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ABSTRACT: We documented qualitative ecological information about non-harvested fish age classes and species from resource users and area residents. Our primary objective was to compile local and traditional ecological knowledge about the distribution, abundance, ecology, and associated changes over time of Pacific herring *Clupea pallasi* and other forage fish species in Prince William Sound (PWS) and the Outer Kenai Peninsula (OK) in Southcentral Alaska. A secondary objective was to provide ecological information to aid in developing study or management plans concerning herring and other forage fish. Both objectives were met by developing an oral interview protocol, selecting and interviewing key informants in 5 Alaskan communities, and developing a geographic database. Researchers tape-recorded and mapped respondents' observations. Survey questions fell into 6 categories: 1) life history stage and species of the fish observed, 2) fish behavior and school characteristics, 3) presence and behavior of co-occurring predators, 4) seasonal spatial distributions observed, 5) decadal shifts observed, and 6) observation and method activity. Forty-eight interviews were conducted. The earliest observation was from 1934. Thirty-seven respondents were commercial fishermen and 17 were pilots. Respondents made most observations of juvenile herring schools from planes. Other observations came from net catches, visual sightings, and sonar output. Most observations were made during summer (June through August), probably due to both shallow distribution of schools and an increase in human activity during this season. In PWS the spring spatial distribution of herring was significantly different from summer and fall-winter, but the latter 2 were not significantly different. Spatial distributions of herring in the OK were significantly different from one another in all 3 seasons, and the differences were more highly significant than in PWS. Most observations concerned juvenile herring, but locations of herring spawning overlap with adult herring, Pacific sand lance *Ammodytes hexapterus*, capelin *Mallotus villosus*, capelin spawning, and eulachon *Thaleichthys pacificus* were also documented. Most respondents were able to distinguish herring from other species by their school shape, school color, behavior, and location within a bay. Some pilots believed sunny days were better than overcast days for distinguishing herring from forage fish schools because herring schools "flash silver" and forage fish (mainly sand lance), also called "feed fish" or "bait fish", look brown or gold. Pilots said that they did not see schools of salmon fry from the air. Juvenile herring were reported as broadly distributed, mainly in bays in PWS and the OK, and easily observed in the summer. Juvenile herring were found at the heads of bays during the winter. They were seen in winter with adult herring in a very limited number of sites. Decadal shifts were observed with an increase in juvenile herring from the 1970s to the 1980s and a much more restricted distribution in the 1990s. In PWS the 1970s distribution was not significantly different from the 1980s, but was highly significantly different from the 1990s. The 1980s and 1990s were also highly significantly different from one another. In the OK all 3 decades were significantly different from one another, and the level of significance was higher than for the PWS pairwise tests. Decadal shifts in the reported extent of juvenile herring distribution matched decadal trends in catches of the PWS adult herring population indicating that traditional ecological knowledge is a potentially valuable source of information for indicators of recruitment and population trends. Juvenile herring overlapped sand lance distribution to a large degree, and capelin and eulachon to a small degree. Herring spawning locations prior to the 1970s not previously reported by the Alaska Department of Fish and Game were documented. Our study preserves knowledge of the historical changes in distribution of Pacific herring in PWS and the OK that predates scientific data collection.

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INTRODUCTION

Managers and scientists need baseline data and an understanding of natural cycles of production from which to measure the perturbations of marine ecosystems. In many cases, key species affected by and influencing ecosystem perturbations are poorly understood and historic information is often unavailable. Despite this lack of historic data, potentially valuable human experience and knowledge are often ignored, partially due to the qualitative nature of the information and unfamiliarity with social science methods (Huntington 2000). Longtime resource users and residents of a region can provide valuable information on historic trends, distribution, life history traits, and general ecology when their knowledge is pooled in a systematic manner. We initiated this project to document personal observations potentially useful to ongoing scientific inquiries.

The potential for using traditional ecological knowledge (TEK) and involving resource users in fisheries research and management has been demonstrated from Oceania (Johannes 1981, 1993) to the North Atlantic (Eythorsson 1993; Pálsson 1994; Huntington 2000). TEK has been documented for marine mammals (Kalxdorff 1997; Huntington et al. 1999) and geese in Alaska (Fienup-Riordan 1999). Canadian researchers have documented TEK of large game, furbearers, waterfowl, ptarmigan *Lagopus* spp. and a variety of fishes, including broad whitefish *Coregonus nasus*, inconnu *Stenodus leucichthys*, Dolly Varden *Salvelinus malma*, and loche or burbot *Lota lota* (Gwich'in Elders 1997). Human use of natural resources in Alaska has been extensively documented by individual researchers and agencies, particularly the Alaska Department of Fish and Game (ADF&G), Division of Subsistence, mainly for the purpose of resource management.

After the 1989 *Exxon Valdez* oil spill in Prince William Sound (PWS), a major detriment in documenting and determining the resulting ecosystem perturbation was the lack of life history information on several ecologically important forage fish species. A lack of early life history information on Pacific herring *Clupea pallasi*, and to a lesser extent, salmon *Oncorhynchus* spp., prevented population-level descriptions of oil spill injury (Brown et al. 1996; Geiger et al. 1996; Templin et al. 1996). Key forage fish life history stages and species in PWS include juvenile and adult herring, juvenile and adult sand lance *Ammodytes hexapterus*, adult capelin *Mallotus villosus*, juvenile salmon, adult eulachon *Thaleichthys pacificus*, and juvenile walleye pollock *Theragra chalcogramma*. Salmon, herring, and to a lesser extent, walleye pollock are also harvested for subsistence and commercial fisheries.

Historical data on the distribution of PWS forage fishes and juvenile forms of herring, salmon, and walleye pollock were limited largely due to the lack of targeted commercial fisheries. Although ADF&G has sampled adult herring and salmon and flown aerial surveys to document the miles of spawn or escapements, the focus has been fisheries management rather than ecological study. However, herring spawning was not regularly documented prior to 1973. Because PWS resource users (commercial and subsistence) have been harvesting and observing several of these species since the turn of the century, we initiated this study to document the PWS local or traditional ecological knowledge.

Indigenous people have lived in and used the resources of PWS, including herring, for 3,000 to 4,000 years (DeLaguna 1956; L. Johnson, Chugach Heritage Foundation, Anchorage, Alaska, personal communication). At the turn of the 20th century, resource use areas expanded and changed with the development of motorized vessels and industries such as fishing, trapping, fox farming, mining, and salmon and herring processing (Lethcoe and Lethcoe 1994). In 1964, an earthquake of magnitude 9.2 on the Richter scale struck PWS. Chenega Island in western PWS uplifted 5 feet and moved 52 feet south. The village of Chenega was completely destroyed and 23 of the 75 residents were killed. The village was abandoned and it was 19 years before a new village of Chenega Bay was established on Evans Island (Lethcoe and Lethcoe 1994). In the latter half of the century, communities bordering PWS on all sides grew and resource use activities occurred year-round. In addition, PWS contains 2 native villages and still has several families or family groups living at a diverse array of remote sites. As a result, resource use patterns have been broadly distributed throughout the sound during the last 45 years. We therefore anticipated a high likelihood that PWS users would be able to report on the seasonal occurrences and locations of juvenile herring and other forage fish from a broad array of potential sites.

The research goal for this project was to collect broad-based ecological information on Pacific herring and other forage fish species through interviews with fishermen, pilots, and long-time residents of Southcentral Alaska. Our project objectives were 1) to provide knowledge on the distribution and trends in abundance of forage fish for research planning, 2) to supplement and validate recent research findings with documented historic information for comparative purposes, 3) to document any previous observations of diseased or abnormal fish, and 4) to provide an additional source of information to examine long-term (decadal) effects of climate change on forage fish. The research goals were descriptive results rather than hypothesis formulation and testing. However, we determined statistical relationships among the seasonal and decadal distributions reported. To our knowledge, this is the first attempt in Alaska to document TEK for the purpose of contributing to fisheries research. Our project differs from other TEK studies in that we did not focus on small-scale traditional or native communities with a strong history of oral tradition. We expanded the definition of TEK to include non-Native commercial fishermen, pilots, and hunters with extensive resource use histories in PWS.

To meet our research objectives we developed an interview protocol, selected and interviewed respondents from PWS, Cook Inlet, and Kodiak communities regarding fishes in PWS and the Outer Kenai Peninsula (OK), and developed a geographic database. We provided this information to cooperating researchers and resource managers for planning purposes for managing herring and other forage fishes. Because we could not anticipate the scope of observations that would be reported, we asked a broad array of questions concerning multiple species' seasonal and interannual distributions. However, the most commonly reported knowledge concerned Pacific herring, which dominate the results presented herein.

METHODS

Methods used elsewhere for TEK research include open-ended or semi-directive interviews, questionnaires, and cooperative fieldwork (Huntington 1998). These methods are constrained by the limitations of interview techniques and the ability of the interviewer and respondent to bridge cultural and experiential differences (e.g., Ives 1980; Briggs 1986; Weiss 1994). We used an interview protocol that also allowed for open-ended discussions, as appropriate to allow systematic analysis of responses while giving an opportunity for gathering relevant information that could not have been anticipated by the interviewer (Huntington 1998). The size of the study area and the information sought led us to choose methods that allowed us to collect as much information as possible from a variety of people.

We designed a draft protocol to gather data on the respondent's history of resource use in PWS and the OK and their knowledge of forage fishes. We conducted a small subset of initial test surveys during the fall of 1997 to evaluate the success of deriving the desired information. As researchers learned about the ways in which respondents observed fish, the questions became more focused (Appendix A). We then solicited referrals by phone and by letter of various individuals, organizations, and Alaska Native communities. Our procedures for contacting and interviewing the public were drawn from protocols adopted by the *Exxon Valdez* Oil Spill (EVOS) Trustee Council (ADF&G 1997) for obtaining TEK for ecological research. The interview protocol was adapted throughout the project to accommodate cultural, occupational, and age differences of the respondents without changing the information sought from each question. As a result, the length of interviews varied considerably, and questions were often repeated or explained more thoroughly.

By February 1998, letters introducing the project were sent to the Traditional Village of Eyak, Cordova District Fishermen United, the village councils of Chenega Bay and Tatitlek, the Valdez Native Association, the Qutecak Native Tribe, and individual respondents in Homer, Alaska. Permission to work in Chenega Bay and Tatitlek was obtained from the village councils.

We chose respondents known to the authors for their experience in fisheries in PWS and those recommended by the above organizations. Interviews were conducted throughout 1998 and all were completed by late summer, 1999. As we interviewed respondents on our initial list, we solicited names of other individuals to interview. We interviewed persons with at least 5 years of experience in a fishery and those who had extensive experience working in PWS or the OK. The respondents had to be interested and able to discuss their knowledge of herring or other "feed fish." The respondents were classified by occupational categories, which helped illustrate their resource-related activities and years of experience within the survey region. We included herring, salmon, longline, and crab fishermen; hatchery and cannery workers; subsistence food gatherers; spotter and charter pilots; mail boat, charter boat, and freight boat captains and operators; and professional biologists. To assess the combined experience of each occupational group, the number of years each respondent was active in PWS or the OK was added within a given category. Most interviews were recorded on audiotape. Before the interview all respondents were asked to read and sign a statement that guaranteed the confidentiality of their information and their anonymity. We did not compare the numbers and content of Alaska Native versus non-Native interviews due to the small number of Alaska Native interviewees and the potential for violations of confidentiality.

The interview questions were in 6 categories: 1) life history stage and species of the fish observed, 2) fish behavior and school characteristics, 3) presence and behavior of co-occurring predators, 4) seasonal spatial distributions observed, 5) decadal shifts observed, and 6) observation method and activity (Appendix A). Observations were categorized as "visual" (from a dock, beach, or boat), from an airplane, from a net catch, or from echo sounder (sonar) displays. The primary focus and first line of questions focused on juvenile herring; however, similar questions about adult herring, herring spawning areas, capelin, eulachon, walleye pollock, sand lance, and osmerid smelt species were asked.

Forage fish was used to refer to any species of small schooling fish the respondent could not identify. Respondents also used the term "bait fish," sometimes in reference to juvenile herring and other times as a general reference to small schooling fish of unknown species. Respondents were asked to clarify their definition of bait fish to distinguish herring from non-herring references. Although we report juvenile herring and forage fish observations, we also collected observations on the location of mixed adult and juvenile herring schools and herring of unknown life stage. Respondents described herring migration patterns and disease in the herring population. They were asked if they had observed disease before 1993 and if they had seen a herring run failure such as occurred in 1993 (Meyers et al. 1994). We recorded information about the presence of fish predators, such as seabirds and marine mammals, associated with schools of fish.

Respondents used colored pens and mylar-covered navigational charts to map the locations of their observations. This allowed us to place observations in areas without names, areas where names are not generally known, or areas where names are not printed on maps. The respondents described their method of observation, for example, catching fish or seeing fish from a plane or on sonar. They described the characteristics of schools of different species, such as the appearance from a boat, airplane, and in sonar displays.

To determine seasonal and decadal trends, respondents were asked to describe seasons and years in which their observations were made. Observations were recorded by season: spring (March–May), summer (June–August), fall (September–November), and winter (December–February). Observations within 2 weeks of the beginning or end of a season were not included in the data analysis for that season. As an example, respondents commonly saw juvenile herring during the last week of May and throughout the summer. If observations were only in the last two weeks of May, they were ignored, and the late May observations were not included in the spring observations. However, if respondents observed herring for 2 weeks or more in May as well as in summer, those observations were recorded in both spring and summer. Observations from fall and winter were combined for analysis due to the small sample sizes those seasons.

The year ranges are the respondents' best estimate of the time the observations occurred. Each year range is therefore considered an approximation. Although respondents often reported decades as the 1970s, 1980s, etc., many respondents described the time of observations as in the early, middle, or late part of a decade. Decades were divided into 3 parts: years 0–3 were the early part of the decade; years 4–6 were the middle part of the decade; and years 7–9 were the late part of the decade. We checked estimated year ranges with respondents before assigning the beginning and ending years. We chose decadal periods based on the ability of respondents to pinpoint time.

A geographic database was compiled using ArcView 3.1 geographic information system (GIS) software (Mathsoft 1998) to summarize and display the data. Data tables were constructed for each of the 6 question categories. Respondents' mapped observations for each fish species' life history stage (adult, juvenile, or herring spawning area), season, and time period were digitized. Therefore, data could be summarized by species, place, season, method of observation, and decade. The database was used to partition PWS into 8 regions extending from Day Harbor (western PWS), to Cape Yakataga (eastern PWS; Figures 1 and 2). Herring observations were summarized by region to compare the relative numbers of observations in particular areas of PWS. Regions were delineated approximately according to the statistical regions used by ADF&G for management because these regions were familiar to respondents. The OK was considered as a separate region, from west of Day Harbor, to west of Port Dick (Figures 1 and 2). Polygons mapped in GIS sometimes extended over 2 regions, thus the observations counted in each region do not sum to the exact numbers in the database.

To find out if changes in participation in commercial fisheries affected seasonal and decadal juvenile herring observations and comparisons, we also examined ADF&G records and compiled the amount of commercial fishing time each year from 1960 through 1996 (ADF&G 1960–1997).

We used spatial statistics and nonparametric tests to determine significant differences in reported seasonal and decadal distributional trends of herring. To test for spatial association between layers (a season or decade), adjusted first-order neighbor weights (Cressie 1993) were assigned to centroids of the polygons in each layer. This weighting method was chosen because

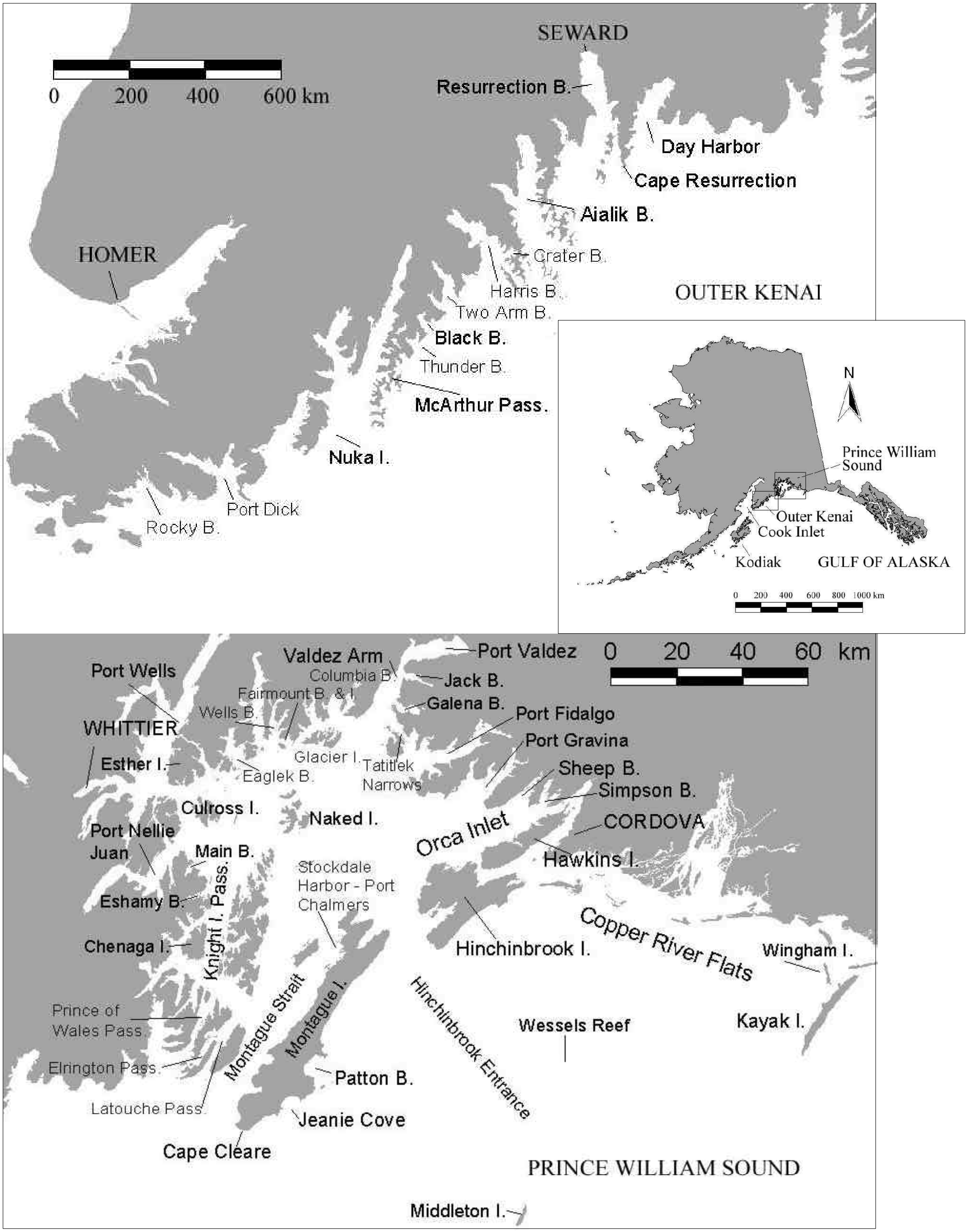

Figure 1. The Prince William Sound and the Outer Kenai study areas including place names.

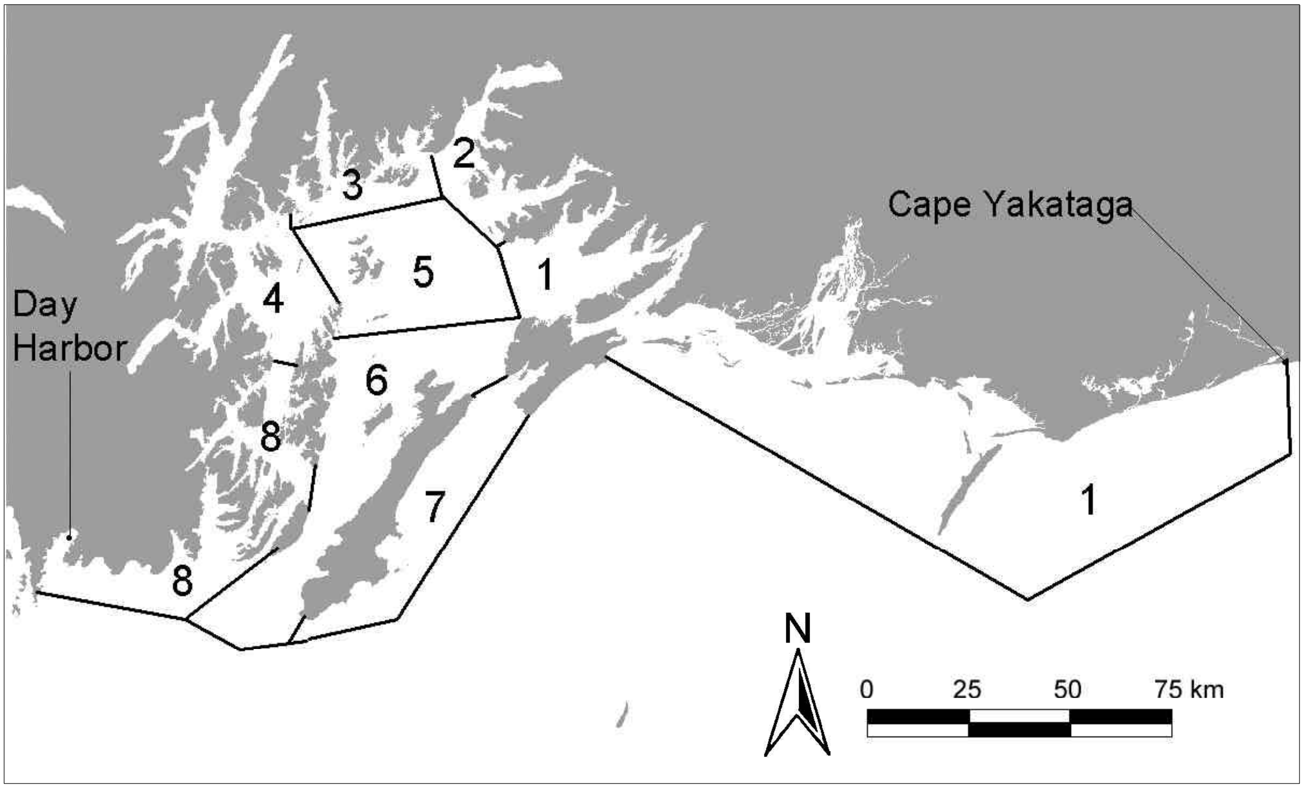

Figure 2. Delineation of the 8 regions used to categorize distribution information from respondents for the Prince William Sound study area.

the polygons were irregular. One or more layers in each analysis were chosen as the reference layer or neighbor object and all other layers were tested against that reference. We then used a spatial correlation algorithm (Geary 1954; Cliff and Ord 1981; Cressie 1993) to estimate an index of spatial association for the centroids of each polygon in a layer compared to the reference. The Geary index values span from zero for high similarity to 10 for low similarity or association. The Geary index distribution for each layer was highly irregular and nontransformable (to Gaussian). We therefore used the nonparametric Kruskal-Wallis rank test (Lehmann 1975) to test for significant differences ($\alpha=0.05$) in the Geary index between groupwise and pairwise seasonal or decadal layers.

RESULTS

Respondents

We conducted 48 interviews: 11 in Homer, 21 in Cordova, 10 in Seward, 3 in Tatitlek, and 3 in Chenega Bay. Respondents' ages ranged from 27 to 75 years; the average and median age was 53 years. Many respondents' activities fell into more than one occupational category (Table 1). Skills and jobs overlapped; 24 of the 35 salmon fishermen also fished for herring, and 10 were also pilots. Of the 17 professional pilots, 13 were herring spotter pilots and 11 were salmon spotter pilots. Nine pilots had been spotters for both salmon and herring fisheries, and 2 were not fishery spotters but flew chartered aircraft for a living. Other occupations represented included teachers, sport fishing charter operators, cannery watchmen, and mail carriers, who participated extensively in sport and subsistence harvests. Fishermen (all fisheries) had a combined 1,091 years of involvement in fishing activities (Table 1). Because fishermen had the vast majority of years of experience, we did not compare interview results by occupation.

Species, Life History Stage, and Schools

Many respondents could distinguish forage fish species and life history stages of herring by behavior and school characteristics. Water conditions, light, wind, the school's proximity to the surface, and the position of the observer on the boat (e.g., on the flying bridge versus the deck) affected the visibility of juvenile herring

Table 1. Number of the 48 respondents involved in each occupational category, and average, median, range, and total number of years of experience by category.

		Years of Experience			
Occupational Category	Number of Respondents	Average	Median	Range	Total
Fishermen	37	31	32	2–68	1,091
Herring Fishermen	26	17	18	2–68	412
Salmon Fishermen	35	29	30	2–68	977
Professional Pilot	17	18	18	1–36	313
Herring Spotter Pilot	13	14	12	1–36	183
Salmon Spotter Pilot	11	6	6	3–8	60
Biologist	5	16	18	5–25	47
Other Occupations	7	24	22	3–42	189

schools. Pilots distinguished juvenile herring schools from other forage fish schools, adult herring, and salmon by their color, size, behavior, and location.

Herring schools seen from an airplane were darker than sand lance or capelin, and a different color than adult salmon schools. Capelin schools were brown, and herring schools were usually black. In cloudy conditions with flat light, herring were harder to distinguish from other small schooling fishes that fishermen called bait fish. With sufficient light, one could see the fish flash. The herring flash was bright silver, but bait fish were brown and gold. The herring flash was also much larger than that of bait fish schools. Sand lance and capelin were often called needlefish, and at times it was difficult to tell which species the local name was referring to. Their schools were described as cloud-like, with ill-defined borders, whereas herring schools had well-defined borders.

Herring were in 10- to 30-ton schools; if the schools were smaller than 10 tons they could be easily confused with bait fish, which were typically in 2- to 5-ton schools. Eaglek Bay was a good place to see 15 to 20 schools of juvenile herring during a peak period, and one school during a slow period.

School behavior was one way to distinguish juvenile from adult herring schools. Juvenile herring were schooled in small, tight, round schools for protection, but a traveling school of adults was shaped like a boomerang or ribbon. This pilot described how the schools appeared:

> Juveniles are just schooled up in round schools. The schools are fuzzy on the edges because you're seeing the top of a cone, and so what you see is the black center where they're near the surface. As they get away from the surface the school gets bigger and bigger, because herring are reluctant to get to the surface, because that's where [the birds and predators are]. Your visibility is why it looks soft on the edges. You're looking through water. Whereas a school that's on a mission, that's on the beaches, is very discernable on the edges. They aren't worried about predators; they aren't worried about schooling for protection. They're heading to go fool around.

Respondents also distinguished juvenile from adult herring by location of schools. Several respondents said juvenile herring liked shallow estuaries at the heads of deep bays. Juveniles were inshore more often at the surface during summer than adult fish, and in protected rocky bays with indentations in the shoreline that let them stay out of the current.

> Rarely do you see them against the beach. All these bays — they seem to always be in calm water, where there isn't a lot of current. They like the backwaters of the bays, so they don't go up on the beaches. If I was looking for herring, I wouldn't be flying the beach, I'd be doing transects across the bays.

Salmon fry were also abundant in summer. However, respondents said that there was no likelihood of mistaking salmon fry for herring schools because salmon fry could not be seen from the air. One pilot described seeing them from land, amongst rocks, but hard to see because they are transparent. He had never seen migrating salmon fry from an airplane and never in 100-ton schools.

> Fry migrate in schools of 100–150 fish. They travel along beaches in small schools – most are too hard to see.

Fishermen observed fish schools from their boats with downward-looking echo sounders, from the decks or flying bridge, and by catching them. They saw herring flipping when schools were near the surface and occasionally caught a few in their nets.

After echo sounders were in common use, many observations referred to electronic pictures. Fishermen use their ecological knowledge of fishes to make educated guesses about electronic displays of fish schools. They consider other information to distinguish schools including season, speed and movements of schools, presence and movement of predators (e.g., seabirds), depth of the schools, known preferred habitats of particular species, school behavior, bottom type, tidal stage, time of day, and definition of schools on the sonar display. Schools of juveniles cannot be differentiated from adults by sonar alone (D. Lodge, Alaska Vocational Training Center, Seward, Alaska, personal communication, 8-11-99). Herring tend to be in tighter schools than salmon, and denser schools produce a more solid echo. Other respondents said they could distinguish between species of fish, such as walleye pollock or herring, and some could differentiate adults and juveniles. One fisherman noted that herring show up a "good red", but walleye pollock are v-shaped and are not as tightly schooled as herring. One respondent said smaller fish are more skittish than adults, are more often seen at the surface in daylight hours, and occur in shallow waters often in protected bays.

Within broad ranges, some fishermen could estimate school size with sonar for schools between 30 and 50 tons, but probably not between 30- and 40-ton schools. Their estimates were formed over years of guiding net catches using sonar and validating their estimates with the catch weight.

Juvenile Herring

Observations of Pacific herring were the most common and contained the most auxiliary information. The PWS juvenile herring database consists of over 2,800 observations by 35 observers for all years and seasons. The OK juvenile herring database consists of over 1,000 observations by 13 observers. Observations of juvenile herring were documented from west of Port Dick on the OK (Figure 1), to Day Harbor (within region 8, Figure 2) to the southeast corner of Montague Island (region 7), and around PWS, from Orca Inlet (region 1) to Port Nellie Juan (region 4) and the bays and passages along Knight Island Passage (region 8; Figure 2).

Average commercial fishing time for all districts increased from about 5,063 hours in the 1960s and 1970s to about 7,000 hours in the 1980s and 1990s. Along with the increase in commercial fishing time, the number of summer observers and resulting observations of juvenile herring increased from the 1970s to the 1980s. From 1990 until 1996, (the year this study was conceptualized) the number of observers decreased, though the average number of observations per year was similar to that of the 1980s (Table 2). However, a marked decrease in the distribution of juvenile herring in the 1990s was observed when compared to the maps of observations in the 1970s and 1980s.

Spatial Distribution in PWS

The earliest observations of juvenile herring were from the summers of 1934 in Tatitlek Narrows (region 2; Table 3, Figures 1 and 2) and 1938 in Port Wells (region 4). Elders reported herring were so abundant the propellers of outboard motors would grind them up.

Bays in the eastern sound (region 1), especially Port Gravina, had the highest number of observations (Table 3, Figure 1). From 1978 until 1994, 4 to 6 respondents each year saw juvenile herring in this area. Schools of juvenile herring were mostly seen from airplanes (*n*=374).

Northeastern PWS (region 2) had the second highest number of observations of juvenile herring in PWS (Table 3), with the most in Port Fidalgo. As in region 1, the schools were seen primarily from an airplane (*n*=319). The overlap in numbers of observers by year was high in region 2. Most observations began in 1970. Between 1970 and 1992 at least 4 observers each year reported seeing juvenile herring in this region. The number of respondents who reported juvenile herring in this region increased to 6 in 1972 and was at least that large until 1979. From 1981 to 1987, there were at least 7 observers every year. One respondent described the distribution of juvenile herring in Valdez Arm and Eaglek Bay in regions 2 and 3 as "patchworks of fish all the way up inside as far up as you can go."

Table 2. Comparison of the average number of observations and respondents per year, and average number of observations per respondent per year in Prince William Sound and the Outer Kenai Peninsula, 1970–1996.

Decade	Total Observations	Average Observations	Average Annual Respondents	Average Annual Observations Per Respondent
Prince William Sound				
1970-1979	799	80	12	7
1980-1989	1,052	105	15	7
1990-1996	766	109	9	13
Outer Kenai Peninsula				
1970-1979	291	29	5	6
1980-1989	481	48	8	6
1990-1996	134	19	6	3

Table 3. Numbers, locations, and method of observations of juvenile herring by region in Prince William Sound. The earliest and most frequently reported locations by region included Orca Bay (OB), Sheep Bay (ShB), Simpson Bay (SiB), Port Gravina (PG), Tatitlek Narrows (TN), Port Fidalgo (PF), Eaglek Bay (EB), Fairmount Island (FI), Kaniklik (K), Granite Bay (GB), Port Wells (PW), Naked Island (NI), Eleanor Island (EI), Knight Island (KI), Montague Strait (MS), Hinchinbrook Island (HI), Port Chalmers (PC), Stockdale Harbor (SH), Jeanie Cove (JC), Patton Bay (PB), and Day Harbor (DH). Regions correspond to areas shown in Figure 2.

	Number		Earliest Observation		Most Frequent		Most Common Observation Method			
Region	Observations	Observers	Year	Location	Location	# Observations	1st	2nd	3rd	4th
1	520	15	1970	OB, ShB, SiB, PG	PG	304	Airplane	Caught	Sonar	Visual
2	485	16	1934	TN	PF	231	Airplane	Visual	Caught	
3	382	14	1970	EB, FI, K, GB	EB	103	Airplane	Caught		
4	357	13	1938	PW	PW	120	Caught	Airplane		
5	393	7	1970	NI, EI	NI	372	Visual	Airplane	Caught	
6	306	18	1970	KI, MS, HI	PC, SH	78	Airplane	Visual	Caught	
7	6	1	1994	JC, PB	JC, PB	6	Airplane			
8	405	12	1970	DH	DH	92	Caught	Visual	Airplane	Sonar

Region 3 also had a relatively high number of observations and a high degree of overlap in the numbers of respondents who saw juvenile herring in this area. Three respondents saw juvenile herring each year between 1981 and 1991. Most observations in this region were from airplanes (n=323) and occurred in Eaglek Bay. At least 3 respondents saw juvenile herring schools in Eaglek Bay each year between 1982 and 1987. Fairmount and Wells Bays also had 3 observers almost every year of the 1980s. Columbia Bay had two observers, but no observations were recorded there after 1979.

At least 5 respondents each year from 1970 to 1986 saw juvenile herring in region 4. The number of observers declined in 1987. Juvenile herring were seen from airplanes (n=121) and were caught (n=119), with a large overlap between the two methods (aircraft observations coupled with catches; n=103).

Most juvenile herring observations in region 5 were visual (n=290). The highest number of observers per year occurred in the late 1980s.

Most observations in region 6 were made from an airplane (n=201). Respondents most often reported seeing herring schools in Port Chalmers and Stockdale Harbor.

Juvenile herring in region 7 were seen in Jeanie Cove and Patton Bay by a fish survey pilot beginning in 1994. He learned to identify schools by comparing catches made at the time of the aerial surveys.

The third highest number of observations of juvenile herring occurred in region 8. In this region, juvenile herring were most often caught (n=138), visually identified (n=123), or seen from an airplane (n=108). At least 3 respondents saw herring in this area each year between 1971 and 1989.

Seasonal distribution in PWS

Respondents indicated that herring distribution varied throughout the year (Table 4, Figure 3). However, comparisons of herring distribution and abundance by season were confounded because most resource-related activity took place in spring and summer. In spring, over half of the respondents were focused on commercial herring fisheries, which usually took place in April. Fishermen tried to avoid juvenile herring, and pilots searched from airplanes for schools of adult spawning herring. In summer most respondents were engaged in the commercial salmon fishery. Pilots flying scientific surveys and charter flights and fishermen who chartered flights to look for adult salmon also saw herring schools along their routes. In fall and winter juveniles were detected with sonar and were seen on the surface of the water in bays when they were attracted to deck lights. Fishermen fishing for shrimp, crab, or adult herring also incidentally caught juvenile herring.

Table 4. Seasonal distribution of juvenile herring observations by area and region in Prince William Sound (PWS) and the Outer Kenai Peninsula (OK).

Region	Spring	Summer	Fall	Winter	Total
1	83	316	94	27	520
2	115	362	5	3	485
3	74	291	17	0	382
4	52	275	19	11	357
5	21	74	153	145	393
6	53	205	48	0	306
7	3	3	0	0	6
8	64	282	41	18	405
Total PWS	465	1,808	377	204	2,854
Total OK	253	642	41	66	1,002

In spring, juvenile herring were observed at several places in PWS while fishermen and spotter pilots readied themselves for the herring fishery. Region 2 had the most observations in spring (Table 4).

Although juvenile herring were observed in Tatitlek Narrows (Figure 1) year-round, a resident of Tatitlek said it was very common to see juvenile herring in Tatitlek Narrows in spring in the 1930s.

> …We always had little fish in the springtime…They told us they were baby herring…There should have been lots of herring around because the babies were here.

In the early 1970s fishermen reported catching juvenile herring in seines in Columbia Bay (Figure 1) while fishing for adult herring. One fisherman said juvenile herring were all around Glacier Island in the early 1970s. Another fisherman recorded a similar observation in his log in the 1970s:

> April 22/23, 1972: Fish caught in Chamberlain Bay, water temperature 37° F; north side of Glacier Island 3-4 inch 'feeders'…April 10, 1978: People were setting on krill and juvenile herring around Growler Bay. April 17, 1978: In Columbia Bay almost all the herring are caught around Emerald Cove. I'm sure someone ran over and set on them, and found out they were juveniles.

Another respondent recorded that someone made a set in 1985 at Glacier Island and caught herring 3 inches long. He reported, "They were very small and gilled in the net. It looked like a silver sheet." Pilots saw juvenile herring schools along the north shore when flying from Sheep Bay to Eaglek Bay (Figure 1). One pilot said he called them juveniles because he "wouldn't set a seine on them."

Another respondent does not remember ever having a problem with juveniles in the spring sac roe fisheries along the north shore. He remembers smaller fish in the commercial harvest at Montague Island:

> In the mid eighties, all the roe fisheries were taking place in Eaglek Bay…those were all adult fish. As time went on we started trying to harvest fish down at Montague [Island], and the fish always got smaller and mixed, they were always smaller there. We had somewhat of a quality problem. I wouldn't consider them juveniles. They were definitely roe herring and they were sellable most of the time. In the spring when we went roe fishing…we never had a set with juvenile fish in it in the northern area at all."

Respondents reported seeing juvenile herring in Stockdale Harbor and Port Chalmers (Figures 1 and 2) during and after the spawn-on-kelp fishery from the mid 1970s to mid 1980s. Port Fidalgo, Galena Bay, and Jack Bay were described as consistent places to see juvenile herring in spring. Several respondents reported

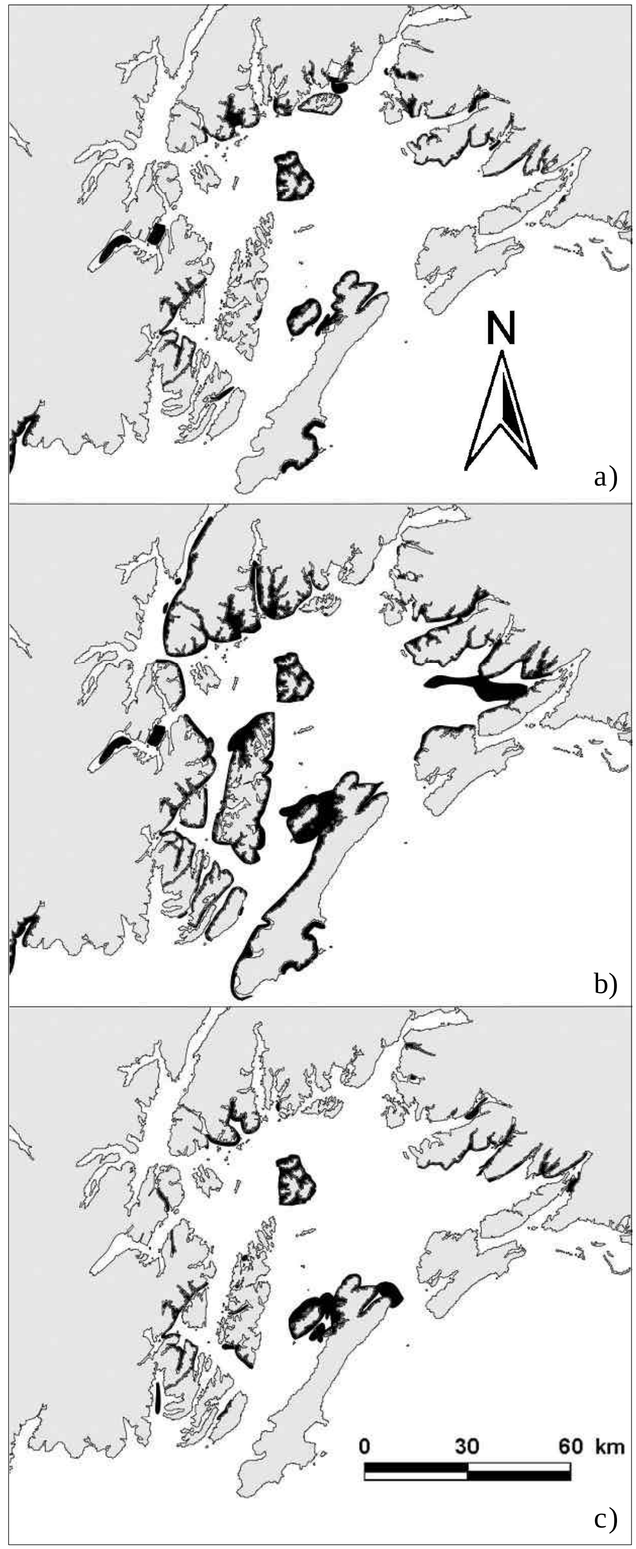

Figure 3. Distribution of juvenile herring observations in Prince William Sound by season: a) spring, b) summer, and c) fall/winter.

juveniles liked deep bays with shallow estuaries. Two respondents also saw juvenile herring in Day Harbor (Figure 1) from the mid 1970s through the 1980s. They saw herring there in spring and summer, but more schools in summer (Figures 3a and 3b).

Several fishermen commented on the presence of juvenile herring in region 4, especially at the head of Port Nellie Juan (Figures 1 and 2). One fisherman saw them several years when he anchored near the north end of Knight Island, around the time of the herring fishery.

The total number of juvenile herring observations peaked June through August. Most respondents (*n*=35) were involved in the commercial salmon fisheries (Table 1). Respondents also engaged in recreational and subsistence activities and charter operations. Over half the observations in the PWS juvenile herring database were made in summer. Juvenile herring were observed in almost all bays and some open areas in PWS (Table 4).

Several respondents commented that the whole sound, rather than a particular bay or set of bays, was important for juvenile herring in the summer (Figure 3b). However, many respondents observed herring in certain areas more than others (Table 4).

Region 2 had the most summer observations followed by regions 1, 3, and 8. Respondents consistently saw juvenile herring in Port Fidalgo and Port Gravina (Figures 1 and 2). One pilot commented "there's always herring in Port Fidalgo," and some bays such as Snug Corner Cove and Irish Cove, smaller bays within Port Fidalgo, "always have herring in them." Within Port Gravina, St. Matthew's Bay and Gravina Rocks were other locations he said always had large schools of age-0 to age-2 herring. He reported large schools of juveniles during the late 1970s at Hell's Hole and Red Head, also in Port Gravina, in midsummer as well.

Pilots reported regularly seeing herring in the bays along the northern shorelines of PWS from Eaglek Bay to Hawkins Island, including Naked Island, Simpson and Sheep Bays (Figures 1 and 2). One had seen juvenile herring schools around Fairmount Island every weekend when he flew his salmon surveys. Port Wells also had juvenile herring schools in summer from 1938 to 1988, with the majority of reported observations there in the 1970s. However, herring were reported to be less abundant in Port Wells than in Orca Inlet.

Another pilot reported that fishermen used to catch sport bait in Port Nellie Juan (Figure 1). From the early 1970s to the mid 1980s he would stop and jig the schools on his way to and from Seward. Over the same period he would also consistently see juvenile herring schools in Day Harbor in spring and summer, though they were more abundant in summer. Fishermen saw juvenile herring in the southwestern passages while seining. From 1971–1991, a seiner occasionally caught 2- to 3-inch herring in his seine while salmon fishing in Elrington Passage. A gillnetter saw ½- to ¾-inch herring in dense schools migrating past Eshamy Bay several years in the period 1967–1975. Another fisherman saw schools while tendering salmon in Prince of Wales Passage.

A Seward charter captain described halibut fishing at the south end of Montague Island near a place charter operators call "Magic Mountain." In 1995–1996 he noticed that the halibut caught there regurgitated juvenile herring.

One pilot saw juvenile herring in the summer on the outer, northwest coast of Montague Island (Figures 1 and 2). Through the 1980s, he flew hundreds of hours looking for salmon and consistently found schools of herring in sheltered areas such as Stockdale Harbor and Port Chalmers.

Fall and Winter Observations in PWS

Because there were substantially fewer observations during fall and winter (Table 4), we combined them in GIS overlays (Figure 3c). Fall and winter had much less human activity than other seasons. Winter fisheries and air traffic were reduced in part due to inclement weather, short days, and the lack of salmon fisheries. In addition, waves, wind, and deeper depth distributions made schools of juvenile herring harder to see without sector-scanning sonar equipment.

Winter observations came from residents living remotely in PWS, from commercial shellfish fishermen, and herring bait fishermen. From 1960 to 1988, PWS was open for crab fishing September through May. Fishermen noted that crab will sometimes go "off the bite" and will not enter pots because they are feeding on something else such as herring moving through the area. From 1960 to 1991 a trawl shrimp fishery occurred in PWS from April through August and from October through December. Fishermen trawling for shrimp also caught juvenile herring.

In the early 1970s, 2 fishermen traveled throughout PWS looking for bait schools. They found herring "everywhere they went, but not in sufficient quantities to harvest." The largest biomasses were at Knowles Head, a point of land between Port Fidalgo and Port Gravina (Figures 1 and 2), and Montague Island.

Region 5, the area around Naked Island and the waters around the islands north of Knight Island had the most fall and winter observations. The large number of observations from this area were from residents of the islands.

Region 1 had the second highest number of observations during fall and winter. From 1977 to 1981 fishermen tried pair trawling for bait herring. They discovered juvenile herring in the bays and at the heads of Port Gravina, Beartrap (within Port Gravina), and Sheep and Simpson Bays when they mistakenly set on juvenile fish, gilling thousands in the trawl. After that they recognized juvenile herring on their sonars and avoided them when fishing in those areas. Another fisherman who used to trawl for shrimp in Simpson Bay for subsistence use caught juveniles in the trawl from 1985 to 1989. The juveniles traveled fast, in front of the trawl, and he could catch them if he increased his speed. He once collected samples of them for ADF&G biologists.

Fishermen say younger fish mix with adults around Montague Island (region 6) during the early fall months. As October nears and progresses, the fish are more segregated, and fishermen are better able to catch larger herring.

> The guys who've fished bait herring will tell you that if you fish this in September (near Montague Island) you get very mixed fish and quite small. Then as October nears, each day you fish, the further you get into it, the larger the fish will become. There's apparently a migration of fish coming into this area. I don't know if they come out of the Montague Trench or what, but this is the area in which you do bait herring. The Cordova guys could describe it better than I could. That is an interesting pattern, the movement of smaller fish to larger fish.

Bait fishermen released catches with too many juveniles particularly near Stockdale Harbor and Port Chalmers. Sometimes during the bait fishery 40 to 80 g fish would gill in the ¼- to ½-inch mesh of the seines. They saw mainly juvenile schools along the 30 fathom contour, and they tended to stay away from that area. Another fisherman reported juveniles were more spread out during fall and winter when fishermen were fishing for bait. He also said juveniles 3 years and younger mixed with adults.

There were few observations in regions 2, 3, and 4 in fall and winter. Four respondents saw juvenile herring in Port Fidalgo, and only one mapped them in Valdez Arm. However, others remembered seeing them in Valdez Arm even if they were unable to place them on a map. Fishermen observed juvenile herring while fishing for bait herring outside Knowles Head and around Goose Island, between Port Gravina and Port Fidalgo (Figures 1 and 2). They reported herring in deep water during winter. A retired fisherman from Tatitlek who used to fish in Valdez Arm said that during the 1950s a Valdez fisherman would catch them in Valdez Narrows near Jack Bay and can them, "just like sardines." He occasionally set his seine on small fish and said they would go right out of the net. In Alutiiq they call the small fish *natwusuk* – "little feed." He said they did not see schools of little fish during the mid 1960s, perhaps because they were not paying attention, but probably because there were not as many around. He saw small fish in Port Fidalgo, specifically at Bidarka Point and Fish Bay. A Tatitlek resident said herring "stay in the Tatitlek area all winter. Other mammals like seals, sea lions, whales, and winter kings all follow them. In the winter, if you find herring, the kings will be there. You can tell where herring are by the birds feeding on them."

Seasonal Distribution Comparisons in PWS

In PWS spring distributions were significantly different from summer and fall-winter (P<0.0001). However, summer and fall-winter distributions were not different from each other (P=0.798). The greatest differences in distribution occurred between spring and summer (c^2=149.6, P<0.0001) followed by the difference between spring and winter (c^2=85.1, P<0.0001).

Juvenile Herring in the OK

Juvenile herring were observed by respondents to be widely distributed along the entire coast of the OK (Figure 4). Herring were generally sighted in late May. In the early 1970s the first fishermen to try catching herring noticed a migration of juveniles into the head of Resurrection Bay near the end of their fishery. One respondent remembered that the juveniles would appear after the spawning biomass, which came into the head of Resurrection Bay during most of May. Airplanes were not in use then for spotting fish schools and fishermen looked for the roe herring with their "flashers" or fathometers. Sometimes the schools would disappear through the net, and the large herring would disappear into deeper water during late May and June.

> May 9, 1971: Tried again, snowed…couldn't bring net in through slush. Juveniles a constant presence – hard to see from water, but seen all over from the air. June 2, 1971: The sea was black with fish from the ferry dock to Lowell Point. Set deep and had enough to sink the corks on the purse, and ended up with only 3 tons plus thousands gilled along the cork line. Most went out through the meshes. All were 2 1/2-inch herring, no other size.

One respondent found 5-inch herring in Crater and Two Arm Bays in March and April while cod fishing. This respondent stated the herring were seen for 3 to 4 years during the period 1991–1995.

As spring turned to summer, the distribution of herring observations broadened to include most of the shoreline of Resurrection Bay, the west side of Nuka Island, and Port Dick (Figures 1 and 4b). The salmon fisheries are held along the coast within 3 miles of shore. Seine fisheries take place less than 1 mile from shore. In addition, several charter boat operators observed juvenile herring while taking customers from Seward east toward PWS and west to Aialik and Harris Bays.

Seven respondents saw juvenile herring in bays along the OK during the summers from 1958 to 1998. Most observations were made in Aialik, Nuka, Resurrection, and Harris Bays along with Port Dick. A pilot working with a fisherman searched the coast for herring during the 1970s. The fisherman caught small herring, which he estimated were the size of capelin. They reported finding juvenile herring "every place they went." Most were age-2 herring, which gilled in the net. The pilot reported that herring live from Harris Bay to Nuka Bay:

> A lot live in Aialik Bay…We'd see them every time we went there from 1972–1975. To see the juveniles you have to get out in June. Juvenile herring like to go up in bays where it is decent" [i.e., more protected].

The pilot saw juveniles from Two Arm Bay to McArthur Passage. Another respondent had seen juvenile herring amid kelp in the rocky areas of Crater Bay, within Harris Bay while cod fishing. They saw them at the surface in the summer for 3 to 4 years between 1991 and 1995.

During summer, 3 respondents saw juvenile herring each year in Aialik Bay from 1982 to 1989 and in Port Dick from 1980 to 1989. Two respondents saw juvenile herring every year in Aialik, Black, Thunder, Nuka, and Harris Bays from 1980 to 1989.

All observations of herring in fall and winter were by 6 respondents who saw them at the head of Resurrection Bay, many in the Seward boat harbor (Figures 1 and 4c). One couple observed herring in Resurrection Bay over a 40-year period, September through November from 1958 to 1998. From December through February, 1969 to 1998, 5 individuals saw herring at either the Seward boat harbor or the head of Resurrection Bay. One respondent described them as 3- to 4-inch herring. Another remembered seeing them in the Seward Harbor every year, but could not remember the first year he had seen them.

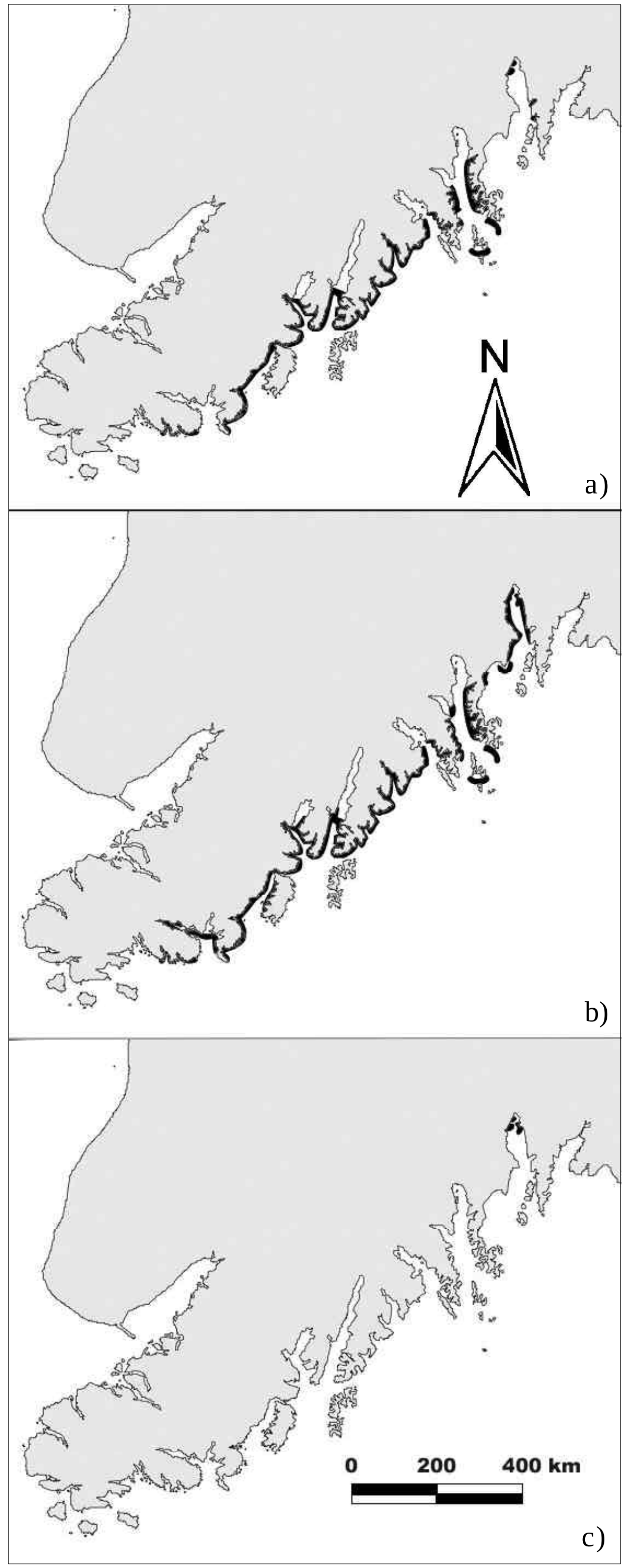

Figure 4. Juvenile herring observations along the Outer Kenai Peninsula by season: a) spring, b) summer, and c) fall/winter.

Seasonal Distributional Comparisons in the OK

Seasonal distributions between spring, summer, and fall-winter were significantly different from one another whether compared pairwise or as a group ($P<0.0001$). Test statistic values were generally higher than in PWS indicating greater seasonal differences in the OK. As in PWS, the spring to summer comparison had the highest test statistic value ($\chi^2=244.9$, $P<0.0001$), spring to winter the second highest ($\chi^2=103.3$, $P<0.0001$), and summer to winter the lowest ($\chi^2=15.4$, $P=0.0001$).

Decadal changes in distribution in PWS and the OK

Due to the low number ($n=4$) and spatial limitation (eastern PWS) of observations before the 1970s, we did not compare distributions for earlier decades in the maps and tables. However, 2 observers reported that juvenile herring were more commonly sighted in the 1930s and 1960s as compared to the 1950s indicating potential changes in abundance between those decades. In contrast, a retired fisherman observed many juveniles in Valdez Arm (where he fished) in the 1950s but very few during the mid 1960s.

In PWS respondents reported more observations and noted that juvenile herring were more broadly distributed in the 1980s than the 1970s (Table 2; Figure 5). Broader coverage of PWS in the 1980s was evident from maps of compiled observations (Figure 5b), with more observations around northeastern and western Montague Island, as well as more observations in Orca Inlet, Port Fidalgo, Naked Island, Fairmount Island, Eaglek Bay, and Esther Island than in the 1970s (Figures 1 and 5a). However, Columbia Bay and the area around Glacier Island had fewer observations in the 1980s than the 1970s. The average number of observations per year for 1990-1996 was about the same as the 1980s (Table 2), though the distribution of juvenile herring was more restricted in the 1990s (Figure 5c) than in the 1970s or 1980s. In the 1990s there were no observations near Hawkins Island; fewer observations along the northern shore, Esther Island, Culross Island; and no observations along northern Knight Island passage by Main Bay and Eshamy Bay. Observations also covered less of Montague Island in the 1990s.

In PWS the average number of respondents decreased each year in the 1990s compared to the 1980s, although the average number of observations per respondent did not. Beginning in 1995, some pilots participated in scientific charter surveys of forage fishes, and as a result, probably made more observations than they otherwise would have or than respondents who did not participate in the surveys.

In the OK, more observations were made in the 1980s than in the 1970s or from 1990 until 1996 (Table

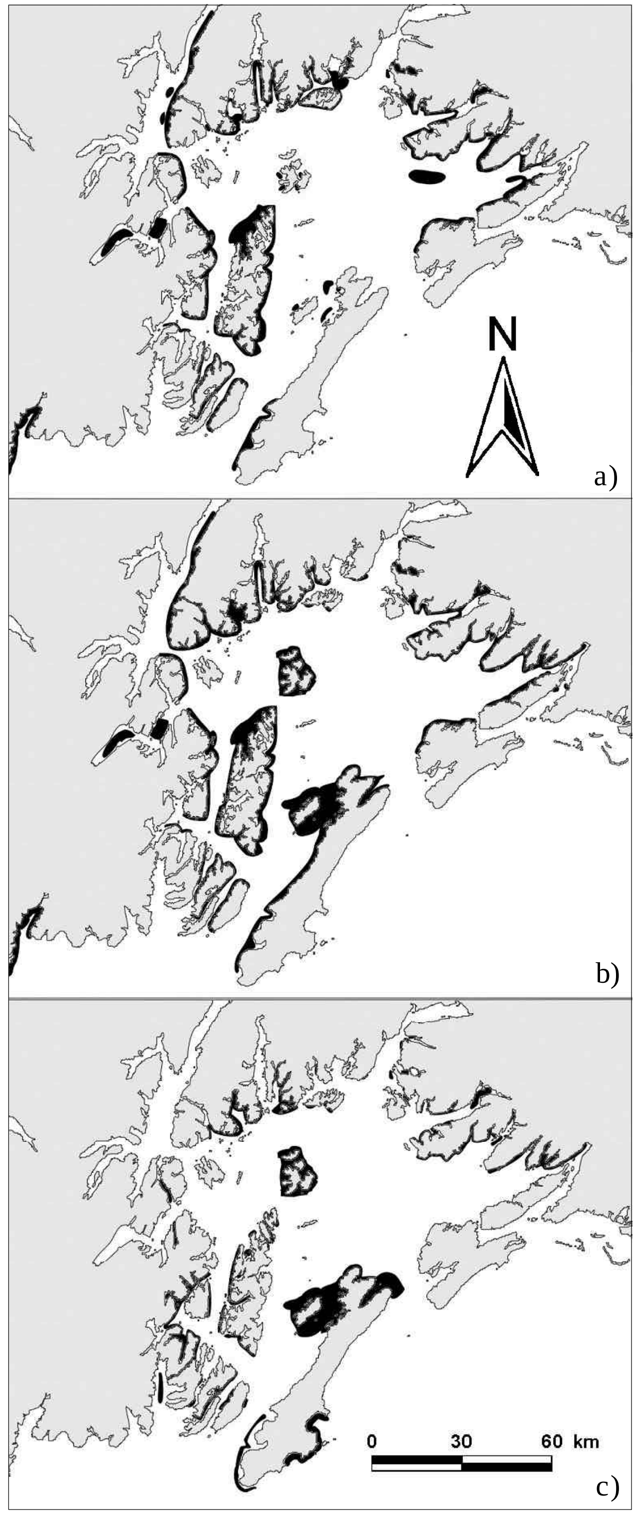

Figure 5. Juvenile herring observations in Prince William Sound by decade: a) 1970s, b) 1980s, and c) 1990s.

2). The average number of observations per year increased from the 1970s to the 1980s and decreased during 1990–1996. The average number of respondents each year was also higher in the 1980s than in either the 1970s or 1990s. The average number of observations per respondent per year declined in the 1990s.

Observations in all bays except Resurrection Bay increased in the 1980s (Figures 1, 6a, and 6b), especially in Aialik, Nuka, and Harris Bays, and in Port Dick. Three observers saw juvenile herring in Port Dick for several years in the 1970s and all years of the 1980s. Respondents said juvenile herring distribution was greatly restricted in the 1990s compared to the previous 2 decades (Figure 6c).

The observation of large numbers of juvenile herring in the 1980s is consistent with large years classes of adult herring reported by ADF&G in the 1980s (Donaldson et al. 1992). Herring cohorts from 1984 and 1988 were particularly large, and during the summer of 1985, biologists reported "an unusually large biomass of herring throughout the area, a significant portion of which were juvenile fish" (Randall et al. 1986).

There was spatial association and disassociation between decadal distributions of juvenile herring in PWS and the OK. In PWS, the 1970s herring distribution, which was spread around the sound, except for Montague Island, was not significantly different (P=0.176) from the 1980s, which was spread around the sound including concentrations at Montague Island (Figure 5). However, the 1970s herring distribution was highly significantly different from the 1990s, when the distribution of herring was less widespread and more concentrated around Montague Island (P=0.0004). The distribution during the 1980s was also significantly different from the 1990s (P<0.0001). The test statistic (χ^2=19.2, P<0.0001) for the 1980s to 1990s comparison was the highest, followed by the 1970s to 1990s (χ^2=12.7, P=0.0004) indicating a relative degree of differences in the distributions between those decades. In the OK, all 3 decades were significantly different (P<0.0001) with an order of magnitude higher test statistic values than those for the PWS pairwise tests. As in PWS, the OK test statistic (χ^2=275.0, P<0.0001) for the 1980s to 1990s comparison was the highest, followed by the 1970s to 1990s (χ^2=198.7, P<0.0001). The results from both PWS and the OK indicate that observers were able to detect a larger change in juvenile herring distribution from the 1980s to the 1990s than from the 1970s to the 1990s.

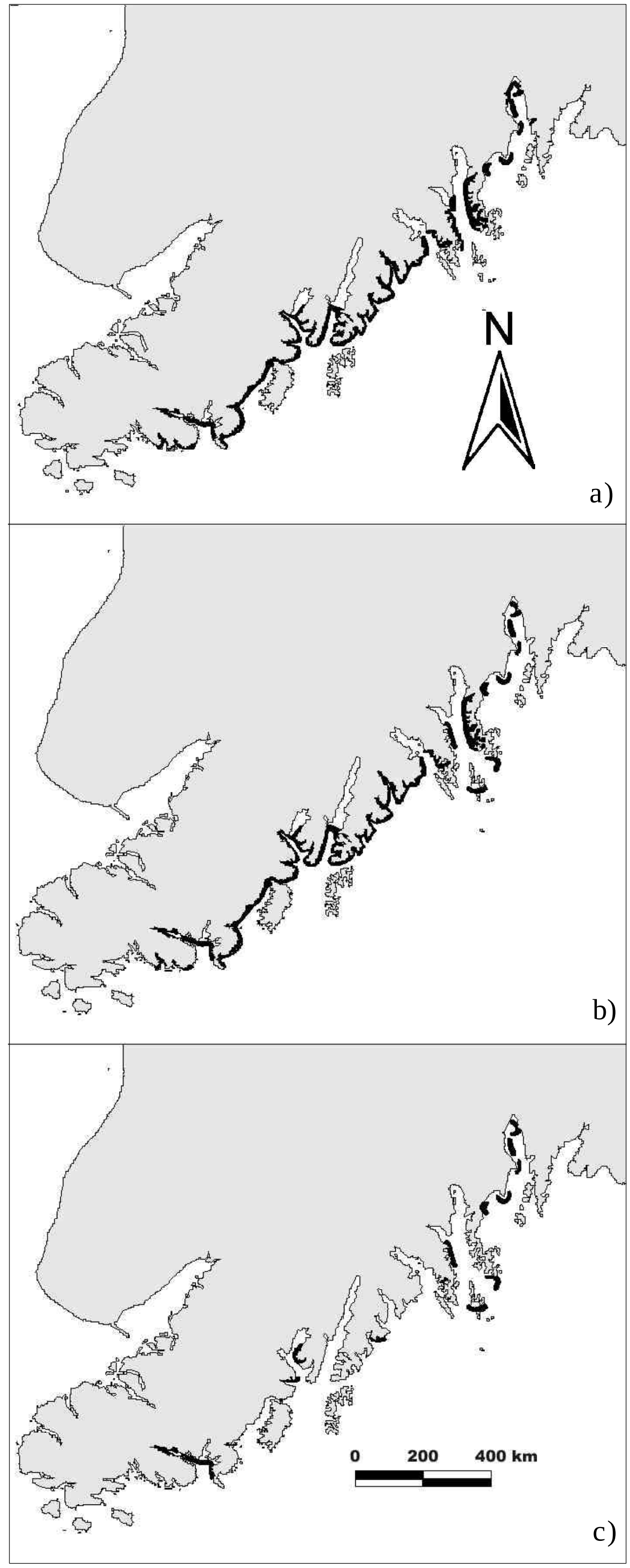

Figure 6. Juvenile herring observations along the Outer Kenai Peninsula by decade: a) 1970s, b) 1980s, and c) 1990s.

Herring Spawning and Eggs

The distribution of spawn documented by ADF&G from 1973 to 1998 (digitized from raw unpublished data, Alaska Department of Fish and Game, Cordova; Brady 1987) occurred primarily on the eastern, northern, and Montague districts of the sound (Figure 7a). However, respondents in this project added historic spawning sites in areas ADF&G no longer monitored by aerial surveys (Figure 7b). In the earlier years, herring spawning was reported by respondents along western coastlines in PWS, in Port Wells, and on the Copper River delta. Native elders observed that spawning patterns have changed since 1964. A Tatitlek respondent reported that his elders told him "uplift from the earthquake may have changed spawning patterns."

Adult Herring Migration Patterns

Nearly all respondents said herring move throughout the year. The changes in spawning areas of commercially-fished populations in PWS are well documented by ADF&G (Alaska Department of Fish and Game, 1960–1997; Brady 1987; F. Funk, Alaska Department of Fish and Game, Juneau, personal communication). However, the extent of herring migration outside of the spring and fall fisheries is not known. Several respondents who fished for bait herring in the fall or for crab in late winter and early spring reported herring moving into PWS through Hinchinbrook Entrance, Montague Strait, and the southwestern passages before the sac roe fisheries. Some said the ocean herring moved into Montague Strait. Several mentioned seeing herring move up Montague Strait prior to the fall bait fishery.

Although the Knowles Head area, between Port Gravina and Port Fidalgo (Figure 1), was acknowledged as a major wintering area for adult herring, many respondents hypothesized that a portion of the adult spawning herring move out of PWS after spawning and return to the sound in the fall, peaking in number by October and disappearing by December.

One respondent observed large schools of herring moving toward PWS from the west off Cape Resurrection, in late summer or early fall during 1991. He described them as domes of 10,000–25,000 ton schools that took 2 weeks to pass Elrington Passage (Figure 1). They did not go up into the sound. Another respondent described a large school of herring moving into Hinchinbrook Entrance in the fall of 1992. Observers knew commercial fishing tenders traveling to Seward crossed large schools of herring moving into PWS through Elrington and LaTouche Passages in the fall (Figure 1). The schools were described as 2 miles long between about 30 fathoms and the surface.

Crab fishermen reported seeing adult herring with their fathometers in winter between Egg Islands, on the Copper River flats, Cape Cleare, and Middleton Island. One mentioned catching cod with herring in their stomachs. Based on their migration pattern through Hinchinbrook Entrance, he thinks herring spend winter between Wessels Reef, Cape Cleare, and Middleton Island, along the shoreline of Montague Island in early spring (Figure 1). "They come in on this point, on the eddy inside of Zaikof, and then enter Rocky Bay."

In late spring a fisherman saw adult herring along Cape Yakataga as he was flying back from the Sitka herring fishery in Southeast Alaska. In late spring and early summer, several fishermen reported adult herring on the Copper River flats, and some reported getting herring spawn on their salmon gill nets, particularly during the 1970s. One respondent had seen large herring (120–140 g) 10 miles off the southernmost point of Kayak Island and to the east every year from May 15 through June 15. He caught them in his salmon gillnet from 1995 through 1997 during daylight. He estimated the schools could have been one mile wide, and of perhaps 10,000–20,000 tons, and in about 40 fathoms of water. A different fisherman regularly saw herring spawn on Wingham Island. Another fisherman thought that herring lived offshore as far east as Yakutat, about 200 km east of Kayak Island (Figure 1).

Other Forage Fish Species and Predators

In PWS respondents reported locations of capelin, capelin spawning areas, eulachon, sand lance, and unidentified species including general references to "smelt." Nearly one-half of the non-herring sightings were reported as "forage fish", species unknown. Over 93% of the non-herring forage fish observations were made during late spring (May) and summer. Only 6% were reported during the fall and winter, and 90% of these were unknown forage fish species. Within PWS, capelin were reported most often in outer bays and exposed beaches in the southwest, north, around northern Montague Island and Hinchinbrook Island during late spring (May) and summer. Capelin also were reported in northwestern PWS during the summer in Eaglek Bay and Esther Passage (Figures 1 and 8a). Capelin spawning was reported on the southeastern exposed beaches of Montague and Elrington Islands and at the head of Day Harbor. In PWS sand lance were reported mainly on beaches and especially in bays in eastern, northern, and southwestern areas (Figure 8b). Eulachon were reported in the

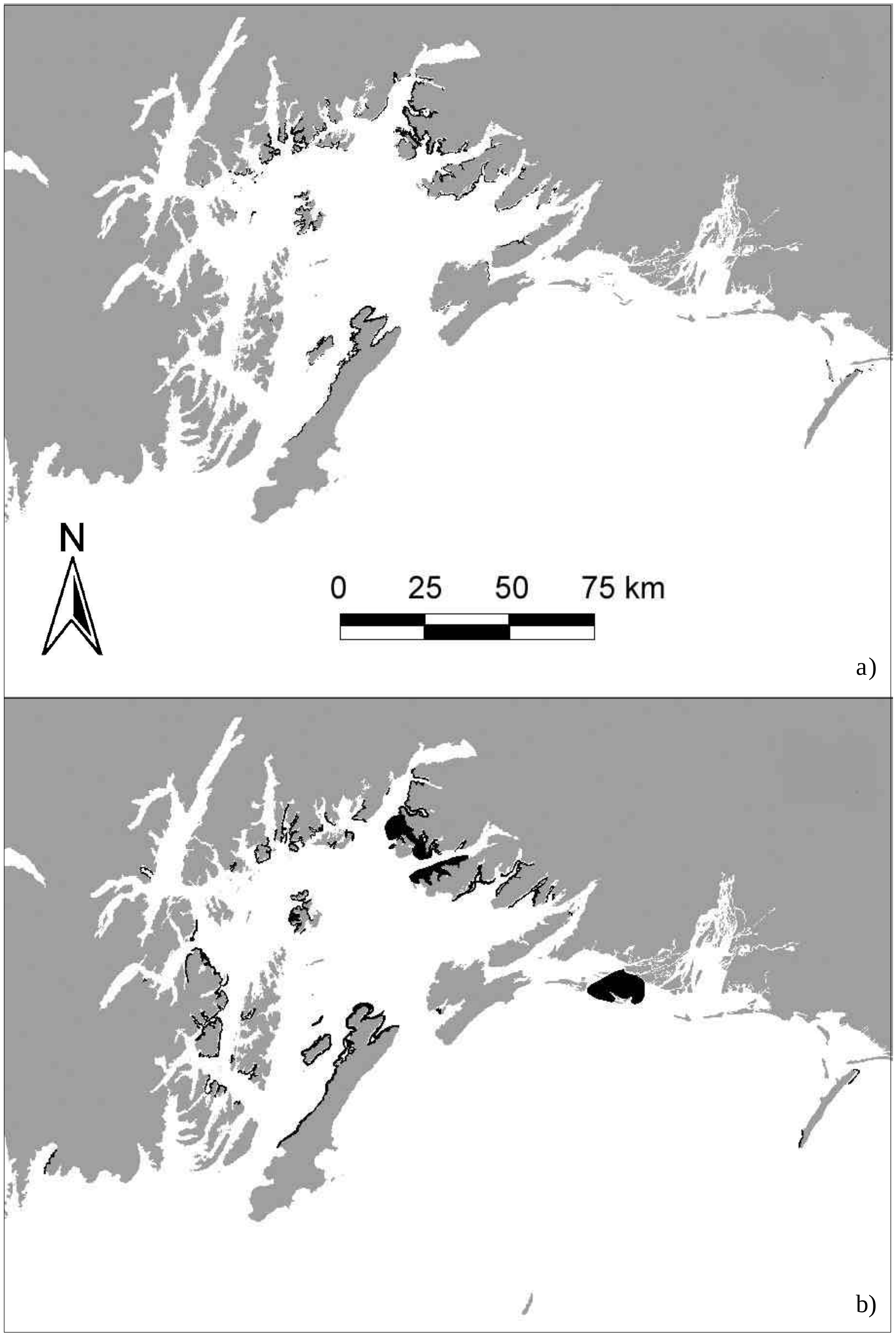

Figure 7. Composite of herring spawning locations: a) documented by aerial surveys in Prince William Sound from 1973 to 1998 (unpublished data, Alaska Department of Fish and Game, Cordova), and b) documented by respondents from this study in Prince William Sound from 1930 to 1998.

southwestern passes of PWS and off the southern tip of Montague Island adjacent to the Gulf of Alaska (Figure 8c). Some residents used gillnets to capture smelt for sport fishing bait, and one respondent recalled seeing them regularly in the Cordova small boat harbor during the winter.

As in PWS, respondents reported other species of forage fishes around the OK. Capelin were in or near Resurrection and Two Arm Bays (Figure 9a). Capelin and unknown smelt species were reported in bays in the OK during the spring and summer. However, a pilot working with a fisherman found capelin only in Resurrection Bay and not along the entire OK coastline, unlike herring. In addition, smelt were reported outside of Two Arm Bay. Sand lance were reported near many of the beaches along the coast from Resurrection Bay to Port Dick (Figure 9b). Eulachon were reported outside of Aialik and Harris Bays during the summer and at the head of Resurrection Bay during the winter (Figure 9c).

The majority (76%) of the fish observations did not mention co-occurring predators. Of the remaining observations, 11% reported co-occurrence with birds, 6% with sea lions *Eumetopias jubatus*, 3% with seals, 2% with killer whales *Orcinus orca*, and 2% with humpback whales *Megaptera novaeangliae*. No attempt was made to summarize the predator data by season, species, or decade.

Disease in Herring

None of the respondents could recall an incidence of disease in herring or other fishes other than in 1993 when viral hemorrhagic septicemia killed much of the PWS herring population (Meyers et al. 1994; Marty et al. 1999).

DISCUSSION

The extent of TEK depends on the activities of, and sharing of knowledge among, area residents and resource users. As patterns of activity shift, knowledge that was previously important for survival can become less significant and, eventually, be lost. Documentation is not an adequate replacement for perpetuation of knowledge within a community, but it is an important means of making information available today and for the future. Through this study, knowledge has been preserved that might otherwise have disappeared within the next few decades.

Knowledge was preserved and project objectives were met primarily through the creation, documenta-

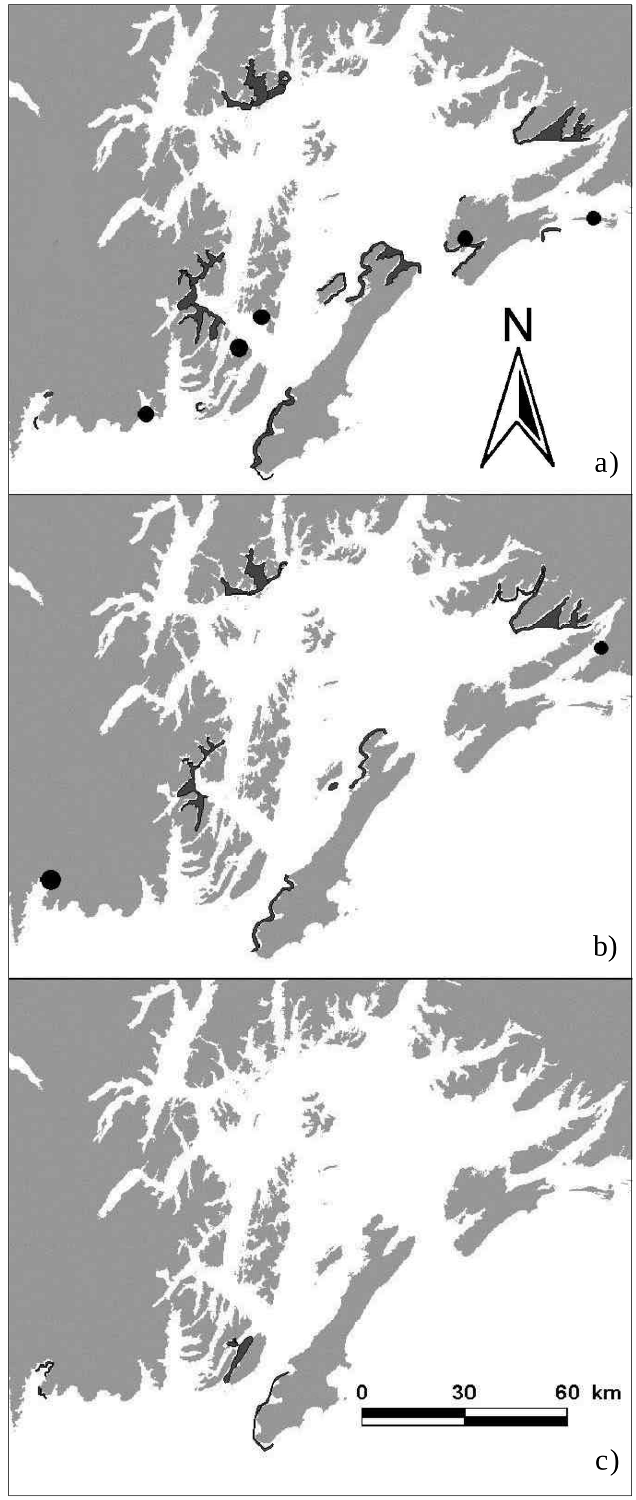

Figure 8. Composite of forage fish species other than herring in Prince William Sound. Locations of schools are denoted by outlined gray polygons and locations of spawn as black dots: a) capelin, b) sand lance, and c) eulachon locations.

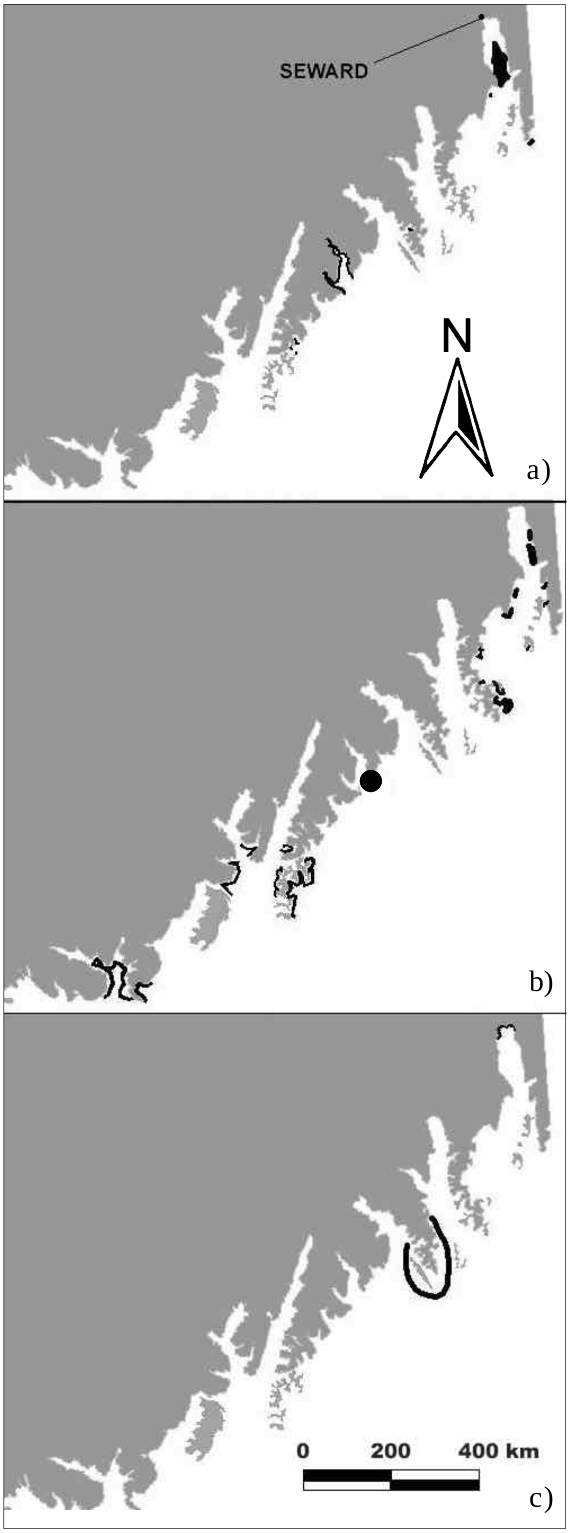

Figure 9. Composite of forage fish species other than herring along the Outer Kenai Peninsula. Locations of schools are denoted by outlined gray polygons and locations of spawn as black dots: a) capelin, b) sand lance, and c) eulachon locations.

tion, and sharing of a GIS TEK database. From the database, information and sample size (number of observations or respondents) could be summarized in tables or maps by a variety of parameters including species, season, and decade. Respondent codes, included in the database, protected the identity of the respondents. New data can be added to the database with relative ease. We recommend this type of geographic documentation of TEK data because of the widespread use of ArcView software, coupled with the ease with which data can be queried or fomatted and displayed.

The main uses of this database include providing information for survey designs of juvenile herring and forage fish, assisting in the interpretation of field observations, validating research findings and observed long-term trends in abundance, and as additional evidence for herring stock structure theories. Brown et al. (1999a, b) used the respondent reports on school characteristics to help identify juvenile herring and distinguish them from other species during the initial stages of their aerial survey program. Our findings were assimilated with data from other sources to develop a geographic database of sensitive marine areas in the region affected by the *Exxon Valdez* oil spill (J. Dahlin, Research Planning, Inc., Columbia, South Carolina, personal communication). We successfully extracted information about identification of species-specific school characteristics, seasonal and decadal spatial distribution of juvenile herring, historic information on how herring spawning patterns have changed, and general distribution information on other forage fish species.

Several respondents said juvenile herring reside nearshore and noted that bays were important for herring development. Others encountered juveniles in shallow estuaries at the heads of deep bays, areas the observers thought were nurseries. This finding of nearshore (<1 km from shore) bay distribution was used to focus initial broad scale juvenile herring survey efforts in the nearshore regions of PWS, although offshore areas were sampled for statistical comparisons (Stokesbury et al. 2000). This distribution pattern is consistent with catches from fishing operations in PWS 70 years ago (Rounsefell and Dahlgren 1932) and with more recent data (Stokesbury et al. 2000). Young of the year Pacific herring were also widely distributed in nearshore (generally <1 km from shore) shallow (<50 m) areas in British Columbia and not mixed with adults (Hourston 1956, 1957, 1959; Haegele 1995).

We found that juvenile herring are broadly distributed in both PWS and the OK (Figures 2, 3, and 4) and can be found there during most seasons. In addition, PWS and OK seasonal distributions were different from one another with the exception of summer and fall-winter distributions in PWS. The similarity between summer and fall-winter distributions in PWS indicates that juvenile herring remain broadly distributed during overwintering. Increased summer activity of the observers (and number of observations, Table 4) did not appear to affect reported seasonal distribution patterns because fall-winter was not different. Juvenile herring are widely distributed in summer and remain in the same broadly distributed nursery bays all winter (Stokesbury et al. 2000). Seasonal distributions were not the same in the OK as in PWS, which may reflect different nursery bay characteristics in the 2 regions resulting in different winter distributions. Historic summer catches coincide with many of the summer locations reported by respondents, especially in southwestern PWS and the eastern OK. Respondents probably observed more herring in the summer (Figures 3 and 4) when school distribution is shallower (Brown and Moreland 2000; Stokesbury et al. 2000) and days are long. Brown et al. (1999a, 1999b) were able to census juvenile herring from aircraft during the summer because of this distribution pattern.

Several respondents reported PWS was one large nursery area and did not identify a particular bay or bays that were more important as nursery areas. However, Port Gravina, Port Fidalgo, Port Wells, Port Chalmers, Stockdale Harbor, and Eaglek Bays were reported as nursery areas more frequently than other PWS bays. Resurrection Bay, Port Dick, Day Harbor, and Aialik Bay were most frequently noted along the OK. Researchers have seen large concentrations of herring in these same bays (Brown et al. 1999a, 1999b; Stokesbury et al. 2000).

Aggregations of both adult and juvenile herring during fall-winter were reported within regions 1, 6, and 8, offering evidence for potential stock structure, especially if separate distributions for these aggregations are maintained throughout all seasons. Respondents reported generally smaller herring at age in the Montague area of region 6 compared to regions 1 (eastern) and 2 (northeastern), providing further evidence of stock differentiation. In addition, respondents reported the same pattern of mixed juvenile and adult herring schools during the winter that was unique to the Montague area region (Stokesbury et al. 2000; Brown and Moreland 2000).

Differences in regional observations between seasons may or may not reflect the apportionment of herring between regions. During spring and summer the greatest number of PWS herring observations were in regions 1 and 2 followed by regions 3, 8, 4, and 6 (Figure 2; Table 4). Region 5 had few observations during these seasons. Due to the broad distribution of activities in all regions, the numbers of observations by region may reflect the true apportionment of herring. In contrast, during fall and winter, region 5 had the highest numbers of observations followed by region 1, then regions 8 and 6. The northern regions, 2, 3, and 4, had few observations during those seasons. Activity was reduced in fall and winter, and the large number of observations in region 5 can be attributed to year-round residents in that region. For those seasons, the numbers of observations by region probably do not reflect true apportionment of herring among regions. From 1995 through 1997, very few herring were observed in region 5 compared to regions 1, 3, 6, and 8 (Stokesbury et al. 2000).

Earlier this century, fisheries biologists grappled with the issue of delineating herring populations between the OK and PWS (Rounsefell 1930). Schroeder (1989) speculated that the OK was an "overflow" juvenile nursery area of the PWS stock and should be managed as part of the PWS population. He reported large numbers of age-1 and age-2 herring along the OK coast in 1981 and 1982, and fish schools observed in 1986 and 1987 were suspected to be young herring. Respondents were in agreement with speculation by fishery biologists about the predominance of juveniles in the OK region and the stock structure relationship between PWS and the OK (Schroeder 1989; Brown and Norcross 2001). However the OK fisheries that occurred in the 1980s were small compared to fisheries that might be expected following such observations of herring abundance. The majority of herring in samples taken from harvests along the OK in 1985–1987 were age-3 and age-4. Meanwhile, biologists reported large numbers of juvenile herring in PWS in 1985. In 1988 PWS had a record number of miles of shoreline spawn, and biologists reported the 1984 year class was the strongest year class since 1976 (Brady et al. 1990). No observed spawning in the OK over the previous 10 years could account for the large quantities of juvenile herring observed in 1981, 1982, 1986, or 1987, or for the large spawning population of age-3 herring in Aialik Bay in 1987 (Schroeder 1989). In 1989 another very large biomass of juvenile herring was observed and sampled along the coast of the OK. Subsequently, commercial harvests in 1991 and 1992 were the largest on record for PWS.

From their observations, respondents explained why large fisheries probably had not developed along the OK. They said that OK juveniles originate from larvae transported from PWS, rear in the OK, and eventually return to PWS to spawn. Some reported large aggregations of juvenile herring moving east into PWS from the OK. They considered the OK a large nursery area for the PWS herring population and resulting commercial fishery. A recent larval drift simulation study underscored the likelihood of "larval leakage" from PWS to the OK (Norcross, et al. 2001; Brown and Norcross 2001) adding further credibility to the respondents' reports. In Canada, Pacific herring stock structure and distribution in a given region is related to ocean circulation patterns within a contiguous continental shelf area and the fidelity of herring spawning to a given region (Hay and McCarter 1997; Hay et al. 1999). The relationship of the OK herring to PWS is highly probable given the connection between the OK and PWS regions via the westward Alaska Coastal Current flow and shared continental shelf area. This has significant implications for management and stock assessment for PWS because the OK is not considered part of the PWS region and is not currently included in herring aerial surveys and stock assessment studies (Donaldson et al. 1992, 1993, 1995).

Respondents observed mixed-age and size-structured schools of herring as well as spawning areas not reported by ADF&G. Mixed-age schools (with juveniles) in PWS previously had been reported to occur after spawning (Rounsefell 1930). The mixed schools observed by respondents were in regions or seasons outside of those studied by ADF&G. Observations that juveniles occur "on top" within a mixed school had never been formally documented to our knowledge in Alaska. However, size structuring within schools is generally observed in many fishes, especially clupeoids (Pitcher and Partridge 1979; Blaxter et al. 1982; Pitcher et al. 1985). The addition of western PWS and the Copper River delta as former spawning areas is also historically significant. Recent observations of adult herring in the vicinity of the Copper River delta, unrecorded in ADF&G records, indicate that a portion of the PWS population is potentially not being monitored.

The decadal differences in juvenile herring abundance reported by respondents are consistent with other records and studies. The slight increase in abundance from the 1970s to the 1980s and the sharp decline in the 1990s are similar to trends reported for adult herring in the ADF&G historic catch records (Donaldson et al. 1995; F. Funk, ADF&G, Juneau, personal communication). The only distributions that were not different were those in the 1970s and 1980s in PWS. The differences between decades were more pronounced in the OK than in PWS. This trend in PWS herring abundance with a peak in the 1980s tracks with long-term climate trends such as the Pacific Decadal Oscillation (Brown and Norcross 2001) and is similar to the response of climate forcing on other fish species in the North Pacific (Beamish 1993; Hollowed and Wooster 1995; Mantua et al. 1997; Beamish et al. 1999).

Respondents also reported specific changes in distribution patterns among the decades that were not recorded by the agencies or studies. Despite greater overall abundance of herring in the 1980s compared to the 1970s, respondents reported a decline in abundance in region 3. Distribution was greatly restricted during the 1990s with a centralization of the population in region 6 and a dramatic decline in regions 1, 2, and 3. A large portion of the fisheries shifted to Montague as well during the 1990s (Funk 1995). Knowledge of these specific area shifts may be important in understanding climatic influences on herring populations.

We were disappointed with the paucity of information provided about forage fish species other than herring. The observations in which species were identified were recorded primarily in late spring through the summer (May through August). The fall and winter observations primarily recorded as forage fish may have included juvenile herring, and were therefore not represented in the results and maps. In addition, respondents rarely remembered decadal trends of species other than herring. Therefore, we could not summarize these data into seasonal or decadal trends. The respondents' observations of eulachon schools off the tip of southern Montague during the summer were similar to the recorded distribution of eulachon schools (Brown and Moreland 2000). Respondents reported that sand lance occurred on beaches in widespread locations in PWS and the OK, including many of the sand lance beaches mapped in recent forage fish studies (Brown et al. 1999b; Brown and Moreland 2000). Capelin were observed by respondents only during spawning at exposed beaches and bays near the entrance and exit to PWS, and in Day Harbor and Resurrection Bay. They were not observed in broadly distributed, nearshore schools as were herring. Non-spawning capelin schools were also noticeably absent from the forage fish aerial surveys despite being sampled quite often in net catches in central PWS (Brown and Moreland 2000). The lack of observations from both respondents and the aerial surveys is probably due to capelin being dispersed in deep waters beyond the range visible from the surface. In addition, because species other than herring were not commercially fished, respondents may not have been as vigilant as they were with herring.

Our data have limitations. The interviews gathered subjective data that cannot be validated. In addition, the accuracy of some information was difficult to assess for inclusion in this database. Although many observations were verified in the field by respondents who sampled the fish schools they saw, all observations, whether verified or not, were included in the database. Researchers may select classes of information based on a variety of parameters, including whether the observations were "verified" by the respondent (i.e., whether they actually caught and identified the fish). In addition, observations were limited to the times and places people were out in PWS or the OK. The distribution and numbers of observations are partly a product of where and when fisheries occurred as well as changes in the technology used to find fish.

For future work, researchers may want to select particular groups of respondents and conduct random samples of potential respondents. The sample size and therefore the time allocated for identifying interviewees will probably increase to accommodate random sampling. We chose not to do this for several reasons. We did not know how many or which class of respondents would best provide the types of information sought. The time we had to locate and interview potential respondents was restricted. However, by using the chain referral method we included retired individuals who no longer held commercial fishing permits but had a lengthy historical perspective, as well as members of occupational groups we had not previously considered, such as charter captains and tour-boat operators. Charter captains were interested in finding areas with forage-fish schools as bait for the species they were chartered to catch. Fishermen who were also pilots provided valuable information because they knew the appearance of several types of fish schools from the air and had a large geographic perspective.

The usefulness of respondent data is maximized by incorporating TEK data collection during the initial stages of study planning and by establishing a set of predetermined criteria or procedures. As an example, 2 criteria were established to use TEK for classification of Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* spawning grounds: 1) the site had to be independently confirmed by 2 or more references or identified by one reference and exist in the immediate vicinity of a confirmed area, and 2) the appropriate substrate and depth for spawning had to be present (E. P. Ames, unpublished data, The Island Institute, Rockland, Maine). Alternative methods for gathering information include regular debriefing of respondents after fisheries or at specific times of the year, paying individuals to conduct regular surveys, and hiring individuals to record observations. Several respondents from this study offered to collect the types of information documented in this project with vessel logbooks or other types of media.

This study suggests that the knowledge of resource users should be considered before conducting research on a large spatial scale where local memory can provide useful historical and validation information. The only requirement is that the study region incorporates residents who have had an extended presence, including commercial and non-Native long-term resource users such as we did. Resource users can provide valuable and cost-effective information about changes in distribution and abundance of herring. With training, they could provide information on many other key or prominent species, including birds and mammals. We therefore recommend establishing a long-term systematic method of obtaining, analyzing, and distributing resource-user information in a geographic or numeric format that can easily be incorporated into other research efforts. The methods used to obtain and compile the information must be clearly stated and generally accepted. This could be a web-based system. The results could benefit resource management programs and long-term monitoring efforts to understand effects of climate change. Such a program would also promote communication among resource users, managers, and researchers, and would facilitate the incorporation of TEK information as we have demonstrated here.

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Appendix A: The interview guide

ID	BIRTHDATE
DATE	COMMUNITY

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

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

1) salmon seine	______ to ______	summer
2) salmon gillnet	______ to ______	summer-fall
3) herring pound	______ to ______	spring
4) herring seine	______ to ______	spring
5) herring gillnet	______ to ______	spring
6) dive	______ to ______	________
7) handpick	______ to ______	________
8) shrimp pot	______ to ______	________
9) bottomfish	______ to ______	________
10) bait herring	______ to ______	________

4. Were you ever a spotter for fisheries?
   a) Which fisheries?
   b) Which years?

1) salmon seine	_____ to _____
2) herring pound	_____ to _____
3) herring seine	_____ to _____
4) other	_____________

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

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

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

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

9. Show on the chart the general area of the sound you use.

10. During what years were you out in the sound the most?
    a) Draw circles around the places you use most intensively.
    b) Describe your activities there/ frequency duration.

Juvenile Herring

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

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

13. Circle the areas you have seen juvenile herring in orange.
    a) What years did you see them there?
    b) What season/time of year did you see them?
    c) Did you identify them? How?
    d) Describe where you see them-nearshore/offshore, surface/deep
    e) Can you recall how much you observed?

14. How often did you see juveniles there? For each observation, mark frequency on the chart or table.
    C = CONSISTENTLY- “I’d see them almost every time I went there this time of year.”
    O = OCCASIONALLY- “I’d see them every once in a while this time of year.”
    R = RARELY- “I remember them showing up there once or twice.”

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

16. Tell me about the changes you’ve seen in abundance of herring in the sound.

Adult Herring

17. Where have you seen schools of adult herring in spring and fall aside from northern Montague Island, Port Gravina, Port Fidalgo, Tatitlek Narrows, and Green Island? Circle the areas you have seen adult herring in red.

18. How did you know they were herring?

19. How often have you seen them there?

20. At each place describe where you saw them – nearshore or offshore, surface or deep.

21. What other animals do or did you see with them?

22. Where do you find adult herring in winter?

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

24. Did you fish for herring for home use or gather spawn on kelp this year?

25. Did you notice any signs of disease?

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

Species other than herrring

27. Did you ever see or catch other forage fish such as sand lance or capelin while out in the sound? Circle the areas you have seen species other than herring in green.
    a) Describe what you saw or caught.
    b) Could you identify them now? How?
    c) When? Give year and season?
    d) Where? Give place. Were they at the surface or at depth?

28. Have you seen them there before?

29. How frequently?

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

31. What other animals do you remember commonly associated with these schools of fish?

Pollock

32. Describe any changes you've noticed in pollock abundance and distribution since you began fishing or working in the sound.

33. Where, what time of year, which years?

34. How often have you seen them there?

35. How does weather or ocean state affect pollock abundance.

36. Did fish ever disappear completely from an area that you fished, hunted or used? Why do you think that they disappeared?