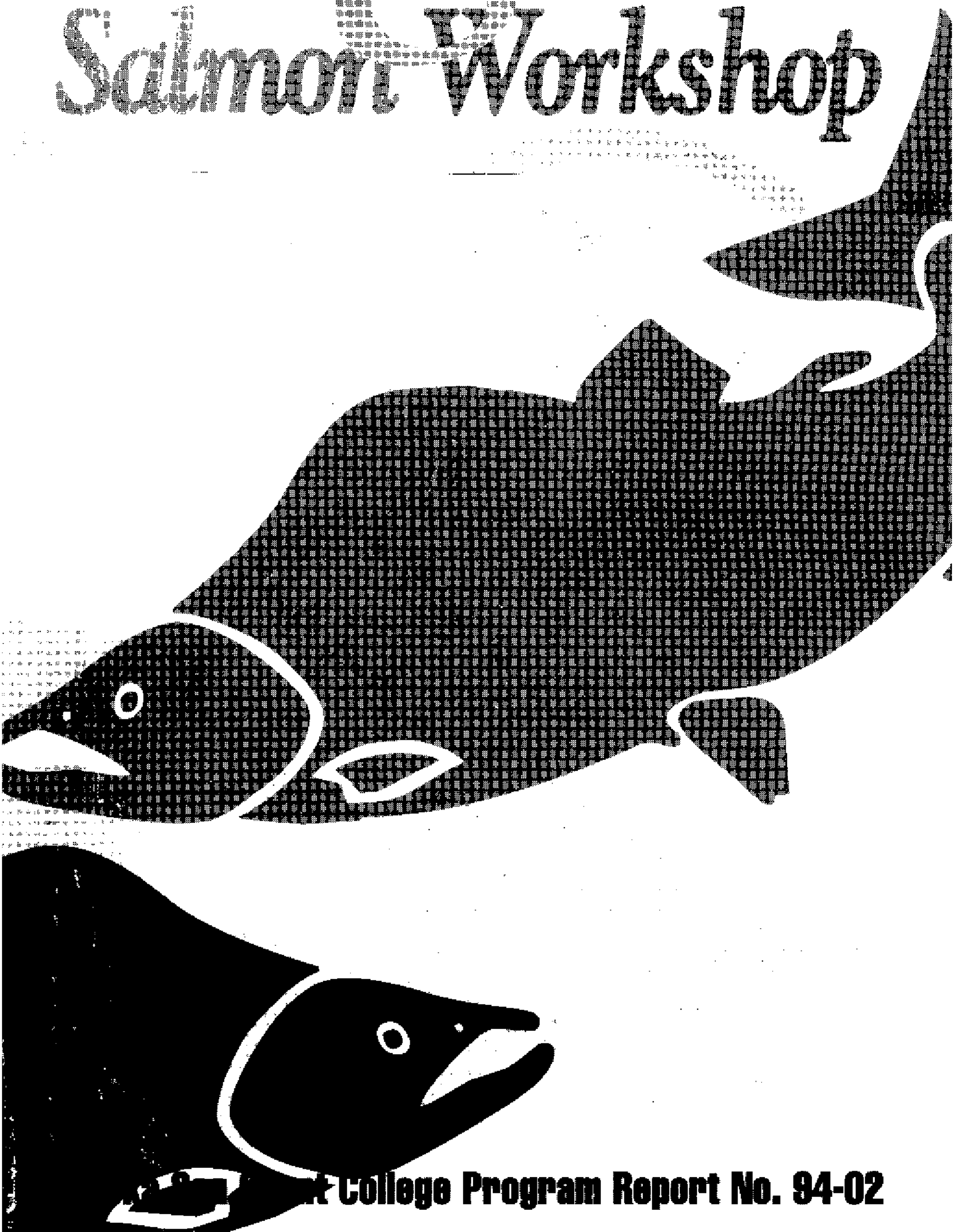
Proceedings of the 16th Northeast Pacific Pink & Chum Salmon Workshop



College Program Report No. 94-02

Proceedings of the 16th Northeast Pacific Pink and Chum Salmon Workshop

Juneau, Alaska

February 24-26, 1993

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AK-SG-94-02
1994
$10.00

Elmer E. Rasmuson Library Cataloging-In-Publication

Northeast Pacific Pink and Chum Salmon Workshop.
Proceedings of the ... Northeast Pacific Pink and Chum Salmon Workshop. —15th (1991)—Vancouver, B.C. : Pacific Salmon Commission : Canada Dept. of Fisheries and Oceans.

(Alaska Sea Grant College Program report ; no. 94-02)

16th workshop published by: Alaska Sea Grant College Program.
Continues: Northeast Pacific Pink and Chum Salmon Workshop. Northeast Pacific Pink and Chum Salmon Workshop.
1. Chum salmon—Congresses. 2. Pink salmon—Congresses. 3. Salmon fisheries—Pacific Coast (North American)—Congresses.

SH348.N6

ISBN 1-56612-024-1

Acknowledgments

The papers in this book were provided on computer disk by the authors and were proofed and formatted by Brenda Baxter. The cover was designed by Susan Burroughs Gibson.

This book was produced by the University of Alaska Sea Grant College Program, which is cooperatively supported by the U.S. Department of Commerce, NOAA Office of Sea Grant and Extramural Programs, under grant no. NA46RG0104, project A/75-01; and by the University of Alaska Fairbanks with funds appropriated by the state. The University of Alaska is an affirmative action/equal opportunity employer and educational institution.

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Foreword

The 16th Northeast Pacific Pink and Chum Salmon Workshop was held in Juneau, Alaska 24-26 February 1993. Over 100 scientists, resource managers, harvesters, and processors attended. The workshop has been held biennially since the early 1960s, not by any formal organization but by volunteer hosts who have traditionally had the meeting in Alaska, British Columbia, or Washington.

The workshop was held in nine sessions organized around an array of topics. Extended abstracts are included in these proceedings. Another tradition of the workshop is that the proceedings are not peer reviewed, a practice that encourages participants to present current work. As a consequence, items in the proceedings should not be cited except as personal communications and with the author's permission.

The workshop was sponsored by the Alaska Sea Grant College Program and the Division of Fisheries, both part of the School of Fisheries and Ocean Sciences of the University of Alaska Fairbanks. Brenda Baxter of Alaska Sea Grant coordinated the workshop.

The Steering Committee included:

Bill Smoker (Chair), University of Alaska Fairbanks
Don Bailey, Fisheries and Oceans Canada
Ted Cooney, University of Alaska Fairbanks
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Alex Wertheimer, National Marine Fisheries Service
Jim Woodey, Pacific Salmon Commission

A Comparison of Diets and Apparent Growth Rates for Juvenile Pink and Chum Salmon Collected in Prince William Sound, Alaska

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From early May through July 1, 1992, juvenile pink and chum salmon were collected in Jonah Bay and at three locations near Evans Island as part of the Cooperative Fisheries and Oceanographic Studies (CFOS) project. Habitats sampled included low gradient beaches, medium gradient coves and steep gradient fjords. Fry were captured with dipnets, beach seines, and a small-mesh purse seine. The stomachs of 777 fry were examined in a laboratory setting on site to elucidate food preferences. Calanoid copepods dominated both the total number and biomass of the pink salmon stomachs, whereas harpacticoid copepods and insects were more characteristic of chum stomachs. Apparent growth rates were obtained from measures of blotted fresh weight determined over the course of the sampling period. In Jonah Bay, both pink and chum fry exhibited growth rates of only 2.0% $bwtd^{-1}$. Older fry captured near Evans Island exhibited apparent growth rates ranging between 5.2 and 7.8% $bwtd^{-1}$. These differences are discussed in relation to the outmigration process, food sources, and changes in ocean temperature.

Introduction

As part of the continuing Cooperative Fisheries and Oceanographic Studies, University of Alaska researchers sampled pink and chum salmon fry in Prince William Sound in an attempt to delineate food preferences and apparent growth rates. From May 13 through June 9, 1992, Jonah Bay, located on the western side of Unakwik Inlet in northcentral Prince William Sound, was the site for collections of juvenile salmon recently outmigrated from the Unakwik river. The mouth of Jonah Bay is narrow and rocky and is characterized by large standing waves during flood and ebb tides. The southern shore of the bay is defined by alternating rocky outcrops and shallow embayments. The head of the bay has several large coves that are suitable for beach seining. The northern shore is a shallow, tidal mudflat.

In order to compare the diets and growth rates of early outmigrating fry with larger fry making their way to the ocean, samples were also collected from June 18 through July 1 near Evans Island in southwestern Prince William Sound by the edge of the Gulf of Alaska. Pink fry samples were obtained from three separate areas; the edge of Foxfarm Harbor and Latouche Passage (hereafter referred to as Foxfarm Cove), the edge of Squirrel Bay and Prince of Wales Passage, and from the middle of Prince of Wales Passage near the four islands just south of Iktua Bay (hereafter referred to as Four Isle Area).

Foxfarm Cove is a shallow bay on the southwestern edge of Elrington Island where fry were sampled only at the mouth; no fry were observed back in the bay. Squirrel Bay is a larger and deeper bay located on the southwestern side of Evans Island. Collections made here were in water of various depths in the bay and also from the boundary between the bay and the passage. The Four Isle Area is characterized by deep water and is approximately halfway between Evans and Bainbridge islands.

Methods

At Jonah Bay, pink and chum salmon fry were most often sampled with an 8 ft. dipnet, but occasionally were collected with a 100 ft. beach seine. Initial samples were obtained from the head and mouth of the bay with intermittent sampling of the southern shore. As time progressed and chum fry became less abundant, we adopted a strategy of sampling the mudflat habitat of the northern shore which provided ample numbers of chums. The southern shore required dipnetting from the skiff, whereas it was possible on the northern shore to dipnet directly from the beach by wading along the shoreline.

Immediately after capture, fry were placed in 32 oz. Nalgene bottles and suffocated. The bottles were then kept on ice in a five gallon bucket prior to analysis back at Cannery Creek Hatchery. Most stomach content analysis was performed within 4-6 hours of collection, while lengths and weights were obtained within 24 hours.

For length and weight measurements, at least 100 fry were placed on wet paper towels to prevent drying. Lengths were recorded to the nearest mm with a pair of calipers. Weights were elucidated to the nearest mg on a Mettler P163 balance. If 200 fry were measured for lengths and weights, every eighth fish would be used for stomach analysis. Otherwise, the first 25 were selected.

Dissecting microscopes were used to open and examine the stomachs of 25 fish per sample. Prey items were identified to taxa and all contents were counted. Data was entered into a Quattro Pro spreadsheet that tallied number and weight totals per taxonomic grouping, as well as averages and standard errors per fish.

Pie chart percentage plots were created for fry prey by number and weight in order to compare the diets of pinks and chums. Stacked bar graphs were made for prey per sampling day by number and weight in order to delineate changes in diet over the course of the sampling period. A natural log transformation of the average fry weight per sample was regressed against the sampling day in order to obtain relative growth rates.

At Evans Island, pink fry were sampled using a 140 ft. purse seine deployed from an 18 ft. aluminum skiff. Up to 5,000 fry were collected at a time and 100 fry were selected at random for length and weight measurements. A subset of 25 of these fry were used for stomach content analysis. These outmigration corridor fry were substantially larger than the Jonah Bay fry and therefore weights were measured to the nearest 0.01 g on a Mettler PE 400 electronic scale. Fork lengths were obtained from a 15 cm wooden fry board. Upon return from camp, the data was entered in the same spreadsheet and similar analyses were performed.

Results

In Jonah Bay, 503 fry were analyzed for stomach contents from 13 separate sampling occasions between May 13 and June 9, 1992. The pink and chum fry were frequently captured from the same school of fish, although their diets were quite different. Figure 1 shows the average numerical breakdown of prey taxa in the pink and chum stomachs. Juvenile pink salmon fed preferentially on calanoid copepods, which were dominant numerically, comprising 68% of the total number of prey. Chum salmon fry in Jonah Bay exhibited a diet dominated by harpacticoid copepods and insects. Harpacticoid copepods comprised 63%, while insects comprised 23% by number. Although calanoid copepods were dominant in terms of numbers in the pink stomachs, they only made up 6% of the chum diet. In contrast, harpacticoid copepods and insects accounted for 86% of the total number of chum prey, but contributed only 25% of the pink prey. Other prey consumed by pink and chum fry included polychaete worms, barnacle nauplii and cyprids, euphausiid shrimp, decapod larvae, amphipods, cladocerans, and cumaceans. Polychaetes, cirripedia, and euphausiid numbers were approximately equal for both pinks and chums.

In terms of biomass, a similar trend is seen (Figure 2). Calanoid copepods comprise 68% of the pink diet and only 18% of the chum diet. Insects dominated chum stomachs, representing 65% of the average weight, but comprised only 12% of the pink stomachs. By weight,

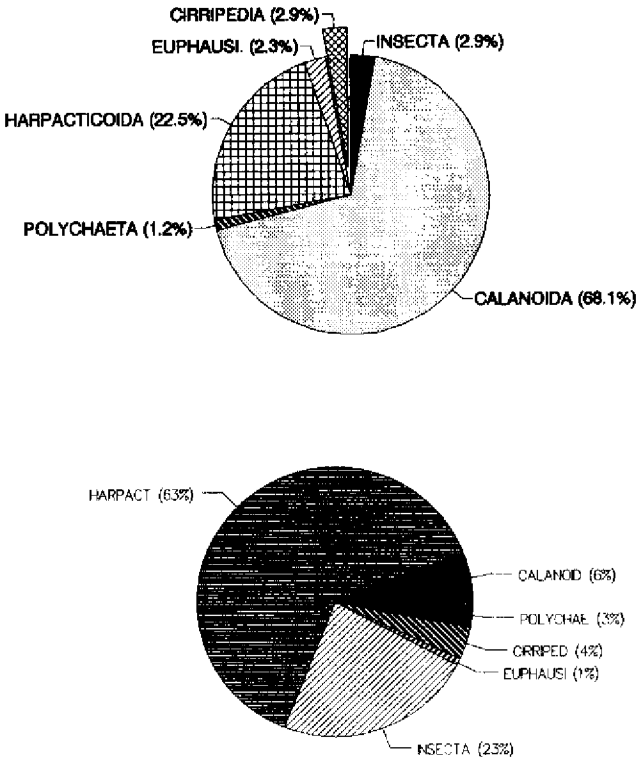


Figure 1. Comparison of juvenile pink (top) and chum (bottom) salmon diets in terms of average abundance of prey taxa found in stomachs. Jonah Bay, May 13-June 9, 1992.

harpacticoid copepods were reduced to 4% of the chum diet. Again, polychaetes, cirripedia, and euphausiids occurred in pink and chum stomachs in similar weights.

The breakdown of pink prey consumed per sampling day is shown in Figure 3. The days with weak calanoid signals reflect sampling at the head of the bay, while the strong signals arose from samples collected near the mouth of the bay, an area characterized by advection of pelagic organisms from Unakwik Inlet.

Figure 4 shows the average amounts of dominant taxa found in the chum stomachs per sampling day. The dominance by harpacticoids (by number) and insects (by weight) is clearly visible, while the increase in

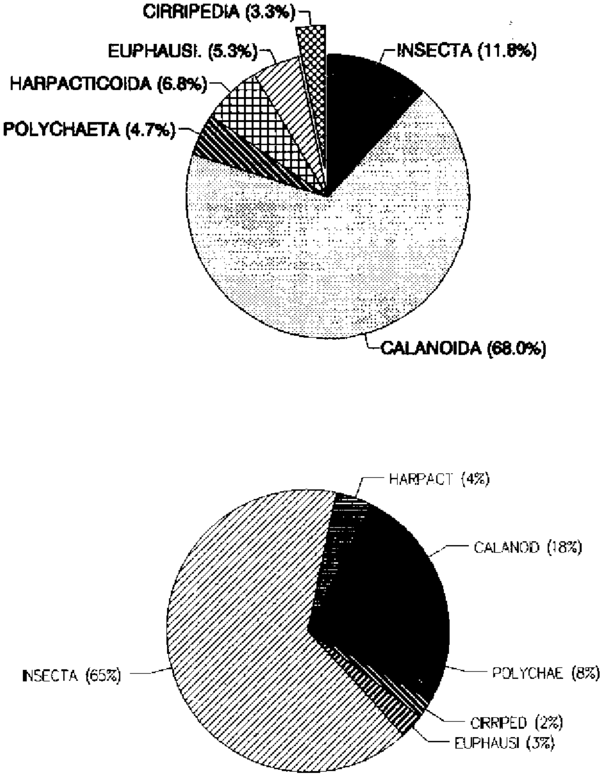
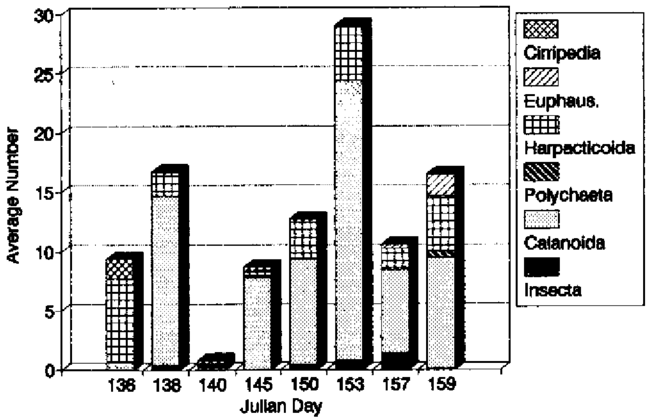


Figure 2. Comparison of juvenile pink (top) and chum (bottom) salmon diets in terms of average biomass of taxa found in stomachs. Jonah Bay, May 13-June 9, 1992.

prey seen at day 150 is a result of starting to sample the tidal mudflat along the north shore of Jonah Bay.

At Evans Island, 274 fry were analyzed for stomach contents on 11 sampling occasions from June 18 to July 1. Only pink fry were found. Four samples were taken each from Foxfarm Cove and Squirrel Bay, while three collections were made from the Four Isle Area.

Looking at the breakdown of average prey per fry per sampling day (Figure 5), we see abundance being dominated alternatively by calanoid copepods and cladocerans (*Evadne* spp. and *Podon* spp.). This is a



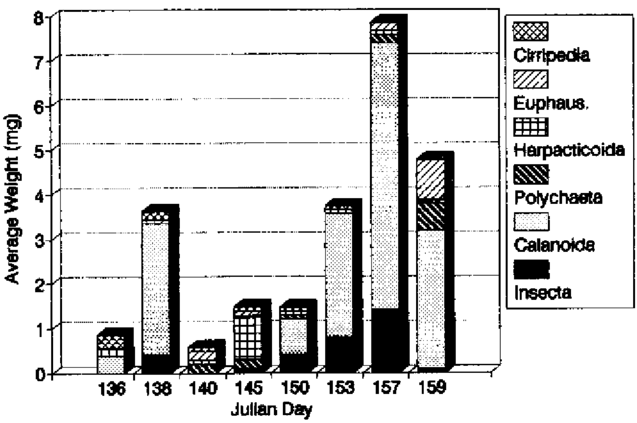


Figure 3. Daily breakdown of juvenile pink salmon diet by number (top) and weight (bottom) in Jonah Bay.

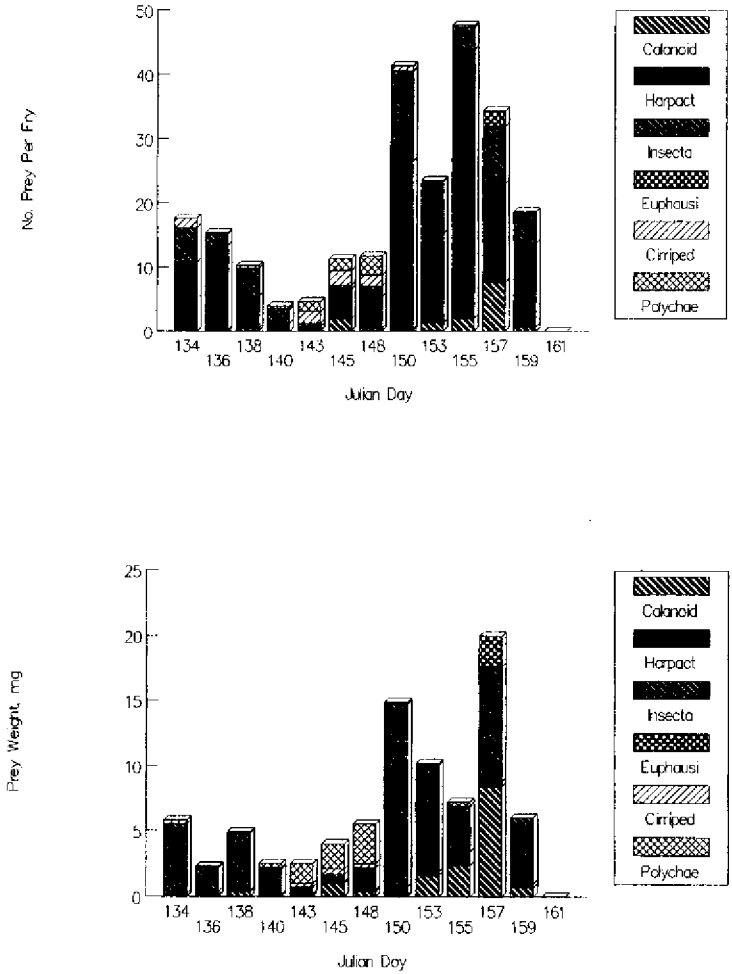


Figure 4. Daily breakdown of juvenile chum salmon diet by number (top) and weight (bottom) in Jonah Bay.

function of the physical characteristics of the sampling areas. The areas representing more oceanic conditions had more calanoida while the less saline neritic areas were characterized by cladocerans. This per day breakdown of prey biomass is striking in that it shows the dominance of the Four Isle Area samples and calanoid copepods.

A comparison of the number of each prey taxa consumed by the Jonah Bay and the Evans Island pinks demonstrates the differences in diet between the two areas (Figure 6). Numerically, calanoid and harpacticoid copepods accounted for 90% of the Jonah Bay pink fry diet while 91% of the Evans Island diet was made up of calanoid copepods (41%), cladocerans (33%), and gastropods (17%). The difference in prey taxa biomass is shown in Figure 7. Calanoida dominated both areas although less so at Jonah Bay (68%) than at Evans Island (83%). Harpacticoid copepods and insects comprised 19% of the biomass of prey found in the Jonah Bay stomachs but were insignificant near Evans Island at 0.6% and 0.8%, respectively.

Other prey organisms found in the various sampling sites near Evans Island included barnacle nauplii and cirri, ostracods, euphausiids, cumaceans, polychaetes, and amphipods. Some of the largest fry (3-6 g) collected from the Four Isle Area had fish in their stomachs. In the last sample, taken on July 1, 14 of the 25 stomachs examined had small fish in them.

The larger the fry grew, the less likely they were to be empty. In Jonah Bay, 20% of the pinks and 14% of the chums were found with empty stomachs. Near Evans Island, 7% of the Foxfarm Cove fry and 3% of the Squirrel Bay fry were empty, while no empty stomachs were found in the Four Isle Area fry.

From Jonah Bay, 1351 pinks and 1259 chums were measured for lengths and weights. The growth of the juvenile pink salmon and juvenile chum salmon is shown in Figure 8. The apparent growth rate calculated from the linear regression of the natural log of average weight on the sampling day for both the pinks and chums, expressed as percent increase in body weight per day ($bwtd^{-1}$), was calculated to be approximately 2%. The accuracy of this estimate is biased by continued outmigration of fry through Jonah Bay.

From Evans Island, 1100 pinks were measured for lengths and weights. The growth of the juvenile pink salmon over the course of the sampling period is shown in Figure 9. A regression of the pooled average weights on the sampling date indicated an apparent growth rate of 2.8% $bwtd^{-1}$ with an r-squared of 0.26. But significant r-squared values for each of the areas regressed separately indicated differences in growth rates between areas. The Foxfarm Cove fry grew at a rate of 5.2% $bwtd^{-1}$

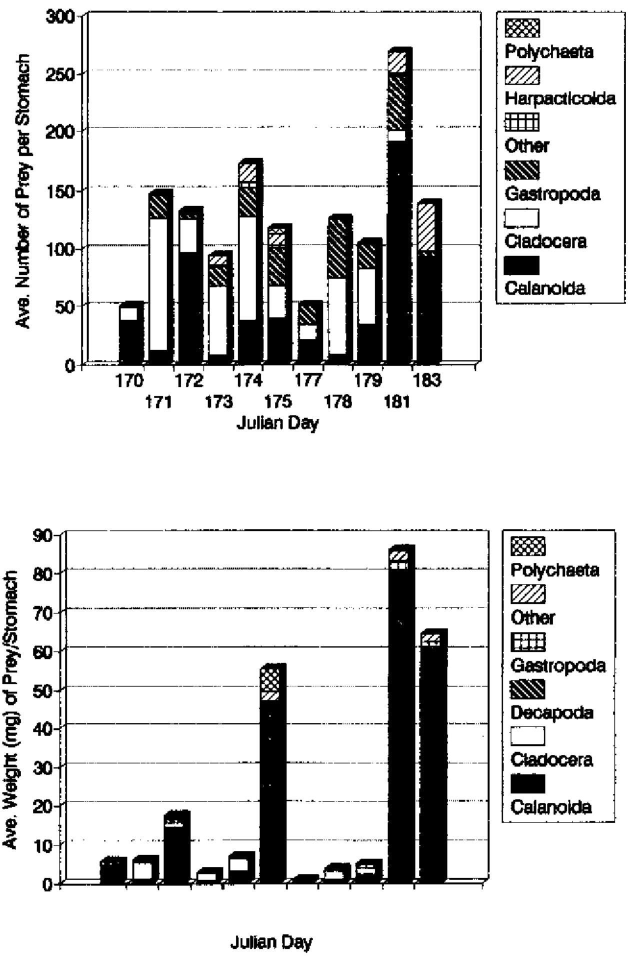


Figure 5. Daily breakdown of juvenile pink salmon diet by number (top) and weight (bottom) at Evans Island.

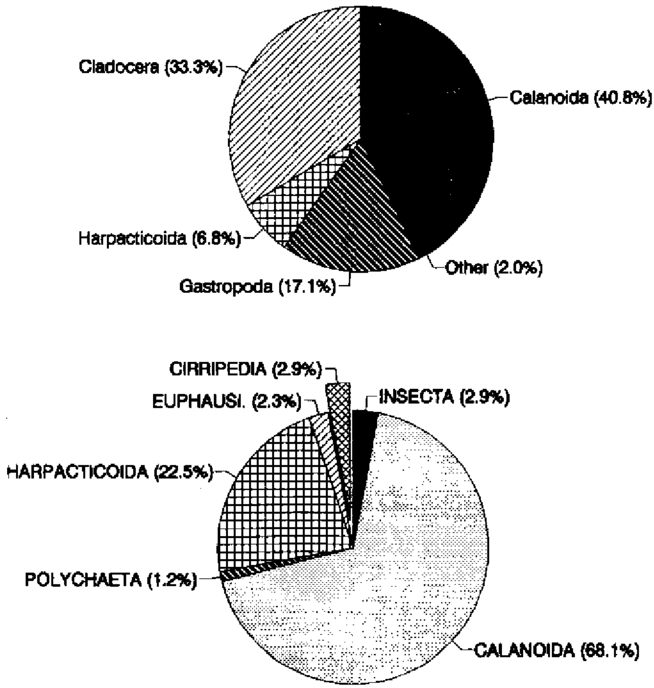
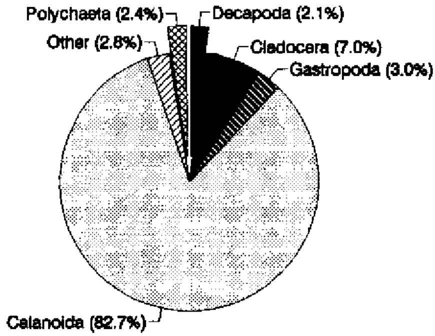


Figure 6. Comparison of average numerical abundance of prey taxa found in pink stomachs between Evans Island (top) and Jonah Bay (bottom).



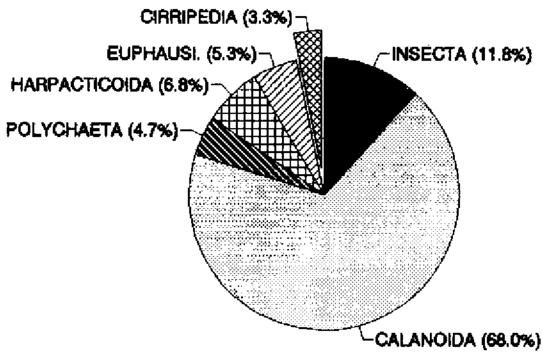


Figure 7. Comparison of juvenile pink salmon prey taxa average biomass between Evans Island (top) and Jonah Bay (bottom).

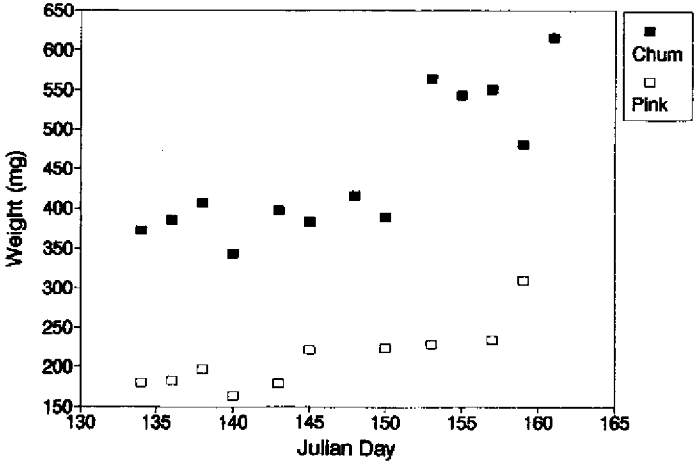


Figure 8. Growth of pink and chum salmon fry in Jonah Bay from May 13 through June 9, 1992.

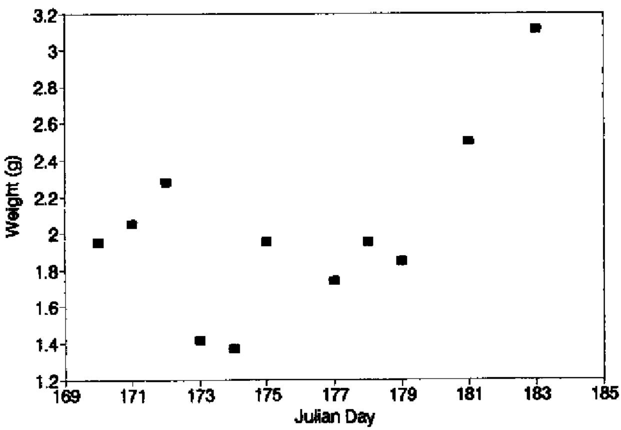


Figure 9. Growth of juvenile pink salmon near Evans Island from June 18 through July 1, 1992.

from an average of 1.42 g and 52.41 mm on June 21 to 1.85 g and 59.26 mm on June 27. The Squirrel Bay fry exhibited the greatest growth rate of 7.8% $bwtd^{-1}$ from an average of 1.95 g and 59.64 mm on June 18 to 2.28 g and 66.73 mm on June 20. The data from June 26 was not used to calculate the growth rate for the Squirrel Bay fry. A gap of 5 days passed between samples 3 and 4 and it is believed that the fourth sample came from a different school of fish. The Four Isle Area fry grew at a rate of 5.4% $bwtd^{-1}$ from an average of 1.95 g and 59.64 mm on June 23 to 3.11 g and 72.63 mm on July 1.

Discussion

The results of this study indicate that there are differences as well as similarities between juvenile pink and chum salmon diets. Calanoid copepods dominated the pink stomachs whereas harpacticoid copepods and dipteran insects comprised the majority of the chum stomach contents. This is in agreement with other studies. For example, Urquhart (1979), Healey (1980), Barnard (1981), Cooney et al. (1981), and Murphy et al. (1988) all found that pinks foraged on a pelagic zooplankton community primarily composed of calanoid copepods. In addition, Kaczynski et al. (1973), Feller and Kaczynski (1975), Levy (1978), Barnard (1981), and Cooney et al. (1981) found that harpacticoid copepods and terrestrial insects dominated the early diets of outmigrating chum fry. Both juvenile pinks and chums feed upon these organisms as well as euphausiids, amphipods, larvaceans, decapod larvae, and barnacle nauplii and cirri. Therefore, the diets of pink and chum fry are quantitatively different but qualitatively similar.

In Jonah Bay, the calanoid copepods were primarily composed of *Acartia* spp., *Pseudocalanus* spp. and *Neocalanus plumchrus*. At Evans Island, the calanoid copepods were *Calanus marshallae*, *Pseudocalanus*, *Metridia* spp., *Acartia* spp., and *Eucalanus bungii*. The insects that the chum fry were feeding on in Jonah Bay were identified as emergent chironomid adults. Pennack (1978) noted that chironomids commonly occur in estuaries and tidal mudflats. The increase in numbers of the epibenthic harpacticoids and insects on June 3 was most likely due to a change in sampling location. We started sampling the shallow tidal mudflat area on the northern shore of Jonah Bay. This appears to represent a preferred feeding habitat of juvenile chums due to the fact that we found more chums there and they had more in their stomachs.

At Evans Island, the dominance by calanoids is consistent with the habitat that was sampled. Most fry were collected on the edge of the passages which are characterized by pelagic zooplankton communities.

The cladocerans' appearance may be explained by the decreased surface salinities due to increasing freshwater runoff. Foxfarm Cove was the shallowest of the areas sampled and this is where most of the cladocerans, harpacticoids, and insects were found dominating the stomachs.

At both Jonah Bay and Evans Island, the later samples contained the most prey items. This may be explained by the later sampled fry being larger and able to hold more contents. The largest fry found at the Four Isle Area had small fish in them and this may be a direct function of the larger mouth size. The badly decomposed fish found in the stomachs were impossible to identify, but their well-preserved eyes looked conspicuously like salmon fry eyes.

The apparent growth rates for the Jonah Bay pinks and chums were calculated to be approximately 2% $bwtd^{-1}$, whereas the Evans Island pinks exhibited higher rates ranging from 5.2% $bwtd^{-1}$ to 7.8% $bwtd^{-1}$. Healey (1979) suggests that a growth rate of 15% $bwtd^{-1}$ is optimal. The growth rates found in the Jonah Bay fry sampled in this study appear to be low. Our low estimation may be due to the continued outmigration of smaller fry into the bay from the river and larger fry out of the bay, the avoidance by larger fry of the nets, and the low temperatures found in the bay (6-7 degrees C). Mortensen et al. (1991) found that food availability and water temperature constrained the growth of early outmigrating salmon fry. The higher growth rates found around Evans Island may be explained by higher temperatures and food availability, as well as the larger fry being able to consume larger prey. Because we have no detailed food field or temperature data, we cannot ascertain how these two factors affected growth.

In conclusion, the question of how food availability and temperature affect growth will be addressed in a more detailed study this coming field season (May-July, 1993). Continued gut analysis, length and weight measurements, quantitative food field descriptions, and measurements of temperature and salinity profiles will be conducted.

Acknowledgments

The Prince William Sound Aquaculture Corporation (Cannery Creek, Esther Island, and AFK hatcheries) were instrumental in providing support logistics essential for successful completion of the field work. The Alaska Department of Fish and Game also supplied invaluable assistance aiding the project. In particular, we would like to thank PWSAC's Jeff Olsen, Jeff Milton, Dave Reggiani, Pat and Dee Hayes, Joe McGraw, Don Gibson, and Susan Holck at Cannery Creek, and ADF&G's Mark Willette, Greg Carpenter, Becky Achton, Beth

Devereaux, and Nancy Ebert. Without the generous support of these two organizations, and Alaska Sea Grant, this continuing study would not be possible. Finally, the enthusiasm and ablebodiedness of Dr. R. Ted Cooney and Kevin Engle during sampling was greatly appreciated.

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Characterizing the Growth Environment for Juvenile Pink and Chum Salmon in Prince William Sound, Alaska

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A consortium study linking the growth conditions for juvenile pink and chum salmon to adult returns in Prince William Sound is based on continuously monitoring ocean temperatures and weather, and seasonally measuring plankton biomass. Satellite-linked oceanographic buoy technology and satellite-measured ocean surface temperatures provide high resolution temporal and spatial thermal histories for comparison with hatchery records of local weather and upper-layer ocean temperatures. Measurements of some of these variables since 1981 afford a means to assess differences within and between years for comparison with levels of wild and hatchery pink and chum salmon production in Prince William Sound.

Introduction

A long-standing body of evidence supports the assertion that pink salmon (and possibly chum salmon) run strength is set by predation on juveniles during early ocean residence (Parker 1964, 1965, 1968 and 1971; Healey 1982; Hartt 1980; Hargreaves and LeBrasseur 1985; Bax

1983). Growth conditions influencing the length of time that juveniles remain in the smallest, most vulnerable sizes probably mediate these losses. Upper-layer ocean temperatures and food (pelagic and epibenthic) are generally thought to be the conditions most affecting early marine growth (Healey 1980, 1991; Urquhart 1979; Walters et al. 1978; Mortensen 1983). Local salmon stocks have probably evolved out-migration strategies to place fry in coastal waters when food stocks are high (Olson and McNeil 1967, Beacham and Murray 1987). Pink and chum salmon fry enter coastal waters in the northern Gulf of Alaska in the early spring over a period of about two months (Bailey 1969, Taylor 1988).

In 1990, the Alaska Sea Grant College Program established a five-year consortium study of pink and chum salmon adult production responses to oceanographic factors influencing fry growth and survival. Alaska Department of Fish and Game, the Prince William Sound Regional Aquaculture Association, and the University of Alaska School of Fisheries and Ocean Sciences are participating in this study. One goal of Cooperative Fisheries and Oceanographic Studies (CFOS) is to determine the degree to which adult run strength can be predicted indirectly from measures of fry growth conditions and/or directly from estimates of fry growth rates. To address these goals, a comprehensive program of coastal ocean monitoring was established to provide information annually on upper-layer temperatures and fry forage populations.

The CFOS Meteorological and Oceanographic Time-Series

The Prince William Sound Aquaculture Corporation (PWSAC) maintains four large salmon hatcheries in Prince William Sound. Personnel at these hatcheries record local weather and oceanographic conditions daily throughout the year; air temperature, barometric pressure, percent cloud cover, precipitation, and wind data are routinely observed. Electronically-controlled temperature recorders (Hugrun/Seamon) measure and store ocean temperatures from the upper 3 m at all hatcheries. Temperature is logged to the nearest 0.1 degrees C hourly or less frequently. The loggers are deployed for monthly periods throughout the year. Sea surface temperatures for the northern Gulf of Alaska are also available from Scripps Institution of Oceanography (Dan Cayan, Climate Research Group). These observations are monthly means derived from vessel observations recorded for a 5 X 5 degree grid (latitude and longitude) in the north Pacific Ocean. The location closest to Prince William Sound is located at 60 degrees N, 145 degrees W. This location includes observations from most of Prince William Sound and a much larger area extending 2.5 degrees further south into the open Gulf.

Meteorological and oceanographic data are also being obtained using a real-time satellite-linked oceanographic buoy (C-LAB 1) located south and east of Naked Island. The buoy measures surface weather (air temperature, barometric pressure, wind speed and direction) upper ocean temperatures (10 depths between the surface and 100 m) and plant florescence in the photic zone (10 m). Measurements are made hourly (10-min average of all sensors) and the data is up-linked to polar orbiting NOAA satellites using Service Argos telemetry. Buoy observations are later retrieved from the Service Argos Regional Data Center (Landover, Maryland) via phone modem (2-hour delay) and archived at the Institute of Marine Science, University of Alaska Fairbanks, and at the Prince William Sound Science Center in Cordova. These same NOAA satellites also provide sea surface temperature (AVHRR) measurements (1 km^2 and 0.5 degrees C resolution) with 15-20 passes per day over Prince William Sound. Selected scenes are being analyzed to measure fine-scale temperature variability in the region.

Alaska Department of Fish and Game (ADF&G) is monitoring water column structure in the deeper regions of Prince William Sound, deploying a self-contained CTD (SeaBird SBE-19) at four locations. These observations are undertaken monthly or more frequently as time warrants each year. ADF&G also provides logistical support (M/V *Montague*) to service C-LAB 1 each year.

All PWSAC hatcheries maintain a seasonal plankton watch each year during late winter, spring, and early summer. At each site, a 0.5-m net (0.243-mm mesh) is towed vertically from 20 m to the surface twice weekly at two locations near each facility. In late winter and early spring, two or more vertical tows may be composited to assure sufficient plankton for a reliable settled volume measurement. In the laboratory, samples are allowed to settle for 24 hr. in graduated cylinders and volumes associated with phytoplankton (brown/green) and zooplankton (pink) are recorded to the nearest ml. Some of these samples are preserved in 10% formalin and saved for taxonomy and enumeration by UAF. ADF&G also samples upper-layer and deeper zooplankton populations at each of the CTD stations. A 0.5-m net (0.335-mm Nitex) is towed vertically from 20 m to the surface and from the seabed to the surface. Samples are preserved in the field (10% formalin) and returned to Cordova for processing (identification, enumeration).

Preliminary Observations

Historical Northern Gulf of Alaska Temperature

The average sea surface temperature for months when juvenile pink and chum salmon are resident in Prince William Sound (April-June) is about 6.8 degrees C (Figure 1). Although no pattern is apparent in this time series, interannual variability is pronounced. One obvious feature of the historical record is the period of very low temperatures that occurred during the early and mid 1970s (1971-1976). No temperatures as low as these have been recorded since that time. Temperatures measured in Prince William Sound (1990-1992 hatchery measurements) are generally lower than those for the larger ocean area that includes the Sound. A significant departure is apparent for 1991. This was a "cold" year in the Sound but only average for the larger ocean region.

Annual departures from long-term mean temperatures (April-July) are similar for other locations in the northern Gulf of Alaska (southeast Alaska and Kodiak) over the same time period (Figure 2). Temperatures in southeast Alaska tend to be consistently warmer than Prince William

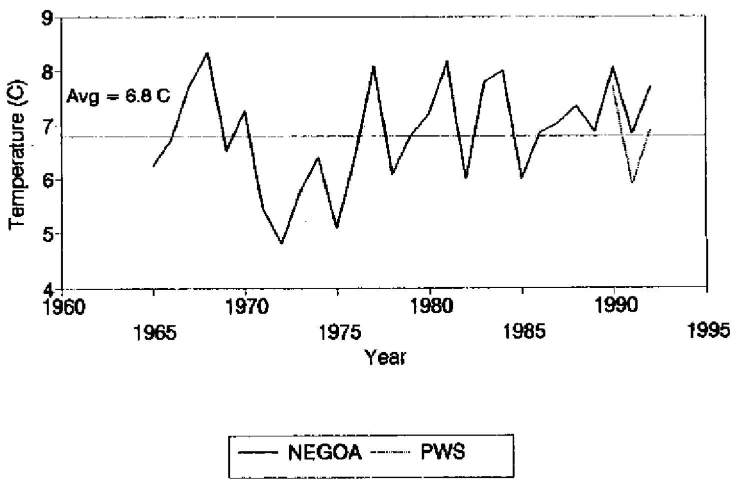

Figure 1. Time series of April-June average sea-surface temperatures for the northern Gulf of Alaska (NEGOA) and Prince William Sound (PWS) over the period 1965-1992. The NEGOA time series includes PWS; the PWS time series was derived from measures at the salmon hatcheries.

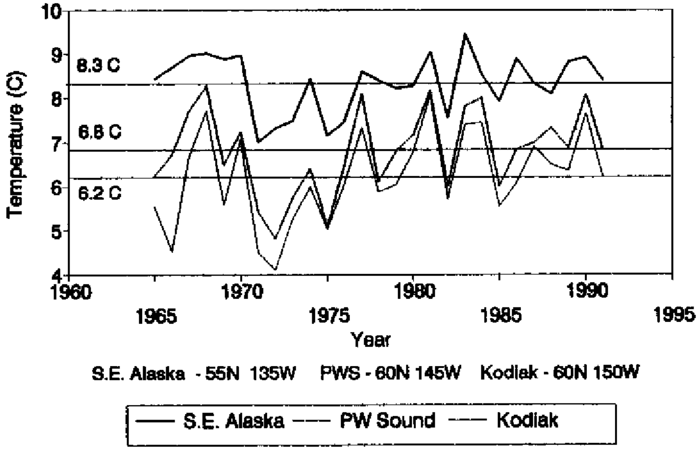

Figure 2. Time series of April-June average sea-surface temperatures for three locations in the northern Gulf of Alaska.

Sound, while conditions near Kodiak are colder. The general coherence between locations in this time series suggests that large-scale phenomena (the size of the Gulf of Alaska or larger) are probably responsible for forcing this year-to-year variability.

Winter/Spring Thermal Cycles in Prince William Sound

The annual winter cooling cycle is promoted by cold air temperatures beginning in late fall and early winter. By 1 January, air temperatures are generally much colder (often below freezing) than the surface water (Figure 3). During the winter and early spring months the ocean gives up heat energy to the atmosphere. However, by late March or early April, solar energy begins warming the lower atmosphere and the surface waters start to acquire heat. Winter minimums in March of 4 degrees C or colder are common for Prince William Sound. Continuous temperature monitoring provides a means for comparing the most recent years; 1990 was the warmest (374 degree days in April-May), 1992 was cooler (335 degree days) and 1991 was cold (277 degree days) for the same period.

A more detailed comparison of air and water temperatures during the calendar spring of these same years demonstrates that not only were the average temperatures different, but the timing of the warming cycle

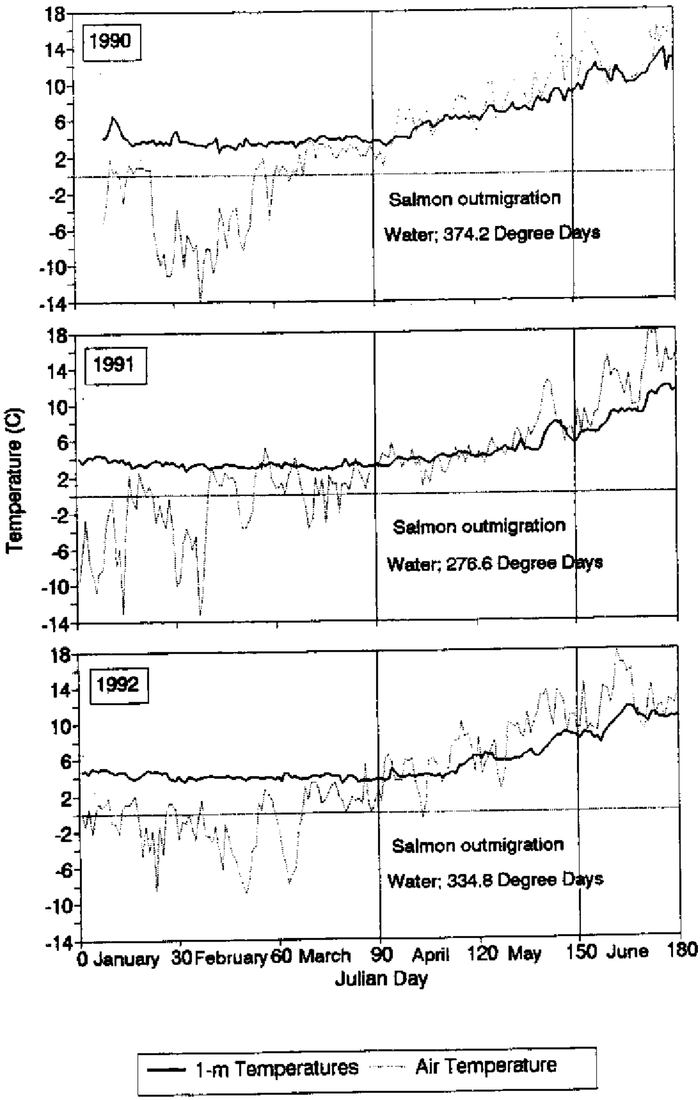

Figure 3. January through June time series of air and surface water temperatures measured at all salmon hatcheries in the years 1990, 1991, and 1992.

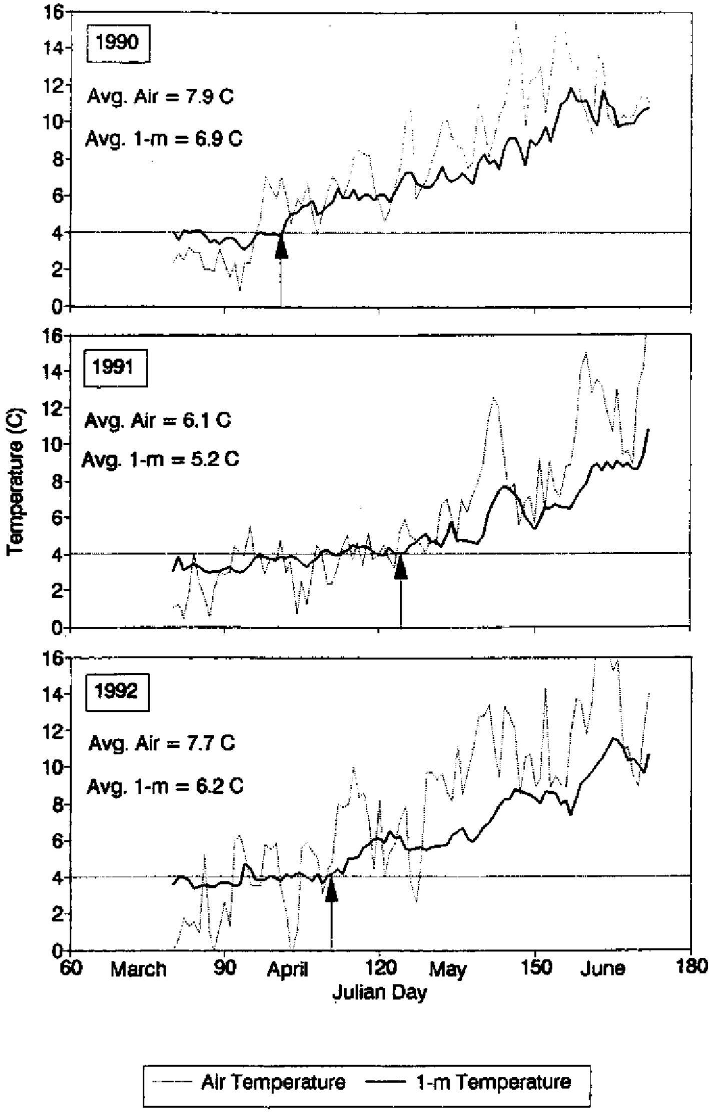

Figure 4. Time series of calendar spring average air and surface water temperatures measured at all salmon hatcheries in the years 1990, 1991, and 1992. The arrow indicates the beginning of the seasonal warming cycle each year.

varied from year to year as well (Figure 4). In 1990, the warmest year, upper-layer warming was initiated in early April. In 1991, the cold year, warming was delayed into the first week of May. In 1992, temperatures at 1 m began departing from the 4 degrees C line in late April.

Regional cloud cover apparently plays a role in determining the initiation of seasonal warming (Figure 5). During the calendar spring of 1990 and 1992, less than one-third of the 90 day period was completely cloud covered (100%). This was in contrast to 1991 when complete cloud cover occurred half of the time. Rapid increases in water temperature usually accompany cloud free days after early April. Since clouds in the region are most often associated with storm events, surface wind-mixing generally cools the surface waters during periods of cloud cover in the spring.

Vertical Profiles of Temperature and Salinity

Seasonal patterns in the thermal structure and salt content of the water column in Prince William Sound reflect seasonal and interannual variability in meteorological and oceanographic forcing in the Gulf of Alaska. Oceanographic winter (February/March) is characterized by generally isothermal temperatures in the wind-influenced upper layers and oceanic salinities (>32.5 ppt). By September, the water column is thermally stratified and significantly less saline in the upper 100 m in response to seasonal warming and increased freshwater input. Interannual differences noted in surface layer temperatures are also apparent in vertical profiles. The surface water was warmer in June 1992 (>15 degrees C) than in the same month the year before (~10 degrees C). Temperatures measured at C-LAB 1 (upper 100 m) compare favorably with sea surface seasonal records averaged at the hatcheries for the late winter and early spring of 1992.

Wind Forcing of the Winter Cooling Cycle

Continuous and concurrent hourly records (C-LAB 1) of upper ocean temperature, air temperature, and wind speed and direction provide a means to evaluate the influence of winter storms on sea surface temperature fields in Prince William Sound. From observations in the month of December in 1991 and 1992, it is apparent that wind direction and air temperature are generally predictable from surface pressure fields. In early winter, low pressure usually accompanies the frequent cyclonic storms that characterize the northern Gulf of Alaska in all seasons. These storms bring warm, moist air into the Sound from the south and southeast. In contrast, higher pressure is usually associated

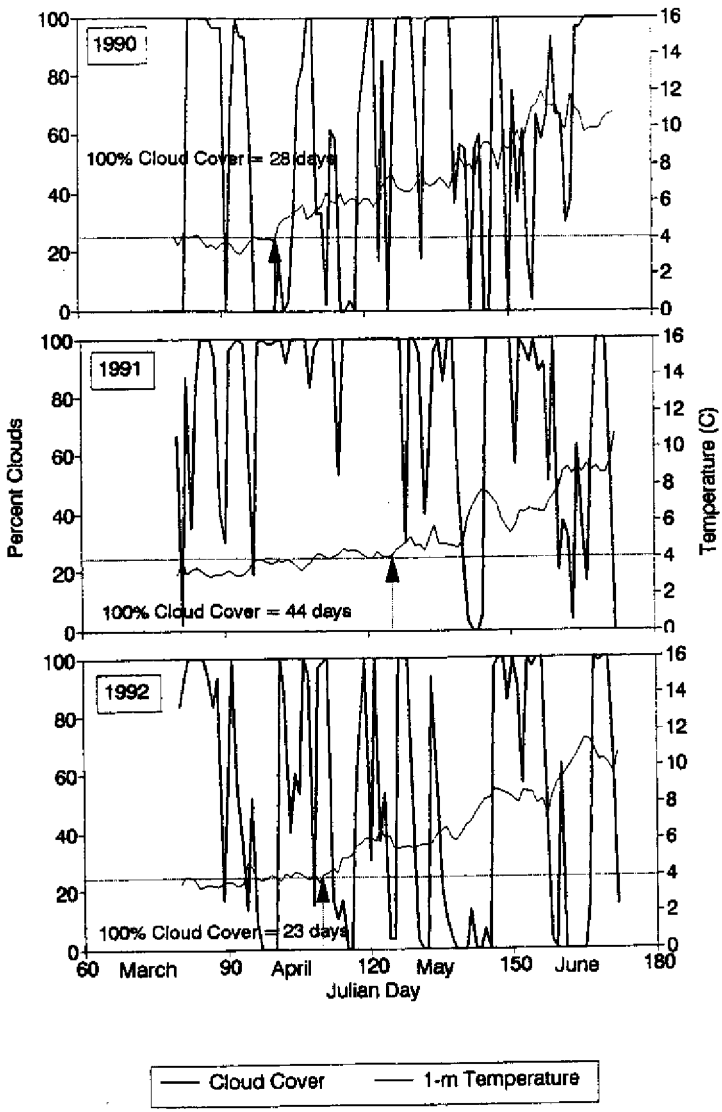

Figure 5. Time series of calendar spring percent cloud cover measured at all salmon hatcheries. The arrow indicates the beginning of the seasonal warming cycle each year.

with cooler, drier continental air draining into the region from the north. This phenomenon occurs in the records for December 1992. During the first two weeks of the month, relatively low pressure resulted in variable winds and air temperatures above freezing. However, as the surface pressure rose in mid-month, air and water temperatures fell precipitously and the winds blew consistently from the north.

AVHRR Surface Thermal Fields

Remotely sensed sea surface temperature fields exhibit measurable spatial variability associated with a variety of features and process in Prince William Sound. Bays and inlets with tide-water glaciers are clearly discernible in the thermal imagery as are tidally mixed passages and narrows and major upwelling zones. Since juvenile salmon inhabit the upper few meters of the water column, sea surface temperature fields measured by satellite offer promise for characterizing features and patterns that are not observed by fixed space buoy and logger measurements, or even from ships. For example, it is not known whether the "cold plume" from Columbia Glacier that occasionally drifts across the mouth of Unakwik Inlet can inhibit the out-migration of wild and hatchery juveniles swimming south to staging areas in the southwestern Sound. Delaying this migration could have serious growth and survival consequences.

Zooplankton Forage Populations

Zooplankton has been collected seasonally at PWSAC hatcheries since the late 1970s. Between 1981 and 1992, biomass estimates have averaged about 2 ml/m^3 with considerable interannual variability evident in the record (Figure 6). Two years, 1985 and 1989, were exceptional for the region. When this information is expressed in terms of the magnitude and duration of the early season zooplankton bloom (food days), year-to-year differences are even more pronounced; 1991 was the worst year for fry forage in the time series.

In most years, the wild fry out-migration from natal streams and hatchery releases occur in the months of April and May. This period also covers the time of the spring zooplankton bloom (Figure 7). Upper-layer zooplankton biomass generally begins to increase in late March and early April, reaching seasonal highs by the first week in May before subsiding in early June. A preliminary taxonomic analysis of samples from 1989, 1990 and 1991 implicate the large oceanic and shelf calanoids (*Calanus/ Neocalanus* spp.) as being responsible for most of the interannual variability in the forage record (Figure 8).

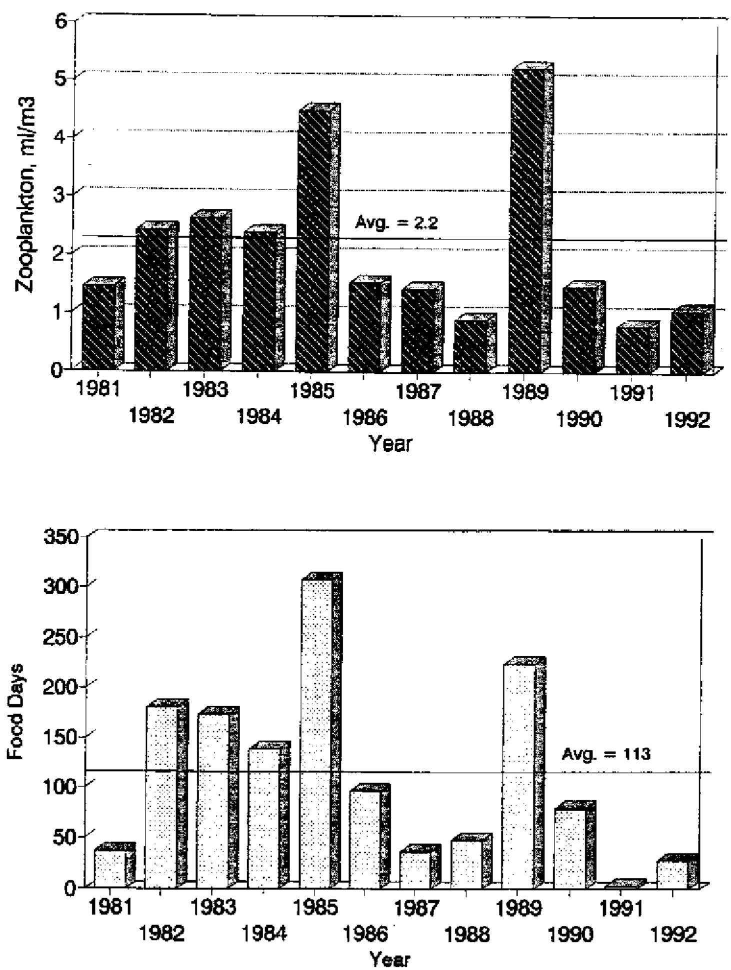

Figure 6. Time Series of average zooplankton settled volumes and calculated food days for observations made at the AFK Hatchery, 1981 through 1992.

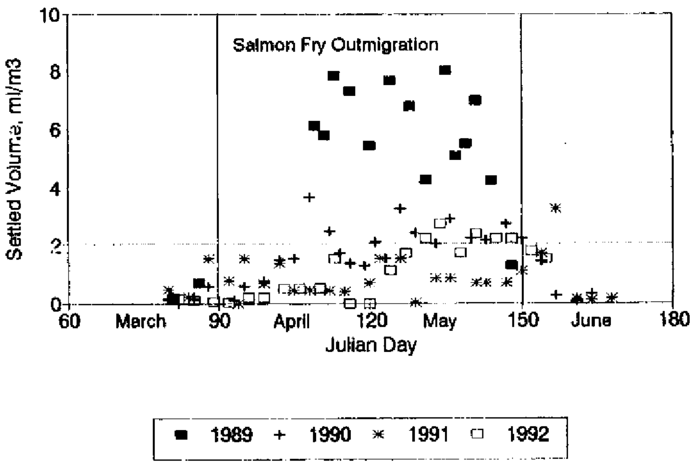

Figure 7. Relationship between zooplankton blooms and the period of the fry outmigration and release from hatcheries.

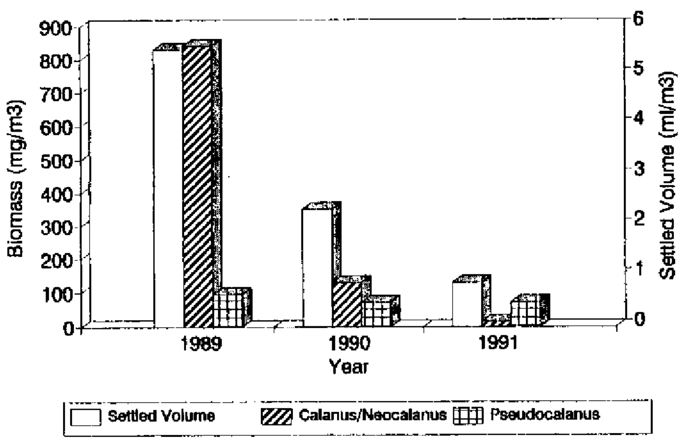

Figure 8. Comparison of settled volumes and the standing stock of large (Calanus/ Neocalanus) and small (Pseudocalanus) calanoid copepods for three years at the AFK Hatchery.

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Cooperative Fisheries and Oceanographic Studies (CFOS): An Update

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A multi-year study of oceanographic and meteorological factors influencing pink and chum salmon production in Prince William Sound was established in 1990. Alaska Department of Fish and Game (ADF&G), the Prince William Sound Aquaculture Corporation (PWSAC), the Valdez Fisheries Development Association (VFDA), and the University of Alaska organized a program of environmental monitoring and experimental studies to determine how conditions influencing the growth of wild and hatchery-reared juveniles might predict adult returns. This investigation was designed to address pre-season forecasting, carrying capacity, wild and hatchery stock competition, optimizing hatchery survivals, and wild and hatchery stock fluctuations. Under levels of constant escapement it is believed that interannual variability in pink and chum salmon production is established primarily by losses to predation during early ocean residence. These losses are thought to be related to how quickly the young salmon grow out of the most vulnerable smallest sizes.

Now in its third year, CFOS is beginning to provide information about several aspects of juvenile salmon growth and also about the magnitude of year-to-year variability in coastal growth conditions: (1) in 8 of 11 years for which seasonal zooplankton stock information is available, spring-time settled volumes accurately predict wild pink salmon returns one year later; (2) the years for which this relationship fails are the warmest and coolest years; (3) coastal ocean temperatures appear to modify the wild out-migration of fry from natal streams; (4) cold conditions extend the out-migration, while warm conditions accelerate the movement of fry from natal streams to the coastal ocean; (5) poor wild survival under cold conditions may be associated with increased losses to in-stream predators and reduced thermally-regulated growth; (6) coded wire tag measures of hatchery fry growth are highly predictive of hatchery adult returns; (7) zooplankton forage stocks in Prince William Sound have been weak following the *Exxon Valdez* oil spill (1989); and (8) the weakness in zooplankton stocks appears to be associated with declining numbers of large oceanic copepods suggesting reduced exchange between Prince William Sound and the adjacent Gulf of Alaska which serves as a source for these copepods.

Size Decreases in Adult Chum Salmon

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Long term changes in size and age at maturity were monitored for two populations of chum salmon (*Oncorhynchus keta*) in western North America. One population was from Fish Creek, a tributary of the Salmon River that enters the ocean at the head of Portland Canal near Hyder, Alaska. Chum salmon from Fish Creek are known for their large size. Size and age samples were collected from this stream from 1972 to 1992. The other population of chum salmon was from the Quilcene National Fish Hatchery (US Fish and Wildlife Service) which is located on the northwestern side of Hood Canal, near Quilcene, Washington. Size and age samples were collected from chum salmon at this facility from 1973 to 1992.

Both the Fish Creek and Quilcene Hatchery populations of chum salmon show significant declines in mean length at maturity of all age groups starting about 1980 (Figures 1A and 1B). The carcass weight difference between age-4 males in 1976, when the mean size was large, and 1991, when the mean length was small, was about 2 kg for both populations. The mean age at maturity for both populations increased while growth decreased. The decrease in size was discussed in relation to anomalies in oceanographic parameters during the past 20 years and the increase in population density of chum salmon in the ocean feeding areas. The arguments are compelling that both factors contribute to the recent declines in size of chum salmon.

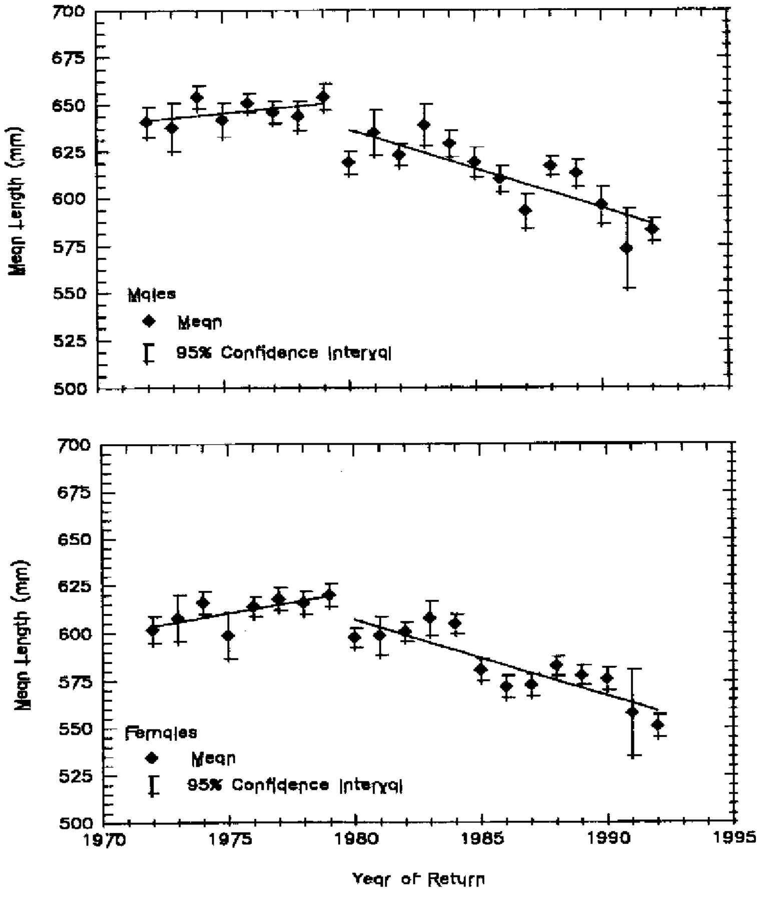

Figure 1A. Mean length and 95% confidence interval of age-4 male and female chum salmon spawners at Fish Creek 1972-1992.

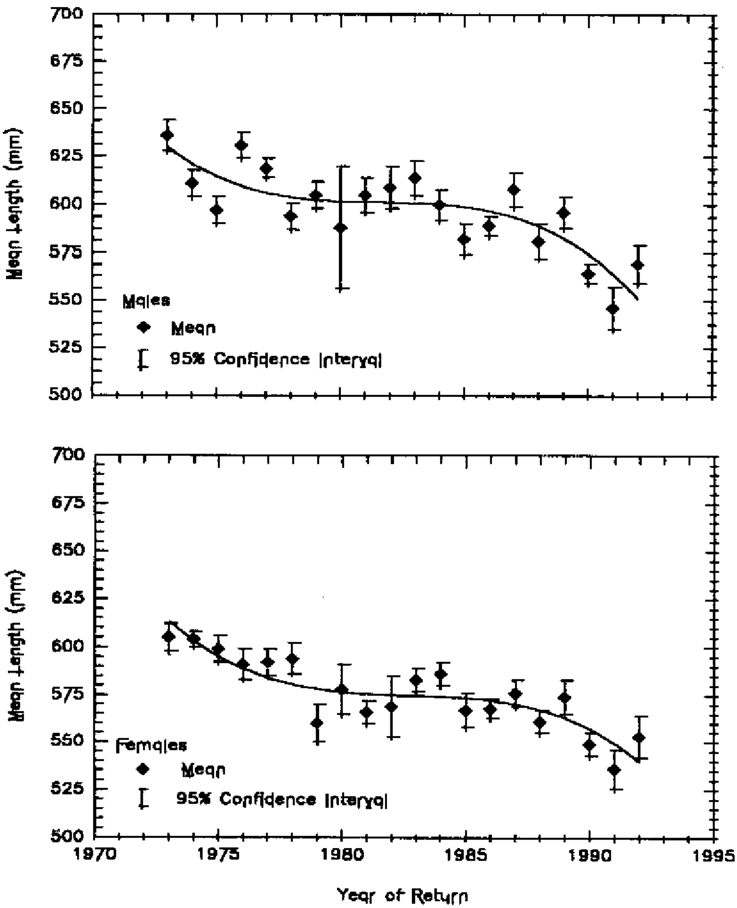

Figure 1B. Mean length and 95% confidence interval of age-4 male and female chum salmon spawners at Quilcene National Fish Hatchery 1973-1992.

Enhancement of the Hood Canal Chum Fisheries

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Introduction

In recent years, salmon enhancement programs have become an increasingly more controversial use of taxpayers money. Certain professionals and lay people alike have targeted enhancement, particularly in the form of hatchery programs, as cost ineffective and resource damaging enterprises. Often the data they use to support their crusade is biased and reflects only a few isolated examples of failures rather than the broad example of successes.

In fact, hatchery programs have accomplished what we as a society have asked them to do, namely produce fish for consumptive uses. Often what we have asked of hatcheries has been inappropriate, in terms of resource protection or enhancement, and in terms of what hatcheries can actually accomplish. For example, the expectation that hatcheries produce fish that can immediately adapt to stream life is probably unreasonable. Criticism of failed outplanting programs has focused on the apparent genetic inferiority of the hatchery fish when in fact the criticism should be focused on the policy of outplanting fish that are not well adapted to a new environment. This lack of adaptation may be due to behavioral differences that are specific to hatchery rearing and do not prepare the fish for stream rearing or because the fish are outplanted a large distance from their natal stream. Oftentimes these programs are not successful because they use a non-native stock (usually of hatchery origin) to supplement natural populations. It is unfortunate that reciprocal tests of transplanted natural origin stocks to foreign watersheds are rarely done or evaluated with the same rigor as hatchery outplantings.

Hatcheries do work as enhancement tools when they are properly used within sound resource programs with sound objectives. The decision to enhance a stock by whatever means is usually made in response to harvest needs. Enhancement decisions are usually made for one of two reasons: (1) increase harvest or harvest potential of a species in a fishery area, or (2) to rebuild natural stocks to increase harvest or maintain harvest potential. In recent years, a third reason for enhancement has been identified: the Endangered Species Act. Enhancement is rarely done for non-consumptive reasons such as to allow the public to view fish in a natural state.

This paper will document the successful enhancement efforts of the Hood Canal hatchery system that were undertaken in response to increased harvest needs in the Hood Canal area. We will show that success, measured in terms of increased harvest, has been achieved through rearing chum salmon in hatcheries and off-station incubators located around Hood Canal (Figure 1). This paper will also discuss some of the negative results of the success of this program.

History of Enhancement in Hood Canal

The first artificial production facilities to rear chum in Hood Canal were the Walcott Slough and Quilcene National Fish Hatcheries which both began operation in 1911. In 1917, approximately one million chum were planted in Walcott Slough located near the Quilcene National Fish Hatchery. In 1953 the Washington Department of Fisheries (WDF) Hoodsport Hatchery began operation. The hatchery is located on Finch Creek which already had an indigenous run of normal timed chum. The first releases from the hatchery were in 1955 but historical chum releases were sporadic as there was little interest in this species prior to 1974. In 1961 WDF's George Adams Hatchery began operation; however, the first return of chum to the facility did not occur until 1977 because emphasis was placed on rearing other species. The Enetai Hatchery, operated by the Skokomish Tribe, and the McKernan Hatchery operated by WDF began operation in 1979. In 1979 WDF established egg box programs on several Hood Canal streams. Plantings from all WDF Hood Canal hatcheries prior to 1974 averaged less than 2 million fish.

Prior to 1974 Hood Canal was a salmon preserve, where commercial fishing was not allowed. All harvest of Hood Canal chum occurred in outer Puget Sound. Tagging studies in 1968 indicated that Hood Canal chum were present from the Discovery Bay area to Pilot Point (areas 6B, 9, 9A, and 10; Figure 1) (Fiscus 1968). Following the Boldt Decision, the salmon preserve status was revoked and fishing was allowed in Hood Canal (areas 12, 12A, 12B, and 12C). In 1977 the Washington State Legislature provided the WDF with money to enhance the production of chum in Hood Canal. Portions of this money were used to build the McKernan Hatchery, increase production at George Adams Hatchery, and run the egg box program. The egg box program has since been replaced by Remote Site Incubators (RSIs) at numerous sites.

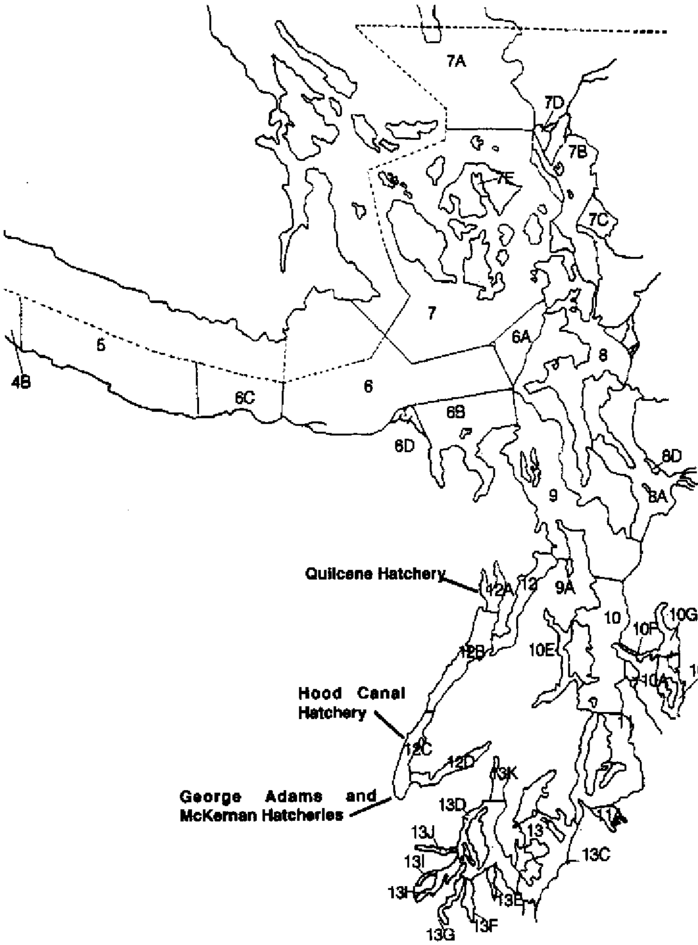


Figure 1. Puget Sound commercial salmon management and catch reporting areas and locations of Hood Canal hatcheries.

Production

The increased production for Hood Canal is shown in Figure 2. Prior to the 1974 brood, total annual Hood Canal hatchery production averaged less than 10 million fry. Beginning with the 1975 brood (1976 releases), production dramatically increased to average over 30 million fry with as many as 60 million fry released in some years. The majority

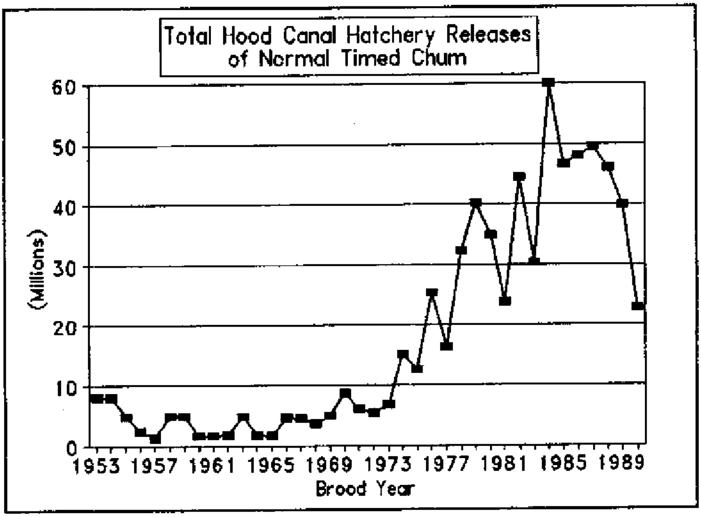


Figure 2. Releases of normal timed chum salmon by brood into Hood Canal from all enhancement projects.

of this production came from the three WDF operated hatcheries and remote site incubation facilities. Production has fluctuated over time due to changes in egg availability and policy direction.

The adult production from Hood Canal is not easily measured. The current methodology utilizes run reconstruction which calculates the relative contribution of Hood Canal chum to the total Puget Sound chum run size by comparing Hood Canal and other Puget Sound escapements. This contribution is then apportioned to the catch of chum from Hood Canal out to the ocean (area 4b; Figure 1). These catch estimates plus escapement estimates are then summed to estimate the total run size for the stock, i.e., the Hood Canal run size entering the Straits of Juan de Fuca. The method assumes that the stock is randomly distributed in mixed stock areas and that the stock is harvested at a constant rate within the fishery area. The catch data are then broken down into component broods using scale analysis so that a total run size per brood is estimated. These estimates are not particularly accurate because oftentimes catch of one stock is misallocated to another stock group. For example, Packer (1992), using genetic stock information (GSI), determined that 40% of the assumed south Puget Sound chum caught in test fisheries in catch areas 9 and 10 were in fact Hood Canal chum. In addition, escapement data to the spawning grounds are not always accurate. Nonetheless, these are the best available data, and are used by both tribal and non-tribal managers.

Results

Two analyses were used to determine if the Hood Canal chum enhancement program is successful. The first method compared the estimated Hood Canal run size, broken down by brood, with the corresponding brood release from Hood Canal hatcheries including RSI programs. The second method compared the estimated brood rearing costs of the enhancement program with the estimated brood ex-vessel revenues generated in the area 12 fisheries.

The trend for both hatchery production and run size has increased over time. Figure 3 shows the trend lines and regression statistics for each of these relationships. A regression of run size on hatchery releases was significant ($p<0.0001$; $r^2= 0.47$; Figure 4). The general trend in adult abundance has mirrored trends in juvenile production. Although this analysis is limited by the quality of the run reconstruction data, it suggests rather strongly that enhancement of the chum population has been successful in terms of adult production.

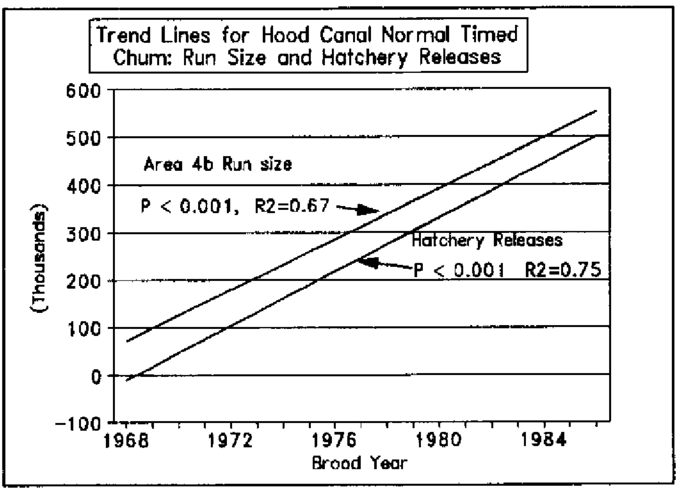


Figure 3. Trend lines for total run size entering catch area 4b and hatchery releases of normal timed Hood Canal chum. Data are for broods 1968-1991.

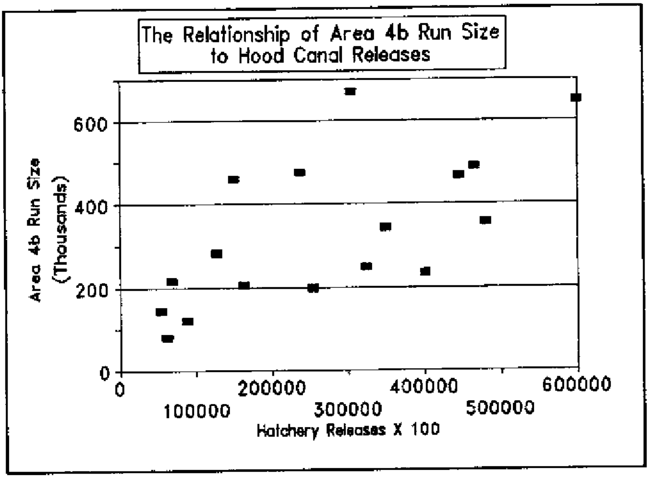
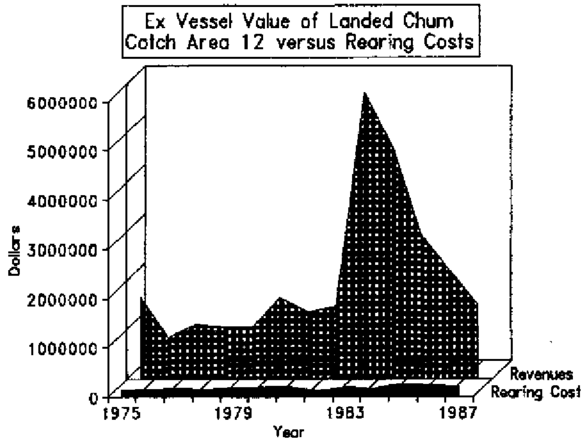


Figure 4. Scatterplot of total run size entering area 4b and hatchery releases of Hood Canal normal timed chum. Data are for broods 1968-1986.

A second measure of the success of enhancement programs is whether revenues generated by fisheries are greater than the costs associated with the enhancement. Cost:Benefit ratios are difficult to calculate so we used a relative comparison of rearing costs with fishery revenues generated in the area 12 fishery. These comparisons were not adjusted for inflation and are based on several assumptions. The first assumption was that the current cost for rearing fish at WDF hatcheries ($2.50/pound of fish) was close to the costs incurred by other chum producers in Hood Canal. The second assumption was that this cost could be applied to all years beginning with the 1975 brood. Thus the cost estimates of enhancement were derived for each brood by taking the total poundage reared and released and multiplying it by $2.50 per pound. Furthermore, each annual cost was multiplied by a 10 year average age distribution to break annual rearing costs into brood rearing costs. The costs associated with producing age 3, 4, and 5 year old fish were then summed to give the rearing costs by brood. The revenues for Hood Canal area 12 chum catches were obtained from ex-vessel poundage that was landed in catch area 12 and all sub-areas. These data were summarized by fisher type (treaty or non-treaty), area, and month. The actual price paid to the fishers in each fishery was multiplied by the pounds landed and summed to give the total estimated value in round pounds. These



Fibure 5. A comparison of ex-vessel revenues generated in fisheries in catch area 12 (Hood Canal) and rearing costs of all enhancement programs in Hood Canal using $2.50/lb of fish reared as the total rearing cost.

data were then broken into various age groupings using an average age breakdown (from broods 1980-1990) of: Age 3-32.2%; Age 4-64.6%; Age 5-3.2%. The revenues generated by each brood were compared with the rearing costs for each brood and are shown in Figure 5. The revenues generated in the area 12 fishery average 14 times greater than the rearing costs. Average rearing costs were $175,307 and average revenues were $2,383,865. Revenues fluctuated each year due to changes in price and proportion of three year old fish (smaller sized fish). Rearing costs were influenced by the poundage released each year. For example, in several years chum were not reared at George Adams Hatchery.

Problems Associated with Enhancement

Increasing the number of harvestable adults does pose some potential problems to both natural stocks and to fishery management. High harvests on more numerous hatchery fish can over-exploit less numerous naturally produced fish. Also, large numbers of juveniles released from hatchery programs could out-compete less numerous naturally produced juveniles in the marine environment. High exploitation rates could reduce the effective number of spawners in some small streams and thus reduce genetic fitness of these populations. Other management problems can exist as well due to by-catch of other species, particularly if the runs of these fish are weak. We looked at the escapement of naturally produced Hood Canal stock and found that annual variations in returns did not appear to coincide with increased harvests of hatchery produced chum. For example, escapements were in decline just prior to the rescinding of commercial fishing restrictions in Hood Canal (Figure 6). Escapements of naturally produced chum increased again before a drastic short term reduction from 1979-1984. After 1984, escapements appear to be stable although somewhat lower than pre-1972 escapements. Several hypotheses have been put forth to explain the recent increase in escapements: (1) the fishery selected for the early returning and spawning fish and the escapements are now composed of later returning fish which avoid most of the fishery, (2) escapements have increased due to straying of hatchery fish or returns from RSI programs. We believe that the recent increases in escapement are due to a combination of regulation changes and returns from RSI programs. Management regulations were adopted in the early 1980s that restricted fishing in Hood Canal after November 20, thus sparing later returning natural fish from excessive harvest rates. Unfortunately, quantitative data to evaluate

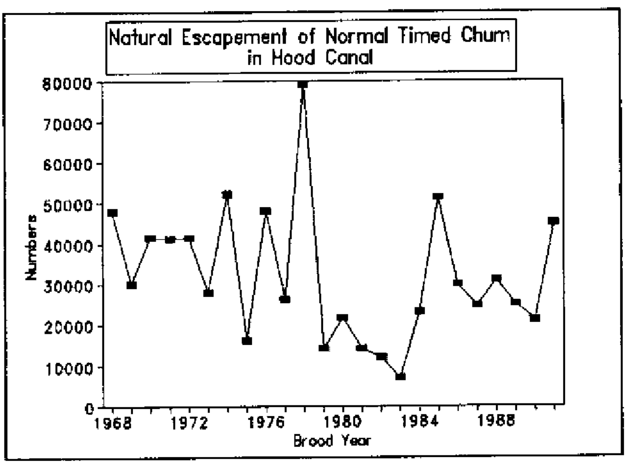


Figure 6. Escapement of naturally produced normal timed chum salmon in Hood Canal by brood.

the RSI program is non-existent and only qualitative observations of apparent increases in escapement in those streams with RSIs are available. It is not likely that the high harvest rates on the hatchery fish have negatively affected the genetic fitness of the natural fish.

Large numbers of hatchery juveniles do not appear to be negatively impacting naturally produced fry in Hood Canal. Simenstad et al. (1980) estimated the excess carrying capacity (the carrying capacity above the number of chum fry already in Hood Canal) of epibenthic feeding chum in 1978 to range from 1.1 million (February) to 0.05 million (June). The excess carrying capacity of outmigrating neritic-feeding chum in 1979 was estimated to range from 1.0 million (February) to 7.1 million (June). The total releases during these two years was 20 million and 30 million fry, respectively. Since the time of this study chum fry production has increased along with increased escapement of natural fish, presumably producing increased numbers of naturally produced fry. Both run size and escapement have remained relatively stable during this time period, indicating perhaps that the carrying capacity was underestimated.

A second concern of large scale terminal fisheries is the by-catch of other non-target species. Currently there is some controversy as to whether the by-catch in the chum net fishery of immature Chinook ("blackmouth") or natural coho is substantial enough to be causing problems in abundance for either species. Both the catches of immature Chinook in the local sport fishery and the escapement of Hood Canal natural coho have declined in recent years. For the latter, escapements have been low enough to restrict sport and commercial fisheries in the Strait of Juan de Fuca and northern Puget Sound. There are groups of citizens who insist these declines are related to the terminal net fisheries for chum. A one year study conducted by WDF (Clocksin et al. 1991) indicated that a total of 268 blackmouth (85-386 80% C.I.) were caught incidentally to a catch of 86,774 adult salmon.

Conclusions

Enhancement of Hood Canal chum has been a largely successful program utilizing hatchery programs primarily and to a lesser extent remote site incubation. The enhancement of Hood Canal chum has resulted in increased catches in the treaty/non-treaty net fisheries. Although focused efforts to evaluate all outcomes of the enhancement have not occurred, the evidence over the time periods for which data can be analyzed points to a successful program that allows for large harvests of predominantly hatchery origin chum. This harvest generates millions of dollars in revenue each year to commercial fishers. The estimated cost of the entire enhancement program is below $200,000 per year. Costs incurred in rearing or in the actual harvest would have to be 14 times greater than those listed here for the cost:benefit ratio to equal 1. Large scale enhancement has the potential for causing problems if not used wisely. Although data are not available to adequately assess the potential impacts caused by enhancement, the production of normal timed chum in Hood Canal appears to be healthy. Enhancement is also no replacement for sound management of the fishery resource.

Acknowledgments

We would like to thank the following people for providing data and suggestions for this paper: Jim Ames and Jim Uehara of the Washington Department of Fisheries. Also, we thank Dr. Ann Blakely, and Tim Tynan and Bill Tweit for their review and comments.

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The Impacts of Success: A Case History of Hidden Falls Hatchery

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Hidden Falls Hatchery was built by the state of Alaska in 1978 on the eastern shore of Baranof Island in Southeast Alaska (Figure 1). During the past 15 years, Hidden Falls Hatchery has established a chum return larger than any outside of Japan. The harvest has created significant economic opportunity for the commercial fishery in Alaska. This

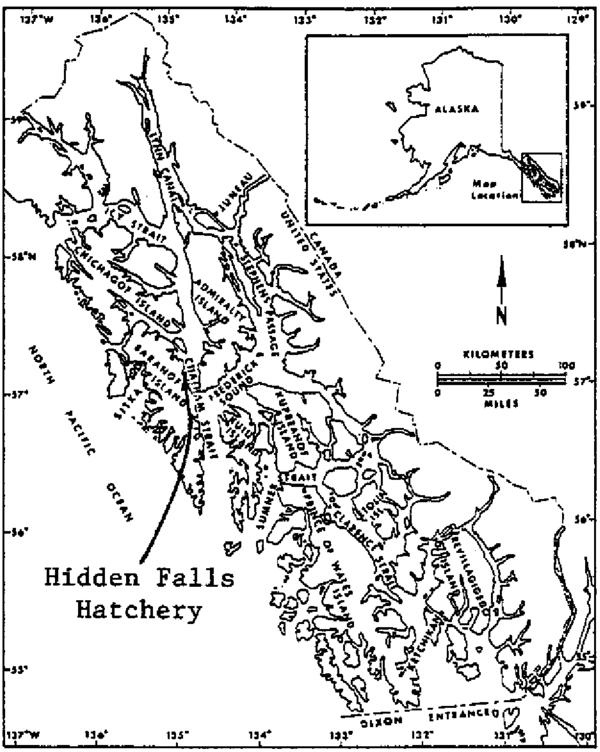

Figure 1. Location of Hidden Falls Hatchery.

paper describes the history and impacts of the chum program at Hidden Falls and identifies factors that have contributed to its success.

Background

The state of Alaska operated Hidden Falls Hatchery from 1978 to 1988. In 1988, the state of Alaska began contracting out operations of state hatcheries to private non-profit regional aquaculture associations to reduce general fund expenditures. Northern Southeast Regional Aquaculture Association (NSRAA) has operated Hidden Falls Hatchery under contract to the state since 1988. Operations and ongoing capital expenses are now paid for through sale of a portion of the returning fish (cost recovery) and from other association revenue.

Hidden Falls Hatchery is located on a site that is well suited for hatchery operations. A 185 acre lake provides water through a dual intake system. Shallow and deep intakes allow some temperature control. The 200 ft. elevation of the lake provides enough head to produce hydropower for the hatchery site. Saltwater bays near the hatchery provide sheltered net pen rearing areas and terminal harvest areas. The site is located in an area that produces few wild salmon minimizing potential conflict with wild stocks during harvest.

Fry History

The production of chum fry from Hidden Falls has developed in three steps (Figure 2). From brood years 1977 through 1981, production was controlled by egg availability as eggs were only available in limited numbers from wild stocks. From 1982 through 1986, fry production climbed to about 20 million fed fry per year which matched hatchery net pen rearing capacity. In 1987, a remote release site was developed at Takatz Bay, approximately 7 miles from the hatchery. With the additional rearing capacity, the release goal increased to the current level of 62 million fed fry. Target release size is 1.5 to 2.0 g.

Adult Returns

Chum returns to Hidden Falls Hatchery have been relatively large, providing surpluses for harvest in most years (Figure 3). Total returns have exceeded 400,000 fish in 8 of the past 12 years. In 1992, over one million chum salmon came back to Hidden Falls, the largest return to date. The relatively good runs in the mid 1980s were the result of fewer fry and higher survival than recent returns. Survivals during the mid-1980s were above 3% (range 3.3-8.0%) while survivals for the brood

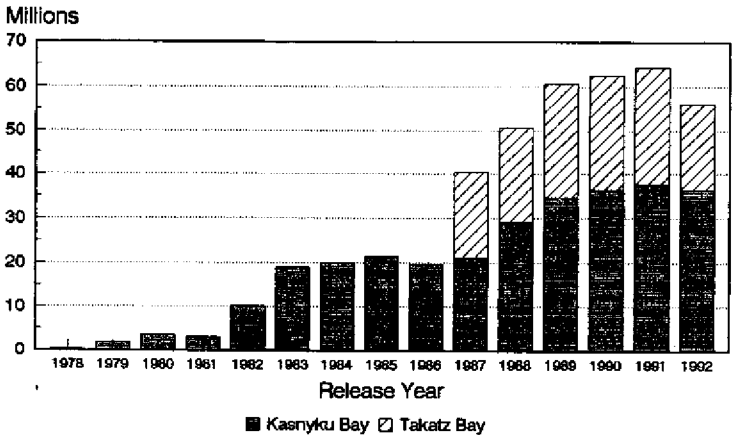

Figure 2. Chum releases from Hidden Falls Hatchery and Takatz Bay, 1977-1987.

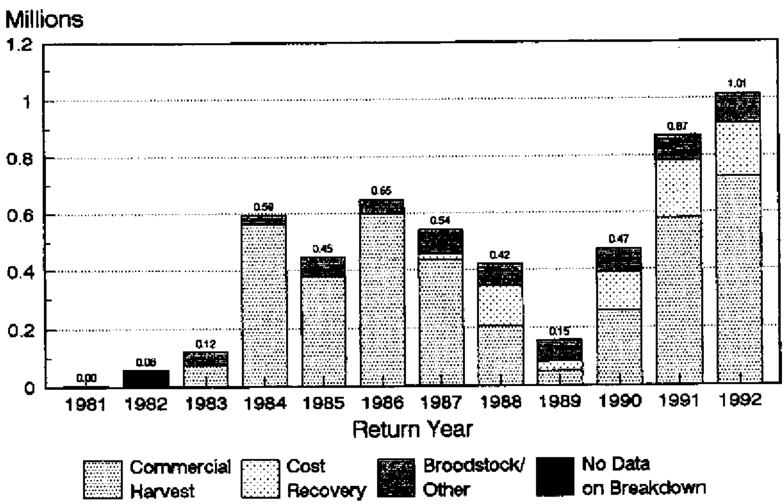

Figure 3. Returns to the Hidden Falls chum program, 1981-1992.

years contributing to the last two years record returns were about 1.7% (Figure 4).

Size of Hidden Falls chum by age at return has decreased over time (Figure 5). Between brood years 1979 and 1988, mean size of 4-year-olds declined from 640 mm to about 580 mm. Average size of 5-year-olds declined from 680 mm to 620 mm over the same period. Both declines are statistically significant (P=0.005 and 0.006 respectively). Similar declines have occurred in wild populations along the west coast of North America (personal communication, J. Helle, NMFS, Auke Bay, Alaska) and by Kaeriyama (1989) in Hokkaido chum returns. Total biomass of chums returning to Hidden Falls has increased, despite the smaller size of individuals (Figure 6). The largest return to date occurred in 1992 when 3.25 million kg returned.

Four years is the dominant age at return for Hidden Falls chum. There may be a shift in abundance toward older fish at return with 5-year-olds becoming a larger proportion of the return (Table 1). To date, the trend is insignificant (P =0.216). Helle and Hoffman (in press) document a shift toward older age at return in other west coast chum populations.

Management Goals

Three management goals influence the strategy used for harvesting chum returns. The primary goal is to have the commercial fishery harvest

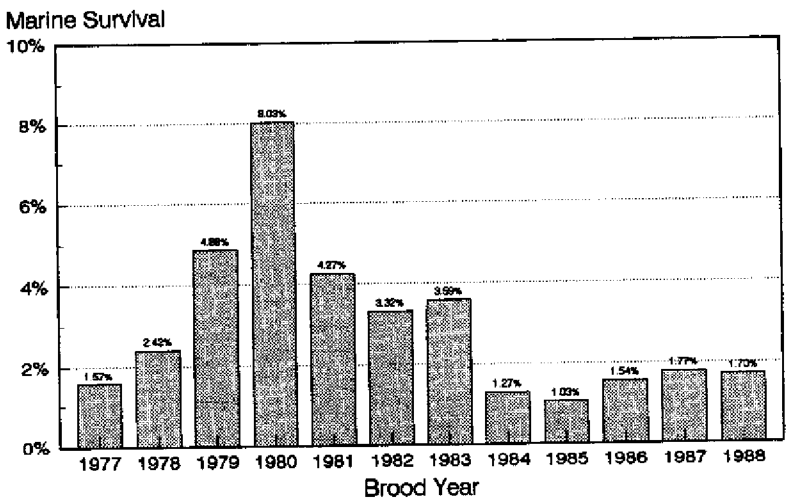

Figure 4. Marine survival by brood year for Hidden Falls chum , 1977-1988.

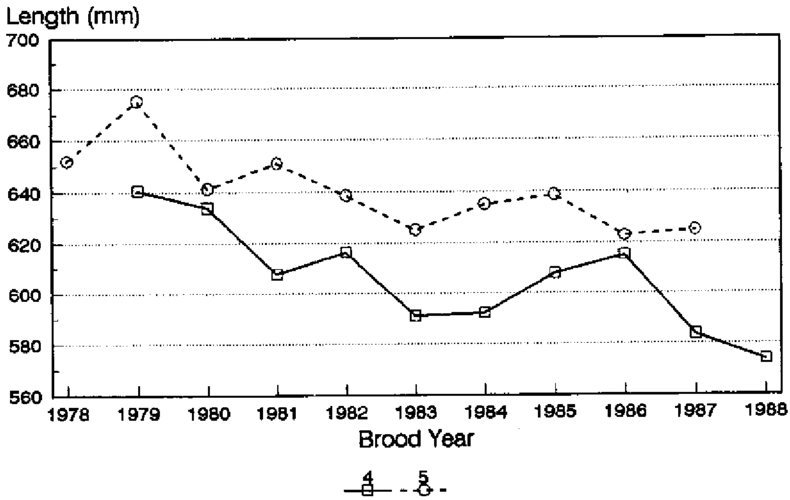

Figure 5. Mean size by age at return, Hidden Falls chum program, brood years 1978-1988.

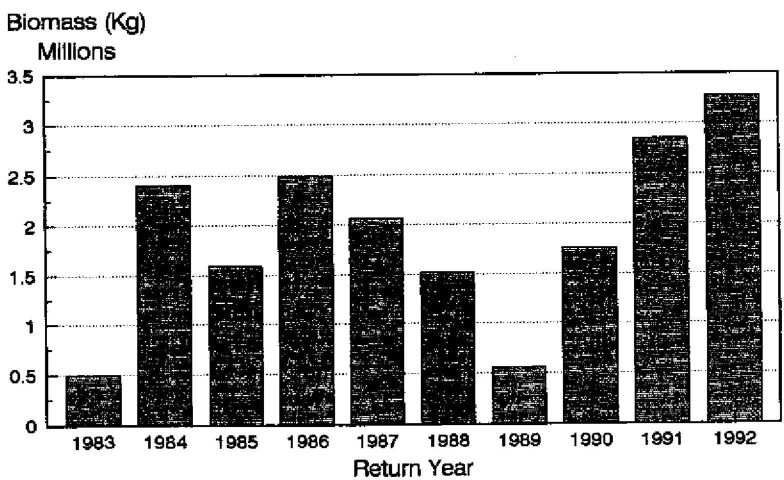

Figure 6. Estimate of biomass of age 4 and 5 chum returning to the Hidden Falls chum program by return year, 1983-1992.

Table 1. Proportion at age of return and mean age at return by brood year for chum salmon returning to Hidden Falls Hatchery, 1978-1987.

Brood Year	Age at Return (Percent)				Mean Age
	3	4	5	6	
1977	0.15%	55.54%	44.31%	0.00%	4.44
1978	3.54	78.61	17.86	0.00	4.14
1979	13.31	58.53	28.16	0.00	4.15
1980	2.15	75.17	22.04	0.64	4.21
1981	3.45	58.66	37.90	0.00	4.34
1982	4.24	77.00	18.76	0.00	4.15
1983	2.21	59.75	36.61	1.43	4.37
1984	9.64	63.98	26.02	0.36	4.17
1985	0.42	35.95	59.23	4.39	4.68
1986	0.25	56.24	42.70	1.81	4.46
1987	1.61	65.54	32.65	- [1]	4.31

[1] Incomplete return.

as many fish with as much value as possible. The second goal is to collect enough eggs to sustain the program and to ensure that all segments of the run are represented. The third goal is to catch enough returning fish to pay for operations and capital improvements at Hidden Falls.

Maximize Commercial Harvest

The goal to maximize the commercial harvest relies both on the number of chum caught and their quality. Value can vary as much as three times depending on skin and flesh color. Darkening (and loss of value) occurs in a matter of a few days when chum reach the terminal area.

Timing and frequency of commercial openings has a dramatic impact on the quality of fish caught. In 1990, after a disappointing return in 1989, NSRAA staff decided to make sure that broodstock and cost recovery goals were met by delaying commercial openings until these goals were nearly reached. Consequently, the first commercial opening was delayed about 2 weeks from the beginning of the return. The quality of the commercial catch was noticeably lower than in other years (Figure 7). Beginning in 1991, NSRAA staff recommended that commercial harvests begin early in the run and occur regularly, at least until run strength could be assessed. This approach placed additional risk that NSRAA cost recovery goals would not be met if the run was weak, but the improvement in quality justified the risk. When commercial openings

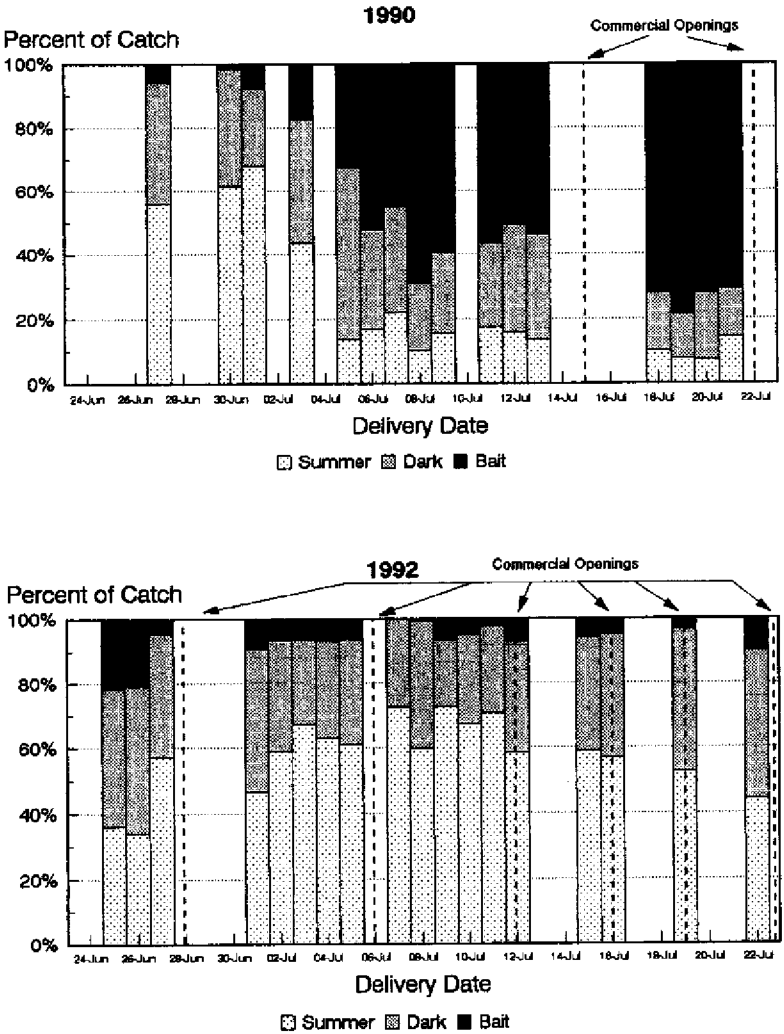

Figure 7. Quality of chum salmon harvested using two different terminal harvest strategies in 1990 and 1992. See text for further explanation.

occur regularly, intensive fishing effort effectively catches all chum in the terminal area preventing fish from accumulating and turning dark. It is not possible to have the same impact as commercial openings with four chartered seiners during cost recovery and broodstock operations.

Commercial openings at Hidden Falls influence the management of the general early season seine fishery in southeast Alaska. During the first opening in 1992, about 70% of the seine boats fishing in southeast Alaska fished at Hidden Falls. In succeeding weeks between 20 and 35% of the fleet participated in openings at Hidden Falls. These boats caught 725,000 chum salmon in 1992 worth $2.3 million (Figure 8). Benefits accrue to seiners fishing other areas as well. While these benefits are harder to quantify, seiners fishing other areas probably benefit from less competition by catching more fish per boat. Managers are more likely to open other areas for seining with the knowledge that fishing pressure will be less. Opening these areas provides catch and effort data useful in making future harvest decisions.

Broodstock Collection

Broodstock collection operations have evolved to place greater emphasis on ensuring that all portions of the run are represented in the

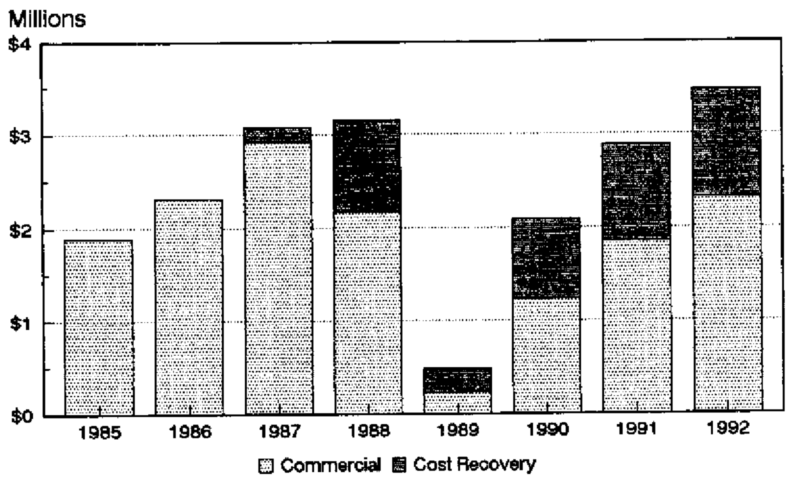

Figure 8. Value of commercial and cost recovery harvest for the Hidden Falls chum program, 1985-1992.

egg takes. Prior to 1987, broodstock was collected at the end of the run after harvest was completed. In 1987, a barrier net was installed which allowed fish from the early and middle portions of the run to be isolated from the harvest area. All portions of the run are now represented in egg takes.

Cost Recovery

Since 1988, about 200,000 chum are harvested and sold by NSRAA to pay for hatchery operations and capital improvements. Cost recovery harvest occurs between commercial openings and involves four contracted seine boats. The sale generates about $1 million annually (Figure 8).

Factors Contributing to the Success of Hidden Falls

There are three important biological factors that I believe have contributed to the success of Hidden Falls chum salmon. The first is fry release timing. Mid-May releases have proven to be the most successful. The second factor is the size of fry at release. Linley (personal communication, NSRAA, Sitka, Alaska) demonstrates a relationship between fry size and adult return. Short term saltwater net pen rearing has allowed us to release the largest fry possible on the appropriate date. The last factor is the hatchery location. While similar approaches have been tried at other sites, the chum program at Hidden Falls has been generally more successful than others. Site-specific factors responsible for higher survival are not understood.

Other factors that contribute to the success of the program relate to the management considerations. Due to run timing and limited wild stock production close to Hidden Falls, Alaska Department of Fish and Game (ADF&G) management has allowed a large harvest area to be used to access hatchery returns. This allows fishermen to aggressively harvest and helps to maintain quality and value. Regular and intensive commercial openings remove chum soon after they arrive in the harvest area and keeps quality at its best. The willingness of the seine fleet to support the hatchery transfer to NSRAA despite the loss of a portion of the return to cost recovery harvest was critical in the transition from general fund support to self-support.

Finally, an overriding factor in generating the success from this program has been the people who have worked hard to make it happen.

Much of the credit goes to Jim Cochran, who managed the hatchery for ten critical developmental years, and his staff. NSRAA staff have continued to work hard to see that the facility generates as much benefit as possible.

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Development of the Pink Salmon Enhancement Program in Prince William Sound, Alaska

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Program Conception

Rationale

The rationale for undertaking an ambitious pink salmon enhancement program in Prince William Sound is described in *Salmon Culture Program* by the Prince William Sound Aquaculture Corporation.[1] The primary author of this prospectus, Wally Noerenberg, identifies the following four reasons for utilizing salmon ranching technology to enhance the existing fishery.

1. A declining trend in fisheries production over the last 30 years (the period 1940-1970) and the high degree of interannual variability in returns of adult pink salmon to Prince William Sound. "Randomly strong, moderate, or weak annual salmon returns must be dealt with in an effort to obtain a reasonable catch share."
2. Real or potential habitat loss due to natural events such as the 1964 earthquake and emerging area use conflicts with other industries such as oil and gas, timber, and recreation. "With Prince William Sound emerging as a focal point for transportation of North Slope oil and gas, for major offshore oil and gas development, for increased timber production and recreational use by adjacent large population centers, lessening of the productive capability of the natural fish environments appears inevitable."
3. The fishery is a significant factor in the long range economies of local communities such as Cordova, Whittier, Valdez and the Native communities of Tatitlek and Chenega. At the low levels of returns that existed at the time of the development of the enhancement program, "substantial economic dependence upon the fishery has become nearly impossible."
4. "The increasing world demand for protein supplies require that

> major production zones, such as the Prince William Sound area fisheries represent, be brought to and maintained at maximum production levels."

Private Non-profit Concept

The decision by the State of Alaska to enter into a fishery rehabilitation program in the early 1970s was a response to years of declining salmon returns. The concept of a private non-profit (PNP) fishery enhancement program was intended to make the public (i.e. the resource users) active participants in this rehabilitation program. The president of the Prince William Sound Aquaculture Corporation (PWSAC), Armin Koernig, stated in *Salmon Culture Program*:

> Participation in the rehabilitation program by fisherman, processing industry and communities will bring a noticeable change in Alaskan fisheries, i.e. from a "managed public" to a responsive, knowledgeable, actively participating public which is willing to share the responsibility for our public fisheries resources.

The PNP concept, as opposed to the private for profit hatchery concept in Oregon and California, was intended to maintain the Alaskan philosophy of public ownership of natural resources. Koernig states:

> The non-profit concept is to serve everyone who fishes in the common property fishery and to assist the state in a common effort to rehabilitate our depressed fisheries.

Enabling Legislation

The legal basis for the PNP program is the Private Salmon Hatchery Act of the 1974 Alaska State Legislature, AS 16.10.400-470. This legislation says in part:

> It is the intent of this act to authorize the private ownership of salmon hatcheries by qualified non-profit corporations for the purpose of contributing, by artificial means, to the rehabilitation of the state's depleted and depressed salmon fishery. The program shall be operated without adversely affecting natural stocks of fish in the state and under a policy of management which allows reasonable segregation of returning hatchery-reared salmon from naturally occurring stocks.[2]

This Private Hatchery Salmon Act also provides for the formation of "regional associations." As a regional association a PNP must be composed of representatives of all interested user groups and possess a board of directors "which includes no less than one representative of each user group that belongs to the association." The concept of a regional association supports the idea of an "actively participating public" and a program that "is to serve everyone who fishes in the common property fishery."

During the winter of 1974-1975 users of the fishery in Prince William Sound including commercial fishing groups, fish processors, local city governments, and Native corporations formed a regional non-profit association, the Prince William Sound Aquaculture Corporation (PWSAC).

Past and Present Pink Salmon Production in Prince William Sound

Growth of Pink Salmon Hatcheries in Prince William Sound

In the prospectus *Salmon Culture Program* a target level of hatchery capacity of 300 million salmon eggs was set. Based on assumptions of survival to various life stages an annual average adult return of 5 million salmon was expected. With the average wild salmon return of 4 million and the expected hatchery production of 5 million, a total annual return of 9 million salmon was expected to Prince William Sound. It was envisioned that PWSAC would provide about two-thirds of the production or 200 million eggs and the state or other private corporations would provide the remaining 100 million.

As the program came on line it became apparent that the fish culture technology would permit production levels much higher than the original 300 million egg concept. The location of operating pink salmon hatcheries in Prince William Sound is shown in Figure 1.

Table 1 depicts the expansion of the pink salmon hatchery program in Prince William Sound in terms of fry releases. The program began in 1975 with the conversion of a salmon cannery on Evans Island to hatchery production of pink salmon. In 1976 the first release of 1.0 million pink salmon fry occurred at the Armin F. Koernig (AFK) Hatchery, formerly Port San Juan. Releases increased annually with increased hatchery production capabilities and knowledge regarding the culture of pink salmon.

The Alaska Department of Fish and Game (ADF&G) Fisheries Rehabilitation, Enhancement and Development (FRED) division began construction of the Cannery Creek Hatchery (CCH) as a 100 million egg

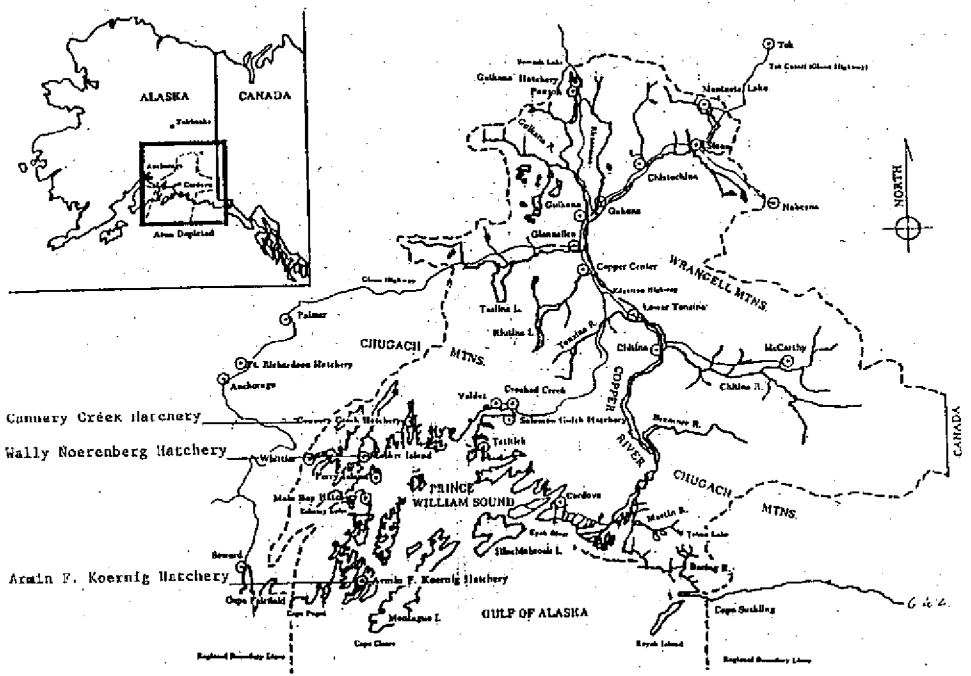

Figure 1. Map of the Prince William Sound area.

Table 1. Prince William Sound Aquaculture Corporation pink salmon fry releases.

Brd Yr	AFK	CCH	WHN	VFDA	MBH	TOTAL
1975	1,000,000					1,000,000
1976	11,010,577					11,010,577
1977	16,950,784					16,950,784
1978	22,774,739					22,774,739
1979	21,500,000					21,500,000
1980	69,787,000	21,289,000		22,000		91,098,000
1981	70,118,000	13,933,000		7,400,000		91,451,000
1982	87,384,533	22,123,000		5,400,000		114,907,533
1983	76,746,000	31,200,000		8,390,000	41,900,000	158,236,000
1984	103,531,000	36,500,000		51,280,000		191,311,000
1985	112,527,515	56,200,000	34,437,214	54,670,000		257,834,729
1986	116,117,645	42,600,000	75,932,715	59,739,413	2,130,000	296,519,773
1987	110,962,557	95,396,455	195,321,335	130,990,000		532,670,347
1988	160,471,718	59,088,345	159,920,122	128,414,000	10,518,470	518,412,655
1989	113,842,866	143,662,511	233,627,908	122,203,000		613,336,285
1990	115,748,552	141,513,625	205,728,325	130,000,000	9,235,054	602,225,556
1991	112,828,924	132,166,249	163,571,419	190,000,000		598,566,592
1992	117,000,000	139,000,000	167,000,000	207,000,000		630,000,000
1993	117,000,000	139,000,000	167,000,000	207,000,000		630,000,000
1994	117,000,000	139,000,000	167,000,000	207,000,000		630,000,000
1995	117,000,000	139,000,000	167,000,000	207,000,000		630,000,000

Data through brood year 1991 from hatchery annual reports; brood years 1992-1995 based on hatchery capacity and assumed survivals.

AFK=Armin F. Koernig Hatchery; CCH=Cannery Creek Hatchery; WNH=Wally Noerenberg Hatchery; VFDA=Valdez Fishery Development Assoc.; MBH=Main Bay Hatchery facility in the late 1970s. Production began in 1981 with a release of 21 million pink salmon fry. ADF&G maintained operation of CCH until 1988 when falling state revenues required that some hatchery operations be contracted to the private sector. PWSAC entered into a contract with the state of Alaska in 1988 to operate CCH as a 147 million egg hatchery.

Plans for a world class multi-species salmon hatchery on Esther Island was among the original concepts for a hatchery program in Prince William Sound. By the early 1980s planning and ultimately construction began on a 300 million egg facility of which 200 million eggs would be pink salmon. The first release of 34 million pink salmon fry from the Wally Noerenberg Hatchery (WNH) occurred in 1986. Pink salmon production at WNH peaked in 1990 when over 233 million pink salmon fry were released.

As a local PNP hatchery operator, the Valdez Fisheries Development Association (VFDA) began operating the Solomon Gulch Hatchery in Valdez in 1981. Their first release of 22,000 pink salmon fry occurred in 1980. Production increased to over 130 million pink salmon fry by 1987. Currently, VFDA is capable of releasing over 200 million fry.

Current Hatchery Capacity

Table 2 defines the current hatchery capacity of pink salmon in terms of green eggs and adult returns for Prince William Sound. At the present production level of 696 million green eggs, an annual adult return of over 27 million hatchery pink salmon is expected.

Table 2. Prince William Sound Aquaculture Corporation pink salmon hatchery production levels.

Site	Green Eggs	Adult Return
AFK	126,000,000	5,700,000
CCH	152,000,000	6,100,000
WNH	188,000,000	9,000,000
VFDA	230,000,000	6,400,000
Total	696,000,000	27,200,000

AFK=Armin F. Koernig Hatchery
WNH=Wally Noerenberg Hatchery
CCH=Cannery Creek Hatchery
VFDA=Valdez Fisheries Development Assoc.

Hatchery and Wild Stock Production—Past and Present

The pink salmon hatchery program did not begin contributing significantly to the Prince William Sound fishery until the early 1980s, Table 3. Prior to that time wild pink salmon returns were highly variable and the fishery unstable. The average return of pink salmon to Prince William Sound for the 20 year period, 1960 to 1979, was 5.1 million. No seine fishery occurred in Prince William Sound in 1972 and 1974.

Table 3. Prince William Sound Aquaculture Corporation pink salmon total return summary.

Year	AFK	CCH	WNH	VFDA	MBH	All Hat	Wild	Hat + Wild
1960							3,193,223	3,193,223
1961							4,498,867	4,498,967
1961							8,762,206	8,762,206
1963							6,652,665	6,652,665
1964							6,049,124	6,049,124
1965							3,436,427	3,436,427
1966							4,122,588	4,122,588
1967							3,468,600	3,468,600
1968							3,608,678	3,608,678
1969							5,233,149	5,233,149
1970							3,789,216	3,789,216
1971							8,423,514	8,423,514
1972							695,963	695,963
1973							3,281,888	3,281,888
1974							1,406,893	1,406,893
1975							5,718,365	5,718,365
1976							3,945,255	3,945,255
1977	44,000				--	44,000	5,812,601	5,856,601
1978	154,620					154,620	4,049,172	4,203,792
1979	552,955					552,955	17,493,110	18,046,065
1980	1,493,489	90,300				1,583,789	14,139,808	15,723,597
1981	2,264,845	141,400				2,406,245	19,679,655	22,085,900
1982	5,134,363	764,200			35,000	5,933,563	17,122,211	23,055,774
1983	3,722,502	469,400		93,000	496,850	4,781,752	11,916,210	16,697,962
1984	2,800,000	1,139,000		200,000	1,200,000	5,339,000	21,037,567	26,276,567
1985	5,030,616	2,594,000		421,000	383,000	8,428,616	19,734,589	28,163,205
1986	4,964,000	853,000		1,240,000	232,000	7,289,000	5,482,529	12,771,529
1987	7,613,160	2,150,000	3,009,391	5,406,153	328,000	18,506,704	13,021,094	31,527,798
1988	6,076,493	227,688	3,866,618	1,057,996	100,000	11,328,795	1,765,936	13,094,731
1989	4,216,577	5,437,597	5,273,676	3,378,761	0	18,306,611	5,846,158	24,152,769
1990	6,804,001	2,505,346	13,497,258	11,019,426	500,000	34,326,031	12,410,753	46,736,784
1991	5,077,391	9,165,668	11,611,307	5,693,196	0	31,547,562	7,693,601	39,240,163
1992	2,655,200	1,706,467	2,079,068	2,121,641	0	8,562,376	2,182,294	10,744,670

Wild pink salmon return data from Alaska Department of Fish and Game annual reports for Prince William Sound. Hatchery pink salmon return data from hatchery annual reports.

AFK-Armin F. Koernig Hatchery; WNH=Wally Noerenberg Hatchery; CCH=Cannery Creek Hatchery; VFDA=Valdez Fisheries Development Association; MBH=Main Bay Hatchery

Hatchery production began increasing significantly after 1980 as the enhancement program came on line. Concurrent with this, wild pink salmon returns reached unprecedented levels, peaking at a record 21 million adults in 1984. Hatchery production peaked in 1990 at 34 million adult pink salmon. Wild stock returns for the 11 year period, 1980 to 1990, averaged 12.7 million adults or 2.4 times the previous 20 year average.

In 1992 production of both wild and hatchery pink salmon fell to 8 and 2 million adults, respectively. The exact cause of this sudden decline in performance is not known, but various investigations are, or have been, in progress gathering biological as well as oceanographic data for wild and hatchery pink salmon in Prince William Sound.

The Prince William Sound Model for Fishery Enhancement Planning

In terms of fish culture, the Prince William Sound pink salmon enhancement program has exceeded the dreams of even the most optimistic of early visionaries. As has been demonstrated, the potential exists to produce many times the pre-hatchery annual return of adult pink salmon. With this success has come a number of challenges. PWSAC in cooperation with ADF&G has developed a fishery planning program recognizing the continued health of the resource and industry is dependent upon many, sometimes opposing, goals.

Integrated Planning

Integrated enhancement planning recognizes that a viable, long term fishery is composed of three interrelated components which must be addressed concurrently. They are: (1) allocation (to all users), (2) production (of wild and hatchery salmon), and (3) resource management. This concept of program planning began in Prince William Sound in 1989.

The key to integrated enhancement planning is the accurate identification of various issues which comprise the above components. Because the PNP concept was developed to allow active public participation in the enhancement program, the public must be actively involved in the identification of issues. Ultimately, public involvement in, and support for, the enhancement program through involvement in the planning process is key to the program's success.

PWSAC Allocation Policy

As a result of the successful application of salmon culture technology, concerns and conflicts arose among the resource users. Public concern manifested itself at the 1989 Alaska Board of Fisheries meeting in Cordova, Alaska. "Numerous proposals submitted by individuals and organizations (to the Board of Fisheries) targeted congestion, gear separation, harvest redistribution and harvest opportunity as symptoms to address or solutions to resolve perceived problems."[3] However, due to the obvious complexity of issues and the unclear allocation implications, the Board of Fisheries took no action on the proposals. In addition, the Board of Fisheries chair charged PWSAC to go to its constituents for solutions.

PWSAC accepted the Board of Fisheries charge by creating the Allocation Task Force and initiating a major public process to identify, discuss, and prioritize enhanced salmon issues. Through this public process the task force members defined nine objectives relative to enhanced salmon in Prince William Sound: (1) reduce congestion in the fishery, (2) minimize impact on wild stocks, (3) promote highest possible fish quality, (4) maximize production, (5) minimize impacts to historical and traditional fisheries, (6) develop and support implementation strategies to achieve policy goal, (7) support subsistence, sport, and personal use needs, (8) encourage and support research, and (9) recognize healthy competition. These nine objectives are inherent in the PWSAC allocation policy statement:

> ...to equitably allocate enhanced salmon resources in Area E between all users through long term planning, production and dedication of financial and human resources.

Allocation of enhanced salmon to commercial fisheries is based upon the long-term historic economic balance that existed since statehood and prior to significant hatchery returns, as determined by ADF&G ex-vessel value records.

PWSAC Production Planning Committee

In June, 1990, the PWSAC board of directors approved the formation of a Production Planning Committee to develop a production plan that "will provide PWSAC management direction needed to produce and release salmon to achieve the corporate allocation goal and fishery objectives which include the development of an economically feasible fishery employing increased production, remote releases, species diversification, and run timing selection."[4] The committee was selected from

PWSAC board members and the public guided by the criteria that members be committed to the process, be willing to attend meetings, and be knowledgeable of the salmon fishery and gear group interests.

The Production Planning Committee created an extensive computer model to evaluate the economic opportunities provided by various production options. Indicative of the concept of integrated planning, the committee was guided by the intent of the allocation policy. The focus was on allocation, economic development, and increased fishing opportunity while considering wild stock management, fish quality, minimal disruption to historic and traditional fisheries, and reduced congestion.

Five objectives were defined by the committee for consideration when planning production options: (1) equitably distribute enhanced salmon as defined by the allocation policy, (2) maximize value to all users, (3) maximize opportunity for all users, (4) the plan is ecologically acceptable, and (5) the plan is achievable.

The Production Planning Committee meets annually to review the past year's production; changing conditions in production; political, marketing, and allocation issues; and to make recommendations for the production plan for the coming year. Recommendations for long term plans are due by January of each year.

Prince William Sound Salmon Management Plan

A complete enhancement plan requires that a fishery management plan be in place to define the framework for future allocation of enhanced salmon. A milestone in Alaskan fishery development occurred when the PWS Regional Planning Team, a state authorized fishery planning group consisting of ADF&G and PWSAC representatives, developed a Prince William Sound Salmon Management and Allocation Plan which was adopted by the Alaska Board of Fisheries in February, 1991.[5] As with the allocation policy, a public process was used to identify, discuss, and prioritize issues. The management plan, which ultimately gained the support of all users, defined a fishery management strategy which recognized the state's responsibility to protect wild salmon, was guided by the PWSAC allocation policy for enhanced salmon, and considered current and future production of wild and enhanced salmon.

Main Bay Hatchery Consensus Document

The Main Bay Hatchery sockeye program is indicative of PWSAC's commitment to integrated planning. Since the original Production Planning Committee document was completed, concern has been expressed within ADF&G that the development plan for Main Bay

Hatchery sockeye salmon production must be based on a knowledge of stock interactions. They urge that more time is needed to evaluate the effects of current Main Bay production in terms of fishery management and possible wild-hatchery stock interaction. In keeping with the spirit of integrated planning, the PWSAC board agreed to reconsider the Main Bay Hatchery development timeline and approved the Draft PWSAC and ADF&G Consensus Points document at their June 1992 board meeting. Seven consensus points are identified: (1) the conceptual production goal for the Main Bay Hatchery is 20 million smolt (4 million adults), (2) a 5-year evaluation program will occur at 6.5 million smolt production level, (3) future production will be determined after the 5-year evaluation program, (4) PWSAC and ADF&G will investigate options to reduce wild stock exploitation, (5) additional management staff will be needed to handle the added work load resulting from expansion, (6) periodic genetic monitoring of wild sockeye salmon populations will be required, and (7) PWSAC and ADF&G will meet annually to review data from the evaluation program.[6]

This document emphasizes the need for fishery evaluation at present sockeye production levels to address the management and biological concerns prior to proceeding with further production. The timeline for Main Bay Hatchery development has been necessarily lengthened by the need for more data to make wise production decisions for the future.

Summary

The Prince William Sound private non-profit pink salmon enhancement program began in the mid 1970s to reverse the trend of declining local fish runs. The concept of private non-profit enhancement was developed to allow active public involvement in the rehabilitation of the fishery resource. This concept was supported by the state of Alaska through the passage of the Private Non-Profit Hatchery Act of 1974. Currently, the enhancement program in Prince William Sound has the potential to produce approximately 27.2 million pink salmon annually.

In terms of fish culture, the Prince William Sound enhancement program exceeded all expectations. However, it became apparent as the program demonstrated its full potential in the late 1980s, that continued success would depend upon much more than quality fish culture. PWSAC, in cooperation with ADF&G, has developed the Integrated Enhancement Planning process. This process recognizes the continued health of the resource and industry is dependent upon the identification, through public involvement, of many sometimes opposing goals.

Integrated enhancement planning addresses allocation (to all users), production (of hatchery and wild salmon) and resource management. These three interrelated components must be considered in the context of various opposing goals such as maximizing production, while minimizing impact on wild salmon and assuring all users are allocated their share of the resource.

Endnotes

[1]Salmon Culture Program. Prince William Sound Aquaculture Corporation. 1975.

[2]Alaska Statutes and Regulations for Private Nonprofit Salmon Hatcheries. Alaska Department of Fish and Game. 1986.

[3]Enchanced Salmon Allocation Task Force Report Number Six. Prince William Sound Aquaculture Corporation. 1990.

[4] Production and Planning Committee Recommendations to the Board. Prince William Sound Aquaculture Corporation. 1991.

[5] Prince William Sound Management and Salmon Enhancement and Allocation Plan. Prince William Sound Aquaculture Corporation. 1991.

[6] PWSAC and ADF&G Consensus Points for the Main Bay Hatchery Program—Draft. Prince William Sound Aquaculture Corporation. 1992.

Non-daily Otolith Increments and Seasonal Changes in Growth of a Pink Salmon (*Oncorhynchus gorbuscha*) Population in Auke Bay, Alaska

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Wild juvenile pink salmon (*Oncorhynchus gorbuscha*) outmigrating from Auke Creek, Alaska, were injected with coded-wire micro-tags and released into Auke Bay to identify their date of marine entry and validate the use of post-release otolith increments as a means to independently determine nearshore residence time. Examination of pre- and post-release fish showed a distinctive transition check corresponding to the time of marine entry, with well defined otolith increments recorded after this transition. Otoliths from fish captured in the bay throughout the outmigration season were analyzed to examine seasonal changes in growth during the outmigration period and to test the hypothesis that otolith increments were recorded with a daily periodicity.

Fish released during the early part of the outmigration season grew more slowly than later outmigrants and this difference was clearly reflected in the growth of the otolith marine zone. Regressions of otolith increments and days were different between early outmigrating, slower growing fish, and faster growing, later outmigrants. Otolith increments were recorded with a near daily periodicity in the slower growing fish, however, faster growing fish clearly recorded significantly more otolith increments than days during their period of marine residency. For all three years combined, increment periodicity was highly correlated with the growth rate of the otolith during the period of early marine residency. Where increment periodicity was less than one per day, SEM analyses showed that this was not necessarily due to counting errors associated with resolution problems. Where more than one increment was produced per day, there was no indication that sub-daily increments could be consistently distinguished from daily increments. This study suggests

that otolith increment periodicity is variable over the outmigration season for Auke Bay pink salmon, that it is not always easy to determine the difference between "daily" and "sub-daily" increments, and that in this situation, increment periodicity was most closely correlated with growth rate of the otolith. As a result, otolith increment number did not represent a reliable indicator of time for determining early marine residency of pink salmon in Auke Bay, Alaska.

Outbreeding Depression in Hybrids of Odd and Even Year Pink Salmon

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Introduction

This report is abstracted from papers that were published previously or are in press (Gharrett and Smoker 1991; Lane et al. 1990; Gharrett and Smoker in press [A and B]; Smoker, Gharrett, and Stekoll in press; Gharrett et al. in press). Some of this was also presented at the 1992 Coho and Chinook Workshop in Boise.

Genetic effects of hatchery stocks on wild stocks may not be as easily discerned as an epizootic pathogen or as over fishing but may be as damaging in the long term. Genetic effects will accumulate over several generations as the genetic composition of the wild stock is modified indirectly or directly from hatchery and management practices. Indirect effects may result from altered natural selection regimes, such as increased competition for finite resources between cultured and wild fish. Artificial selection may follow inappropriate harvest strategies that incidentally exploit a particular temporal segment of the natural population.

Direct genetic effects could result from introgression of hatchery-stock genes into the wild population if the two were genetically different. If the rate of introgression were large, the wild population would be "swamped" with alleles derived from hatchery fish. A continuous trickle of genes from the hatchery stock might also alter the genetic composition of the wild population, decrease the fitness of the population if they are maladaptive, or both.

Another potential effect of the introgression of cultured fish into adapted, wild populations is outbreeding depression, the disruption of adaptive gene complexes. The potential for this result is discussed here.

Genetic Infrastructure in Auke Creek Pink Salmon

We have observed temporal and spatial substructure of pink salmon populations in Auke Creek that appears to be both the cause and consequence of genetic infrastructure. Timing of the return is bimodal, one peak spawns in August and the other in September. Overlap occurs only in years of abnormally low stream flows during late August. Within each temporal component, the majority of fish spawned above tidal influence but a small component spawned intertidally. Progeny return to the same section of the stream and at the same time of the spawning season as their parents.

The genetic basis to the temporal and spatial substructure of the population has been confirmed with genetic marking (Gharrett et al. in press) and by breeding studies performed to estimate the heritable component in return timing (Smoker et al. in press). Genetic determinants of return and spawning time probably exist in most salmon populations and have been exploited in salmon husbandry.

The importance of timing to adaptedness also has been demonstrated by observation over several generations that embryos from late-spawning parents survive incubation in Auke Creek substantially better than do embryos from early-spawning parents (Gharrett, in prep). Marine survival during those years has favored the early-spawning fish.

Outbreeding Depression in Auke Creek Pink Salmon

The genetic structure we observed results from the environmental experience of the population. The life history characteristics of a population are central to its success. Such traits are quite complex and result from the expression of numerous loci. As a result of natural selection, only the most successful combinations of alleles survive in a population over time, only one or a few of the many possible combinations for the species. The variability that persists around these successful combinations ensures that the population will be able to meet the demands of an environment that is predictable only within a range. Hybridization of populations that have found different genetic solutions to the environmental challenges may disrupt the successful combinations and decrease the fitness (productivity) of the population. This is outbreeding depression. We tested the possibility that outbreeding depression could occur in salmon populations by hybridizing even- and odd-year pink salmon in Auke Creek. Because pink salmon have a rigid 2-year anadromous life cycle, there are two genetically isolated lines: one line spawns in even years and the other in odd years. Both lines spawn in Auke Creek and presumably experience very similar average environments.

We hybridized even- and odd-year pink salmon from Auke Creek and examined two generations of returns. If different coadapted genomes evolved in each of these two genetically isolated lines, one might expect to observe outbreeding depression in hybrids between these lines. We observed decreased survival in the F_2 generation and increased fluctuating bilateral asymmetry; which may reflect destabilization of developmental canalization, symptoms of outbreeding depression.

Implications for Other Salmon Populations and Species

The genetic infrastructure in a population results from directed processes such as selection (both natural selection and artificial selection related to fishing mortality), straying (gene flow), and mate selection and from random processes (sampling error in finite populations) acting on the available genetic material. We would expect, therefore, that in salmon populations, adaptive gene complexes evolve in a population in response to local selection pressures and random chance; each population or distinct segment of a population should be genetically distinct. Although allozyme studies often suggest that the genetic compositions of salmon in different streams within a locality are similar, this does not necessarily mean that intrapopulation structure is not significant, that there are no coadapted gene complexes in a population segment. A reasonable interpretation of these allozyme similarities is that gene flow among the streams slows divergence of these neutral biochemical genetic traits, but that gene flow need not prevent the evolution of unique coadapted genomes when a trait is acted on by natural selection.

Even within a coadapted genome, i.e. within a population segment, variation is important. Such variation is critical for the long term success of the Auke Creek populations. For example, the significant additive genetic variation for timing that we observed and the relationship between timing and survival in different years illustrate the importance of genetic variability to the population. If individuals in a population return to spawn over a span of time, it is likely that at least some of the population will return to the stream when temperature and stream flow conditions are conducive to spawning and survival of developing embryos. This logic can be extended to other important portions of the life history.

Concerns for Wild Populations

The primary concern raised by the likelihood of introgression of cultured salmon into wild populations is that resultant genetic changes will alter the genetic structure and infrastructure of the wild population, reduce interpopulational variation, or both. As a result, it is probable that the average fitness (productivity) of the population will be reduced and in the extreme may compromise the species as a whole.

To determine the direct genetic impact of introgression by cultured salmon into wild populations, resource managers first need to have a good understanding of the structure and dynamics of the genetics of wild populations, of the interactions among them, and of the relationship between the genetic diversity present and the environmental fluctuations which the populations experience. Such information is generally not available for salmon. Although allozyme data are widely available, these data are generally inadequate for characterizing intrapopulational structure. Information about population infrastructure is not beyond reach, however, as has been demonstrated at Auke Creek.

Information about interactions among wild populations is also poor; we need to know how much straying occurs and how it relates to environmental variability and the dynamics of the populations. Much of the available data are from observations of marked or tagged fish. Unfortunately, using such markers to estimate gene flow is problematic. Although spawned-out, tagged fish on the spawning grounds is presumptive evidence of spawning by tagged salmon, it is neither evidence of successful contribution of genetic material nor reliable evidence of homing or straying.

With insight into the genetics of wild populations, resource managers could begin to assess the potential direct genetic impacts from interactions with cultured stocks. The most important questions for cultured stocks involve the extent and dynamics of their straying. Researchers need to quantify straying for a variety of situations involving broodstock origins (e.g. local or transplanted), remote releases, and various hatchery practices that might increase straying.

Acknowledgment

This work is a result of research sponsored by the Alaska Sea Grant College Program, cooperatively sponsored by NOAA, Office of Sea Grant and Extramural Programs, Department of Commerce, under grant number NA90AA-D-SG066 (project number R/02-17), and the University of Alaska with funds appropriated by the state.

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Homing and Straying Patterns of Coded Wire Tagged Pink Salmon in Prince William Sound

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Homing and straying patterns of coded-wire tagged pink salmon (*Oncorhynchus gorbuscha*) originating from four hatcheries and six streams in Prince William Sound (PWS) were assessed for the 1991 return year. PWS hatcheries released 615 million pink salmon fry in 1990. Of these, 1,032,000 fry were tagged with coded-wire tags using 32 unique tag codes. Outmigrations from six study streams yielded 2,120,000 wild stock pink salmon fry of which 258,000 were tagged. Coded tags identified a fish's release location, its release or outmigration date and, for hatchery-bred salmon, the rearing strategy employed prior to release. Initially, tagged juvenile salmon were recovered during their early marine life and were used to compare growth and survival for salmon from oiled and unoiled areas of PWS. Tagged adults returning in 1991 were recovered in commercial fisheries allowing managers to assess the contribution of an individual hatchery's or stream's production to the overall commercial catch and to compare the ocean survival of salmon stocks of known oil exposure history.

During the enumeration of the wild pink salmon escapements to 46 streams in PWS (Figure 1), over 814,000 spawned out pink salmon carcasses were examined for a missing adipose fin denoting the presence of a coded-wire tag. In addition, over 90% of the 1991 broodstock collections at all four hatcheries were similarly inspected for the presence of coded-wire tagged fish. One hundred and eleven tagged pink salmon of hatchery origin were recovered in 25 of the 46 streams examined and 152 stray wild fish were recovered in 26 of the 46 streams. Straying pink salmon from Wally H. Noerenberg Hatchery (WHN) on Esther Island comprised 56% (62 tagged fish) of the total number of hatchery strays recovered and were found in 18 of 46 streams examined. Eighteen of these tagged fish from WHN were recovered from a single stream. Pink salmon from Armin F. Koernig Hatchery (AFK) in southwest PWS comprised 27% (30 tagged fish) of the total numbers of hatchery strays and were recovered in 15 streams. One AFK tagged pink salmon was

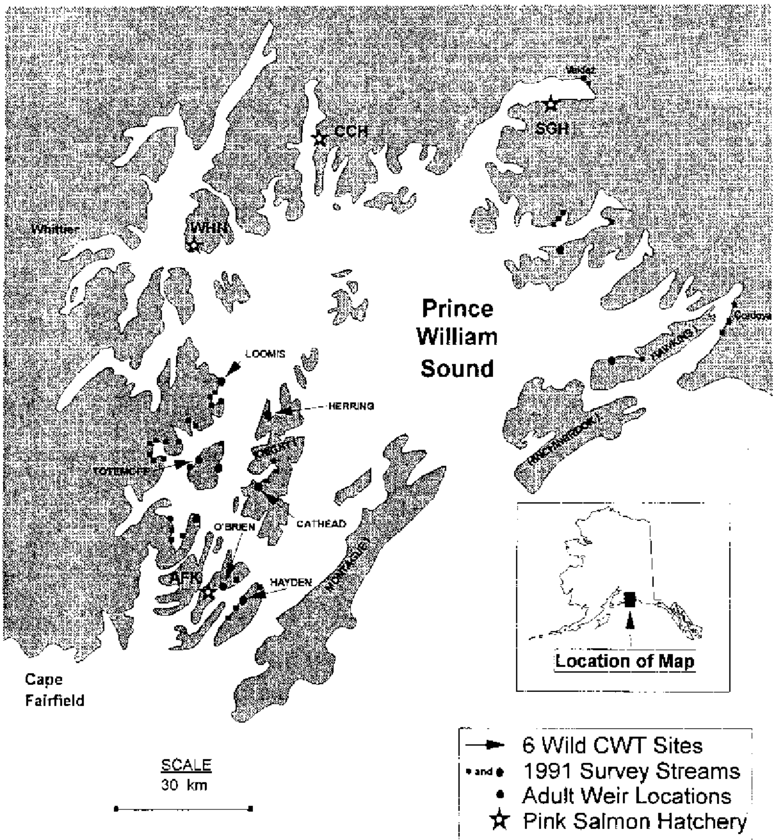

Figure 1. Prince William Sound, Alaska, showing locations of wild stock tagging sites, pink salmon hatcheries, and 1991 stream surveys.

recovered at Irish Creek located in eastern PWS approximately 135 km from AFK hatchery. Pink salmon from Solomon Gulch Hatchery (SGH) in Valdez comprised 7% (8 tagged fish) of the stray hatchery tagged salmon and were recovered in four streams. Pink salmon from Cannery Creek Hatchery (CCH) comprised 10% (11 tagged fish) of the total number of hatchery strays and were recovered in nine streams. It should be noted that a majority of the tag recovery effort was directed toward streams in the western, oil impacted areas of PWS close to where wild stock tags were applied in 1990. Therefore, streams nearer to both

Cannery Creek and Solomon Gulch Hatcheries did not receive tag recovery efforts comparable to streams in oil impacted areas.

In examining broodstock collections for evidence of straying, 12 tagged pink salmon out of a total of 1,241 broodstock recoveries were found to be from a hatchery other than their natal location and three were found to be from tagged wild stocks. No AFK tagged pink salmon were recovered at other hatcheries although one WHN tagged fish and one tagged wild fish were recovered at AFK. Three CCH, six SGH, and one tagged wild fish were recovered in the broodstock collection at WHN. Conversely, two WHN tagged fish were recovered in the CCH broodstock. At SGH, one tagged wild fish, whose natal stream was over 120 km away, was recovered in the SGH broodstock.

A total of 619 tagged pink salmon originating from the six wild stock tagging sites were recovered from streams. Three of the wild stock tagging sites (Loomis Creek, Herring Creek, and Hayden Creek) are located in oiled locations and three (Totemoff Creek, Cathead Creek, and O'Brien Creek) are in unoiled locations, all in western PWS. For fish tagged at Loomis Creek, 150 of 164 fish (91%) were recovered in their natal stream. The remaining 14 fish were recovered at nine different streams located from one to 60 km away from Loomis Creek. Of those fish tagged at Hayden Creek on LaTouche Island, 86 of 95 (91%) were recovered at their natal stream. The remaining nine fish were recovered in six different streams located between two and 30 km from Hayden Creek. At Herring Creek on Knight Island (the most heavily oiled wild stock tagging site), 55 of 117 tagged fish (47%) were recovered on site. The remaining 62 tags were recovered at 14 different streams from six to 38 km away. Fourteen tagged fish from Herring Bay Creek were recovered at Loomis Creek and an additional 21 tagged fish from Herring Creek were recovered in a single stream in Eshamy Bay approximately 15 km away.

At Totemoff Creek on Chenega Island, 110 of 141 tagged fish (78%) were recovered on site. The remaining 31 fish were recovered at 13 different creeks. Two tagged fish from Totemoff Creek were recovered at streams in eastern PWS some 100 km from Totemoff Creek. Eleven tagged fish from Totemoff Creek were recovered at a single creek less than two km from Totemoff Creek. At O'Brien Creek, 29 of 32 tagged fish (91%) were recovered on site while the remaining three fish were recovered at three different streams located between four and 38 km away. At Cathead Creek, 37 of 70 tagged fish (53%) were recovered on site and the remaining 33 fish were recovered at 13 different creeks located from three to 30 km away.

In 1990, hatchery bred pink salmon in PWS were tagged at a ratio of approximately 1:545 while the six wild stocks were tagged at ratios ranging from approximately 1:3 to 1:15. By expanding the number of tagged fish recovered in a stream to be representative of their untagged cohorts, it appears hatchery fish contributed approximately 47% of the total escapement to Loomis Creek; 15.5% to the Herring Creek escapement; 23% of the Hayden Creek escapement; 26% of the O'Brien Creek escapement; 11.4% of the Totemoff Creek escapement; and 6% of the Cathead Creek escapement. Hatchery contributions at all 46 streams surveyed daily ranged from 0% to 47% (Figure 2).

In examining the escapements to the six wild tagging streams, Loomis Creek had the greatest number of fish straying into the creek (20 hatchery tagged fish and 16 wild tagged fish). At the same time those fish tagged at Loomis Creek strayed the least of the tagged wild stocks. Conversely, fish tagged at Cathead Creek showed a strong tendency to stray while the creek itself received the fewest number of stray hatchery (2) and wild (0) tagged fish. Expanded coded-wire tag recoveries at these six streams suggest that natal returns were third in the amount of fish comprising the escapement, behind hatchery strays and wild strays (Figure 3).

Our understanding of the magnitude of the straying phenomena in PWS is limited both geographically, by those streams extensively examined in 1991 and, quantitatively because of the use of expanded coded-wire tag to estimate straying by untagged fish. However, some

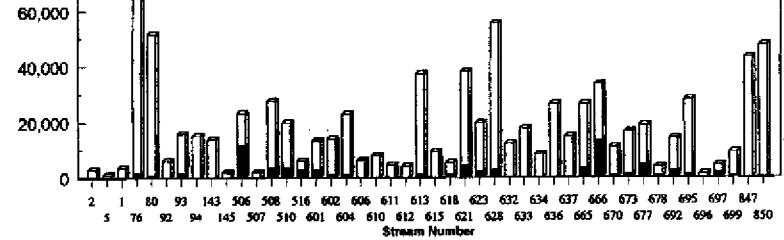

Figure 2. Hatchery pink salmon contributions to the 1991 escapements of 46 streams based upon expanded coded-wire tag recovery data.

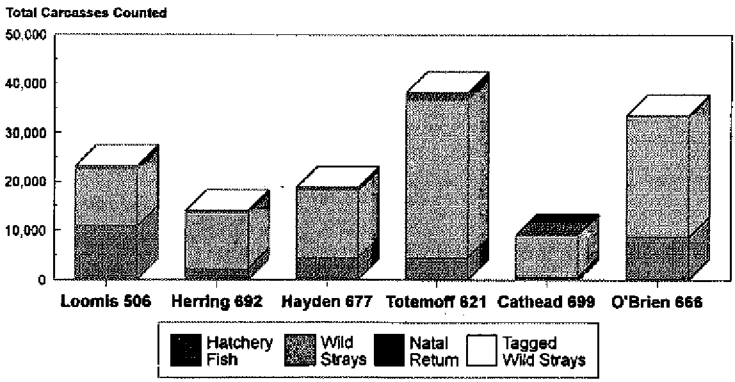

Figure 3. Adult pink salmon returns in 1991 to six wild stock tagging streams based upon expanded coded-wire tag recovery taga.

interesting patterns in straying behavior are evident. Pink salmon from WHN and AFK hatcheries showed a tendency to stray into streams near the hatcheries and along traditional migration corridors. Particular streams also tended to attract multiple strays, both of wild and hatchery origin, while other nearby streams did not. Many of the streams where no hatchery tags were recovered tended to be in bays and coves not connected to Knight Island Passage or LaTouche Passage. Also of interest is the fact that of the six stream recoveries of tagged-fish from SGH, four were associated with a remote release project that released fish near the village of Tatitlek in Port Fidalgo.

The numerous wild stocks in Alaska contain the genetic resources necessary for continued production of salmon under shifting environmental conditions. Wild pink salmon in Prince William Sound are unique in that they are predominantly (75%) intertidal spawners, a characteristic which enhances their chances for continued reproductive success especially during harsh winters. The predominance of intertidal spawning and other adaptations of wild pink salmon populations in PWS may be lost over time because of the significant amount of straying by hatchery stocks. The Genetic Policy of Alaska acknowledges that genetic diversity buffers biological systems against disaster, either natural or human-induced. Maintaining genetic diversity both within and between local populations is essential for the long-term sustained production of Alaska salmon. A danger exists in areas with enhanced populations like PWS where rapid expansion of hatchery production coupled with increased exploitation rates on these enhanced fish can result in the eventual collapse of the wild stocks. Straying by hatchery salmon combined with increased exploitation rates on wild stocks and any deleterious effects of the oil spill may be putting significant numbers of wild pink salmon populations at risk. The long term productivity of Prince William Sound's wild pink salmon stocks will depend upon the conservation of the genetic diversity among and within the wild stocks.

New Conceptual Models of High-seas Migrations of Pink and Chum Salmon

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Stock-specific conceptual models of ocean migrations of pink and chum salmon in the literature are based largely on data from high-seas tagging operations conducted before 1972. Over the past 20 years, there have been major changes in the production of Pacific Rim salmon stocks, but there is little or no information on concomitant changes in high-seas distributions and migrations of Pacific salmon. In this paper, recovery data from high-seas tagging operations in 1972-1992 are used to update high-seas migration models (based on 1954-1971 data) for regional stocks of maturing pink and chum salmon migrating in the northeastern North Pacific Ocean. The updated models show some significant extensions, particularly to the south, in the known ocean ranges of regional stocks of maturing Asian and North American pink and chum salmon. Because these range extensions generally correspond to areas where tagging effort was increased in 1972-1992, the high-seas tag recovery data cannot be used to show recent changes in ocean distribution and migration patterns of pink and chum salmon.

Introduction

The most frequently cited conceptual models of high-seas migrations of pink and chum salmon are those of Takagi et al. (1981) and Fredin et al. (1977, based on data from Neave et al. 1976). These stock-specific models are based largely on coastal and freshwater recovery data from tagged fish released in the North Pacific Ocean before 1972 during International North Pacific Fisheries Commission (INPFC)-related research. Abundance data for the combined runs of Asian and North American fish indicate that populations of Pacific Rim pink and chum salmon have essentially doubled over the past 20 years (Figure 1). The increase in abundance of northeastern Pacific stocks of salmon since 1978 has been attributed to such factors as good management (i.e., near-optimum escapements), the reduction in high-seas fishing, more favorable ocean temperatures, and reduced predation in the ocean during winter months (Rogers 1984). Regardless of the mechanisms underlying the increase in abundance of pink and chum salmon, an interesting

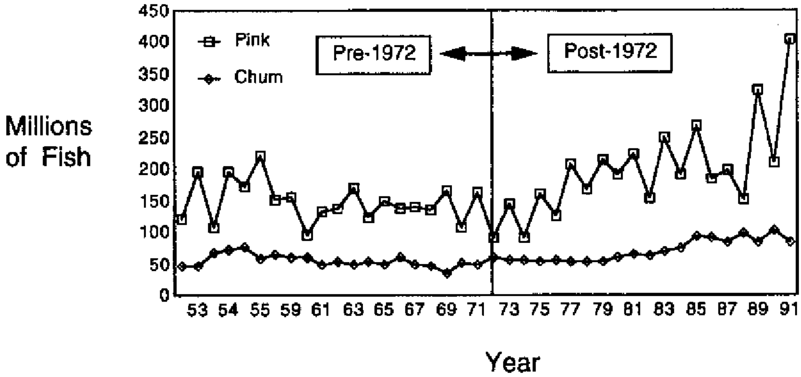

Figure 1. Abundance of combined runs of Asian and North American pink and chum salmon, 1952-1991, catch + escapement in millions of fish (D.E. Rogers, Fisheries Research Institute, University of Washington, Seattle, pers. comm.).

question is whether or not there have been accompanying changes in high-seas distribution and migration patterns of Asian and North American stocks.

In this paper, recovery data from 1972 to 1992 releases of salmon tagged on the high-seas are used to update the Takagi et al. (1981) and Fredin et al. (1977) models, and the results are considered with respect to whether they indicate recent changes in ocean distribution and migration patterns of pink and chum salmon.

Methods

High-Seas Salmon Tagging

From 1954 through 1991, Canada (1960-1967 and 1987-1990), Japan (1954-present), and the United States (1954-1978, 1980, and 1982) participated in cooperative salmon tagging in the Bering Sea and North Pacific Ocean as part of the coordinated research program of INPFC. In the early years of the INPFC program, Canada and the United States did a considerable amount of salmon tagging, primarily in the central Aleutians area and in the Gulf of Alaska, but after the 1960s the Canadian and U.S. programs were greatly reduced (Burgner 1992; Margolis 1992). Since 1978, the major objective of the INPFC research program was to identify stocks migrating in the area of the Japanese high-seas driftnet fisheries (particularly in the areas southwest of 46 degrees N, 175 degrees W). Most of the salmon tagging in this area was done by Japan (Myers et al. 1993).

In addition to the INPFC-related tagging, the USSR's Pacific Research Institute of Fisheries and Oceanography (TINRO) and the Fisheries Research Institute (FRI), School of Fisheries, University of Washington, under contract from the U.S. National Marine Fisheries Service, Auke Bay Laboratory, conducted cooperative high-seas salmon tagging operations from 1983 through 1991. Most of the tagging operations during cooperative USSR-U.S. research were done in the central North Pacific Ocean and Bering Sea.

The methods used for salmon tagging by the four countries were similar. Salmon were caught during research vessel operations at sea, primarily with floating longline or purse seine gear. Scales and other biological data were collected, and live fish were tagged and released. The tag most frequently used was a ¾ in red (or orange) and white plastic disk that was attached to the fish near the dorsal fin. Each disk was labeled with a unique number and the name of the release agency. Release locations, dates, tag numbers, species, and other pertinent information were recorded and reported in summary form to INPFC.

Because of the large recovery area and the relatively small number of tagged fish released annually, the high-seas tagging program relied largely on voluntary return of tags by fishermen, processors, and others finding tagged fish in coastal or freshwater areas. Recoveries from high-seas tagging experiments were reported by Canada, Japan, and the United States in the form of INPFC documents. Aro et al. (1971) of Canada created an INPFC tag recovery computer database by coding all recoveries reported by all nations during 1956-1969, and K.V. Aro updated the database every two or three years through 1979. Personnel at FRI have maintained and updated the high-seas tag recovery database since 1980.

Data Analysis

For the analyses presented in this paper, I used the all-agency high-seas tag release and recovery computer databases archived at FRI. The data were divided into two periods, 1954-1971 and 1972-1992, based on the year of release of tagged fish. These periods were selected because the earlier period (1954-1971) included most of the tag recovery data that were used in previous conceptual models of ocean migrations of pink and chum salmon (Neave et al. 1976; Fredin et al. 1977; Takagi et al. 1981). The number of tagged fish released during the two periods was summarized by species and release agency (i.e., country).

The tag recovery data were grouped into geographical region of recovery (referred to in this paper as "regional stocks") using the same regions that were used in the Takagi et al. (1981) and Fredin et al. (1977)

conceptual models. The number of recoveries of fish tagged in their last summer at sea was summarized by period (1954-1971 and 1972-1992), regional stock, and species.

Takagi et al. (1981) defined six regional stocks of pink salmon based on the similarity in their patterns of high-seas migration. In this paper, updated models are presented only for those four regional stocks of pink salmon that are known from tagging data to migrate in the north-eastern Pacific Ocean: (1) Washington-British Columbian stocks, (2) southeastern, central, and southwestern Alaskan stocks, (3) western Alaskan stocks, and (4) eastern Kamchatkan-Anadyr Bay stocks.

Fredin et al. (1977) combined the North American stocks into two groups based on similarity in high seas distributions: (1) western Alaskan stocks, and (2) all other North American stocks. Asian chum salmon were divided into three groups: (1) western Bering Sea stocks, (2) northern Okhotsk Sea stocks, and (3) Japan, Kurile Island, and south Sakhalin stocks. Chum salmon from all of these regional stock-groups are known from tagging data to migrate in the northeastern Pacific Ocean. In this paper, the tag recovery data for chum salmon from the three Asian regions were combined into one group (Asia). Updated models are presented only for North American and Japanese chum salmon that were tagged during their last summer at sea (i.e., maturing fish).

The ocean release locations of tagged fish later recovered in coastal and freshwater areas in the pre- and post-1972 periods were plotted using a computer mapping package, and new information on ocean migration patterns was added to computer illustrations of the Takagi et al. (1981) and Fredin et al. (1977) models.

As a measure of whether the tag recovery data can be used to show changes in ocean migration patterns between the pre- and post-1972 periods, the spatial distribution of tagging effort was examined for pink salmon. The difference in the number of tagged fish released during the two periods was calculated for 2 degrees latitude by 5 degrees longitude areas. Areas where tagging effort increased during the 1972-1992 period were compared graphically to areas where significant changes in ocean ranges were observed.

Results and Discussion

Approximately 150,000 tagged pink salmon were released by the four countries from 1954 to 1992 (Figure 2). Overall releases of tagged pink salmon decreased substantially, by almost 70%, in the recent (1972-1992 period). A similar number of tagged chum salmon (approximately 150,000) were released since 1954. Total releases of tagged chum salmon

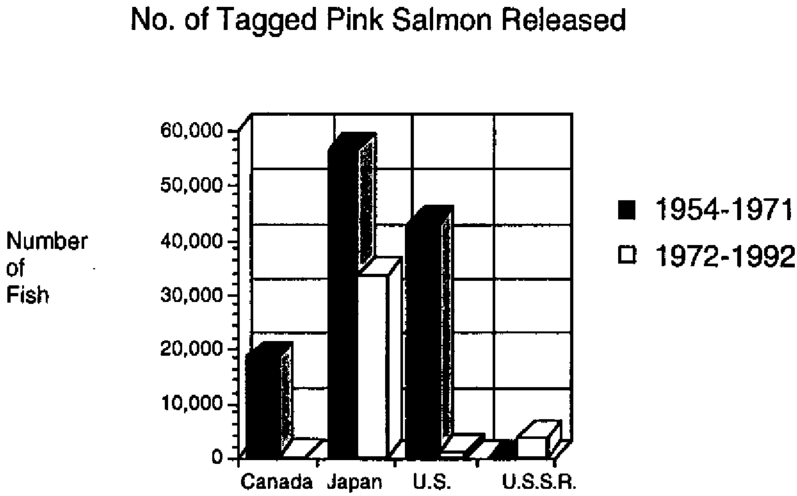

Figure 2. Number of tagged pink salmon released by Canada, Japan, the U.S., and the U.S.S.R. during high-seas tagging operations in the North Pacific Ocean and Bering Sea, 1954-1971 and 1972-1992.

decreased by about 50% in the recent (1972-1992) period, although Japan's chum salmon tagging effort actually increased in the recent period (Figure 3).

All of the coastal and freshwater recoveries of tagged pink salmon during the recent period (1972-1992) were from fish tagged during their last spring and summer at sea (maturing fish). There were no recoveries from the Washington-British Columbian region; 13 from the southwestern, central, and southeastern Alaskan region; 15 from the western Alaskan region; and 67 from the eastern Kamchatkan-Anadyr region (Figure 4).

Recoveries of chum salmon that were tagged in 1972-1992 during their last spring and summer at sea (maturing fish) were more numerous than those of pink salmon, but there were few recoveries from North America (Figure 5). Most of the 390 recoveries in Asia were from the Japan region (368 fish). Coastal and freshwater recoveries of chum salmon that were tagged at sea as immature fish in 1972-1992 were less numerous (2 in North America and 62 in Asia).

All of the models of Takagi et al. (1981) have the same features: the arrows indicate the direction of migrations at various life history stages and the shaded area represents the known range of ocean distribution. There is no new tag recovery information in the high-seas database to update the model for British Columbian-Washington pink salmon

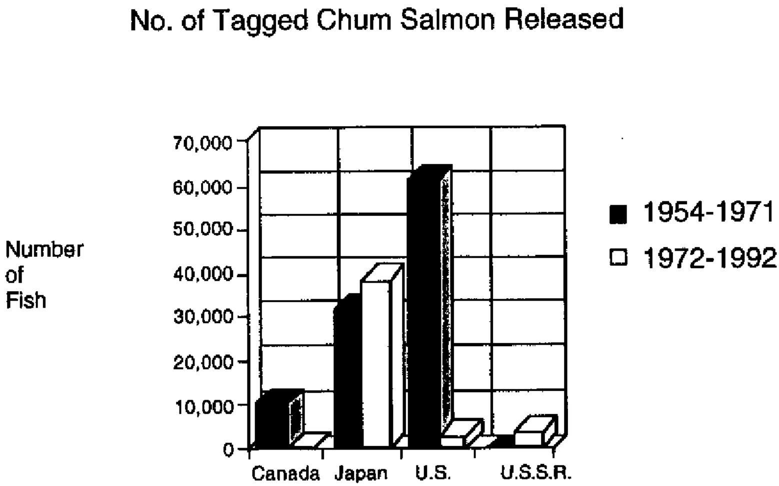

Figure 3. Number of tagged chum salmon released by Canada, Japan, the U.S., and the U.S.S.R. during high-seas tagging operations in the North Pacific Ocean and Bering Sea, 1954-1971 and 1972-1992

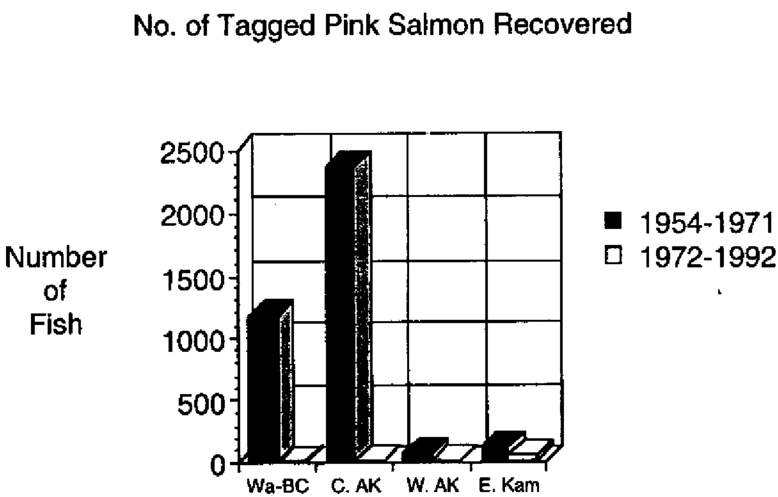

Figure 4. Number of recoveries of pink salmon tagged in 1954-1971 and 1972-1992 and recovered in coastal or freshwater areas of four geographic regions: (1) Washington and British Columbia (Wa-BC), (2) southwestern, central, and southeastern Alaska (C. AK), (3) western Alaska (W. AK), and (4) eastern Kamchatka to Anadyr Bay, Russia (E. Kam). All recoveries in the 1972-1992 period were from fish tagged during their last spring and summer at sea (maturing fish).

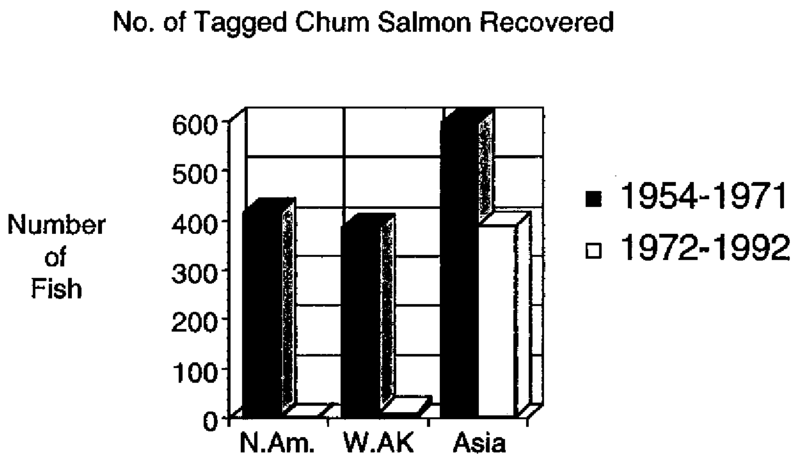

Figure 5. Number of recoveries of chum salmon tagged in 1954-1971 and 1972-1992 during their last spring and summer at sea (maturing fish) and recovered in coastal or freshwater areas of three geographic regions: (1) all areas of North America south of western Alaska (N. Am.), (2) western Alaska (W. AK), and (3) all areas of Asia (Asia).

(Figure 6). In Figures 7-9, the dashed lines indicate the extensions in the known ocean ranges based on new information from the recoveries of tagged fish released in 1972-1992. For pink salmon recovered in the southwestern, central, and southeastern Alaskan region, there is a significant extension in range to the south in the western Gulf of Alaska (Figure 7). For pink salmon recovered in the western Alaska region, there is a significant extension in range to the south in the central North Pacific, and a westward extension in range in the central Bering Sea (Figure 8). For pink salmon recovered in the east Kamchatkan-Anadyr region, there is a significant extension in range to the south in the western North Pacific and eastward across the North Pacific to about 170 degrees W (Figure 9).

In the Fredin et al. (1977) models for chum salmon, the arrows indicate the extent and apparent direction of migration (Figures 10 and 11). For western Alaskan chum salmon there is only one significant new recovery in the recent period (indicated by the plus sign in Figure 10). This recovery extends the known range of western Alaskan chum salmon to the south of 46 degrees N latitude in the central North Pacific Ocean. There is no new data from the 1972-1992 period for chum salmon from other North American stocks. In Figure 10, the asterisks along the

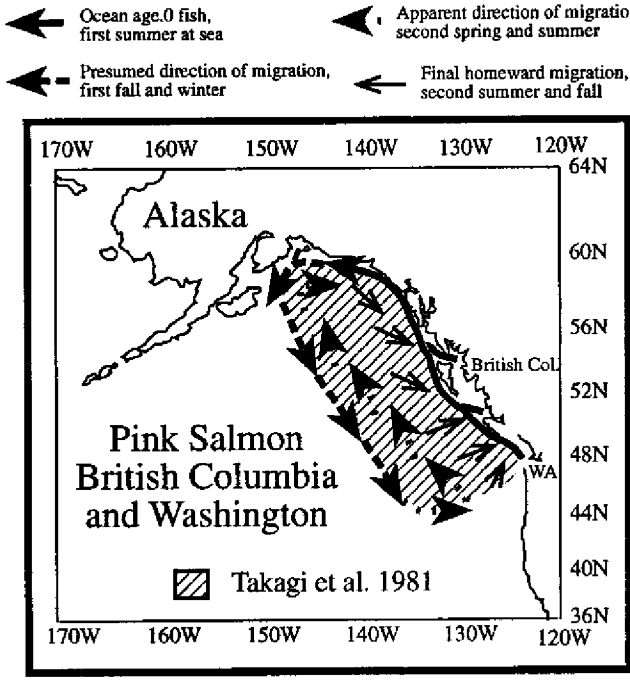

Figure 6. Conceptual model of ocean distribution and migrations of pink salmon originating in British Columbia and Washington (adapted from Fig. 90, Takagi et al. 1981). The arrows indicate the direction of migrations at various life history stages. The shaded area represents the presumed area within which southeasterly migrations occurred during the first fall and winter, and the area occupied during northwesterly migrations during the second spring and summer.

central Aleutians represent some recoveries of pink salmon in the south Alaska Peninsula area from pre-1972 releases that were not included in the Fredin et al. (1977) model. For chum salmon recovered in Japan, there are significant extensions to the south in the western North Pacific and eastward to about 160 degrees W, and also in the central Gulf of Alaska (Figure 11). There are also extensions to the east in the Bering Sea near Unimak Pass and along the south side of the Alaska Peninsula.

The updated migration models show significant extensions in the known ocean ranges of maturing Asian and North American pink and chum salmon, particularly to the south, during their last spring and summer at sea (Figures 6-11). A graphical analysis of the tag release and recovery data for pink salmon shows that these extensions in ocean ranges generally correspond to areas of increased tagging in the 1972-

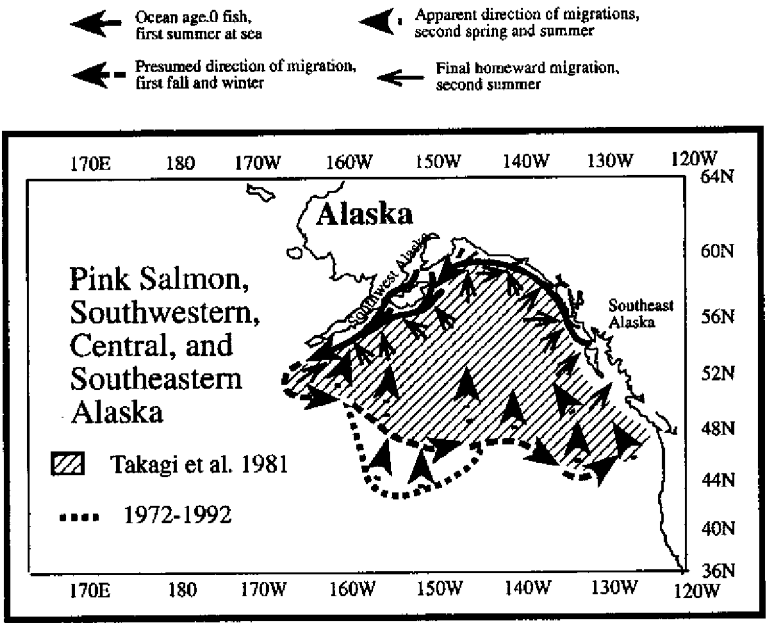

Figure 7. Conceptual model of ocean distribution and migrations of pink salmon originating in southwestern, central, and southeastern Alaska (adapted and updated from Fig. 91, Takagi et al. 1981). The arrows indicate the direction of migrations at various life history stages. The shaded area represents the presumed area within which southeasterly migrations occurred during the first fall and winter and the area occupied during northwesterly migrations during the second spring and summer (Takagi et al. 1981). The dashed line indicates the extension in the known ocean range during the second spring and summer at sea based on recoveries of tagged fish released in 1972-1992.

1992 period (Figure 12). Because of differences in the spatial distribution of high-seas tagging effort between the 1954-1971 and 1972-1992 periods, the high-seas tag recovery data cannot be used to determine if there have been recent changes in ocean distribution and migration patterns of regional stocks of pink and chum salmon migrating in the northeastern Pacific Ocean.

Acknowledgments

Funding for this work was provided by the Auke Bay Laboratory, Alaska Fisheries Science Center, U.S. National Marine Fisheries Service (NOAA Contr. No. 50ABNF100027).

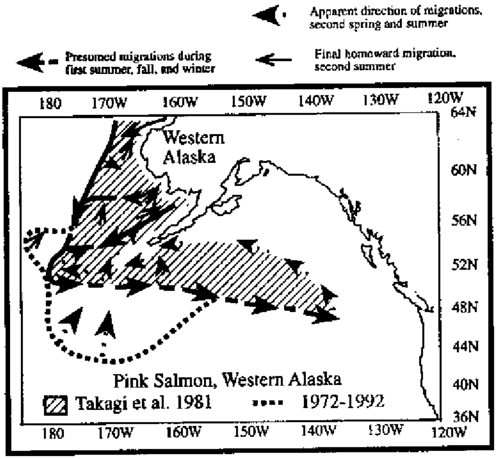

Figure 8. Conceptual model of ocean distribution and migrations of pink salmon originating in western Alaska (adapted and updated from Fig. 92, Takagi et al. 1981). The arrows indicate the direction of migrations at various life history stages. The shaded area represents the presumed area within which seaward migrations occurred during the first fall and winter and the area occupied during migrations toward areas of origin in the second spring and summer (Takagi et al. 1981). The dashed lines indicate extensions in the known ocean range during the second spring and summer at sea based on recoveries of tagged fish released in 1972-1992.

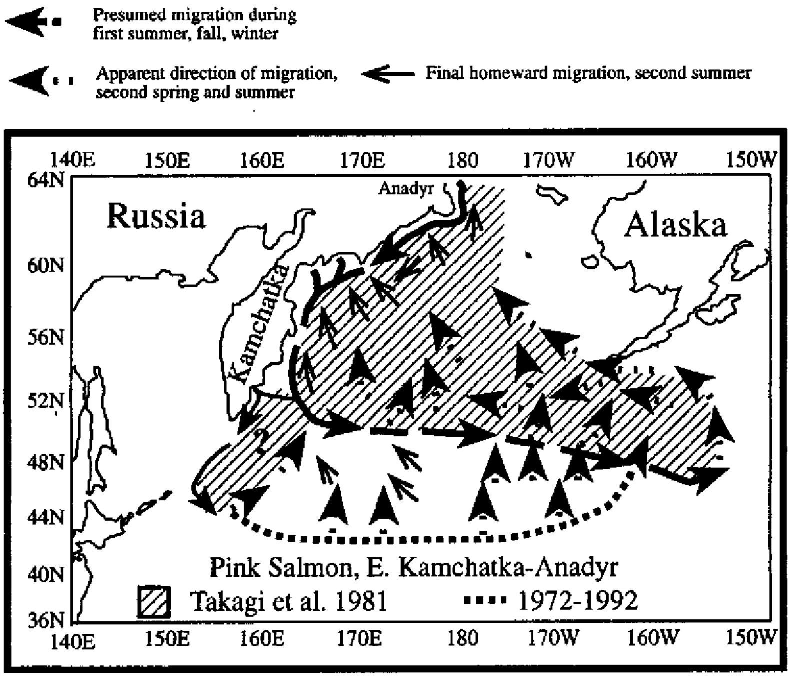

Figure 9. Conceptual model of ocean distribution and migrations of pink salmon originating in eastern Kamchatka and northward to Anadyr Bay (adapted and updated from Fig. 93, Takagi et al. 1981). The arrows indicate the direction of migrations at various life history stages. The shaded area represents the presumed area within which seaward migrations occurred during the first fall and winter, and the area occupied during migrations toward areas of origin in the second spring and summer (Takagi et al. 1981). The dashed lines indicate extensions in the known ocean range during the second spring and summer at sea based on recoveries of tagged fish released in 1972-1992.

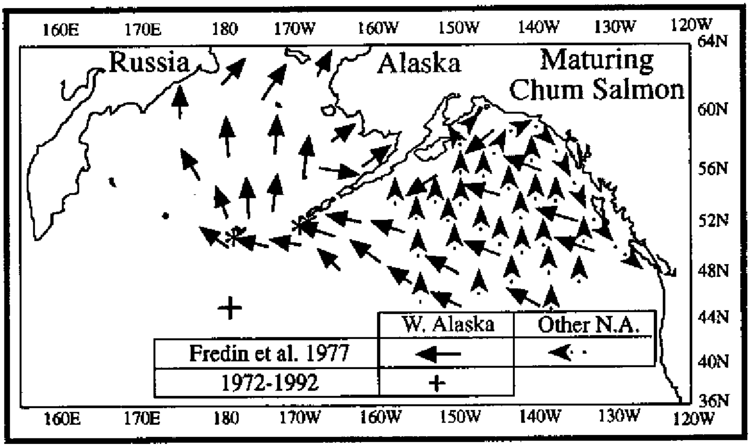

Figure 10. Conceptual model of spring and summer ocean distribution and migrations of maturing chum salmon originating in western Alaska (W. Alaska) and all other areas of North America (Other N.A.) (adapted and updated from Fig. 3.22.C, Fredin et al. 1977). The arrows indicate the extent and apparent direction of migration. There is only one recovery (indicated by the plus sign) from releases of tagged fish in 1972-1992 that provides new information on the ocean distribution of maturing North American (western Alaska) chum salmon. The asterisks along the central Aleutians represent some recoveries of pink salmon in the south Alaskan Peninsula area from pre-1972 releases that were not included in the Fredin et al. (1977) model.

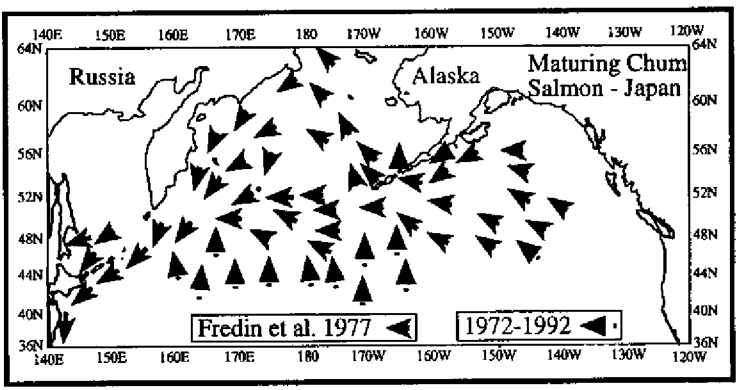

Figure 11. Conceptual model of spring and summer ocean distribution and migrations of maturing chum salmon originating in Japan (adapted and updated from Fig. 3.21.C, Fredin et al. 1977). The arrows indicate the extent and apparent direction of migration.

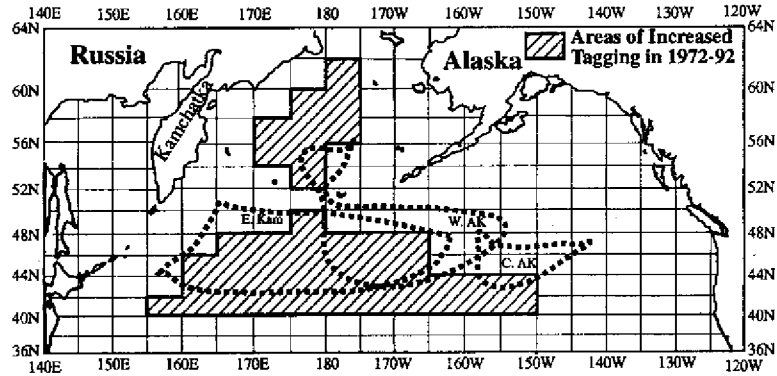

Figure 12. Comparison of tag release effort and 1972-92 range extensions for pink salmon. The areas where high-seas tagging effort (number of tagged fish released) in 1972-92 was higher than in 1954-71 are indicated by shading. The dotted lines represent the extensions in known ocean distributions of maturing pink salmon from three regional stocks: (1) eastern Kamchatkan-Anadyr Bay stocks (E. Kam), (2) western Alaskan stocks (W. Kam), and (3) southeastern, central, and southwestern Alaskan stocks (C. AK) based on recoveries of tagged fish from 1972-1992 releases (from Figs. 7-9).

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Predicting Northern Southeast Alaska Pink Salmon Returns by Early Marine Scale Growth

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Pink salmon (*Oncorhynchus gorbuscha*) experience the major part of their total marine mortality during their first months in estuarine or coastal waters (Parker 1968). Predation is considered a major cause of mortality among fishes, particularly when they are young and are vulnerable to predators at a specific critical size stage (Shepherd and Cushing 1980). Predators often fed selectively on smaller Pacific salmon (*O.* spp.) juveniles (Parker 1971, Karpenko 1984, Hargreaves and LeBrasseur 1985), thus larger, faster growing salmon will have a higher probability of surviving.

Growth in salmon length has been directly correlated with scale width (Clutter and Whitesel 1956, Bilton 1975, Healey 1982, Stohr 1984). Healey (1982) demonstrated rapid early marine growth, as shown on scale circuli, was associated with reduced predation on juvenile chum salmon (*O. keta*). Marine survival of coho salmon (*O. kisutch*) was strongly and positively correlated with faster early marine growth on the scales of returning adults (Holtby et al. 1990).

This paper examines the relationships between scale growth the first marine year on adult pink salmon returning to Auke Creek, Alaska, to that of the relative survival and size of those salmon that year to: (1) Auke Creek, and (2) the larger geographic area surrounding it, northern Southeast (NSE) Alaska (AK). Recent applications of the scale data for forecasting pink salmon returns are also described.

Study Area

Auke Creek is located on the mainland of NSE AK near Juneau (Figure 1). The creek is 457 m long and flows from Auke Lake, a 72 ha dystrophic lake. Located above tidal influence in the creek is a weir and hatchery (Taylor et al. 1981); nearly all pink salmon spawn above the weir. Pink salmon fry and adult counts from Auke Creek during the study period are shown in Table 1.

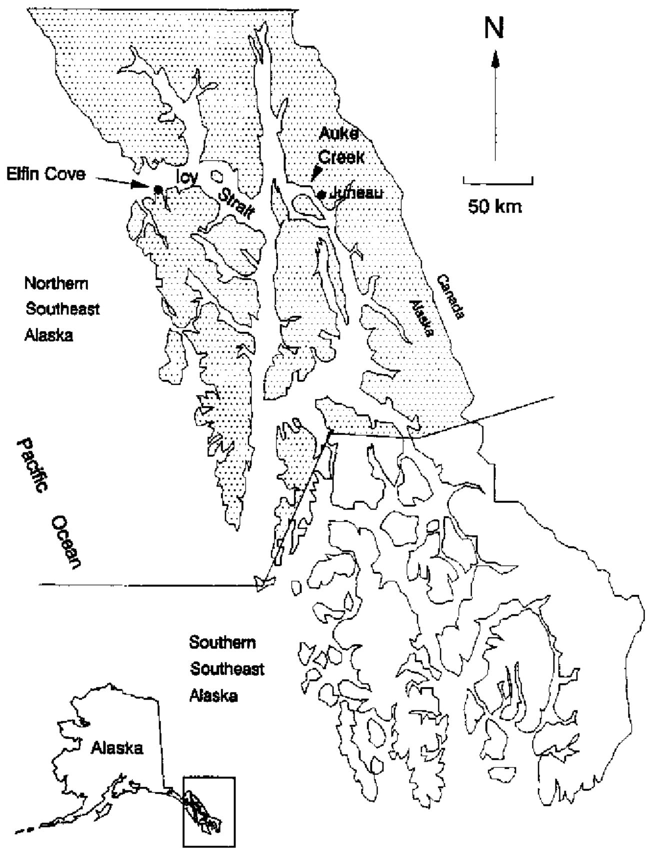

Figure 1. Map of Northern Southeast (NSE) Alaska (AK).

Table 1. Marine survival of wild Auke Creek pink salmon returning in 1979-1992.

Year of Return	Number of fry that produced the return	Number of Adults Returning			Marine Survival (%)
		Escapement	Estimated Catch	Total Run	
1979	114,182	12,396	112	12,508	11.0
1980	23,270	929	16	945	4.1
1981	74,047	9,299	2,747	12,046	16.3
1982	83,526	8,887	3,529	12,416	14.9
1983	126,766	21,855	4,150	26,005	20.5
1984	164,784	5,115	768	5,883	3.6
1985	169,552	24,124	7,544	31,668	18.7
1986	110,000	2,089	97	2,186	2.0
1987	70,459	7,117	1,418	8,535	12.1
1988	26,253	7,060	99	7,159	27.3
1989	74,912	4,173	1,257	5,430	7.2
1990	74,170	19,382	2,670	22,052	29.7
1991	98,355	6,653	2,257	8,910	9.1
1992	243,037	20,972	3,857	24,829	10.2

Methods

Scales

Scales were taken from female pink salmon from Auke Creek in September 1979-1989 and 1991-1992. Scales from males were too badly resorbed to use. Scales were taken from the "preferred" area on the salmon where scale formation began: between the origins of the dorsal and adipose fins, and between the first and third rows above the lateral line (Bilton 1985). The scales were removed with jeweler's forceps from live or dead fish and mounted on gummed paper. Impressions of the scale surface were made on clear cellulose acetate cards (Clutter and Whitesel 1956).

All scale impressions were examined with a microfiche reader and the best scales selected for analysis. Selected scales contained all of the scale area out to the first marine annulus and enough of the scale so that the anterior-posterior axis (the anterolateral line) could be determined. A Calcomp Digitizing Tablet was used to count scale circuli and measure distances between circuli. The same reader digitized all circuli along an axis 20 degrees off the anterolateral line from about 50 fish each year. Scale growth was determined from the center of the scale focus to the outer edge of the last circuli in the first marine annulus. All distance measurements were at a magnification of 100X.

The annual means of ten separate scale growth measurements were used as the independent variables in single correlation analysis of scale growth to survival/size each year. Six measurements were the distances between three consecutive circuli intervals out to the 18th circuli (Table 2). Because the maximum number of circuli on some scales was 18, intervals beyond 18 circuli were not analyzed. A seventh variable was the ratio of scale distance focus-circuli 3/circuli 9–12 (Table 2). The last three growth measurements included the entire marine year: total width distance, number of circuli, and mean distance between circuli (Table 2). The relationships between scale growth and survival/size indices were examined for all years (13), odd years (7), and even years (6).

Correlation With Survival And Size

Six survival/size measures (associated variables, Table 2) were correlated with the scale growth measurements. Estimates of the marine survival of Auke Creek pink salmon were based on the counts of fry and resulting returning adults (Table 1). The number of adults returning to the creek included the escapement through the weir and the estimated

Table 2. List of independent variables (scale growth intervals) and associated variables (survival and size data) used in the correlation analysis of the scale growth of Auke Creek (A.C.) pink salmon to relative survival and size of pink salmon to the creek and Northern Southeast (NSE) Alaska (AK) those same years.

Independent Variable	Associated Variable
Focus (F) - Circuli (C) 3	Relative survival
C3-6	Marine survival, A.C. fish
C6-9	Numbers of fish, NSE AK return
C9-12	Ratio, NSE AK return/spawner
C12-15	Number of fish, NSE AK catch
C15-18	Relative size
Scale ratio, F-C3/C9-12	Mean length, A.C. fish
F-end of annulus	Mean weight, NSE AK fish
Number of circuli	
Distance between circuli	

catch of those stocks intercepted in NSE AK (Anon. 1990). For NSE AK, three relative survival indices (Table 2) were obtained of pink salmon from a brood year. The first was the number of fish in the return, i.e., the estimated escapement to "index" streams in the area, plus the commercial catch. Escapement indices were multiplied by 2.5 to expand escapement indices to total escapement. The second measure, the return/spawner ratio, was derived by dividing the number of fish in the return by the number of fish in the escapement that produced the return. The third measure of relative survival was the NSE AK catch.

Two estimates of the relative size of returning pink salmon (Table 2) were used for each year. The first was the mean mid-eye to fork of tail length (MEFT) of pink salmon sampled for scales at Auke Creek, whereas the second was the mean weight (kg) of pink salmon in the NSE AK purse seine catch.

Pre-season Forecasting

Starting in 1992, pre-season predictions of pink salmon returns to NSE AK were made from scale growth measurements taken from adults starting to enter the fishery. The scales were taken from troll caught pink salmon on June 24-26 near Elfin Cove, Icy Strait (Figure 1). This strait is the major seaward corridor of NSE AK pink salmon returning from the Gulf of Alaska (Hoffman 1982). For forecasting, the scale growth measurements from the Icy Strait fish were applied to least squares linear regression models of the most highly correlated Auke Creek scale growth to NSE AK salmon survival/size associations.

Results

Hindcasting Survival and Size

Scale growth of returning Auke Creek pink salmon adults was significantly ($P \leq 0.05$) correlated to the marine survival indices (i.e., returns, returns/spawner, catch) of NSE AK adult pink salmon the same year. Scale growth from focus (F) to circuli (C) 3 and C3-6, the scale growth ratio (F–C3/C9-12) and total scale growth (F to end of annulus) were all significantly and positively related to NSE AK pink salmon survival (13 associations, Table 3). Scale growth distance C9-12 was also significantly correlated, but the relationship was negative with NSE AK pink salmon survival (3 associations, Table 3). No significant ($P \leq 0.05$) correlation was evident between scale growth and the marine survival of Auke Creek pink salmon.

The greater the early marine scale growth of returning Auke Creek pink salmon adults, the smaller the adults that returned to NSE AK and

Table 3. The 23 significant ($P \leq 0.05$) coefficients of correlation (r) and probabilities (P) of relationships between scale growth intervals on returning pink salmon to Auke Creek, 1979-1989, 1991-1992 (and odd and even years in that period) and the relative survival and size of pink salmon returns to Northern Southeast Alaska and Auke Creek. The "r" values are not adjusted.

			Scale Growth Interval									
	Survival/ Size		F-C3		C3-6		C9-12		F-C3/C9-12		F-end of annulus	
Location	Measure	Database	r	P	r	P	r	P	r	P	r	P
N. SE AK	Return	All yrs	0.57	(0.04)	-	-	-	-	-	-	-	-
		Odd yrs	-	-	-	-	-0.91	(0.00)	0.92	(0.00)	-	-
		Evn yrs	-	-	-	-	-	-	-	-	0.83	(0.04)
	Return/ Spawner	All yrs	0.63	(0.02)	-	-	-	-	0.70	(0.01)	-	-
		Odd yrs	0.79	(0.04)	-	-	-0.88	(0.00)	0.98	(0.00)	-	-
		Evn yrs	-	-	-	-	-	-	-	-	-	-
	Catch	All yrs	0.65	(0.02)	0.66	(0.05)	-	-	0.60	(0.03)	-	-
		Odd yrs	0.74	(0.05)	-	-	-0.84	(0.02)	0.93	(0.00)	-	-
		Evn yrs	-	-	-	-	-	-	-	-	0.83	(0.04)
	Mean Wt of Fish	All yrs	-0.55	(0.05)	-	-	-	-	-	-	-	-
Auke Crk	Mean Length of Fish	All yrs	-0.70	(0.01)	-0.73	(0.01)	-	-	-0.61	(0.03)	-	-
		Odd yrs	-0.91	(0.00)	-0.87	(0.01)	-	-	-0.83	(0.02)	-	-
	Total Relationships		8		3		3		7		2	

Significant Relationships	
All year total	10
Odd years total	11
Even years total	2
Total	23

the creek. Scale growth F–C3 on the Auke Creek adult salmon was significantly (P≤ 0.05) but inversely related to the mean individual weight of pink salmon returning to NSE AK that year (1 association, Table 3). Scale growth F–C3, C3–6, and the scale growth ratio (F-C3/C9-12) on Auke Creek fish were all significantly and inversely related to the mean MEFT length of returning pink salmon to the creek (6 associations, Table 3).

Thus, scale growth on returning Auke Creek pink salmon was often related to NSE AK pink salmon survival indices, with fast growth out to circuli 6 (positive "r" values, Figure 2) and slow growth from circuli 6-12 (negative "r" values, Figure 2) associated with better survival. Fast Auke Creek scale growth out to circuli 6 was associated with smaller returning NSE AK pink salmon (negative "r" values, Figure 2) that same year.

From the 180 correlations attempted between scale growth and survival/size, scale growth F-C3 and the scale growth ratio were most highly correlated with pink salmon survival and size, accounting for 15 of the 23 significant (P≤ 0.05) relationships (Table 3). Only 2 of the 23

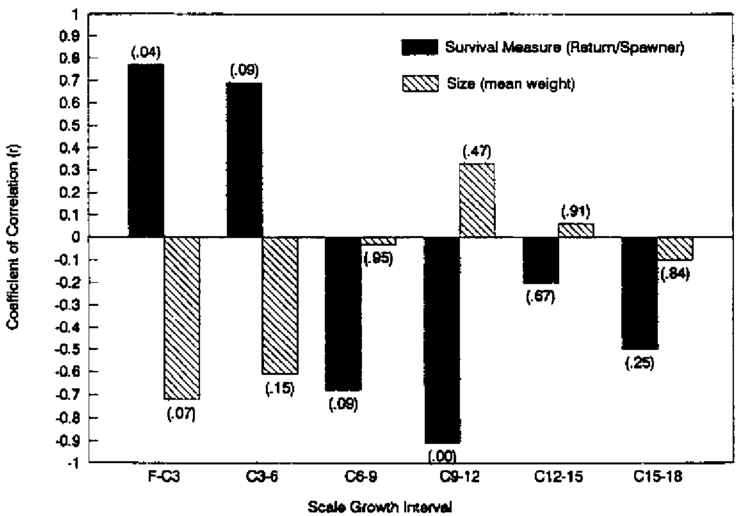

Figure 2. Correlation of coefficients (r) of scale growth intervals to NSE AK pink salmon survival measure (return/spawner) and size (mean fish weight, kg), odd year data. Probability (P) of relationships between scale growth and survival/size measures are shown in parentheses.

significant relationships included scale growth beyond 12 circuli (Table 3).

When the relationships we examined were separated into odd-and even-brood years, correlations were greater for the odd year fish. In odd years, 11 significant ($P \leq 0.05$) relations were evident between scale growth and survival/size in the early marine period (out to the 12th circuli, Table 3); in even years, none occurred in that period (Table 3). In even years, only total scale growth (F-end of annulus) was significantly related to NSE AK pink salmon survival indices (2 associations, Table 3).

Pre-season Forecasts

In 1992, the first pre-season predictions of NSE AK pink salmon survival indices and size were made from scale growth measurements taken from 96 pink salmon adults caught in Icy Strait. Based on the scale

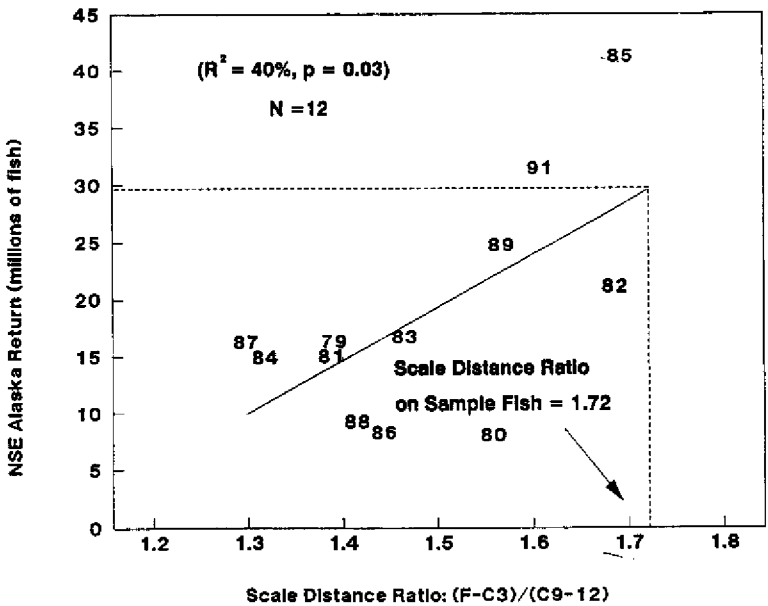

Figure 3. Predicted 1992 NSE AK pink salmon return (millions) based on applying the scale distance ratio measurement on scales of 1992 adult pink salmon sampled in Icy Strait to the Auke Creek pink salmon scale growth to NSE AK pink salmon return model (1979-1989, 1991 data). $Y = -50.28 + 46.36X$.

ratio (F–C3/C9–12) measurement from these scales, a return and catch of 30 (Figure 3) and 16 (Figure 4) million fish respectively was forecast; the actual return and catch was 30 and 16 million, respectively. Based on the scale growth measurement (F–C3) from the fish sampled in the strait, the mean individual weight of returning NSE AK pink salmon in 1992 was predicted to be 1.35 kg (Figure 5); the actual weight was 1.5 kg.

Discussion

Pre-season forecasts are vital to the fisheries managers for regulating the returns and to the fishers, processors, and marketing institutions for maintaining the economic health of the pink salmon fishery. Current forecast methods in NSE AK rely on spawner/recruit relationships, modified by winter air temperatures (Geiger and Savikko 1992). This study was originally conceived to determine if scale growth could explain the wide variations in the marine survival of Auke Creek pink salmon

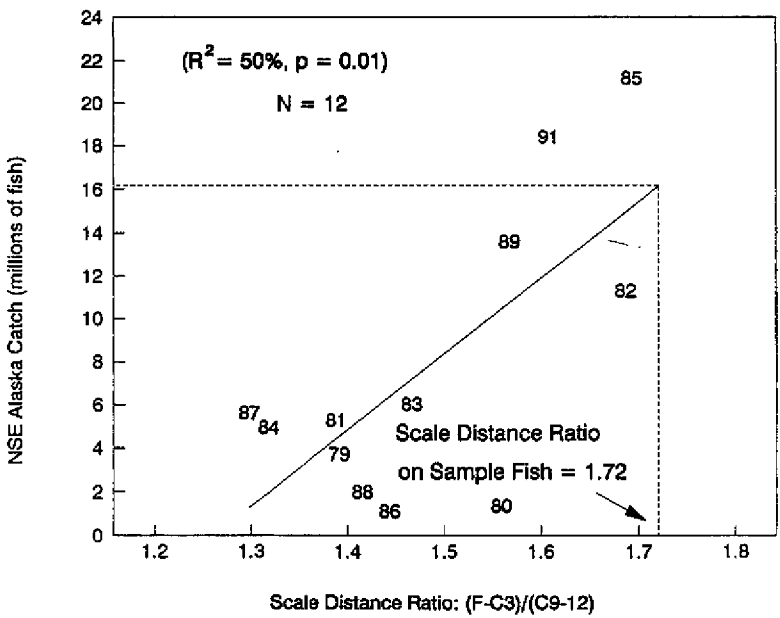

Figure 4. Predicted 1992 NSE AK pink salmon catch (millions) based on applying the scale distance ratio measurement on scales of 1992 adult pink salmon samples in Icy Straight to the Auke Creek pink salmon scale growth to NSE AK pink salmon catch model (1979-1989, 1991 data). Y = –44.42 + 35.20X.

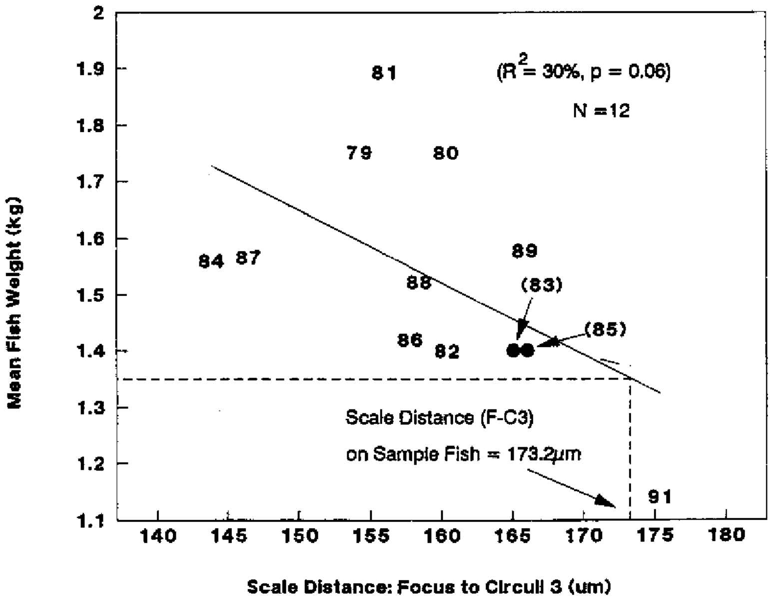

Figure 5. Predicted mean weight (kg) of individual fish in the 1992 NSE AK pink salmon run based on applying the scale distance measurement F-C3 on scales of 1992 adult pink salmon sampled in Icy Straight to the Auke Creek pink salmon scale growth to NSE AK pink salmon size model (1979-1989, 1991 data). Y = 3.57 −0.013X.

(Table 1); it did not. However, Auke Creek pink salmon scale growth may be a useful index for forecasting the survival/size of NSE AK pink salmon. Auke Creek pink salmon scale growth was a significant (P=0.05) hindcast predictor of the relative survival indices and mean weight of pink salmon returning to NSE AK. Furthermore, when applying pink salmon scale growth measurements obtained from adults sampled in Icy Strait to the best regression models of Auke Creek scale growth to NSE AK salmon survival indices, the first pre-season forecasts of NSE AK pink salmon returns and catch were remarkably close.

Eleven significant survival/size predictors resulted based on Auke Creek pink salmon scale growth out to six circuli. Pink salmon scale growth begins at 6 cm FL (Pearson 1966, Kaeriyama 1989). In Auke Bay, AK, 6 cm pink salmon juveniles were abundant in the offshore waters in June (Mortensen and Wertheimer 1988). Pink salmon with 3 and 6 circuli on their scales were 9 and 12 cm FL respectively (Pearson

1966); that size fish were still in the inside waters of NSE AK in July (Jaenicke and Celewycz 1994). This paper reveals the earliest marine scale growth (particularly out to 3 circuli) was positively related to pink salmon survival. This supports Parker (1971) and Hargreaves and LeBrasseur (1985) who concluded that rapid early marine growth of pink salmon was important in reducing their vulnerability to predators and that size selective predation was probably a major cause of mortality of the fish during their early marine period.

Early marine scale growth was positively related to survival, but later marine scale growth was negatively related to survival (this study). By considering two scale growth measures (F–C3 and C9–12) as a ratio, the best predictors of survival resulted. These relationships suggest two critical periods in the early marine survival of the NSE AK pink salmon: one early (6-9 cm fish) and one later, when the fish develop 9-12 circuli. Pink salmon with 9-12 circuli had a mean FL of 14 and 16 cm respectively (Pearson 1966). This is the approximate size the fish entered the Gulf of Alaska through Icy Strait in August (Jaenicke and Celewycz 1994). The C9–12 scale growth to survival relationship indicates density-dependent growth occurs inside NSE AK and/or the Gulf of Alaska when survival was higher during the earlier phase. This suggests when growth conditions are favorable and many faster growing juvenile salmon escape predators initially, the survivors encounter density-dependent limitations in growth further seaward, resulting in smaller size as returning adults. Supporting this contention is the significant but negative relationship between the earliest marine scale growth and size of returning pink salmon observed in this study.

Continued scale sampling of Auke Creek pink salmon adults and expanded scale sampling of pink salmon (juveniles and adults) in Southeast AK is needed to further determine the merits of the scale forecast method. However, any associations between scale growth and survival/size reported here do not include the very earliest marine growth of the pink salmon. Pink salmon emigrate to sea at approximately 3 cm FL (Heard 1991) but do not form scales until 6 cm FL (Pearson 1966, Kaeriyama 1989). Research is now underway to compare scale growth patterns to otolith growth patterns of juvenile pink salmon to determine if otoliths capture a more complete record of early marine growth.

Acknowledgments

We especially thank Sidney Taylor, Alex Wertheimer, and Jack Bailey (retired) of the National Marine Fisheries Service, Benjamin Van Alen, Karl Hofmeister, Carmine DiCostanzo, and Herman Savikko of the

Alaska Department of Fish and Game, and Ole Mathisen of the University of Alaska Fairbanks for their support and advice during this project.

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Southeast Alaska Winter Air Temperature Cycle and Its Relationship to Pink Salmon Harvest

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Pink salmon (*Oncorhynchus gorbuscha*) harvests during 1960-1992 are positively correlated with both average winter air temperatures and brood year escapements. Average winter air temperatures in Southeast Alaska are cyclic and linked to the sea surface temperature cycle in the Gulf of Alaska. The 18.6-year lunar cycle, with its associated tidal currents, has been implicated in high latitude sea temperature cycles. The peak historical harvest period of the late 1930s and early 1940s occurred when the winter temperature cycle was at its minimum. The population crash which started after 1941 and continued through 1960 was attributed to inadequate brood year escapement levels. The population recovery of the early 1980s to early 1990s was attributed to both improving environmental conditions, and increased escapement levels. If escapements are maintained near their current level (i.e. an index of 12 to 13 million), the harvest will probably become cyclic and linked to the winter air temperature cycle. Maintaining adequate escapements is also expected to result in average harvest levels well above those which occurred during the last two lows in the winter air temperature cycle.

Introduction

Pink salmon stocks in Southeast Alaska began a decline in the early 1940s, as evidenced in the harvest statistics, and did not fully recover until the mid-1980s (Figure 1). The rebuilding of Southeast Alaska's pink salmon stocks in recent years, to all time record harvest levels, occurred during the same period in which both average winter air temperatures and brood year escapement levels increased. Winter air temperatures in Southeast Alaska are cyclic (Figure 2); the current cycle began to decline in 1990. The purpose of this paper is to review the historical pink salmon harvest, escapement index, and winter air temperature data and speculate on the extent to which the declining winter air temperatures in the upcoming years will influence pink salmon harvests.

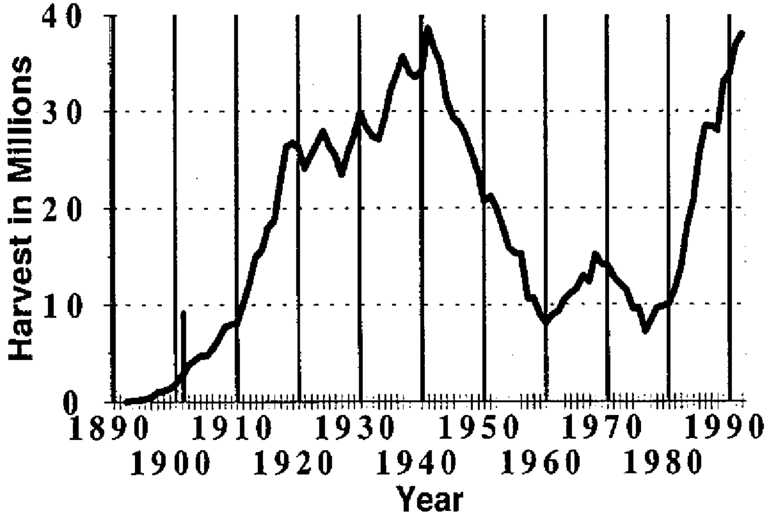

Figure 1. Southest Alaska pink salmon harvest 1892-1992 (8-year moving average).

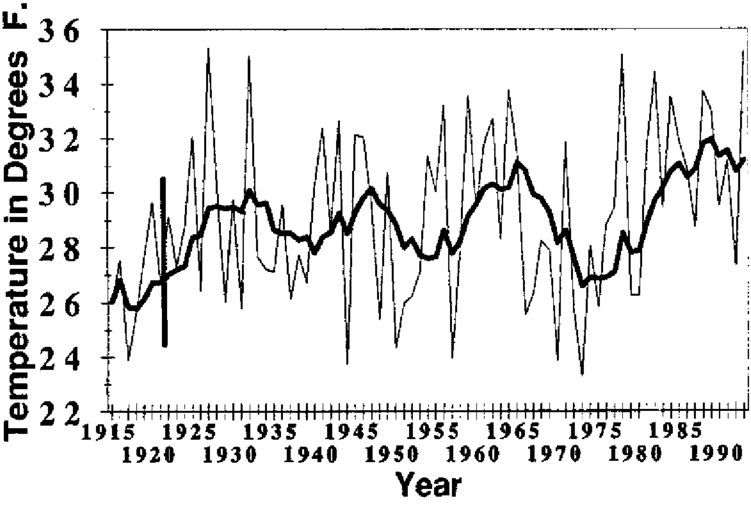

Figure 2. Average daily minimum winter (Nov 1 to Feb 28) air temperatures and 8-year moving average, Wrangell and Sitka, Alaska.

Methods

The pink salmon harvest data from 1892 through 1959 were obtained from Eggers and Dean (1987). Harvest and escapement data from 1960 through 1992 were obtained from the Alaska Department of Fish and Game (ADF&G) computerized databases. The harvest data is a summation of all fish ticket data regardless of gear type or harvest code. The escapement indices for Southeast Alaska were obtained by summing the individual district escapement indices, which were calculated by summing the highest escapement count made on each stream surveyed in the district and adjusting for the number of streams not surveyed within that district. The number of streams in each district is defined as the number of streams for which an escapement count was available at least once during 1960 through 1992. The number of streams not surveyed in each district was multiplied by the average escapement count to all streams within that district having a peak escapement count of less than 10,000 pinks. No attempt was made to expand the escapement index to represent an estimate of the total pink salmon escapement.

All moving-average graphs were computed as an 8-year average. Any one point on the line represents the average of that year plus the seven previous years. This method was selected over the more conventional method of averaging an equal number of years before and after the year in question, so that the 1992 data would be directly comparable to all other years, except the first 7 years of the database. A short vertical line intersecting the data line delimits the point at which the moving average line has less than 8 years in the moving average calculation.

The daily temperature data was obtained from National Oceanic and Atmospheric Administration's Climatological Data publications. The upwelling and sea surface temperature data files were provided by Bob Marshall (ADF&G, personal communications). An explanation of how the upwelling indices were computed can be found in Marshall (1992).

Results and Discussion

A long-term (approximately 50 year) trend exists in Southeast Alaska pink salmon harvests (Figure 1). The same trend is present in both northern and southern Southeast Alaska (Figure 3). Reliable escapement data is only available from 1960 to present, and consequently, it is not possible to construct a graph of the pink salmon runs (catch + escapement) prior to 1960. However, with the exception of the initial development of the fishery, from the late 1800s to the early 1900s, the harvest graph does provide an estimate of the change in the relative abundance of pink salmon through time.

The first commercial salmon harvests in Alaska occurred near Klawock and Old Sitka in 1878 (Mosier 1898). The low harvest shown in Figure 3 from 1890 through the early 1900s was the result of minimal harvest and processing capabilities and lack of markets for pink salmon, rather than a reflection of run magnitude. The harvest of pink salmon was increased only after the stocks of more preferred species had been depleted. Mosier 1899, stated in his report on the operations of the United States Fish Commission steamer *Albatross* for the year 1898:

> In 1889 the packs were made from the streams near the canneries—that is, from the "home streams"—and nearly all were redfish [sockeye salmon], with a few cohoes and probably very few humpbacks [pink salmon], for the latter were not in favor and few were packed. In 1897 the pack for the same section [Ketchikan Area] is double the 1889 pack, but they are nearly all humpbacks. The pack of redfish is certainly very much less, yet al.l the streams within 70 or 80 miles of the canneries have been scoured with all the gear that could be revised or used.

The increasing pink salmon harvests from the early 1900s through 1919 parallel increasing fishing effort. The number of salmon traps, the principal gear type in the early 1900s, increased from 57 in 1908 to 416

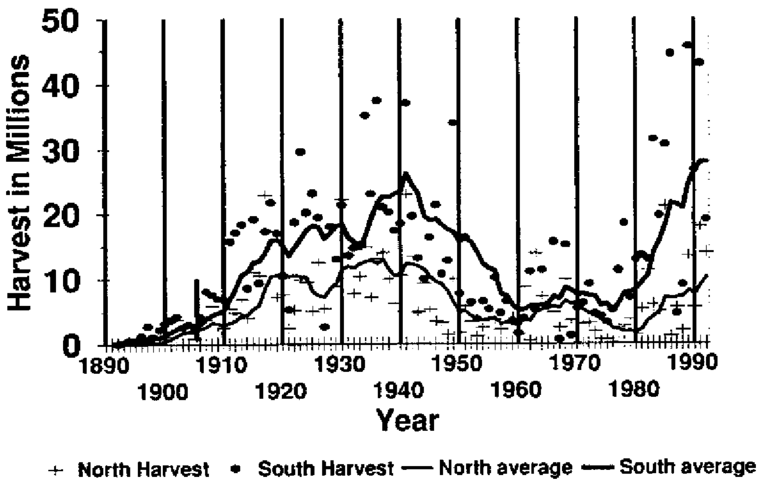

Figure 3. Northern and southern Southeast Alaska annual pink salmon harvest with 8-year moving average (1892-1992).

in 1919 (Alexandersdottir 1987). A market glut then resulted, and the number of traps was reduced from 472 in 1920 to 107 in 1921. Consequently, the decrease in the harvest in 1921 shown in Figure 3 does not reflect a real reduction in return magnitude. Effort quickly rebuilt after 1921 until 1924 when the White Act was established. The White Act mandated that 50% of a year's return be allowed to escape, and this management strategy was in force until Alaska's statehood in 1960. The harvest graph shown in Figure 3 provides an index of run magnitude during this period. Harvest also provides an index of return from 1960 to 1992 because the management strategy during that period was to achieve constant (optimum) escapements, and harvest only those pinks which were in excess of the estimated optimum escapement. The estimate of optimum escapement has increased through the years. The average escapement index achieved during the first 10 years after statehood was 6.2 million, while the average escapement index achieved over the last 10 years was 12.9 million. Consequently, although harvest does provide an index for return from 1960 to 1992, it is not a constant relationship. As escapements were increased, harvest represented a decreasing percentage of the total run.

The lack of reliable escapement data prior to 1960 makes a detailed evaluation of the historical relationship between pink salmon survival and winter temperatures impossible. However, during the 1960 to 1992 period, winter temperatures were apparently influencing survival. There were no large harvests for runs which experienced cold winter temperatures during their brood year (Figure 4). However, there were low harvests for runs that experienced warm winter temperatures. A portion of the variability in the harvest-winter temperature relationship shown in Figure 4 can be explained by low brood year escapement indices. Including both brood year escapement indices and average winter temperatures into a multiple linear regression results in an R^2 value of 0.74 (Figure 5). The regression model used to produce Figure 5 included return years 1967 through 1992, with 1987 and 1988 excluded from the analysis as outliers. The predictions for 1987 and 1988 were included on the graph to show the extent of the errors which occurred in those years. Because winter temperatures have been shown to influence pink salmon survival (Figures 4, 5) and winter temperatures in Southeast Alaska are cyclic (Figure 2), it would be logical to expect the pink salmon harvest in Southeast Alaska to be cyclic.

The average pink salmon harvest has increased along with the average winter temperatures during the last half of the recent temperature cycle, which appears to have peaked in 1989 (Figure 6). However, harvests did not follow the winter temperature cycle during the previous

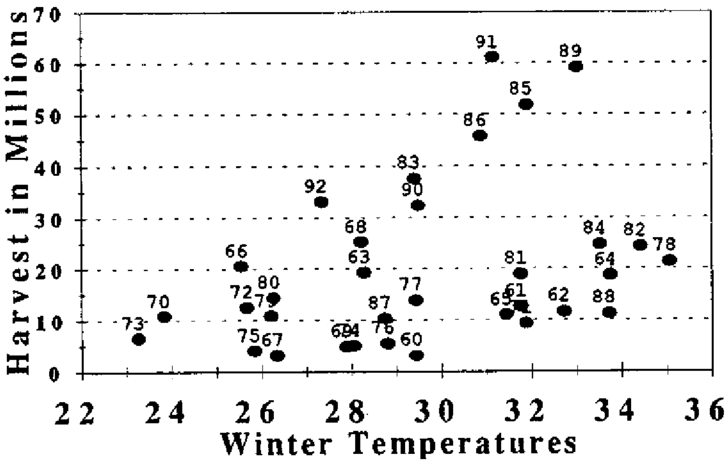

Figure 4. Southeast Alaska pink salmon harvest versus winter air temperatures (1960-1992).

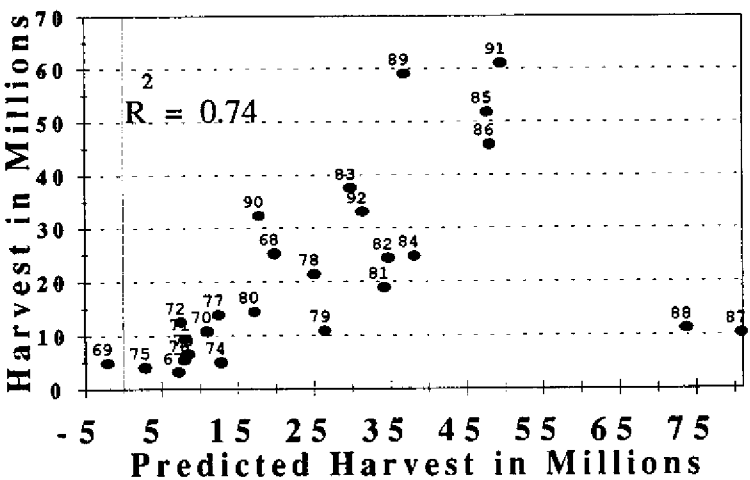

Figure 5. Predicted versus observed pink salmon harvest using winter air temperatures and brood year escapement index.

three cycles. In fact, the peak harvest period in the late 1930s and early 1940s occurred during a period that corresponds to temperature cycle lows. There is no known environmental cycle which occurs with a frequency similar to the Southeast Alaska pink salmon harvest pattern (Figure 1), and consequently, fishing is suspected. If the peak harvest period in the late 1930s and early 1940s occurred at the expense of escapements, the crash after 1940 would be expected. The minimal response in harvest during the temperature cycle peak in the mid to late 1960s (Figure 6) may have been the consequence of inadequate escapement levels. Figure 7 suggests that the optimum escapement index level is well above 6 million, which was the average escapement index achieved during the mid to late 1960s. The relationship between brood year escapement index and harvest from 1960 to 1992 suggests that the optimum escapement index for Southeast Alaska is at least 12 million (Figure 8). It also suggests that over-escapement levels come into play somewhere above 15 million. However, the actual cause of the poor returns in 1987 and 1988 is still under investigation. Upwelling indices off Dixon Entrance and Sitka during 1987 and 1988 were the lowest of the study period (Figure 9), and this condition may be related to factors that decreased the survival of the 1987 and 1988 returns.

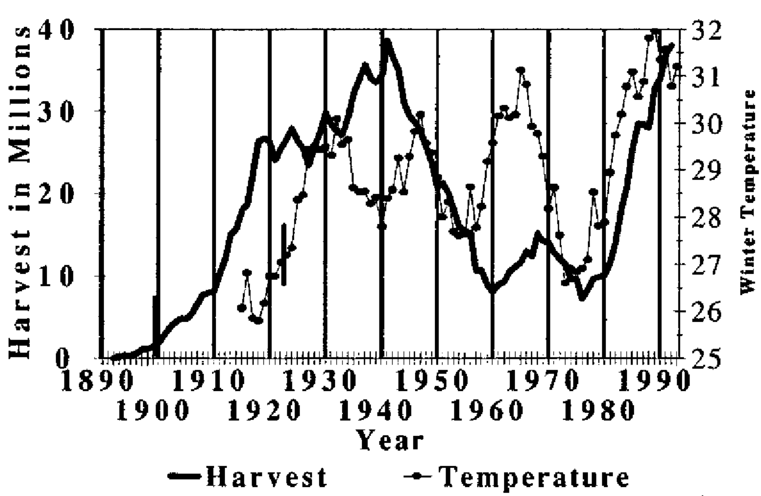

Figure 6. Southeast Alaska pink salmon harvest versus winter air temperatures (8-year moving average).

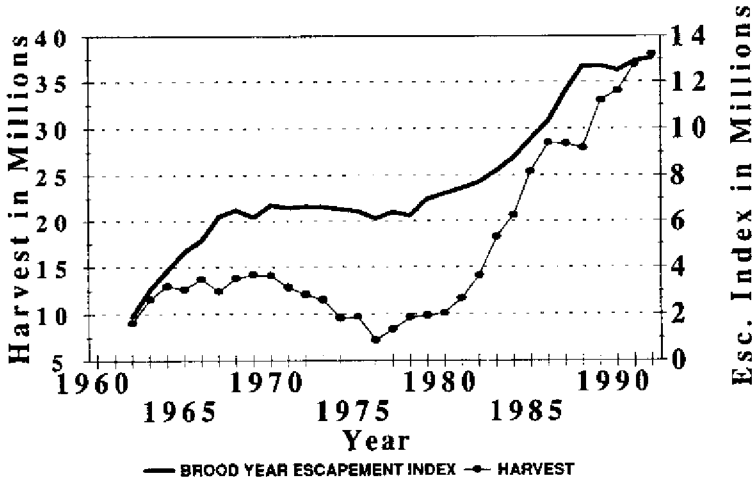

Figure 7. Brood year escapement index versus harvest (8-year moving average).

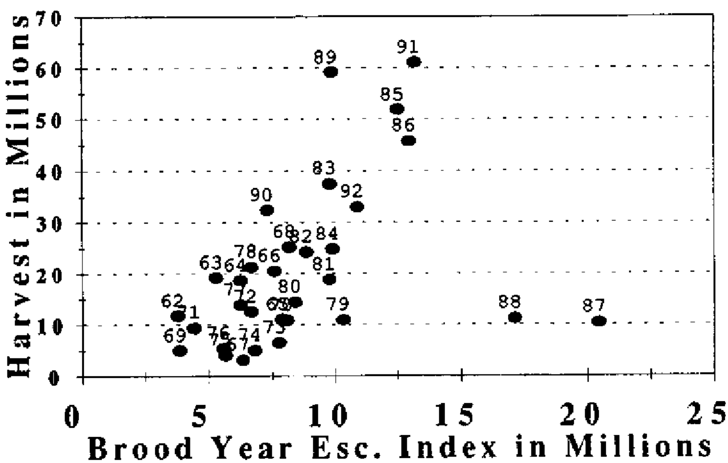

Figure 8. Southeast Alaska brood year escapement index versus harvest.

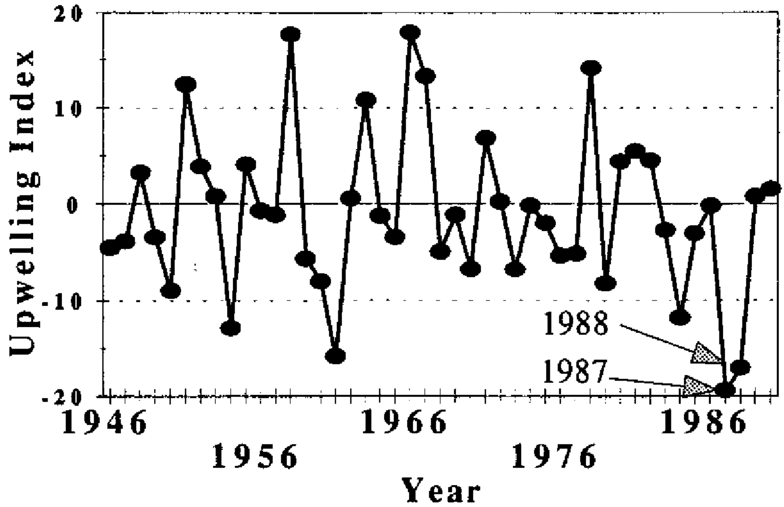

Figure 9. Upwelling index during June and July from Dixon Entrance and Sitka.

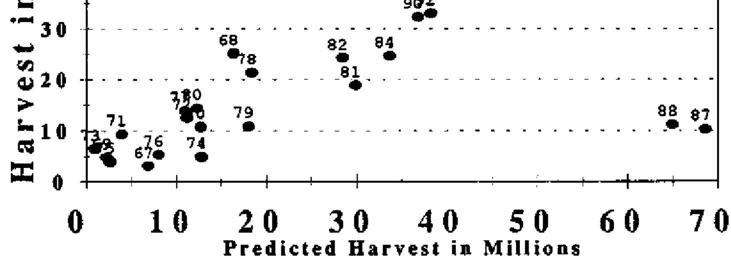

Figure 10. Predicted versus observed harvest using escapement index, winter air temperature, and sum of previous two brood year escapement indices.

Maintaining high escapement levels may have a beneficial effect beyond the brood year generation. The relationship among winter air temperatures, brood year escapement indices, and harvest, shown in Figure 5, can be improved by adding one more escapement parameter to the model. Including the sum of the previous two brood year escapement indices raised the R^2 from 0.74 to 0.90 (Figure 10). Both of these models included return years 1967-1992 with 1987 and 1988 omitted from the regression as outliers. The predictions which would have been obtained for 1987 and 1988 were included in the graphs to show the extent of the errors. The mechanism of the apparent interaction is unknown, although two possibilities are: (1) that additional redd building activities associated with high escapement levels removes fine sediment from the spawning substrate, thus improving egg to fry survival for future generations, and (2) that high straying levels from large escapements result in marginally productive streams receiving adequate escapements.

The periodicity of the winter air temperatures in Southeast Alaska, is likely related to cyclic changes in the sea surface temperatures in the Gulf of Alaska. The average monthly sea surface temperatures from four stations located at latitude 55 degrees N, and longitudes 155, 150, 145, and 140 degrees W, follow the same cycle as winter air temperatures in Southeast Alaska (Figure 11). Royer (1992) found a relationship between sea surface temperatures in the Gulf of Alaska and the 18.6-year lunar cycle.

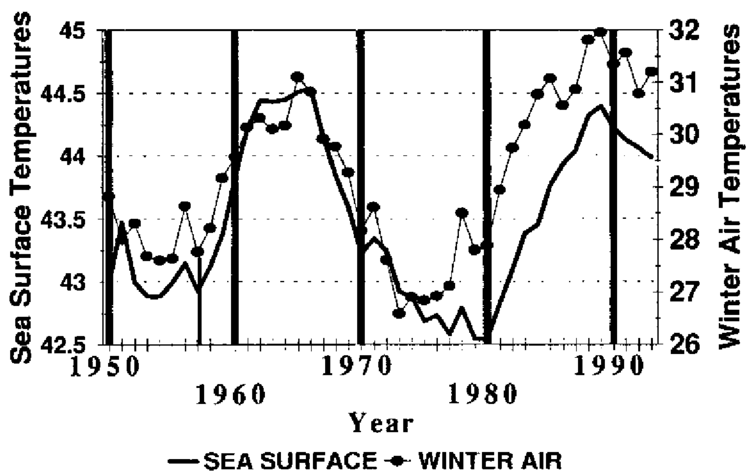

Figure 11. Winter air temperatures versus sea surface temperatures in the Gulf of Alaska (8-year moving average).

Conclusions

1. The average winter temperatures of Southeast Alaska are cyclic, and closely linked to the 18.6-year Gulf of Alaska sea surface temperature cycle reported by Royer (1992).

2. During 1960 through 1992, Southeast Alaskan pink salmon harvests were influenced by both winter temperatures and brood year escapement indices.

3. The decline in the pink salmon returns after 1940 was probably the result of over-harvesting (under-escapement) because the peak harvests during the late 1930s and early 1940s were occurring at a time when the winter temperature cycle was at a low point.

4. The pink salmon population did not recover during the winter temperature cycle peak of the mid-1960s when the average escapement index was approximately 6 million.

5. The pink salmon population did recover during the high point of the last winter temperature cycle when average escapement index levels reached 12 million.

6. If escapement levels are held near optimum, the pink salmon harvest in Southeast Alaska will probably become cyclic and linked to the winter air temperature cycle.

7. If the escapement levels are held near optimum, it should be possible to maintain average harvest levels well above those which occurred during the last low point of the winter temperature cycle in the 1970s.

Acknowledgment

Contribution PP-077 of the Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau.

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Forecasting Adult Returns of Hatchery Reared Chum Salmon

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Introduction

Hidden Falls hatchery is located on the east shore of Baranof Island, approximately 20 air miles due east of Sitka, Alaska. It has been operated by the Northern Southeast Regional Aquaculture Association (NSRAA) since 1988, and prior to that by the Alaska Department of Fish and Game. The hatchery provides primarily chum salmon, but also chinook and coho salmon for common property harvest in southeast Alaska.

Returns of chum salmon to terminal area have averaged 451,000 over the period of operation (i.e. 1980-1992). The 1992 harvest of 924,000 represented 20% of the total chum salmon catch for the south-east region, and had a direct value of approximately $3,500,000. Because of its importance to the commercial fishery, predicting return size has been an integral part of the hatchery program. The need for improved forecast accuracy, however, has increased in recent years because NSRAA pays for the program entirely through cost recovery operations, which reduces the number of fish available for commercial harvest. Equitable allocation of the resource among salmon producers and the fishing industry is an important function of the private, non-profit (PNP) hatchery program, and NSRAA is firmly committed to achieving this objective. This paper identifies the factors which contribute to adult production and outlines the approach used to forecast annual returns.

Methods

Release History and Strategy

Releases of chum salmon fry from Hidden Falls have ranged from 213,000 in 1978 (1977 brood year) to 64,300,000 1991 (Figure 1). Prior to 1986, all releases were in Kasnyku Bay (i.e. hatchery site), and included both fed and unfed fry. Releases of unfed fry, however, were largely unsuccessful and discontinued after 1985. Beginning with the

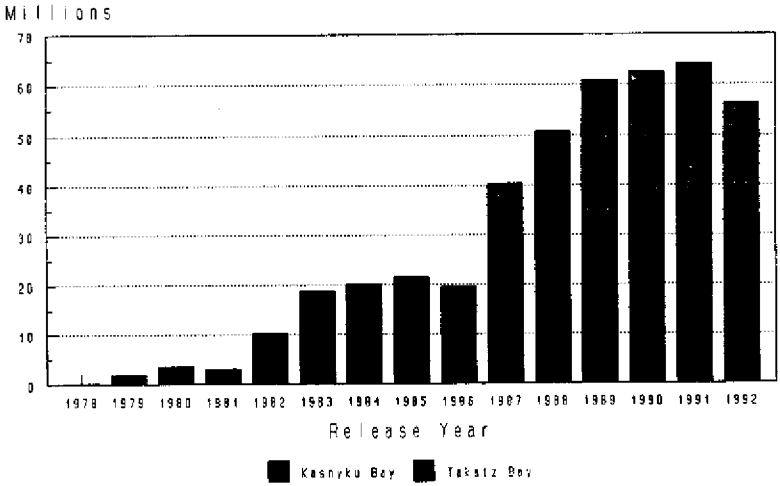

Figure 1. Number of fed fry released by site for Hidden Falls chum salmon.

1986 brood, NSRAA established a remote release site at Takatz Bay, five miles south of Kasnyku Bay. Releases at Takatz have averaged approximately 24 million annually.

Fry are ponded directly to saltwater in mid- to late March and released in mid- to late May. Size at release for fed fry has ranged from 0.6 to 2.2 grams at Hidden Falls, and 1.1 to 1.5 grams at Takatz. Temperatures during the period typically range from 4 degrees C in March to 8-10 degrees C in May.

Effect of Release Size and Number on Adult Return

Adult returns have varied from a low of 3,400 in 1981 to a high of 1,026,000 in 1992 (Figure 2), and age at return within brood years has averaged 3%, 64%, 32% and 1%, respectively, for the three, four, five and six year age classes. The relation between the total number of fry released and the adult return by brood year is shown in Figure 3. The relation is non-linear with the largest releases included, indicating that adult returns have not increased proportionately with the number of fry released.

Ocean survival for Hidden Falls chum salmon has averaged 3.1% and has ranged from a low of 1.03% for the 1985 brood to a high of

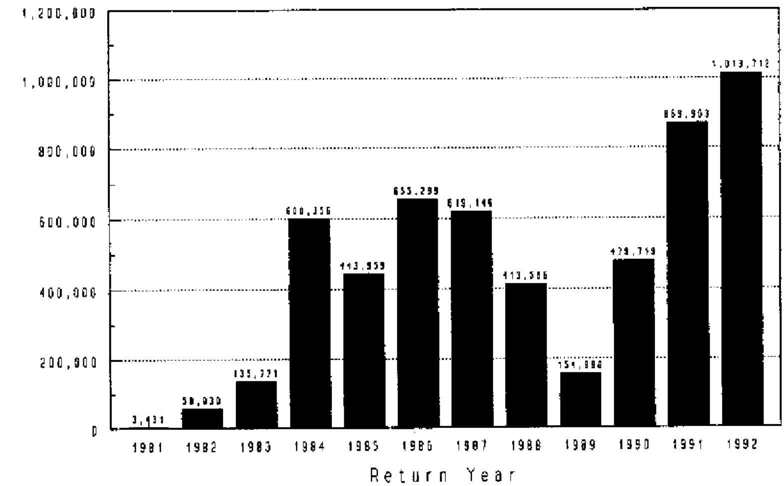

Figure 2. Adult return for Hidden Falls chum salmon for the period 1981 to 1992.

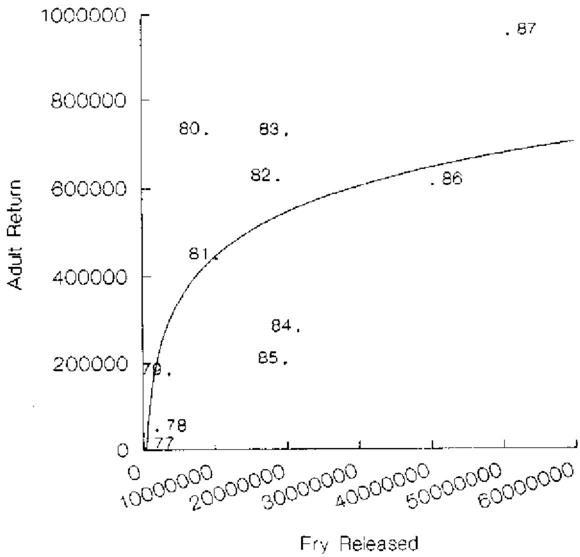

Figure 3. Total adult return by brood year in relation to the number of fry released for Hidden Falls chum salmon. Line was fit by least squares.

8.03% in 1980 (Figure 4). The effect of size at release on marine survival is shown in Figure 5. In contrast to the nonlinear relation between the number of adults in the return and the number of fry released, survival as a percent of the release has increased proportionately with the average size of fry released ($r=0.74$, $p<0.01$).

Forecasting Approach

The model used to predict the annual return is based on the observation that the total *number* of adults produced from each brood year is related to the number of fry released, and that the *proportional* survival is partly determined by the size of fry released. The combined effect of these variables on the return for each brood year is multiplicative, i.e. the total return is a function of the biomass of the fry at release. Evidence also suggests that the number returning in a particular age class is related to the number in the previous age class, (e.g. age 5 returns in year t are related to age 4 returns in year t–1).

Returns of age 3 and age 6 adults are based on historic average across all brood years. The mean number of age 3 fish has been ~13,000 and for age 6 ~3,500.

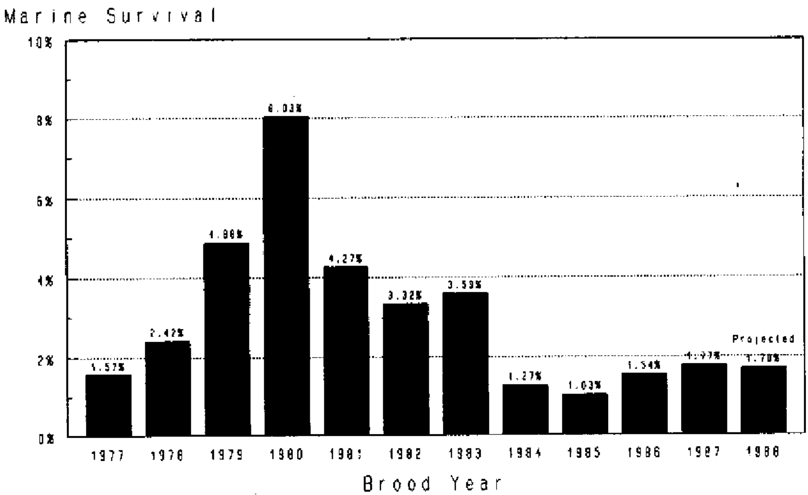

Figure 4. Marine survival as a percent of the release by brood year for Hidden Falls chum salmon.

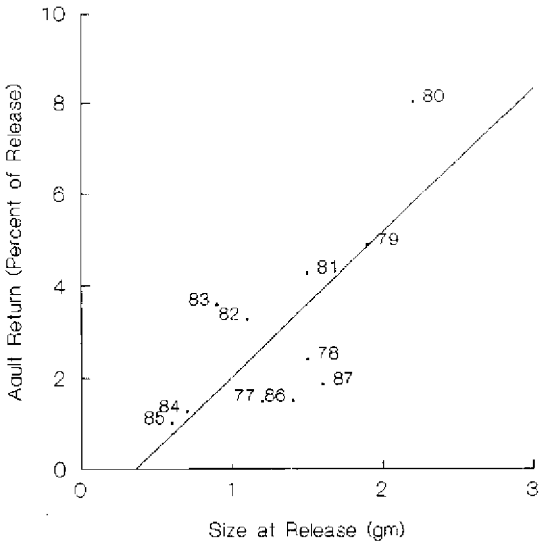

Figure 5. The influence of fry size (gm) at release on the marine survival of Hidden Falls chum salmon (r=0.74, p=0.009).

Age 4 and age 5 returns are predicted by linear regression. For the age 4 return, the best fit model is

$$N_4 = \alpha(N_r W_r)^\beta$$

where N_4 is the number of age 4 adults, N_r is the number of fry released, W_r is the mean fry weight at release in grams. Taking the natural logarithm of both sides yields

$$\ln(N_4) = \ln(\alpha) + \beta(M_r),$$

where M_r is the biomass in kilograms at release. Applying the model to the historical data base through 1992 results in

$$\ln(N_4) = 2.404 + 1.008(M_r)$$

with F=79.70, p<0.001 and r=0.94. For the age 5 return, the regression model is

$$N_5 = 30864 + 0.382(N_4)$$

with F=17.59, p=0.002 and r=0.81. These relations are illustrated in Figures 6 and 7.

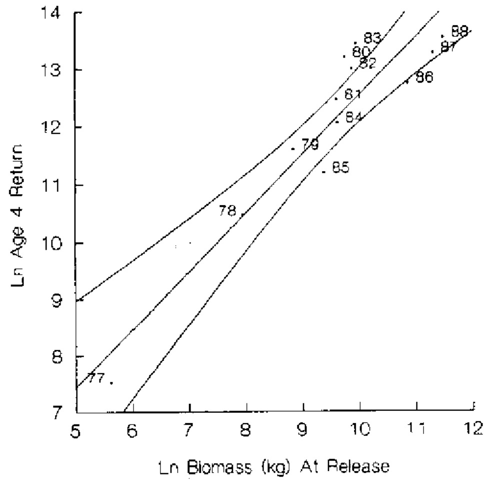

Figure 6. Log transformation of the relation between age 4 returns and the biomass at release for Hidden Falls chum salmon ($r=0.94$, $p<0.001$). Numbers in figure indicate brood year.

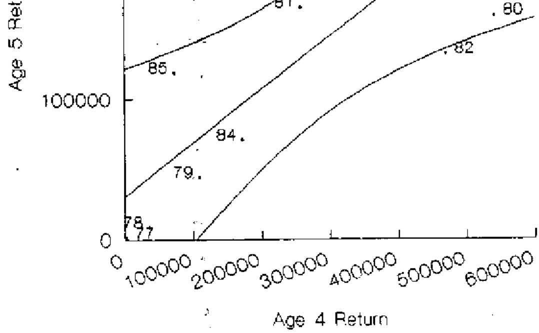

Figure 7. The relation between the age 5 return in year t and the age 4 return in year t–1 for Hidden Falls chum salmon ($r=0.81$, $p=0.002$). Confidence limits are 95%. Numbers in figure indicate brood year.

In practice, the regression models are used to only approximate the returns by age class. The actual prediction is adjusted by the dynamics of the recent return history. For example, the return by age class appears to exhibit a time trend effect (Figure 4). From 1980 to 1984, age 4 returns were above the prediction, but more recently (1984-1987) have fallen below. Similarly, the age 5 return falls above the regression line in four of the last five years, whereas it was less than predicted in six of the seven years from 1977 to 1982. To account for this, the predicted value for the return from each age class is multiplied by the ratio between the observed and predicted return from the previous year.

Results and Discussion

In 1992, the first year this method was applied, the regression models predicted an age 4 return of 1,366,800 (range 446,500 to 3,727,500 at the 95% confidence limits) and an age 5 return of 235,700 (range 143,400 to 365,900). The log age 4 return for 1991 was approximately 95% of the log value predicted from the regression, and the age 5 return for the 1986 brood was approximately 15% greater than predicted. Applying these proportions to the regression estimates, the age 4 return was predicted to be 674,000 and the age 5 return 270,000. Added to this were 16,000 for the 3 and 6 year age classes, for a total return forecast of ~960,000.

The actual return for 1992 was approximately 1,028,000, including catch outside the terminal area. The terminal catch, plus escapement, was estimated at 990,000. The age composition of the return included 714,000 4 year olds and 298,000 age 5, which, respectively, were 6% and 10% greater than predicted. Thus, for the first year, the general model performed reasonably well.

Whether the degree of accuracy achieved in 1992 can be maintained depends on several factors. First, additional releases of up to 30 million fry from the area are planned within the next several years. If Figure 3 is indicative of the variability in adult returns at large release numbers, the precision of the estimate may decline.

Second, because fry size at release influences ocean survival, size variation within broods may also affect adult abundance. Mortality due to "pinheading" during rearing has ranged from 0 to 5%, and considerable variation in size is typical in years of high rearing mortality. Since mortality of chum salmon during ocean residence is apparently biased toward smaller individuals (Parker 1971), it is possible that greater size variation within broods may increase variability in ocean survival. Although changes in diet and feeding practices have largely eliminated "pinheading" mortality, size variation during rearing is also influenced by factors such as temperature, and the effect of this variation in the model is not yet known.

Finally, changes in ocean conditions over the long term may alter marine survival independent of the effects related to the number and size of fry released. The extent to which the observed time trend effect in marine survival can be attributed to the carrying capacity of near shore environment is unclear. Ocean distribution of chum salmon is affected by both temperature and currents (Neave et al. 1976, Hartt 1980), and the possibility that changes in these conditions influence survival cannot be discounted. Moreover, hatchery releases have increased dramatically since the mid-1970s, particularly in Asia (Kaeriyama 1989), and density-dependent effects on survival must also be considered. These factors interact in complex ways to influence marine survival, and accurate estimates of adult returns may depend on better understanding these processes.

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Forecasting Run-timing and Abundance of Migrating Adult Pink Salmon Using Sex Ratio Information

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Introduction

Fishermen and fishery managers have long observed larger numbers of male adult pink salmon *(Oncorhynchus gorbuscha)* during the first half of the run, complemented by larger numbers of females during the second half. From this phenomenon, a general rule-of-thumb has emerged within the fishery which suggests that: (1) When the catches are showing more males than females, the run is considered less than half over. (2) When the catches are showing equal numbers of males and females, the run is considered near its mid-point. (3) When catches are showing more females than males, the run is considered more than half over. The utility of using sex-ratio data as a tool in forecasting the run-timing and abundance of adult pink salmon in-season is explored through the analysis of purse-seine fishery data collected by the Alaska Department of Fish and Game (ADF&G) from commercial fishing district 104 in southeastern Alaska.

Modeling

The logistic regression model is a generalized linear model specially suited for modeling binary, or more generally, binomial response data (Aiken et al. 1989; Chambers et al. 1992). A binary response variable y may be encoded y=1 if a male is observed, and y=0 if female. The mean over several such observations is a binomial random variate and an estimate of p the proportion of males in the population at the time the sample was taken.

The logistic regression model takes the mean response parameter p as a logistic function of the predictor variable time *(t)*,

$$p = \frac{e^{\alpha+\beta t}}{1+e^{\alpha+\beta t}} \qquad \text{(EQ1)}$$

Fishery Management

Pink salmon in southeastern Alaska move onshore into territorial waters then along the outer coasts of the Alexander Archipelago. They enter inside waters through several main portals on their way to their spawning areas. These portals include Icy Straits in the northern, Sumner Straits and lower Chatham Straits in the central, and Dixon Entrance in the southern parts of the region. In these areas large gauntlet fisheries are conducted harvesting fish from many mixed stocks of pink salmon.

Pink salmon are targeted by the purse-seine fleets which account for an average of 90% of the annual pink salmon harvest for the southeastern Alaska region (ADF&G 1990). Other gear types contributing to the catch of pink salmon in the region are drift gill-net (5%), troll (2%), and Annette Island fish trap (2%) (ADF&G 1990).

Currently ADF&G uses sex ratio information collected from pink salmon caught in the commercial purse-seine fishery, as a qualitative measure of run progress (Hoffmeister 1992). The run is assumed to be more than half over when the sex-ratio in the commercial catch has clearly shifted to less than 50% males. Assessment and anticipation of run progress is made on the basis of comparisons to sex-ratio patterns of past years and manager experience.

Run-timing Estimation

The objective of the in-season run-timing forecast is to predict the day of the mid-point of the run as early in the season as possible. As has been previously noted, this event corresponds closely with the day of 50% males. The day of 50% males will correspond to the point of inflection of a logistic curve fit to the declining proportion of males.

These analytic properties of the logistic model are the basis of forecasting the mid-point of the run using sex ratio information. By fitting the sex ratio data by day to the logistic function previously described, the inflection point of the sex ratio curve $\bar{T}$ may be estimated as the ratio of the intercept and slope parameters from the fitted logistic model.

$$\hat{T} = \frac{-\hat{\alpha}}{\hat{\beta}}$$

The variance and bias correction for T may be estimated by the delta method and are shown in equations 2 and 3 below.

$$var(\hat{T}) = var(\frac{\alpha}{\beta}) \approx (\frac{-\alpha}{\beta})^2 \left(\frac{var(\hat{\alpha})}{\alpha^2} + \frac{var(\hat{\beta})}{\beta^2} - \frac{2}{\alpha\beta} cov(\hat{\alpha}, \hat{\beta}) \right) \quad \text{(EQ 2)}$$

$$E(T) \approx \frac{-\alpha}{\beta} + \frac{1}{2\beta^2} \left(-cov(\alpha, \beta) + \frac{2\alpha var(\beta)}{\beta} \right) \quad \text{(EQ 3)}$$

(Seber 1982).

This method (whose estimator will now be referred to as the one-stage estimator) may be adapted to incorporate historical sex ratio information which may be particularly useful early in the season or any other time marked by low or irregular sampling. This adaptation follows from the hypothesis that the general pattern or rate of sex ratio transition is conserved between seasons and is characterized by the slope parameter β. Inter-annual variations in the sex ratio pattern then, is primarily a property of run timing and is characterized by the intercept or location parameter α. The slope parameter is estimated from the combined historical data, then fixed as an offset in the second stage estimation of the intercept, estimated from the current years data conditional upon the first stage estimate β. Estimation of the intercept parameter is again weighted by a binomial weighting factor. Variance and bias correction for this alternative estimator of T (now referred to as the two-stage estimator) are derived from the conditional variance and expectation equations.

$$E(\frac{\alpha}{\beta}) = E_1(E_2(\frac{\alpha}{\beta}|\beta)) = \alpha E_1(\frac{1}{\beta}) = \frac{\alpha}{\beta} + \frac{Var_1(\beta)}{\beta^3} \quad \text{(EQ 4)}$$

$$Var(\frac{\alpha}{\beta}) = Var_1(E_2(\frac{\alpha}{\beta}\bigg|\beta)) + E_1(Var_2(\frac{\alpha}{\beta}\bigg|\beta))$$
$$= \frac{\alpha^2}{\beta^2} \left(\frac{Var_2(\alpha)}{\alpha^2} + \frac{Var_1(\beta)}{\beta^2} \right) \quad \text{(EQ 5)}$$

where subscript 1 refers to the estimation of β from historical data in the first stage, subscript 2 refers to the estimation of α in the second stage, conditional upon the first stage estimate β.

Abundance Estimation

Abundance estimation is based upon the time-density method proposed by Mundy and Mathisen (1981) and follows from the theoretical relation

$$Nq_t = I_t \qquad \text{(EQ 6)}$$

where N *is* the annual abundance, I_t is the CPUE index of abundance, and q_t *is* the catchability coefficient, both at time t. From equation 6 it follows that

$$N\sum_t q_t = \sum_t I_t$$

or

$$\hat{N}_t = \frac{\sum_t I_t}{\sum_t \hat{q}_t} \qquad \text{(EQ 7)}$$

In equation 7, $\hat{N}_t$ *is* an estimate of total annual abundance made at time t from the ratio of the CPUE index I_t and the estimated catchability coefficients $\hat{q}_t$, both summed over time. The critical issue here is the estimation of the $\hat{q}_t$. These values are estimated from the fitted values of a three parameter, time dependent, logistic model fit to historical CPUE data and annual abundances through non-linear least-squares,

$$Q_t = \frac{K}{(1+e^{a+bt})} \qquad \text{(EQ 8)}$$

where

$$Q_t = \sum_{i=1}^{t} q_i = \frac{1}{N}\sum_{i=1}^{t} I_i$$

Estimating Abundance Using Run Timing Information

The main idea for incorporating migratory timing information with abundance estimation is to relocate the historic migratory time density (or cumulative catchability coefficient distribution) to a new time location as predicted by the sex ratio information. This is accomplished by estimating a shift parameter δ as the difference between the historic mean day of arrival $\bar{T}$ and the predicted day of an even sex ratio $\hat{T}$

$$\delta = \bar{T} - \hat{T} \qquad \text{(EQ 9)}$$

The distribution of predicted daily proportions p_t or daily catchability coefficients q_t is then shifted on the time scale to be centered about a new center at

$$T = \bar{T} - \delta \qquad \text{(EQ 10)}$$

If T has been corrected for bias then δ is also unbiased and the variance of δ is equal to the variance of as T

$$Var(\delta) = Var(\bar{T} - \hat{T} = Var(\hat{T})$$

The abundance estimator is then

$$N_t = \frac{\sum_{i=1}^{t} I_i}{\sum_{i=1}^{t+\delta} q_i} = \frac{\sum_{i=1}^{t} I_i}{Q_{t+\delta}} \qquad \text{(EQ 11)}$$

The variances for the time shifted abundance estimator is derived using the conditional variance delta-method.

$$var(N) = E(var(N|\delta)) + var(E(N|\delta)).$$

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Changing Sex Ratios During Spawning Migration of Pink Salmon in Southeast Alaska

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Introduction

It is a well documented fact that the males of many salmonid fish populations are the first to arrive on the spawning grounds. The obvious survival value is to insure male gametes are available when the first eggs are being deposited.

It is not well established that parity of the sexes prevails among the fry. According to a Russian paper by Persov (1964), males dominate in odd years and females in even years. This has been observed both for hatchery-produced pink larvae and in natural populations. However, the sample sizes were small, usually ranging from 200 to 500 specimens, and presumably taken once during the season and with great variability from hatchery to hatchery. Until this has been verified, we shall assume that there are the same number of males and females in populations of fry migrating to the estuaries.

The general life history of pink salmon, especially from Southeast Alaska, includes a stay of several months in the inshore water before the juveniles commit themselves to the Coastal Jet which brings the fish to the northwestern part of the Gulf of Alaska. The young pink salmon enter the oceanic part of the Gulf of Alaska late in the year for the first time where they remain until July/August the following summer when shoreward migration to the spawning grounds takes place.

Sex Ratios in High Sea Samples

Some spawning populations of pink salmon have more females than males. In Hooknose Creek in British Columbia, females outnumbered males in nine out of ten years (Hunter, 1959). Golovanov (1982) reported similar findings for two streams in the Magadan Region. Ivankov (1968) reported a male surplus from 1.4 to 2.0 in the Kuril Islands. He attributed this to selective removal of females by high sea gillnets. Yefanov and Chupakhin (1982) questioned this and considered a higher survival of males due to lower energy losses in their gonadal development. Many factors like selective harvest may change the sex ratio in spawning populations. It is, therefore, of importance to establish sex ratios among pinks caught in the open ocean.

The Japanese training ship, T/V *Oshoro Maru,* from Hokkaido University in Hakodate, makes annual cruises to the Gulf of Alaska. Fishing takes place with gillnets having variable mesh sizes ranging from 29 mm to 167 mm stretched measure. The nets are set at 6 PM and retrieval commences at 4 AM the next day. Every fish in the entire catch is measured, weighed, and a scale sample taken. Material collected in three years were available, viz. 1988, 1989, and 1990. The fishing stations were all outside the 200 mile economic zone except a few stations in 1988. Tagging experiments have demonstrated a considerable mixing of feeding pinks in the ocean from all districts in the Gulf of Alaska. Although gillnets are selective, it was assumed that catches from a battery of variable mesh gillnets produced a representative sex ratio at a station.

A total sex ratio for the three seasons, giving each station equal weight, is 49.8% males, or almost parity of the sexes (Table 1). But when one looks at the individual stations, there is great variability from station to station, and no definite trend similar for all three years. One cannot only look at sex ratios, but time of sample and the relative strength of the various races feeding together in the ocean are equally important. It is assumed that the same number of males and females are present on the open sea.

Relationship of Sex Ratios to Cumulative Catches

The pink salmon enter the spawning streams of the Southeast Alaska archipelago through four main portals: Icy Strait, Lower Chatham Strait, Sumner Strait, and Dixon Entrance (Figure 1). These locations provide excellent opportunities for in-season run estimation. It appears that the cumulative numbers of salmon entering the coast for a spawning stream follow a sigmoid-curve. Since run timing is an inherited character, it is largely invariant and average run timing curve can be used for in-season sequential run estimates. This was formally explored by Mundy (1979) and Mundy and Mathisen (1981). Today, average run timing curves are an integral part of most salmon management systems.

Table 1. Stations and percentages of male pink salmon by date. R/V *Oshoro Maru* experimental gillnetting.

Year	1988			1989			1990		
Longitude	Station	Date	%Male	Station	Date	%Male	Station	Date	%Male
160.0 W	13	7/6	49.5	10	7/1	42.6	7	6/30	44.0
158.0 W				11	7/2	36.3	8	7/1	
157.0 W	14	7/7	59.5						
156.0 W				12	7/3	41.2	9	7/2	51.2
154.0 W	15	7/8	74.4	13	7/4	33.4	10	7/3	41.2
152.0 W	16	7/9	62.2	14	7/5	38.4	11	7/4	57.9
150.0 W	17	7/10	59.4	15	7/6	31.2	12	7/5	34.8
148.0 W	18	7/11	55.7	16	7/7	44.8	13	7/6	29.8
146.0 W	19	7/12	63.8	17	7/8	59.4	14	7/7	48.0
144.0 W	20	7/13	46.7	18	7/9	58.8	15	7/9	77.6
142.0 W	21	7/14	56.0	19	7/10	50.3	16	7/10	55.8
141.0 W				20	7/11	29.9	17	7/11	53.1
140.5 W				21	7/12	30.1			
140.0 W	22	7/15	60.7				18	7/12	63.4
139.5 W				22	7/13	66.1			
139.0 W				23	7/14	72.7			
138.0 W	23	7/16	60.7	24	7/15	35.8			
137.0 W	24	7/17	57.6	25	7/16	65.0			
136.5 W				26	7/17	62.5			
136.0 W	25	7/18	45.4						
135.0 W	26	7/19	42.5						
134.0 W	27	7/20	40.7						
Mean			55.7			47.0			46.4

Depending upon environmental factors such as air or water temperatures, run timing may move backward or forward a few days. The width of a window under which successful reproduction can take place decreases from south to north. Southeast Alaska, being almost in the center of pink salmon distribution in Alaska, has a window spanning two months, and consequently, there is room for shift in run time. However, some of the manifestations seen today of shift in timing are caused by the composite nature of salmon runs to Southeast Alaska with three principal groups, early, middle, or late spawning, respectively, before August 15, from August 15 to September 15, and after September 15. The variable strength, especially of the early runs, can change the total timing curve. At present, our knowledge of pink salmon migration does not allow separation between these three run components, and the run at an entrance portal must be treated as a unit. This will be examined for some districts.

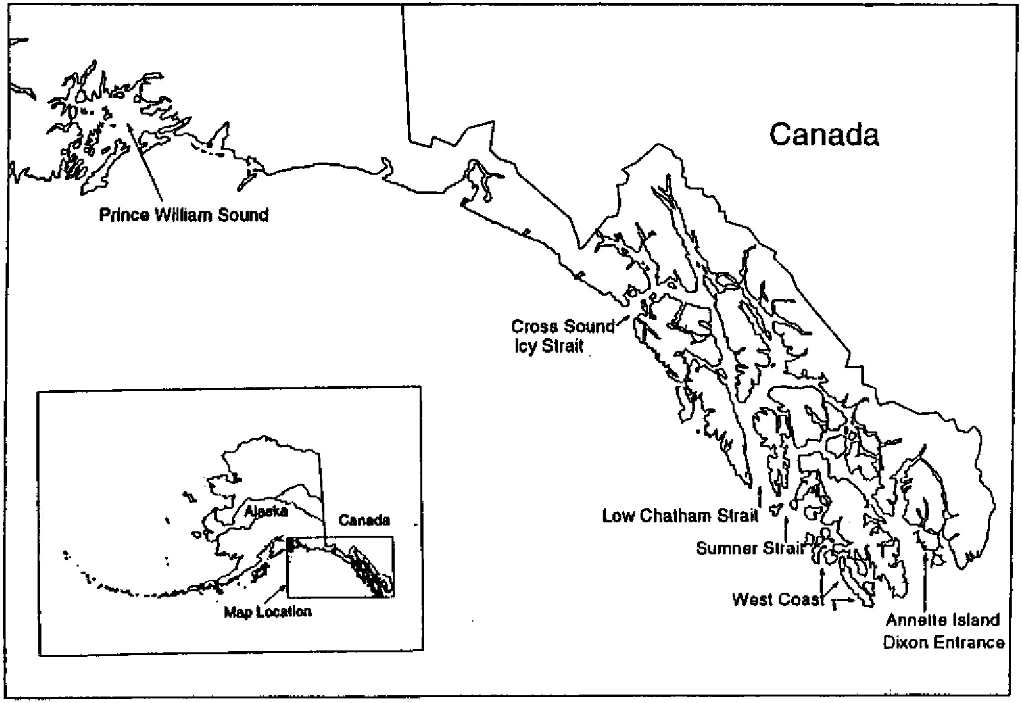

Figure 1. Map of Southeast Alaska and Prince William Sound with main entrance portals of pink salmon to the spawning grounds.

The Relationship Between Sex Ratio and Total Cumulative Catches

District 104

The data from District 104 represent catches taken from incoming schools of pink salmon to the southwestern coast of Southeast Alaska and the area can be considered an entry portal. The dates when the cumulative catches reached 50% vary 11.25 days for reasons discussed above (Figure 2). In spite of this, the time when the sex ratio reached 50% varied from a maximum of 3.75 days to 0 days. A sex ratio of 50% is, therefore, a vary practical and useable indicator of run timing whereby expected catches for the entire season can be predicted. Seemingly, there is a bias since sex ratio reached 50% before the cumulative catches. It is not clearly understood what is causing this.

Annette Island

The 50% point for cumulative catches has a range of 4.4 days (Figure 3). This smaller range is probably due to the fact that the traps are closer to the spawning grounds and there are fewer years involved. Some variability is also introduced by an irregular brailing schedule for the traps.

Armin F. Koernig Hatchery in Prince William Sound

The catches here represent a terminal run with timing governed by the donor stocks. The timing of 50% catches has a range of 5.6 days and maximum time between the 50% catch mark and the 50% sex ratio was 3.13 days (Figure 4.)

Applications

Our ability to make accurate pre-season forecasts of pink salmon runs to Southeast Alaska, is limited and an early verification is desired by the fishing industry. In order to allow time to make adjustments in processing operations, in-season run estimates should be made during the first few weeks of fishing. Such estimates must be based on cumulative catches rather than on sex ratios due to the greater variance of the latter parameter.

However, the sex ratio is a valuable auxiliary parameter in assessing the midpoint of the run. At this time, the information may have more relevance to the setting of pink salmon prices rather than run estimations. The confidence limits of run estimates are narrow at this time.

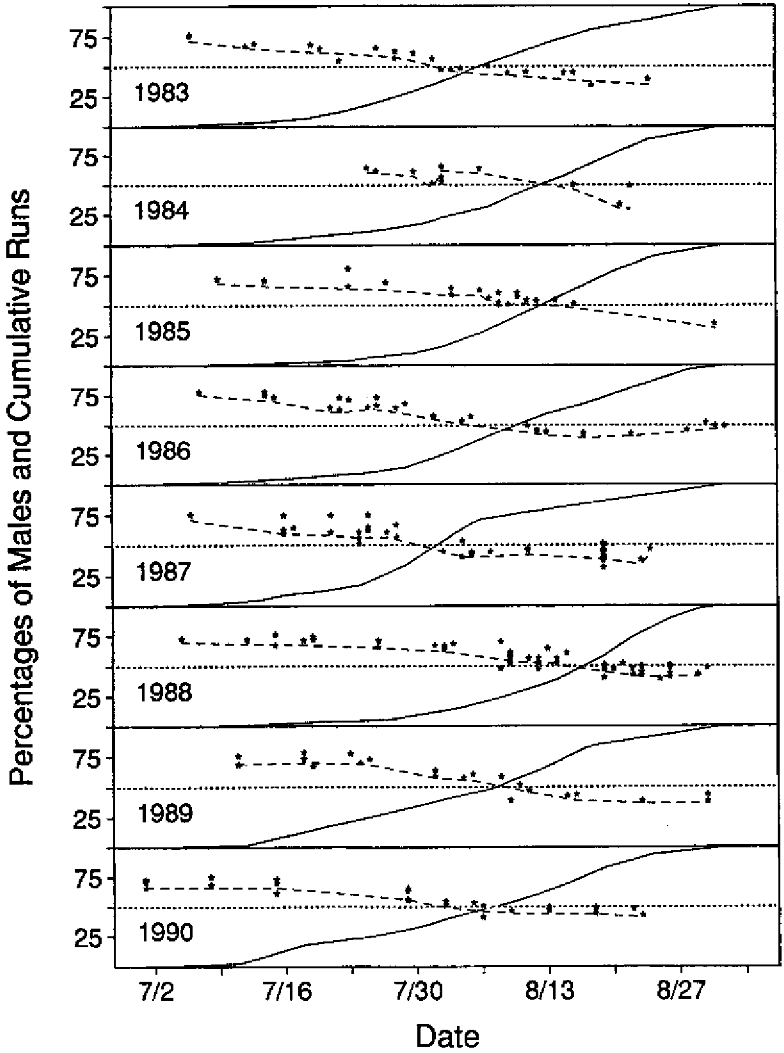

Figure 2. Cumulative catch curve and changes in sex ratios 1983-1990 from the southwestern coast of Southeast Alaska (District 104).

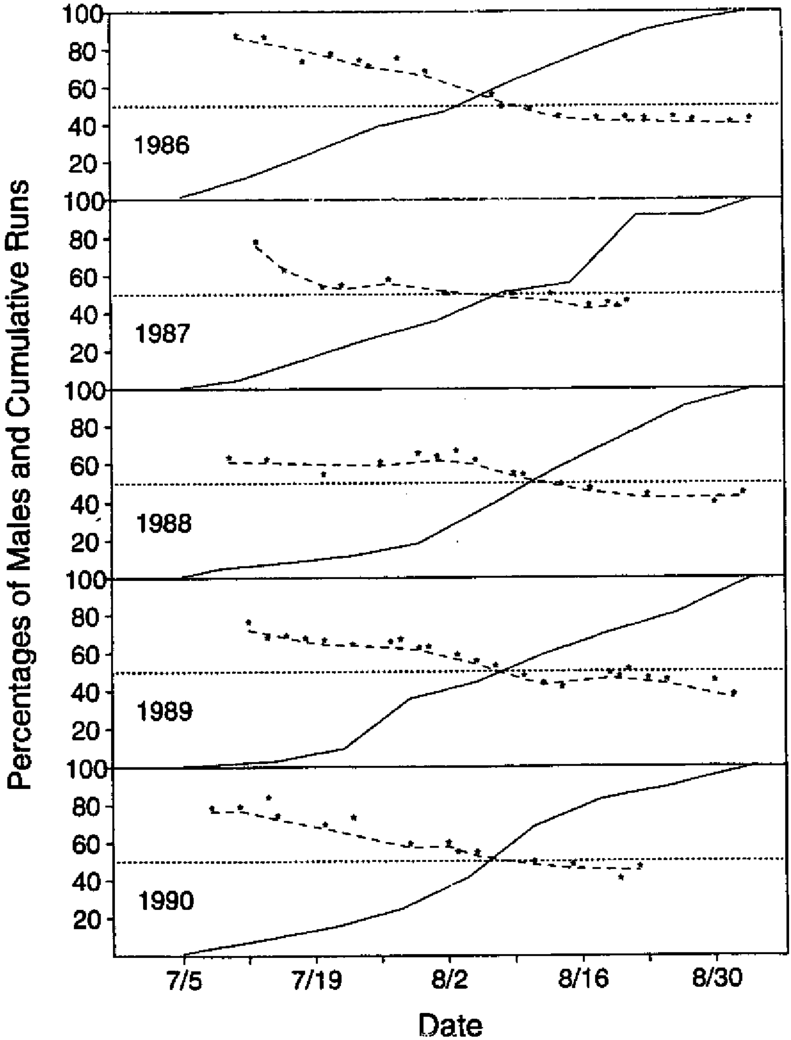

Figure 3. Cumulative catch curve and changes in sex ratios 1986-1990 for traps at Annette Island.

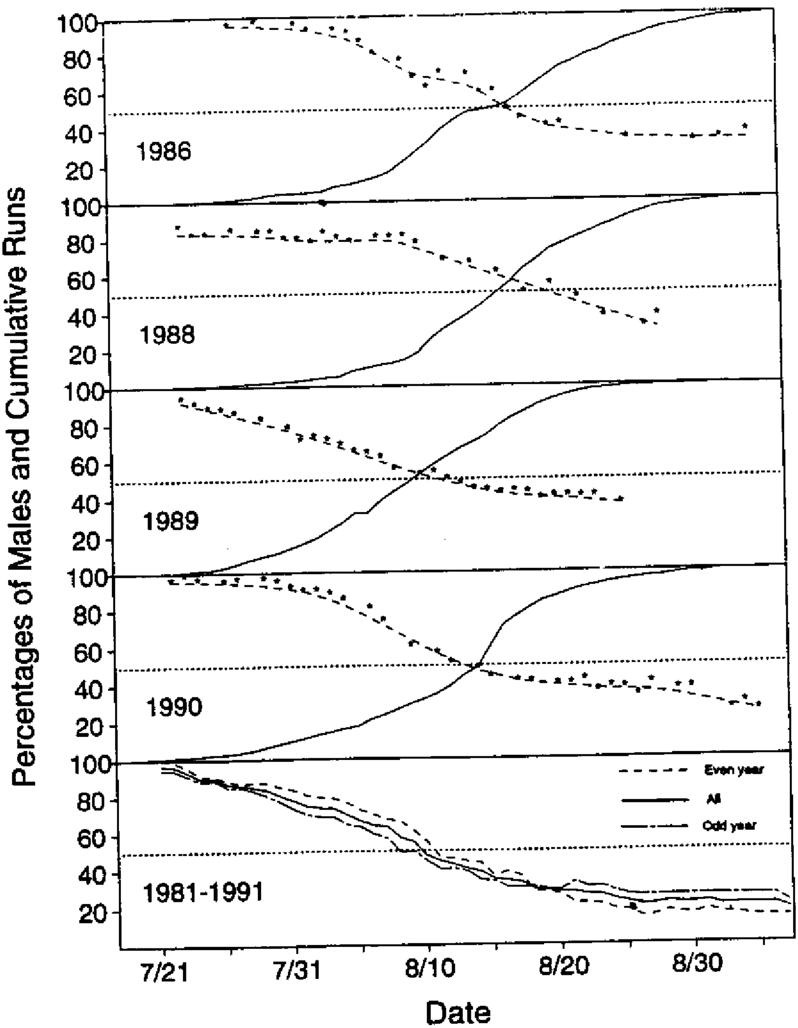

Figure 4. Cumulative catch curve and catches in sex ratios 1986-1990 for terminal harvest at A.F. Koernig Hatchery in Prince William Sound.

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Southeast Alaska Mapping with Catch and Escapement Overlaying

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Alaska Department of Fish and Game staff are developing a computer mapping application to overlay in-season catch and escapement information and open areas. Southeast Alaska mapping with catch and escapement data overlaying is in development. Coast outline maps of the region are available in a scale of 1 to 250,000. Smaller maps may be generated by specifying the maximum and minimum latitudes and longitudes. They may be annotated with commercial fisheries statistical area boundaries and other data. Catch or escapement data comparisons for the mean of prior years can be displayed with current year data for catch areas or by stream location.

Stock Separation by Thermally Induced Otolith Microstructure Marks

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Mass marking hatchery salmon through the effect of thermal manipulations on the otoliths in the egg and early alevin stages can provide an effective means to evaluate the success of hatchery release strategies, to identify the contribution of hatchery salmon to the commercial fishery, and to aid in the management of natural salmon production. The marks are induced by dropping the water temperature rapidly by at least 3 degrees C to impose a "check ring" on the microstructure of the otolith. By controlling the number and the spacing of the check rings, distinctive codes can be created to distinguish between groups of hatchery releases. Previous studies have indicated that this is a viable method for marking 100% of the released fish while inducing no extra mortality or cost beyond that needed for heating/chilling the water to induce the marks. The relative ease in inducing thermal marks has enabled 52 different release groups containing over 327 million marked fry of all five salmon species to be released into Alaskan waters by the spring of 1993. Despite the volume of these releases, fisheries biologists and managers have only recently addressed the issues associated with recovering the marks from adult salmon in the commercial fishery. In reviewing the potential for thermal mass marking, Crandall et al. (1990) made recommendations that new releases be considered carefully because at that time the methods to recover the thermal mark from adult fish were still being developed. This paper is intended to be a summary about how these concerns are being addressed. The argument is presented that thermal mass marking can be an effective tool for management because of the ease of its application, the relatively small samples needed to obtain adequate estimates of hatchery contribution, and the recovery of thermal marks is fairly rapid using conventional grinding and polishing methods, despite a high degree of variation in individual otolith shape.

Introduction

Inducing thermal marks in otoliths as a tool for mass marking has been reported and demonstrated in a number of recent studies (Brothers 1985; Mosegaard et al. 1987; Volk et al. 1990; Munk et al. 1992).

Otoliths are part of fishes vestibular apparatus and reside in the cranial cavity. They are composed of calcium carbonate and protein and are formed by the process of biomineralization. When thermal marks are induced by dropping temperatures rapidly by several degrees Celsius, a type of metabolic shock, the result is a brief interruption of calcium carbonate precipitate, with a possible increase in organic deposition. This brief interruption of otolith growth occurs on the growing surfaces of the otolith. When viewed with transmitted light, the protein component, which is optically dense, appears as a dark ring against the light background of the relatively translucent calcium carbonate. The number and spacing of the thermal rings can provide a coding sequence used to distinguish hatchery releases from each other and from wild stocks. During subsequent growth, the record of thermal disruptions is preserved in the otolith microstructure, but obscured by the overlaying material. Recovering the mark requires removing a portion of otolith to allow viewing of the microstructural core.

In Alaska this method for mass marking salmonids has gained considerable attention, and as a result numerous releases have occurred to date (Table 1). Pilot projects undertaken to determine the feasibility of marking pink salmon include a small scale attempt at the Solomon Gulch Hatchery in 1988 (Paul McCollum, Valdez Fisheries Development Association, personal communication), and a marking experiment at Auke Creek Hatchery in a cooperative study by the University of Alaska, the Department of Fish and Game, and the National Marine Fisheries Service in 1989 (Munk and Smoker 1990). The first large-scale marking of pink salmon and the first marking of chum salmon took place at the Douglas Island Pink and Chum, Inc. (DIPAC) Gastineau Hatchery with the 1990 brood year (Munk and Smoker 1991). The hatchery installed a

Table 1. Summary of thermally marked salmon releases in Alaska.

Species	Hatchery	Brood Years	Number of Groups	Releases (millions)	Recovery Plan
Pink	VFDA	88	1	-	Pilot study
Pink	Auke Creek	89, 90	2	-	Pilot study
Pink	DIPAC	90, 91,92	3	131	In Prep.
Chum	DIPAC	91, 92	4	127	?
Chum	Hidden Falls	91	1	10	?
Sockeye	Snettisham	88 thru 92	26	35	US/Can
Sockeye	Trail Lakes	90, 91, 92	11	22	?
Coho	DIPAC	91, 92	2	2	?
Chinook	DIPAC	91, 92	3	0.5	?
TOTAL			52	327.5	

heating system specifically designed for thermal mass marking. This first large-scale marking demonstrated that the method was cost effective with heating fuel consumption of approximately $^1/_3$ gallon of fuel oil/hour/ million pink salmon and $^1/_2$ gallon/hour/million chum salmon (Munk et al. 1992). Using the system in 1992 , the cost of marking 61 million chum and 50 million pinks was under $10,000 (Ladd Macaulay, DIPAC, personal communication). The thermal mark has been recovered from the adult pink salmon of this initial release in mixed stock fisheries (ADF&G Otolith Lab, unpublished data) as well as from local stream systems adjacent to the hatchery (Eric Volk, Washington Department of Fisheries, personal communication and ADF&G Otolith Lab, unpublished data).

In addition to thermally marking pink and chum salmon, mass marking sockeye salmon has also been ongoing. Since 1988, sockeye reared at the Central Incubation Facility at the state of Alaska Port Snettisham Hatchery have been thermally marked and released into Canadian Lakes as part of Annex IV of the U.S./Canada Salmon Treaty. To date over 26 different release groups have been thermally marked. Recovery of the marks is being used to determine the success of the outplanting (ADF&G Otolith Lab, unpublished data, and Bruce Morley, Canada Department of Fisheries and Oceans, personal communication) and will be used to help allocate the returning adults between U.S. and Canadian commercial fisheries.

Applications

Essentially there are three primary reasons for embarking on a thermal mass marking program. One is for the determination of ownership and to allocate the enhanced fish among different groups, particularly in instances in which coded wire tagging is impractical. This is one of the motivations behind the sockeye thermal marking as part of the U.S./Canada treaty. A second reason is a need by the hatcheries themselves to evaluate the success of their release strategies and the contribution of the fish to the commercial fisheries. This is one of the primary motivations for the large releases to date by hatcheries.

The third reason for thermal marking is because of a direct management concern over the impact of large scale releases on the state of Alaska's ability to manage the fishery for wild stocks. Alaska state statute (AS: 16.05.730) directs that fish stocks shall be managed consistent with sustained yield of wild stocks. In large scale hatchery releases, mass marking 100% of the fish provides a numerical sampling advantage over conventional coded wire tagging methods which is limited to marking a relatively small proportion of the fry (as low as 1 in 600).

Provided the returning adults can be randomly sampled, the numbers required to determine the relative proportions of hatchery to wild fish through the otoliths is several orders of magnitude smaller than the numbers required to be examined for adipose finclips which indicate a coded wire tag might be present. Figure 1 provides a graphical display of how the sample size necessary to construct a confidence interval range around the proportion of marked fish, (in this example 20% hatchery), is relatively invariant of the actual population size. Assuming random sampling, even for a population of infinite size, only a sample size of 385 is necessary for an approximate 95% confidence interval within a precision of 5% of the estimated hatchery proportion. This relatively small number of otoliths that are needed to determine the proportions in any time-area strata, however, creates an additional burden to ensure that the otoliths are a random sample from the population of interest.

Recovering Thermal Marks

The quality of thermal mark imposed is the most important determinant on the ability to recover the marks in the returning adults. Unless the hatcheries maintain strict temperature control before, during, and after the marking period, the quality of mark can be compromised. In addition marking during hatching should also be avoided because it can

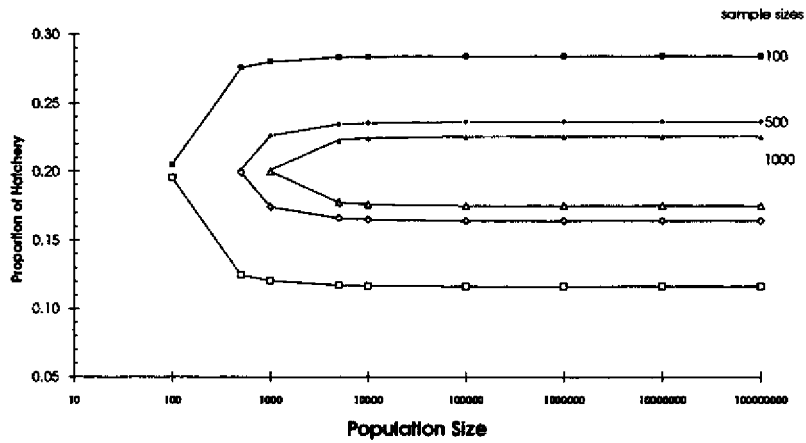

Figure 1. Upper 95% confidence range (black symbols) and lower 95% confidence range (open symbols) for samples sizes of 100, 500, and 1000, around an estimate of 20% hatchery contribution over a range of population sizes. The figure illustrates how the sample sizes needed to achieve a degree of precision are relatively independent of actual population size.

Table 2. Component variation of measurements of the left and right otoliths from 46 adult pink salmon returning to the Gastineau Channel Hatchery. The high within individual component illustrates the variable nature of otolith morphology and difficulties likely to be encountered in developing automated otolith processing methods.

	Percent component variation	
Measurement	Within Individuals	Between Individuals
Otolith length (major axis)	34.7	65.3
Otolith width (minor axis)	35.3	64.7
Otolith surface area (flat projection)	26.1	73.9

affect the appearance of the mark. Creating good quality marks in northern climates is currently an active area of research and recommendations on marking protocols are being prepared.

In pink salmon, recovering the thermal marks from adults requires the ability to remove up to 400 microns of overlaying material (1 micron = 1/1000 mm) and the ability to distinguish features down to 1 micron in size. Variation in otolith shape and size, however, makes it difficult to determine a fixed amount of material to remove to consistently expose the microstructure of the otoliths. The intrinsic variation of otolith shape can be illustrated by comparing the within-individual variation of otolith size with the between-individual variation. Table 2 shows the estimates of the variance components of otolith length, width, and projected surface area from both the left and right otoliths of 46 pink salmon that returned to the Gastineau Hatchery in 1992. There was no systematic difference in these size measurements between the left and right otoliths, however, the component variation between the two otoliths within individuals is almost half that of the variation between individuals. If one considers a mixed stock fishery and species in which multiple age classes are present, the variation in otolith size could be quite large, and it would present a problem in using automated processing methods.

This variability in otolith morphology is the reason why manually processing individual otoliths presents advantages over automated, multiple-sample processing to remove constant amounts of material. The procedure for processing otoliths involves dissecting the otoliths from the fish, mounting the otoliths individually on glass slides using thermal plastic cement, and exposing the microstructure by removing overlaying material using successively finer grits of abrasives on a mechanical grinding wheel. During the removal process, the experienced worker may view the otolith through a compound microscope several times and make judgment about how much more material to remove. By varying the pressure applied to the otolith, as well as the choice of abrasives, the worker is able to achieve a high degree of control on material removal. By viewing the otolith during this process a decision on the presence or absence of the thermal mark in the otolith microstructure can be made. If the mark is there, experience has shown that it can be observed while there might be as much as 20 microns of overlaying material yet to remove. Certainty is increased by getting closer to the microstructural core, though if too much material is removed all traces of the mark may disappear.

Figure 2 shows the microstructure of a pink salmon adult otolith after the final polishing step. This fish, obtained from the commercial catch, was released by DIPAC hatchery in 1990. The identifying thermal marks are indicated in the figure by the letter A. When viewing the otoliths with transmitted light, the appearance of the microstructure is dependent upon the orientation of the crystalline bundles of calcium

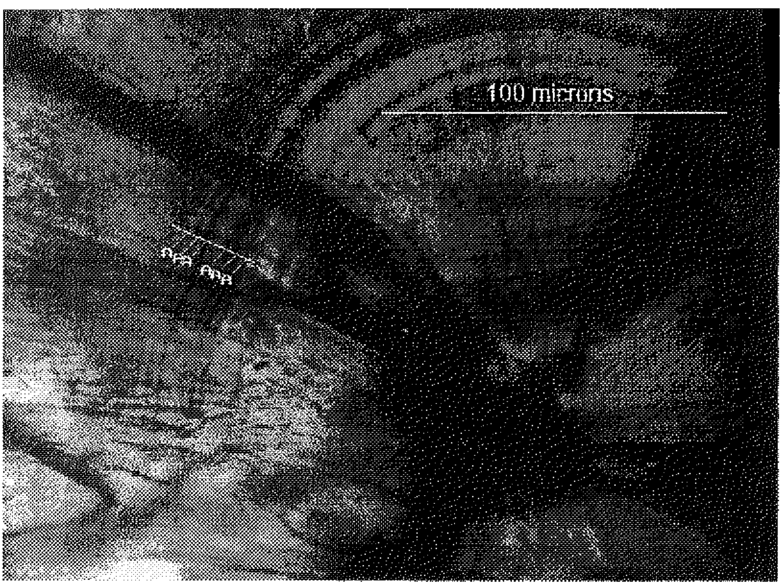

Figure 2. Thermally marked adult pink salmon otolith with the DIPAC 90 mark (Munk and Smoker 1991) recovered from a mixed stock fishery in 1992 and processed in the Alaska Department of Fish and Game's Otolith Lab. Thermal rings indicated with the letter A. The digital image was taken with a compound microscope using transmitted light at 200 power. A 100 micron scale is included.

carbonate which can scatter light, the location of dense proteinaceous regions which can absorb light, and by fractures running through the otolith which will deflect light and appear as dark swaths in the image. During removal of the overlaying otolith material by grinding, the optical characteristics change, resulting in a complex array of light and dark fields. The best locations to view the thermal marks are in fields uninterrupted by fractures in which the crystalline bundles run perpendicular to the viewing plane. In those cases the 'shadows' of the optically dense protein deposits associated with thermal marks appear in contrast to uniform background of normal growth.

Because the decision on the presence or absence of a mark is a highly dynamic process, closely associated with the removal of material, it does not easily lend itself to an automated *bar-code reading* approach. This method, however, is quite rapid, and we believe quite accurate, given good quality thermal marks. In a matter of a few minutes processing, a judgment is made on each otolith, or given the vagaries of otolith morphology, a non-decision is made and the next otolith from the sample examined. A pair of otoliths are removed from each fish, and the companion otolith is held in reserve and can be used as a check on the initial decision. Two people processing can be used as an additional means of determining precision, and a blind test of known samples used to gage accuracy.

Given clearly defined objectives and an adequate sampling program, we believe detecting otolith thermal marks can be used as an effective tool to aid in-season management decisions.

Acknowledgment

Contribution PP-082 of the Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau.

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Recent Trends in Pink Salmon Harvest Patterns in Prince William Sound, Alaska

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Prince William Sound is the site of Alaska's largest experiment in hatchery enhancement of salmon runs. In 1991 and 1992, 29% and 14% of the state's pink salmon catch came from Prince William Sound. Beginning in the mid-1980s, large runs of hatchery-produced pink salmon began to equal, then far exceed, the returns of wild pink salmon in Prince William Sound. Before the large-scale hatchery production, catch trends were a simple, obvious, and easily measured index of the health of the wild pink salmon in Prince William Sound. Now that hatchery production is far greater than wild production, catch trends simply reflect hatchery production capacity, and the health of the wild stocks is much harder to assess. Similarly, because the catch of wild-stock salmon is no longer easily observed without expensive and complex stock separation studies, the wild-stock harvest rates are not easily measured. The scale of the hatchery production and size of the wild stocks give reason for concern; the target exploitation rate on the hatchery stocks is in excess of 90%—far higher than what wild stocks can sustain. By looking at aggregate escapement levels and using tagging studies of hatchery contribution to the fisheries, the wild stocks appear to be healthy. However, a deeper look at wild-stock harvest rates and escapement estimates reveals some alarming trends.

The Alaska Department of Fish and Game (Sam Sharr, ADF&G Area Research Biologist in Cordova, Alaska, personal communication) studied the errors in pink salmon escapement estimates in Prince William Sound as part of its examination of the affect of the 1989 *Exxon Valdez* oil spill. This effort led to revised escapement estimates of pink salmon escapement from 1963 through 1992 and showed that historic escapement and recruitment was larger than previously reported. These new escapement estimates have not yet been published, and have only been circulated in draft form. They are available from the Alaska Department of Fish and Game in Cordova, Alaska. Heard (1991) and Eggers et al.. (in press) described catch and escapement in Prince William Sound, so that recent overall average harvest rates were estimated to be near 65%. With the new information it appears recent overall harvest rates were nearer to 45%. I will refer to the older escapement estimates as the "index-spawner units," while the new estimates will be referred to as the "new units." Because managers have described their escapement objectives in terms of the index-spawner units, this view of escapement better measures management's effectiveness. Because the new units are on the same scale as the catch, these new units are more useful for studying salmon biology and stock productivity.

Since Alaskan statehood, the harvest policy in effect in Prince William Sound has been a constant escapement goal policy, with the goal near 1.0 to 1.4 million fish, in the index-spawner units. Figure 1 shows the estimated harvest rates as a function of run sizes, in the new units. Also shown is a curve which describes the target harvest rate for a fixed escapement goal of 5 million spawners, in the new units. An escapement of 5 million in the new units is near 1.4 million fish in the index-spawner units, even though there is not a one-to-one correspondence between the two ways of generating escapement estimates. For this particular escapement goal, observations below the curve represent years of underharvest, while years above the curve represent years of overharvest. If the harvest policy had been a fixed harvest rate policy, the

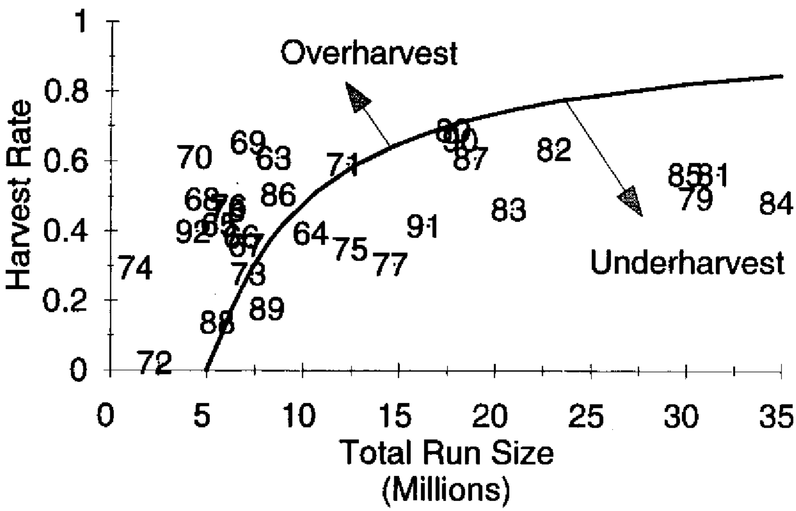

Figure 1. Estimated harvest rates on Prince William Sound wild-stock pink salmon as a function of estimated run size. Run size was estimated using the Exxon Valdez revised escapement estimates and is larger than previous run size estimates. The thick black line represents the target harvest rate for a fixed escapement goal of 5 million.

observations should lie around a horizontal line. The actual observations give the impression that a hybrid harvest policy had been in place. Note observations tend to fall around a horizontal line near 45% for large stock sizes, while very low harvest rates are observed only at low stock sizes. The average harvest rate at stock sizes below the goal is held up by large harvest rates at similar stock sizes in some years.

Figure 2 shows the estimated sound-wide escapement, in index-units from 1965 to 1992. This graphic shows three periods: a period from the mid-1960s to the late-1970s when management failed to achieve the escapement objectives, the period from the late-1970s to the mid-1980s when management allowed underharvest, and finally the late-1980s to 1991 when management seems to be closer than ever to achieving the escapement goals.

The escapement history for each individual fishing district tells a somewhat different story. Figure 3 provides district-specific escapement estimates from 1965 to 1991, the last year available by individual districts at this time. The escapement history in District 221 (Eastern District) looks similar to the sound-wide history, with periods of below the objectives, above the objectives, and in recent years, near the objectives.. The escapement in District 226 (Southwestern District) shows high escapements in the recent period, while the escapements in District 227 (Montague District), and District 228 (Southeastern District) are

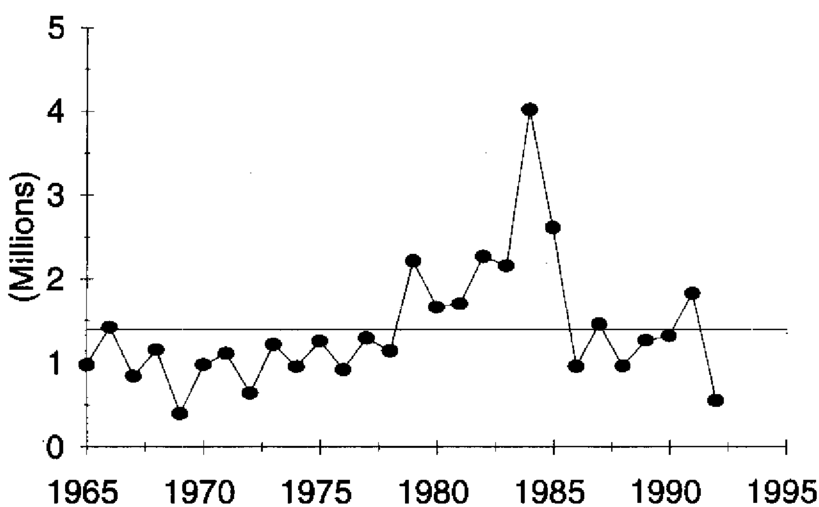

Figure 2. Aggregate estimated escapement of Prince William Sound wild-stock pink salmon in ADF&G index-spawner units from 1965 to 1992.

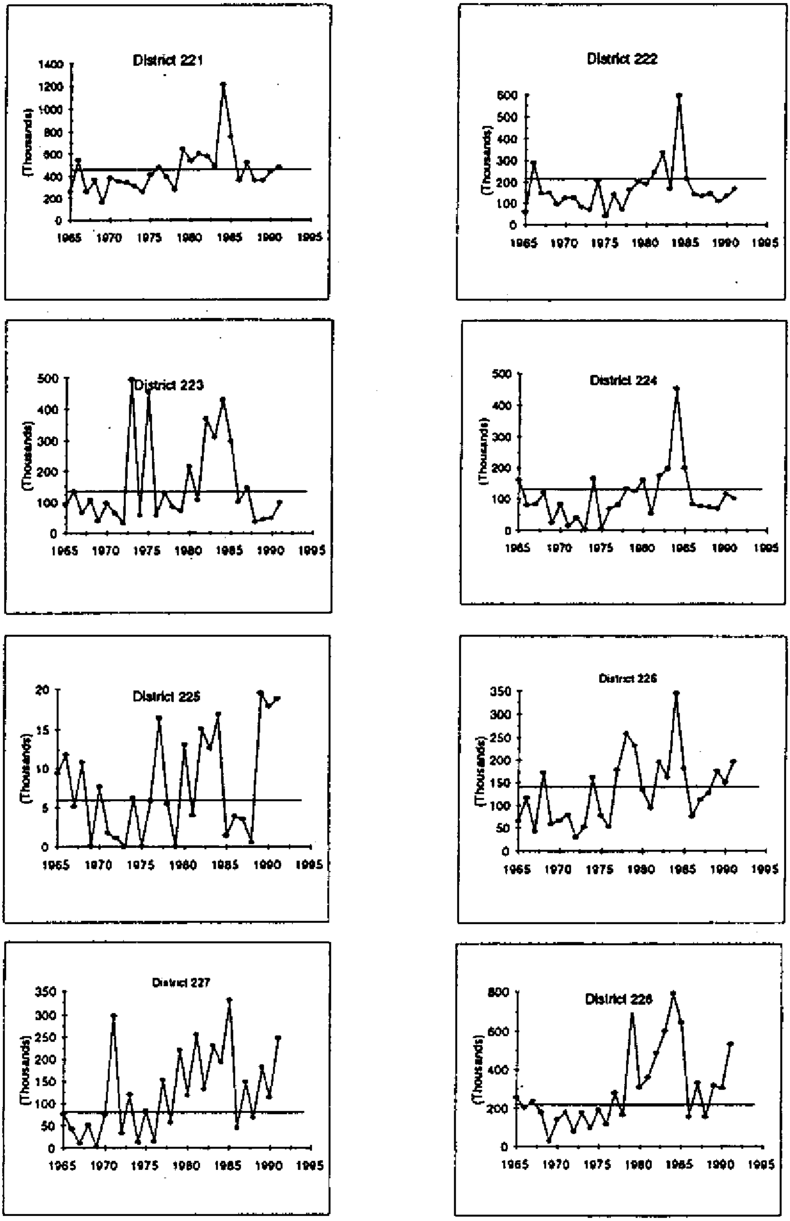

Figure 3. District specific estimated escapement of Prince William Sound wild-stock pink salmon in ADF&G index-spawner units from 1965 to 1991.

consistently higher than the escapement objectives in the recent period. However, the history in District 222 (Northern District) shows the recent escapements are similar to the early period, when managers consistently failed to reach escapement objectives. The escapement history for District 223 (Coghill District) shows recent escapements even lower than the previous period of under-escapement

Why have managers failed to reach escapement objectives in District 222 (Northern District) and especially District 223 (Coghill District)? Is there something about those stocks that has resulted in lowered stock productivities? Templin et al. (in these proceedings) estimated harvest rates using run reconstruction methods. For the years they examined, they estimated that the northern stocks actually have above-average productivities—but these stocks have experienced the largest harvest rates in the sound. What their model points out is that the Coghill Stock is harvested at a rate unknowable to the fishery managers, in the District 226 (Southwestern District), District 225 (Eshamy District), District 224 (Northwestern District), and District 222 (Northern District). The net effect is a high harvest rate. In years of low wild-stock abundance, the harvest is restricted to hatchery terminal areas in District 226 (Southwestern District) and District 223 (Coghill District); but even then, the wild-stock harvest rates remain relatively high in the hatchery terminal areas. The current information strongly suggests overfishing of Prince William Sound's northern stocks in mixed-stock fisheries.

Based on yet unpublished coded wire tag estimates, the entire 1992 wild run was needed for spawning escapement. Yet, for a variety of reasons related to the need to harvest the hatchery return, the harvest rate on wild salmon was held to nearly the recent average. Escapement was at disastrously low levels in some streams. In 1994 the return of hatchery-produced pink salmon will again be expected to be tens of millions. The overall harvest rate on these hatchery fish will be required to be over 90%. There may not be any harvestable surplus of wild fish because of the severe overharvest in 1992, yet the need to harvest the hatchery fish will constrain the wild-stock harvest rates to some high level. This may be the beginning of a downward spiral that each year will be more and more costly to get out of.

Managers may not have the authority or the means to correct the problem of overharvest of the northern stocks. Effective solutions and remedies can only come after a full understanding of the problem. Effective action will depend on the manager's ability to articulate the causes to the fishing fleet. An accurate picture of the fraction of wild and hatchery fish is available for only five years. In that time the fishery has changed from nearly half wild fish in 1987, to over 90% hatchery fish with severe overharvest of wild stocks in 1992. The stock separation studies that have allowed us to describe the problem are not even a permanent part of the Prince William Sound management program. These studies have been funded since 1989 as part of the *Exxon Valdez* oil spill assessment, and are expected to end soon. The charge to protect wild stocks will surely be impossible once the wild stocks are unobservable in the fishery. The conflicting objectives of protecting the wild stocks and maintaining high harvest rates on hatchery stocks may be impossible with the tools managers now have, and will surely be impossible without future stock separation studies.

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A Run Reconstruction of the Wild Pink Salmon Fishery in Prince William Sound

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Introduction

The manager of a salmon fishery must balance present economic opportunity against future wild salmon production. The ratio of harvested fish to the total run is referred to as the harvest rate. The number of salmon required for spawning depends on the population's productivity; target harvest rates for wild salmon are typically below 50%. Given the manager's vicarious control of fishing effort, the target harvest proportion is difficult to achieve even with a single population of salmon.

Mixed-stock fisheries are even more difficult to manage, because of the inability to attain the target harvest rate for each stock. One may have to balance the underharvesting of productive stocks with possible overharvesting of less productive stocks. The situation is simplified if the stocks may be temporally or spatially separated or if they are similarly productive. The realized seasonal stock-specific harvest rate depends on interacting patterns of fishing effort and salmon abundance.

The Prince William Sound pink salmon (*Oncorhynchus gorbuscha*) fishery has harvested roughly 22 million fish per year since 1979. The hatchery fish to wild fish composition of the catch is roughly 4:1, making the hatcheries the major contributors to the catch. Because hatcheries require fewer spawners to produce a return of mature fish, these stocks can sustain harvest rates above 90%. Domination of the fishery by hatchery produced pink salmon makes it more difficult to conserve the wild stock.

The Sound boasts well over 1,000 streams along 3,000 miles of coastal habitat perfectly suited to the production of pink salmon. One could define each stream population as a separate stock; however, we choose to define the stocks by escapement within the salmon management district boundaries (Figure 1).

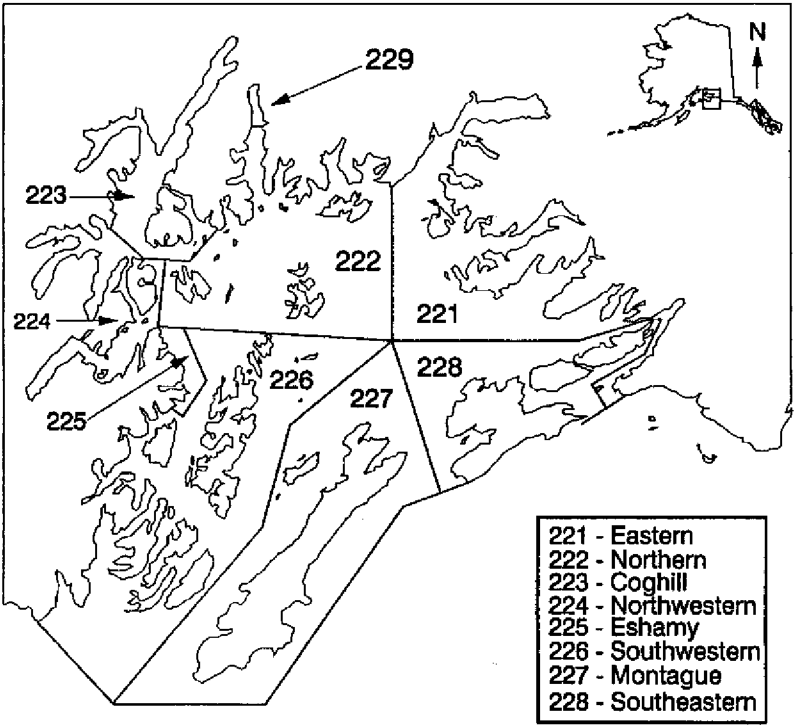

Figure 1. Prince William Sound salmon management districts.

Presently there is no way to distinguish stock composition of the catch during the fishery. Thanks to a program of coded wire tagging (CWT) hatchery released fry begun in 1987, hatchery and wild pink salmon can be distinguished after the fishery has occurred.

Separation of the individual wild stocks is a secondary, but very important concern. Because each wild stock is characterized by its own productivity and timing, each should have its own target harvest rate. Current management practice seeks to meet a target escapement level for each stock, making harvest rates a symptom, not a goal of the fishery. Without a feasible means to empirically effect the separation of wild stocks, it is impossible to measure stock-specific harvest rates.

We have developed a mathematical model to reconstruct the history of each stock as it passes through the fishery. Using escapement, catch, and tagging data, the run reconstruction generates information on harvest rates, run sizes, spatial and temporal distributions and catch contributions. This stock-specific information will be useful in the management of the mixed-stock pink salmon fisheries.

Methods

We reconstruct the 1991 wild pink salmon fishery in Prince William Sound. The reconstruction only involves salmon of wild origin, so hatchery fish were removed from the data using catch contribution estimates from CWT information.

The escapement of stock *n* is measured as the daily number of salmon entering the streams of district *n*. Escapement is estimated with a variation of an algorithm developed by Hilborn, Bue, and Sharr (personal communication), by assuming a normal distribution of daily salmon escapement and a constant stream-life for each district.

The model accumulates salmon in a harvestable pool in each District. The size of each pool is controlled by inputs and outputs which take the form of daily catch and escapement and movement between pools (Figure 2). By combining the Eshamy District (225) with the Southwestern District (226) and the Unakwik District (229) with the Northern District (222), 7 pools and 7 stocks are modeled. We assume

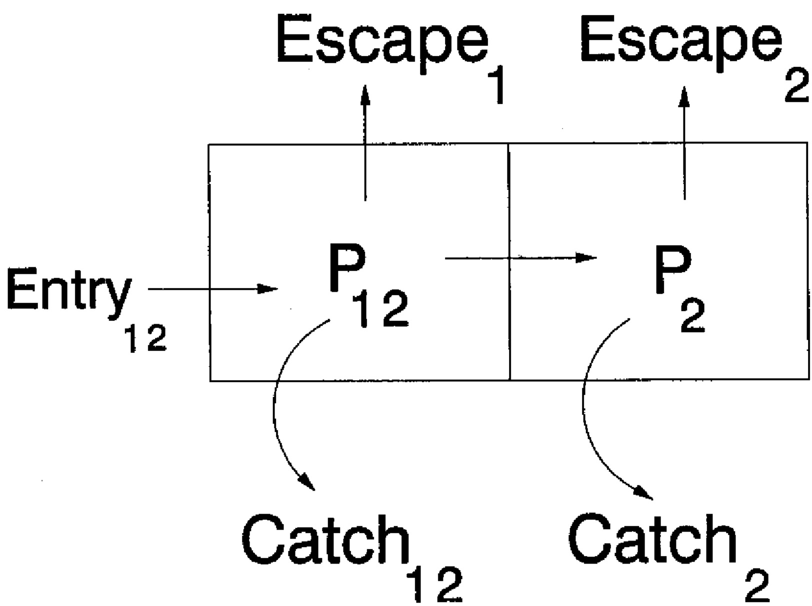

Figure 2. Two-stock/two-district model of inputs and outputs. Subscripts denote stock of origin.

that final escapements, migration pathways, and transition probabilities are known and that all fish are equally vulnerable to capture. The fishery is then reconstructed with the following relationships:

$$\underline{P}_{tn} = \Theta_n \underline{P}_{t+1,n} + \underline{c}_{tn} + \underline{e}_{tn} \qquad (1)$$

$$c_{tnd} = C_{td} \; * \; \frac{P_{tnd}}{\sum_{n} P_{tnd}}, \qquad (2)$$

where,

$\underline{P}_{tn}$ = vector of district abundances of stock *n* on day *t*

Θ_n= 8X8 matrix of transition probabilities

$\underline{c}_{tn}$ = vector of district catches of stock *n* on day *t*

$\underline{e}_{tn}$ = vector of district escapements of stock *n* on day *t*

C_{td} = observed mixed-stock catch in district *d* on day *t*.

Equation (1) computes the daily abundances of a stock of fish from the inputs and movement probabilities. The equation is iterated backward in time making $\underline{P}_{tn}$ dependent on $\underline{P}_{t+1,n}$. The matrix Θ_n contains transition probabilities that control the movement of salmon between districts and between the Sound and the Gulf of Alaska. These probabilities are derived from the results of a 1992 ADF&G radio-tagging study in the Sound. The vector of escapements $\underline{e}_n$ has only one non-zero element, the one that corresponds to the district of escapement. The catch removal (2) from stock *n* on day *t* in district *d* is computed as a function of its relative abundance in the pool of available fish and the observed mixed-stock catch for the same district and day. Due to the construction of the fishery backward in time, catch and escapement are considered to be additions to the pool.

Seasonal estimates of stock-specific catch removals are computed as

$$c_n = \sum_{d} \; \sum_{t} c_{tnd} \qquad (3)$$

By adding the total catch c_n to the total escapement of a stock we compute the initial size R_n of the stock before entry to the fishery. From this we can compute the harvest rate μ_n experienced by the stock as

$$\mu_n = \frac{c_n}{R_n} \qquad (4)$$

We examine the model's sensitivity to errors in escapement timing and migration rates. These errors are applied to the Coghill district (223) stock, because it has an unusually high predicted harvest rate. To test the sensitivity of the results to escapement timing, the whole escapement entry distribution was shifted by 10 days, earlier and later. Sensitivity to transition rates was tested by first doubling then halving the rate of movement through the entire sound.

Results and Discussion

The results of the reconstruction of the 1990 and 1991 pink salmon fishery are given in Tables 1 and 2, respectively. Predicted run sizes for each stock are generally within the range of expected returns for the escapèments in 1988 and 1989, between 2 and 3 returns per spawner. The exceptions are the predicted returns to district 223 each year. An actual return of 5.25 million salmon in 1990 would indicate that 38 adults returned for every spawner in 1988.

The observed harvest rate experienced by the pooled wild stocks was 68% and 43% in 1990 and 1991, respectively. The seasonal harvest rate estimated for each wild stock is not evenly distributed among the stocks. The stock-specific harvest rates are a direct result of the computed stock-specific catches. These in turn result from the spatial and temporal distribution of a stock and the pattern of harvest. We would expect a

Table 1. Results from reconstruction of 1990 Prince William Sound wild pink salmon fishery.

Stock	221	222	223	224	226	227	228	Total
Escapement	1557.727	549.444	154.288	451.216	1912.574	475.192	1082.136	6181.570
Catch removal	3697.204	1134.589	5091.391	591.783	2690.635	10.658	9.746	13226.010
Initial stock size	5254.037	1684.002	5245.626	1042.988	4603.200	485.847	1091.882	19407.580
Harvest rate	0.70	0.67	0.97	0.57	0.58	0.02	0.01	0.68
(1.0 = 1000 salmon)								

Table 2. Results from reconstruction of 1991 Prince William Sound wild pink salmon fishery.

Stock	221	222	223	224	226	227	228	Total
Escapement	2318.536	852.908	378.311	525.270	2405.747	1384.119	1794.346	9658.019
Catch removal	1113.807	471.630	2826.060	143.721	2864.132	0.000	0.000	7419.351
Initial stock size	3431.270	1324.452	3204.339	668.983	5269.873	1384.109	1794.345	17077.370
Harvest rate	0.32	0.36	0.88	0.21	0.54	0.00	0.00	0.43
(1.0 = 1000 salmon)								

higher harvest rate on a stock that traverses more fisheries or composes a large portion of the pool during periods of large catches. Stock 223 is subject to harvest in four fisheries: 222, 223, 224, and 226. In each fishery, it contributes significantly to the pool at time of harvest. Thus, a higher predicted harvest rate than the other stocks is not unreasonable. Stock 221 also migrates through four fisheries, but its earlier time of migration allows it to miss much of the harvest pressure in districts 222 and 226. The very high harvest rates predicted for stock 223 in both years reveal problems in the model assumptions.

The assumptions underlying the reconstruction model are controversial. Data on the number and distribution of escaping salmon are notoriously difficult to obtain and analyze. The direction and speed of adult salmon migration requires more than one year of tagging to quantify. Applying equal vulnerability to all fish in a management district is questionable when considering the size of the fishing area and the concentration of the fishing effort. Some analysis of the model's sensitivity to violation of the assumptions is necessary and may explain the misallocation of salmon to 223.

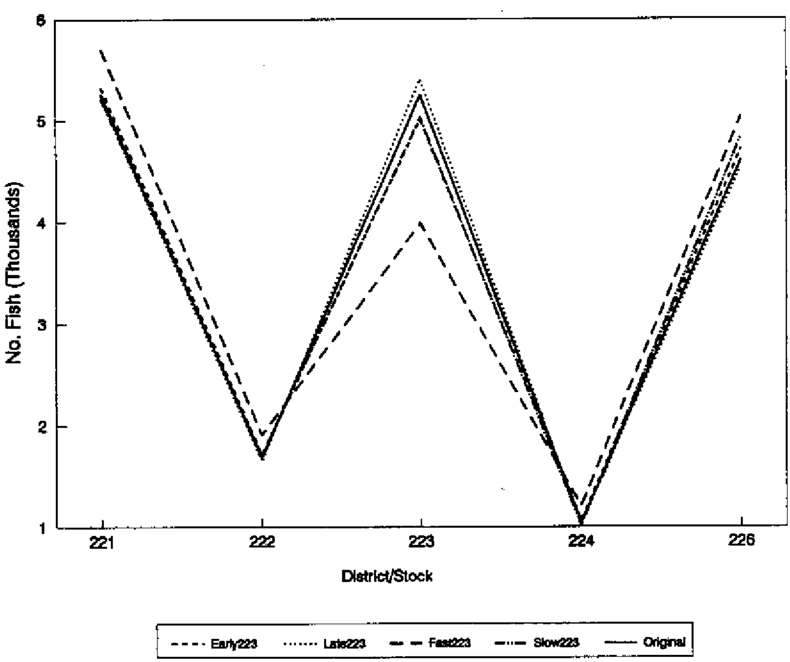

Figure 3. Reconstructed run size sensitivity analysis.

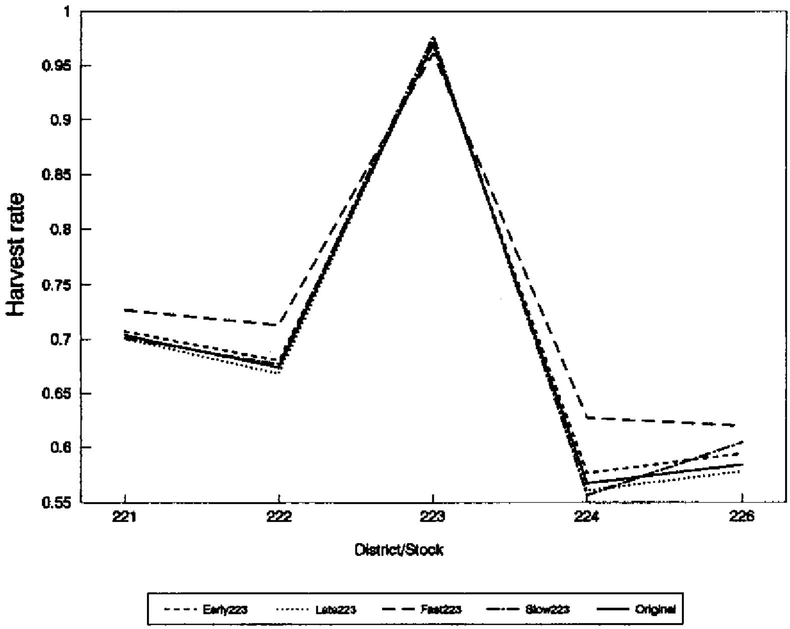

Figure 4. Reconstructed harvest rate sensitivity analysis.

Due to the mechanics of the reconstruction, we expect that changes in the relative composition of the harvestable pools of fish will affect the resulting distribution of harvest. By shifting the escapement timing of stock 223 we shift its distribution within each of the districts it traverses. Changing the transition parameters of stock 223 increases or decreases an individual fish's vulnerability by changing its rate of travel. Figures 3 and 4 indicate that this is true. The timing of escapement of 223 does not appear to have much effect on its harvest rate, which is probably due to the intensity of the harvesting effort along its migration path. Changes in migration rates did have an appreciable effect. Slower migration did not significantly change the number of fish harvested from the stock, but faster migration reduced the catch. These results imply that errors lie within our specification of salmon movement. More study is necessary to fully understand salmon migration in Prince William Sound.

Run reconstruction is a potentially important tool for managing pink salmon fisheries in Prince William Sound because it allows a manager to assess the effects of harvest decisions on individual wild stocks.

Use of the Geographic Information System in Aquatic Habitat Management

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The channel type, an inventory and mapping tool for stream classification based on stream reaches, was incorporated into the Geographic Information System (GIS) to facilitate manipulation and storage of stream inventory data.

The basic component of the channel type is the fluvial process group which describes the interrelationship between runoff, landform relief, geology, and glacial or tidal influences on erosion and depositional processes. Channel type inventories provide key information on fish habitat utilization, habitat capability and enhancement options. Most Tongass National Forest, state, and Native Corporation streams in Southeast Alaska have been mapped using the channel type method.

The GIS is hierarchical with the watershed being the base unit. Attributes within the watershed polygon can be denoted with arcs (stream segments, or other line features) or points (site-specific features) depending on configuration.

Information entered into GIS by stream segment (arcs) includes channel type, process groups (aggregation of channel types), stream length, fish numbers and distribution by species, woody debris distribution, etc.

Point information is usually key habitat features, physical or human features, barriers, habitat improvement structures, stream gauges, fish weirs, point sediment sources, etc.

The goal is to manage most of the data now stuffed in files and bookcases and newly acquired information in a permanent, readily accessible aquatic habitat database retrievable at the watershed or project level from which reports and/or resource maps can be created.

Assessment of Injury to Pink Salmon Eggs and Fry

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This study is part of an integrated group of Natural Resources Damage Assessment Fish/Shellfish (NRDA F/S) Studies conducted to quantify damage to pink salmon *Oncorhynchus gorbuscha* as a result of the *Exxon Valdez* oil spill. Each study attempted to determine the injury to salmon at different stages of the life cycle. Wild pink salmon play a major role in the Prince William Sound ecosystem. Salmon are prey to a variety of terrestrial and marine mammals and birds, while also providing a pathway for nutrient transfer from marine to near-shore and terrestrial ecosystems. Wild pink salmon also contribute to the region's commercial fisheries.

Up to 75% of the wild pink salmon which spawn in Prince William Sound use intertidal areas (Helle et al. 1964). These areas are highly susceptible to contamination from marine oil spills. Moles et al. (1987) and Rice et al. (1975) found that pink salmon eggs and pre-emergent fry were adversely affected by exposure to crude oil and that the effect was most acute in intertidal environments. The 24 March 1989 spill from the *Exxon Valdez* occurred just prior to the spring migration of salmon fry and contaminated many intertidal spawning areas in central and southwest Prince William Sound.

This study evaluated: (1) the immediate effects of oil exposure on pre-emergent pink salmon numbers in the spring of 1989, (2) the effect of intertidal oil exposure on pink salmon egg mortality, and (3) the effect of intertidal oil exposure on pink salmon egg to pre-emergent fry survival. Samples were also collected for histopathological and mixed-function oxidase analysis. This project concentrated on southwestern Prince William Sound although streams from Montague Island and eastern Prince William Sound were sampled to provide a broader perspective.

Study streams were selected using the following criteria: (1) adult salmon returns were expected to be large enough to provide a high probability of success in egg and fry sampling, (2) egg and fry sampling had been done in past years, and (3) streams which had low to no oil impact (controls), were selected near high oil impact streams. Pink salmon fry remain in the stream where they were deposited as eggs. This trait allowed oiled and control sites to be located in close proximity to each other, thus reducing any geographical affect on the findings.

Forty-eight streams were sampled for pre-emergent fry in 1990, 1991, and 1992. These included 25 streams historically sampled to forecast adult pink salmon returns and 23 additional streams from the oil impact area. Thirty-one streams were sampled for pink salmon egg mortality in 1989, 1990, and 1991. The streams sampled for egg mortality were included in the group of streams sampled for pre-emergent fry.

The methods used for both egg and pre-emergent fry sampling were similar to those described by Pirtle and McCurdy (1977). Sampling was stratified by tide zone to control for possible differences in egg mortality or overwinter survival due to salinity, temperature, predation, oil, or a combination of these factors. Four zones, three intertidal and one above tidal inundation, were sampled whenever possible for each stream: 1.8-2.4 m, 2.4-3.0 m, 3.0-3.7 m above mean low water and upstream of mean high tide (3.7 m). Zone boundaries were established with a surveyor's level and stadia rod and staked prior to sampling. No sampling was done below the 1.8-2.4 m zone as survival was expected to be low (Helle et al. 1964). Upstream sample areas were often within the reach of extreme high tides (3.7-4.6 m) since ice and snow often limit the extent of upstream sampling.

Separate linear transects were established within each zone for egg and pre-emergent fry surveys. Although most transects were 30.5 m long, some were shorter due to steep stream gradients. Transects were placed in riffle areas where spawning was observed during escapement surveys conducted by NRDA F/S Study 1. Transects ran diagonally across the river; fry survey transects started downstream against the right bank and moved upstream to the left bank, while egg survey transects started downstream against the left bank and moved upstream to the right bank. This placement of egg and fry transects reduced sampling overlap and the influence of fall egg sampling on spring fry abundance.

Fourteen circular digs, each 0.186 m^2, were systematically made along each transect. The number of digs was a compromise between reducing variance and the practicality of conducting the study. Fewer digs were completed in narrow stream channels to avoid excessive sampling of the stream.

Stream oil exposure classifications were based on visual observations (NRDA F/S Studies 1 and 2) and hydrocarbon content of 1989 mussel tissue (*Mytilus* sp.) samples (NRDA F/S Study 1). Hydrocarbon analysis of mussel tissue and mixed-function oxidase analysis of pre-emergent fry generally agreed with visual observations of stream oil contamination. Histopathological analysis failed to detect lesions in pre-emergent fry, although results from another study (Fink 1992) indicate the fry may have been collected too early in their life to have developed lesions.

Since the annual pre-emergent pink salmon fry density survey conducted by the Alaska Department of Fish and Game, Division of Commercial Fisheries, was underway at the time of the spill, many streams were sampled for pre-emergent fry density prior to or immediately after oil exposure. An additional session of sampling was also done approximately two weeks after the spill. This second survey allowed some streams examined during the first sampling session to be examined for immediate effects of oil contamination.

Few dead pink salmon fry were found either prior to or shortly after oil exposure. Only 9 of the 52 transects examined contained more than five dead fry. No increase in fry mortality was detected between the first and second samplings, although only 3 of the 14 streams examined were oiled. Likewise, no difference in fry density was detected between the first and second sampling.

Egg mortality was significantly greater in oiled streams in 1989, 1990, and 1991. We believe these differences indicate an affect due to oil exposure. The 1989 investigation detected a statistically significant difference in egg mortality ($p=0.0001$) between oiled and control streams. Examination of stream zone contrasts indicated that egg mortalities were greater in oiled streams and that statistical differences were due to elevated egg mortality in the intertidal zones. Mean mortalities for the oiled and control streams were 0.174 and 0.104.

The 1990 egg mortality study also showed a statistically significant difference ($p=0.0008$) between oiled and control streams. Again, examination of stream zone contrasts indicated greater mortalities in oiled streams with the statistical difference confined to the upper intertidal zone. Mean egg mortalities for the oiled and control streams were 0.295 and 0.195.

Egg mortality results were consistent with perceived oil contamination. Among oiled streams, all intertidal zones were contaminated in 1989 whereas in 1990 oil remained only in the upper intertidal zone.

The 1991 evaluation demonstrated very significant egg mortality differences between oiled and control streams ($p=0.0001$). Inspection of stream zone contrasts indicated that egg mortalities in all zones were greater for the oiled streams. Mean mortalities for the oiled and control streams were 0.433 and 0.221. This finding was unexpected and at this time remains unexplained. We have hypothesized that the continuing and increased mortality is the result of genetic damage sustained by the eggs and alevins which incubated in oiled gravel during the fall of 1989 and spring of 1990. We are presently evaluating this hypothesis through a series of controlled rearing experiments.

No significant difference in egg-to-fry survival was detected between oiled and control streams for 1989 to 1990, 1990 to 1991, or 1991 to 1992. We feel these results were due to insufficient power in the sampling design or sampling levels to detect differences rather than a true lack of change.

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Diet of Juvenile Pink and Chum Salmon in Oiled and Non-oiled Nearshore Habitats in Prince William Sound, 1989 and 1990

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The diets of juvenile pink and chum salmon were studied in nearshore habitats in oiled and non-oiled areas of Prince William Sound after the March, 1989 *Exxon Valdez* oil spill. Food consumption by pink and chum salmon was not lowered in the presence of oil. Stomach fullness and food quantity were similar in oiled and non-oiled areas in both 1989 and 1990. Oil globules or sheen were observed, however, in both pink and chum salmon stomachs from oiled sites in 1989. Because no oil was observed in fish stomachs from non-oiled sites in 1989 or from any site in 1990, these observations suggest that ingested oil could be a route of hydrocarbon contamination. Pelagic zooplankton averaged 69% of pink and 56% of chum salmon diet biomass. Small and large calanoid copepods were the primary zooplankters consumed by pink and chum salmon, respectively. Diets in oiled and non-oiled areas changed from 1989 to 1990. Pink salmon fed more on zooplankton in oiled areas than in non-oiled areas in 1989, but both pink and chum salmon fed less on zooplankton in oiled areas than in non-oiled areas in 1990. Conversely, both species utilized epibenthic prey less in oiled areas in 1989, and more in oiled areas in 1990. These interannual changes in diet between oiled and non-oiled areas could have been caused by differences in distribution of fish, distribution of prey, or effects of oil.

The Impact of the *Exxon Valdez* Oil Spill on Juvenile Pink and Chum Salmon and their Prey in Nearshore Marine Habitats

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·The objectives of this study were to determine the impact of the oil spill on juvenile pink and chum salmon during their initial period of marine residency in nearshore habitats. Field studies in 1989 and 1990 compared: (1) exposure to and contamination by hydrocarbons, (2) distribution, abundance, size and nominal growth rates, (3) feeding habits, and (4) prey abundance for these fish between pairs of oiled and non-oiled locations in western Prince William Sound. Detailed results from this research will be published by The American Fisheries Society in the *Proceedings of the Exxon Valdez Oil Spill Symposium.*

Contamination of salmon fry by oil in 1989 was shown by significantly elevated mixed-function oxidase (MFO) activity in pink and chum salmon fry from oiled locations, and by the presence of hydrocarbons in tissues of pink salmon fry collected in oiled locations. The composition of hydrocarbons in the tissues and the cell types where MFOs were induced indicated that ingestion, either of whole oil or oil-contaminated prey, was the primary route of contamination. Oil was also observed in the stomachs of a small percentage of pink and chum salmon collected at oiled sites in 1989. We found no evidence of continued contamination of pink and chum salmon fry in the nearshore marine environment in 1990.

Juvenile pink and chum salmon were more abundant in the non-oiled area in both 1989 and 1990. However, we concluded that the differences observed in abundance were more likely due to geographic differences or distribution of spawning populations rather than to exposure to oil because the pattern of abundance did not change as exposure levels diminished. In 1989, pink salmon fry were significantly smaller and had significantly lower nominal growth rates in oiled locations relative to non-oiled locations. These differences were not observed in 1990. Chum salmon fry were larger in oiled locations in both 1989 and 1990; because chum salmon were rare in the oiled habitats sampled, data were insufficient to compare growth rates for this species.

Pelagic zooplankton dominated the diet of juvenile pink and chum salmon in both 1989 and 1990. Feeding of pink and chum salmon was not reduced in oiled locations. Available prey for juvenile salmon was also as high or higher in oiled locations as in non-oiled locations.

We concluded that pink salmon fry were contaminated by oil in the nearshore marine environment in 1989, and that this contamination led to lower growth rates. Temperature, prey availability, and feeding efficiency were as high or higher in oiled locations as in non-oiled locations in 1989, and therefore do not explain the reduction in growth observed. Because slower growth during the initial marine residency of salmon can reduce the marine survival of salmon populations, the oil spill probably reduced the productivity of populations of pink salmon that utilized contaminated nearshore habitats.

Impacts of the *Exxon Valdez* Oil Spill on the Migration, Growth, and Survival of Juvenile Pink Salmon in Prince William Sound

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This study focused on the effects of the *Exxon Valdez* oil spill (EVOS) on the migration, growth, and survival of juvenile pink salmon during the first two months of their marine residence in Prince William Sound (PWS), Alaska. Coded-wire tagged (CWT) juvenile salmon released from four hatcheries in PWS in 1989, 1990, and 1991 were the principal tool used to study migration, growth, and survival. The migration of juvenile pink salmon released from the Armin F. Koernig (AFK) Hatchery appeared to have been affected by oil contamination from the EVOS in 1989. Recoveries of juvenile CWT pink salmon and visual observations of juvenile salmon abundance indicated that much higher numbers of fry from AFK Hatchery were present along the southern coast of Knight Island in 1989 than in 1990 and 1991. Insufficient data is available to determine if hydrocarbon concentrations in the environment were at a level sufficient to cause an avoidance reaction in juvenile pink salmon. However, a greater frequency of P4501A enzyme induction in juvenile pink salmon recovered near the AFK Hatchery indicated that the fish were exposed to hydrocarbons. There was no apparent effect of oil contamination on the migratory behavior of juvenile pink salmon released from the Wally H. Noerenberg (WHN) Hatchery in 1989.

The growth rate of juvenile pink salmon in PWS appeared to be reduced by oil contamination from the EVOS in 1989. Growth rates of juveniles released from the AFK Hatchery in 1989 were significantly lower ($P=0.034$) in the moderately-oiled area near the hatchery than in the lightly-oiled area along the southern coast of Knight Island. Growth rates of juvenile pink salmon released from the AFK Hatchery were lower in the previously oiled area in 1990 ($P=0.097$) and 1991 ($P=0.085$), but the difference was marginally significant. Growth rates of juveniles released from the WHN Hatchery in 1989 were significantly lower ($P=0.011$) in the moderately-oiled area near Main Bay than in the

non-oiled area near WHN Hatchery. Growth rates of juveniles released from the WHN Hatchery in these same areas were not significantly different in 1990 (P=0.125) and 1991 (P=0.883).

Exposure to hydrocarbons from the EVOS appeared to reduce the growth rate of juvenile pink salmon by 0.76 to 1.00% body weight day^{-1} in 1989. The observed differences in growth rate do not appear to be caused by measurement or sampling error, or differences in food consumption rate, prey composition, or water temperature. The observed reduction in growth rate was associated with a significantly greater (P<0.05) frequency of cytochrome P4501A enzyme induction in oiled areas compared with non-oiled and lightly-oiled areas in 1989. The greater frequency of P4501A enzyme induction in oiled areas is direct evidence that fish in oil-contaminated habitats expended energy to depurate hydrocarbons leaving less energy available for somatic growth. Insufficient data is available at the present time to determine if the level of hydrocarbon exposure was sufficient to cause the estimated reduction in growth rate attributed to oil contamination. The growth of juvenile CWT pink salmon in 1989 was significantly related (P=0.016) to survival to the adult stage. Based upon this relationship, the reduction in juvenile growth attributed to oil contamination in 1989 likely caused a 1.75-2.31% reduction in survival to the adult stage. The adult pink salmon return to PWS in 1990 was thus lower than if the EVOS had not occurred.

Effects of Crude Oil Ingestion on Growth and Microstructure of Juvenile Pink Salmon (*Oncorhynchus gorbuscha*) Otoliths

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Juvenile pink salmon (*Oncorhynchus gorbuscha*) were fed a commercially prepared food contaminated with three levels of crude oil: 0.37 X 0.03 mg oil per g food (low-oil treatment), 2.8 X 0.2 mg/g (mid-oil treatment) and 35 X 4 mg/g (high-oil treatment). Over 8 weeks, growth of sagittal otoliths and number of growth rings (increment number) in these groups were compared to untreated controls. Significant differences ($P \leq 0.05$) in otolith growth among all oil levels and the controls were evident after one week. Significant differences in increment number among mid- and high-oil treatments and the controls were produced by the second week of the experiment. By week 6, growth of otoliths in all oil treatments was significantly less than in controls, and increment number was significantly less in mid- and high-oil treatments than in controls. All fish were fed clean food after week 6, but otoliths remained smaller and increment number less in treated groups through the remainder of the experiment. Reduced otolith growth and increment formation with increasing oil concentration followed a pattern similar to that of somatic growth. Because check marks can be used as references to index the history of a fish, otolith deposits in wild fish conceivably could be used to estimate the impacts of a major environmental disturbance, such as the *Exxon Valdez* oil spill. In our experiment, changes in otolith structure did not disappear when fry were returned to clean food; the otolith had faithfully recorded the event in its microstructure.

This paper will appear in the Proceedings of the International Symposium on Fish Otolith Research and Application, January 23-27, 1993, published by the University of South Carolina Press.

Bibliographies of Pink Salmon (*Oncorhynchus gorbuscha*) and Chum Salmon (*O. keta*) Literature

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Two major salmon literature collections are now available at the Library of the Auke Bay Fisheries Laboratory (ABFL). Both collections were assembled and used in the preparation of the chapters on pink and chum salmon in the book *Life Histories of Pacific Salmon*, edited by C. Groot and L. Margolis, and published by the University of British Columbia Press in 1991.

The bibliography of pink salmon literature consists of approximately 2,400 papers published on pink salmon and covers the period of 1792 through 1992. Approximately one half of the papers listed in this bibliography are available as reprints in the Auke Bay Library; the remaining citations are accessible via interlibrary loan programs.

The collection of chum salmon literature was assembled by the late Professor Ernest O. Salo and donated to ABFL library by Mrs. Salo. The collection also includes many foreign translations and other difficult to locate chum salmon literature that did not appear in Salo's life history bibliography. The literature collection will be kept intact for use by NMFS and other scientists in the conduct of continuing salmon research. All citations in the bibliography are available as reprints in the Salo collection at ABFL.

A final published version of the pink salmon bibliography should be available as a NOAA Technical Memorandum in late 1993/early 1994. A draft copy of the bibliography can be acquired as an ASCII or WordPerfect file by anyone who sends a formatted double side, high density, 5-inch floppy disk to:

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