

*Exxon Valdez* Oil Spill  
Restoration Project Annual Report

Juvenile Herring Growth and Habitats

Restoration Project 95320T  
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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**Study History:** Restoration Project 95320T was initiated as a core project of the Sound Ecosystem Assessment (SEA; PWSFERPG 1993), an integrated, multi-investigator ecosystems study of 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 apparently due to a viral infection (VHSV). Viral infection by this agent 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. This study differs from traditional herring fisheries research because of the ecological context within which these species are examined. Models are used to link physical processes to distribution of larval herring and food production in retention areas, evaluations of nursery habitat within retention areas, and overwinter survival of young herring. A sensitivity analysis, examining variations in life history parameters at different stages of development and the resulting changes in survival and recruitment, suggested that the larval and juvenile phases are critical to stock recovery and should be the focus of the SEA herring program. It is the survival of those life stages which will ultimately determine recruitment and the rate of recovery of the herring population in PWS.

**Abstract:** We focused on the distribution, feeding and condition of ages 0-2 herring (juvenile) in order to characterize their habitat. Herring were collected incidentally during net sampling for pink salmon in 1994 and 1995. Aerial surveys were conducted to analyze broad scale herring distribution in 1995. Juvenile herring were more widely distributed than adults. Preliminary results suggested that four major areas have high densities of juveniles: 1) eastern, 2) central, 3) southwestern Prince William Sound, and 4) bays in the outer Kenai Peninsula. Juveniles were abundant and available to net sampling during April, June through early August, and October. Age-0 herring migrated or moved to nearshore waters in late summer. Distribution and movements of juvenile herring in May, September and through the winter months are poorly understood. Herring were found in bays or shallow shelves with tidal mixing (less than 200 m from shore and 50 m in depth). In 1996, the distribution data and habitat characteristics will be compared with stomach contents and condition indices to evaluate differences between areas affecting survival. Historic and traditional knowledge will be compiled with the 1996 sampling data. This preliminary work enabled us to design a biologically and statistically rigorous survey and sampling plan for FY96.

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

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## INTRODUCTION

Pacific herring (*Clupea pallasii*) is a key species in the marine ecosystem of Prince William Sound (PWS). The health of the apex predator community may depend on the magnitude of herring recruitment and the condition of individual fish. The PWS herring population decline has had significant negative impacts on the commercial and subsistence fisheries. PWS herring are presently listed by the EVOS Trustee Council as damaged and not recovering. Direct restoration of this species is not practical. However, understanding and monitoring the recovery of this species is important in order to improve stock assessment for management of commercial fisheries and to guide restoration of the injured species that feed upon them.

Determining biological and physical parameters influencing early herring life history stages in PWS is important for understanding recruiting processes affecting population recovery. Previous exposure to oil, severe ocean conditions, limited food availability, and density-dependent mortality may have been the cause of the recent disease event and 1993 crash of the PWS herring population (Brown et al. 1995; Pearson et al. 1993; Brown et al. 1996). In 1993 the PWS herring population was at an all time high, several of the dominant year classes had been exposed to oil, the heavily impacted 1989 year class were recruiting as four-year-olds, food was scarce, and sea surface temperatures were relatively cold during the two previous years (Brown et al. submitted). In 1995, the biomass of herring in PWS reached a historic low and further losses of juvenile herring could compromise recovery. A recent herring recruitment model suggests that survival rates and the probability of individuals being retained in the population are higher in distinct spawning areas (Campbell and Graham 1991). Management of herring in Maine now includes spawning closures at various time and places along the Maine coast based on larval transport and survival data (Campbell and Graham 1991). Our research will provide information on the processes of survival of early life history stages of herring in PWS that can be used by managers to facilitate the recovery of the population.

The member/vagrant theory hypothesizes that a sufficient number of individuals must be retained within a spatial area, defined by the restrictions of sexual reproduction (i.e. being in the right place at the right time), for the population to continue over time (Sinclair 1988). Individuals that are retained produce the next generation while individuals that are not become vagrants, and do not contribute to the next generation of that population, although they may become founders of new populations. Larval distribution is a critical aspect of retention, however, larval research can be expensive and time-consuming. Initially, we plan to use the SEA ocean dynamics model to simulate larval drift and compare that simulation to larval distribution data collected in 1989 (Norcross et al. submitted). We will attempt to determine nursery grounds based on physical and biological characteristics, i.e. develop conceptual habitat models of herring nursery or retention areas. This technique of formulating conceptual models of nursery areas has been applied to demersal fish and is

currently being used by the principal investigator for flatfish nursery areas around Kodiak Island (Norcross et al., 1995). We hope to focus future studies on index areas in order to understand processes affecting losses within these areas and larval drift.

In 1995, we proposed to: (1) identify nursery areas for juvenile herring; (2) characterize those areas according to physical and biological parameters, and (3) start a time series to develop indices of relative abundance and condition of herring.

Preliminary results addressing the FY95 objectives enabled the formation of a statistically rigorous survey design for 1996 to examine juvenile herring distribution and habitats. This also allowed us to focus the general FY95 objectives into concise objectives dealing with the specific characteristics of the PWS herring stock in FY96. Herring were collected as ancillary data from net sampling for salmon conducted April - July 1994 and 1995, primarily on the western side of PWS. Additionally, aerial surveys were conducted specifically to analyze broad scale herring distribution in 1995. Broad-scale temporal and spatial patterns of distribution have been analyzed and small scale measurements from the acoustic data will be analyzed this winter. After locating the herring, we began to compile the data sets needed to characterize the nursery areas through measurements of the associated physical (temperature, salinity, depth, bathymetry, distance from shore, currents, and fluctuations in light levels) and biological parameters (zooplankton and predator densities). Once we have described juvenile herring distribution patterns using acoustic, aerial and net sampling survey data, we will examine the temporal consistence of these patterns (Fargo et al. 1990). We will examine regional, seasonal, and differences in patterns and relate these patterns to changes in physical and biological parameters. From these data, key areas of herring recruitment can be determined and an index of relative abundance can be developed. To have confidence in this index, it will be necessary to analyze the distribution and abundance of herring in PWS for several years to interpret similarities and differences among years and sub-populations. Knowing fluctuations in year-class strength prior to recruitment to the fishery, using a fishery-independent method, would be extremely valuable to management agencies and the fishing profession. The Principal Investigator, using a similar technique, demonstrated significant differences in annual recruitment patterns of a demersal species, summer flounder (*Paralichthys dentatus*), at a level that affected the fishery in four years (Norcross and Wyanski 1994).

Definitions:

**Juvenile herring** are considered to be ages 0-2.

**Nearshore/offshore** to be determined from the oceanography of PWS, from a pilot study across fronts and through vertical structures within fronts.



### **Nine Regions for Distribution Analysis (Figure 1):**

1. Southeast Area: includes Orca Inlet, north side of Hawkins Island, Sheep and Simpson Bays, and Port Gravina.
2. Northeast Area: includes Port Fidalgo, Tatitlek Narrows, Blight Island, Valdez Arm and Port.
3. North Shore: includes Glacier Island and waters west of Pt. Freemantle, Long, Wells, and Unakwik Bays west to Kinniklik, Eaglek Bay west to Ragged Pt.
4. Northwest Area: includes Esther Island, Port Wells, Wells Pass., Perry and Culross Islands, Port Nellie Juan, and Knight Island Passage to Pt. Nowell.
5. North Central Sound: Naked Island and Smith Islands; northeast side of Knight Island; pelagic region east of Naked Island to Johnstone Point on northern Hinchinbrook Island.
6. South Central Sound: Montague and Green Islands and Montague Straits including east side of Latouche.
7. Hinchinbrook Entrance: eastern shore of Montague Island and Port Etches on Hinchinbrook.
8. Southwest Area: south Knight Island Passage from Pt. Nowell and including islands, bays and passes to Port Bainbridge; the western boundary is Cape Puget.
9. Outer Kenai: Bays and outer coast from Cape Puget west to Nuka Pt. including Resurrection and Aialik Bays.

### **Herring work in relation to SEA hypotheses**

#### ***Under Lake/River Program***

Determine the trajectory of free-drifting larvae and their distribution as age-0 juvenile herring using a larval drift simulation. Determine differences in zooplankton concentrations between areas due to variations in zooplankton production and transport to nursery areas.

#### ***Under Predator/Prey Program***

This hypothesis was developed primarily for pink salmon. Since herring are annual residents of PWS and the surrounding area and predation varies according to life stage, distribution of herring and predators, we will construct hypotheses on predation processes once primary habitats have been located and characterized. We will derive a proxy measure for mortality, most likely due to predation, through the overwintering survival model. The

assumption is that herring under a certain energetic content are more susceptible to predation.

***Under Herring Overwintering Program***

Determine how the condition of juvenile herring entering their first winter and winter ocean conditions affect survival, measured by changes in relative abundance of those fish.

**OBJECTIVES**

In the original study plan for FY95, the following **initial objectives** were listed:

1. Begin to determine relative spatial and temporal abundance, growth of and primary predators on juvenile herring in eastern and western regions of PWS.
2. Begin to compare seasonal differences in the parameters listed in objective one.
3. Relate seasonal and annual differences in juvenile herring population parameters to relative abundance of prey resources and predators (including birds) sampled at the same time and locations. Confirm primary predators with information on stomach contents or behavioral observations where possible.
4. Determine the physical characteristics of habitats where herring aggregations are found including temperature, depth, salinity, distance from shore, time of day and tide cycle at capture, and current profile at that time and place.
5. Begin work on a predictive model of age-0, -1, and -2 herring location knowing the location and relative abundance of embryos at the natal habitats, the information gained through this and other studies, and the ocean circulation within the sound for any given year.

We were able to restate our first year **research questions** more clearly once we began to examine and understand the information available on juvenile herring:

- 1) Does distribution of embryos and ocean circulation affect the distribution of juvenile herring?
- 2) What are the physical (temperature, salinity, current structure, depth, distance from shore) and biological (trophic structure) characteristics of juvenile herring habitat?
- 3) Are there differences in distribution and condition (length and weight at age, energetic, stable isotopes) of age-0 and older juvenile herring in relation to habitat?

We proposed to evaluate the nursery habitat for juvenile herring in order to understand processes affecting survival and recruitment. In order to do this, we relied on other projects within and outside of SEA to provide us with the data sets needed to examine the idea of "optimal versus suboptimal" habitats. Some of the data sets needed were not available until the end of the fiscal year and many others are still being formulated. Our first year was more information gathering than analysis and once we understood the data available within the predetermined sampling confines, we were ready to **restate our objectives** and more clearly define our research direction:

- 1) Determine diel vertical distribution of juvenile herring.
- 2) Determine horizontal distribution of juvenile herring by regions of PWS and Outer Kenai.
- 3) Determine nearshore/offshore distribution of juvenile herring.
- 4) Determine temporal distribution of juvenile herring, i.e., where herring are throughout summer season.
- 5) Use above information to develop field study plan for 1996.

## **METHODS**

### **Data Compilation**

A large part of our efforts have been and will continue to be devoted to compiling data sets from other projects funded by EVOS. We have compiled the net sampling data from 1994-1995 SEA pink salmon (Willette, 95320-A & E) and 1994-1996 APEX forage fish databases (Haldorson). Data from net sampling includes age, weight, length (AWL), condition, energetic content (Paul, 95320-U) and isotopes (carbon nitrogen ratios and delta C-13 values; Kline, 95320-I). We will also rely on other projects for collections of habitat characteristics including zooplankton species composition and concentrations (Cooney, 95320-H), CTD, acoustic Doppler and other oceanographic parameters describing regions and sites (Vaughan and Salmon, 95320-M), and density of competitors such as age-0 and -1 pollock (Thomas, 95320-N; Haldorson, APEX). Finally, we have developed databases for broadscale distribution information on herring, other schooling fish, and foraging birds from our 1995 summer aerial surveys. The compilation of these data sets allows us to conduct analyses on several spatial and temporal scales. Currently, there is a three month lag between our data collection and the beginning of analysis. There is a six to ten month lag between data collection, our receiving the data, and preparing for analysis of other SEA and APEX projects. These time lags must be considered in project planning and allowances must be made by the funding agencies. Multidisciplinary efforts of this scale require more time than single investigator efforts.

## **Net Sampling**

In 1994 and 1995, researchers sampled predators and prey of pink salmon, including both juvenile and adult herring, in the western corridors of PWS. Sampling gear included mid-water trawls, anchovy seines, gillnets, hoop traps and small tow nets. Diel surveys (24 hr sampling) were conducted during the months of April through September from Esther Island to the passages in southwestern PWS in 1994. During the months of April and May 1995 sampling effort focused around Esther Island, and at three isolated locations where herring typically occur (Port Gravina, Orca Inlet, and Zaikof Bay). Seine catches of herring under 150 mm (fork length) and over 150 mm were extracted from the R-base database where catches were archived. Catch data were sorted by numbers of herring collected in each size category, for each month, to examine horizontal and seasonal distribution. The distance from shore of each fish collection (measured using the ship's radar) was plotted to determine the nearshore/offshore distribution. Information on the diel migration of herring was not obtainable from the catch data. Acoustic data sets will be used in the future to assess the three dimensional distribution over 24 hr as well as seasonal time scales.

## **Aerial Surveys**

Broad scale aerial surveys covered PWS and Outer Kenai from Hinchinbrook Entrance to Nuka Point. A survey of the entire area required 3-6 hours of observations daily for 5 days using a Cessna 185 float plane at an altitude of 305 m (1000 ft). When lower altitudes were flown, due to a low cloud ceiling, it was noted in the data base. A hand held GPS connected to a lap top computer with a flight log program recorded latitude, longitude, and time of day on a 2 second interval. At the beginning of each flight the pilot, weather, water visibility, wind, wind direction, tide stage, and other notes concerning the survey were recorded in the log program. Information such as fish schools, approximate surface area of schools, foraging birds or mammals, or other oceanographic features were also recorded on the computer log program. Criteria developed to characterize fish schools closely followed that used by the Alaska Department of Fish and Game for the past twenty years (Lebida and Whitmore 1985; Brady 1987). In 1995, we tried to eliminate tidal effects on the distribution of fish schools by flying during the flood tide whenever possible. Fish school shape was described as round (characteristic shape for herring; Misund 1993), oblong, U-shaped, irregular or streak (jellyfish often form long white "streaks"). Suspected species composition (generally herring, capelin or sandlance for fish schools and kittiwakes or glaucous-winged gulls for birds) and any validation (visually identification or fish collection) of school was recorded. Bird behavior was recorded as foraging, resting on water, resting on shore, aggregated tightly on water over school, traveling or flying in a "broad area search". Fish schools sighted during the surveys were counted and roughly categorized by size or approximate surface area of school:

|        |  |
|--------|--|
| small  | surface area $\leq 50 \text{ m}^2$                         |
| medium | surface area $> 50 \text{ m}^2$ but $\leq 450 \text{ m}^2$ |

large surface area > 450 m<sup>2</sup> with an estimate noted

In 1995, the surface area of schools was estimated by categorizing school size. Surface area estimates of schools were made with a sighting tube constructed of PVC pipe with a grid drawn on mylar on the end. The tube is 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:

$$X = A ( L / F ) \text{ (Bering Sea Herring Operation Plan: 1981; Brady 1987).}$$

The use of the grid is particularly important for estimating the size of large schools. For elliptical shaped schools, maximum length and maximum width will provide a rough estimate of surface area; for irregularly shaped schools (U-shaped, long wavy bands, etc.) measured length and width of separate sections were combined to calculate a total estimate. Ground reference points of known or easily measurable surface areas, such as a helipad, should be used to train the eye to the scale on the sighting tube grid for any specific altitude flown prior to each survey series.

## RESULTS

Prince William Sound was divided into nine regions and all the data was categorized into these regions (Figure 1). Net sampling in 1994 and 1995 and aerial surveys in 1995 revealed spatial and temporal aspects of juvenile herring distribution. Some of the aerial data from May and early June of 1995 is currently being digitized because the log program was not available at the time of recording. Data from acoustic surveys to accompany the net sampling data were not available for incorporation in this report, as they are presently being analyzed. From these preliminary analysis we designed a biologically focused, statistically rigorous survey for the 1996 field season. The following results are preliminary.

### Horizontal

In 1995, herring, especially juveniles 0-2 years of age, were found over a wide area based on aerial observations (Figure 2-4). Although juvenile herring were broadly distributed, there seem to be areas where greater numbers are concentrated: 1) Port Gravina in eastern PWS, 2) northern Montague Island and Green Island, 3) southwestern PWS, including Whale and Jackpot Bays and Port Bainbridge, and 4) Resurrection and Aialik Bays in the outer Kenai Peninsula. Orca Bay and Inlet including Middle Ground Shoal may also be an important area and may encompass Port Gravina as the primary eastern PWS rearing area. Visual plots of net catches for 1994 and 1995 provided little information about the horizontal distribution of herring because net sampling was restricted to limited parts of the sound (Willette 95320-A&E; Figures 5-20). However, in areas where net sampling and aerial surveys were both conducted (Figure 2, 19 and 20), observations were generally in agreement.

## **Temporal**

Juvenile herring were most abundant in net catches from June and least abundant in April during the springs and summers of 1994 and 1995 (Figure 21). Prior to 1995, no surveys conducted during other times of the year. From the air, herring appeared to be most abundant in late June through early August (Figures 2-4). The net catch results indicate a seasonal flux of juvenile herring to nearshore waters in PWS starting in May.

## **Nearshore/Offshore**

In 1994 and 1995, there were no nearshore descriptions of hydrography and bathymetry, only distance from shore and depths were recorded. Juvenile herring were most abundant within 200 m of shore in depths less than 50 m based on net collections (Figure 22). Catches were log transformed to reveal trends in the data. From the air, fish schools were generally observed nearshore (Figure 23) and more herring were found inside bays than in passes (Figures 2-4). Large concentrations of herring schools were observed off Green Island, near northern Montague Island. Herring were observed over the extensive shallow shelves (less than 50m in depth) in that region.

In late July to early August, age-0 herring were observed in nearshore waters particularly near Green Island, northern Montague and Snug Corner Cove inside Port Fidalgo.

## **Diel Vertical**

Diel vertical migration of herring was not well documented in the data sets available. Surface schools of small age-0 and -1 herring were observed from the floats of the survey plane in tight schools which would contract and expand in response to visual stimulus. In deeper water, the surface schools would dive in response to the aircraft and foraging gulls at the surface. The acoustic data (Thomas, 95320-N) from areas over a 24 hr period will reveal more detail and will be available in the near future.

## **1996 Survey Design**

Based on results from cruises in 1994 and 1995 and anecdotal information from historic fisheries and ADFG surveys, we have designed a survey for FY96. This survey will focus on collecting data to meet the goals and objectives identified by the Herring Work Group of SEA.

## ***Field Survey Design***

Broadscale aerial surveys will continue during the summer when surface schools are visible. When conducting aerial surveys, we will following the same methodology described in this report. The difference between 1996 and 1995 surveys will be the coordination with vessels. We will conduct aerial surveys simultaneously with acoustic surveys and net sampling. In a pilot study, we will use a compact airborne spectrographic imagery system to more accurately assess school surface area and compare this information to trained observers (CASI; Nakashima and Borstad, 1993; Funk et al., in press). This instrument is becoming increasingly cost-effective to use and may become an important tool for long term monitoring

of not only juvenile herring, but other forage fish visible from aircraft (G. Borstad, Seattle, WA, personal communication).

Surveys conducted from vessels will have two basic components: 1) broadscale reconnaissance, and 2) diel investigations at specified sites. Both components will be conducted in each of the nine regions we have identified (Figure 1). During the FY96 field season (Fall 1995 through summer of 1996), we will conduct 10-12 reconnaissance surveys and visit 9-11 diel sites within the nine regions. In 1996, we will complete an analysis of the broadscale distribution data that will allow us to identify critical regions. For the 1997 season, we will reduce the numbers of reconnaissance and diel surveys to 6 focusing on the critical regions. Our goal is to conduct one reconnaissance and one diel survey in each region identified for study. Each set of a reconnaissance and a diel survey will take two days to complete.

During broadscale reconnaissance surveys, the objective is obtain regional scale relative abundance indices of juvenile herring and other fish species using fishing and scientific acoustics. The species making up the acoustic targets will be identified using net collections. Reconnaissance surveys will be conducted over a 12 hr period. Surface migrations of pelagic fishes at night has been well documented (Mais 1974). In PWS, adult herring are more easily enumerated using acoustics at night (DeCino et al). During the fall and spring surveys, the entire reconnaissance survey period is dark. During the summer surveys, the 12 hr survey period will encompass sunset, dark of night and sunrise. The reconnaissance surveys consist of an acoustics vessel, a seiner, trawler and fish processing vessel. During the 12 hours, the acoustic vessel will be mounted with a horizontal scan, vertical (20 degree, 50 KHz), and Biosonics 70KHz Digital and 200 KHz Analog sonars (Thomas, 95320-N) and driven in a series of onshore and offshore zig zags. The vessels will proceed from a maximum offshore distance of one nautical mile and approximately 200 m depth to a minimum onshore depth of 10 m. The seiner and trawler will be dispatched to sample aggregations or layers of fish for verification of acoustic targets. A maximum random subsamples of 1000 fish of each species collected will be measured (fork length) and used to translate acoustic targets into individuals per meter cubed. A random subsample of 450 herring from each herring aggregation will be collected for measurements of weight and age in addition to the length measurements. GPS coordinates will be logged on laptop computer software and schools or acoustic layers observed on the horizontal scan or vertical sonars will be recorded while maintaining a vessel speed of approximate 9-11 knots. When a concentration of targets that look like herring are observed, the vessel will slow to 4-6 knots and the acoustic sonars will be deployed. This design will survey a much larger area as acoustic measurements of target density will only be collected in the presence of targets. In areas surveyed using the horizontal scan, but without data from the Biosonics gear, density of the target species is assumed to be near zero with a threshold density established by measurements taken with the scientific sonar. Both data sets, from the horizontal scan or Biosonics gear will be used in the broadscale distribution analysis. For statistical treatment of potentially dependent transects collected in a zig zag manner, zigs will be separated from zags and treated as replicates (for a more detailed description of treatment of acoustic data see

Thomas, 95320-N). The result will be two matching sets of parallel offshore and onshore transects.

At the diel sites, identified as juvenile herring aggregation areas within a region, an 12-18 hr survey will be broken into four 2-4 hr sampling periods. Diel sites will be approximately 10 to 20 km<sup>2</sup> in surface area. A site will consist of an entire bay or section of shoreline along an island or in a pass. The first sampling period will begin at sunset (1800 hours). The second period will occur during the early evening (2200 hours). The third period will occur during the late night (0200 hours). The fourth period will begin at sunrise (0800 hours). A light meter will be deployed on shore or on the crow's nest of the acoustics vessel to measure light level for 5 minute intervals. The vessel configuration for diel surveys will consist of an acoustic, a seiner, a nearshore trawler, a nearshore oceanography and a fish processing vessel.

The acoustics vessel will be outfitted with the two frequencies used for the reconnaissance survey as well as a 420 KHz vertical system. During each 2 hr sampling period, a series of parallel acoustic transects will be conducted perpendicular to shore. The minimum number of transects needed for statistical significance for biomass estimates or relative abundance is 12 (Thomas, 95320-N). A single nearshore transect parallel and close to shore will also be conducted to provide more detail for the description of nearshore distribution using primarily the side looking mounted sonar. The methods for processing this data are currently being worked out by Dick Thorne, Biosonics, Jay Kirsch, Prince William Sound Science Center (PWSSC; 95320-N) and Ken Coyle (APEX Predators), UAF. The chief scientist aboard the acoustic vessel will identify fish schools for target verification and dispatch the seiner or trawler to sample them.

The seiner will be dispatched one half hour after the start of each 2 hr sampling period to sample the upper 30 m of the water column. The seiner will use two 200 m long anchovy seines with stretched mesh size of 25 mm, one 35 m and one 20 m deep. The trawler will sample deeper layers. The trawler will use with a 400 mesh eastern trawl with approximately 300 kg, 1.52 X 2.13 m Nor' Eastern Astoria V trawl doors. Headrope and footrope lengths of 21.34 and 28.96 m respectively. The estimated fishing height and width of the net are 2.74 and 12.20 m respectively. This trawl has 10.16 cm mesh in the wings and body, 8.89 cm in the intermediate and cod end, and a 3.18 cm cod end liner. A net sounder will be attached to the head rope of the trawl to provide information on fishing depth and size of opening of the trawl. The trawler will also have a 3 1.0 mm NIOs (Tucker trawl) with cable, double messenger system, and codends to validate smaller targets. Trawls will be towed a distance of 1.85 km (1 nautical mile) measured with the ship's GPS. The trawler will keep a constant speed of 4.6 km per hour (2.5 knots). Start time for fishing will be recorded when the net is set at a specified length of cable and depth. Stop time will be recorded as soon as cable retrieval has begun. Samples will be collected according to protocols outlined in a cruise plan.



The nearshore oceanography vessel will follow an independent set of protocols during the 18 hr diel. They will define nearshore versus offshore areas using oceanographic descriptions, define physical boundaries of the nursery areas, and assess the vertical structure of the water column through the tide cycle. Detailed methodology for nearshore oceanography sampling is being developed cooperatively with Vaughan and Gay, SEA Oceanography (95320-M). This vessel will also be used to collect discrete zooplankton samples. The equipment on board will include 2 Seabird CTDs, an Acoustic Doppler Current Profiler (ADCP), an Optical Plankton Counter (OPC) with continuous measuring CTD both mounted on an aquashuttle for towing, and 2 .3 mm mesh vertical plankton nets. The ADCP will be mounted to the side of the vessel. The vessel will follow transects designed to meet the sample objectives at about 11-15 km per hour (6-8 knots) using the ADCP and OPC. After each set of continuous transects, the vessel will go to a series of discrete sites for CTD and zooplankton casts. In addition to visiting each diel site and collecting descriptive habitat data, the oceanography vessel will sample four sites of similar dimensions to the diel sites to provide information on habitats void of herring.

Finally, the fish processing vessel will be dispatched to a fixed location and set up for the processing of samples from the two fishing vessels. During reconnaissance surveys, the processing vessel will head to a location well ahead of the reconnaissance fleet and anchor. Half way through the reconnaissance survey, catches from the fishing boats will be delivered to the processing vessel. The remainder of the samples will be delivered at the end of the reconnaissance. All vessels will converge at the diel location following the end of the reconnaissance, anchor and rest. At the end of each 2 hr sampling period during the diel survey, the catch from each fishing vessel will be delivered to the processing vessel. Samples will be processed according to the protocols listed in the cruise plan.

### ***Planned Data Analyses***

There are three categories of analysis planned for the data collected during this survey (Figure 24):

- 1) analysis of broadscale (nine regions PWS to Outer Kenai) spatial and temporal distributions using aerial and acoustic data.
- 2) habitat analysis, comparing biological and relative abundance indices of juvenile herring with biological and physical habitat characteristics from each diel site. The analysis will be conducted on three time scales: 24 hr, seasonally, and annually.
- 3) diet and feeding analysis.

### ***Horizontal broadscale distribution***

The acoustic/net collection data will provide mean values of several biological indices on different spatial scales (km<sup>2</sup>, diel sites, regions). These indices include average density (g/m<sup>3</sup> and individual/m<sup>3</sup>) of acoustic herring targets (verified by net sampling as juveniles herring during reconnaissance surveys), size at age, and condition indices (Fulton's index

and energetic content; Paul, 95320-U), and surface area of schools spotted from summer aerial surveys. Position, numbers and sizes of schools will continue to be recorded to calculate the aerial extent of herring within each sample region. We will use power analysis to estimate appropriate sample size and examine the problems of autocorrelation (randomizing the data being one possible solution). We will then apply ANOVA procedures to detect significant differences in the biological indices between regions and regression analysis.

The aerial survey data (CASI and trained observers) will provide spatial distribution information of schooling fish, primarily herring. These two techniques will be compared to determine their precision and accuracy. It will then be possible to divide these observations into a nested quadrat design, randomize the data on different spatial scales and apply quadrat techniques to interpret these data (Gunderson 1993). Using quadrat analysis it will be possible to describe the observed spatial distributions statistically and compare them to random (Poisson), contagious (negative binomial) or regular distributions. It will also be possible to determine mean surface area of fish schools on different temporal scales, such as, tidal phase, day time, seasonal, and spatial scales, such as, km, diel sites (bays versus passes), regions, and PWS. Examining these spatial distributions on temporal and seasonal scales will lead to the underlying physical and biological parameters influencing these distributions. Once these distributions and the parameters influencing them are determined it will be possible to estimate their effect on herring survival and recruitment into the PWS stock.

#### *Habitat analysis*

For this analysis we will use a series of multivariate techniques in an iterative process using data collected at the diel sites. We will follow a nested design using three time scales starting with 1) annual means for sites, 2) followed by monthly or seasonal means, and 3) finishing with means within a 24 hr time period. In this manner, important processes affecting biological production operating within each of these time scales will be identified. Multivariate procedures may include principal component analysis to reveal selectivity patterns, clustering, ordination procedures, canonical correlation analysis and ending with multiple regressions. Biological indices used as dependent variables will include size and age, feeding analysis, condition indices, carbon nitrogen ratios, delta C-13 values, and relative abundance from acoustic and aerial surveys. Independent variables include zooplankton concentrations (all time scales), CTD data (all time scales), surface area to flow ratios for nursery areas (12 months), current profiles and tidal flows (all time scales), regional oceanographic descriptions (12 months), characterization of vertical structure in water column (12 months), relative abundance of competitors (age 0-1 pollock, all time scales), and abundance of marine mammals and sea birds (all time scales).

#### *Diet and feeding analysis*

Data on juvenile herring feeding behavior will be collected on several spatial and temporal scales. Juvenile herring during each diel sample will be dissected and their stomach contents will be identified. Thus it will be possible to determine if vertical migration occurs primarily for feeding and how much daily energy is acquired. It will also be possible to

correlate this data with the age-weight-length, oceanographic and isotope data and condition indices to compare spatial (diel sites, regions) and temporal (seasonal and annual) variations.

We will work with other investigators in the herring working group of SEA to use the results of these analyses to develop the model products (see summary of model components in discussion). These results will provide critical input for those models.

## DISCUSSION

We were able to determine the 1995 summer broadscale horizontal distribution of juvenile herring in PWS through the results of the aerial survey. This data set provided limited information on juvenile herring as net collections and acoustic surveys were not conducted simultaneously and the 1995 field surveys focused on salmon, which required a different sampling protocol. Visual plots from net catches (Figures 5-20) were deceiving since net surveys were concentrated in the western corridor and three discrete sites around the Esther hatchery in 1995. Because the net sampling of 1994 and 1995 occurred largely in passes and in the mouths of bays, it may be that many of juveniles farther in the bays were not sampled. Analysis of the acoustic data from 1994 and 1995 (collected simultaneously to net catches) will reveal more detail about relative abundance and vertically distribution in the limited areas herring were sampled.

Juveniles were seasonally abundant during the months of April, and June through to early August in 1994 and 1995. Age-0 herring were observed by aerial survey to recruit to nearshore waters in late July and early August, presumably just after metamorphosis (based on trawl surveys from 1989; Norcross et al. submitted). Presently the overwintering distributions of juvenile herring in PWS are unknown, however, our surveys in October 1995 and March 1996 will begin to describe these distributions.

A detailed analysis of the physical characteristics of each area, especially oceanographic qualities (salinity, temperature, bathymetry, current profiles, mixing), will help us describe juvenile herring nearshore habitats. Preliminary observations indicate that herring tend to rear in areas of significant tidal mixing where food is entrained, but which provide adequate shelter over shallow shelves (S. Gay, 95320-M, personal communication).

Juvenile and adult herring appear to undergo significant diel migrations cued by light levels (Evans et al. 1975). In the summer, with high light levels most of the day, herring may spend their day avoiding predators and their relatively short lived periods of dark feeding on zooplankton. In Zaikof Bay on northern Montague Island, juvenile herring were observed on the bottom or schooled in tight balls close to the surface. At dusk, herring seem to spread out over a wider area to feed. During daylight in the summer, we observed a school spreading out to feed until the school received a visual stimulus, such as shadow from our airplane or diving bird, caused them to reform a tight school and flee. Analysis of

acoustic data as well as better designed surveys will enable us to document this vertical aspect of juvenile herring distribution and determine its underlying biological significance.

We were able to develop a survey design targeted to answer questions posed by SEA about the early life history of juvenile herring. This was largely based on the aerial survey data and data provided by the first two years of related projects in SEA. We have also been able to develop a SEA herring research direction because of the formation of working groups within SEA. A Herring Working Group has developed a conceptual herring recruitment model which will guide our next 3 years of research.

A Pacific herring recruitment model is being developed by integrating various submodels, each of which focuses on an early life history stage. We hypothesize that, like other clupeids, year-class strength of Pacific herring in Prince William Sound (PWS) is determined during its early life history (Blaxter and Hunter, 1982; Stocker et al. 1985). All field and laboratory experiments for all involved components of SEA in FY96-97 will 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. The Lake/River hypothesis applies to transport and distribution of herring at the larval stage. We will use the Ocean Dynamics Model (Mooers and Wang, 95320-J) to conduct simulations of larval drift to predict the distribution of age-0 herring within PWS. We expect to be able 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 Herring Overwinter Survival Model is based on the hypothesis that survival of herring through their first winter is key to survival and ultimate year-class strength of juvenile herring and is dependent upon the condition juvenile herring and overwinter ocean conditions. We will approach this hypothesis by examining the distribution and condition of herring in the fall, throughout the winter and again in the spring. We hypothesize that there will be a decline in condition indices over the winter. We further hypothesize that differences in the fall condition indices of juvenile herring between areas is related to geographic location and the physical and biological conditions that characterize these locations. The Summer Habitat Model will compare the relative abundance and condition of juvenile herring between locations in which habitat characteristics have been documented to determine "optimal" versus "suboptimal" nurseries. The Summer Habitat Model will link with the Overwintering Survival Model and together they will produce a Herring Recruitment Model for the first two years of the life history of PWS herring.

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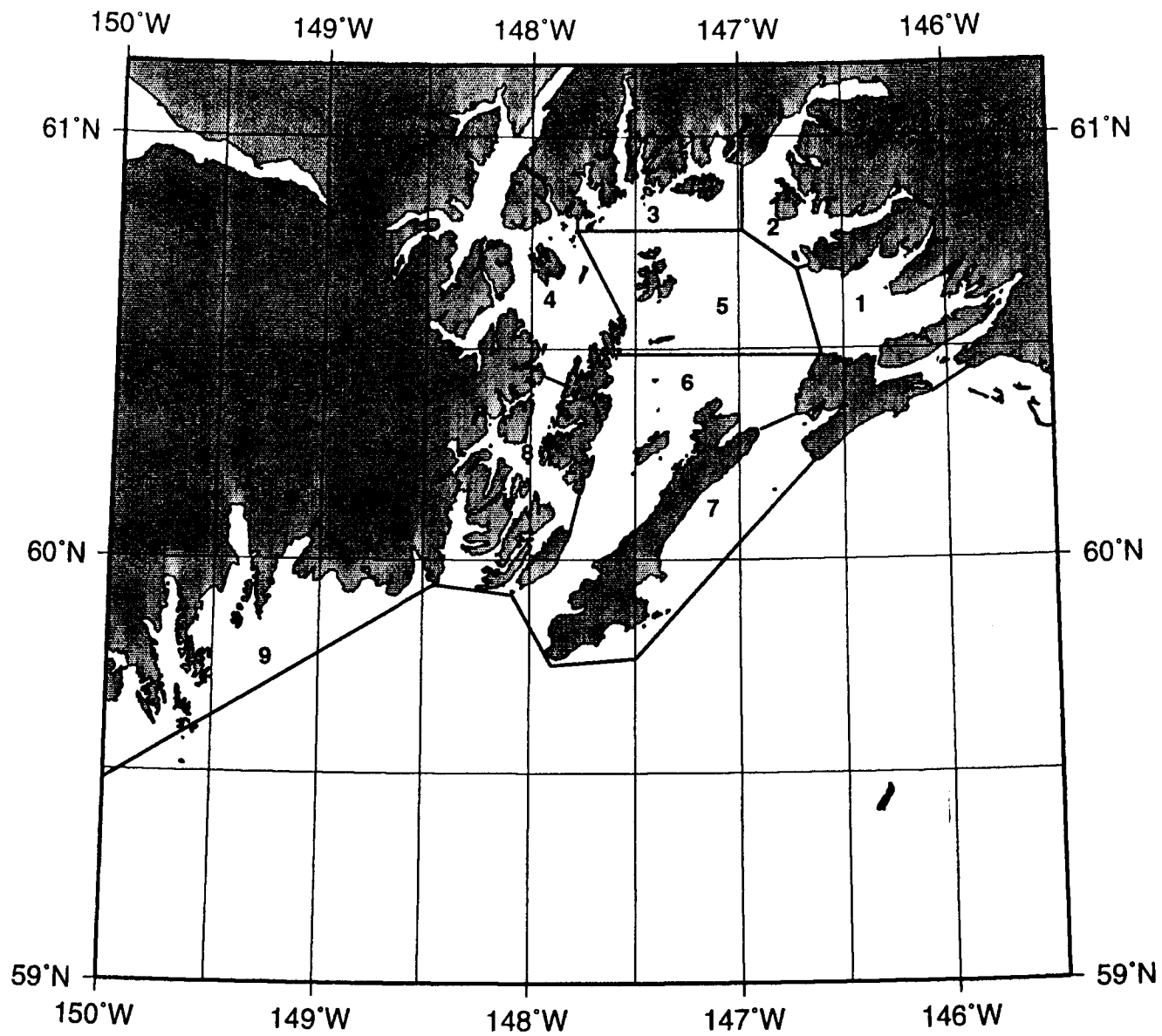


Figure 1. Regional divisions of Prince William Sound for the analysis of broadscale Pacific herring distribution.

# PWS Sampling June 1995 Aerial Surveys

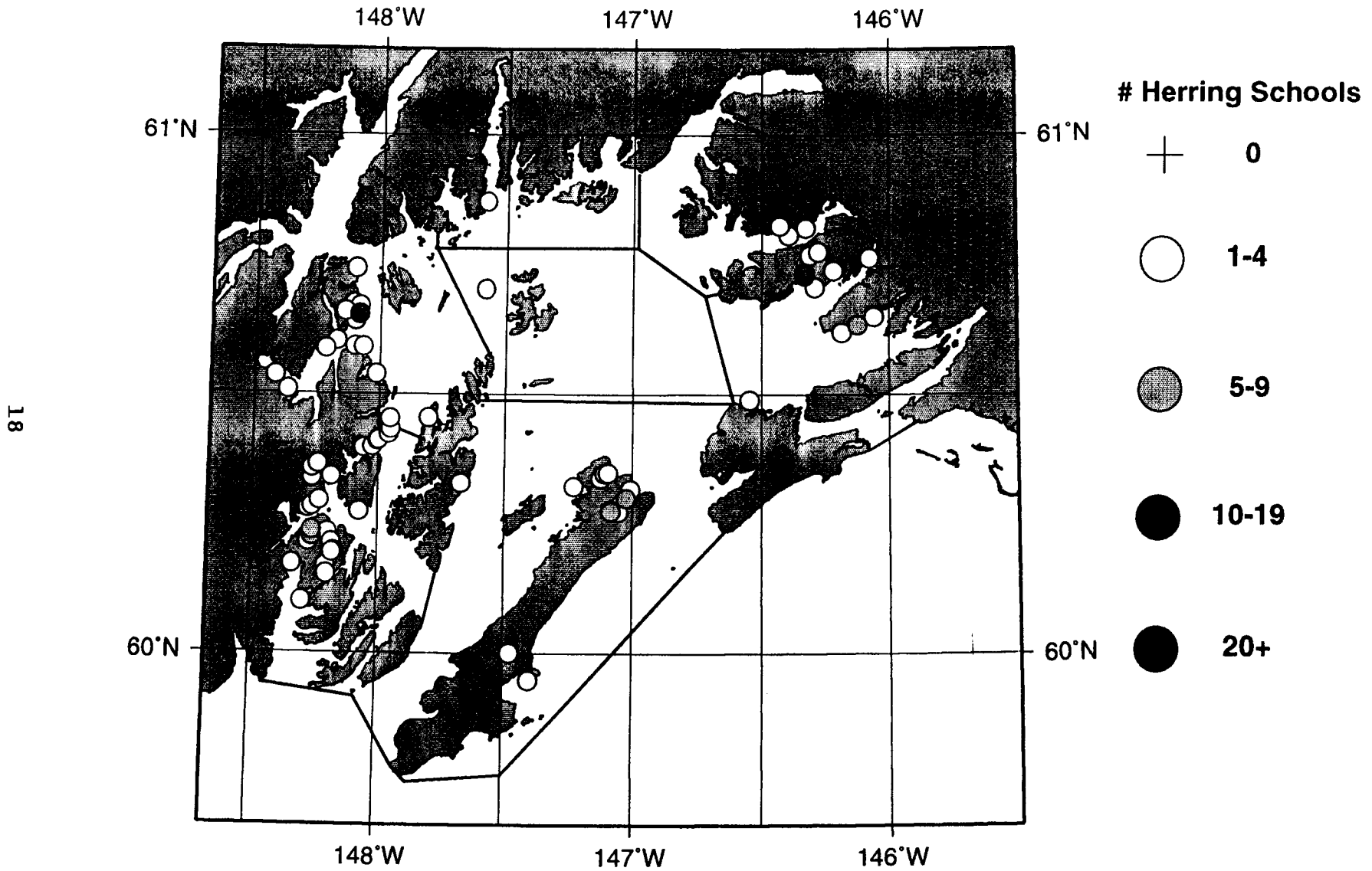


Figure 2. Distribution of Pacific herring schools in Prince William Sound in June, 1995.



# PWS Sampling July 1995 Aerial Surveys

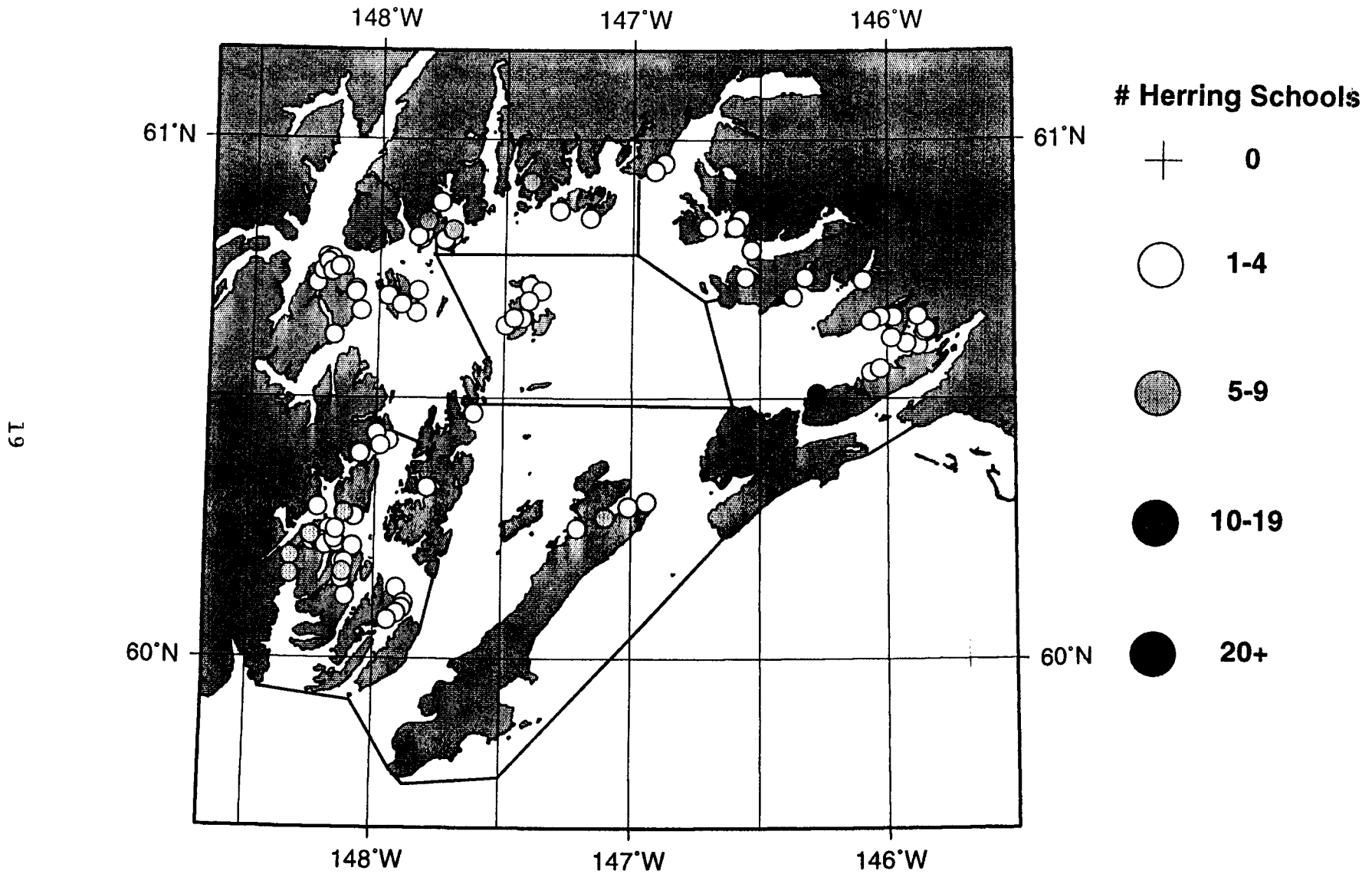


Figure 3. Distribution of Pacific herring schools in Prince William Sound in July, 1995.

# PWS Sampling August 1995 Aerial Surveys

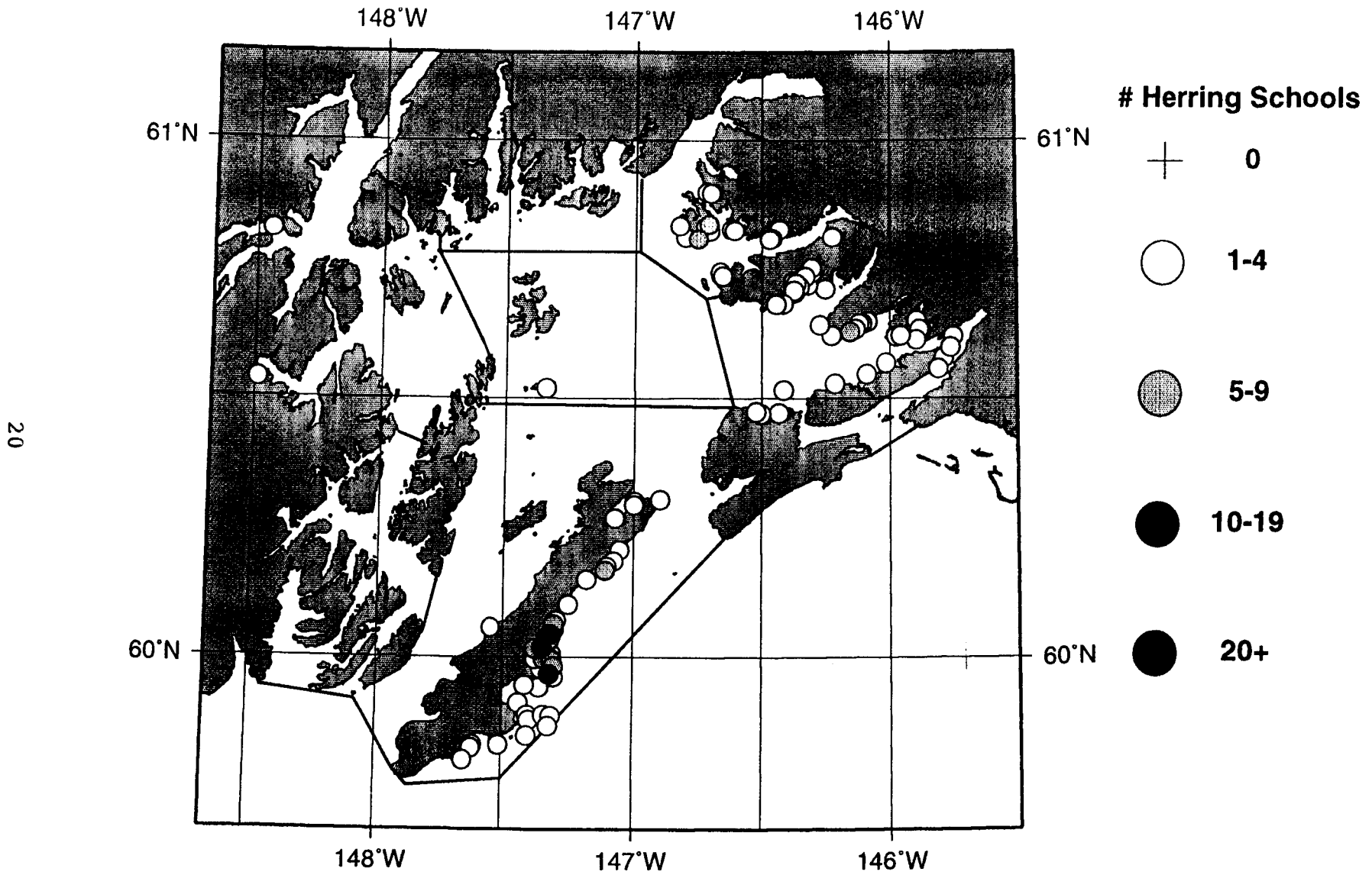


Figure 4. Distribution of Pacific herring schools in Prince William Sound in August, 1995.

# PWS Sampling April 1994 Less Than 150 mm

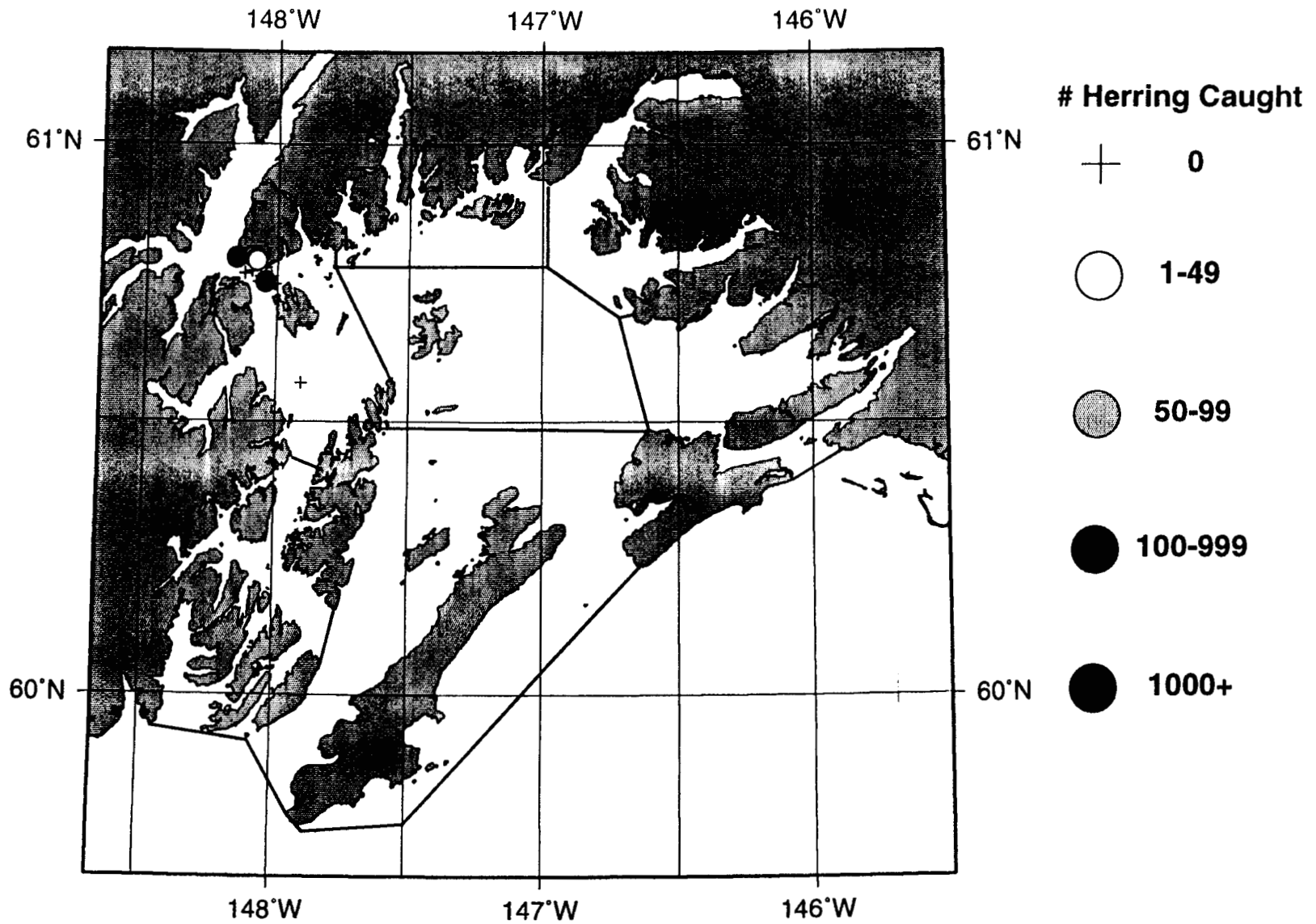
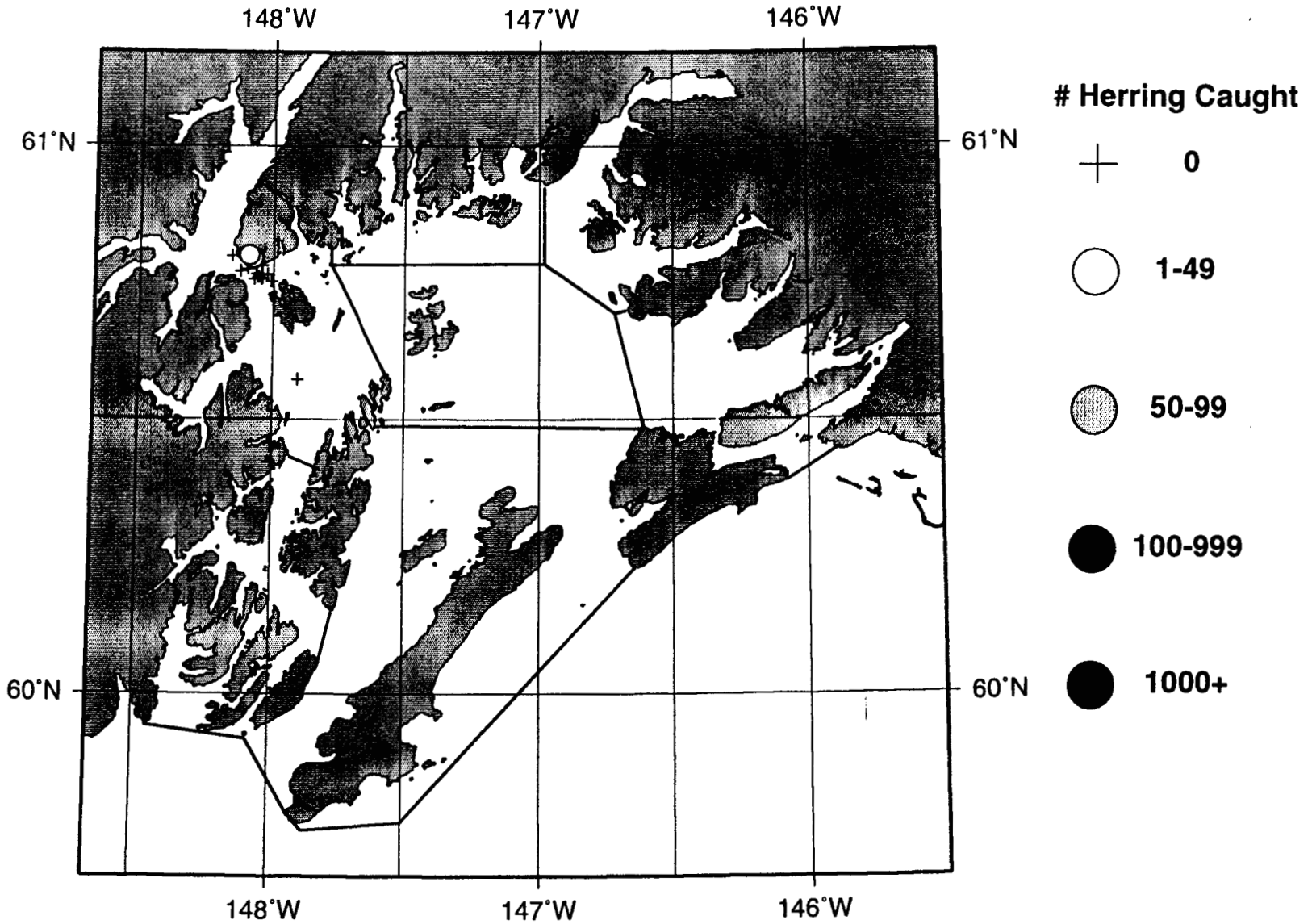


Figure 5. Net catches of Pacific herring less than 150 mm fork length on the west side of Prince William Sound in April, 1994.

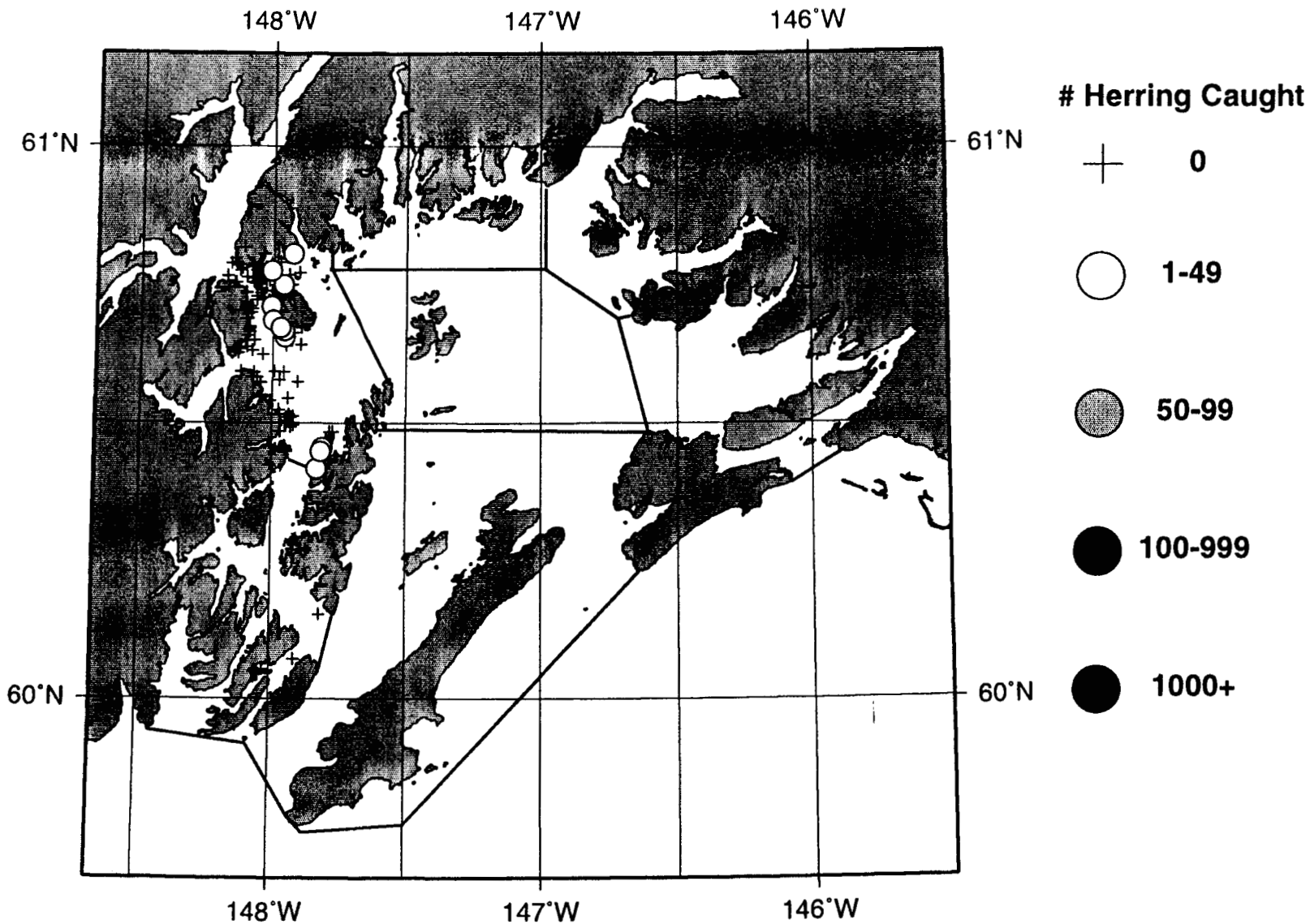
# PWS Sampling April 1994 Greater Than or Equal to 150 mm



22

Figure 6. Net catches of Pacific herring greater than or equal to 150 mm fork length on the west side of Prince William Sound in April, 1994.

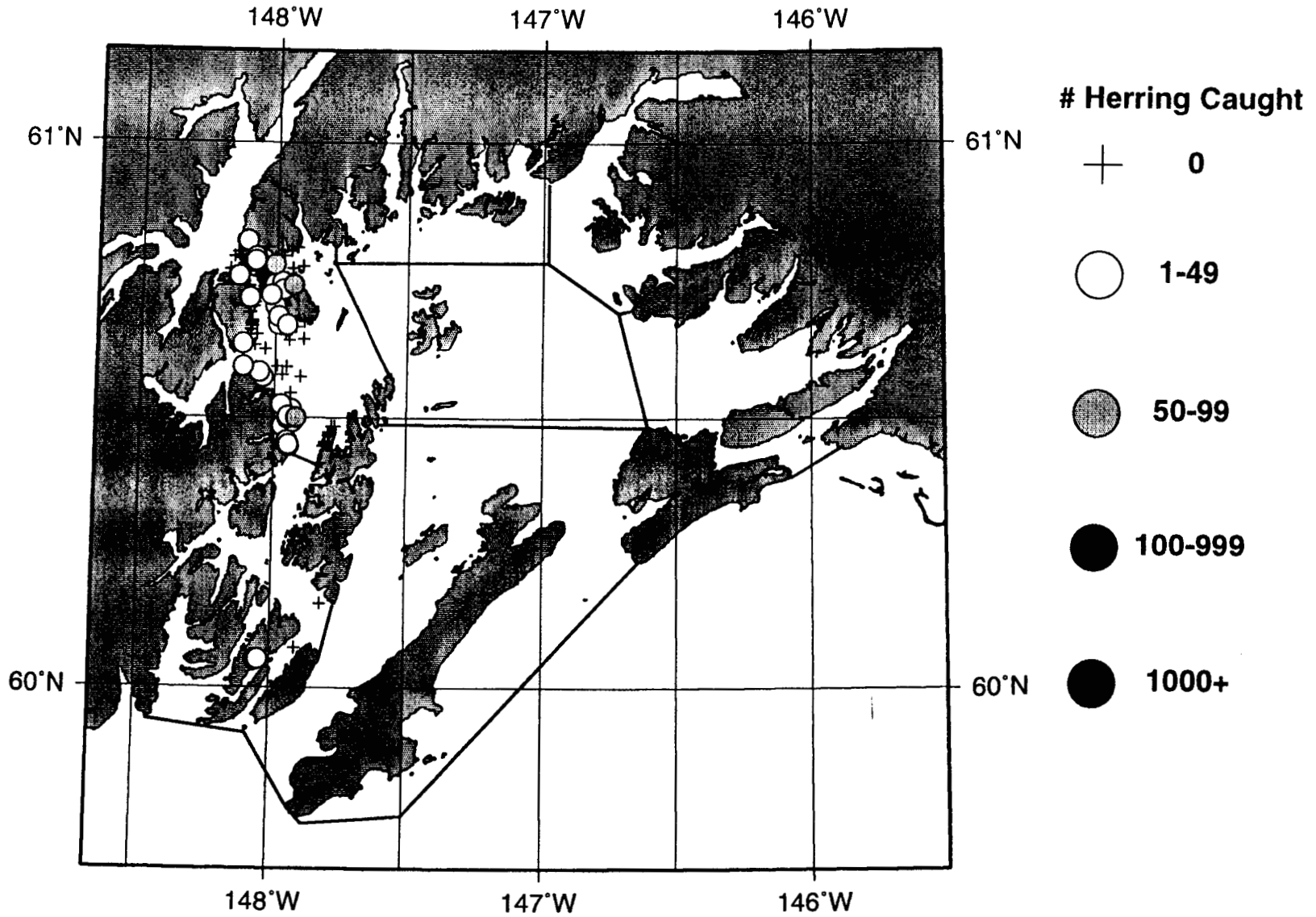
# PWS Sampling May 1994 Less Than 150 mm



23

Figure 7. Net catches of Pacific herring less than 150 mm fork length on the west side of Prince William Sound in May, 1994.

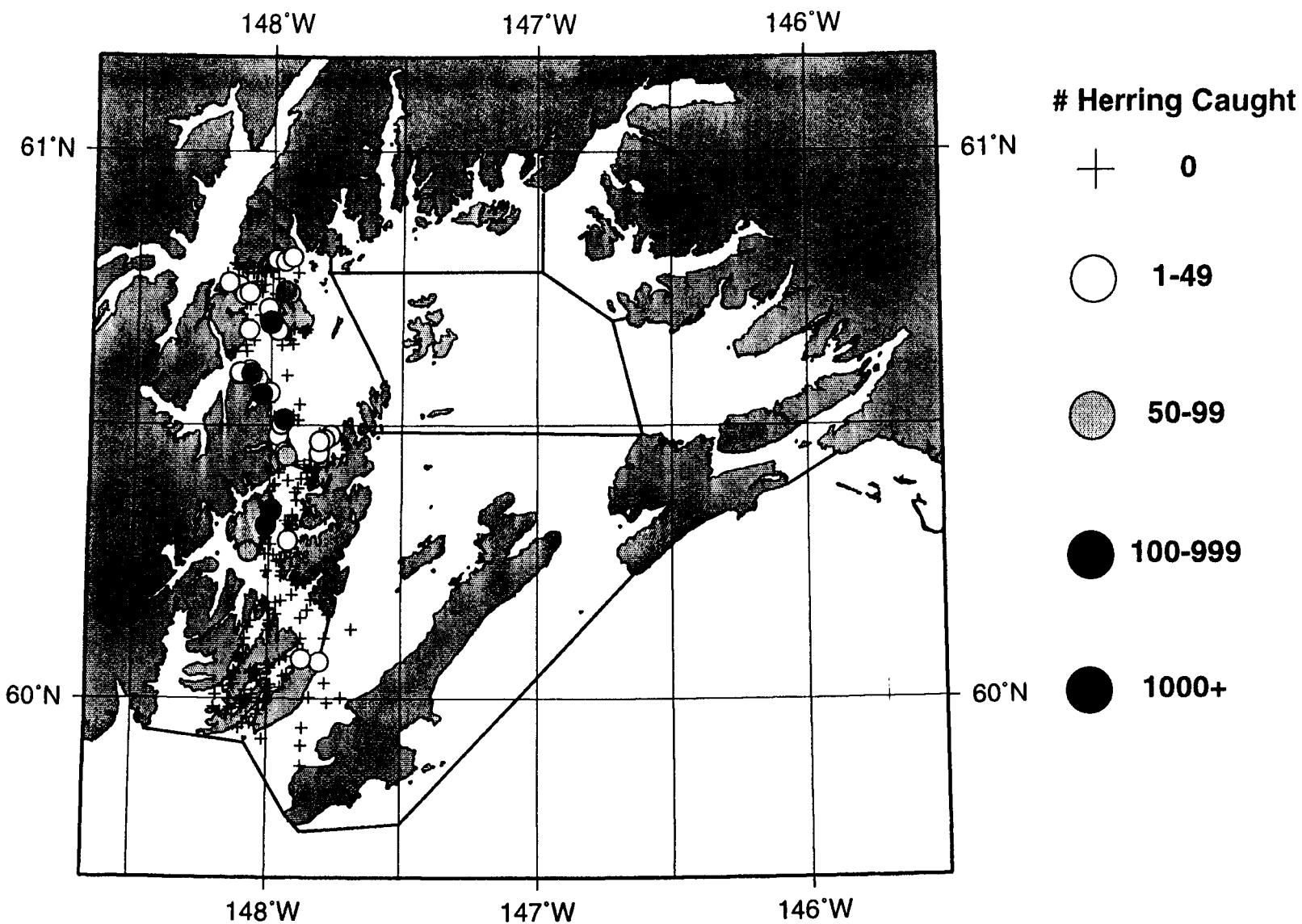
# PWS Sampling May 1994 Greater Than or Equal to 150 mm



24

Figure 8. Net catches of Pacific herring greater than or equal to 150 mm fork length on the west side of Prince William Sound in May, 1994.

# PWS Sampling June 1994 Less Than 150 mm



25

Figure 9. Net catches of Pacific herring less than 150 mm fork length on the west side of Prince William Sound in June, 1994.

# PWS Sampling June 1994 Greater Than or equal to 150 mm

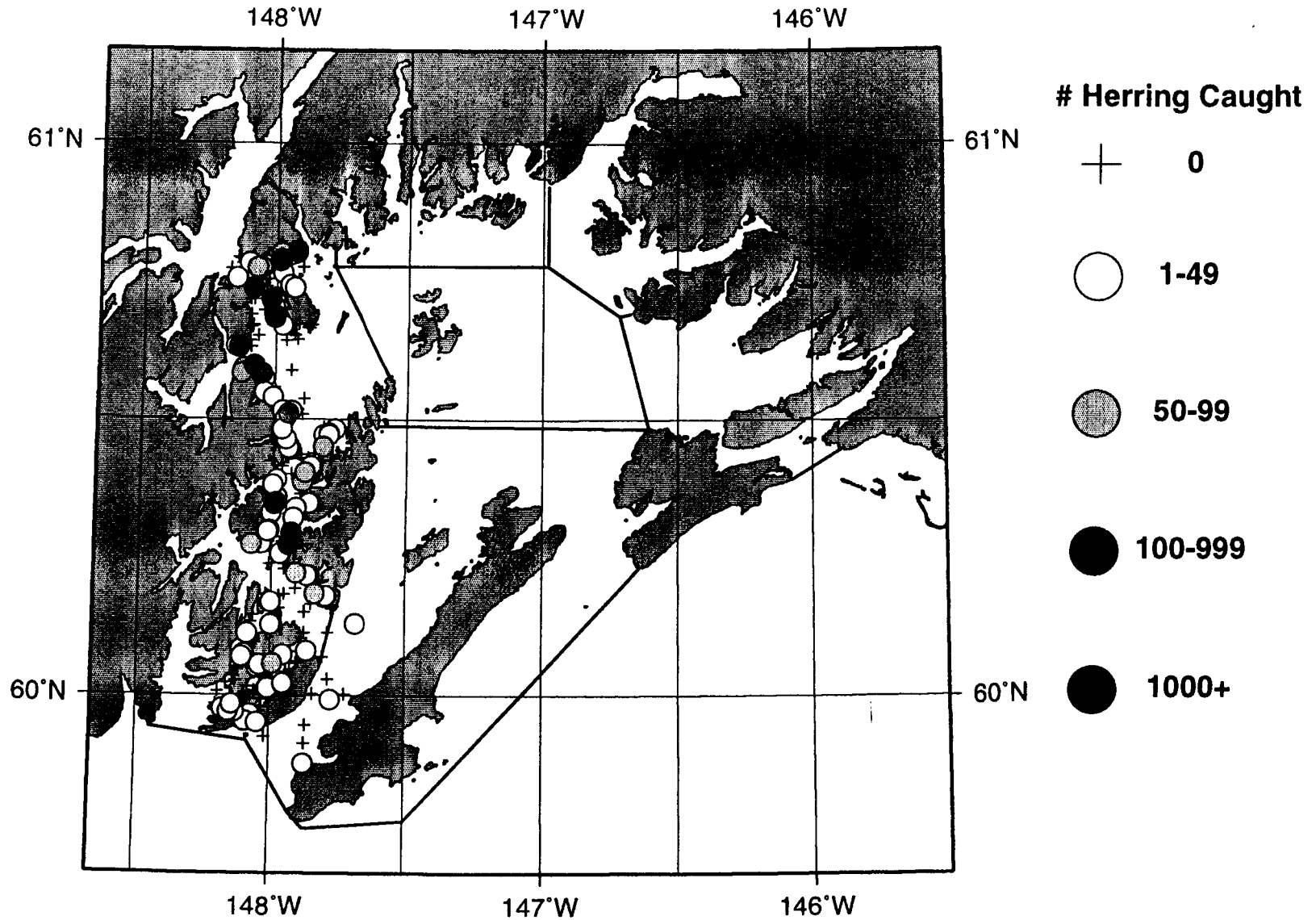
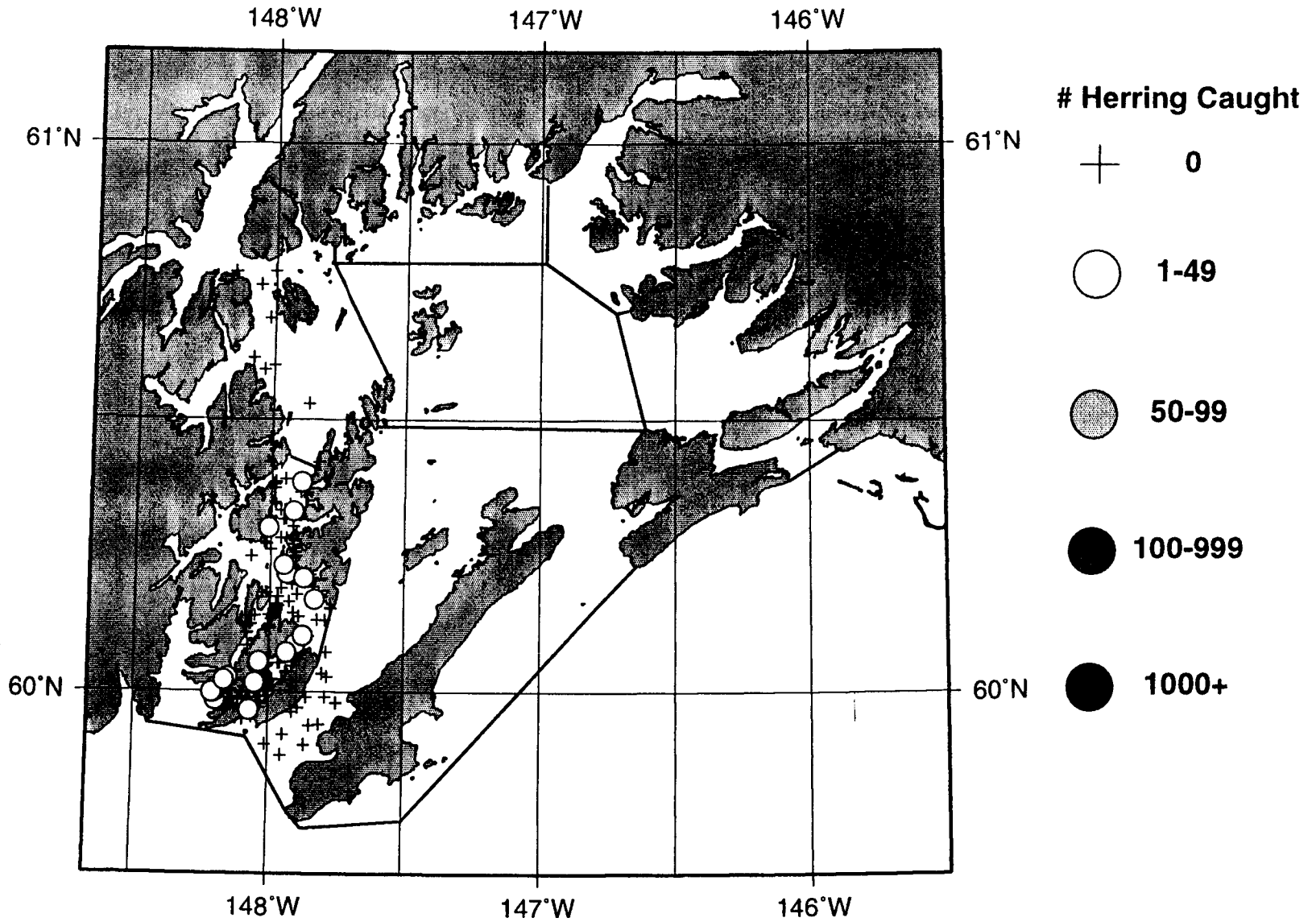


Figure 10. Net catches of Pacific herring greater than or equal to 150 mm fork length on the west side of Prince William Sound in June, 1994.



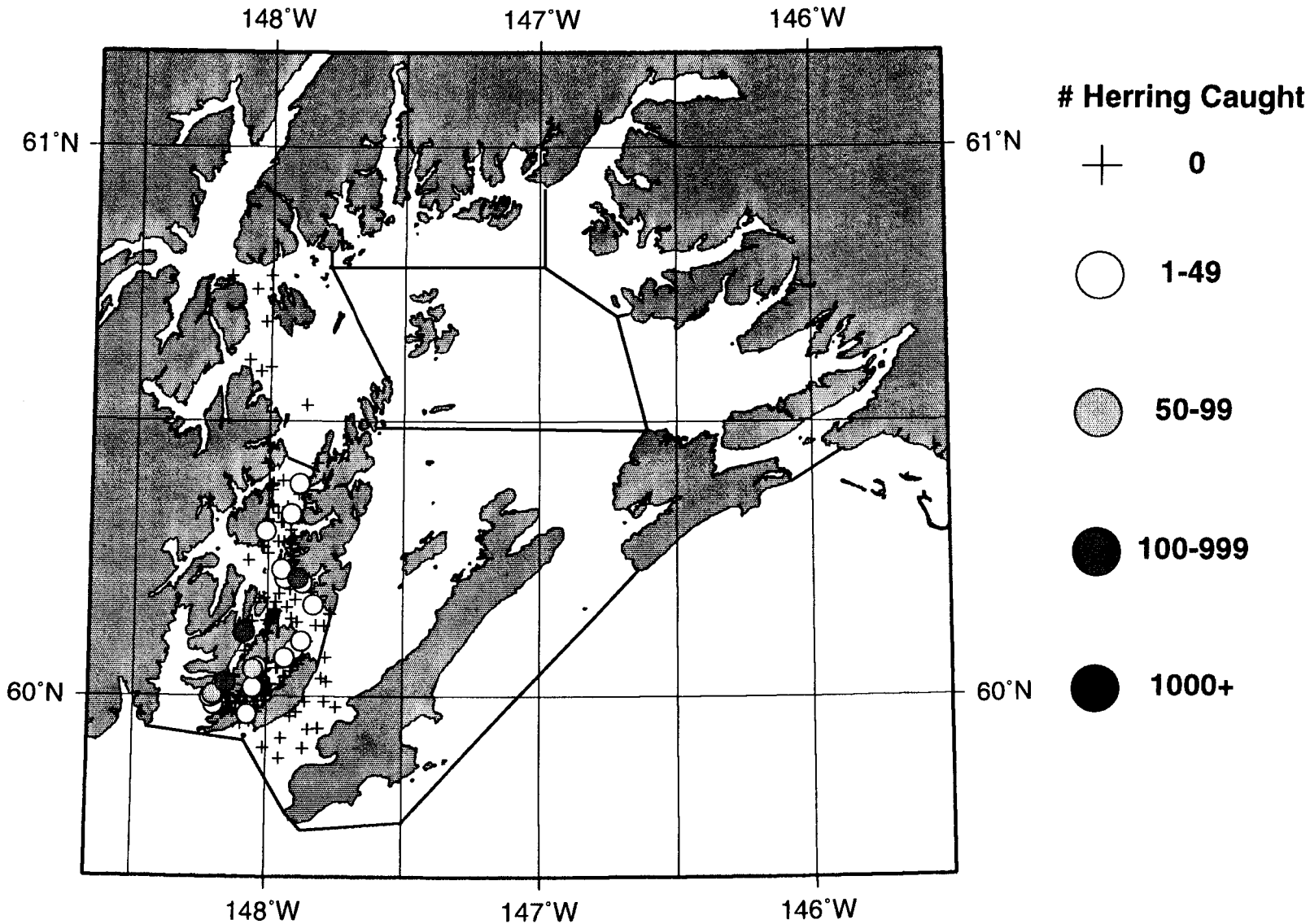
# PWS Sampling July 1994 Less Than 150 mm



27

Figure 11. Net catches of Pacific herring less than 150 mm fork length on the west side of Prince William Sound in July, 1994.

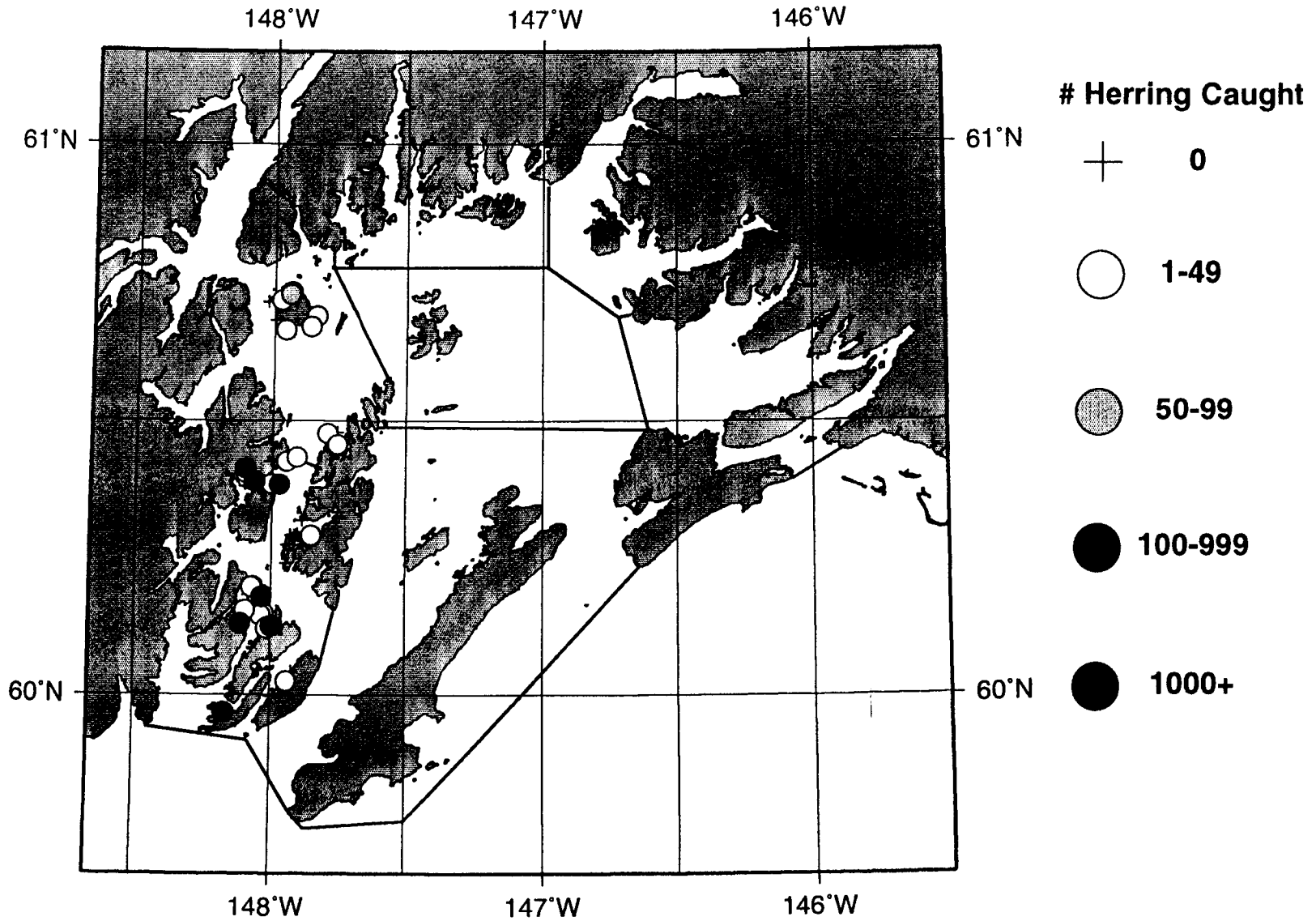
# PWS Sampling July 1994 Greater Than or Equal to 150 mm



28

Figure 12. Net catches of Pacific herring greater than or equal to 150 mm fork length on the west side of Prince William Sound in July, 1994.

# PWS Sampling Aug/Sep 1994 Less Than 150 mm



29

Figure 13. Net catches of Pacific herring less than 150 mm fork length on the west side of Prince William Sound in May, August through September, 1994.

# PWS Sampling Aug/Sep 1994 Greater Than or Equal to 150 mm

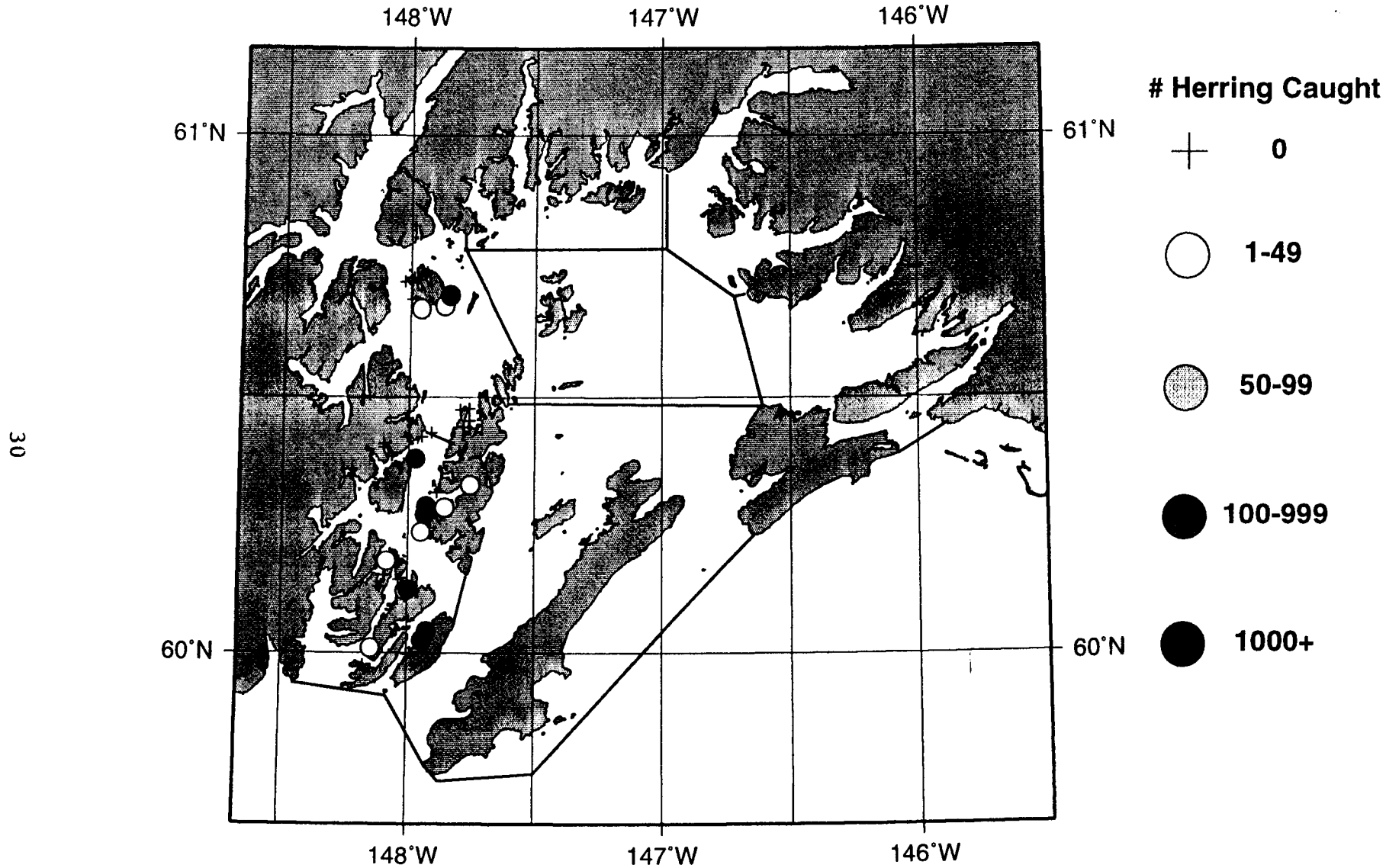
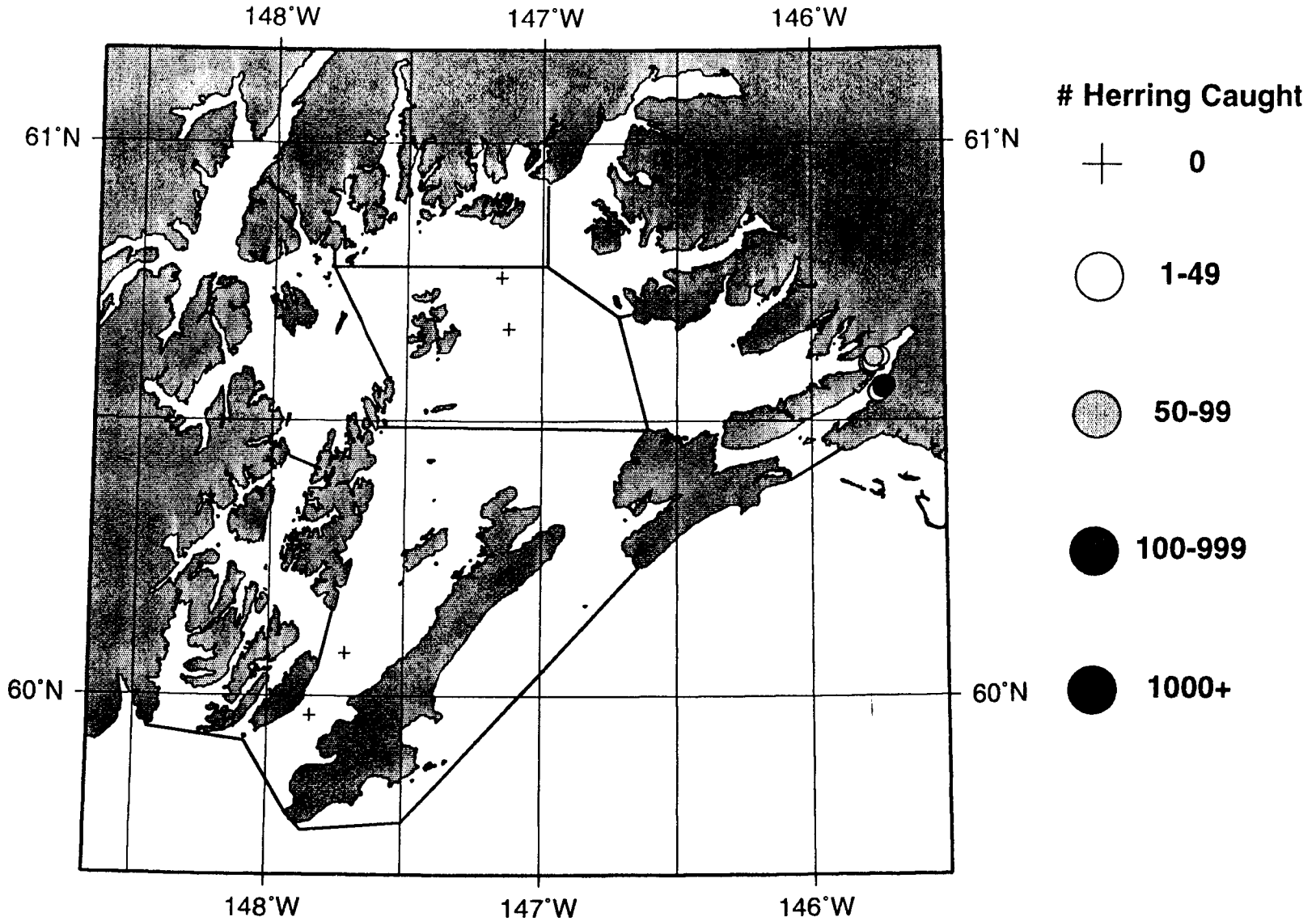


Figure 14. Net catches of Pacific herring greater than or equal to 150 mm fork length on the west side of Prince William Sound in August through September, 1994.

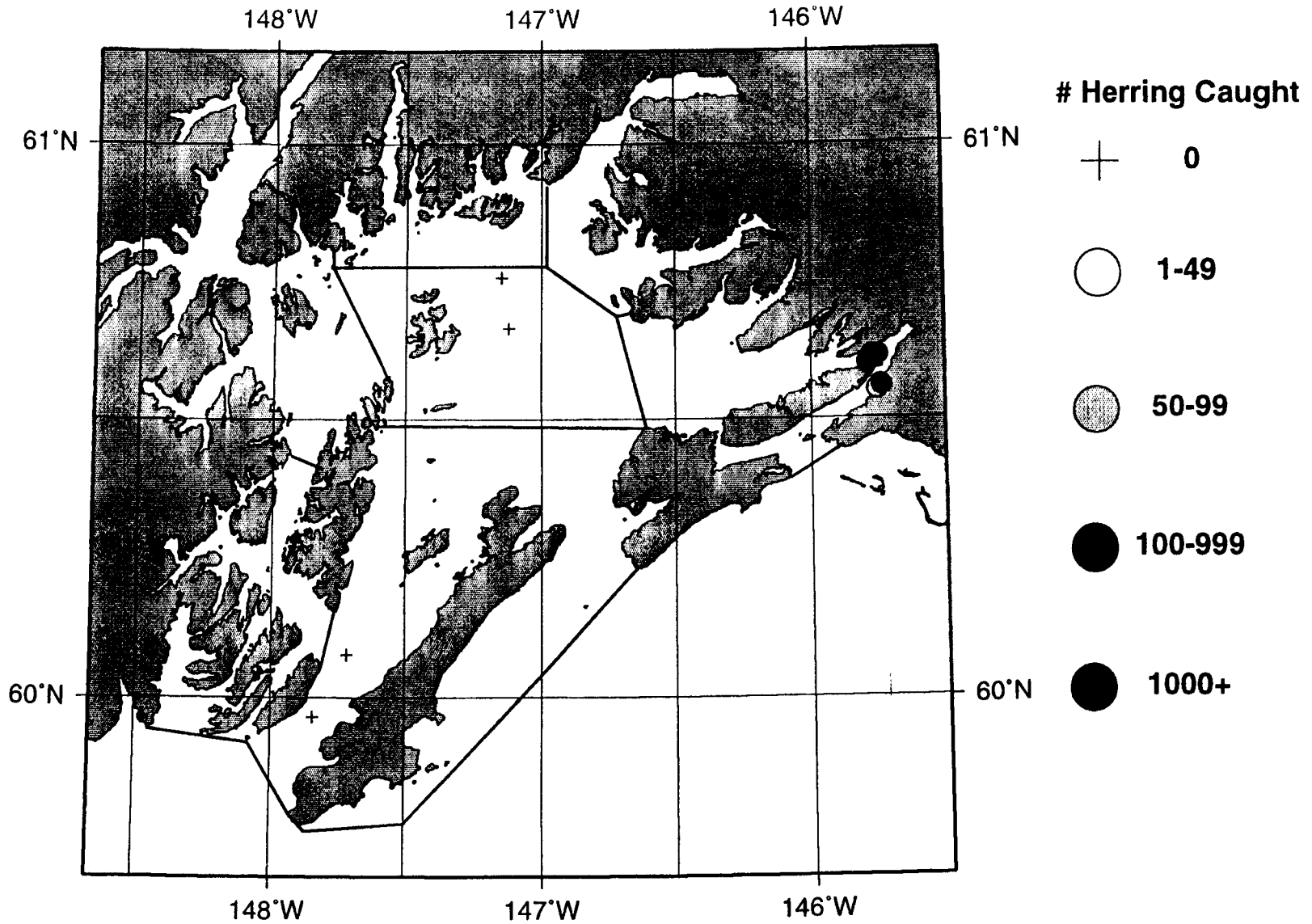
# PWS Sampling April 1995 Less Than 150 mm



31

Figure 15. Net catches of Pacific herring less than 150 mm fork length on the west side and other selected sites within Prince William Sound in April, 1995.

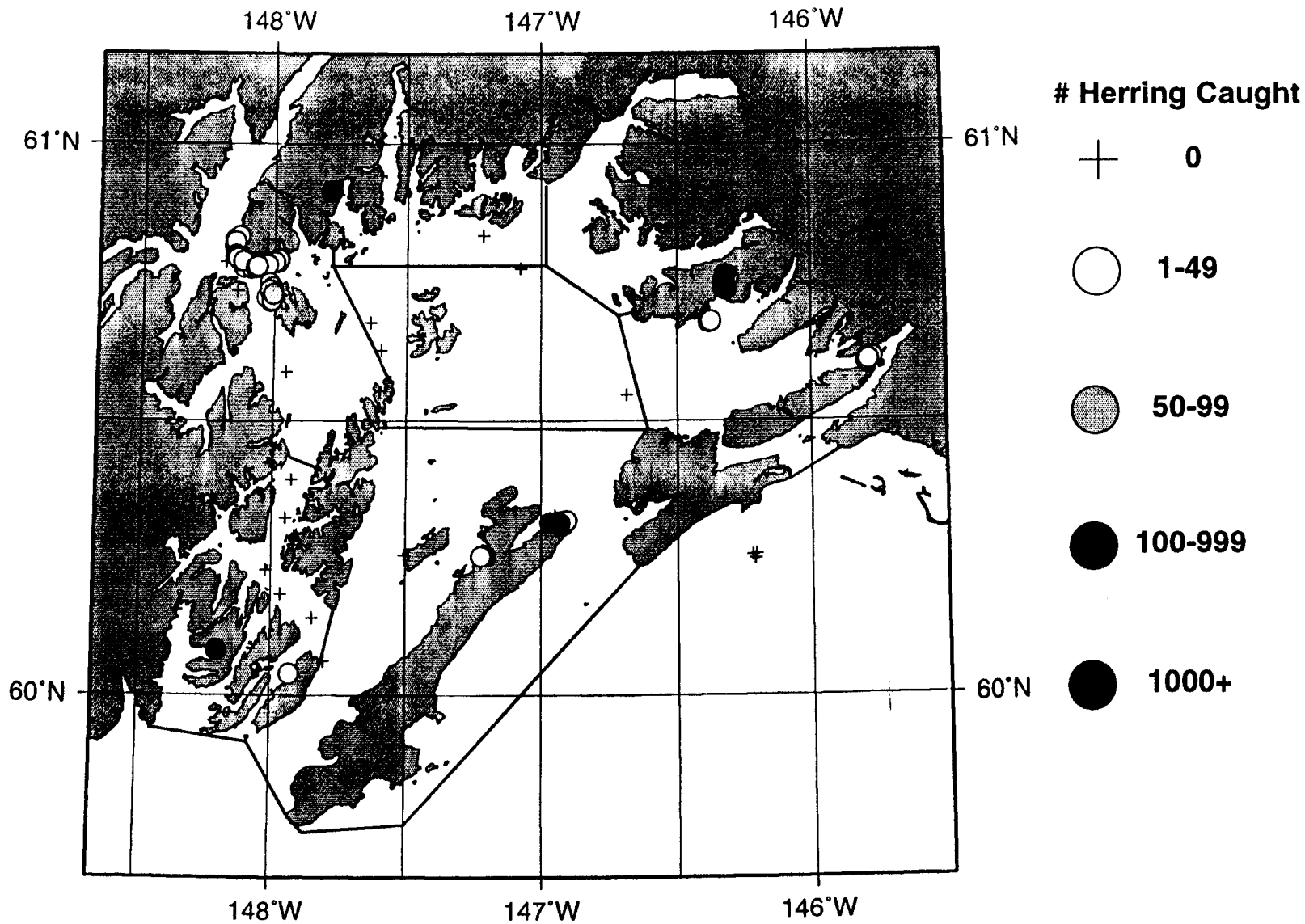
# PWS Sampling April 1995 Greater Than or Equal to 150 mm



32

Figure 16. Net catches of Pacific herring greater than or equal to 150 mm fork length on the west side and other selected sites within Prince William Sound in April, 1995.

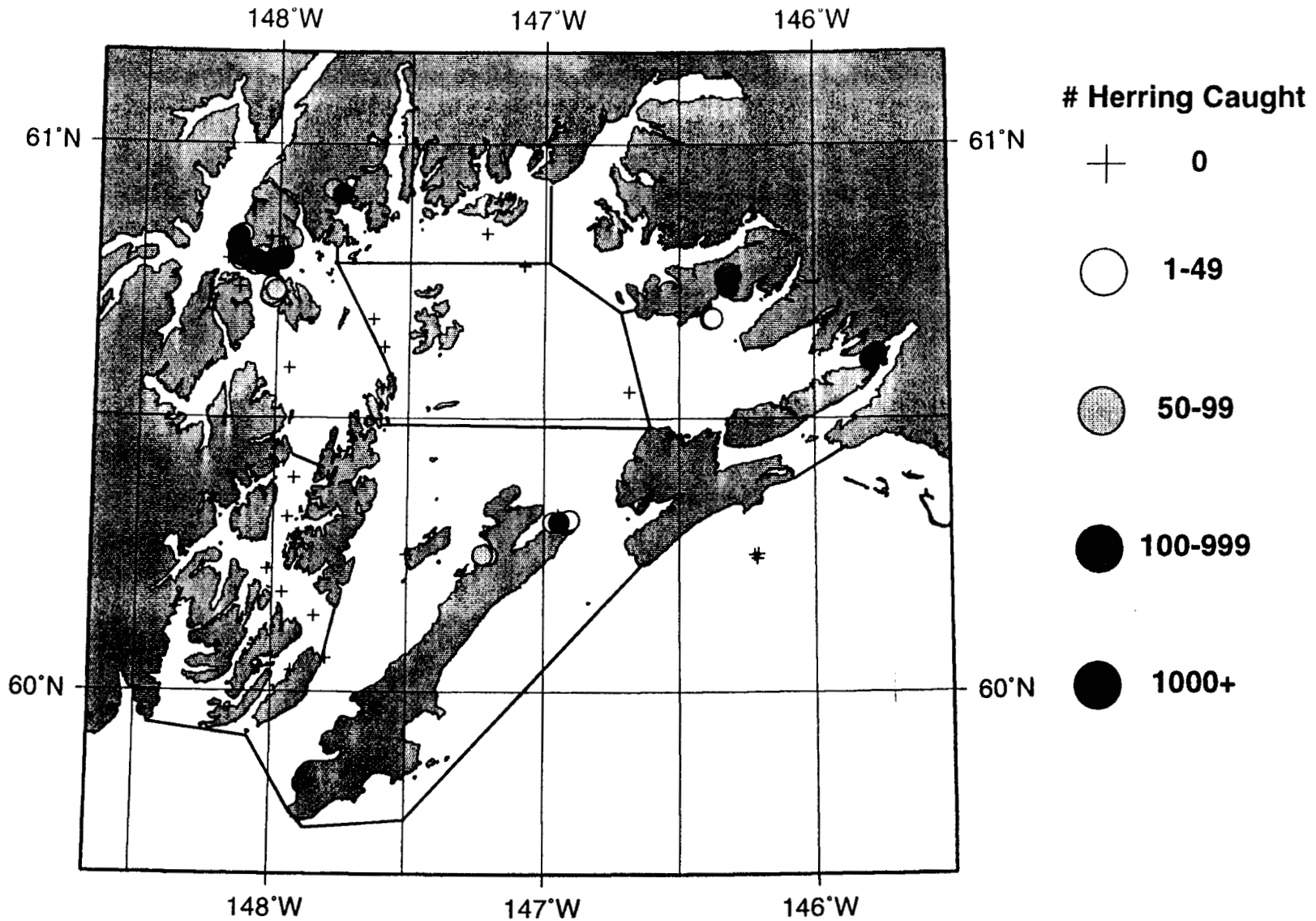
# PWS Sampling May 1995 Less Than 150 mm



33

Figure 17. Net catches of Pacific herring less than 150 mm fork length on the west side and other selected sites within Prince William Sound in May, 1995.

# PWS Sampling May 1995 Greater Than or Equal to 150 mm

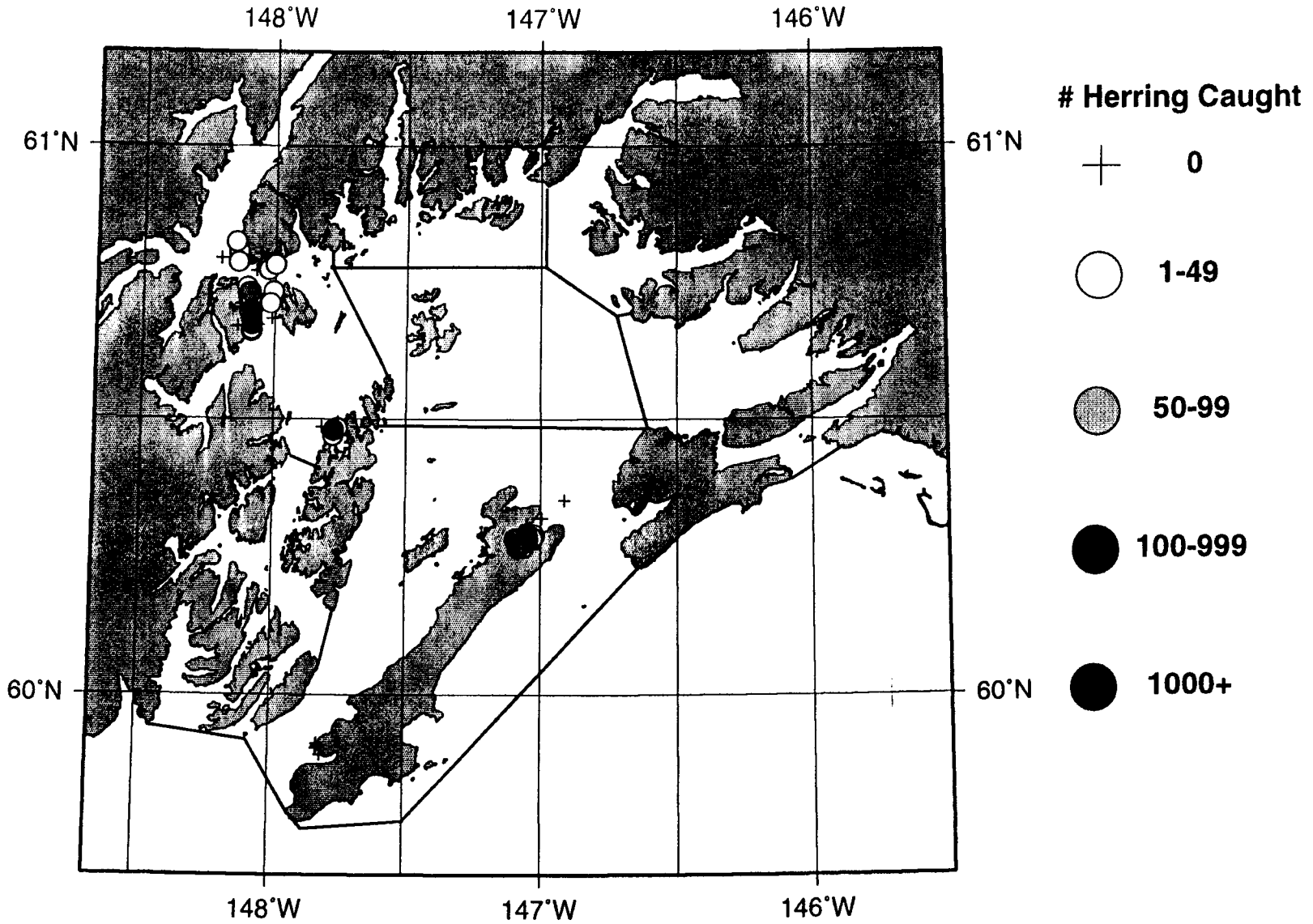


34

Figure 18. Net catches of Pacific herring greater than or equal to 150 mm fork length on the west side and other selected sites within Prince William Sound in May, 1995.



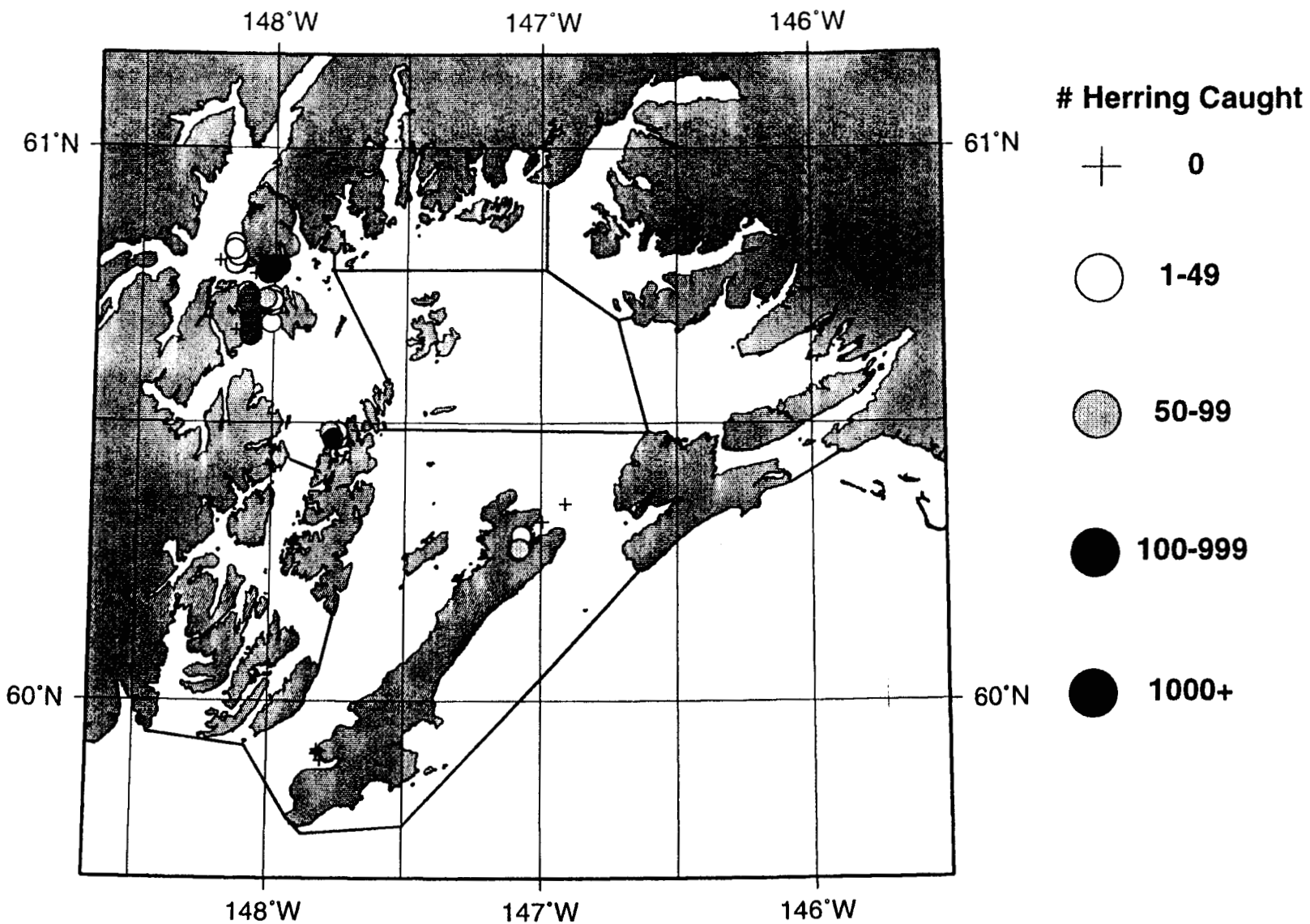
# PWS Sampling June 1995 Less Than 150 mm



35

Figure 19. Net catches of Pacific herring less than 150 mm fork length on the west side and other selected sites within Prince William Sound in June, 1995.

# PWS Sampling June 1995 Greater Than or Equal to 150 mm



36

Figure 20. Net catches of Pacific herring greater than or equal to 150 mm fork length on the west side and other selected sites within Prince William Sound in June, 1995.

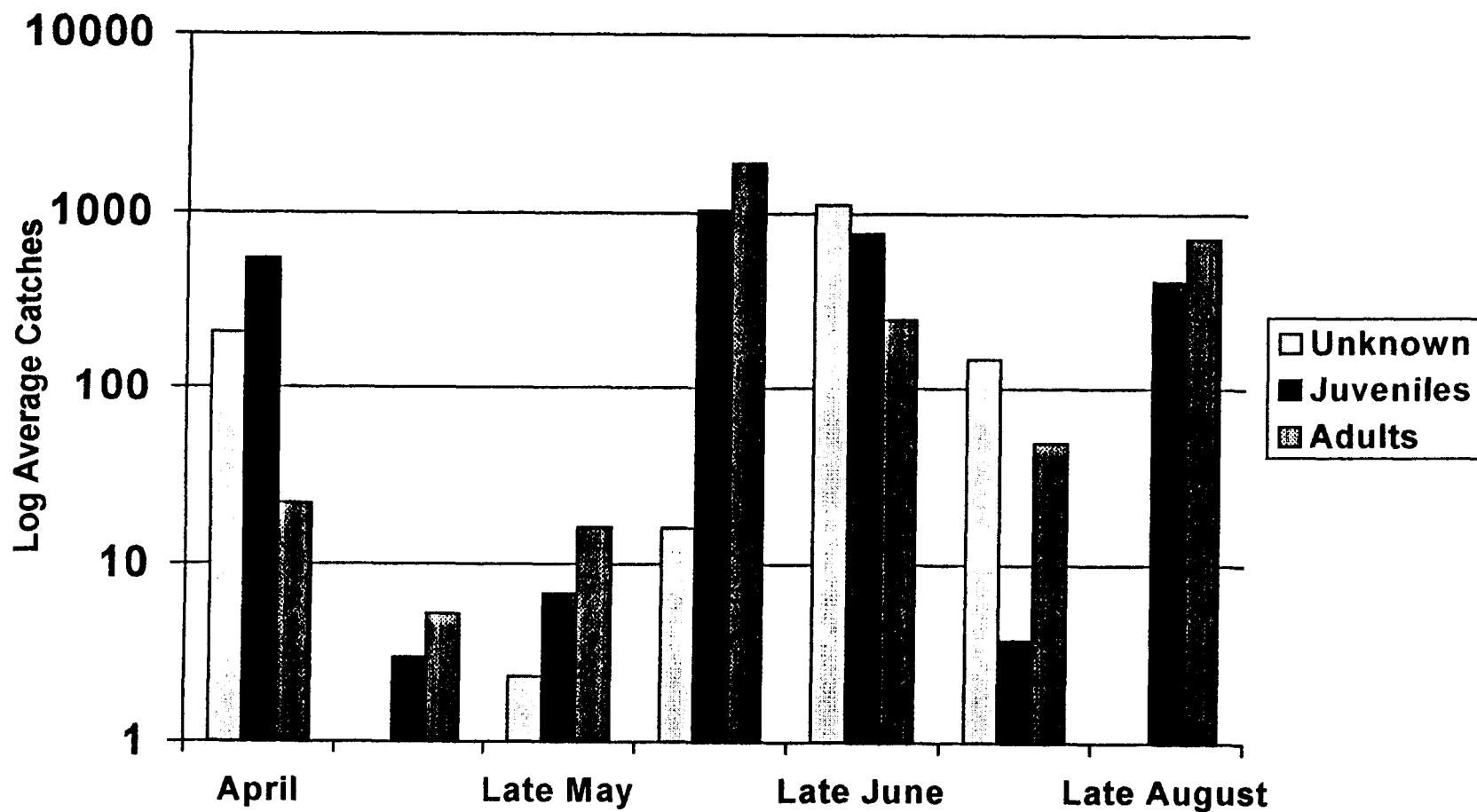


Figure 21. Seasonal distribution of log transformed net catches of Pacific herring less than and greater than 150 mm fork length, juveniles and adults respectively, collected primarily in western Prince William Sound in 1994. Herring that did not have length measurements were classified as unknown.

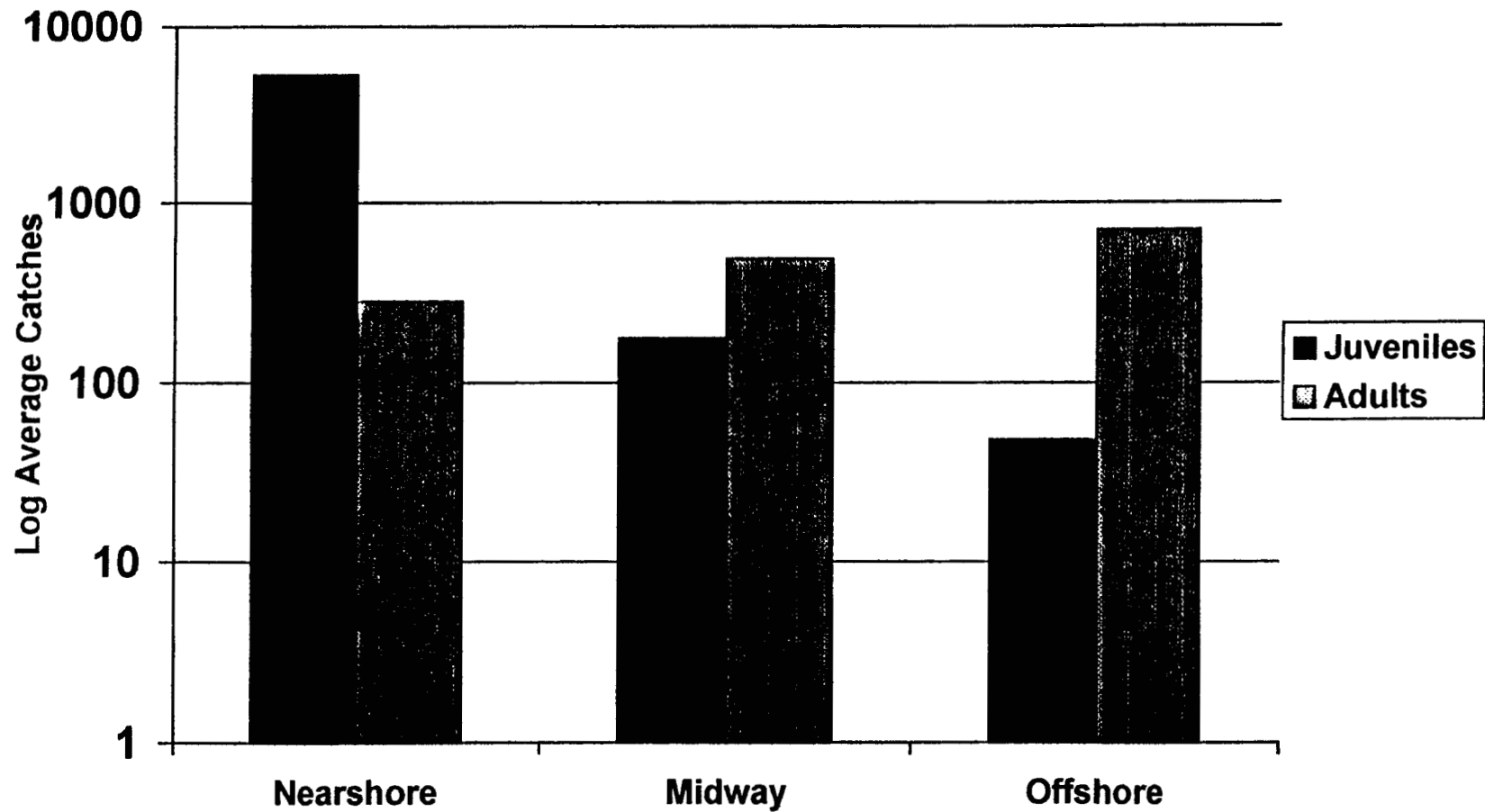


Figure 22. Distance from shore (m) measured by radar of log transformed net catches with juvenile Pacific herring less than 150 mm fork length and Pacific herring over 150 mm fork length in 1995. Nearshore was less than 150 m, midway was 151-300 m and offshore was over 300 m.

# PWS Sampling August 1995 Aerial Surveys

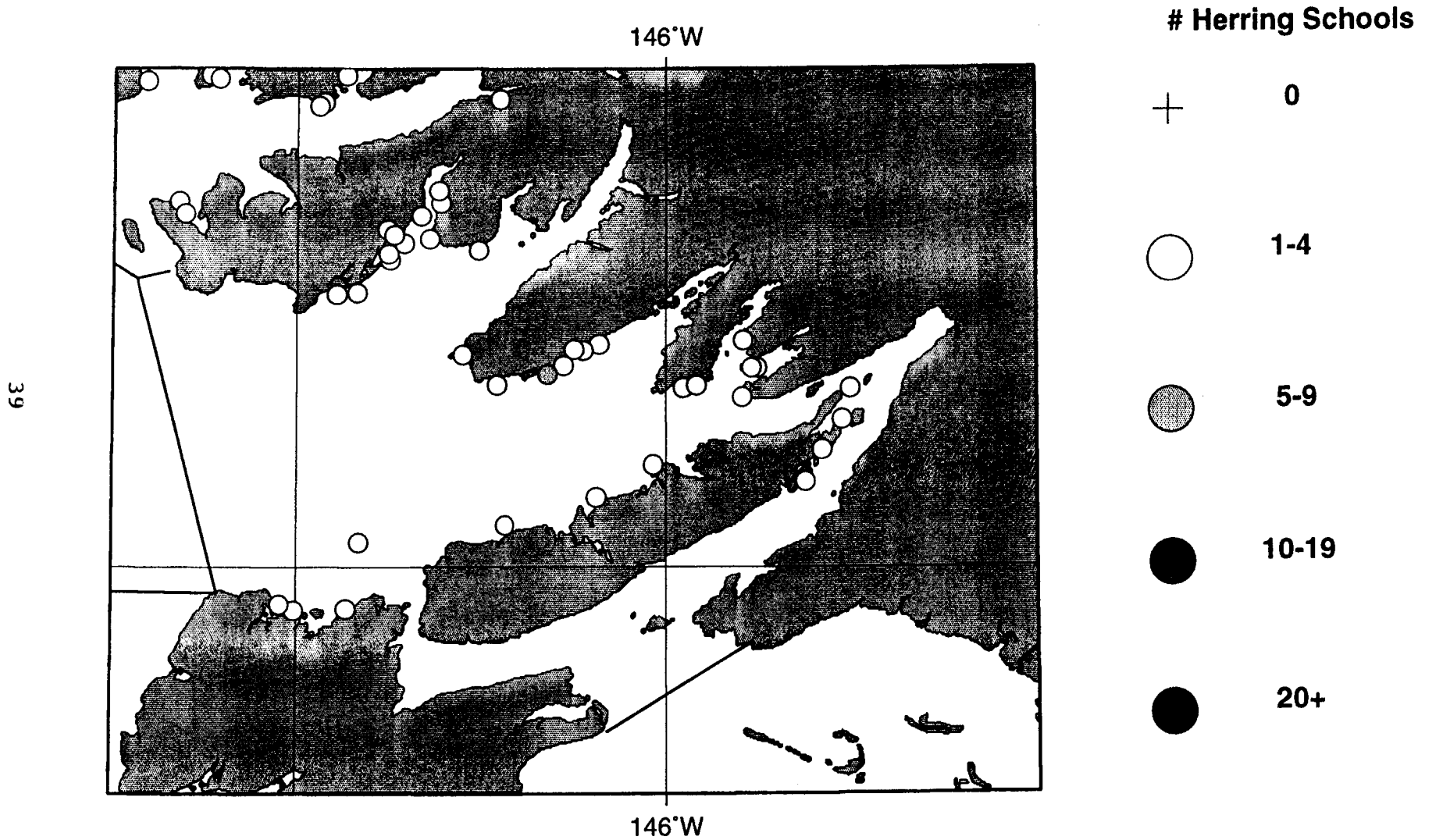


Figure 23. Distribution of Pacific herring schools within the eastern region (1) of Prince William Sound in August, 1995.

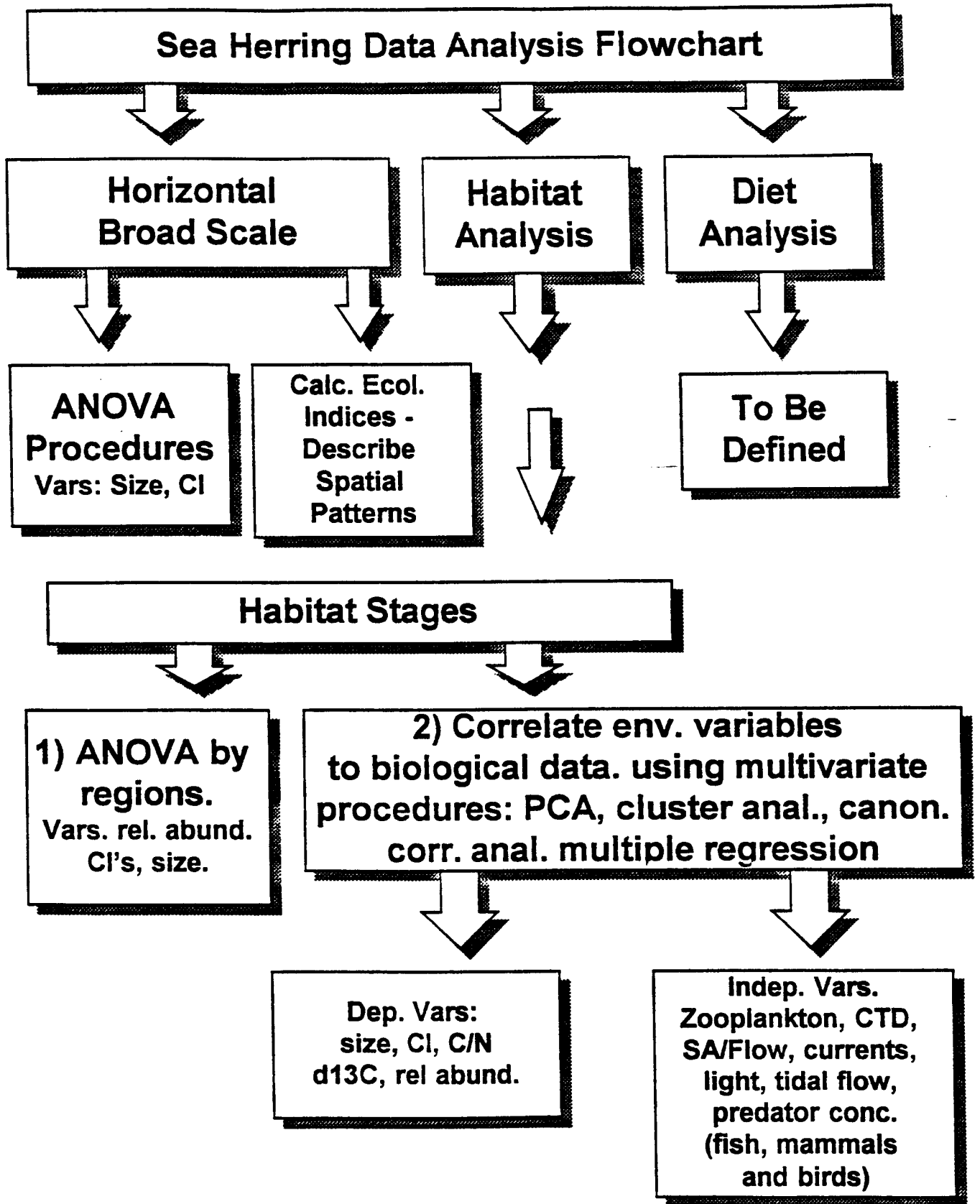


Figure 24. Planned analyses of Pacific herring distribution, population and condition indices, stomach contents, and physical and biological habitat characteristics from data collected in 1995 and 1996.