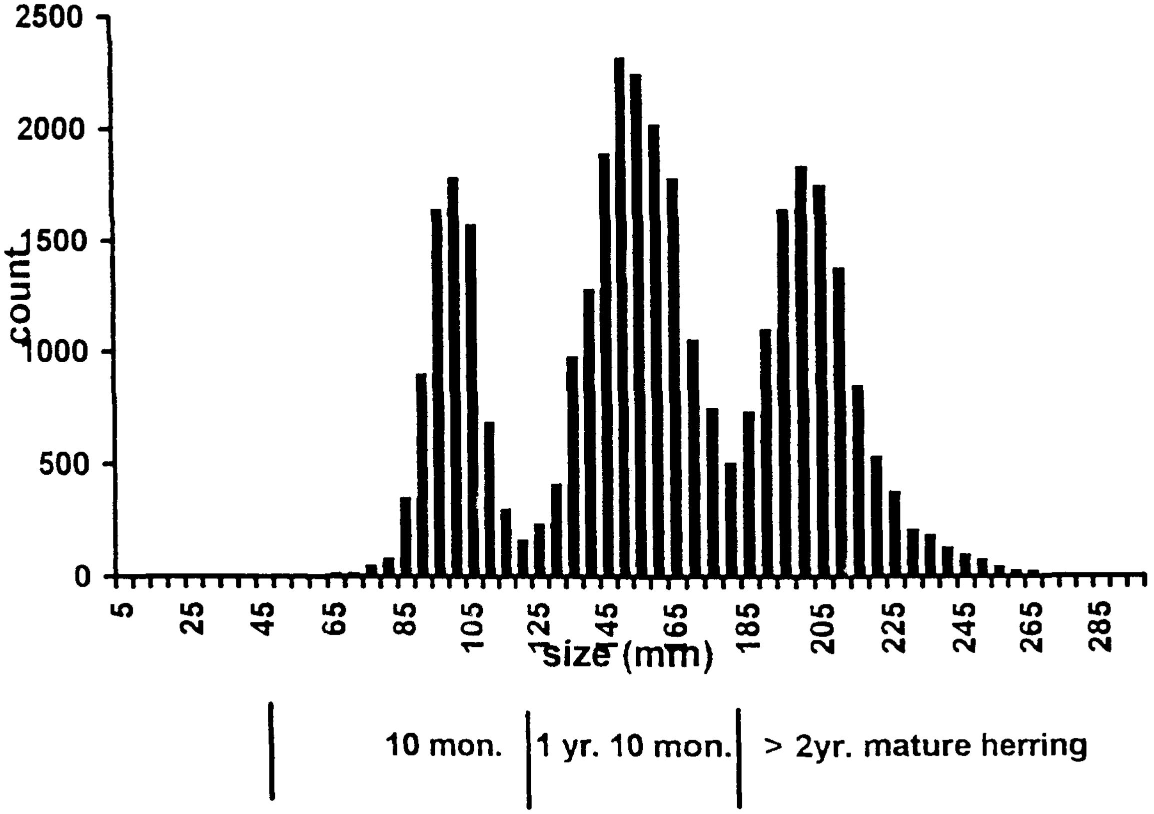


Figure 5. Size ranges of herring collected during March 1996 cruise.

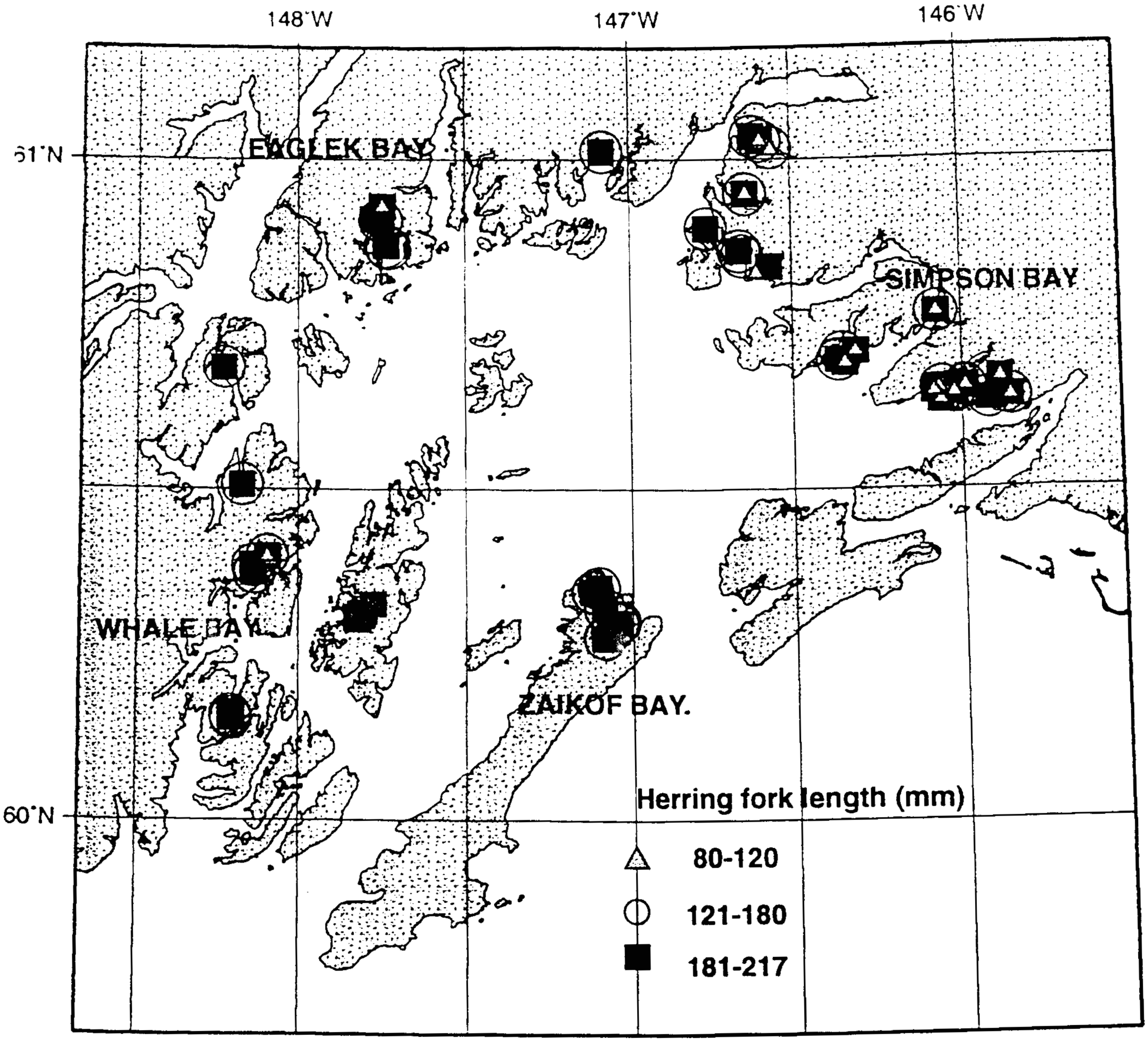


Figure 6. Spatial distribution of Pacific herring in Prince William Sound March 1996; present/absent data, i.e. if a size mode represented 10% of the catch it is marked.

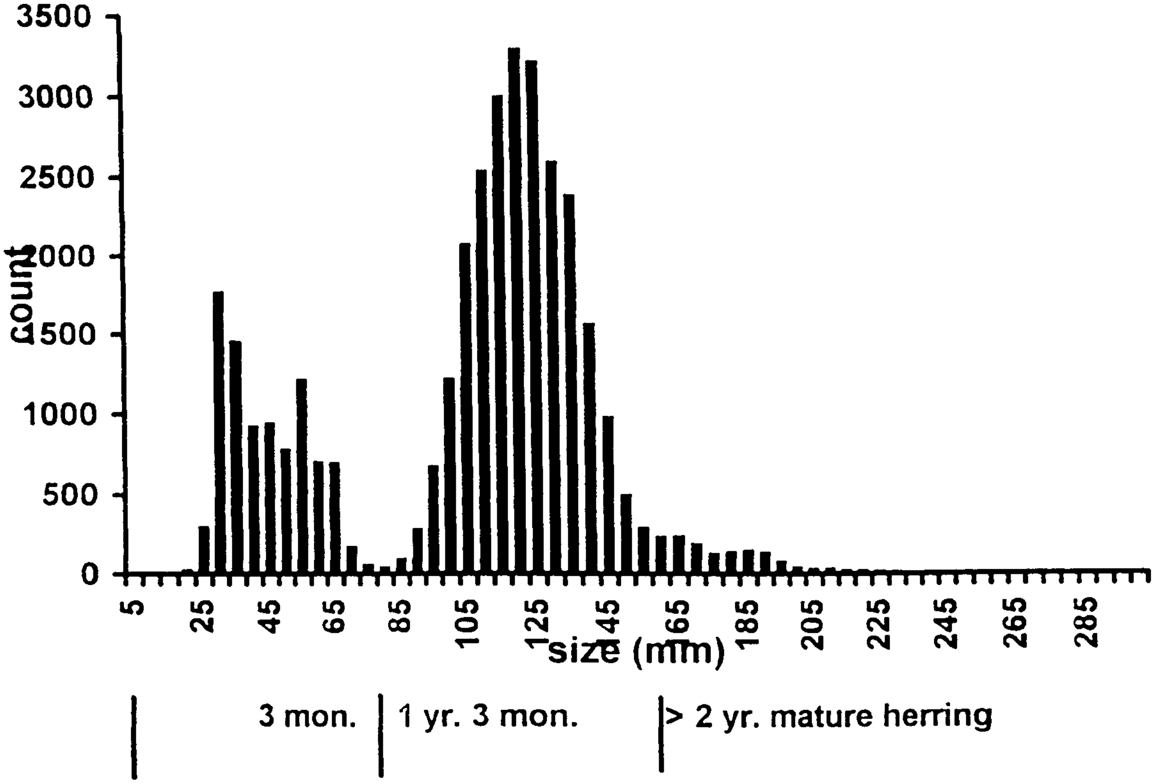


Figure 7. Size ranges of herring collected during July-August 1996 cruise.

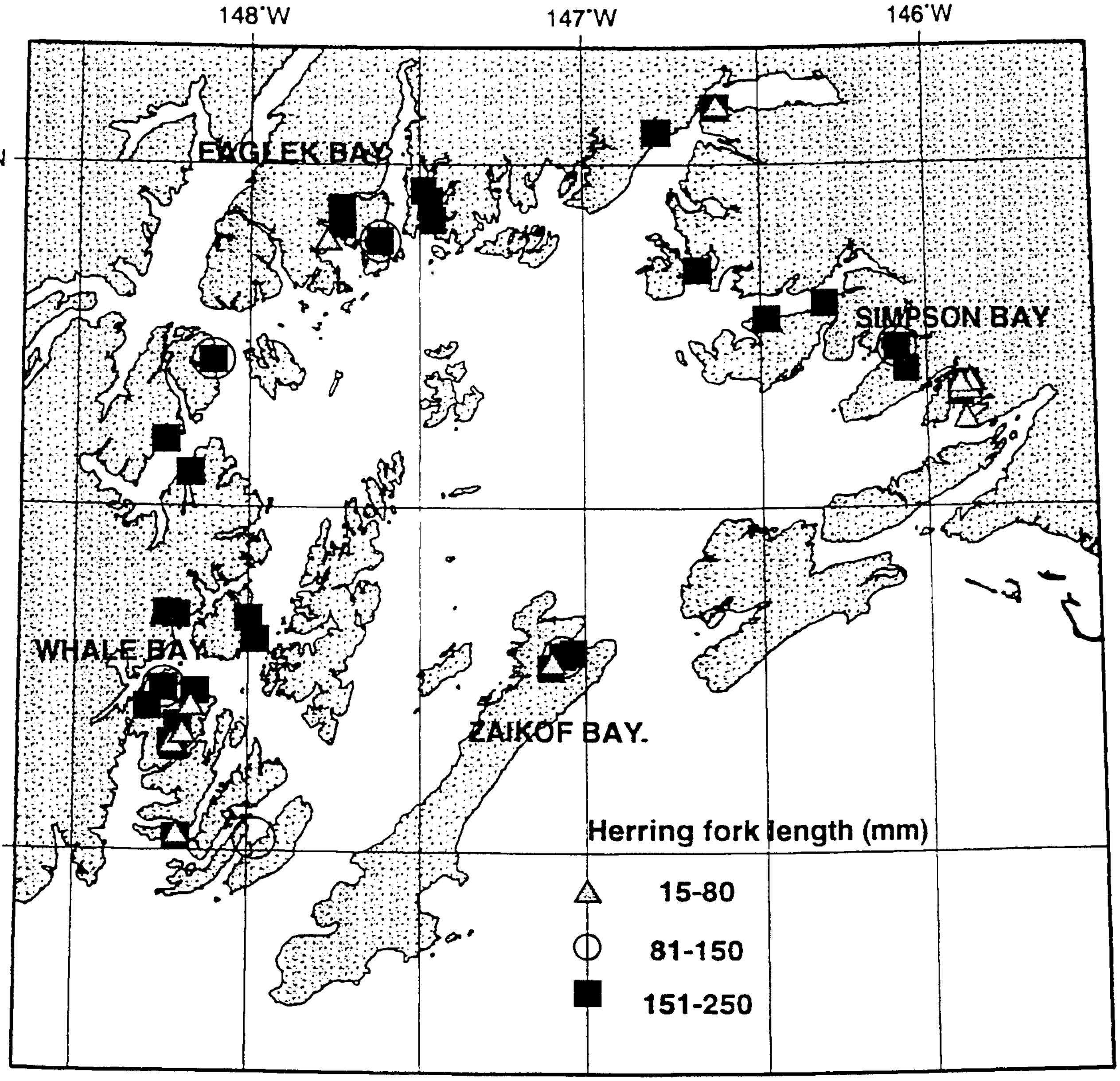


Figure 8. Spatial distribution of juvenile herring in Prince William Sound July-August 1996; present/absent data, i.e. if a size mode represented 10% of catch it is marked.

Apendix I

Evelyn D. Brown and Brenda L. Norcross. 1997. Assessment of Forage Fish Distribution and Abundance Using Aerial Surveys: Survey Design and Methodology. Draft for Fisheries Research

Assessment of Forage Fish Distribution and Abundance Using Aerial Surveys: Survey Design and Methodology

Fisheries Research

Evelyn D. Brown and Brenda L. Norcross
University of Alaska Fairbanks, School of Fisheries and Ocean Science, Institute of Marine Science
P.O. Box 757220, Fairbanks, Alaska 99775-7220, U.S.A.

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Abstract

Broadscale aerial surveys were conducted in Prince William Sound and Outer Kenai, Alaska in 1995 and 1996 to provide information about distribution and relative abundance of juvenile Pacific herring and other forage fish including Pacific sandlance. Flight paths and sightings along shoreline transects were recorded using a laptop computer with automatic logging from a GPS. Survey condition bias was reduced by establishing weather and tidal stage criteria for flights. Each species of fish has a characteristic shape, color and sometimes behavior. Photographic documentation of the different schools is used for measuring differentiation ability and correcting observations. Sightings are compared to diver and net catch observations to provide validation of aerial identification. A PVC tube with a mylar grid held at a specific angle was used to measure the surface area of schools. The frequency distribution of schools sizes was used to establish a preferred altitude and a visual swath within which detection was uniform. The measurements were corrected for altitude and used to calculate fish density. A narrow-strip line transect best describes the survey design. Abundance estimates are a function of visual swath, surveyor bias, spatial distribution pattern (probability of detection) and school density along the transect line. Accuracy is established using results of double counts. Precision is established by calculating detection probabilities based spatial patchiness and by comparing density estimates to independent counts from acoustics or other remote sensing devices. An example of aerial survey data, including temporal and spatial trends in fish abundance and bird foraging activity, is described.

Introduction

Little was known about the distribution and relative abundance of juvenile Pacific herring, *Clupea pallasi*, and other forage fish in Prince William Sound (PWS), Alaska prior to the *Exxon Valdez* oil spill in 1989. Herring, sardines, anchovy, capelin, and sandlance are known to school in tight aggregations with distinctive shapes and are often found in oceanic surface waters (Mais 1974; Squire 1978; Fresh 1979; Blaxter and Hunter 1982; Hara 1985a; Misund 1993; Carscadden et al. 1994). Many pelagic fish are arranged in shoal or school groups (Cram and Hampton 1976; Smith 1978; Fiedler 1978). Distribution of herring and capelin is thought to be contiguous with known areas of seasonal aggregations unique to a particular population (Templeman 1948; Campbell and Winter 1973; Sinclair 1988; Stocker 1993).

In Prince William Sound (PWS), locations of herring (mainly adults) in the summer are known from historic fishing sites (Rounsefell and Dahlgren 1931) and archaeological records of native middens (DeLaguna 1938). Locations of spring adult spawning aggregations have been recorded since 1973 by the Alaska Department of Fish and Game (ADFG) (Brady 1987; Biggs et al., 1992). Anecdotal information from biologists and fishermen indicates that groups of small herring schools are visible from the air "all over the sound" during the summer (unpublished data, E. Brown and J. Seitz, University of Alaska, Fairbanks; Dan Sharp, personal communication, ADFG, Cordova). These historic records indicate that: 1) the summer distribution of adult herring is much broader than in the spring, 2) summer catches often included juvenile herring (age 2 or less) while spring catches at spawning sites did not, 3) juvenile herring are broadly distributed in PWS, and 3) there are large fluctuations in relative abundance of herring over a several year period reflecting variability in year class strength. If the scale of distribution and numbers of juvenile herring schools varies (probably in relation to year class strength), increased knowledge would alert us as to the availability of herring as forage food and to the health of the fishery in the future.

Information about distribution is needed in order to design effective surveys to assess populations. If the exact location of fish aggregations are not known and the distribution is highly contiguous, the number or size of sampling units or transects needed to assess distribution can be large (Fiedler 1978; Lo and Hunter, in prep). Ship surveys used to resolve distribution questions can be costly because they are slow, sonar beams (used to assess schools acoustically) are narrow and cover a small swath of water, and have limited access to many nearshore areas where fish may aggregate. Conversely, surveys from aircraft are relatively cost-effective because they are fast, the sampling swath in measured in hundreds of meters instead of meters, and they are not limited by shallow water. In addition, aerial surveys can cover a region over a shorter period of time enabling researchers to compare distributions from two separate regions in a single temporal period.

Fishermen have used aircraft to locate schooling fishes for many years (Lo et al. 1992; Hunter and Churnside 1995). The Alaskan herring fisheries have long depended on aircraft for stock assessment and to guide fishing vessels (Brady 1987; Funk et al. 1995). Canadian researchers in British Columbia have observed juvenile herring schools from the air during the summer and have initiated a summer juvenile herring survey to provide indices of future recruitment (Jake Schweigert, Department of Fisheries and Oceans, Nainaimo, British Columbia, Canada, personal communication).

Aerial surveys typically lack precision and are not sufficiently accurate to provide a stand alone estimate of stock biomass (Krebs 1989; Gunderson 1993; Hunter and Churnside, 1995). Variability due to sighting conditions, changes in vertical distribution of fish schools, and surveyor bias largely go unmeasured (Hunter and Churnside, 1995). In recent years, access to military technology has lead to an increased use of sophisticated light sensing and radar equipment for aerial fish school assessment that can eliminate some of the variability and bias and improve accuracy of aerial surveys (Hunter and Churnside 1995). However, this equipment is still relatively expensive to use.

This study measured and recorded sighting conditions, surveyor bias and variability due to changes in vertical distribution by: 1) correlating aerial survey with acoustic survey results (which provide an independent measure of fish density; Cram and Hampton 1976) and 2) using spectrographic imagers, which record without bias (Borstad et al. 1992; Funk et al. 1995), simultaneously with aerial techniques. The purpose of this paper is to demonstrate that aerial surveys can be designed and conducted to effectively and efficiently assess the distribution and relative abundance of near-surface schooling fishes. A secondary objective is to integrate the results of this survey with sea bird and marine mammal sightings since lack of forage fish has been cited as possible cause for recently observed population declines in Alaska (Merrick et al. 1987; Pitcher 1990; Loughlin et al. 1992; Hatch and Piatt 1994; Piatt and Naslund 1995)

School Shapes, Recognition, and Measurement

Different fish species have characteristic shapes and sometimes color. Herring have been described as round (Misund 1993; Figure 1) and often brown in color (Brad Hiel, Alaskan Fish Spotters Assoc., Homer, Alaska, personal communication). Capelin are often described as gray with dynamic crescent or U-shaped shaped schools (Carscadden et al. 1994). Anchovy schools are crescent or irregularly shaped (Squire 1978; Hara 1985a) and become more elongated at night (Hara 1985b). Schools of juvenile sandlance occur nearshore in dense, but not opaque, irregularly shaped schools (Martin Robards, U.S. Fish and Wildlife, N.B.S., Anchorage Alaska, personal communication; Figure 2). Jellyfish, especially moon jellies (*Aequorea sp.*), are easy to identify from the air because they are white, they form large irregularly shaped aggregations, and they remain stationary when the airplane lands for visual inspection (Figure 3). In this study, school shapes were described as round (Figure 1; generally herring), oblong (Figure 2), crescent or U-shaped (generally capelin; Carscadden et al. 1994), irregular, or streaks (Figure 3; generally jellyfish).

Fish schools were counted and surface area was estimating using a sighting tube. The sighting tube was constructed of PVC pipe with a grid drawn on mylar on the end (Figure 4). The focal length of the tube was 216 mm and can be calibrated for ground distance covered by reference line (X) for any survey altitude, when length of the grid reference line (L), focal length of the tube (F), and survey altitude (A) are known, by using the equation:

$X = A\,({}^{L}/_{F})$ (Lebida and Whitmore 1985; Brady 1987). (1)

At an altitude of 305 m (1000 ft) the following categorical school sizes were related to a specific length or tick-mark on the mylar grid and correspond to the listed school diameter using equation 1:

dab	0.05-0.15 ticks or 0.7-2.1 mm on the tube represents a 1-3.0 m school diameter on the ground
small	0.20-0.30 ticks or 2.8-4.1 mm represents a 4.0 - 5.8 m school diameter
medium	0.40-0.70 ticks or 5.5-9.7 mm represents a 7.8 - 13.7 m school diameter
large	0.75 ticks or 10.4 mm and larger represents a school 14.7 m school diameter or larger (Figure 4).

The use of the grid was particularly important for large schools. For elliptical shaped schools, maximum length and maximum width provided a rough estimate of surface area; for irregularly shaped schools (U-shaped, long wavy bands, etc.) length and width of separate sections were measured and combined to give a total estimate. In 1995, the surface area of schools was estimated by categorizing school size and checking occasionally with the tube for eyesight calibration. In 1996, the surface area of every school was directly measured with the tube. Video or still cameras were taken as often as possible to provide validation of school recognition when matched with catches and for measurement of recognition error (explained below).

Field Data Collection

Broad scale aerial surveys covered PWS and Outer Kenai from Hinchinbrook Entrance to Nuka Point (Figure 5). A survey of the entire area required 6 days and consisted of 3-6 hrs each day flying a Cessna 185 float plane at approximately 110 knots. An area approximately 1/5 the size of PWS (about 3,400 km^2) was denoted at the beginning of each survey day and the pilot followed the shoreline within this area to the best of his ability. Areas inaccessible due to topography or weather were not sampled. The transect or shoreline was followed in a single line but double backs were allowed when school or recorded feature density was high to ensure total counts within a given swath area. Since the flight path was recorded, the increase in sampling frequency of areas with high feature densities was measured to ensure that proper statistical weighting was given.

Preferred Altitude

The preferred altitude range was established at 275 - 365 m (900-1200 ft) based on school size. Juvenile herring schools (modal frequency 3-50 m^2; Figure 6) were much smaller than spawning aggregations (modal frequency 100 - 300 m^2 measured in Bristol Bay; Funk et al. 1995). Therefore the preferred altitude for herring (Lebida and Whitmore, 1985) or capelin (Carscadden et al. 1994) spawner surveys (457 m or 1500 ft) was too high to distinguish 1 m^2 schools. An altitude of 305 m (1000 ft) provided a swath width of 762 m (Figure 7) but allowed distinction of an object as small as the smallest school observed as well as a single gull or sea otter. At times lower altitudes were flown due to a low cloud ceiling, but each altitude change was noted on the computer during the survey.

Visual Swath

The visual swath, dependent on altitude, was established in 1995. By flying repeatedly over a familiar landscape (an airport runway with numbers and letters) at each possible altitude, the transect or swath width was established perpendicular to the airplane. The swath width included the area within which we could accurately observe features that were a similar size to schools or gulls we encountered during the survey (Figure 7) and that could be measured with the sighting tube held at a fixed angle of 30 degrees (Lebida and Whitmore, 1985). Ground reference points of known or easily measurable surface areas, such as a helipad, were used to train the eye to the scale on the sighting tube grid for any specific altitude flown prior to each survey series.

Preferred Season

Plots of monthly herring school counts and total school surface area recorded per survey day for PWS in 1995-96 are plotted in Figures 8 and 9. Although in both years, there was a sharp increase in the numbers of schools observed per survey from May until June, there was a decrease in total surface area of schools observed per survey in 1996. In 1996, observation of a number of large spawning schools in May was followed by a shift in school size with increased numbers of smaller schools showing up in June. Since surface area is exponentially related to school radius (πr^2) a few large schools will result in significantly more surface area than many small schools. By July, numbers of schools and school surface areas increased in 1995, but decreased in 1996. The downward trend in

August occurred in both years, but counts that month were only slightly less than in July. From these preliminary results, we determined that the preferred months to census juvenile herring was June and July in order to avoid including adult spawners in the data and to fly at a time when numbers of surface schools are at a maximum.

Preferred Tide Stage and Time of Day

We tried to account for or eliminate the effects of time of day or tide stage on the survey results by flying repeat surveys during the day or flying during the same tide stage whenever possible. Carscadden et al. (1994) preferred sunny days with the sun angle between 20° and 45° in order to reduce glare and lands shadows for aerial photography of capelin schools but did not mention tide as affecting survey results. Borstad (personal communication, G.A. Borstad Assoc., Sidney, British Columbia) preferred sunny days with the sun directly overhead for aerial imaging of schools. Although we did not target surveys for a particular time of day, we did target surveys for the slack low or flood tide stage (Lebida and Whitmore, 1985), noting in the log program whenever this was not possible. In order to explore the effects of tide or time of day, all sightings of herring schools within the months of June and July were categorized into three daylight and three tidal components: early (0600 to 1000), midday (1030-1430), early evening (1600-2000), flood tide, ebb tide and low tide (no surveys were done at slack high water). Survey results were standardized by sightings per survey (all surveys approximately equal in length). Although there were more schools and surface area of schools counted during midday and ebb tide periods, the means were not significantly different ($p>0.05$) from mean sightings taken other periods. Because of the high variability of the data, this analysis of means should be repeated using duplicate surveys of single bays or regions flown within a 48 hr period. Based on preliminary results, we concluded that our criteria for tide preference was appropriate for future surveys.

Data Collection

Both flight path (transect) and features along path were recorded during the survey. A hand held GPS connected to a lap top computer with a flight log program recorded latitude, longitude, and time of day in a 2 second interval. At the beginning of each flight, information detailing pilot, weather, water visibility, wind, wind direction, tide stage, wave height and other notes concerning the survey were recorded in the log program. Information or "sightings" such as numbers of fish schools, species of fish, surface area of schools, numbers of birds or mammals, behavior of birds, or oceanographic features (tidal fronts) were recorded on the computer log program. Net captures, acoustic surveys, diver surveys, validation via landing on top of schools, or observations recorded on film were also recorded on the log program. However, school validation was often a post-processing procedure since net catch, acoustic, or other data had to be matched after editing and since not all validation efforts were observed from the air. For each observation, the computer logging was interrupted, the sighting noted and the approximate location linked to the last latitude and longitude recorded. Single or double letter codes were developed for fish, bird and mammal species (such as h for herring, sd for sandlance, kw for kittiwakes, hs for harbor seals etc). Bird behavior was recorded as foraging or plunging (pl), resting on water (rw), resting on shore (rs), aggregated tightly on water over school (tw), traveling (tr) or flying in a "broad area search" (bs).

In order to minimize the effect of survey condition bias on accuracy of the results, we selected criteria for determining whether a survey should be flown or not. 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 300m, or on rainy days.

Survey Design and Data Analysis

Adaptive sampling methods using a modified line transect were adopted for this survey. The main data output is a measure of relative (rather than absolute) density of fish schools and other detectable events such as foraging gulls (Iron 1992). Using anecdotal information from fishermen and aerial surveyors, it was determined that most of our observations were likely to be nearshore. Although we sampled offshore to test this hypothesis, we choose to modify the standard line transect (Thompson 1992; Krebs 1989) by following a shore line as a transect path. We sampled offshore areas when crossing bays and bodies of water to reach other shorelines. We eliminated the problem of decreasing detectability with distance perpendicular to the transect center (Krebs 1989; Gunderson 1993) because we established an altitude dependent visual swath with uniform detectability (described in previous section). Therefore, we assumed that detectability was a function of survey conditions (water visibility, precipitation, surface water disturbances or wind-driven waves), glare, spatial distribution of schools and school aggregates, and surveyor bias. This method is equivalent to the "narrow-strip" method suggested by Thompson (1992). Only features observed within the visual swath were recorded. It is therefore likely that density or abundance estimates derived from this survey are a function of: 1) effective area surveyed (altitude), 2) detectability, and 3) density of the detection's along the transect line (Thompson 1992). Surveyor bias is related to density because counting error increases with counting rate (especially in situations where there are a lot of schools; Gunderson 1993). In this situation, most surveyors tend to undercount (Krebs 1989). It is for this reason that a measure of survey bias is critical.

Estimating Density

Using narrow-strip transect methodology we can ignore the probability of sightings with distance estimates. The narrow-strip is the visual swath. Density is estimated using the following equation (Thompson 1992):

$$\hat{D} = \frac{y_0}{2w_0L} \qquad (2)$$

where y_0 is the number of fish or total surface area of fish schools spotted along the transect length L, w_0 is the maximum distance from the center line to which delectability is uniform ($2w_0$ is equivalent to swath width), and $\hat{D}$ is the estimate of fish schools or school surface area along that transect section. Within a study region with an area A, the total number of fish schools or school surface area ($\hat{\tau}$) is estimated as:

$$\hat{\tau} = A\hat{D} = \frac{Ay_0}{2w_0L} \qquad (3)$$

Because transects were not selected randomly, we do not attempt to expand the density estimates to areas not surveyed. Since all schools recorded were inside the visual swath, no observations are left out of the analysis. This removes the disadvantage of using narrow-strip methodology since generally observations are left out of the analysis (Thompson 1992). It would be difficult to use other methods of expansion of the data since estimates of distance off transect line were not estimated in this survey.

Estimating Accuracy and Precision

In order to use the survey as an index of abundance, the accuracy and precision of the survey results had to be established. In order to establish precision which is most affected by surveyor bias, synoptic independent or double counts were completed (Seber 1982; Rivest et al. 1995). By comparing recults from two individual surveyors to one another, a level of error or bias can be estimated and used to account for vaiability is survey results. Rivest et al. (1995) found that aerial surveyor visibility bias measured using double counts was relatively small (10-13% of total). Simultaneous double counts eliminates the confounding bias from variable survey conditions, generally encountered when estimating individual surveyor bias, since both surveyors experience the same survey conditions during each count. In order to measure individual ability to recognize schools, several surveyors are shown up to 100 randomly sorted photographs of pre-identified fish schools and scored on their accuracy in identification . This identification error along with surveyor bias is incorporated in the estimates of fish school density. Higgins (1990) found that bias from aerial surveyors is best represented by a linear correction model with a multiplicative error term. With only four repeat surveys conducted with independent counts, the results of the double counts and estimates of surveyor bias are not included in this report.

Estimation of accuracy of this technique is critical in order to apply it as an abundance estimator. Since herring are generally clustered in discrete aggregations or school groups (Templeman 1948; Cram and Hampton 1976; Blaxter and Hunter 1982; Sinclair 1988; Stocker 1993), detection of the schools is a function of the diameter of both school aggregations and individual schools (Hunter and Churnside 1995). Since the probability of school detection (*p*) affects the confidence in the abundance estimate (Thompson 1992; Lo and Hunter, in prep.), the number of swaths or transects flown should be a function of *p*. The following two equations can be used to estimate *p* within length of coast or ocean L:

$$p = 1 - \prod_{i}^{M} [1 - \frac{x_i + y}{L}] \qquad (4)$$

and

$$x_i = \underset{j}{Y} x_{ij} \qquad (5)$$

where y is the swath width, x_i is the diameter of fish school group i and x_{ij} is the diameter of fish school j within aggregation i. Lo and Hunter (in prep.) ran simulations on how swath width affected the probability of detection of anchovy schools and found that the chance encounter with an aggregation of schools given the size of the habitat had much more effect on *p* than the swath width. For herring in PWS, because of the reduced area of distribution as compared with pelagic anchovy, *p* is probably more affected by swath width.

Accuracy of the density estimates collected by air can only be truly estimated by comparing aerial survey results to results of an independent survey of relative biomass, which is assumed to be a true value. Optimally, the aerial and acoustic surveys are synoptic. Acoustic measurements were made in several areas overlapping aerial transects. Both data sets are plotted graphically; overlapping catches, acoustic sightings identified by target strength are compared to sightings of herring schools and other fish. In 1996, overflights were conducted synoptically with both broadscale and repeat acoustic surveys (within particular bays) and with diver surveys. An example of the overlay of this data is presented in the results.

Regional and Seasonal Distribution Comparisons

All processed and corrected flight data was plotted graphically. Visual reviews of the plots reveal the type of distribution (contiguous) and approximate size of school aggregates. For statistical analysis, the size of a particular sampling unit (approximate size of aggregates) are estimated to use as replicates within a particular region of interest. Besides visual analysis, the surface area in a sample unit is determined by gridding each region into successively smaller units and examining the means and variance of each grid size. The comparison of the means to the variance indicates the type of distribution, whether random, contiguous or regular. The distribution type is confirmed by calculating a poison (random) and negative binomial (contiguous) and comparing the calculated distributions to the actual distributions observed to determine the best fit. The actual size of the spatial aggregation (ecological unit) is estimated by calculating indices of dispersions (e.g. Mortisita's Index or Standardized Index; Krebs 1989). An alternative method is to conduct a power analysis to determine the unit size that gives us the lowest variance in the ANOVA. However, this latter method may not provide enough information. The optimal range of sample units (school aggregation size) for analysis is described in km^2 . The range in size of the ecological unit may vary with fish density and habitat type. This possibility can be examined via this type of analysis.

For statistical comparisons, the density of fish is estimated for each ecological unit within a given season or year and compared for significant differences. The densities of units are compared to similarly gridded observations of other fish species whether gathered by aerial means or acoustics as well as hydrographic data (water temperature and salinities).

An Example of Aerial Survey Results

Herring and Pacific sandlance (*Ammodytes hexapterus*) schools seen from the air in 1996 from two regions in PWS (Figure 5) were plotted with bird observations along with identification of schools by divers and net catches. Herring and sandlance school surface areas by location were plotted for southwestern (July 17-18; Figures 10) and central PWS (July 20-21; Figure 11). The total lineal distance flown for each day was 227.64 km on 7/17, 215.05 km on 7/18, 97.21 km on 7/20 and 175.75 km on 7/21. Diver-identified fish schools (Steve Jewett, personal communication, University of Alaska, Fairbanks) and net captures (Lew Haldorson, personal communication, University of Alaska, Juneau) were plotted to show validation of aerial identified species. When the surface areas of schools along the transect were plotted (Figures 12 and 13), the patchy aggregations of school groups was obvious pointing to a contiguous distribution. These plots serve as an example of how the data can be analyzed visually prior to statistical treatments. Bouts of predation by gulls (Figure 10-11), diving birds, and marine mammals were easily discernible from the air.

Densities of school surface areas were also calculated from the survey data for these four days. Although herring schools were much more numerous in the SW area than sandlance (Figure 12), sandlance schools were larger and dominated over herring in terms of density in both areas. In the SW area, the density of herring was 1.12 X 10^{-5} m^2 school surface area · m^{-2} transect area versus 1.36 X 10^{-5} for sandlance (Figure 14). In the central area, sandlance schools were more numerous (Figure 13) and the density (5.67 X 10^{-5}) was much higher than in the SW area (Figure 14). Herring were less numerous and densities were lower (4.13 X 10^{-6}) in the central area compared to the SW.

Two of the most commonly sighted fish species from the air during the months of this survey were herring and sandlance. Herring schools were characteristically round and opaque with a dark brown coloring and generally found at an average of 24 m (St Dev. 32 m) from shore (Figure 1). Sandlance schools were oblong or irregularly shaped, gray in color and translucent to the bottom (Figure 2; bottom features such as rocks or changes in substrate were easily seen through the school) and found much closer to the beach on an average at 4 m (St. Dev. 1.2 m) from shore. In 1996, herring schools averaged 47.2 m^2 (St. Dev. 63.31) while sandlance schools averaged 190.8 m^2 (St. Dev. 382.7). Because of the variability in school size, size alone was not always sufficient to differentiate the two within the data set. However, because over 95% of the herring schools were characterized as round and 90% of the sandlance schools were characterized as oblong or irregular, the two can be differentiated by shape. The actual measurements of individual ability to recognize schools will provide a more quantitative estimate of the differentiation.

Proportions of schools associated with foraging birds were summarized in 1995. In May the proportion of schools with birds was 50% increasing to 71.1% in June (Figure 15). Foraging fell off in July to 57.6% with the declining trend continuing in August to 42.3%. There is no doubt that the majority of these birds were actively foraging on the schools since of the 276 behaviors recorded, 104 were plunging and 121 were milling (behaviors associated with actively feeding birds; Irons 1992). The trend of increasing proportion of schools with birds was opposite the trend in abundance of schools and school surface area (Figures 8 and 9). This may represent predator swamping (large numbers of schools available compared to numbers of birds), a restriction in bird foraging area due to nesting activity (personal communication, Dave Irons, US Fish and Wildlife Service, Anchorage, Alaska), or prey switching whereby alternate prey is available to the birds. The results of this survey provides sea bird researchers a "bird's eye" view of the seasonal forage available to the birds as shown their association with schools and behavior.

Discussion and Recommendations

The shortcomings of aerial survey as a monitoring tool are obvious. There is surveyor bias (overcounting or undercounting), survey conditions can greatly affect survey results (which we reduced by flying in fair weather), silt from river runoff can impact the ability to see into the water column, and only a small percentage of schools sighted from the air can be validated via catches or divers. The strengths of this survey method are that a large area can be covered in a short period of time and the costs are far less than a survey conducted from vessels alone.

This survey provides information about overlap in distribution between the two species readily visible from the air (herring and sandlance) as well as seasonal and spatial changes in bird and mammal foraging on fish schools. This information may give sea bird and mammal researchers insight as to changes in diet, condition and reproductive success of their respective study animals. It can specifically provide insight as to when prey switching occurs for birds. An example would be that observed reductions in gulls associated with fish schools spotted from the air may coincide with out migration of salmon fry from streams and increased predation by birds on those fry. This phenomena was observed from the air in 1996 between May and June in eastern PWS. Logerwell and Hargreaves (1996) found a negative relation to forage fish and sea bird density, but they cite the cause as fish avoidance of the nets. The same problem can occur with boat avoidance during acoustic vessel surveys. In addition, forage fish are often in areas where vessels, acoustics and nets cannot reach. All of these problems are avoided when using an airplane.

When coupled with net catch and habitat data, the seasonal and interannual trends in observations of surface schools can be better interpreted. The increase in surface schools nearshore in June and July may be due to increases in food availability or predator avoidance. This habitat data is available for the years this survey was conducted. The difference in seasonal distribution of surface schools between the two years shown in Figures 8 and 9 could be due to differences in year class strength. Pacific herring in PWS metamorphose from the larval stage in July (Norcross et al. 1996) and are likely observed from the air as new schools starting during that month. In June, only age-1 juvenile herring are likely to be visible from the air. Depending on which year class was stronger, the peak of numbers and surface areas of schools may vary between the two months. Catch data available for the years of this survey will provide the answer.

Although we are just beginning to plot and analyze the data, it was important to document the work we have done and compare it to other survey techniques. Aerial survey methodology has improved dramatically in the past 10 yrs. The use of GPS, high resolution and night vision cameras, and remote sensing devices (Nakashima and Borstad 1993) such as LIDAR (light detecting and ranging derived by analogy from radar; Oliver et al. 1994) and CASI (compact airborne spectographic imager; Borstand et al. 1992) have allowed researchers more precision in mapping flight paths and visual swaths as well as unbiased survey results (Hunter and Churnside, 1995). Although the remote sensing tools are efficient, they are expensive and take highly trained staff to operate. The methods outlined for this survey are much cheaper due to lower technology, but have the associated problems of surveyor bias. The results and utility of this survey could be greatly improved with the correlation to synoptic acoustic data and by conducting a companion CASI survey for at least a portion of the survey area. With the correlation to independent survey methods, we can determine the amount of precision expected from our survey results and decide if this tool alone is sufficient to answer the research questions posed. It may be that the most cost-effective yet sufficiently accurate monitoring tool available may be a combination of a broadscale survey using the techniques described in this report paired with a smaller scale acoustic and CASI survey.

Acknowledgments

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Figures

Figure 1. A juvenile Pacific herring school seen from the air in Prince William Sound (Bill Ostrand, photo)

Figure 2. A juvenile Pacific sandlance school seen from the air in Prince William Sound (Evelyn Brown, photo)

Figure 3. An aggregation of moon jellyfish seen from the air in Prince William Sound (Evelyn Brown, photo)

Figure 4. Diagram of the sighting tube and the mylar grid with tick marks for measurements of schools.

Figure 5. Map on the survey area on the south-central coast of Alaska with delineation of the southwestern and central survey areas within Prince William Sound.

Figure 6. Frequency distribution of herring and sandlance schools sizes in Prince William Sound.

Figure 7. The visual swath in meters established flying over known, land-marked distances on the ground at different altitudes.

Figure 8. Seasonal variation in numbers of herring schools observed per survey from the air in 1995 and 1996 in Prince William Sound.

Figure 9. Seasonal variation in total surface area of schools observed per survey from the air in 1995 and 1996 in Prince William Sound.

Figure 10. Aerial observations of herring, sandlance, unknown forage fish, jellyfish, and foraging birds plotted with diver observations and net catches conducted within the same 24 hr period in southwestern Prince William Sound on July 17 and 18, 1996. The circles (fish), diamonds (jellyfish), and squares (birds) are sized by total surface areas of schools, aggregations, or total numbers of birds observed at each location.

Figure 11. Aerial observations of herring, sandlance, unknown forage fish, jellyfish, and foraging birds plotted with diver observations and net catches conducted within the same 24 hr period in central Prince William Sound on July 20 and 21, 1996. The circles (fish), diamonds (jellyfish), and squares (birds) are sized by total surface areas of schools, aggregations, or total numbers of birds observed at each location.

Figure 12. Surface area (m^2) of herring and sandlance schools sighted along the survey transect in southwestern Prince William Sound on July 17 and 18, 1996.

Figure 13. Surface area (m^2) of herring and sandlance schools sighted along the survey transect in central Prince William Sound on July 20 and 21, 1996.

Figure 14. Density of herring and sandlance schools (m^2 surface area of schools / m^2 surface area of transect) in southwestern and central Prince William Sound sighted on July 17, 18, 20 and 21, 1996.

Figure 15. Percentages of fish schools sighted from the air with birds associated with them in Prince William Sound in 1995 from May until August.

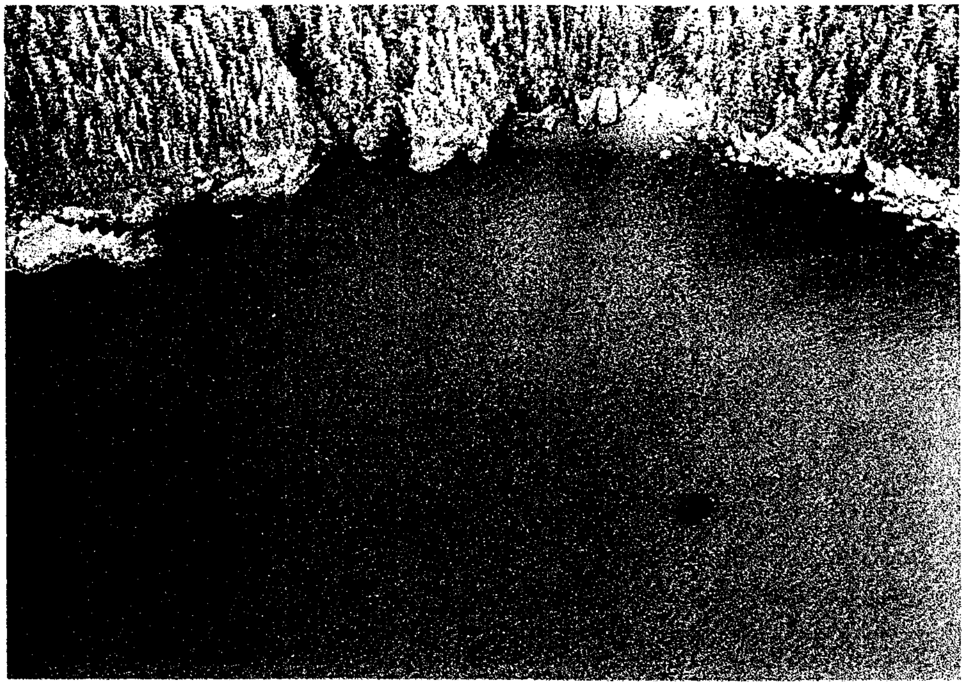


Figure 1. A juvenile herring school seen from the air in Prince William Sound (Bill Ostrand, photo)

Figure 2. A juvenile Pacific sandlance school seen from the air in Prince William Sound (Evelyn Brown, photo)

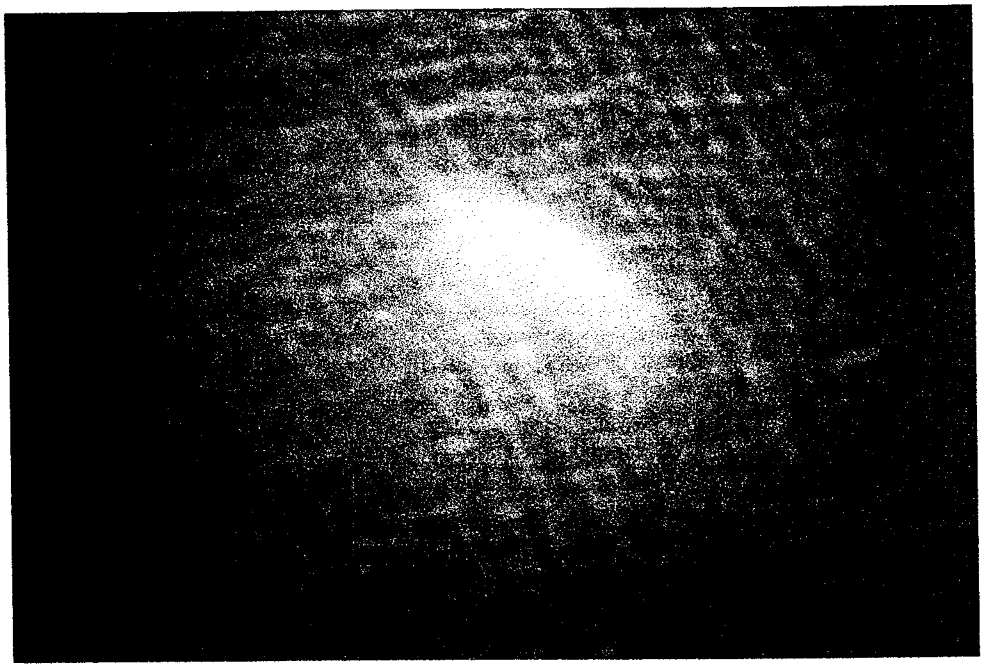


Figure 3. An aggregation of moon jellyfish seen from the air in Prince William Sound (Evelyn Brown, photo)

Figure 4. Brown and Norcross, 1997

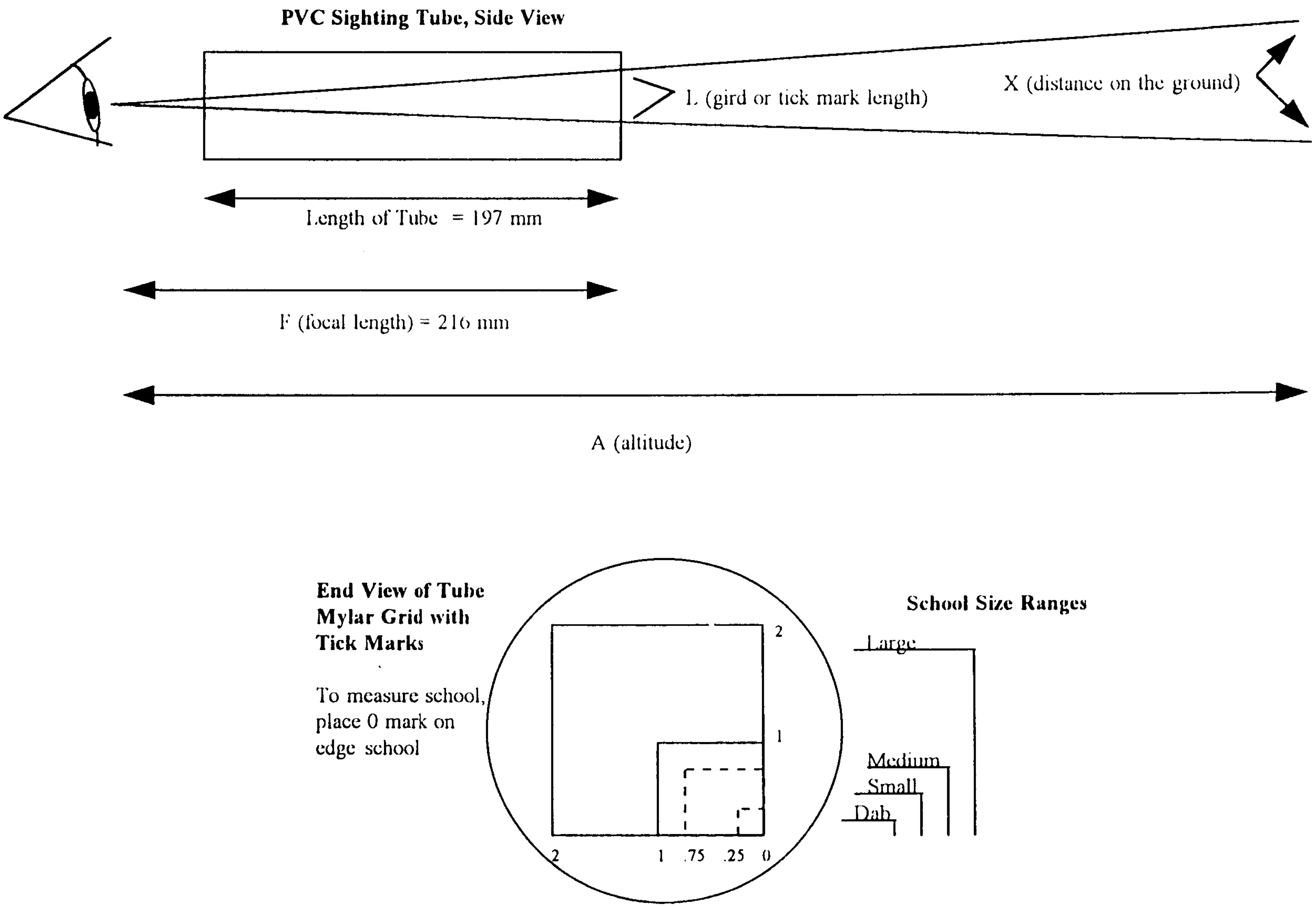


Figure 5. Brown and Norcross, 1997

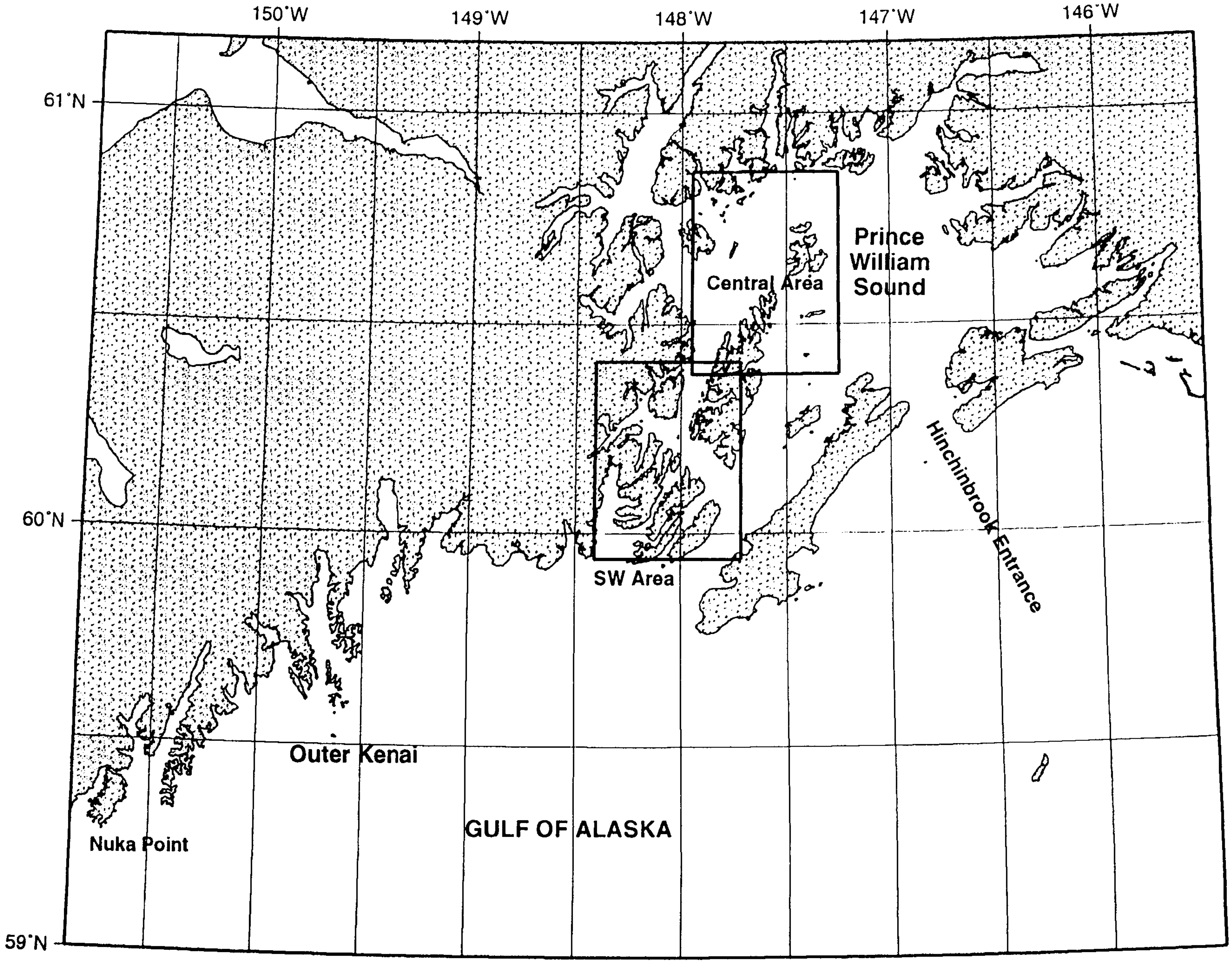


Figure 6. Brown and Norcross, 1997

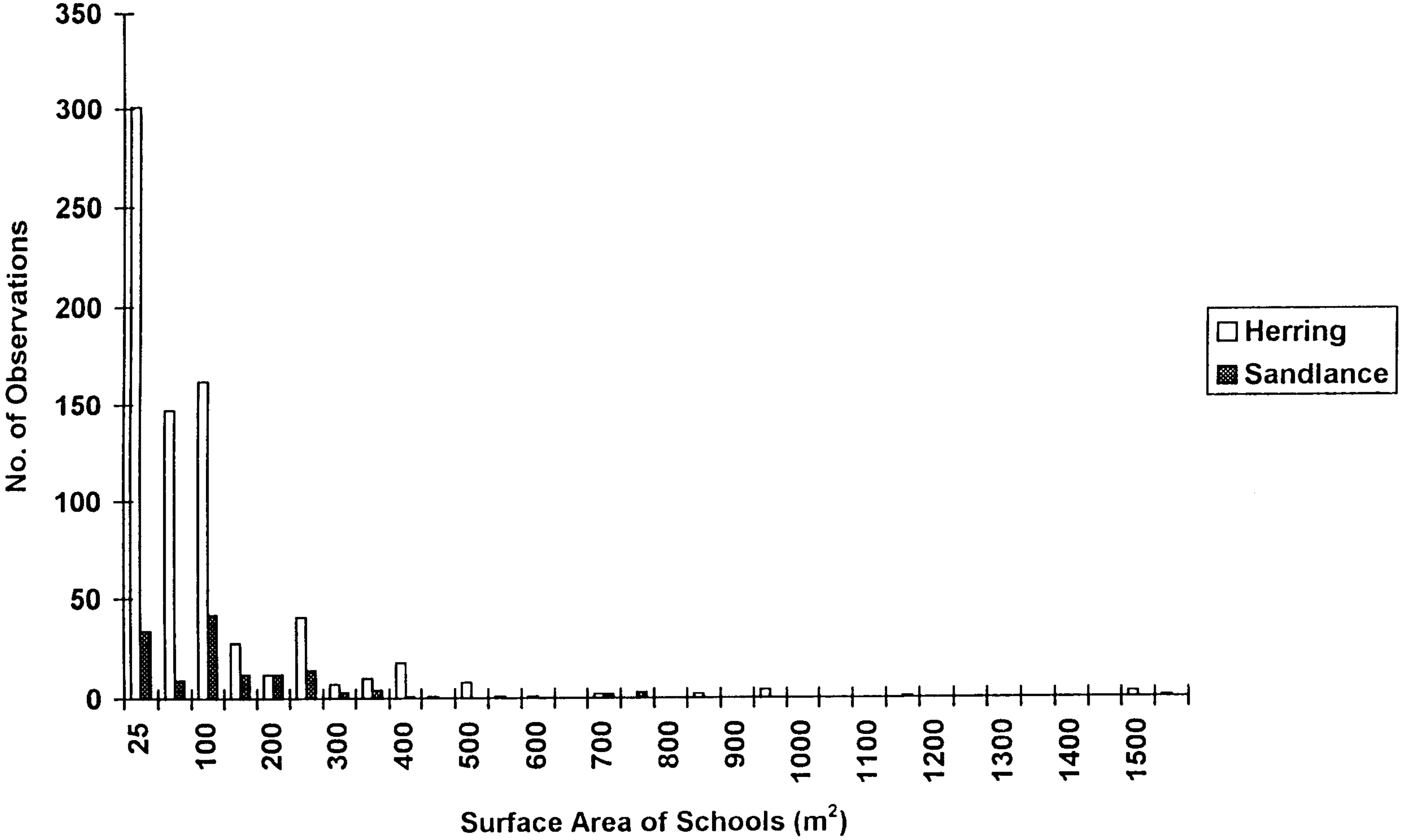


Figure 7. Brown and Norcross, 1997

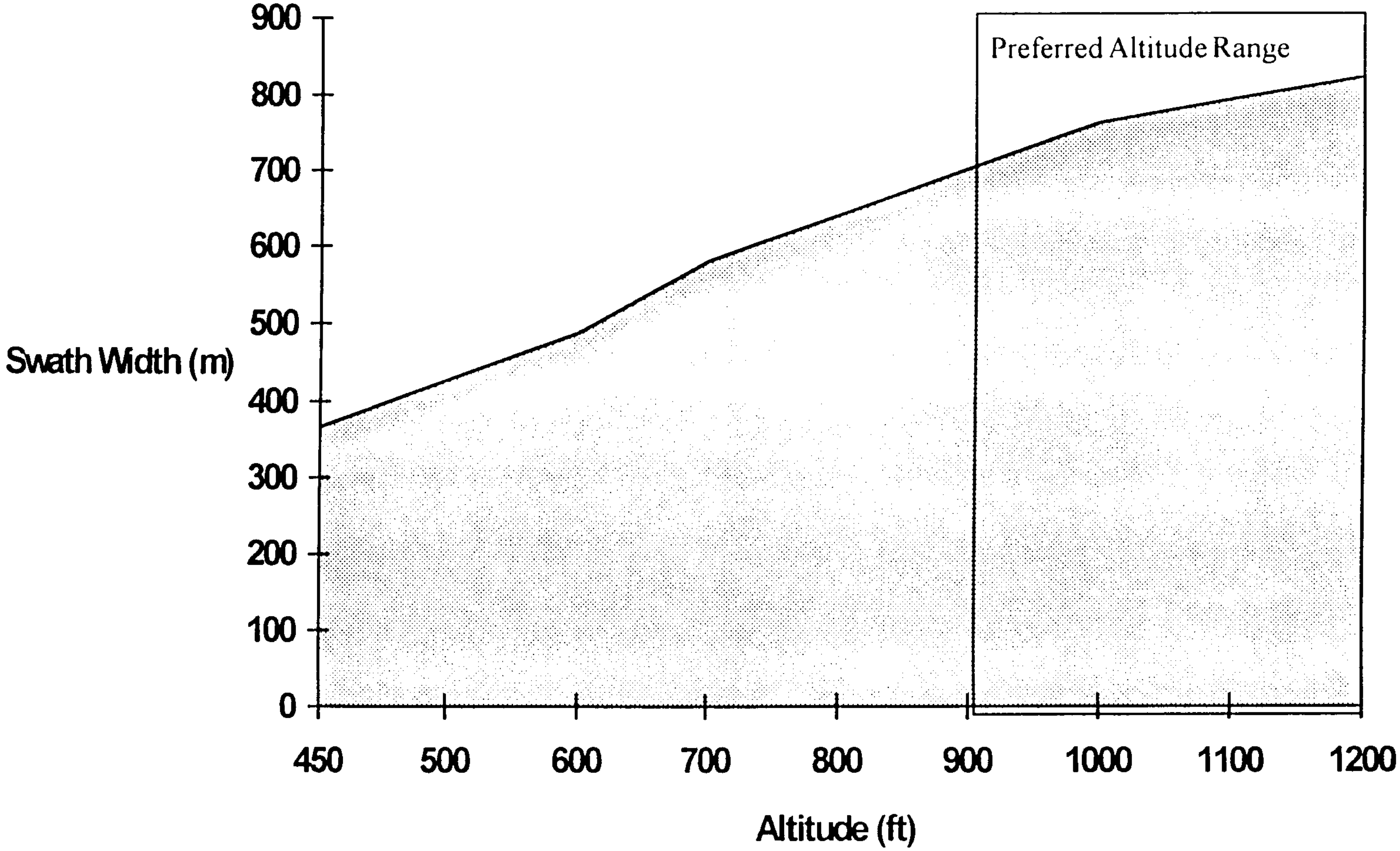


Figure 8. Brown and Norcross, 1997

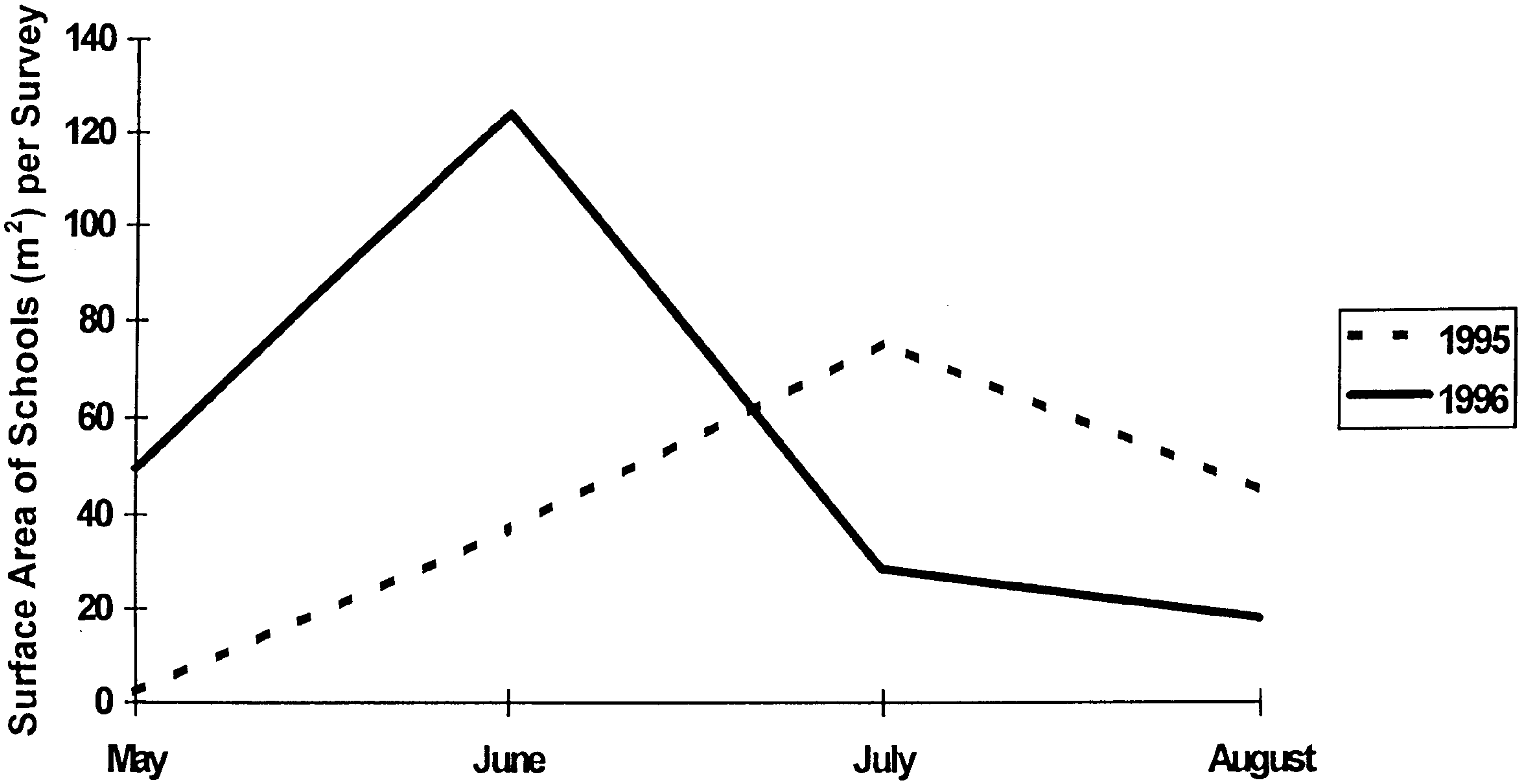


Figure 9. Brown and Norcross, 1997

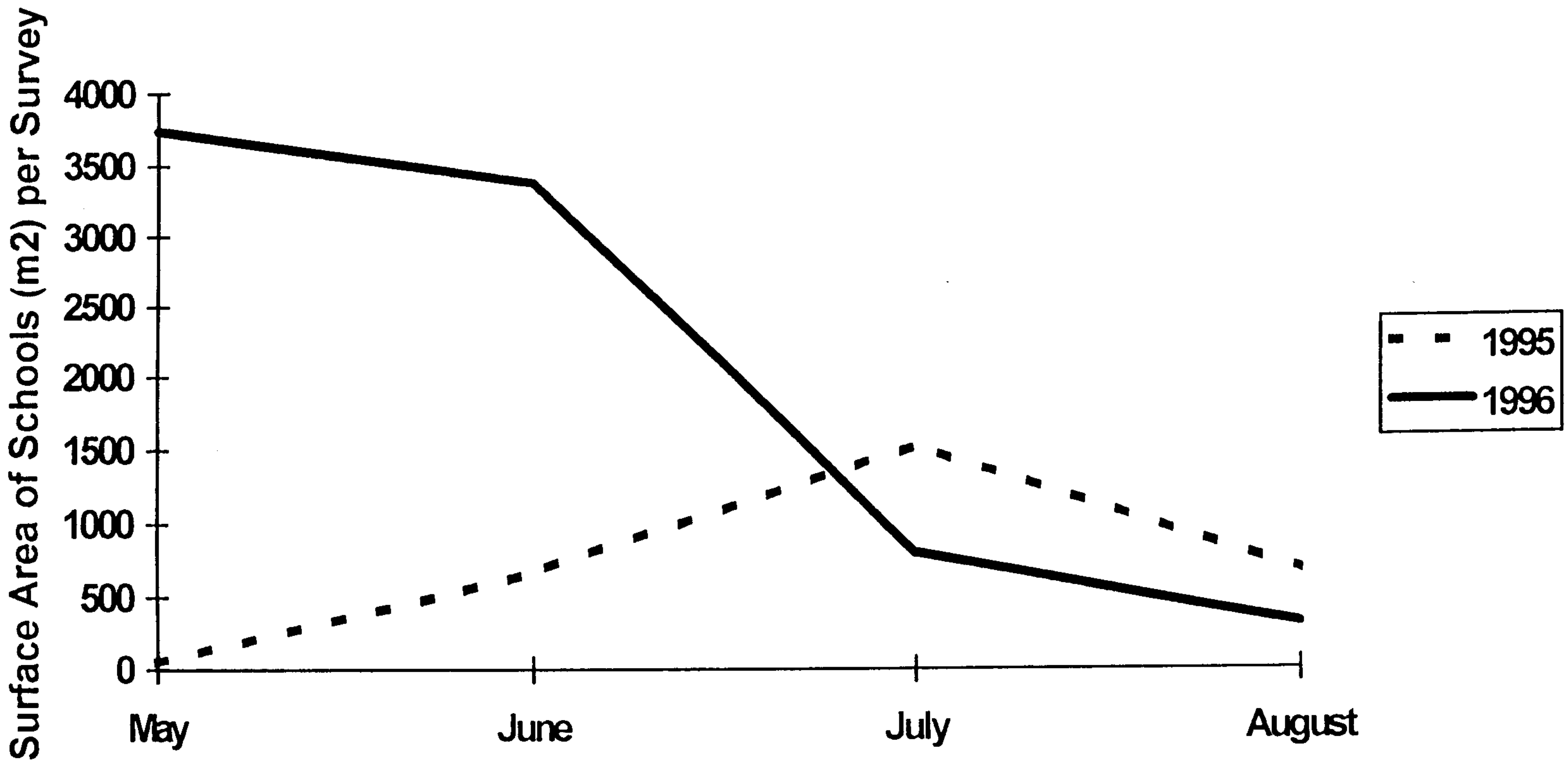
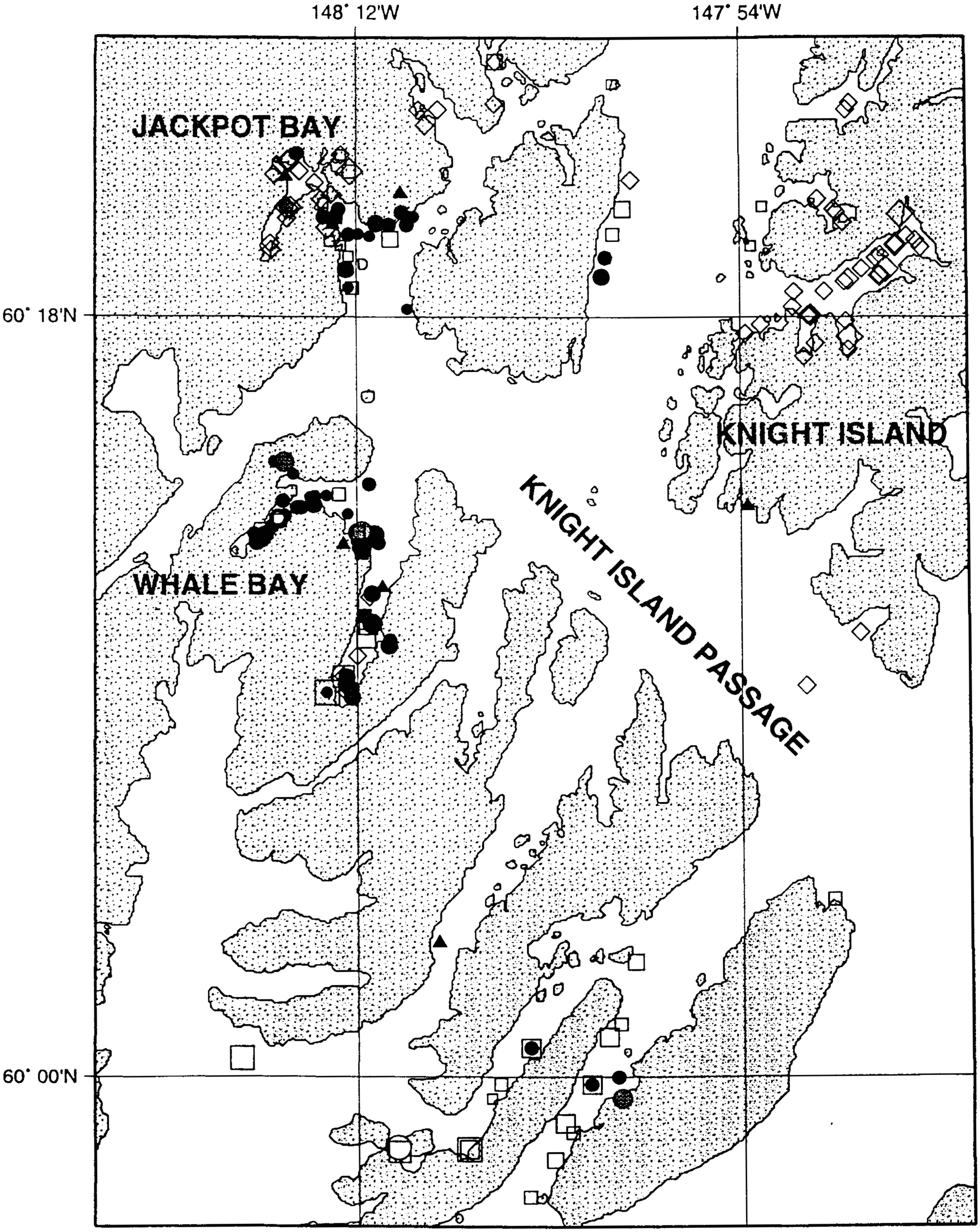


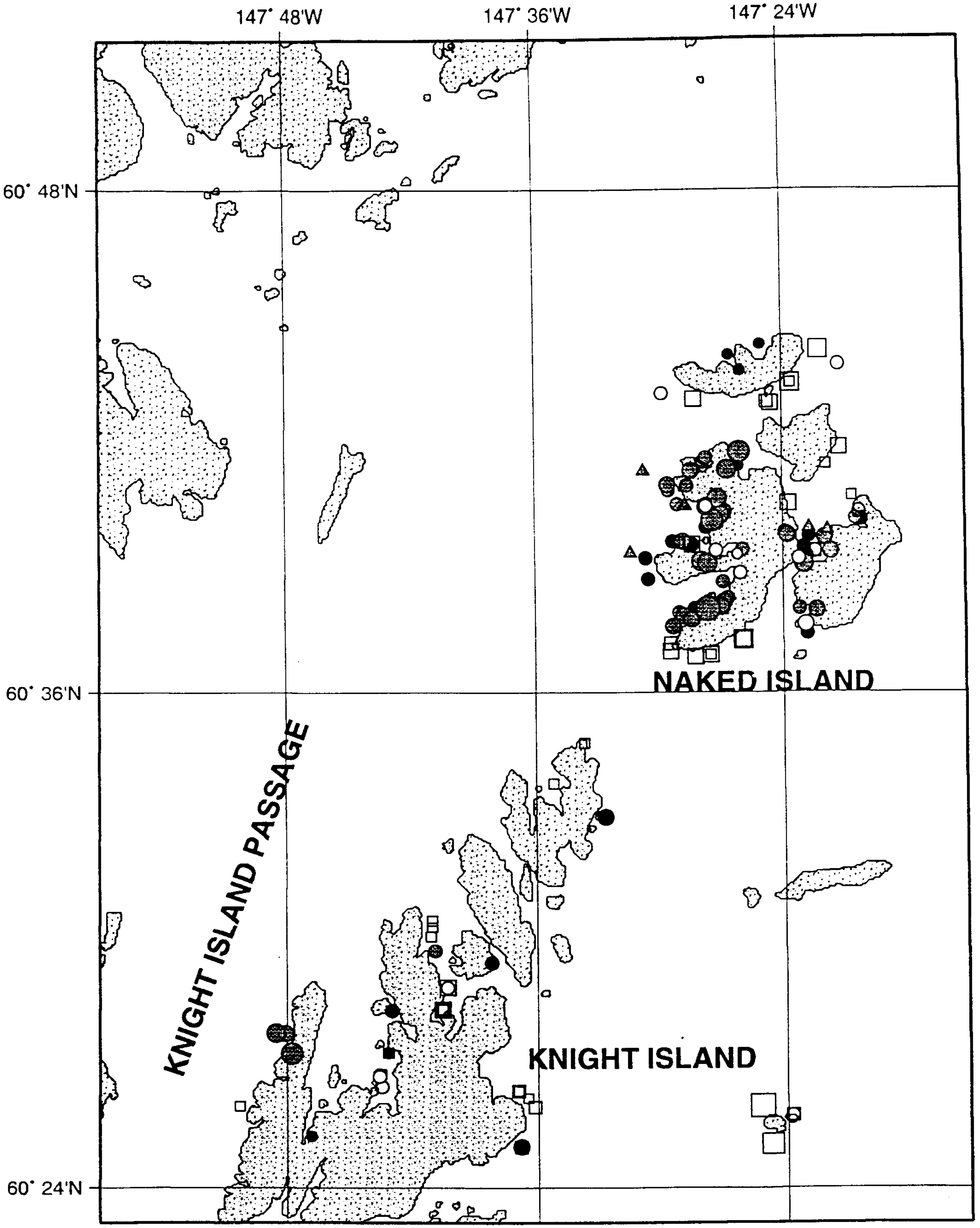
Figure 10. Brown and Norcross 1997



Key: Aerial Observations | Net Catches & Diver Observations

● Herring
○ Unknown Fish
▲ Herring
● Sandlance
□ Birds
◇ Jelly Fish

Figure 11. Brown and Norcross, 1997



Key: Aerial Observations | Net Catches & Diver Observations

● Herring

○ Unknown Fish

▲ Sandlance

● Sandlance

☐ Birds

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Figure 12. Brown and Norcross, 1997

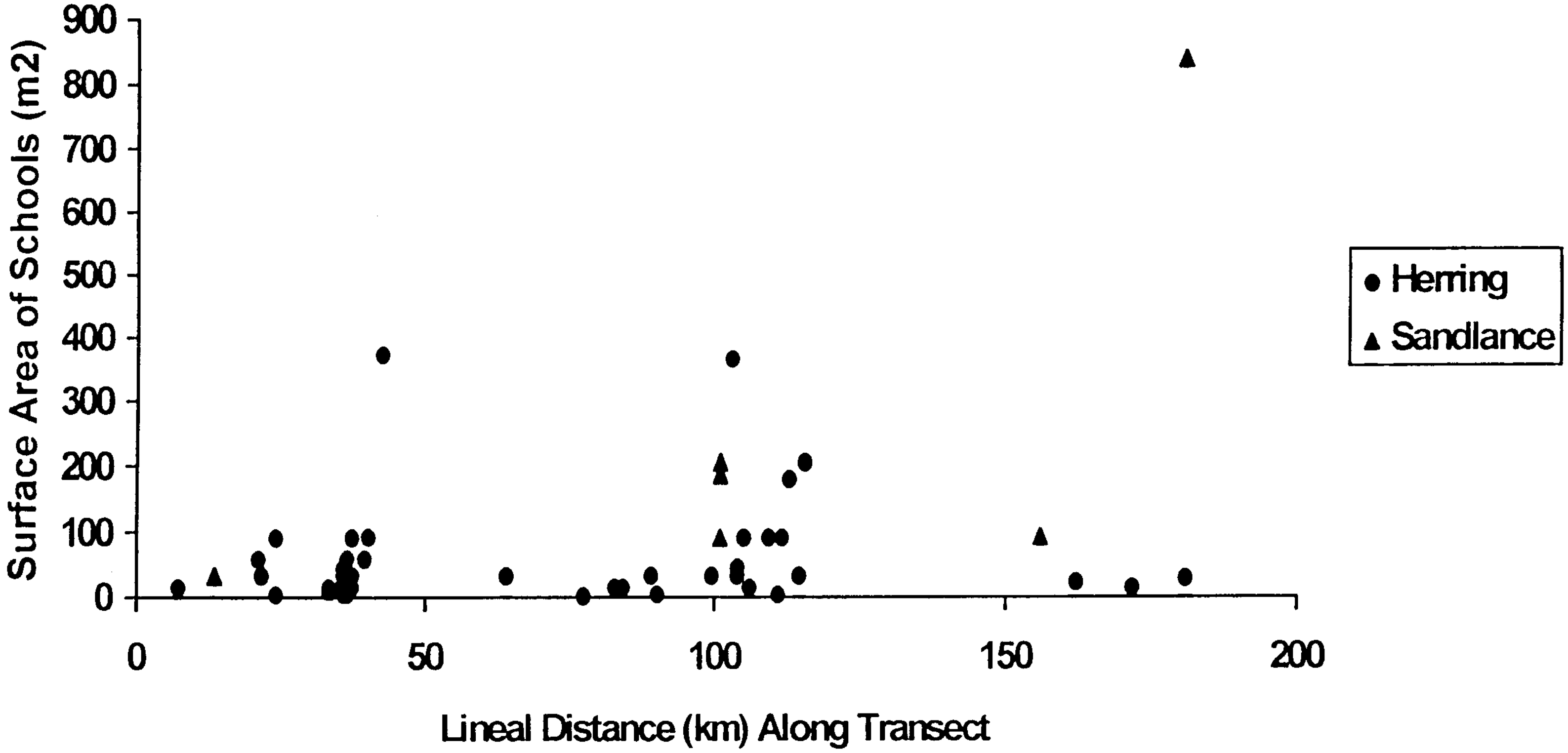


Figure 13. Brown and Norcross, 1997

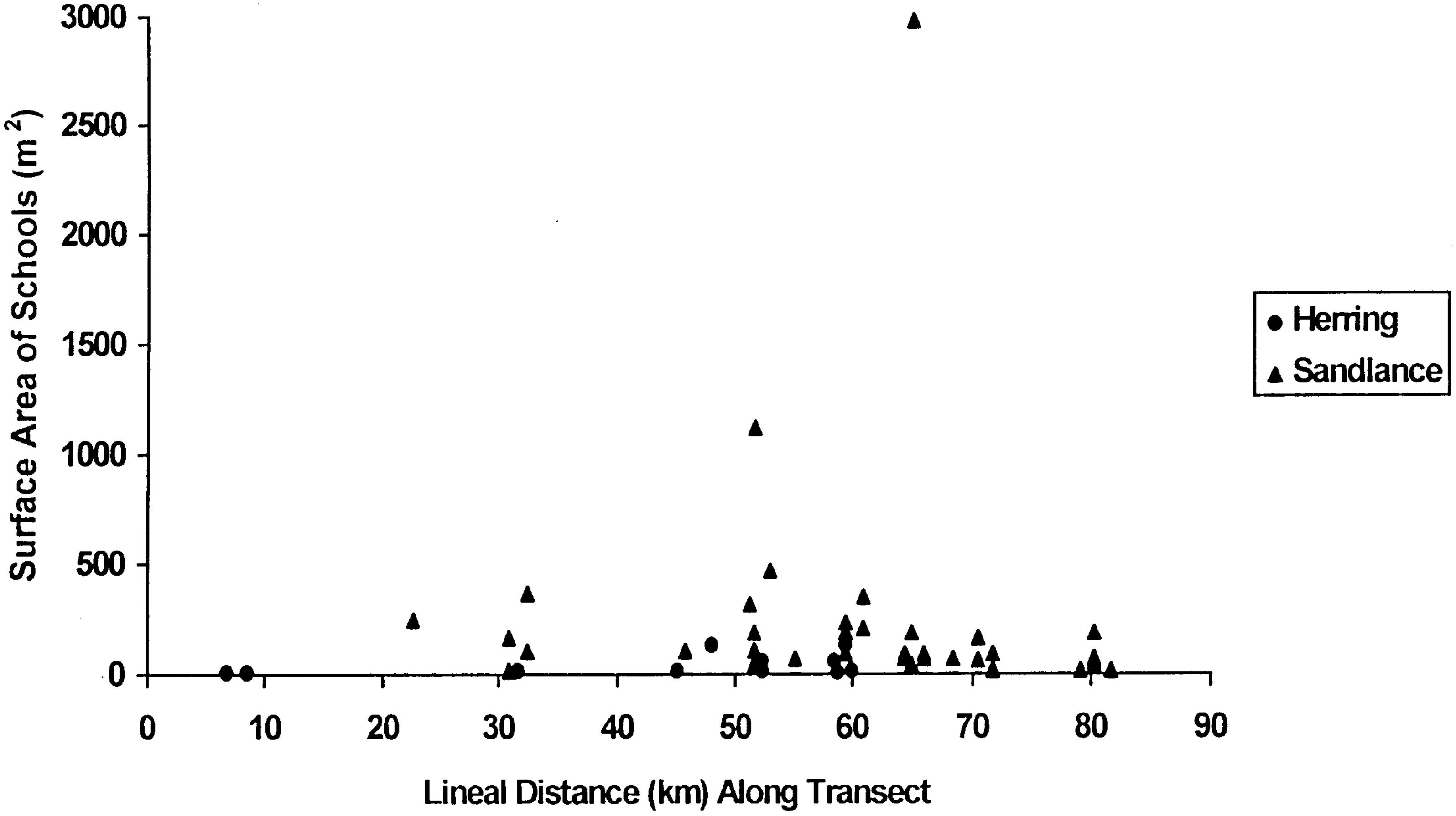


Figure 14. Brown and Norcross, 1997

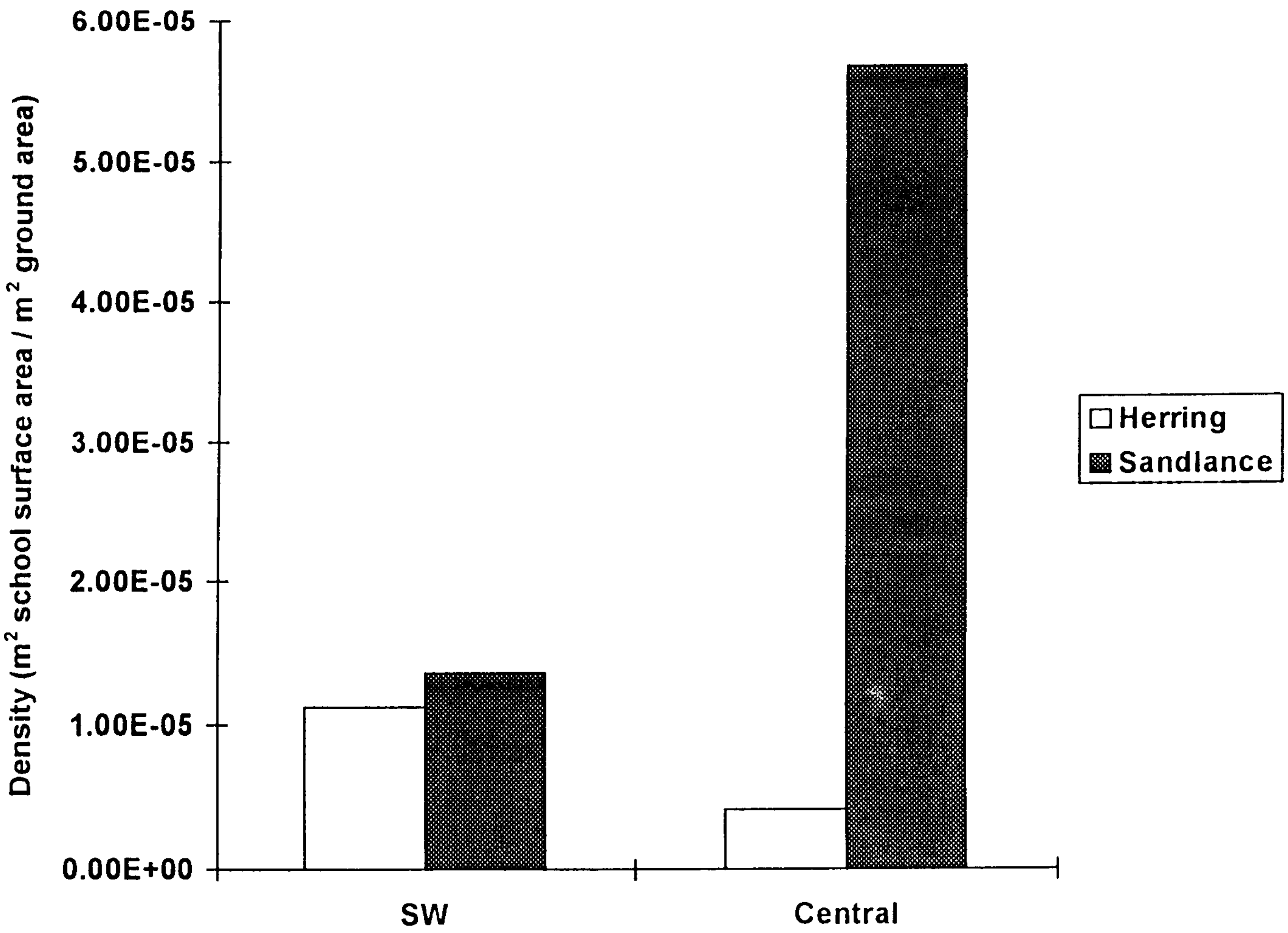
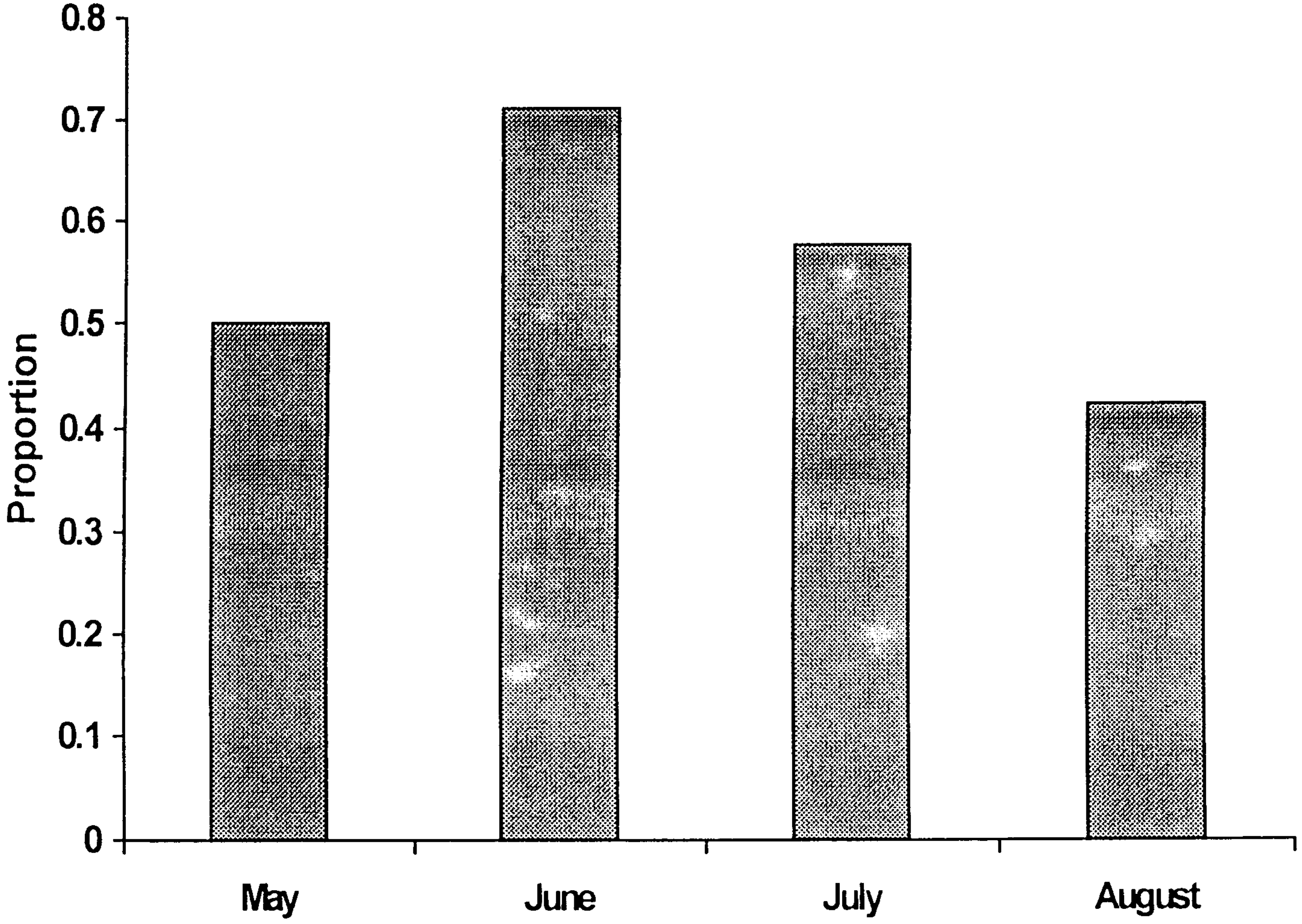


Figure 15. Brown and Norcross, 1997



Apendix II

Foy, R. J., B. L. Norcross, A. Blanchard. 1997. Spatial and Temporal Differences in the Diet of Herring (Clupea pallasi) in Prince William Sound, Alaska

DRAFT

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

Robert J. Foy
Brenda L. Norcross
Arny Blanchard

Introduction

Pacific herring, Clupea pallasi Valenciennes, are distributed along the Asiatic and North American continental shelves in the North Pacific Ocean. In Prince William Sound, Alaska, herring have historically been an important fish commercially as well as biologically. Reduced abundances resulting in the closure of the commercial fishery have led to questions about the recruitment processes in Prince William Sound. When studying recruitment it is important to understand underlying mechanisms that create variation at particular stages in the development of the fish (Houde 1987; Miller et al. 1991). Although no one factor completely dominates the variation found in year-class strength, it is important to determine the life history stages and mechanisms within those stages that that dominate the variance in mortality and therefore control recruitment. Starvation and slow growth rates can lead to high mortality and decreased recruitment. An important aspect of herring recruitment variation, therefore, is that associated with the feeding behavior and success of larvae and juveniles prior to recruitment.

Bollens et al. (1992) found a lack of overlap in ichthyoplankton and their prey suggesting an increased dependence on the juvenile stage for variability in recruitment based on food consumption. This suggests the need to look beyond the larval stage of some fish species to account for temporal and spatial patterns in feeding related to the variability in recruitment. We believe the juvenile stage of herring development incurs a significant amount of variation in mortality and therefore recruitment to older stages, and we hypothesize that much of the variation in herring mortality in Prince William Sound can be explained through the understanding the feeding ecology of juveniles. A study of herring juvenile feeding ecology necessitates an understanding on both temporal and spatial scales within Prince William Sound. Little is known of the feeding ecology of juvenile herring in Prince William Sound, especially with respect to spatial and temporal characteristics. Identification of seasonal prey species in herring diet is an important first step to understanding the trophic interactions of herring and its prey. 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

Herring were collected from 24 sites in Prince William Sound (Figure 1), Alaska during April, May, June, October, and November of 1995 and March of 1996. Each site was an area, usually a bay, where at least one catch of fish was made. 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 and also from a trawl vessel with a 40 m x 28 m, 150 mm mesh mid-water wing trawl net. From each catch, 15 fish less than 150 mm were randomly sampled. Fork length was measured before each fish was preserved in a 10 percent buffered formaldehyde solution. After at least 24 hours of preservation, samples were transferred to 50 percent isopropanol for transport and further analysis.

In the laboratory, each fish was blotted dry, weighed, and measured before the stomach was removed. The stomach was removed and weighed to the nearest 0.001 g. After stomach contents were removed, the stomach was reweighed to determine gut content weight. Prey in the stomach were identified to the lowest possible taxonomic level.

After diet identification, prey were pooled into nine taxonomic categories from each site to facilitate further analysis (Table 1). An index of relative importance (IRI) (Pinkas 1971) was calculated for each prey category in each bay.

The IRI was calculated as:

$$IRI = (N + W) * F$$

where N = number of prey, W = percent weight of prey, and F = percent frequency of fish consuming the prey. An IRI was calculated for each prey taxon category consumed by herring at each of the sites.

Four sites (Simpson Bay, Eaglek Bay, Whale Bay, and Zaikof Bay) were analyzed individually throughout the year in order to compare spatial and temporal differences in prey IRI's.

An analysis of variance was used to compare the mean lengths of herring among the four bays as well as among months in each bay. Although March samples were from 1996, we chose to compare them in chronological order by month in order to analyze the complete feeding period from spring to fall.

Results

A total of 1200 herring were randomly sampled from all sites in Prince William Sound across the six sampling periods (Figure 1). Prey were placed into categories based on their taxonomic class or order (Table 1). Prey that constituted less than one percent of the stomach contents were placed in the 'other' category. In March 1996, 665 fish were sampled from 18 sites in Prince William Sound (n ranged from 10 to 121 herring per site). Total IRI's for prey categories across the sound in March ranged from 0 to 38 percent;

large calanoid copepods were the most important prey (Figure 2). In April and May of 1995, 150 fish were sampled from 4 sites (n ranged from 22 to 68 herring per site). Total IRI's for prey categories ranged from 0 to 81 percent in April and 0 to 55 percent in May (Figure 2). Large calanoid copepods were the most important prey in both months. In June of 1995, 75 fish were sampled from 2 sites (n was 21 and 54 herring per site). Total IRI's for prey categories ranged from 0 to 74 percent. Medium calanoid copepods were the most important prey categories. In October of 1995, 166 fish were sampled from 6 sites (n ranged from 19 to 72 herring per site). Total IRI's for prey categories ranged from 0 to 68 percent. Larvacea were the most important prey categories. In November of 1995, 144 fish were sampled from 3 sites (n ranged from 15 to 69 herring per site). Total IRI's for prey categories ranged from 0 to 50 percent. Larvacea were the most important prey categories followed by medium calanoids (IRI = 36 percent).

Of the sites previously described, 4 bays which were repeatedly sampled, were used for spatial analysis. Eaglek Bay in Northwest Prince William Sound was only sampled once in March, 1996. Stomach contents from 121 herring were analyzed from Eaglek Bay. Euphausids were the most important diet group (IRI = 82 percent), followed by small calanoids, malacostraca, large and medium calanoids (Figure 3).

Simpson Bay in Northeast Prince William Sound was sampled in two months. In March of 1996 and October 1995, stomach contents of 27 and 72 herring, respectively, were analyzed from Simpson Bay. IRI's revealed that in March cerripedia (barnacle larvae) were the dominant prey category while in October, Larvacea was dominant (Figure 3). Small and medium calanoids were found in smaller quantities in October.

Whale Bay in Southwest Prince William Sound was sampled in two months. In March of 1996 and October 1995, stomach contents from 44 and 30 herring, respectively, were analyzed from Whale Bay. Small calanoids were the most important prey species in March with much smaller amounts of barnacles, medium, and large calanoid copepods (Figure 3). In October, Larvacea comprised most of the important categories followed by small calanoid copepods and minor amounts of euphausids, large, and medium calanoid copepods.

Zaikof Bay in Southeast Prince William Sound was the only site at which all four timer periods were sampled. In March of 1996, gut contents from 53 herring were analyzed from Zaikof Bay. Large calanoid copepods were the dominant prey category followed by medium calanoid copepods (Figure 3). In May of 1995, gut contents from 22 herring were analyzed. Large calanoid copepods were again dominant followed by medium and small calanoid copepods. In June of 1995, gut contents from 54 herring were analyzed. Small calanoid copepods were the most important prey followed by lesser amounts of barnacles, cladocera, and medium calanoid copepods. In October 1995, gut contents of 30 herring were analyzed. Larvacea were the most important prey category followed by malacostroca and small calanoid copepods.

The mean lengths of the herring from the four bays in March and October used for gut content analysis were found to be significantly different ($P < 0.001$ for both months) (Table 2). The analysis of herring lengths within each of the four bays found that lengths of herring were significantly different in each month from each bay ($P < 0.001$ in each case).

This study showed both spatial and temporal shifts in the importance of herring prey categories. A first look at the importance of prey categories over all sites sampled reveals that large calanoid copepods dominate the juvenile herring diet in March, April, and May of 1995 and 1996 (Figure 2). In June, however, the large species of copepods became significantly less important whereas medium calanoid copepods dominated the prey chosen by juvenile herring. And finally in the fall, species of larvacea dominated the diet content of herring.

After encountering temporal variability around Prince William Sound, it was necessary to focus on four bays to detect any variation in prey importance on a finer level. Temporal variability was evident within each bay with prey switching between spring, summer, and fall months (Figure 3). Substantial spatial variability was also found between the bays. Barnacle nauplii were significantly more important in Simpson Bay in March 1996 than the other bays. Though they were present in Whale Bay and Zaikof Bay to a lesser extent, they were not found in Eaglek Bay. As found in the analysis of the overall Sound, large calanoid copepods were the most important prey categories in the spring months in Zaikof Bay. Euphausids were the most important prey categories in Eaglek Bay in March 1996. The most consistent feeding pattern was found in the fall with larvacea as the most important prey categories in each of the 3 bays sampled. It is interesting to note, however, that the second most important category in each bay was different. Small calanoid copepods in Whale Bay were relatively important with an IRI of 39 percent in October. In Zaikof Bay, malacostraca species were relatively important with an IRI of 24 percent in October.

Discussion

The shifting of prey importance in the diet of herring is both a function of the shifting of prey species dominance as well as probable changes in the selectivity by the fish. It is not sufficient to measure total prey biomass within preferred prey sizes of larval redfish (Sebastes spp) (Anderson 1994). Availability of prey categories was found to be instrumental in determining the observed feeding conditions. When Atlantic herring in the Baltic Sea prey on a mixed diet of zooplankton, mysids, and amphipods, faster growth rates due to higher energy densities result than when the diet consisted only of zooplankton (Arrhenius and Hansson 1993). Faster feeding rates would also would also increase growth rates resulting in better condition (Ware 1975; Shepherd and Cushing 1980; Houde 1987; Andersen 1994). As herring grow larger and gape size increases, larger prey with perhaps greater energetic value should become available. Spatial distribution of herring in Prince William Sound is related to isotopic and energetic values (Kline and Paul in review). They hypothesize that there is a shift in carbon source as a result of fish size. Therefore, a larger fish has a different prey selection available to it. Spatial differences in prey composition as well as changes in prey selectivity due to fish growth could help to explain why herring have different isotopic and energetic values. Such comparisons emphasize the need to incorporate an understanding of the zooplankton biomass present in order to develop selectivity indices and compare to gape size estimates in future studies.

It is important to note that the IRI's used in this study are an averaged index of prey importance. Choosing the scale of the index to be at the level of each bay limits a discussion of prey importance to that within each bay. It may prove useful in future studies to further divide the herring into discrete length categories to assess the importance of prey with respect to the fish size. Table 2 points out that the length frequencies encountered in each bay were significantly different and could possibly drive the spatial and temporal differences in prey importance discovered.

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Table 1. Taxon list showing diet groupings (bold) for index of relative importance analysis. Foy and Norcross 1997

- Copepoda
  - **Calanoida (large)**
    - *Calanus marshallae*
    - *Candacia columbiae*
    - *Eucalanus bungii*
    - *Euchaeta elongata*
    - *Metridia ochotensis*
    - *Neocalanus cristatus*
    - *Bradyidius saanichi*
  - **Calanoida (medium**
    - *Acartia tumida*
    - *Calanus pacificus*
    - *Centropages abdominalis*
    - *Epilabidocera longipedata*
    - *Lucicutia flavicornis*
    - *Metridia ochotensis*
    - *Metridia pacifica*
    - *Pseudocalanus* spp
  - **Calanoida (small)**
    - *Acartia clausi*
    - *Acartia longiremus*
    - *Eurytemora pacifica*

- **Cirripedia** (cyprid and nauplius)

- Branchiopoda
  - **Cladocera**
    - *Evadne* spp
    - *Podon* spp

- **Larvacea**
  - *Oikopleura* spp

- **Malacostraca**
  - Cumacea
  - Decapoda (zoea)
    - *Crangon* spp
  - Isopoda
  - Amphipoda
    - Gammaridea
    - Hyperiidea
  - **Euphausiacea**
    - *Euphausia* spp

- **Other**
  - Arachnida
  - Insecta
  - Ostracoda
  - Copepoda
    - Cyclopoida
    - Harpacticoida
    - Poecilostomatoida

  - Gastropoda
  - Bivalvia

  - Polychaeta (larva and juvenile)
    - *Sagitta* spp

  - Bryozoa (larva)
  - Chaetognatha
  - Cnidaria
  - Nemertea

Table 2. Mean (standard error) lengths and sample size of herring sampled in four bays and four months in Prince William Sound. Foy and Norcross 1997

	March		May		June		October	
Site	n	mean (se)	n	mean (se)	n	mean (se)	n	mean (se)
Simpson Bay	29	122.9 (3.2)					91	80.9 (1.7)
Eaglek Bay	146	140.7 (2.3)						
Whale Bay	60	115.6 (3.3)					30	94.9 (1.5)
Zaikof Bay	100	172.5 (3.0)	22	106.6 (0.9)	60	107.3 (0.9)	31	75.4 (1.9)

PRINCE WILLIAM SOUND

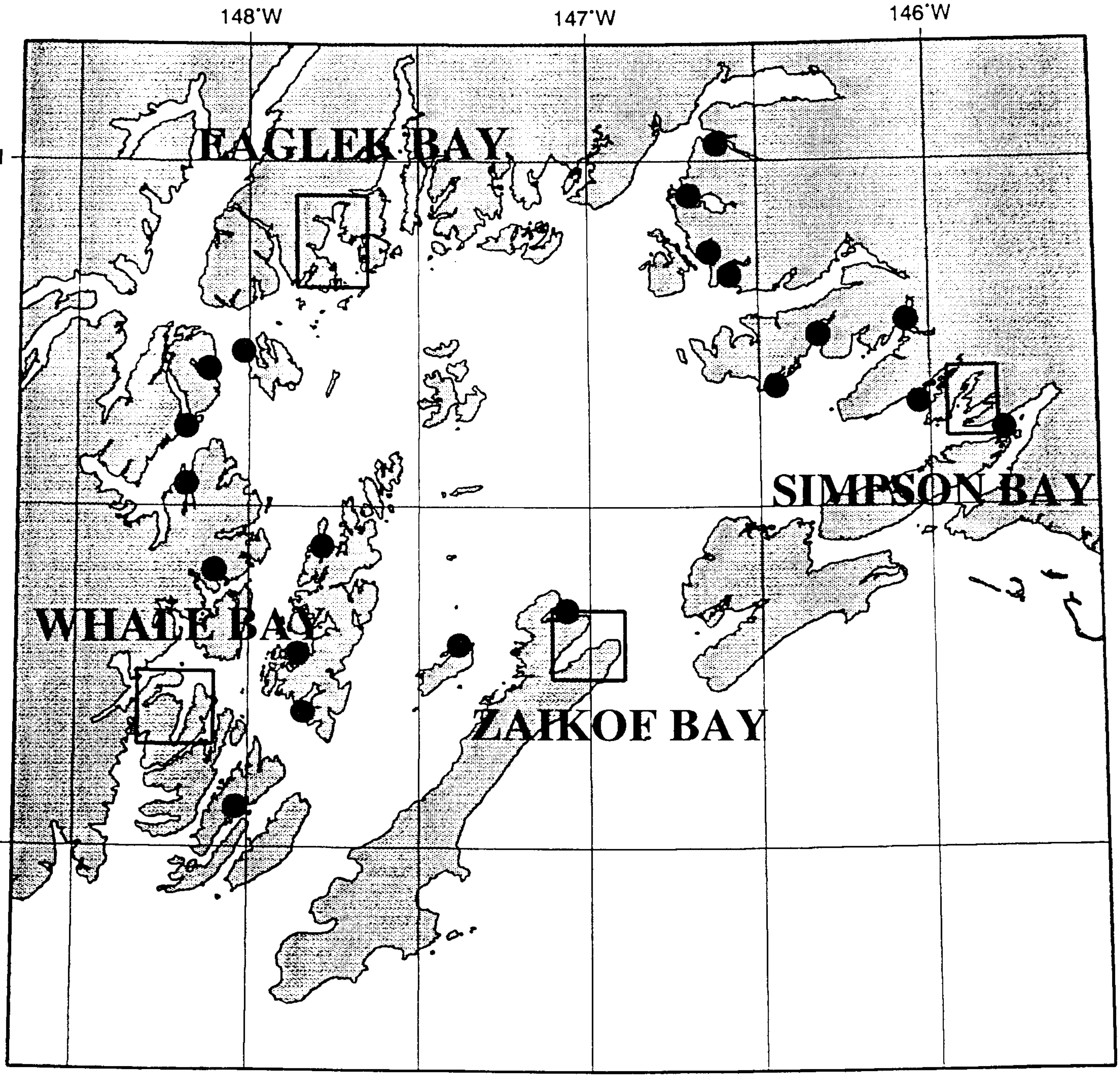

Figure 1. Sampling sites in Prince William Sound. Boxed bays represent primary research sites.

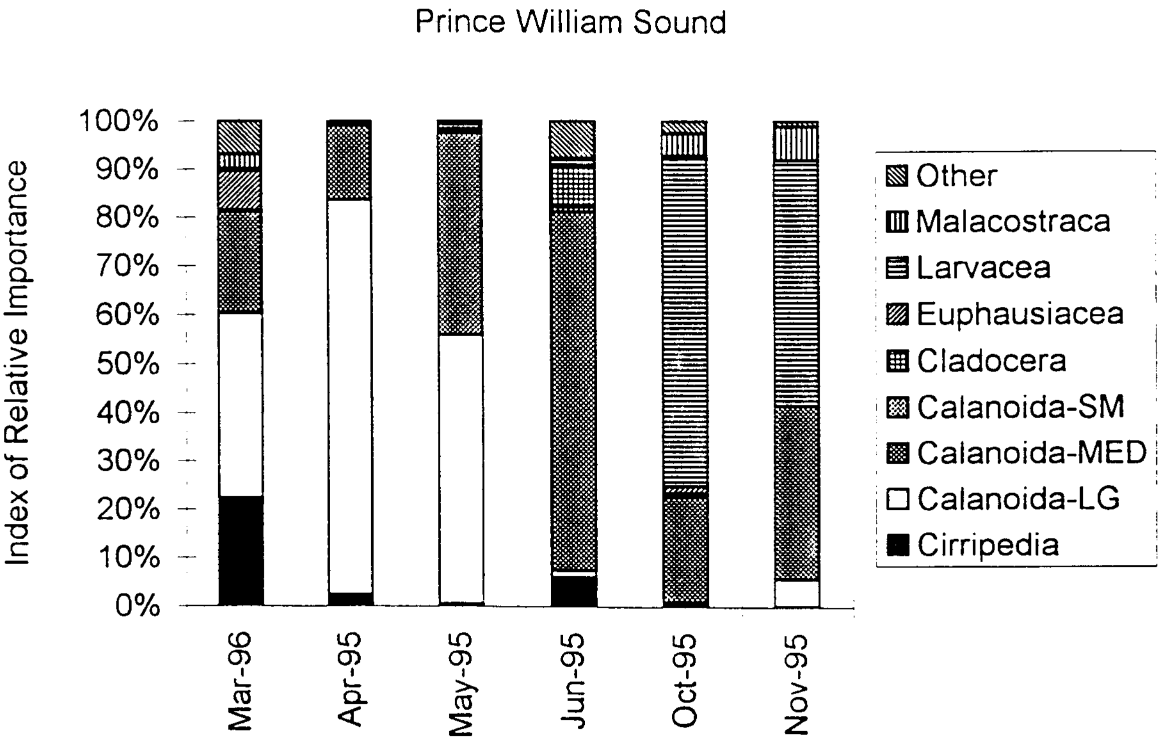

Figure 2. Average Indices of Relative Importance of herring diet from all sites sampled in Prince William Sound. Foy and Norcross 1997

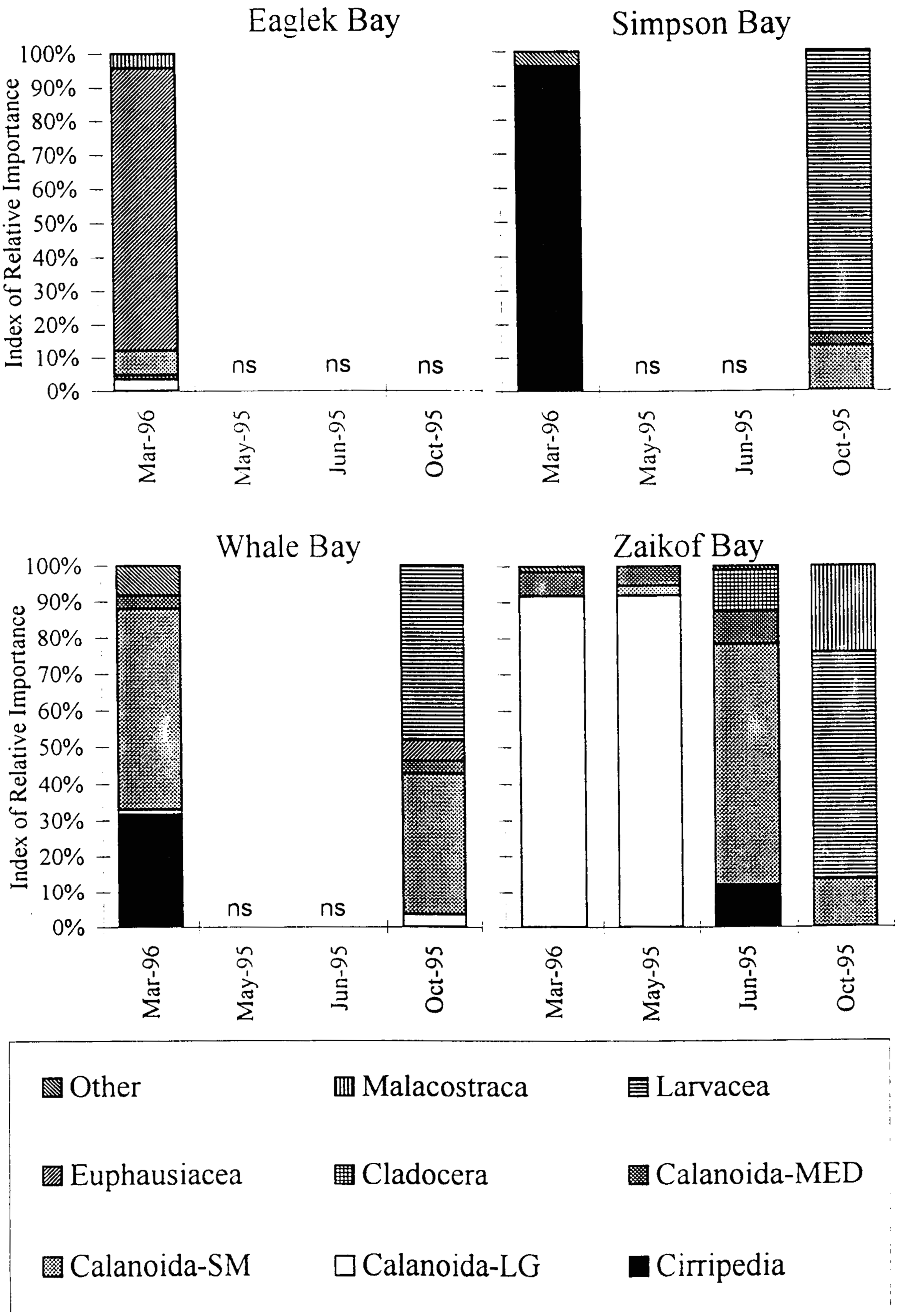

Figure 3. Indices of Relative Importance of herring prey in four bays in Prince William Sound. ns = no sample. Foy and Norcross 1997