



United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-468
January 2000



Biological Characteristics and Population Status of Anadromous Salmon in Southeast Alaska

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Cover art by: Detlef Buettner

Abstract

Halupka, Karl C.; Bryant, Mason D.; Willson, Mary F.; Everest, Fred H. 2000.

Biological characteristics and population status of anadromous salmon in southeast Alaska. Gen. Tech. Rep. PNW-GTR-468. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 255 p.

Populations of Pacific salmon (*Oncorhynchus* spp.) in southeast Alaska and adjacent areas of British Columbia and the Yukon Territory show great variation in biological characteristics. An introduction presents goals and methods common to the series of reviews of regional salmon diversity presented in the five subsequent chapters. Our primary goals were to (1) describe patterns of intraspecific variation and identify specific populations that were outliers from prevailing patterns, and (2) evaluate escapement trends and identify potential risk factors confronting salmon populations. We compiled stock-specific information primarily from management research conducted by the Alaska Department of Fish and Game. We used mainly exploratory and descriptive statistical procedures to examine patterns of intraspecific variation, and linear regression to evaluate escapement trends. We describe the most pervasive limitations of available data and recommend cautious evaluation of our results. These reviews nonetheless provide insight into the ecological and evolutionary ramifications of intraspecific variation for managing diversity and sustaining productivity of salmon resources.

Keywords: Pacific salmon, *Oncorhynchus*, southeast Alaska, intraspecific diversity, population status, variation.

Contents

1	General Introduction
1	Purpose, Scope, and Objectives
3	Study Area
6	The Database
7	Methods
11	Acknowledgments
11	Literature Cited
15	Coho Salmon (<i>Oncorhynchus kisutch</i>)
15	Abstract
15	Introduction
20	Methods
25	Results
45	Discussion
52	Risk Factors
54	Conclusions
58	Acknowledgments
58	Literature Cited
67	Chinook Salmon (<i>Oncorhynchus tshawytscha</i>)
67	Abstract
68	Introduction
77	Methods
78	Results
91	Discussion
98	Risk Factors

100	Conclusions
104	Acknowledgments
104	References
113	Sockeye Salmon (<i>Oncorhynchus nerka</i>)
113	Abstract
113	Introduction
119	Methods
121	Results
139	Discussion
147	Risk Factors
149	Conclusions
153	Acknowledgments
153	References
165	Pink Salmon (<i>Oncorhynchus gorbuscha</i>)
165	Abstract
165	Introduction
175	Methods
178	Results
195	Discussion
200	Risk Factors
202	Conclusions
204	Acknowledgments
205	References
215	Chum Salmon (<i>Oncorhynchus keta</i>)
215	Abstract

215	Introduction
220	Methods
222	Results
236	Discussion
244	Risk Factors
247	Conclusions
249	Acknowledgments
249	References
255	English Equivalents

General Introduction

Purpose, Scope, and Objectives

Fisheries program managers of the Tongass National Forest (U.S. Department of Agriculture, Forest Service) identified the need to summarize biological characteristics and determine population status of anadromous salmonids in southeast Alaska because of declines in stocks of anadromous salmonids in California, Oregon, Idaho, and Washington (Nehlsen and others 1991). The purpose of this paper is to identify distinct or sensitive stocks that may require special consideration during planning of land-management activities within the Tongass National Forest, and to determine population trends as stable, increasing, or declining.

We reviewed stocks of coho (*Oncorhynchus kisutch*), chinook (*O. tshawytscha*), sockeye (*O. nerka*), pink (*O. gorbuscha*), and chum (*O. keta*) salmon in southeast Alaska. Steelhead are reported separately (Lohr and Bryant 1999). For each species, we established a context for evaluating potentially distinctive populations by beginning with a summary of the life history typical of populations in the region. Management and enhancement programs also were reviewed to assess the potential for these programs to either contribute to unusual levels of variation or pose a risk to wild stocks. Stock-specific data, collected primarily by the Alaska Department of Fish and Game (ADF&G) in their management research programs, were the basis of our analyses of biological characteristics and population trends. Results of these analyses are discussed in the context of managing salmon diversity and in regard to conceptual issues in ecology and evolutionary biology. The final component of each species report is an evaluation of natural and human-caused risk factors that may contribute to declines in salmon abundance. Stock-specific risk factors are evaluated for stocks with distinctive characteristics or declining populations.

Background

We defined a stock, following Ricker (1972) and Nehlsen and others (1991), as a population of fish that spawns in a particular tributary of a drainage, during a particular time of year. This definition implies that gene flow among stocks is limited. Although low rates of gene flow often are assumed to be sufficient to homogenize allele frequencies among populations, gene flow does not preclude evolutionary divergence (Slatkin 1987). Biologically distinctive stocks are those that diverge from other stocks in the region in their expression of one or more phenotypic characteristics. Body length, migratory timing, and various demographic characteristics were the bases of our analysis of biological distinctiveness. We evaluated demographic characteristics of populations as indicators of distinctive features of most individuals in these populations. The traits we evaluated were limited to those considered to be

relevant to commercial fisheries management, because these are the only traits for which data are available for enough stocks in southeast Alaska to make a comparative analysis possible. These traits are only a small sample of characteristics important to salmonid diversity, and they are not necessarily the traits most likely to display local adaptation.

Stocks that display distinctive phenotypic characteristics may be important to the evolutionary potential of their species, assuming that some component of the variance in those phenotypic traits is heritable. Moderate levels of additive genetic variance have been found in most life-history traits of salmonids analyzed (Hard 1995). Phenotypic plasticity in response to environmental variables is common in salmonids (reviewed in Ricker 1972), but the basis of plasticity may be heritable (Thorpe 1994, Thorpe and others 1983). Phenotypic variation also may facilitate and accelerate evolutionary processes (West-Eberhard 1989); therefore, populations exhibiting particular patterns of phenotypic plasticity may possess unique elements of genetic diversity.

Analyzing phenotypic traits to identify components of intraspecific diversity provides a useful complement to genetic analysis (Utter and others 1993). Patterns detected by phenotypic analysis reflect different evolutionary processes that operate at different spatial and temporal scales compared to patterns detected by genetic analysis (Utter and others 1993). For example, electrophoresis can fail to distinguish populations having highly divergent life histories (e.g., Sacramento River winter-run chinook; Bartley and others 1992), and more sophisticated (and costly) techniques such as analysis of mitochondrial DNA polymorphism may correlate better with phenotypic divergence (Nielsen and others 1994). Lack of significant variation in allozyme frequencies measured electrophoretically should not be interpreted as signifying a lack of adaptive variation in phenotypic traits (Smoker and others 1993). We incorporated genetic information (primarily from allozyme analysis) into our evaluation to define broad-scale ancestral lineages (Utter and others 1993) and to identify particular stocks with unusual allele frequency combinations. For all species, though, a limited subset of stocks in the region have been sampled for genetic analysis, and the degree of overlap between stocks included in genetic surveys and stocks for which biological data are available differs considerably among species. Areas inhabited by stocks identified as distinctive, based on phenotypic characters, may be the most appropriate focus of future biochemical and genetic studies.

We have attempted to describe the diversity of anadromous salmon at several levels. Specific populations with distinctive characteristics represent the finest level of resolution for intraspecific diversity. At larger geographic scales, stocks can be grouped by shared characteristics such as patterns of allozyme frequencies and use of particular spawning habitats, migratory pathways, or timing windows. These factors used to group stocks can influence or reflect patterns of gene flow and natural selection and therefore are relevant to the evolutionary dynamics of these groups. The baseline survey of hierarchical levels of diversity presented here will provide a comparative basis for evaluating future patterns of diversity as well as ongoing trends in biological characteristics.

We used escapement estimates from stream surveys and weir counts to determine population status of stocks. Estimates of total returns are preferable for evaluating abundance because escapement can be strongly influenced by harvest patterns, but total return estimates were available for very few stocks. The time series of

escapement data begins in 1960, when several species were generally at low abundance levels. Thus, stable or increasing abundance trends, resulting from rebuilding efforts, improved habitat management, and natural factors, are not surprising. Escapement data collected before 1975 are not strictly comparable to the post-1975 data, but we have included many pre-1975 surveys in our analyses to broaden the coverage of this paper to as many stocks as possible. Since 1975, the Alaska Department of Fish and Game (ADF&G) has sought to verify and standardize its escapement estimation techniques, but many difficulties remain. Numerous intrinsic and idiosyncratic factors limit the precision of escapement survey techniques; most escapement survey techniques provide indices of escapement that are subject to a wide range of variation owing to combinations of these factors (Cousens and others 1982) nonetheless, the demographic status of stocks is commonly evaluated by using escapement trends (e.g., Baker and others 1996, Nehlsen and others 1991), because survey counts or other indices of escapement often are the only information available for many stocks in a region.

Specific human-caused and natural risk factors may be related to specific biological characteristics or stock status. In most cases, specific risks were difficult to assign, because of severe limitations in the data or absence of stock-specific data. Stock-specific risk factors were identified where possible for stocks with distinctive characteristics or declining populations. Risk factors in broad categories were evaluated for each species.

The needs for additional research on salmon populations in southeast Alaska are great. The economic importance of salmon fisheries in southeast Alaska has been responsible for most research and monitoring of salmon populations. As a result, most data have been collected to manage and allocate harvest at sustainable levels. Studies of individual populations and watersheds usually are short term and often address only specific aspects of the life history or effects of management—either fishery or habitat—within one or two watersheds. All together, these studies consider only a small proportion of the stocks in the region. Most stocks monitored for fisheries-management purposes do not inhabit watersheds that either have been or are being intensively managed for timber harvest. Studies of intensively managed watersheds typically do not have good escapement records or records that extend for multiple years. A long-term monitoring program is needed, as well as additional baseline data. Likewise, additional surveys of genetic diversity are needed to define stock groups at finer levels of resolution. The ecology and evolutionary biology of salmon in southeast Alaska offer a wealth of promising research opportunities. In the chapters that deal with each species, we identify specific research needs and propose tentative explanatory hypotheses, thereby seeking to stimulate research to address gaps in understanding the life history, ecological relations, and biodiversity of salmon in southeast Alaska.

Study Area

The geographic area covered in this report includes all of southeast Alaska from the international boundary at Dixon Entrance, north and west to Cape Suckling (fig. 1). We also included large transboundary river systems, such as the Stikine, Taku, Chilkat, and Alsek drainages, whose stocks spawn in British Columbia and the Yukon Territory.

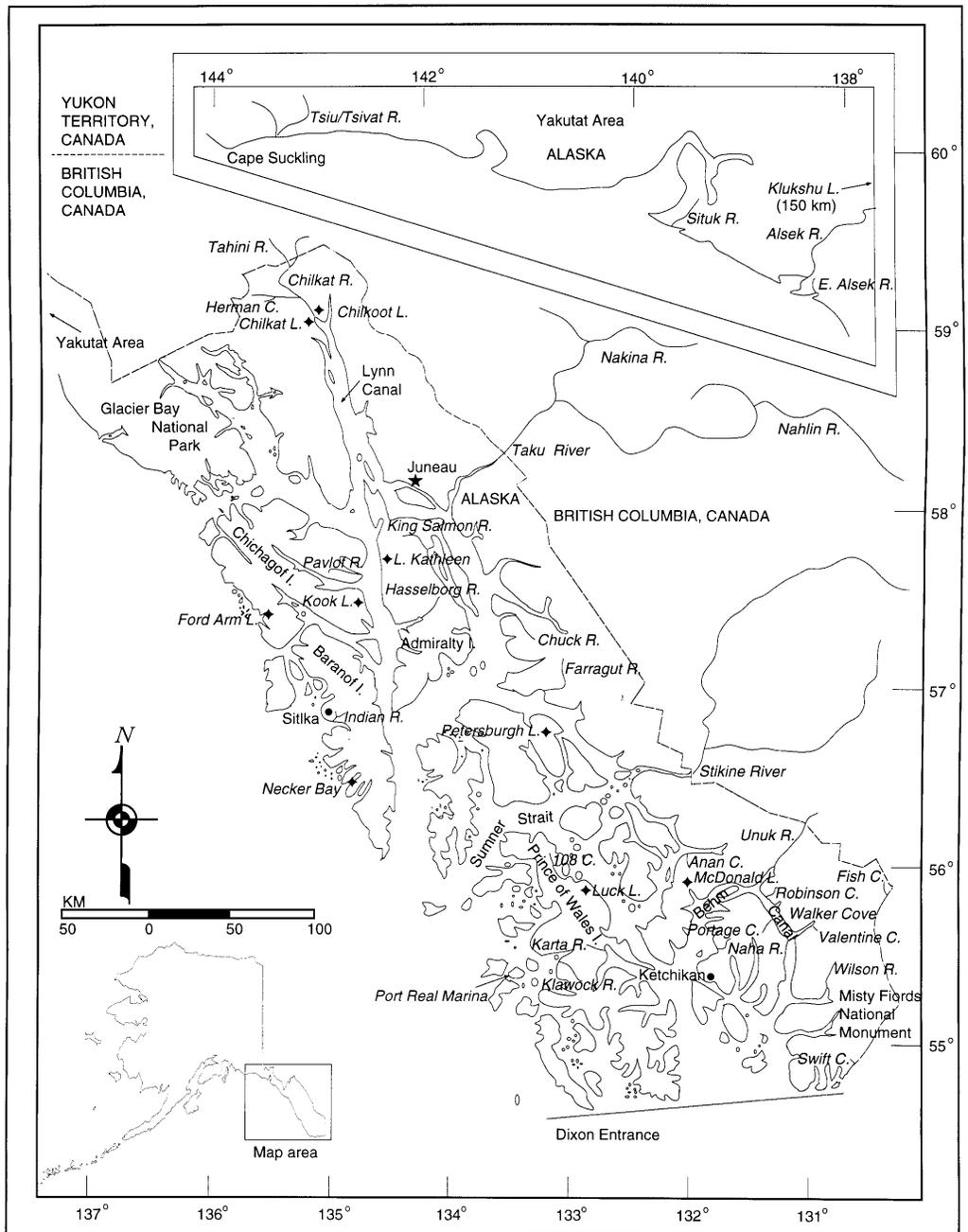


Figure 1—The study area, with approximate locations of some geographic features mentioned in the text.

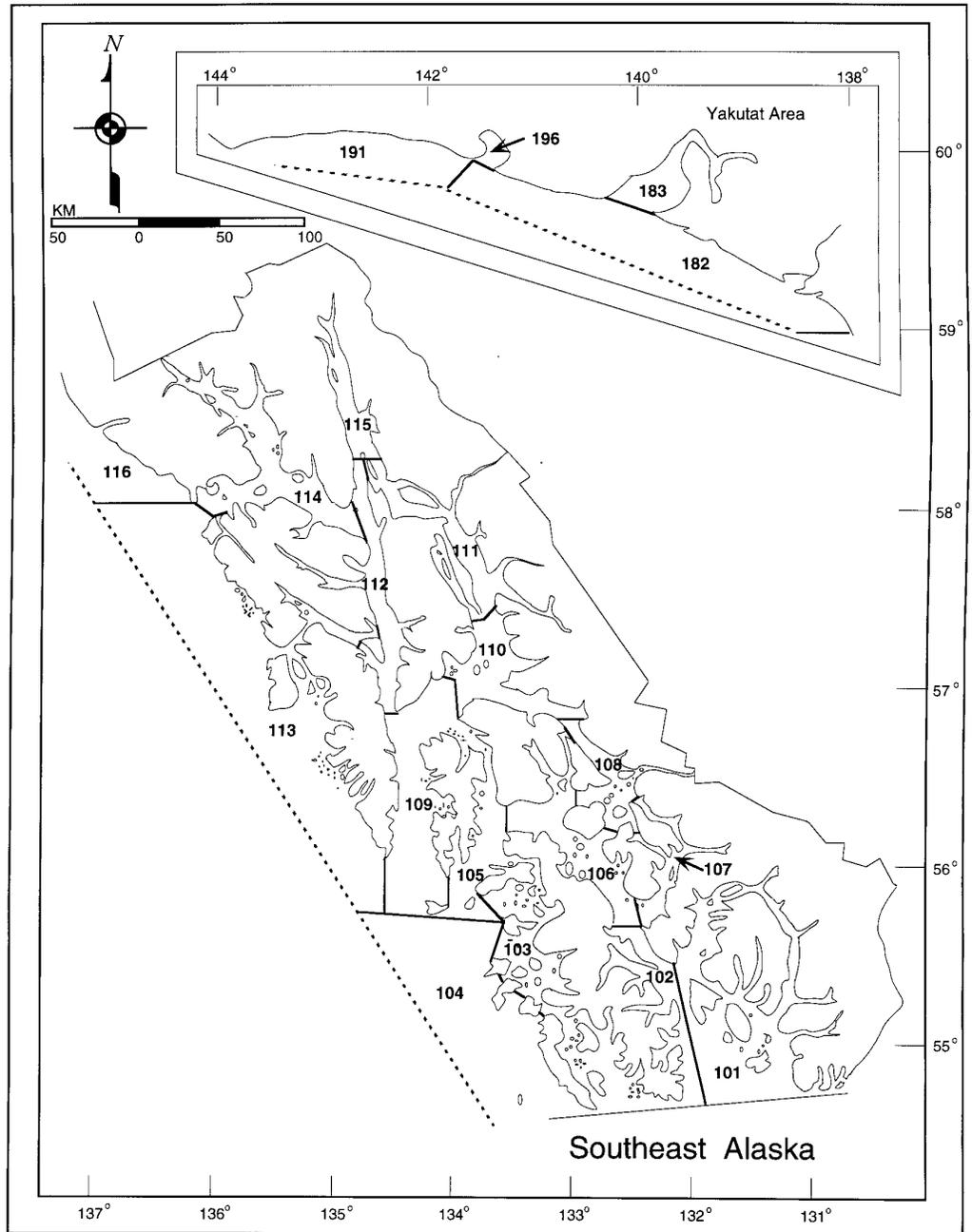


Figure 2—The study area, with the approximate locations of statistical districts used by the ADF&G Division of Commercial Fisheries.

Stream numbers in this report are those used by the ADF&G, Division of Commercial Fisheries. These numbers are abbreviated versions of the numbers assigned and catalogued by the ADF&G, Habitat Division (1994). The first three digits of these numbers also designate the commercial fishing statistical areas in the region (fig. 2). All data tables are organized by ascending stream number.

Our intent was to evaluate wild stocks of anadromous salmonids within southeast Alaska; however, widespread official and unofficial stocking of fish raises the possibility that some nonnative stocks were inadvertently included. The interaction of wild and artificially reared fish in southeast Alaska is poorly documented, but many studies from other regions document the impacts of hatchery fish on wild stocks (reviewed in Goodman 1990, Thomas and Mathisen 1993).

The Database

Our primary sources of stock-specific biological data for southeast Alaska were reports and computerized data files from ADF&G. Other sources of data were reports by the Pacific Salmon Commission (PSC), National Marine Fishery Service (NMFS), USDA Forest Service, U.S. Fish and Wildlife Service (USFWS), and the former U.S. Bureau of Fisheries (USBF). A comprehensive search of the primary literature for papers on salmonid research in Alaska was conducted using the Dialog database.¹ Current volumes not covered by the Dialog system were searched with Current Contents or by inspection. Very few data from the primary literature were available for inclusion in this report series, however. Anecdotal reports from fisheries biologists also contributed to the database. Electronic versions of the database are available from the primary author.

All data were compiled and analyzed by return year rather than brood year. Because our primary goals were to describe variation and identify distinctive stocks, we placed a high priority on including as many stocks as possible in our analyses. Return-year compilations enabled us to include additional stocks in our analyses, because they did not require several consecutive years of sampling, as brood-year compilations do. Many salmon stocks in the region have not been sampled for enough consecutive years to complete brood-year analysis but have been sampled for enough non-consecutive years to provide reliable estimates of means and variances across years. Many more populations in the region have been sampled for less than 4 years. We have included these stocks in comparative analyses under the implicit assumption that the few years sampled are representative. Of course, the likelihood of this assumption being fulfilled decreases with decreasing numbers of sample years. Stocks determined to have distinctive characteristics, based on limited sampling, require additional sampling for confirmation.

Throughout this report we have used the European system for designating the age of fish. In this system, the number of winters the fish have spent rearing in freshwater after emergence are separated from the number of winters spent in saltwater by a period. For example, a fish of age class 1.3 has spent one winter in freshwater and three winters in saltwater; an age 0.4 fish emigrated to saltwater soon after emergence and spent four winters in the ocean.

¹The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

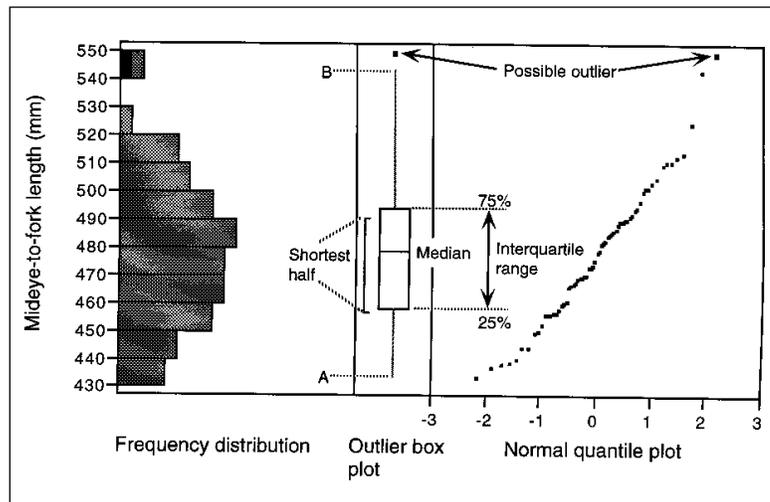


Figure 3—Frequency distribution, outlier box plot and normal quantile plot used to identify distinctive stocks. In the frequency distribution, values increase toward the top of the plot so that if the plot is viewed in the typical vertical orientation, values decrease from left to right. In the outlier box plot, the ends of the box are the 25th and 75th quantiles. The difference between these values is the interquartile range. The ends of the “whiskers,” labeled A and B, are the outermost data points from their respective quartiles that fall within the distance calculated as 1.5 x (interquartile range). Points beyond the whiskers are potential outliers and are highlighted in all three plots. The normal quantile plot provides a visual way to assess both the overall normality of a variable distribution and which points deviate most from the normal expectation. A normal distribution would have all points on a diagonal straight line. Each point in the normal quantile plot represents the mean value of a stock included in the analysis. The shortest half, marked with a bracket, is the most dense 50 percent of the observations (SAS 1994).

Methods Data Analysis Procedures

Statistical procedures consisted primarily of descriptive statistics. The primary goals for these descriptive procedures were to detect stocks deviating from the overall distribution of a given variable for their species and to illustrate the range of variability present throughout the region. Distributions of biological variables were generated by plotting mean values (calculated across all sample years) from all studied stocks in southeast Alaska. Studied stocks were not a random sample of all stocks in the region. Most stocks were chosen for study because they were either representative of a certain population type in the region or thought to be of particular importance to commercial or sport fisheries. The ADF&G has not explicitly attempted to include stocks reported anecdotally as distinctive in its management research programs.

When many populations had been sampled for a particular biological characteristic, we identified distinctive stocks by using the graphic procedures described by Tukey (1977; also SAS 1994). This analysis produces a standard frequency distribution, an outlier box plot, and a normal quantile plot (fig. 3). In the outlier box plot, points beyond the whiskers are extreme values or potential outliers, which for our purposes represented distinctive stocks.

We used the Shapiro-Wilk *W*-statistic to verify the presence of outliers. This statistic tests for the presence of an undefined number of discordant values in a random sample, assuming a normal population (Barnett and Lewis 1978) and also can be applied as a test of the null hypothesis that the data are a random sample from a normal

population (SAS 1988). A significant test result therefore can be interpreted as indicating both the existence of outliers and a nonnormal sample distribution. Discordant values identified in the plot then can be excluded, and the Shapiro-Wilk statistic reevaluated to determine if outliers were the cause of the previously significant test result. To use this procedure, we applied standard transformations to all nonnormal distributions to approximate normality. In cases where the Shapiro-Wilk *W*-statistic yielded a nonsignificant result, but the box-and-whisker plot indicated the presence of an outlier, we relied on the graphic analysis.

We preferred a graphic approach to outlier detection over specific discordancy tests for two reasons: (1) most discordancy tests are based on specific underlying probability models—for many of our variables the most appropriate model was unclear; and (2) we suspected the existence of multiple outliers in both directions for many variables, and most test procedures are designed to detect a given number of outliers (one or two) and are susceptible to "masking" by multiple outliers, even when used consecutively (Barnett and Lewis 1978).

Outlier analysis was not possible for nominal characteristics of populations, such as use of unusual habitats or geographic locations for spawning. For these characteristics, distinctive populations were identified from descriptive or anecdotal information. For these cases, we have provided as much supportive information as is available.

When biological evidence suggested that the entire region was not an appropriate scale for analysis, subregional analyses were conducted. Separate analyses were conducted, for example, for pink salmon in northern and southern subregions, because tagging studies of pink salmon indicated that little intermingling occurs between stocks located on opposite sides of Sumner Strait (see fig. 1). Likewise, if different habitat types were known to have effects on biological characteristics of a species, separate analyses were conducted on stocks found in the different habitat types (e.g., lake- vs. river-type sockeye salmon stocks).

Descriptive statistics for migratory timing past weirs or traps (both juvenile emigration and spawning migrations of adults) were calculated by the formulas of Mundy (1984). We also calculated an index of spawning-run timing based on the timing of escapement surveys. This index took the form of a mean date of spawning migration; it was calculated by converting the date of the highest survey count for each year to a Julian date and computing an ordinary mean of these Julian dates. This index was calculated only for those stocks with 7 or more years of surveys.

Age structure of stocks was evaluated by comparing both mean freshwater age (MFWA) and mean saltwater age (MSWA) among stocks, as well as proportions of total escapement samples in each age class. Both were calculated as the mean number of years spent in freshwater or saltwater, respectively, weighted by the number of individuals sampled from each age class. These weighted means served as overall indices facilitating both comparison of stocks and analysis of interannual variation in age structure of a single population. Age-structure comparisons based on means were supplemented with comparisons of proportions of stocks in each age class, because mean calculations can obscure patterns such as bimodal age distributions.

The linear regression method of Konkel and McIntyre (1987) was used to evaluate trends in spawning escapement. The independent variable was time in years, and the dependent variable was peak escapement count. This analysis was conducted only on stocks with counts from at least 7 years. Trends in escapement counts were categorized as increasing, declining, or stable (having no significant trend). A two-tailed P-value of 0.05 was used for this test with $n - 2$ degrees of freedom. Similar regression procedures were used to evaluate temporal trends in body size, run timing, age structure, and sex ratio. Although the presence of nonlinearity or auto-correlation is likely in these analyses of time-series data, we did not examine residuals to check for these deviations from regression assumptions (Draper and Smith 1981). With the coarse data involved, and the many analyses to be conducted, we sought a simple indicator of trends.

We categorized data quality for spawning escapement surveys as “good,” “fair,” or “poor” to provide a subjective basis for evaluating the reliability of calculated abundance trends. Our assessment of data quality was based on the total number of years surveyed, consistency of survey type (methodology), number of surveys per year, the distribution of survey effort through time, and the presence-absence of apparently anomalous survey counts. Significant population trends calculated from “fair” and “poor” data sets should be regarded as provisional.

The distribution of variance components for adult body lengths were evaluated by using a modified version² of the SAS VARCOMP procedure (SAS 1988). This procedure reconstructed a nested analysis of variance from available body length data (sample sizes, mean lengths, and standard errors) and partitioned total variance into components attributable to differences among streams, differences among years within streams, and differences among individuals within streams and years. This analysis required a balanced data set, relatively large samples, and data for at least 5 years for each stock included. These requirements limited the number of stocks that we could include in the analysis. This analysis nonetheless provided an important tool for interpreting patterns of variation in adult body lengths among stocks.

In addition to statistical analysis, the demographic status of populations was evaluated in view of water quality assessments. Lists of streams for which the ADF&G had collected escapement survey data were compared to lists of “impaired” and “suspected” water bodies compiled by the Alaska Department of Environmental Conservation. An impaired water body or segment of a water body has definitive and credible documentation of a violation of State Water Quality Standards or documentation of impairment of designated uses, as established in the Water Quality Standards. A suspected water body does not have monitoring data or other definitive documentation establishing violation of the Water Quality Standards or use impairment due to point or nonpoint sources, but information indicates that pollutant sources are present, the water body is affected, and water quality violations may be occurring or may have occurred. Further investigation is needed to establish whether the water body is impaired (ADEC 1992). All stocks inhabiting impaired or suspected water bodies for any portion of their life cycle were tabulated because exposure to contaminants may render these populations susceptible to decline.

² Written by Tim Max, Station Statistician, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, P.O. Box 3890, Portland, OR 97208.

Limitations of Biological Data

We conducted all other statistical tests by using SYSTAT (1992) and following application guidelines provided in Sokal and Rohlf (1981). Coefficients of variation calculated for run timing, age, and sex-ratio characteristics included the correction for small samples specified by Sokal and Rohlf (1981). All statements of statistical significance were based on the probability criterion that $P < 0.05$. In some cases, we discuss “nearly significant” results ($0.05 < P < 0.1$) when sample sizes were small or trends were apparent but statistical tests did not reach the 0.05 criterion.

We encountered difficulties in interpreting the data because it was collected by a variety of investigators, for various purposes, from numerous locations, at different times, and with different methods. The data limitations we encountered can be categorized into three general types: (1) insufficient sampling (within years, across years, and among populations); (2) lack of consistency and comparability; and (3) low accuracy and precision. Various data sets evaluated in this paper suffered from these limitations to different degrees. The following general patterns were apparent, but these limitations were not universal, and for each species some very reliable data sets exist for individual populations.

Body length data were limited by small sample size, length of sample time, variations in sample sites, and use of different types of length measures. Within years, body size of most species can change throughout the migration season, and samples from only one or a few consecutive days may not be representative of the entire population. Samples taken throughout the season at weirs are the most reliable. For many populations, the number of years sampled were not sufficient to evaluate temporal trends in body size or to adequately characterize interannual variation. A small proportion of coho and chum salmon populations were sampled for body length. The difficulty of inconsistent measurements could generally be overcome by transforming data with regression equations (Pahlke 1989), but in some instances the type of length measure could not be determined and data were not included in analyses.

Migratory timing data from weirs tended to be incomplete for all species, except sockeye salmon. In most cases, weir operation was discontinued before completion of the run, and the size of the uncounted proportion of the run was unknown. Accuracy of weir counts was sometimes doubtful when differing counts for the same run were reported in different sources. Furthermore, a wide range of circumstances, such as floods, can prevent a weir from being “fish tight.”

Our index of run timing was confounded primarily by all the problems of consistency and accuracy associated with escapement surveys. Escapement surveys in the region are conducted primarily for pink salmon with other species counted secondarily. Thus the timing of surveys is oriented toward peak pink salmon escapements and may not reflect the true run timing of other species.

Data on age composition suffered from many of the same limitations described above for length data. Sample sizes often were inadequate to characterize age composition with a high level of confidence. Estimates of overall age structure are enhanced by sampling throughout the run, because different age classes can predominate in different run segments. In addition, the accuracy of age data for some species, especially coho salmon, is questionable in some situations. The proportion of jacks (male fish that return in the fall after one summer in the ocean) is not known for most populations.

Like age structure, sex ratio often varies predictably through a run; therefore, repeated sampling is recommended. This sort of repeated sampling is best accomplished at a weir, but even weir estimates of sex ratio can be confounded by jacks passing undetected through a weir.

Because these limitations of data quality were so widespread, we conducted most of our analyses of biological characteristics on grand means calculated across all years sampled. This approach should provide reasonable estimates of true means, assuming errors or biases in the data vary randomly in direction. We discuss all instances where biases may be systematic.

Acknowledgments

R. Baker, through her initiative, diligence, and meticulous work, was essential to the completion of this report.

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Coho Salmon (*Oncorhynchus kisutch*)¹

Abstract

Intraspecific variation in biological characteristics among coho salmon stocks in southeast Alaska was evaluated for up to 48 stocks, and regression analyses of escapement trends were conducted for 129 stocks, a very small portion of the estimated 2,300 stocks in the area. The biological characteristics of coho stocks that rear primarily in lake, river, or stream watershed types, as well as interior (east and north of the Coast Mountains) and coastal locations, were compared. Smolts from lakes and rivers tended to be larger than those from streams. Stocks from watersheds with lakes have higher mean freshwater ages, a wider range of age classes, and higher survival rates than stocks from watersheds without lakes. Stocks spawning in the interior had lower mean freshwater ages, male-biased sex ratios with few or no precocial males, and low survival rates, compared to stocks spawning near the coast, and these differences were more pronounced than differences among watershed types. Redoubt Lake and the Tsiu River system support clearly distinctive coho stocks. Sixteen additional stocks may have distinctive characteristics. Most stocks have stable escapement trends, with 7 percent (nine stocks) showing significant increases, and 5.4 percent (seven stocks) showing significant declines from 1960 to 1992.

Keywords: Coho salmon, *Oncorhynchus kisutch*, southeast Alaska, intraspecific diversity, conservation, age distribution, run timing, sex ratio, body size.

Introduction Life History

Coho salmon inhabit a broad range of habitat types and spawn in nearly 4,000 watercourses throughout southeast Alaska and in the headwaters of transboundary rivers in British Columbia and the Yukon Territory (ADF&G, Habitat Division 1994). Because of the high probability of gene flow within drainages, these 4,000 spawning sites are estimated to support 2,300 coho salmon populations (Baker and others 1996). The wide range of habitats used by coho salmon reflects the plasticity of this species. The following generalized summary of coho salmon life history provides a starting point for describing the wide range of life history variation displayed by populations of this species in southeast Alaska.

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Coho salmon typically return to the outside waters of southeast Alaska in July and August and enter freshwater in September and October. The direction of the return migration generally moves from northwest to southeast along the coast. Relatively little is known about the migration routes used by specific coho salmon stocks (Schmidt 1988). Migratory pathways that have been studied indicate some stocks follow a direct route (e.g., Politofski Lake) and others take complicated paths to their natal stream (e.g., Kegan Lake; Shaul and others 1984, 1986). In general, run timing is earliest in outer coast stocks on islands and latest in northern mainland stocks (Van Alen and Wood 1986). Most spawning occurs in late October and November; however, some runs return as early as mid-July and adults may hold for several months before spawning. Spawning areas tend to have groundwater seepage or high intergravel flow rates, and small low-gradient tributaries are commonly used. Hatching of eggs occurs in about 50 days. Fry typically emerge from the gravel in April. In southeast Alaska, all juveniles spend at least 1 year rearing in freshwater before emigration, and most juveniles rear in freshwater for 2 years. This schedule contrasts with coho salmon stocks in southern British Columbia and the Pacific Northwest, where most juveniles spend 1 year in freshwater. The availability of suitable rearing habitat is considered to be the limiting factor for most coho salmon populations. Optimum rearing habitat for coho juveniles is typically found in small streams, beaver ponds, off-channel areas of river flood plains, and lakes (Bryant 1985a, 1985b; Elliott and Reed 1974; Gray and Marriott 1986). These areas all feature a complex habitat structure with abundant aquatic and bank cover (McMahon 1983). Coho smolt typically migrate in May and early June. The mean length of age 2.0 smolts in southeast Alaska is nearly 100 mm.

Most coho salmon in southeast Alaska spend about 16 months in saltwater before returning to spawn. Individuals that spend 28 months in the ocean are rare. Adult body length in escapements averages 618 mm for males and 634 mm for females. Coho salmon from northern stocks typically are larger than those from southern stocks. This difference may reflect the later timing of the run for northern stocks, which provides additional opportunity for growth in the summer of return (Van Alen and Wood 1986).

Survival of rearing juveniles to return as adults, based on coded-wire-tag studies of 13 coho stocks, is 5.6 percent (SE = 0.2 percent) and includes both the late segment of freshwater rearing and oceanic life history stages. The estimated mean ocean survival rate, from smolt emigration to adult return, is 10 percent (SE = 0.69 percent) for six coho stocks in southeast Alaska, when all years for which data are available are included in the average. During the late 1980s, however, estimated ocean survival averaged 14 percent (Shaul and others 1991).

Jacks are males that smolt in late spring and return to spawn in the fall, after spending only 4 to 5 months in saltwater. The proportion of jacks present in spawning runs has been determined for few stocks in southeast Alaska.

Management

Coho salmon are a valuable resource in the commercial, sport, and subsistence fisheries of southeast Alaska. In 1987, 1.5 million coho were harvested in southeast Alaska fisheries (Wood 1992). The \$17-million value of this harvest was the highest single-species contribution to the total economic value of all salmon species

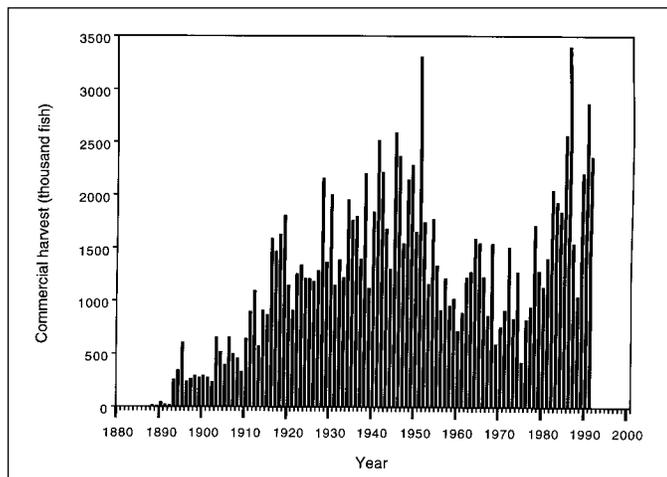


Figure 4—Annual commercial harvest of coho salmon in southeast Alaska, 1888 to 1991 (data from Rigby and others 1991).

harvested in the region for that year. Coho salmon harvests during the late 1980s and early 1990s averaged over 2 million fish per year, nearly double the average annual harvest for the previous 30 years (fig. 4). The high economic value of coho increases the pressure for high-level harvests and artificial enhancement of run sizes.

General management goals include the maintenance of sustained-yield fisheries and escapement levels that will sustain stocks. Management of coho salmon in southeast Alaska is based on inseason assessment of relative annual abundance. Catch or catch-per-unit-effort data from ongoing fisheries are used to evaluate run strength and guide inseason management decisions. The effectiveness of inseason management decisions is evaluated by postseason spawning escapements and exploitation-rate estimates [catch/(catch + escapement)] for particular “indicator” stocks.

Acquisition of data to manage the fishery is difficult, in part because it is primarily a mixed-stock fishery (harvesting fish from several watersheds in a common fishery). Furthermore, the spawning migrations return to fresh water in fall and winter during inclement weather and high water flow. All these factors contribute to the complexity and cost of obtaining data. As a result, most data are derived from a small and limited subset of the stocks throughout southeast Alaska.

During the 1970s, management research used marked juveniles or smolts from 29 locations to determine migration and exploitation patterns (Shaul 1994). From 1982 to 1991, research shifted to more intensive studies of the population dynamics of a small number of indicator stocks considered representative of larger areas (Hugh Smith Lake for southern inside waters, Ford Arm Lake for northern coastal waters, and Auke Lake and Berners River for northern inside waters [Shaul and others 1986, 1991]). All stocks within an area are assumed to experience similar environmental conditions, to have similar migration patterns, and to incur similar exploitation rates. These studies form most of the database available for analyzing stocks throughout southeast Alaska.

Enhancement

Enhancement activities, primarily through hatcheries, can affect run size, genetic composition, and life history of coho salmon. Before 1955, enhancement of coho salmon in southeast Alaska was limited to egg transfers and releases, and to relatively small-scale hatchery production lasting only a few years at a few sites (Roppel 1982). The first site of hatchery coho production in southeast Alaska was Callbreath hatchery, located on what is now called Hatchery Lake near McHenry Inlet in the South Etolin Island Wilderness. The average number of returning adult coho salmon counted at the hatchery barricade was 840 from 1894 to 1900 when separate records for coho salmon were maintained (Roppel 1982). The only record of the number of coho sac fry produced by the hatchery was 750,000 in 1904. The coho fry produced were released near the hatchery or transferred to nearby Falls Creek, also on McHenry Inlet. Coho salmon also were produced briefly (1903) at Olive Creek, south of Wrangell, at Fortmann hatchery on the Naha River from 1903 to 1906, and at Yes Bay hatchery from 1908 to 1909 (Roppel 1982). At the Fortmann hatchery, the 1903 coho brood stock was taken from Miller Lake in Moira Sound, but in subsequent years Naha River coho salmon were used (Roppel 1982). All fry produced were released near the hatchery. After 1906 the Fortmann hatchery focused on sockeye production and coho salmon were actively persecuted because of the perceived negative effects of predation by coho juveniles on sockeye fry (Roppel 1982). At Yes Bay hatchery, coho salmon were used as food for sockeye fry after very limited attempts at coho production.

The earliest transfer of large numbers of coho eggs recorded by Roppel (1982) was conducted by A.J. Sprague between 1917 and 1920. During this period, at least 700,000 eyed eggs and fry from unknown sources were transferred to Baranof Lake, a lake that did not support any anadromous salmon runs due to a barrier falls. No further coho salmon enhancement activities were recorded by Roppel (1982) until 1953, when eggs were taken from Reflection Lake on the Cleveland Peninsula and planted in the Wolf Creek system north of Ketchikan (Roppel 1982).

More extensive enhancement of coho salmon did not begin until 1955 when the Deer Mountain hatchery began releasing coho salmon derived from Soos Creek, Washington, Buschmann Creek (Hugh Smith Lake), Reflection Lake, and Ward Creek brood stocks into Ketchikan Creek. From 1955 to 1959, large numbers of coho fry from all these brood stocks were transferred to seven other lakes and streams in the Ketchikan area that did not have native anadromous runs (Manzanita, Whipple, and Deer Creeks, Smugglers and Tsa Coves, and Ella and Princess Lakes; Roppel 1982). From 1978 to 1990, Snettisham hatchery was a major producer of coho salmon in northern southeast Alaska, but the coho program at this facility has been discontinued. Snettisham brood stock was derived primarily from the Speel River, with supplemental eggs taken from the King Salmon River, Pavlof Lake, and Montana Creek. Releases of Snettisham coho occurred near the hatchery as well as at Indian, Sweetheart (both near the hatchery), Twin, and Dredge (Juneau) lakes, and Fish (Douglas Island), Sheep, and Salmon (Juneau) Creeks.

Nine large hatchery programs currently are producing coho salmon in southeast Alaska (table 1). Hatchery production of coho salmon is concentrated in southern southeast Alaska, with the first five hatcheries listed in table 1 clustered in the Ketchikan area.

Table 1—Hatchery programs producing coho salmon in southeast Alaska

Hatchery	Management	Location	Brood stock sources	Release sites	Annual egg-take goal
Whitman Lake	SSRAA ^a	Herring Bay, George Inlet, South Revillagigedo Island	Chickamin River	Whitman Lake Nakat Inlet Kendrick Bay Neets Bay Earl West Cove Neck Lake	5,000,000
Beaver Falls	SSRAA ^a	George Inlet, South Revillagigedo Island	Reflection Lake (from Ward Lake)	Neck Lake	1,500,000
Deer Mountain	Ketchikan Indian Corp.	Ketchikan	Reflection Lake (from Ward Lake)	Ward Lake Ketchikan Creek Mountain Point Bold Island Lakes Blank Inlet Gem Cove Margaret Lake Neets Bay	400,000
Neets Bay	SSRAA ^a	Neets Creek, Neets Bay, North Revillagigedo Island	Chickamin River	Neets Bay	500,000
Bell Island	American Aquaculture Corp.	Bell Island, West Behm Canal	Reflection Lake	Bell Island Creek	(not available)
Klawock River	City of Klawock	Klawock River, West-Central Prince of Wales Island	Klawock River	Klawock River	3,000,000
Port Armstrong	Armstrong-Keta, Inc.	Jetty Lake, South Baranof Island	Blanchard Lake Deer Lake	Armstrong Bay	650,000
Crystal Lake	ADF&G ^b	Crystal Lake, Blind Slough, Mitkof Island	Duncan Creek Mitchell Creek Portage Creek	Crystal Creek Mitchell Creek Portage Creek St. John's Creek	30,000
DIPAC	Douglas Island Pink and Chum, Inc.	Salmon Creek, Gastineau Channel, Juneau	Steep Creek Montana Creek Sheep Creek Pavlof River	Gastineau Channel Sheep Creek Twin Lakes Auke Bay Picnic Creek Davidson Creek Fish Creek	1,000,000

^a SSRAA = Southern Southeast Regional Aquaculture Association.

^b ADF&G = Alaska Department of Fish and Game.

Source: Information primarily from hatchery management plans provided by S. McGhee, ADF&G Division of Commercial Fisheries, 1255 West 8th Street, Juneau, AK 99802.

Numerous habitat enhancement projects, which include instream structures, stream habitat modifications, or fish ladders for coho salmon, have been completed in southeast Alaska. Descriptions of many of these projects have been compiled by Bibb (1987) and Parry and others (1993). No comprehensive review has been completed for numerous projects that stocked coho salmon above barrier falls. Examples include Banner, Deer, Osprey, Ludvik, and Tranquil Lakes on Baranof Island, Sea Lion Cove Lake on Kruzof Island (see Crone and Koenings 1985), and Sweetheart and Indian Lakes near Snettisham. Coho presmolts were stocked in Margaret Lake after the construction of a fish ladder (Bryant and others 1994).

Methods

Stock Discrimination

Coho salmon stocks discussed in this report are defined entirely by geographic location and timing of the runs. Preliminary attempts to develop genetic stock discrimination for selected coho stocks are in progress at the NMFS Auke Bay Laboratory, but no regional surveys have been completed.² Scale-pattern analysis has been successfully employed to separate wild and hatchery stocks (Wood and Van Alen 1987), but hatchery stocks are not included in this review. Some differences in scale patterns among wild stocks are described (Gray and others 1981). The usefulness of these characteristics in stock separation has not been evaluated, however.

We categorize coho salmon stocks in southeast Alaska into three groups, based on watershed type. These watershed types are (1) small to medium streams without lakes, (2) drainages containing lakes, and (3) large mainland rivers. The life histories of coho stocks may be affected in consistent ways by easily identified watershed characteristics.

Roughly 2,000 coho salmon stocks in southeast Alaska are found in small to medium streams. Coho populations in these systems tend to consist of fewer than 1,000 spawners, often less than 200 spawners. The age structure of these stocks is relatively simple, to consisting of fewer age classes than populations found in other watershed types. Production of juveniles is highly variable through time, which reflects the relative instability of this environment. Nonetheless, these systems are estimated to provide roughly 60 percent of the annual return of coho salmon to southeast Alaska (Elliott and Kuntz 1988). Fewer data for our analyses were available for coho salmon in stream systems than in lake systems.

Coho salmon populations found in drainages containing lakes are characterized by spawning escapements between 1,000 and 8,000 individuals, large smolts, high survival from juvenile to adult, high variability in duration of freshwater residence of juveniles, relatively stable production patterns, and relatively high proportions of jacks in spawning populations. Coho salmon inhabit about 200 lake-containing drainages in southeast Alaska. Lake systems provide the most data of the three general watershed types.

Coho populations in large rivers provided the least data for our analyses; consequently, statements about general patterns are tentative. The Stikine River may be a major producer of coho salmon in the region (Shaul and others 1984), but there are few data for these stocks. The average annual inriver harvest of coho salmon from the Stikine River was over 7,700 fish from 1979 to 1987. In interior tributaries of the Taku and Alsek Rivers, freshwater survival of juveniles appears to be reduced, possibly due to increased predation rates (Shaul 1990). Production of smolts appears to be highly variable, perhaps due to the dynamic nature of the rearing environment. Spawning escapements in large river watersheds differ widely throughout the region. The Tsiu-Tsivat River system west of Yakutat may support the largest population in the region with total inriver returns of greater than 100,000 individuals reported historically (Shaul and others 1987). The frequency of jacks in these stocks tends to be less than 1 percent.

² Personal communication. 1996. A. Gharrett, professor of fisheries, University of Alaska Southeast, 210 Anderson Building, 11120 Glacier Highway, Juneau, AK 99801.

Biological data (other than escapement survey counts) were available for only 48 (2.1 percent) of the estimated 2,300 coho stocks in southeast Alaska (Baker and others 1996). Of these, 26 stocks inhabit lake-containing watersheds, 12 are in watersheds with small to medium streams, and 10 occupy large rivers or tributaries to large rivers (table 2). Lake systems are disproportionately represented (56 percent of studied systems, but only about 10 percent of all watersheds with coho salmon). More information is available for large coho salmon stocks than for small stocks. Watershed classification of each system was based either on site descriptions contained in reports or inspection of U.S. Geological Survey topographic maps. Watershed classification of each stock was not clear in some cases (e.g., lakes, such as Speel, Windfall, and Chilkat Lakes, that connect closely with mainstem rivers). In such cases, classification was based on professional judgment about which watershed types were predominantly used by rearing coho salmon.³

Table 2—Location and rearing habitat type for coho salmon stocks for which biological data are available

Stream			Location		
Number	Name	Habitat type ^a	General ^b	N. latitude ^c	W. longitude ^c
101-29-006	Vallenar Creek	S	I	55°22'37"	131°49'39"
101-30-075	Hugh Smith Lake	L	MC	55°05'56"	130°38'40"
101-80-068	McDonald Lake	L	MC	55°57'53"	131°50'19"
101-90-050	Naha River	L	I	55°35'34"	131°35'33"
102-30-067	Kegan Lake	L	I	55°02'11"	132°12'16"
102-60-087	Karta River	L	I	55°33'36"	132°34'35"
102-70-058	Snaky Lakes	L	I	55°45' ^d	132°42' ^d
103-15-027	Klakas Lake	L	I	55°01'35"	132°21'51"
103-80-031	Warm Chuck Lake	L	I	55°46'28"	133°27'44"
103-90-010	Sarkar Lake	L	I	55°57'05"	133°12'33"
103-90-030	Staney Creek	S	I	55°49'12"	133°09'11"
106-30-051	Hatchery Creek	L	I	55°56'25"	132°58'14"
106-41-010	Salmon Bay Lake	L	I	56°14'11"	133°11'10"
106-43-021	Castle River	R	I	56°38'35"	133°15'14"
107-10-030	Black Bear Creek	L	MC	55°43'35"	132°10'00"
108-70-002	Stikine River	R	MC	56°36' ^d	132°23' ^d
109-10-009	Sashin Creek	S	I	56°22'49"	134°39'04"
109-20-013	Falls Lake	L	I	56°49'28"	134°41'58"
111-17-010	King Salmon River	R	I	58°02'36"	134°20'18"
111-32-032	Taku River	R	MC	58°25'32"	133°58'25"
111-32-068	Johnson Creek	S	MC	58°30'22"	133°52'57"
111-32-066	Yehring Creek	S	MC	58°30'06"	133°47'03"
111-32-203	Wilms Creek	S	MC		
111-32-254	Little Tatsamenie Lake	L	MN	58°25' ^d	132°20' ^d
111-32-260	Hackett River	R	MN		
111-32-270	Nahlin River	R	MN	58°48' ^d	132°01' ^d
111-32-280	Dudidontu River	R	MN	58°47' ^d	132°03' ^d
111-33-034	Speel Lake	L	MC	58°08'04"	133°42'55"
111-50-007	Windfall Lake	L	MC	58°30'26"	134°43'32"
111-50-042	Auke Lake	L	MC	58°23'17"	134°37'49"

³ Personal communication. 1996. L. Shaul, fisheries biologist, Alaska Department of Fish and Game, 802 3d Street, Douglas, AK 99824.

Table 2—Location and rearing habitat type for coho salmon stocks for which biological data are available (continued)

Stream			Location		
Number	Name	Habitat type ^a	General ^b	N. latitude ^c	W. longitude ^c
111-50-052	Montana Creek	S	MC	58°22'54"	134°35'46"
111-50-056	Steep Creek	S	MC	58°24'56"	134°34'30"
112-42-025	Kadashan Creek	S	I	57°42'08"	135°13'05"
112-50-010	Pavlof Lake	L	I	57°50'39"	135°02'54"
113-22-008	Politofski Lake	L	I	56°44'36"	134°56'36"
113-22-028	Plotnikof Lake	L	I	56°33'51"	134°53'56"
113-41-032	Salmon Lake	L	I	56°57'46"	135°08'54"
113-41-043	Redoubt Lake	L	I	56°54'07"	135°12'36"
113-62-005	Eagle River	S	I	57°15' ^d	135°40' ^d
113-62-008	Sinitsin Creek	S	I	57°19' ^d	135°44' ^d
113-66-006	St. John Creek	S	I	57°17' ^d	135°32' ^d
113-73-003	Ford Arm Lake	L	I	57°35' ^d	135°53' ^d
115-20-010	Berners River	R	MC	58°50'49"	134°58'08"
115-32-032	Chilkat Lake	L	MC	59°13'33"	135°30'54"
115-33-020	Chilkoot Lake	L	MC	59°19'15"	135°32'37"
182-30-020	Klukshu Lake	L	MN		
182-70-010	Situk River	R	MC	59°26'47"	139°33'58"
192-42-020	Tsiu River	R	MC	60°04' ^d	143°07' ^d

^a L = lake; R = river; and S = stream.

^b I = island; MC = mainland coastal; and MN = mainland interior.

^c Latitude and longitude are given for mouths of streams and rivers.

^d Value interpolated from topographic maps.

Source: ADF&G 1994 for most locations.

We also compared coho populations in coastal and interior sites. Coho stocks inhabiting coastal and interior sites were expected to show differences in biological characteristics, because of considerable differences between these different geographic zones in climate, fish communities, and difficulty of migration. However, because relatively limited data were available for five interior stocks (Hackett, Dudidontu, upper Nahlin, and Tatsamenie Rivers—all Taku River tributaries in British Columbia; and the Klukshu River—a tributary of the Alsek River in the Yukon Territory), most comparisons made between interior and coastal habitats were descriptive rather than inferential.

Data Analysis Procedures

We compared and identified general patterns in the biological characteristics of coho populations found in the three watershed types, as well as compared interior and coastal stocks. These categories provided a convenient and intuitive separation to evaluate potentially sensitive or biologically distinct stocks. Most of the comparisons were among the three watershed types.

Biological characteristics included juvenile and adult (primarily from escapement data) length, mean freshwater ages (MFWA) of juvenile, smolt, and adult fish, and migration timing of smolt emigration and immigration of returning adult fish. Demographic variables included escapement indices (estimates of population size), exploitation rates, and freshwater and marine survival. Compared to databases for other species

of Pacific salmon in the region, more data were available on characteristics of rearing juvenile coho, including body length for 28 stocks and emigration timing for 7 stocks. Consistent data were not available for all variables, and sample sizes differed among variables depending on availability of adequate data.

Six stocks were included in the variance-component analysis of adult fork lengths. Stocks were included based on the criteria of having at least 5 years of sampling with samples of at least 15 individuals of each sex in the 2.1 age class, the only age class that could be evaluated. The years sampled were not the same for all stocks.

Migratory timing characteristics were evaluated for 24 stocks with daily weir counts and 126 stocks for which our run-timing index could be calculated (see "General Introduction"). Six of the systems with weirs also were included in the run-timing index sample. Because of differences in data-collection methods and calculation procedures, mean dates from weirs and surveys were not comparable. Timing statistics also were compiled and compared for coho smolt emigration from seven systems monitored with fyke nets or traps.

Escapement survey data for 129 coho stocks with at least 7 survey years were taken entirely from the computerized data files maintained by ADF&G, Division of Commercial Fisheries. This sample represented about 5 percent of all coho salmon stocks in the region. For coho salmon, escapement survey records span 1960 to 1992, but only 20 percent of all stocks we analyzed were surveyed in 15 or more of these years. Escapement counts made at weirs were extracted from ADF&G and USFWS reports. Some weir counts for coho salmon collected before 1950 by the USBF also are included in this report. Analysis of trends in abundance was hampered by the lack of consistent census methods and limited sample size. Furthermore, escapement data series for most coho stocks began in the 1970s or 1980s, after many factors may have already resulted in declines in abundance.

Mean freshwater age and proportions of escapements in each age and sex class were used to describe the age structure of 31 coho salmon stocks. Adult MFWAs were calculated for each sex separately as well as combined. Jacks were not included in the calculation of MFWAs, because of inconsistent sampling of jacks from escapements. The protocol for sampling the age structure of escapements frequently consists of single, brief visit to each run. This sampling regime cannot detect seasonal shifts in age structure. Short-term sampling may be adequate for small stocks with relatively brief runs, but serious bias can result from a few days of sampling from large stocks with protracted runs.⁴⁵ The most reliable age-structure data came from stocks sampled throughout their runs at weirs. Interannual variation in MFWA was examined only for stocks sampled at weirs. Because of the numerous limitations associated with age-structure data, we relied entirely on grand means from all sample years for our analyses of age-structure outliers. Age-structure analyses based on small samples and few sample years should be regarded as highly provisional.

⁴ Personal communication. 1996. M. Haddix, limnologist, Alaska Department of Fish and Game, 2030 Sea Level Drive, Suite 215, Ketchikan, AK 99901.

⁵ Personal communication. 1996. T. Zadina, fisheries biologist, Alaska Department of Fish and Game, 2030 Sea Level Drive, Suite 215, Ketchikan, AK 99901.

Mean freshwater ages and percentages in each age class were also calculated from samples of juveniles (18 stocks) and emigrating smolts (9 stocks); these samples could not be separated by sex. The age structure of juvenile coho samples may be biased because of differences in trap efficiency for age classes, particularly age 0.0 fry, which may be undersampled when large (6.25 mm) mesh traps are used to capture juvenile fish.

Systematic errors in aging may be present in some age estimates, in particular those for 1982 and 1983⁶ (also see footnote 3). The ADF&G is in the process of reevaluating its scale-aging procedures for several species, including coho salmon. Since 1984, coho salmon aging techniques have been applied with enhanced consistency but still may contain systematic errors (see footnote 3). Some portion of observed patterns or trends in age structure of coho stocks may be an artifact of ongoing changes in ADF&G scale-aging techniques.

Sex-ratio values were derived from escapement age-structure or body-length samples, whichever contained the most individuals. We expressed sex ratio both as a numeric ratio, with the male portion of each sample standardized to one, and as the percentage of each sample consisting of males. Statistical evaluation of sex ratios was conducted only on weir samples; we assumed these samples were unbiased in regard to sex. Because of the possibility of run-timing differences between the sexes, weir samples were included only from years in which weirs were operational for the entire run.

Survival rates from smolt to adult return or juvenile to adult return were compiled for 19 stocks of coded-wire-tagged coho salmon juveniles. Despite differences in methods used to estimate survival (Elliott and Kuntz 1988; Elliott and Sterritt 1990, 1991; Elliott and others 1989; Gray and others 1978; Josephson 1985; Schmidt 1985, 1986, 1987, 1988, 1990; Schmidt and DerHovanisian 1991; Shaul 1989, 1990; Shaul and Koerner 1988; Shaul and others 1986, 1987, 1991), computed values can be compared within each age class. Estimates of survival of rearing juveniles to time of adult return incorporated some proportion of survival in freshwater as well as ocean survival. Estimates for smolt survival rates reflect marine mortality. Estimates were based on total return (catch and escapement) and reflect natural mortality. Only four stocks had sufficient data to allow evaluation of long-term temporal trends in survival.

The term "exploitation rate" is used here to refer to the total catch of a stock by all fisheries divided by the total return (catch plus escapement) (Shaul 1988). Methods used to estimate exploitation rates also can be found in Elliott and Kuntz 1988; Elliott and Sterritt 1990, 1991; Elliott and others 1989; Gray and others 1978; Josephson 1985; Schmidt 1985, 1986, 1987, 1988, 1990; Schmidt and DerHovanisian 1991; Shaul 1989, 1990; Shaul and Koerner 1988; and Shaul and others 1986, 1987, 1991. Again, these estimates are roughly comparable despite differences in estimation techniques used by various authors.

⁶ Personal communication. 1996. S. Elliott, fisheries biologist, Alaska Department of Fish and Game, 802 3d Street, Douglas, AK 99824.

One major goal of this project, to identify distinctive coho salmon stocks, was thwarted by the paucity of studied stocks relative to the total number of stocks in the region. Intensive study of indicator systems provided the long-term temporal data sets necessary to understand patterns of temporal variation, but these systems may not represent the full range of geographic variation found throughout the region. If the small sample of stocks for which biological data exist is representative of the distribution of variation among all stocks in the region, then stocks identified by outlier analysis as distinctive are likely to represent unusual elements of regional intraspecific diversity. The existing small sample was chosen because it was considered by ADF&G to be typical among stocks found in different watershed types in different districts, but it is difficult for such a small proportion of stocks to represent the spectrum of variation. Stream stocks clearly were undersampled.

For various reasons, data for coho salmon are particularly prone to the limitations described in the “General Introduction.” Most of the reasons for limited data quality are associated with the late run timing of most coho salmon stocks; i.e., coho run timing coincides with periods of high precipitation and increased stream flow, resulting in logistical difficulties, poor visibility, and inconsistent sampling effort and survey methodology. Furthermore, most weirs at which coho salmon are enumerated and sampled for biological characteristics are operated primarily for sockeye salmon, and frequently the weirs are removed before completion of the coho salmon runs. Early weir removal has obvious effects on run-timing statistics and abundance estimates, and because age composition and sex ratio can vary during the course of a run, termination of sampling before run completion can introduce bias into data for these characteristics as well. Potential sources of bias should be kept in mind when evaluating our results for these characteristics. Sampling and counts conducted at weirs, nonetheless, provide the most detailed data available for biological characteristics of coho stocks.

Results

For each variable considered, results are generally presented in the following sequence. First, comparisons among watershed types are presented and basic patterns described. Second, age classes and sexes are compared within stocks, and age-sex effects on biological variables such as body length are considered (the number of stocks studied was inadequate to conduct multivariate analyses). Third, results of analyses conducted to examine relations among biological variables are presented. These analyses were possible in only a few cases. Fourth, chronological trends are presented. Finally, stocks are identified that deviate substantially from typical patterns described in any of the preceding analyses.

Body Length

Juveniles and smolts—Rearing habitat did not have any consistent effects on fork lengths of rearing juvenile coho salmon. Fry in stream systems appeared to be smaller than fry in other watershed types (fig. 5A), but the stream watershed type is represented by samples from only two streams that are in the same drainage. Fork lengths of juvenile (age 1.x) coho salmon did not differ consistently among watershed types (fig. 5B); the data set for age 2.x was too small to analyze. Chilkat Lake juveniles were consistently the largest measured in all age classes, but an insufficient number of stocks were sampled to conduct outlier analysis.

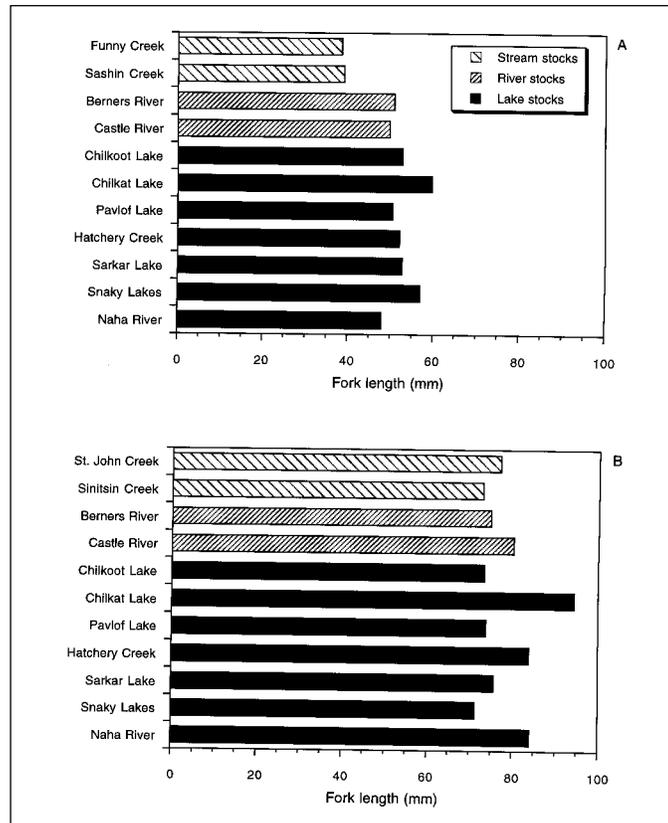


Figure 5—Body lengths of rearing coho salmon juveniles by habitat type: (A) age 0.x, (B) age 1.x. Plotted values are means for all years sampled, for each stock. Means are for samples taken in June and July only.

Smolts of all ages emigrating from stream systems were consistently smaller than those emigrating from lake and river systems (fig. 6). The difference in body size between watershed types increased with increasing freshwater age (fig. 6). Smolts from Eagle River were consistently the smallest in all age classes (fig. 6). The minimum length of coho salmon smolts in southeast Alaska is about 70 mm. Combining data from all systems, the mean size of smolts increased by about 15 mm for each additional year spent in fresh water. In all cases where early and late samples were taken during the same season, larger smolts of a given age class emigrated later.

Adults—A graphic comparison of watershed types indicated no consistent pattern of adult body size (mideye-to-fork length) variation by watershed type for either sex (fig. 7). Severely unbalanced sample sizes precluded statistical comparisons among watershed types; 20 of the 27 stocks sampled inhabited lake systems. All watersheds were pooled for subsequent analyses of body length.

Male and female adult body lengths were significantly different for all age classes (paired t-tests, maximum $P = 0.02$; females always larger); sexes were evaluated separately in all comparisons. Male body length did not differ significantly among freshwater age classes (Kruskal-Wallis, $P = 0.39$, nonsignificant [NS]) but female size increased significantly with increasing freshwater age (Kruskal-Wallis, $P = 0.01$).

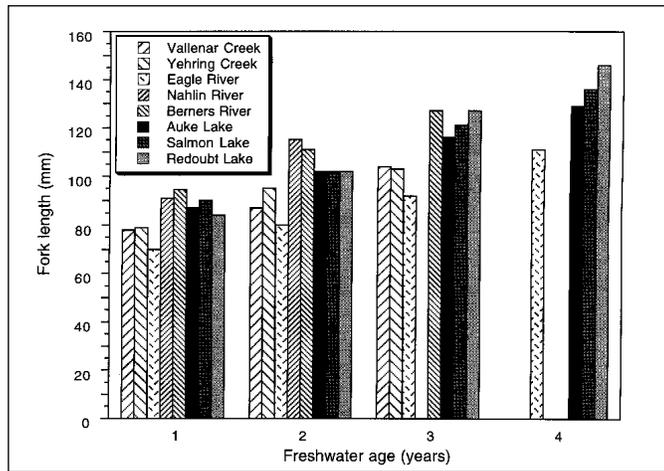


Figure 6—Body lengths of coho salmon smolts by freshwater age, stock, and habitat type. Despite its name, Eagle River is considered a stream stock (see table 2). Plotted values are means for all years sampled for each stock. Samples taken in mid-April to May only.

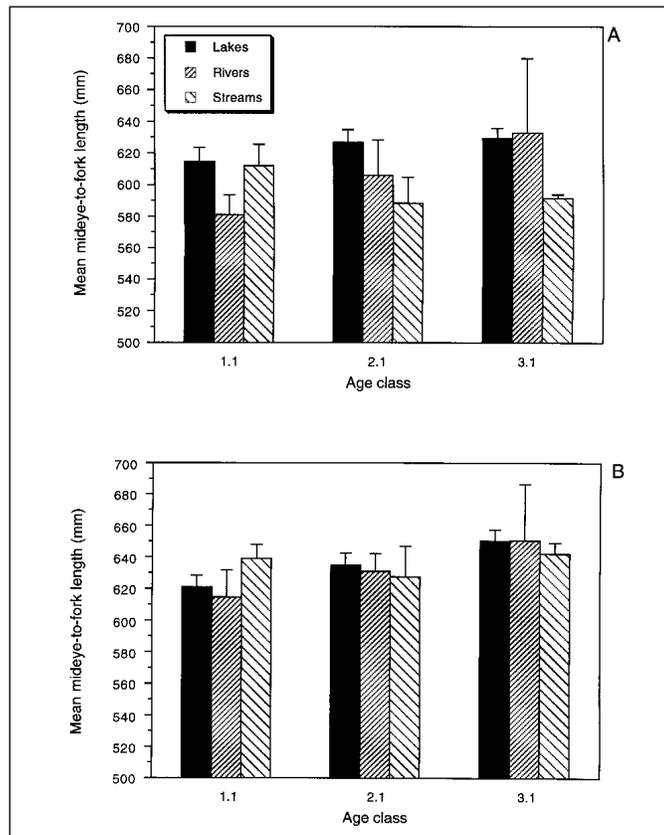


Figure 7—Body lengths of coho salmon adults by habitat type: **(A)** males, **(B)** females. Plotted values are grand means for all stocks in each of the three habitat types. Bars give standard errors of grand means. Sample size differs with sex and age class but never exceeds 20 for lake stocks, 4 for river stocks, and 3 for stream

The body sizes of males and females within stocks were correlated (age class 1.1, $r = 0.78$, $P < 0.0001$; age class 2.1, $r = 0.82$, $P < 0.0001$; age class 3.1, $r = 0.55$, $P = 0.032$). When male and female body sizes within each stock were compared, no stock showed an unusual pattern of sexual dimorphism.

Variance-component analysis indicated that over 90 percent of total variation in male body length and 89 percent of female body-length variation were attributable to differences among individuals within the six stocks evaluated (table 3). Interannual variation within stocks was twice as great in females (11 percent) as in males (5.5 percent). For females, variation among stocks was negligible.

Table 3—Variance component analysis of age 2.1 coho salmon mid-eye-to-fork lengths from escapement samples^{a,b}

Source of variation	Degrees of freedom	Type 1 sum of squares	F-test	Error term	Expected mean square	Variance component	Percentage of total
Males							
Total	3,507	18,758,882			5,348.98	5,403.81	100
Stocks	5	850,769.69	4.57	Years	170,153.94	215.23	3.98
Years	24	892,654.85	7.60	Error	37,193.95	296.27	5.48
Error	3,478	17,015,457			4,892.31	4,892.31	90.53
Females							
Total	3,663	9,895,958.2			2,701.60	2,724.68	100
Stocks	5	209,493.73	1.15	Years	41,898.75	-9.74	0
Years	24	877,062.69	15.08	Error	36,544.28	300.52	11.03
Error	3,634	8,809,401.8			2,424.16	2,424.16	88.97

^a Variance components computed from means, standard errors and sample sizes.

^b Stocks included in the analysis:

101-30-075 Hugh Smith Lake
 111-32-066 Yehring Creek
 111-50-042 Auke Lake
 113-41-032 Salmon Lake
 113-73-003 Ford Arm Lake

No significant temporal trends were found in adult body-length variation from 1982 through 1990 for the eight stocks analyzed (table 4). Nine of sixteen regression coefficients were negative, and only one result approached significance (Salmon Lake males, slope = -0.73, $P = 0.06$). Interannual variation in body length was high, but this variation did not show any consistent trend during the relatively short period covered. A regression analysis on the body weights of commercially caught coho salmon in southeast Alaska from 1958 to 1985 (Marshall and Quinn 1988) revealed a nonsignificant trend of decline ($R^2 = 0.09$, $F = 2.59$, $P = 0.12$).

Table 4—Regression analysis of trends across years in mideye-to-fork lengths from coho salmon escapements

Stream		Males					Females				
Number	Name	No. years sampled	R-squared	Slope	P-value	Significance	No. years sampled	R-squared	Slope	P-value	Significance
101-30-075	Hugh Smith Lake	6	0.11	0.33	0.52	NS	6	0.22	0.46	0.35	NS
111-32-032	Taku River	5	0.05	-0.23	0.71	NS	5	< 0.00	0.003	0.99	NS
111-32-066	Yehring Creek	5	0.09	0.30	0.63	NS	5	0.27	0.52	0.37	NS
111-50-042	Auke Lake	6	0.01	-0.10	0.85	NS	6	0.004	0.07	0.90	NS
113-41-032	Salmon Lake	7	0.53	-0.73	0.06	NS	8	0.07	-0.26	0.54	NS
113-41-043	Redoubt Lake	7	0.10	-0.10	0.83	NS	7	0.01	-0.11	0.82	NS
113-73-003	Ford Arm Lake	5	0.46	-0.68	0.21	NS	7	0.40	-0.64	0.25	NS
115-20-010	Berners River	5	0.01	-0.11	0.86	NS	5	0.006	0.08	0.90	NS

NS = not statistically significant

Females from Pavlof Lake in the 1.1 and 2.1 age classes were distinctively small (fig. 8). The spawning migration of this stock also is unusually early (see “Adult Spawning Migrations,” below). The Pavlof Lake stock was among the stocks with the smallest body sizes in all age and sex classes for which data were available. There is a positive association between age 2.1 adult body sizes and mean dates of spawning migrations from systems with weirs (males, $N = 20$, $R^2 = 0.12$, $b = 0.34$, $P = 0.16$, NS; females, $N = 20$, $R^2 = 0.57$, $b = 0.57$, $P = 0.01$).

Timing

Smolt emigration—The grand mean emigration date for smolts in all years in all seven systems measured was 21 May (Julian date of 141, SE = 2.2 days). Daily count data indicated that, although the mean date of migration was relatively consistent both within and among stocks, the duration of runs differed considerably both among years within stocks and among stocks (table 5).

No differences in emigration timing were apparent among watershed types. The single year of data available from the Nahlin River indicated late emigration timing, which may be attributed to the colder climate associated with the interior location of this drainage. Salmon Lake and Eagle River stocks, both near the outer coast, had the earliest emigration timing.

Adult spawning migrations—Klawock River, Warm Chuck Lake, and Redoubt Lake were three locations where both historic and contemporary weir counts were available. In all three cases, the contemporary mean migration dates were later than those from the recent past. The mean migration date of adult coho salmon returning to the Klawock River from 1930 through 1938 was about 10 days earlier than that observed between 1982 and 1987; similarly, returns to Redoubt Lake were about

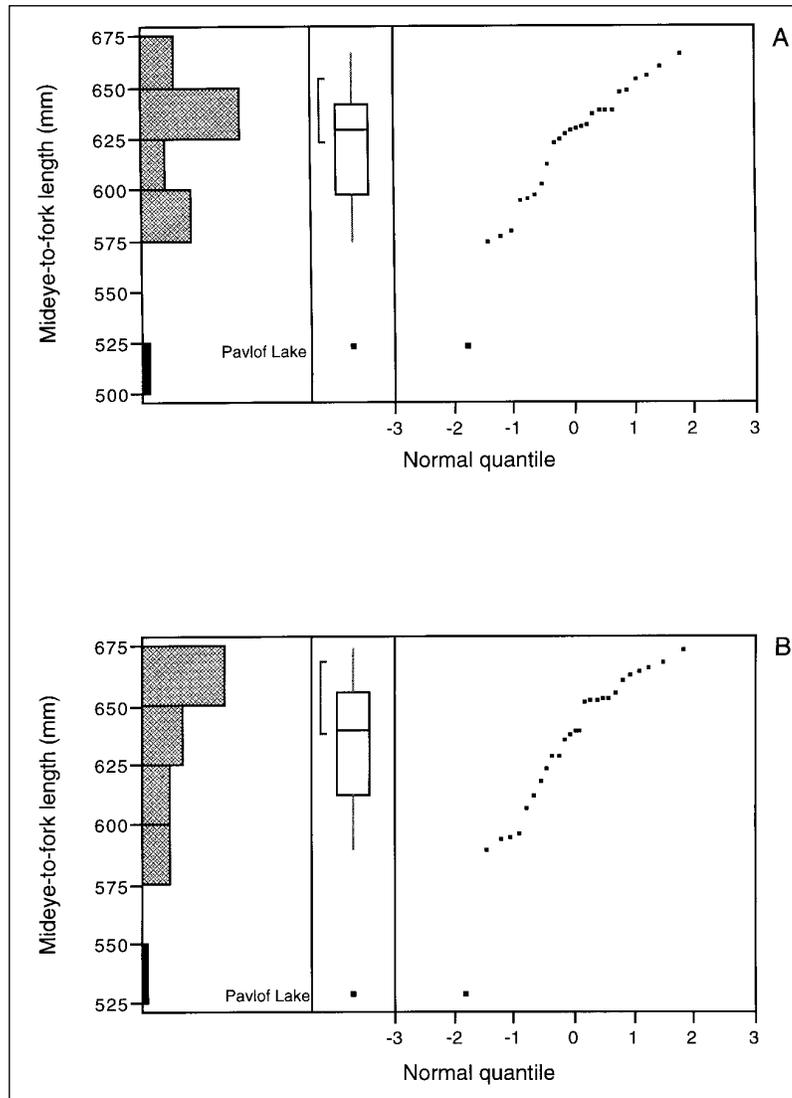


Figure 8—Frequency distributions, outlier plots, and normal quantile plots for mid-eye-to-fork lengths of **(A)** age 1.1 females, N = 26, and **(B)** age 2.1 females, N = 27. For both age classes, females from the Pavlof Lake stock are distinctively small. Both distributions are significantly non-normal by the Wilks test but become acceptably normal when the Pavlof Lake data point is removed.

10 days earlier from 1953 through 1957 than from 1982 through 1988. Returns to Klawock River after 1980 may have been influenced by the presence of the hatchery on the river. During the same period, Redoubt Lake was fertilized to increase primary productivity.

The mean date of spawning migration at Salmon Lake showed no prevailing trend across the 8 recent years for which daily weir count data were available ($R^2 = 0.002$, $P = 0.92$ NS). At Auke Lake, 20 years of daily weir counts from 1971 through 1990 showed a nearly significant trend toward earlier migration ($R^2 = 0.19$, $P = 0.06$ NS).

Table 5—Coho salmon smolt emigration counts and timing

Stream					Mean date			
Number	Name	Notes	Year	Total count	Calendar	Julian	Variance	Source
101-29-006	Vallenar Creek	^a	1988	4,177	18-May	138	19.06	Elliott and others 1989
109-10-006	Sashin Creek	^b	1968	1,440	24-May	144		Crone and Bond 1976
		^c	1967	1,400	25-May	145		"
			1964	334	24-May	144		"
			1963	1,599	24-May	144		"
			1962	2,865	27-May	147		"
			1961	2,489	28-May	148		"
			1960	1,258	10-Jun	161		"
			1959	1,587	27-May	147		"
			1958	1,015	20-May	140		"
			1957	1,961	24-May	144		"
	1956	928	15-Jun	166		"		
	Mean					148		
	SE					0.72		
111-32-032	Taku River Canyon Island)	^d	1961		24-May			Meehan and Siniff 1962
111-32-066	Yehring Creek		1989	9,654	25-May	145	31	Elliott and Sterritt 1990
			1987	5,853	25-May	145	52.96	Elliott and Kuntz 1988
111-32-270	Nahlin River	^e	1990	2,053	11-Jun	162	11	Elliott and Sterritt 1991
113-41-032	Salmon Lake	^f	1990	7,494	4-May	124	108	Schmidt and DerHovanisian 1991
			1989	6,683	11-May	131	49.78	Schmidt 1990
		^g	1988	7,281	09-May	129	21.76	Elliott and others 1989
		^h	1987	10,952	11-May	131	71	Schmidt 1988
		^{h,i}	1986	7,397	16-May	136	35	Schmidt 1987
	^{h,j}	1985	6,834	27-May	147	33	Schmidt 1986	
	^k	1984	4,089	12-May	132	17	Schmidt 1985	
	Mean					133		
	SE					1.03		
113-62-005	Eagle River	^l	1990	2,880	5-May	125	64	Schmidt and DerHovanisian 1991
		^m	1989	3,259	10-May	130	66.04	Schmidt 1990
			1988	3,919	11-May	131	45.44	Elliott and others 1989
	Mean					129		
	SE					1.07		
Total mean					21-May	141	44.58	
Total SE							2.21	

^a Weir out 28 April through 2 May and on 22 May and 28 May.

^b Mean dates reported for Sashin Creek are actually the date of the largest outmigration.

^c Counting procedure changed from total to partial counts: holding facilities were inadequate for retaining all smolts captured.

^d Midweek date from week with largest catch.

^e Rapidly melting snow produced flood conditions during most of May. Few smolt were caught during this period because the nets were plugged with debris.

^f Fyke net washed out or deactivated because of high water 27-29 March and 19-22 April.

^g Partial night of trapping on 12 May and no fishing done on 13-14 May because of high water.

^h To calculate mean dates where cumulative totals for 3 or 4 days were given rather than daily counts, equal portions were allocated for each day.

ⁱ Fyke nets were not fished 12-16 April owing to low water levels.

^j Fyke nets were not fished 14-16 May owing to high water.

^k Traps were not set on 22 April and 28 April.

^l Fyke net washed out on 4 May. Fyke net washed out on 17 May.

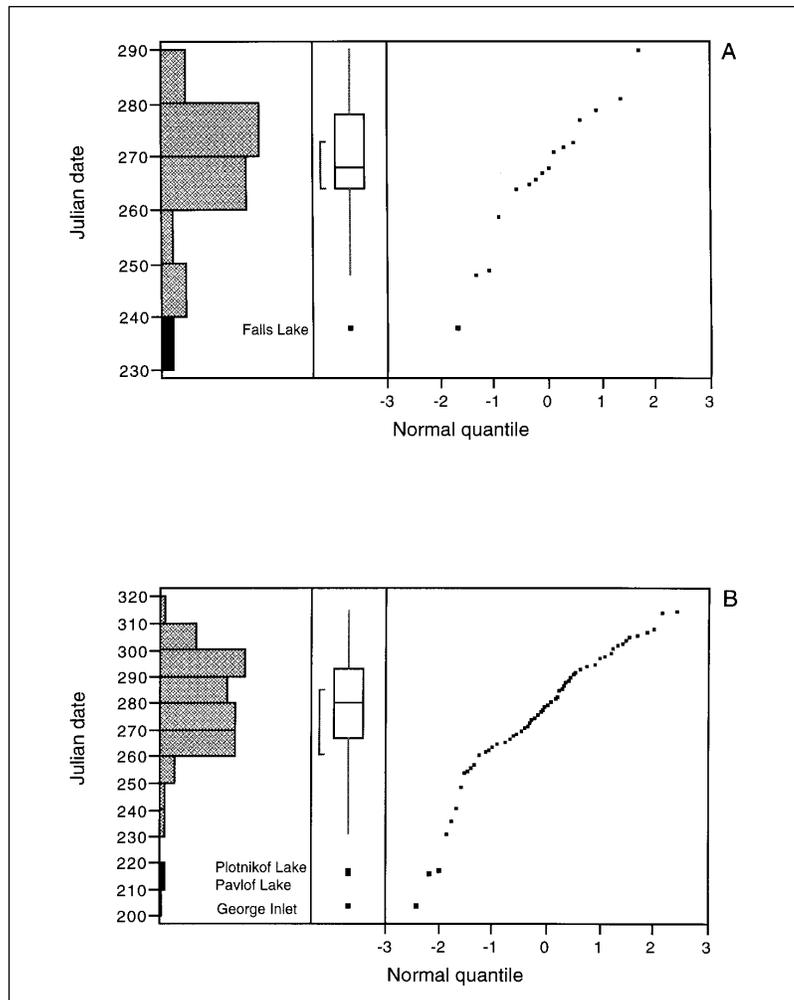


Figure 9—Frequency distributions, outlier plots, and normal quantile plots for **(A)** mean dates of passage at weirs, $N = 21$, and **(B)** index dates based on the timing of peak escapement survey counts, $N = 126$. The Falls Lake stock has a distinctively early weir mean date, 26 August, and a small mean escapement of 129 fish. The Salt Chuck-George Inlet, Pavlof Lake, and Plotnikof Lake stocks all have distinctively early-run timing, with peak escapement surveys typically occurring during the first 2 weeks of August. The George Inlet and Pavlof Lake stocks are small, with mean escapement estimates of 159 and 158 fish, respectively. The mean estimated escapement for Plotnikof Lake is nearly 1,400 fish.

The grand mean date of adult spawning migrations was 27 September (Julian date 270; $N = 21$ stocks with daily weir counts). The Falls Lake stock had a distinctively early mean date of migration among the 21 stocks contained in the overall distribution (fig. 9A). The mean migration date for jacks was 23 September (Julian date 266; $N = 10$ stocks). The Nahlin River stock returned early in comparison to other stocks in the upper Taku drainage (see Elliott and Sterritt 1991), but the grand mean date for the Nahlin stock was not an outlier.

Outlier analysis of run timing index dates (N = 126 stocks) indicated that three stocks had unusually early run timing (Salt Chuck-George Inlet, Port Banks [Plotnikof Lake], and Pavlof Lake; fig. 9B). No stocks were detected with exceptionally late migration timing, but this result probably reflects a lack of surveys late in the year during adverse climatic conditions. Coho stocks in Lynn Canal migrate later than most stocks, but none of the stocks for which data were available was an outlier from the run-timing distribution. Late run timing often is correlated with spawning in glacial systems (Shaul 1989), because delaying until after the onset of colder weather may enable spawners to avoid high concentrations of glacial silt. Some coho stocks in the Yakutat area (e.g., Tawah Creek) are known to spawn in February and even into March (see footnote 3), perhaps because winter water temperatures there are relatively warm.

Demography

The demographic variables evaluated for coho salmon stocks were escapement trends and magnitude, the effects of water quality on population status, age structure (of rearing juveniles, emigrating smolts, and spawning adults), sex ratio of spawning adults, survival, and stock exploitation rates.

Escapement—Among the five stocks monitored at weirs, the only significant result was a decline in the number of jacks counted at the Salmon Lake weir. Among stocks monitored with escapement surveys, nine of 128 stocks increased significantly, and seven decreased significantly (using stocks with at least seven records from 1960 to 1992 and fair data quality; table 6). Of the nine increasing stocks, four were near Juneau and exhibited high returns during the past 5 years when coho returns were also high to the Douglas Island Pink and Chum (DIPAC) hatchery on Gastineau Channel in Juneau. Three declining stocks on Mitkof Island (Bridge, Lee's Cabin, and Powerline Creeks) are all in small streams within 1 km of Crystal Lake hatchery that are affected by variable rates of straying by returning hatchery fish and interception in commercial and sport fisheries for hatchery returns.⁷

Most of the stocks with declining escapements occurred in stream systems (six of seven stocks); the lone exception was the Port Banks (Plotnikof Lake) stock (table 6). Increasing stocks were less likely to occur in lake-containing watersheds (7 percent of 27) than in stream or river systems (33 percent of 21; Fisher test, $p = 0.03$).

Because lake systems often are considered more stable in their production of coho salmon than stream systems, we compared variation over time (coefficient of variation) in weir escapement counts for these two watershed types. Coefficients of variation for lakes ranged from 23 percent to 73 percent, but the only available stream (Sashin Creek) coefficient was 141 percent.

The Tsiu and Tsivat River stocks had the highest escapements among the 124 stocks included in the outlier analysis of survey data (fig. 10). The coho salmon stocks in these rivers have been noted historically for their exceptional productivity (Shaul and others 1987).

⁷ Personal communication. 1996. F. Cole, staff officer, U.S. Department of Agriculture, Forest Service, Tongass National Forest, Stikine Area, P.O. Box 309, Petersburg, AK 99833.

Table 6—Coho salmon stocks with significantly declining escapement trends

Stream		Location			Data quality	Possible factors
Number	Name	VCU ^a	General	Land use ^b		
101-71-041	Indian Creek	796K	Misty Fiords National Monument	Wilderness	Fair	Unknown
105-10-024	Bear Harbor Creek	409S	Kuiu Island	Wilderness	Fair	Unknown
106-44-024	Bridge Creek	451S	Mitkof Island	LUD III	Fair	Habitat degradation; hatchery effects, road culverts
106-44-026	Lees Cabin Creek	451S	Mitkof Island	LUD III timber harvest	Fair	Habitat degradation; hatchery effects; road culverts
106-44-027	Powerline Creek	451S	Mitkof Island	LUD III timber harvest	Fair	Habitat degradation; hatchery effects; road culverts
111-50-065	Johnson Creek	33C	Douglas Island	Private	Fair	Habitat degradation
113-22-028	Plotnikof Lake	344C	South Baranof Island	Wilderness	Fair	Unknown

^a VCU = USDA, Forest Service value comparison unit; approximately equivalent to a watershed; K = Ketchikan Area; S = Stikine Area; and C = Chatham Area.

^b LUD = land use designations:

LUD II = roadless areas

LUD III = multiple use

LUD IV = intensive resource use (especially logging)

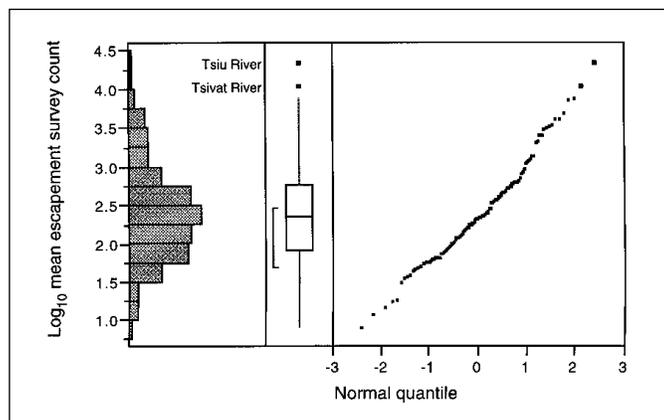


Figure 10—Frequency distribution, outlier plot, and normal quantile plot for mean peak escapement counts of stocks included in escapement surveys, N = 126. The Tsiu and Tsvat River stocks are distinctively large, with mean escapements over 22,000 and 11,000 fish, respectively. These rivers are close together on the Yakutat forelands.

Water quality and demographic status—Coho salmon stocks in water bodies currently listed as impaired in southeast Alaska (N = 9; table 7; ADEC 1992) were typically small, with peak survey counts of less than 100 individuals. The only larger stock in an impaired water body is in Rowan Bay on Kuiu Island, but survey counts differed in methods and timing and ranged from 0 to 936. Of the coho stocks that spawn in suspected water bodies, only 6 stocks had 7 or more years of escapement surveys, enough to permit analysis of population trends. Montana Creek showed a significant population increase that can be attributed to the DIPAC hatchery. Furthermore, Montana Creek is relatively undisturbed in the upper part of the watershed. In contrast, the coho stock in nearby Lemon Creek, a heavily impacted stream with gravel extraction, timber harvest, and urbanization, began with low numbers and decreased further. In Lemon Creek, 57 fish were counted in 1974; in the following years, counts ranged between 15 and 5 fish with no fish observed during the last survey in 1985. No stocks with distinctive biological characteristics were found in either impaired or suspected water bodies.

Table 7—Coho salmon stocks in impaired or suspected water bodies

Stream		Location		Pollutant source types ^a	Comments
Number	Name	VCU ^a	General		
Impaired water bodies					
101-47-015	Ward Cove	749K	Ketchikan	IN, Debris	High count, 1,550 fish in 1985, below 100 fish since 1987, but surveys early. Highly manipulated population.
109-52-007	Rowan Bay	402S	Kuiu Island	TH	Variable survey methods, high count 936 fish in 1971. No recent surveys.
111-40-010	Lemon Creek	32C	Juneau	UR, PP, MI, LF, SM, GM	High count 57 fish in 1974. Last count in 1985, 0 fish.
111-40-012	Vanderbilt Creek	32C	Juneau	UR, GM, LF	50 fish counted in 1984
111-40-015	Salmon Creek	32C	Juneau	UR, DDE, PCB	Possible introgression of hatchery fish.
111-40-089	Lawson Creek	33C	Douglas	UR, RD, CH, SM	12 fish in 1984, only count.
111-50-060	Duck Creek	32C	Juneau	UR, PP, LF, CH, RD, LD	High count 80 fish in 1992. Possible hatchery fish
113-41-017	Granite Creek	311C	Sitka	UR, GM	2 fish in 1981.
115-32-091	Sawmill Creek	NA	Haines	UR, ST, CH, SM, RD	20 fish in 1976, 1 fish in 1979, no counts since.
Suspected water bodies					
101-45-016	White River	748K	Ketchikan	TH	Small run, < 40 fish.
101-47-025	Ketchikan Creek	751K	Ketchikan	UR, IN, SE	Very variable counts.
102-70-058	Thorne Bay	586K	Thorne Bay	IN, UR, SE, SM	Poorly documented. High count 63 fish in 1986.
103-60-059	Port St. Nicholas Creek	NA	Craig	TH, UR	Variable; high count 200 fish in 1982.
103-90-030	Staney Creek	588K	Prince of Wales	TH	Variable; 1,114 fish in 1986, 37 fish in 1988. Mean USBF weir count 1929-32, 9,101 fish.
111-40-007	Switzer Creek	32C	Juneau	UR, DDT	Variable run strength up to 227 fish in 1991.
111-50-052	Montana Creek	27C	Juneau	UR	Run expanding, 2,208 fish in 1992.
111-50-062	Jordan Creek	27C	Juneau	UR, LD	Variable run, 785 fish in 1992.
112-65-024	Greens Creek	144C	Hawk Inlet	PP	Small, poorly documented, run. Three fish in 1989.

Table 7—Coho salmon stocks in impaired or suspected water bodies (continued)

Stream		Location		Pollutant source types ^b	Comments
Number	Name	VCU ^a	General		
113-41-021	Sawmill Creek	318C	Sitka	LF	Poorly documented. High count 100 fish in 1985.
113-72-002	Klag Bay	271C	Klag Bay	MI, TA, metals	Poorly documented. High count 2,000 fish in 1963, only 2 fish in 1980.
115-20-007	Johnson Creek	16C	Berners Bay	TA	Small, poorly documented run. High count of 28 fish in 1984

NA = not available.

^a VCU = USDA, Forest Service value comparison unit; approximately equivalent to a watershed; K = Ketchikan Area;

S = Stikine Area; and C = Chatham Area.

^b Pollutant source types:

CH = channelized stream

DDE = dichlorodiphenylchloroethane

DDT = dichlorodiphenyltrichloroethane

GM = gravel mining

SE = sewage discharge

SM = streambank or shoreline modification

ST = septic tanks

IN = industrial

LD = land development

LF = landfill

MI = mining

TA = tailings

TH = timber harvest

UR = urban runoff

PCB = polychlorinated biphenyls

PP = petroleum products

RD = road runoff

Source: ADEC 1992; ADF&G computerized escapement database.

Age structure—Mean freshwater age of juveniles did not show a clear pattern of variation among watershed types (fig. 11). Some interior mainland rivers had very low juvenile MFWAs, especially the Dudidontu (MFWA = 0.02 years). The low MFWA may be attributed to immigration of nomad fry from upstream habitats (Chapman 1962). Low fry-to-juvenile (age 1.x) survival is likely in main stream habitats (Bryant 1985a).

The MFWA of lake smolts (N = 5 stocks) was typically higher than that of stream (N = 3) or river (N = 2) smolts (fig. 11B). Twenty to fifty percent of smolts in lake systems spent at least 3 years rearing in fresh water, but only 2 to 13 percent of stream smolts and 0 to 21 percent of river smolts spent 3 years in fresh water. The Nahlin River had the lowest smolt MFWA (1.12 years), with 88 percent of the smolt cohort emigrating after 1 freshwater year. The MFWA of Nahlin River returning adults was higher than that of smolts and juveniles, however (table 8). The Nahlin is a tributary of the Taku, and the juveniles from the Nahlin may have moved downstream into the Taku River drainage rather than emigrating to salt water. Older and larger smolts may experience better ocean survival, which could account for the high MFWA of adults relative to smolts (Holtby and others 1990). This pattern observed for the Nahlin stock was based on single samples for each life history stage, and the samples do not correspond to a single cohort.

In contrast to the Nahlin River stock, MFWA of smolts was greater than that of adults (sexes combined for comparison of life history stages) in 15 of 24 cases in which the MFWA of an emigrating smolt cohort could be compared to the MFWA of that same cohort when it returned to spawn (Elliott and others 1989). Such changes may indicate that differential survival among age classes occurred during the period between samples (specifically, better survival for younger smolts), or there were sampling errors.

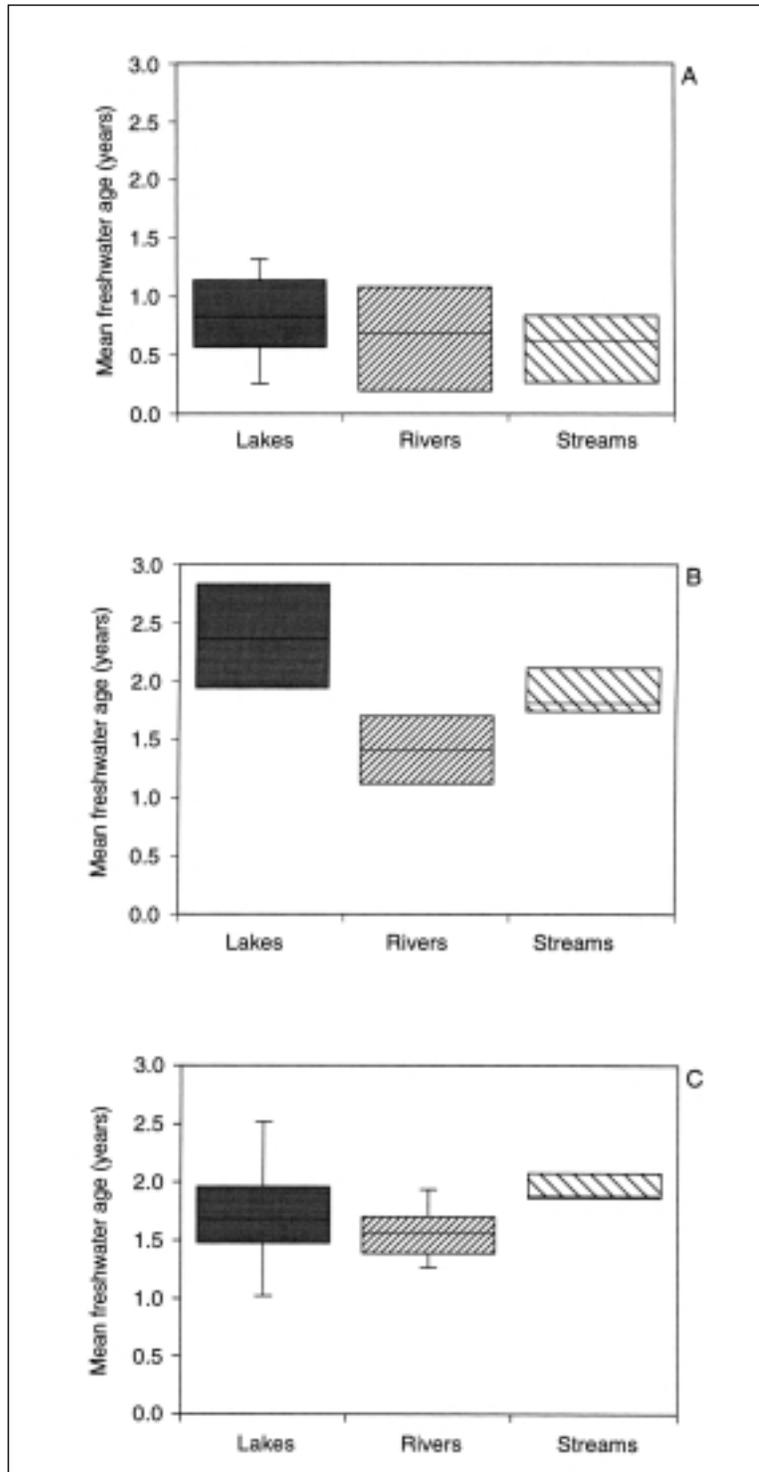


Figure 11—Mean freshwater ages (MFWA) by life history stage and habitat type: **(A)** rearing juveniles, **(B)** smolts, and **(C)** adults. Horizontal lines denote medians, boxes enclose ± 25 percent of distributions, and bars indicate ranges. Boxes enclose entire range when sample sizes are very small.

Table 8—Summary of age distributions of coho salmon escapement samples

Stream		Males								Females								
Number	Name	No.	Age classes						Age classes									
			1.0	2.0	1.1	2.1	3.1	4.1	MFWA ^a	No.	2.0	1.1	2.1	3.1	4.1	MFWA ^a	MFWA ^a	
			-----Percent ^b -----						Years		-----Percent ^b -----						Years	
101-30-075	Hugh Smith Lake	1,326	0	4	24	57	14	1	1.92	1,672	0	18	62	18	1	2.03	1.93	
101-80-068	McDonald Lake	64	0	0	70	27	3	0	1.33	95	0	65	31	3	1	1.40	1.37	
101-90-050	Naha River	166	0	0	16	58	23	3	2.13	183	0	15	63	19	3	2.11	1.96	
102-30-067	Kegan Lake	110	0	0	42	58	0	0	1.58	93	0	44	56	0	0	1.56	1.57	
102-60-087	Karta River	514	0	0	43	52	5	0	1.62	340	0	40	56	4	0	1.65	1.64	
103-15-027	Klakas Lake	426	0	0	72	27	0	0	1.28	528	0	73	34	0	0	1.43	1.36	
103-80-031	Warm Chuck Lake	556	6	3	70	21	0	0	1.28	638	0	70	26	0	0	1.25	1.26	
103-90-010	Sarkar Lake	35	0	0	43	54	3	0	1.60	84	0	57	43	0	0	1.43	1.48	
106-41-010	Salmon Bay Lake	480	0	3	12	52	25	6	2.26	484	4	9	49	33	7	2.39	2.34	
108-70-002	Stikine River	119	2	1	62	34	0	0	1.36	48	0	44	54	2	0	1.58	1.39	
109-20-013	Falls Lake	187	0	1	26	70	3	0	1.76	171	0	32	67	2	0	1.70	1.73	
111-17-010	King Salmon River	17	0	0	65	29	6	0	1.41	20	0	50	40	5	5	1.65	1.54	
111-32-032	Taku River	3,582	0	0	45	52	2	0	1.57	2,295	0	40	57	2	0	1.62	1.57	
111-32-066	Yehring Creek	1,026	0	0	16	81	2	0	1.85	1,140	0	13	86	2	0	1.89	1.87	
111-32-260	Hackett River	117	0	0	42	53	5	0	1.63	81	0	35	62	4	0	1.69	1.67	
111-32-270	Nahlin River	229	0	0	9	90	2	0	1.93	162	0	4	96	0	0	1.96	1.94	
111-33-034	Speel Lake	715	0	6	34	59	1	0	1.64	683	0	29	69	1	0	1.72	1.68	
111-50-042	Auke Lake	825	0	13	17	54	10	1	1.95	691	0	16	69	13	1	1.99	1.97	
111-50-052	Montana Creek	45	0	0	29	47	24	0	1.96	57	0	30	60	9	2	1.82	1.88	
111-50-056	Steep Creek	20	0	0	25	65	10	0	1.85	20	0	40	45	15	0	1.75	1.79	
112-50-010	Pavlof Lake	42	0	0	36	64	0	0	1.64	28	0	32	61	7	0	1.75	1.69	
113-22-008	Politofski Lake	335	1	11	33	51	4	0	1.67	234	0	34	62	3	0	1.70	1.68	
113-41-032	Salmon Lake	781	1	21	9	34	18	5	2.29	492	3	10	53	27	6	2.31	2.30	
113-41-043	Redoubt Lake	859	1	8	20	55	12	5	2.01	705	0	13	56	20	10	2.30	2.09	
113-62-005	Eagle River	25	0	0	0	96	4	0	2.04	26	0	0	88	12	0	2.12	2.08	
113-73-003	Ford Arm Lake	1,225	0	6	10	43	24	5	2.30	1,042	0	12	42	32	6	2.35	2.32	
115-20-010	Berners River	1,335	0	0	35	63	2	0	1.68	827	0	29	69	3	0	1.74	1.71	
115-32-032	Chilkat Lake	303	5	0	20	79	1	0	1.81	282	0	14	83	3	0	1.89	1.84	
115-33-020	Chilkoot Lake	358	0	0	18	77	5	0	1.87	377	0	20	77	3	0	1.82	1.84	
182-30-020	Klukshu River	40	0	0	98	3	0	0	1.03	43	0	98	2	0	0	1.02	1.02	
192-42-020	Tsiu River	26	0	0	85	15	0	0	1.15	15	0	53	47	0	0	1.47	1.27	
Total mean			0.5	2.5	36.3	52.3	6.7	0.8	1.7		0.2	33.5	56.9	7.8	1.4	1.8		
Total SD			1.4	4.9	24.5	21.4	8.1	1.8	0.3			0.9	22.8	19.4	9.7	2.6	0.3	
Total CV			275.6	197.7	68.1	41.3	121.5	219.7	18.5		394.4	68.5	34.4	125.3	194.5	18.4	18.1	

^a MFWA = mean freshwater age. MFWA calculations do not include jacks or jills.

^b Percentages may not add up to 100 because rare age classes have been omitted and because of rounding.

Adult MFWAs showed no clear differences among watershed types (fig. 11C), in contrast to the smolts. Variation in age structure among stocks was substantial, and roughly equivalent, for both sexes (table 8).

No stock had either a single-sex or a combined MFWA that was an outlier from the distribution of all stocks sampled. The Tsiu River (N = 46 fish in 1 sample year) and Redoubt Lake (N = 1,564 fish during 7 sampling years) stocks had distinctive differences between sexes in MFWA, with females spending, on average, nearly 4 months longer in fresh water than males (fig. 12).

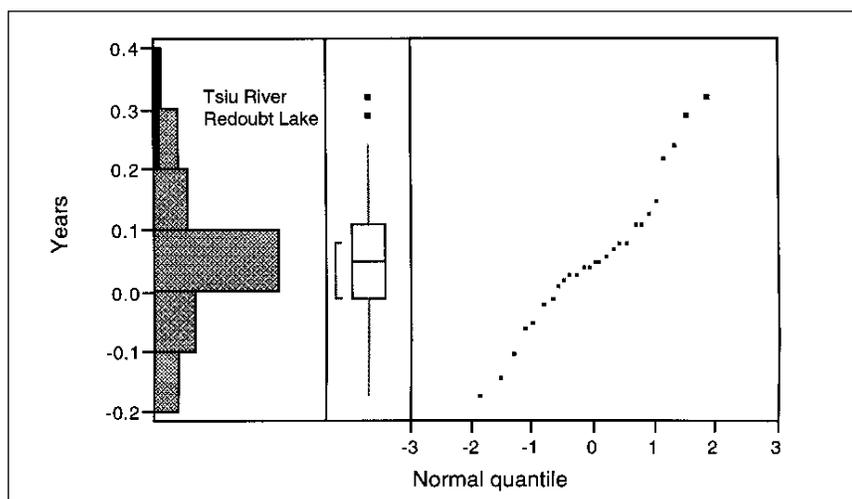


Figure 12—Frequency distribution, outlier plot, and normal quantile plot for MFWA differences between males and females in coho salmon escapements, N = 31. The Tsiu River and Redoubt Lake stocks have distinctively high levels of sexual differences, with females remaining in fresh water, on average, nearly 4 months longer than males. The sample from the Tsiu River consists of only 46 fish from a single year, but the Redoubt Lake sample includes over 1,500 fish sampled during 7 years.

Adult MFWA increased through time in two of four testable stocks (Hugh Smith Lake and Redoubt Lake; table 9). Both systems have been exposed to increased nutrient inputs, through lake fertilization programs. Suburban development around Auke Lake may account for the nearly significant increase ($P = 0.08$). The Salmon Lake stock did not show a significant trend in MFWA for either adults or smolts.

Because MFWA analysis can obscure unusual bimodal age distributions, we conducted outlier analyses on the proportions of individuals found in predominant age classes. The Klukshu River stock had distinctively high proportions of age 1.1 individuals, and correspondingly low proportions of age 2.1 individuals, for both sexes (fig. 13). However, the Klukshu River has been sampled for age distribution for only one year, and that sample consisted of only 83 individuals. The Eagle River stock had a distinctively high proportion of age 2.1 males, based on a sample of 25 fish from a single year (fig. 13).

Sex ratio—Three lake stocks (of 13 stocks sampled at weirs) in southern southeast Alaska had escapement sex ratios significantly skewed in favor of females (Hugh Smith Lake, Klakas Lake, and Warm Chuck Lake; table 10). The large sample sizes for these three stocks made a nonsignificant result unlikely. Yehring Creek (one of two stream stocks sampled at a weir) also had a sex ratio significantly skewed in

Table 9—Regression analyses of trends across years in mean freshwater age (MFWA) of coho salmon stocks

Stream				Regression			
Number	Name	Adult (AD) or smolt (SM)	No. years sampled	R-squared	Slope	P-value	Trend ^a
101-30-075	Hugh Smith Lake	AD	6	0.87	0.93	0.006	**
		SM	6	0.14	0.38	0.46	NS
111-50-042	Auke Lake	AD	6	0.58	0.76	0.08	NS
		SM	15	0.16	-0.40	0.14	NS
113-41-032	Redoubt Lake	AD	6	0.74	0.86	0.03	*
		SM	6	0.39	0.63	0.19	NS
113-41-032	Salmon Lake	AD	6	0.09	0.31	0.56	NS
		SM	6	0.01	0.09	0.87	NS

^a * = 0.05 > P > 0.01; ** = 0.01 > P > 0.001; and NS = not statistically significant.

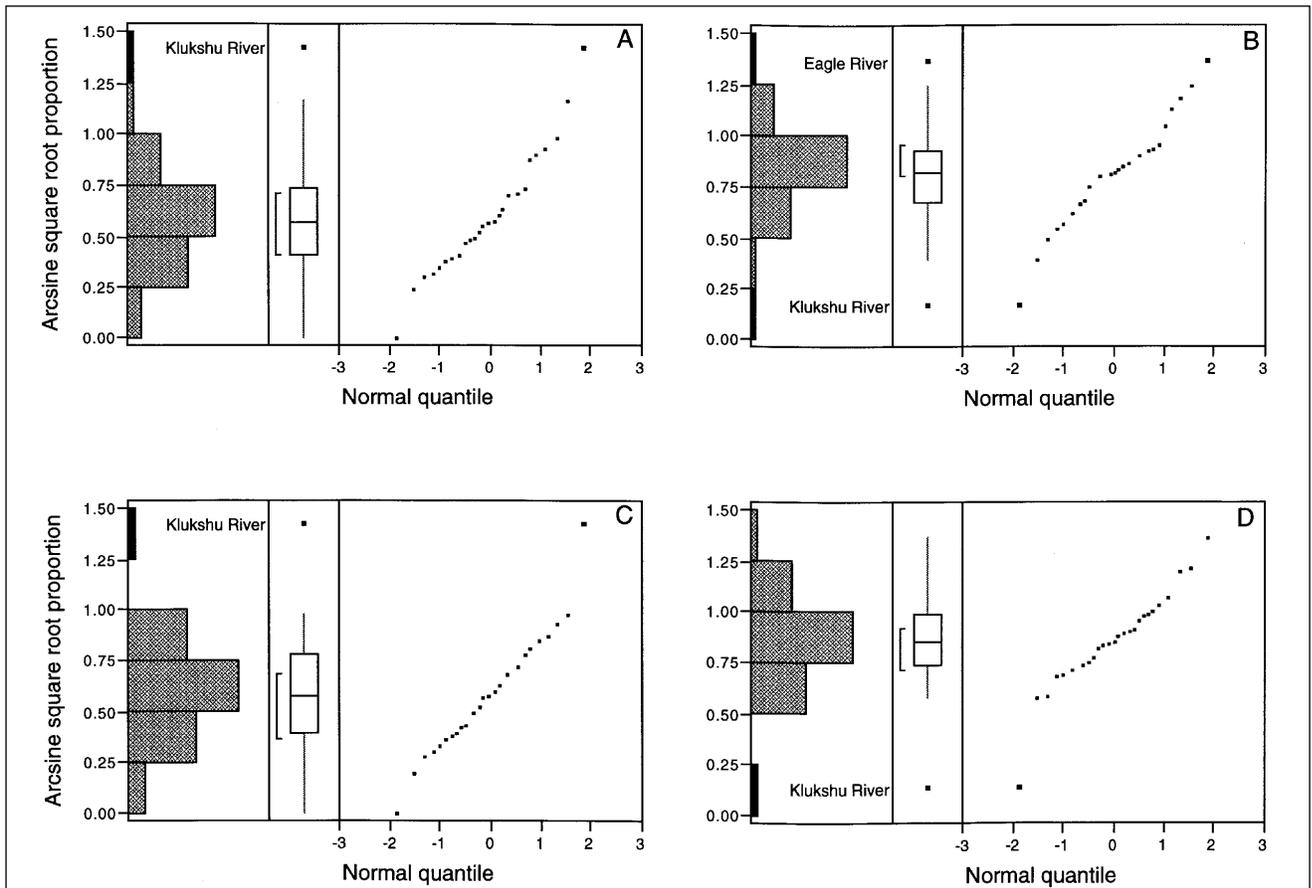


Figure 13—Frequency distributions, outlier plots, and normal quantile plots for proportions of individuals in escapement samples by age and sex class: (A) age 1.1 males, (B) age 2.1 males, (C) age 1.1 females, and (D) age 2.1 females; N = 31 for all distributions. The Klukshu River stock has distinctively high proportions of age 1.1 males and females and distinctively low proportions of age 2.1 individuals. The Eagle River stock has a distinctively high proportion of age 2.1 males in escapement samples. The sample sizes for both the Klukshu and Eagle Rivers are small, N = 83 and 51 fish, respectively.

Table 10—Analysis of escapement sex ratios for coho salmon stocks sampled at weirs

Stream		Sex	No.	Proportion		Chi-square value	P-value ^b	Fisher exact test P-value ^b
Number	Name			males	Sex ratio ^a			
101-30-075	Hugh Smith Lake	M	1,324	0.44	1:1.27	19.84	< 0.001 ***	< 0.001***
		F	1,668					
	(jacks excluded)	M	1,262	0.43	1:1.33	26.47	< 0.001 ***	< 0.001 ***
		F	1,654					
103-15-027	Klakas Lake	M	426	0.45	1:1.22	5.47	0.02 *	0.02 *
		F	528					
103-80-031	Warm Chuck Lake	M	556	0.47	1:1.13	2.82	0.09 NS	0.1 NS
		F	638					
	(jacks excluded)	M	503	0.44	1:1.27	8.01	0.005 **	0.005 **
		F	638					
106-41-010	Salmon Bay Lake	M	259	0.49	1:1.04	0.14	0.71 NS	0.76 NS
		F	271					
	(jacks excluded, 1987 only)	M	244	0.47	1:1.13	0.66	0.42 NS	0.45 NS
		F	270					
109-20-013	Falls Lake (1983 and 1984 only)	M	127	0.51	1:0.96	0.02	0.89 NS	0.93 NS
		F	124					
111-32-066	Yehring Creek (1988 only)	M	152	0.40	1:1.50	8.42	0.004 **	0.005 **
		F	232					
111-32-260	Hackett River	M	117	0.59	1:0.69	3.30	0.07 NS	0.09 NS
		F	81					
111-32-270	Nahlin River ^c	M	229	0.59	1:0.69	5.78	0.02 *	0.02 *
		F	162					
111-33-034	Speel Lake	M	714	0.51	1:0.96	0.34	0.56 NS	0.57 NS
		F	683					
	(jacks excluded)	M	668	0.50	1:1.00	0.04	0.85 NS	0.88 NS
		F	678					
111-50-042	Auke Lake ^c	M	825	0.54	1:0.85	5.93	0.02 *	0.02 *
		F	691					
	(jacks excluded)	M	684	0.50	1:1.00	0.02	0.89 NS	0.91 NS
		F	691					
113-22-008	Politofski Lake	M	331	0.59	1:0.82	8.38	0.004 **	0.004 **
		F	234					
	(jacks excluded)	M	290	0.55	1:1.22	3.11	0.08 NS	0.08 NS
		F	233					
113-41-032	Salmon Lake ^c	M	781	0.61	1:0.64	33.22	< 0.0001 ***	< 0.0001 ***
		F	492					
	(jacks excluded)	M	520	0.52	1:0.92	0.97	0.32 NS	0.35 NS
		F	476					
113-41-043	Redoubt Lake	M	507	0.55	1:0.82	4.92	0.03 *	0.03 *
		F	412					
	(jacks excluded)	M	433	0.51	1:0.96	0.34	0.56 NS	0.59 NS
		F	409					
113-62-005	Eagle River	M	25	0.49	1:1.04	0.01	0.92 NS	1 NS
		F	26					
113-73-003	Ford Arm Lake ^c	M	1,224	0.54	1:0.85	7.24	0.007 **	0.007 **
		F	1,043					
	(jacks excluded)	M	995	0.49	1:1.04	0	0.49 NS	0.51 NS
		F	1,039					
115-32-032	Chilkat Lake (1987 only)	M	282	0.51	1:0.96	0.04	0.83 NS	0.86 NS
		F	275					
115-33-020	Chilkoot Lake	M	358	0.49	1:1.04	0.25	0.62 NS	0.64 NS
		F	377					

^a Male portion of ratio standardized to 1.

^b * = 0.05 > P > 0.01; ** = 0.01 > P < 0.001; *** = 0.001 > P; and NS = not statistically significant.

^c Jacks are counted thoroughly.

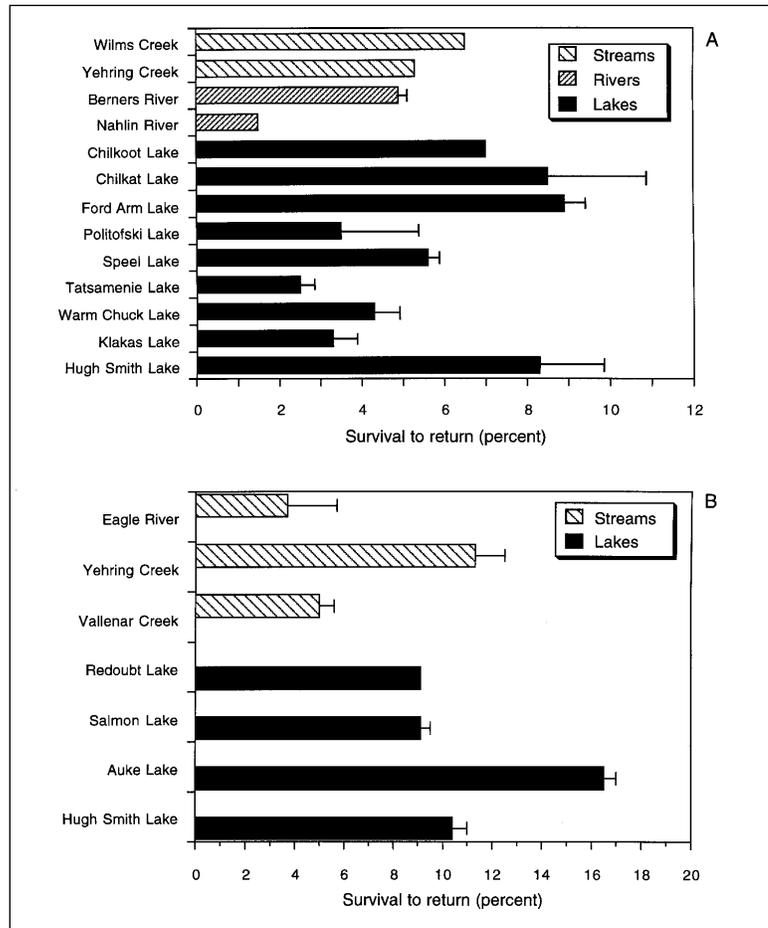


Figure 14—Estimated rate of survival until return of coho salmon stocks by life history stage and habitat: **(A)** estimates for rearing juveniles, and **(B)** estimates for smolts. Plotted values are means of estimates for all years. Bars give standard errors of these means. The Nahlin River and Tatsamenie Lake stocks are in interior habitats. No estimates of smolt survival from river stocks were available.

favor of females. Both the Nahlin and Hackett River stocks had sex ratios skewed in favor of males, and for the Nahlin River the skew was significant, and jacks were rare (table 10). In contrast, in other samples that included all age classes and in which significant deviations from a 1:1 sex ratio were found, removal of jacks yielded sex ratios that did not differ from 1:1.

The proportion of jacks in different stocks ranged widely, with lake stocks generally having greater jack proportions than other watershed types (see footnote 3), but jacks are not thoroughly counted in most locations. In the few systems studied, the frequency of jacks is usually very low (less than 1 percent), but jacks comprised an average of nearly 30 percent (SE = 0.79 percent) of the total annual run at Auke Lake from 1971 through 1988.⁸

⁸ Taylor, S.G. 1989. Life-history characteristics of coho salmon, *Oncorhynchus kisutch*, in the Auke Creek system, southeastern Alaska. Unpublished manuscript-53. [Pages unknown]. On file with: Pacific Northwest Research Station, Forestry Sciences Laboratory, 2770 Sherwood Lane, Juneau, AK 99801.

Table 11—Estimates of coho salmon survival and exploitation rates

Stream		Year tagged	Mean survival rate ^a		Mean exploitation rate ^a	Source
Number	Name		Juvenile	Smolt		
-----Percent-----						
101-29-006	Vallenar Creek	1988		5.0		Elliott and Sterritt 1990
101-30-075	Hugh Smith Lake	1980-1988	8.3 (2)	10.4 (8)	62.1 (8)	Elliott and Sterritt 1990, Shaul 1990, Shaul and Koerner 1988, Shaul and others 1991
103-15-027	Klakas Lake		3.3 (2)		72.7 (2)	Elliott and Sterritt 1990, Shaul and Koerner 1988, Shaul and others 1991
103-80-031	Warm Chuck Lake		4.3 (3)		37.7 (3)	Shaul and others 1991
106-41-010	Salmon Bay Lake				57.3 (1)	Shaul and Koerner 1988
111-32-066	Yehring Creek		5.3 (1)	11.3 (2)	81.5 (5)	Elliott and Sterritt 1990, 1991; Gray and others 1978; Shaul 1990
111-32-203	Wilms Creek		6.5 (1)			Elliott and Sterritt 1990
111-32-254	Tatsamenie River		2.5 (3)		73.7 (2)	Elliott and others 1989; Shaul 1989, 1990
111-32-270	Nahlin River		1.5 (1)		57.1 (1)	Shaul 1989
111-33-034	Speel Lake		5.6 (5)		55.9 (5)	Josephson 1985, Shaul 1989, Shaul and others 1991
111-50-042	Auke Lake			16.5 (8)	42.8 (12)	Elliott and others 1989; Elliott and Sterritt 1990, 1991; Shaul and others 1987; Shaul and others 1991
113-22-008	Politofski Lake		3.5 (2)		30.6 (2)	Shaul and others 1991
113-41-032	Salmon Lake	1983-1989		9.1 (7)	52.6 (7)	Elliott and others 1989; Schmidt 1985, 1986, 1987, 1988, 1990; Schmidt and DerHovanisian 1991
113-41-043	Redoubt Lake	1987		9.1 (1)	43.0 (1)	Elliott and others 1989
113-62-005	Eagle River	1988-1989		3.7 (2)	54.4 (2)	Schmidt 1990, Schmidt and DerHovanisian 1991
113-73-003	Ford Arm Lake	1980-1986	8.9 (6)		51.4 (7)	Shaul 1990, Shaul and Koerner 1988, Shaul and others 1991
115-20-010	Berners River	1974, 1980-1987	4.9 (7)		76.5 (8)	Gray and others 1978, Shaul Koerner 1988, Shaul 1990
115-32-032	Chilkat Lake		8.5 (3)		80.2 (1)	Shaul and others 1986, Shaul and others 1991
115-32-032	Chilkat River		8.9 (1)			Gray and others 1978
115-33-020	Chilkoot Lake		7.0 (1)		85.0 (3)	Elliott and Kuntz 1988, Shaul and others 1991

^a Number in parentheses is number of sample years.

Juvenile-to-adult survival—Juvenile survival was lowest for river stocks, because of the very low value for the Nahlin River (fig. 14A). The two interior stocks (Nahlin River and Tatsamenie Lake) had lower juvenile survival rates than all coastal stocks (table 11). Smolt survival tended to be lower in stream stocks than in lake stocks (fig. 14B).

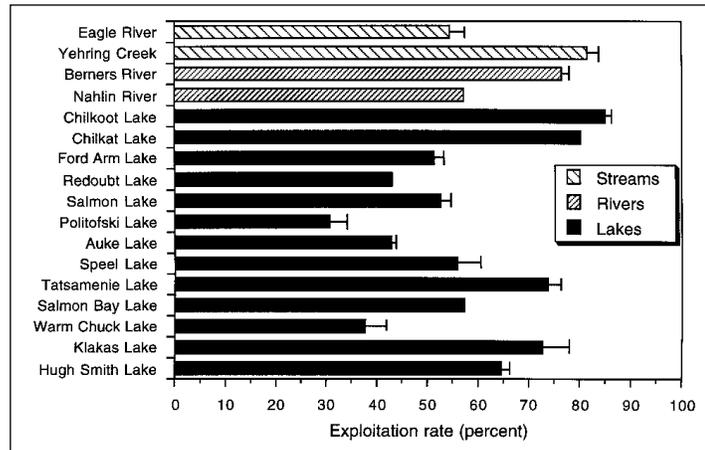


Figure 15—Estimated exploitation rates for coho salmon stocks by habitat. Plotted values are means of estimates for all years. Bars give standard errors of these means.

Hugh Smith Lake, Salmon Lake, and Berners River stocks all showed nonsignificant, negative temporal trends in survival from 1980 to 1989 (Hugh Smith Lake, $b = -0.42$, $P = 0.30$ NS; Salmon Lake, $b = -0.55$, $P = 0.20$ NS; Berners River, $b = -0.28$, $P = 0.50$ NS). Auke Lake showed an increasing trend ($b = 0.58$, $P = 0.10$ NS). Only for these four stocks were there enough annual records to allow evaluation of longitudinal trends in survivorship.

Exploitation rates—Exploitation rates did not differ consistently among watershed types (fig. 15), but watershed types were less likely to affect exploitation rates than were geographic location and migratory pattern. Exploitation rates on coho stocks from islands were significantly lower than on mainland and interior stocks (Kruskal-Wallis, $P = 0.04$). Stocks in the Lynn Canal, stocks in the Taku region with normal run timing (except Auke Lake), and stocks in extreme southern southeast Alaska had the highest exploitation rates. Stocks on the outer coast generally had the lowest exploitation rates. There was no significant correlation between exploitation rate and juvenile-to-adult survival.

From 1983 to 1989, exploitation rates increased significantly ($R^2 = 0.76$, $b = 0.87$, $P = 0.01$) for the Salmon Lake stock. Significant trends in exploitation rates were not observed for the Hugh Smith Lake, Auke Lake, Ford Arm Lake, and Berners River stocks.

Anecdotal Reports

The following stocks were discussed briefly in reports or were mentioned in discussions with fisheries biologists as having distinctive biological characteristics. These stocks are mentioned here to call attention to their potentially distinctive characteristics and to promote further research. The Hasselborg River coho salmon rear in a salt lake rather than freshwater habitats and apparently attain high growth rates. Use of estuarine habitats by juveniles has also been reported for Ford Arm Lake and Kadake Creek (Schmidt 1986, Shaul and others 1986). In the latter two cases, large

juveniles were caught moving upstream into fresh water in the fall, and these juveniles showed signs that they had been in salt water: they were sensitive to handling and lost scales easily (see footnote 6). Lucky Cove, south of Ketchikan (see footnote 3), Reflection Lake on the upper Cleveland Peninsula,⁹ Hamilton Creek south of Kake (see footnote 6), and Ward Creek on west Admiralty Island (see footnote 3) are considered to have early run timing and partial migration barriers. Weir counts for the Karta River suggest that an early run of coho begins to enter this system in late June. The run continues through September. Early and prolonged migration timing, combined with the presence of two lakes and a partial migration barrier in this system, suggest two separate stocks may be present (see footnote 3).

Discussion Evaluation of Results

Patterns of variation in biological variables were generally hard to discern with a high level of confidence. Variation in the data resulted from natural variation, differences in methods of collection, and small, often poorly distributed samples, which either precluded statistical analysis or contributed to considerable loss of power for statistical tests. A few trends nevertheless warrant further consideration. The weakness of the database clearly emphasizes the need for more rigorous and specific studies on the status and ecology of coho salmon stocks.

One of the clearest habitat-related patterns to emerge was the distinction between interior and coastal coho salmon stocks by age structure, sex ratio, and fry-to-juvenile survival. Studies of coho salmon stocks in British Columbia have established several heritable morphologic, physiological, and behavioral differences between interior and coastal stocks (Rosenau and McPhail 1987; Taylor and McPhail 1985a, 1985b, 1985c; see also McGeer and others 1991). Similar patterns for these biological characteristics may occur in southeast Alaska stocks. Interior spawning stocks that pass through southeast Alaska represent important components of regional coho salmon diversity.

Body length—Fry that were rearing in streams tended to be smaller than fry from other watershed types, but no differences were apparent for other age classes of juveniles. Swain and Holtby (1989) found no differences in body length in their comparison of lake- and tributary-stream-rearing coho in British Columbia. These authors did find, however, morphological differences in body depth, fin coloration and placement, and aggressive behavior among coho from different watersheds. Heritable differences in body depth, head length, and fin size also have been found between juveniles rearing in interior versus coastal streams in British Columbia (Taylor and McPhail 1985b), but standard length was not an important variable in the discriminant function analysis derived in this study. Similar differences may be found among southeast Alaska stocks, because juveniles of these stocks commonly spend at least 1 more year in fresh water than do British Columbia populations. The extended period in fresh water might emphasize morphological differences among juveniles reared in different watershed types.

⁹ Personal communication. 1996. C. Denton, fisheries biologist, Alaska Department of Fish and Game, 2030 Sea Level Drive, Suite 215, Ketchikan, AK 99901.

The size of coho smolts is considered relatively consistent throughout the range of the species (Sandercock 1991). We found, however, an apparent trend for stream smolts to be smaller than smolts from rivers and lakes and that the difference in body length between watershed types tended to increase with increasing smolt age. This pattern suggested that stream-rearing coho typically emigrate soon after reaching the length threshold for smolting. Slow growth rates of stream-rearing coho also may contribute to reducing the proportion of jacks produced in this watershed type, because smolt size is positively correlated with the rate of jack return (Bilton and others 1982, Iwamoto and others 1984). Across all watersheds, larger coho salmon smolts tended to emigrate later in the spring.

Mortality rates of juvenile coho salmon in different watershed types may be more important than growth rates in determining duration of freshwater residence (see footnote 3). Differences in habitat stability and productivity patterns may influence trade-offs between growth and mortality rates for rearing coho among rearing habitats. Mortality rates are likely to be higher in streams subject to increased variation in environmental variables, such as temperature and flow regimes, than in systems offering refuge in lakes that buffer environmental fluctuations. Higher freshwater survival in lake-containing systems may favor individuals that stay in the freshwater environment longer and migrate to sea at a larger size and thus survive better when they reach salt water (Holtby and others 1990).

Female coho salmon tend to be larger than males. Female body size is positively related to fecundity and competitive ability, but these characteristics do not necessarily confer enhanced reproductive success in all situations (Fleming and Gross 1989; Holtby and Healey 1986, 1990; van den Berghe and Gross 1989). Selective harvest of large males could contribute to the observed size differences. The significant difference between the body sizes of age x.1 males and females may reflect a weakly bimodal distribution of male body sizes (see footnote 3). Most age x.1 male coho salmon in escapements have a size distribution similar to that of females, but a small proportion of age x.1 males tend to be smaller than all females, thus reducing the male mean body size. The causes and consequences of small size in some age x.1 males are unknown.

Increasing freshwater age was associated with greater body size in females but not in males. This result may reflect the tendency for the largest male smolts, typically the oldest, to return as jacks. Female fecundity increases greatly with increasing body size, but the same relation may not hold for males; in some situations small males or jacks can have high reproductive success (Holtby and Healey 1986, 1990). Males may forage in ways that reduce their risk of mortality rather than maximize their rate of growth, resulting in a size-at-age distribution that is skewed to smaller sizes relative to females (Holtby and Healey 1990).

Although Wood (1992) discusses a decline in body weight for coho salmon from 1983 to 1987 in troll, seine, gill-net, and Canadian inriver fisheries, we found no significant long-term temporal trends in body length for fish sampled from escapements for the eight stocks tested (table 4).

Variance-component analysis indicated that about 90 percent of total variation in adult body length was found among individuals within stocks, and that among-stock variation made a negligible contribution to overall variability. This result is surprising given the wide range of watershed types used by stocks included in this analysis. No stocks with particularly early or late run timing, however, could be included in this analysis.

The small body size of the Pavlof Lake stock is distinctive among studied stocks and reflects the positive relation between body size and run timing for southeast Alaska stocks. This stock returns to fresh water in July and August rather than in fall. The smaller body size of summer-run stocks may be the result of the loss of 2 additional months in the ocean. Growth rates in the final months of ocean existence are extremely rapid, up to a 10-percent increase in body mass per week in some stocks (Gray and others 1981; see footnote 3). The positive association between body length and mean migration date supports this interpretation. Small body size per se may not be favored in these stocks, but rather may be a contingent result of an early run, which is advantageous (see "Timing," below).

Timing—Three stocks (Pavlof Lake, Salt Chuck-George Inlet, Plotnikof Lake) have substantial migration barriers during low flow (see footnotes 3 and 6) and have early run timing. Early run timing might be favored in these stocks to take advantage of flow rates that facilitate passage by the barriers (see Gray and Marriott 1986 for discussion of Plotnikof Lake). A similar situation may occur in the Nahlin and Dudidontu River stocks. Both stocks return and spawn early in the upper Taku River drainage, above difficult passages in the Inklin River (see footnote 6). In addition to migration barriers, these interior stocks also may be responding to the relatively cold thermal regimes of their spawning streams. The Nahlin and Dudidontu drainages do not contain lakes that could serve as thermal buffers. Early spawning dates may be required to enable eggs to accumulate the thermal units necessary for development and hatching (Tang and others 1987; see footnote 3).

Because early-run stocks may depend on critical flow conditions to circumvent difficult obstacles, any disruptions to watersheds that alter hydrologic characteristics of these streams could have a detrimental effect on these stocks. Run-timing differences can be effective reproductive isolating mechanisms. Therefore, coho salmon stocks with early return timing could show unusual patterns of genetic variation. Not only are these stocks valuable as a potential source of genetic variation, but they also have important fisheries values. These stocks have been favored for the development of hatchery brood stocks (see footnote 9) because early returning coho, both hatchery and wild, provide important sport fishing opportunities between the end of chinook runs and the onset of typical coho runs in the autumn. Enhancement projects that circumvent existing barriers may compromise the integrity of early-run stocks.

Adults of some coho salmon stocks that inhabit systems containing large lakes are summer-run fish that return early and hold in fresh water for 1 to 4 months before spawning (e.g., Hugh Smith Lake; see footnote 3). This behavioral characteristic also could serve to isolate populations reproductively, if they spawn at a different time than later returning fish. Observations from Margaret Lake populations show that summer-run fish tend to spawn earlier than fall-run fish, but individuals from both runs spawn

together.¹⁰ The late-spawning strategy offers some clear advantages in terms of egg and alevin survival because late fall and winter freshets that cause bedload movement or scouring of the substrate can be avoided. However, the relative probabilities of adult mortality in fresh versus salt water are not known. Early movement into fresh water also implies foregone opportunity for growth. Finally, this strategy is probably constrained to systems with relatively high water temperatures that will produce rapid development of eggs once they are spawned. Further investigation of the distribution of this behavioral strategy, as well as its ecological correlates and evolutionary consequences, would be valuable.

Demography, declining stocks—No overall geographic pattern was present among the declining stocks, but three stocks were located on Mitkof Island, and the other two stocks on Mitkof Island that had an adequate number of escapement records for analysis also showed nearly significant declines in escapement. Mitkof Island stocks may reflect the synergistic negative effects of habitat degradation due to logging and road building, overexploitation associated with Crystal Lake hatchery operations, and an active local fishing community. Indian and Bear Harbor Creeks and Port Banks (Plotnikof Lake) are in pristine areas. Data quality was only fair for all these stocks owing to inconsistencies in the frequency, timing, and methods used to survey escapements.

Six of seven declining stocks are in stream systems and, with the exception of the Indian Creek stock, have relatively small escapements (mean escapement counts less than 250 fish). These small stream stocks are considered most susceptible to population declines (Elliott and Kuntz 1988). Small escapements caused by poor ocean survival or overharvest, or both, combined with the relative instability of stream habitats, which can cause high rates of egg or juvenile mortality, all contribute to the heightened potential for declines in small stream stocks. Estimates of juvenile production per spawner in two coastal stream stocks are highly variable (Schmidt and DerHovanisian 1991).

Age structure—The age structure of lake stocks tends to include more freshwater age classes and more individuals in older age classes than river or stream stocks (table 8). Lake-containing systems may support a mixture of different genetic morphs with different growth patterns. Studies of juvenile coho salmon in lakes and streams in British Columbia have revealed differences in morphology and behavior between juveniles that rear in stream versus lake habitats (Swain and Holtby 1989). These differences were found to persist when juveniles of both types were raised in a common laboratory environment, which suggests a genetic basis to these traits. Phenotypic plasticity could not be conclusively ruled out based on the experiments conducted. Determining the cause of variation in biological characteristics of coho juveniles in different habitats is important for understanding the dynamics of these populations (Swain and Holtby 1989). Adaptive differences may enhance productivity by reducing intraspecific competition (Swain and Holtby 1989). If genetic differentiation occurs among coho salmon stocks spawning in different segments of the same drainage, optimal productivity from that drainage may depend on maintaining the existing polymorphism.

¹⁰Bryant, M.D.; Frenette, B.J. Manuscript in preparation. Colonization of the Margaret Lake watershed by anadromous salmonids. Available from: M.D. Bryant, Pacific Northwest Research Station, Forestry Sciences Laboratory, 2770 Sherwood Lane, Juneau, AK 99801.

The relatively high proportion of cases (62.5 percent) in which MFWA declined between smolt and adult samples from the same cohort was unexpected, in view of the expected positive relation among smolt age, size, and ocean survival. We propose several hypotheses to explain this unexpected pattern. (1) In watersheds with both lake (rapid juvenile growth) and stream (slow growth) habitats, stream-reared smolts may be both older and in less robust condition than lake-reared smolts, and enhanced survival of the lake-reared smolts could explain a system-wide decline in MFWA from smolts to adults. (2) Older and larger smolts may be more likely to return as jacks (Bilton and others 1984, Schmidt 1987), and returning jacks are undersampled or not sampled at most locations. At Auke Lake, where jacks are accurately enumerated at a weir, a nearly significant correlation exists between the difference in MFWA from smolt to adult and the proportion of jacks that occur in the escapement for a given year ($r = 0.79$, $P = 0.06$). (3) Errors in aging either adult or juvenile coho by scales¹¹ could produce spurious patterns. (4) Older, larger smolts may, in fact, experience reduced ocean survival (Holtby and Healey 1986). (5) Commercial and sport fishing could selectively remove the largest and oldest adults. Experiments are underway to test these alternative hypotheses.

Increases in MFWA of adults through time is difficult to explain, given that smolt MFWA did not show a parallel pattern in all systems. Possibly ocean conditions are changing to increasingly favor the survival of older smolts. The trend of increasing adult MFWA also has been detected in harvest from all fisheries (Wood 1992; Wood and Van Alen 1987, 1990). Where smolt MFWA also is increasing, cold winter temperatures are probably responsible for slow growth that results in a longer freshwater rearing period (Wood and Van Alen 1987).

Sex ratio—The sex ratio of stocks in interior rivers is unusual, in that the Nahlin and Hackett River samples are skewed in favor of males and jacks are virtually absent. Coastal stocks show either a female-biased sex ratio or a high incidence of jacks that result in a male-biased sex ratio. The latter form of sex-ratio bias could result from very few jacks being taken in commercial fisheries (see Wood and Van Alen 1987). It is also possible that the apparent difference between interior and coastal stocks is actually the result of errors in determining the sex of returning coho (see footnote 3). It is relatively difficult to accurately determine the sex of sexually immature fish returning to coastal systems, compared to fish handled at weirs near interior spawning tributaries (see footnote 3).

Survival and exploitation rates—The low juvenile-to-adult survival rates of interior stocks compared to coastal stocks may reflect differences in the fish communities present in interior versus coastal systems (Shaul 1990). Juvenile coho rearing in interior systems face increased predation pressure from abundant resident populations of northern pike (*Esox lucius*), burbot (*Lota lota*), and lake (*Salvelinus namaycush*) and rainbow trout (*O. mykiss*) as well as competition for rearing habitat and food resources from juvenile chinook salmon, Dolly Varden (*S. malma*), rainbow trout, grayling (*Thymallus articus*), and lake chub (*Couesius plumbeus*) (Shaul 1988; see footnote 3). Increased predation risk and competition may exclude many coho juveniles from the best foraging habitats.

¹¹ Personal communication. 1996. S.G. Taylor, fishery biologist, National Marine Fisheries Service, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801.

The current ADF&G guideline for the maximum long-term average exploitation rate for coho salmon stocks is 70 percent (Shaul 1994). Hugh Smith Lake, the indicator stock for southern inside waters, and some Lynn Canal stocks are consistently exploited at rates near this target (table 11). In general, stocks that pass through the most fisheries during their spawning migrations incur the highest exploitation rates (Shaul and others 1991). Small stocks are particularly vulnerable to high exploitation rates (Hilborn 1985), which may or may not be sustainable (Elliott and Kuntz 1988).

Conceptual Issues

Four topics regarding the evolution and ecology of coho salmon populations are discussed: (1) population genetic structure and the effects of straying rates of adults and movements of juveniles; (2) community ecology of rearing salmonids, especially the interspecific interactions of juvenile coho salmon with juveniles of other salmonid species; (3) body size, sex ratio, and hypotheses of coho salmon life history evolution; and (4) the possible evolutionary and ecological consequences of landslides for salmonid populations and communities.

Population genetic structure—In general, genetic divergence among populations is inhibited by migration and consequent gene flow. If, however, a population is sufficiently large and selection favoring an allele different from that carried by migrants is strong and stable, the homogenizing effects of gene flow can be counteracted, and genetic differentiation among populations can occur. Very little allozyme variation has been detected in coho salmon populations (Bartley and others 1992, Wehrhahn and Powell 1987), and coho show the lowest mean heterozygosity of the five major Pacific salmon species (Allendorf and Utter 1979). Coho salmon from southern British Columbia were much less polymorphic than Oregon coho, but this analysis (Wehrhahn and Powell 1987) omitted the highly polymorphic transferrin locus. Wehrhahn and Powell hypothesized that this difference is due to a severe population bottleneck for British Columbia coho salmon during postglacial recolonization. The estimated number of migrants for the wild stocks studied was about six per spawning population (Wehrhahn and Powell 1987). This estimate is significant, because it suggests that a spawning population of 1,000 individuals could diverge if their local allele confers a selective advantage in heterozygotes of 0.005. Wehrhahn and Powell (1987) conclude that coho spawning populations of greater than 1,000 individuals are evolutionarily significant even if they exhibit no obviously unique characters, because these populations have increased *potential* for diversification.

Coho salmon straying rates are thought to be low in undisturbed populations (Labelle 1992, reviewed in Sandercock 1991). Strays typically accounted for less than 1 percent of returning adults in 14 stocks studied on Vancouver Island (Labelle 1992). The mean straying distance reported by Labelle (1992) was 15.7 km, and more than 50 percent of strays originated in streams within 7 km. Genetic factors, exposure to foreign water sources during rearing, flow rates, and interactions among these factors were important predictors of straying rates. In one system, strays accounted for over 40 percent of the escapement, probably due to enhancement procedures in an adjacent river (Labelle 1992). Four of the stocks had escapements in excess of 1,000 individuals, and the estimated straying rate for these stocks was 1.3 percent.

Although the population genetic structure of coho salmon in southeast Alaska is unknown, it may differ substantially from that described for other regions. We present two reasons why greater genetic diversity may occur in southeast Alaska coho populations. (1) Coho salmon in southeast Alaska rear for a longer period in fresh water.

This may enhance the accuracy of homing and might reduce straying rates. Reduced straying (gene flow) increases the potential for evolutionary diversification. Furthermore, many populations in southeast Alaska have escapements in excess of 1,000 individuals and are pure wild stocks that have not been subject to enhancement or water diversions. (2) The source populations that colonized southeast Alaska after the last ice age may have been different or more diverse than those that colonized more southerly regions. Gharrett and others (1987) believe chinook salmon recolonized southeast Alaska from both northern refugia in the Yukon River basin and the Pacific Northwest. If coho salmon followed a similar pattern, greater genetic diversity among the founders may contribute to higher current levels of variability.

On the other hand, there are two reasons why diversity may be lower in stocks in southeast Alaska. (1) The landscape in southeast Alaska is younger than areas to the south, and glacial retreat is continuing to open new habitats. This young landscape may favor straying as an alternative life history tactic (Quinn 1984). Furthermore, in this young landscape, sufficient time may not have passed since colonization to permit genetic divergence among stocks. (2) Several cases of unusual juvenile movements have been documented in southeast Alaska. One juvenile female, tagged in the lower Berners River, was captured at Auke Lake, after movement across about 50 km of salt water (see footnote 3). Juvenile coho tagged in Wilms Creek, across the Canadian boundary in the Taku River drainage, have been captured in smolt traps on Yehring Creek nearly 20 km distant (Elliott and Sterritt 1990). Juvenile coho also have been found in streams having no apparent spawning habitat. Whether there are any population genetic effects of movements by nomadic juveniles is unknown.

Community ecology—Competitive and predatory interactions among coho and other salmonids, including resident trout and char, all having prolonged freshwater rearing periods, are complex. Habitat displacement of coho salmon juveniles may occur in the presence of abundant chinook salmon in the Nahlin River (see footnote 3). In addition, because juvenile coho in southeast Alaska use lakes as rearing habitat, competitive and predatory interactions can occur with sockeye salmon fry even though some habitat partitioning occurs. They may compete for food resources where they overlap, and coho salmon that are rearing in lakes may prey extensively on recently emerged sockeye (Ruggerone and Rogers 1992). Understanding predator-prey relations among rearing salmonids could help to explain productivity patterns; for example, sockeye production per spawner is higher in Chilkoot Lake than in Chilkat Lake, perhaps because the clearer waters of Chilkat Lake facilitate predation by coho salmon and other predators. Chilkat Lake coho salmon juveniles were the largest juveniles of all systems for which data were available, implying exploitation of a rich food resource. Chilkat Lake sockeye salmon are known, furthermore, to exhibit very prolonged spawning and emergence periods, which could serve to make emerging sockeye salmon available to predators for a substantial portion of their rearing period.

Interactions of coho salmon with pink and chum salmon, which do not have extended rearing periods, also may be important. The observed correlation between the strength of coho and pink salmon returns to southeast Alaska (Gaudet 1989) may be explained, in part, by coho smolts preying on emigrating pink salmon fry; coho salmon selectively prey on juvenile pink salmon (Hargreaves and LeBrasseur 1985).

If feeding on abundant pink salmon fry results in enhanced early ocean growth for coho smolts, greater ocean survival could be expected (Holtby and others 1990). A strong positive relation between biomass of pink salmon carcasses and recruit-per-spawner ratios of coho salmon was reported in the Skagit River, possibly because mass spawning by pink salmon produced more invertebrate drift, and juvenile coho can feed directly on eggs and adult carcasses of pink salmon (Michael 1995). These enhanced feeding opportunities could lead to increased coho salmon smolt size and associated increases in marine survival.

Life history evolution—Several studies have found that large body size confers a significant reproductive advantage to female coho, chinook, and sockeye salmon (Fleming and Gross 1989; Gross 1984, 1985; Healey and Heard 1984; van den Berghe 1984; van den Berghe and Gross 1984). Despite the apparent advantages of large body size, wide variation in female sizes occurs both within and among coho salmon populations. Broad variation may represent an evolutionarily stable strategy, with several interacting environmental factors and frequency-dependent selection causing females of different sizes to achieve equal fitness (Holtby and Healey 1986). Elaborating on this hypothesis, van den Berghe and Gross (1989) and Fleming and Gross (1989) argue that breeding competition among female coho salmon can select for increased body size, and that the effects of this selection may be tempered by abiotic selection factors such as the relative arduousness of spawning migration. They claim that differences in morphology reflect heritable responses to varied and fluctuating selection pressures.

Landslides and salmonid evolutionary and community ecology—The abundance and species composition of juvenile salmonids in the Dudidontu River differed profoundly from the Nahlin River (Shaul 1988), although both rivers are interior tributaries of the Taku River. In the Dudidontu River, juvenile anadromous salmonids were less abundant, and resident species, particularly Dolly Varden, were more numerous. Frequent blockages along the Dudidontu may favor resident life history strategies over anadromous strategies for some species (Shaul 1988). Intermittent spawning by anadromous salmonids resulting from frequent blockages and flow restrictions might temporarily release juveniles of resident salmonids from competition and perhaps allow them to colonize a broad range of rearing habitats. Although coho salmon are generally successful competitors, predation by dense populations of adult residents could delay successful recolonization by anadromous populations.

Risk Factors

Although current data indicate that coho salmon stocks in southeast Alaska generally have stable abundance trends, several risk factors raise concerns about the future status of coho salmon in the region. The following list is not comprehensive but outlines what we consider to be the most significant risk factors for southeast Alaska coho salmon stocks.

1. A lack of stock-specific information is both a risk factor in itself and increases the problems generated by other risk factors. Stock-specific information is not available for over 90 percent of the coho salmon stocks in the region. Existing evidence indicates considerable biological variation among coho populations, but an adequate assessment of biological characteristics and stock status cannot be achieved by extrapolating from a historical sample of only 2 percent of all populations, especially because that sample is not drawn proportionately from the range of freshwater habitat types used by coho salmon.

Current management of coho stocks in southeast Alaska is based on data collected primarily from lake-containing systems, but other habitats account for a significant proportion of the coho salmon harvested in southeast Alaska (Elliott and Kuntz 1988). Because lakes tend to buffer fluctuations in environmental conditions, production of coho salmon from lakes tends to be more stable than production from other, more dynamic, habitats. Management decisions based on lake production may fail to account for greater variation in coho salmon production in streams and rivers than in systems with lakes; therefore, the potential for overexploitation of stream and river stocks is higher. Small streams with small populations are the most sensitive to the threat of overexploitation (Elliott and Kuntz 1988, Hilborn 1985) and thus may be useful as indicators for management strategies. Insufficient information was available to determine if the range of variation in ocean survival and resulting run strength of indicator stocks are representative of stocks in other habitat types, such as streams. If stream stocks have greater variation in ocean survival, as they do in freshwater survival, management strategies based on the run strength of lake-inhabiting indicator stocks could expose stream stocks to unsustainable exploitation levels. Most data on the population dynamics of coho salmon stocks have been collected during a period of exceptionally high marine survival. During periods when marine survival is near normal, coho salmon stocks may not be capable of sustaining high exploitation rates without experiencing declines in abundance.

Patterns of coho salmon migration in southeast Alaska complicate management (Shaul and others 1986). Conservation of weak stocks by time and area closures may not be an option for most stocks because they pass through numerous fisheries over an extended period en route to their spawning streams. The ongoing trend of greater proportions of the total coho salmon harvest coming from early-season, mixed-stock troll fisheries exacerbates this situation. Interior spawning stocks are of special concern in this regard. In particular, the sustainability of the extremely high exploitation rates estimated for Hugh Smith Lake (southern inside area) in recent years and for Lynn Canal stocks is questionable. Long-term declines have occurred in coho salmon stocks from Georgia Strait, British Columbia, that had exploitation rates ranging from 75 to 80 percent (Canada Department of Fish and Oceans 1990, cited in Shaul 1994). Caution is advisable in view of limitations on management prescriptions for rescuing declining stocks.

Fisheries for other salmonid species often harvest a substantial incidental catch of coho salmon. Run timing thus becomes an important biological trait influencing vulnerability. Declines in the early-run coho salmon stocks in the Skeena River may be caused by overharvest of coho salmon by the fishery directed at a large sockeye run (Sprout and Kadowaki 1987). A similar threat faces early-run Taku drainage stocks, such as those found in the Nahlin River. Coho salmon from Lynn Canal stocks that have relatively late runs also are harvested in a fishery directed at large, late chum salmon runs to the Chilkat River.

2. Habitat degradation continues to be a major threat. Over the long term, a growing human population and increasing global demands for natural resources will lead to increasing habitat destruction or disruption. Degradation of habitat quality over large areas of the Pacific Northwest has contributed to the decline in abundance of coho salmon in that region (e.g., Nehlsen and others 1991). In the Pacific Northwest, habitat degradation initially occurred in scattered locations across the landscape (Frissell 1993), and observable effects of the problem were delayed. Similar events may be occurring in southeast Alaska; for example, the loss of wood and the subsequent effects on stream habitat continue to be observed in watersheds logged more than 30 years ago (Bryant 1980; 1985a).

The effects of land uses on salmonid habitat is reviewed in Meehan (1991); problems arise from changes in stream structure, sediment production, and thermal regimes. Vulnerability to changes in thermal regimes probably differs with watershed type. Many coho salmon populations in southeast Alaska inhabit stream watersheds unbuffered by lakes, and they often use tributary streams for spawning and rearing (Gray and Marriott 1986). The thermal regimes of small stream habitats may be particularly sensitive to disruption, and coho salmon populations, like those of other species of Pacific salmon, show population specific patterns of variation in incubation rate, growth, and development that appear to be adaptations to local thermal regimes (Beacham and Murray 1990, Konecki and others 1995). Furthermore, small-stream systems offer fewer refuges for residents when habitats are disrupted.

3. Artificial enhancement of salmon stocks through hatcheries has the potential to adversely affect natural runs via overexploitation (artificially raising the number of harvestable fish, followed by increased harvests that take both hatchery and natural runs) and genetic introgression from hatchery stock to wild runs. These concerns are amplified by the geographic location of hatcheries and release sites; for example, the Neets Bay and Whitman Lake hatcheries are located along the migration pathway of Behm Canal stocks. Currently, coho salmon stocks in southeast Alaska do not appear to be experiencing the potentially deleterious effects of artificial enhancement on a broad scale. Were coho salmon production increased at several hatcheries, the situation could change, however.

Conclusions

Coho salmon can spawn and rear in a wide range of habitats, and coho are capable of passing obstacles that are barriers to the migration of other anadromous salmon. Consequently, an estimated 2,300 coho salmon stocks are found throughout the study region. Sampling for biological characteristics was limited to 48 (2.1 percent) of these stocks, and 129 stocks (5.6 percent) were represented by sufficient escapement survey data to permit regression analysis of abundance trends. The late run timing of coho salmon and the logistical problems that accompany poor weather and high stream flows generally diminished the quality of biological data and escapement survey estimates for coho salmon in the region. The potential biases associated with limited data also should be taken into account when evaluating the results presented here. We compared stocks inhabiting 27 lake, 10 river, and 11 stream watersheds and 5 interior and 43 coastal locations to look for patterns of variation among these watershed types. The clearest watershed-related pattern to emerge was the distinction between interior and coastal coho salmon stocks: interior stocks had low MFWAs, sex ratios skewed in favor of males with jacks virtually absent, and low survival rates compared to coastal stocks. Interior-spawning stocks that pass through southeast Alaska represent important components of regional coho salmon diversity.

Smolts from streams tend to be smaller than smolts from lakes or rivers. Stocks rearing in lake watersheds had higher MFWAs and contained more age classes than stocks found in other watershed types. Lake stocks also tended to have higher survival-to-return rates than river or stream stocks. Across all watersheds, adult females were significantly larger than males, and female body size increased significantly with increasing freshwater age. Nearly 90 percent of total variation in adult body size, among six stocks analyzed, occurred among individuals within stocks. Small body size, early run timing, and presence of a partial barrier to migration were associated among several stocks in the region.

No biochemical, genetic, or scale pattern analysis data were available for separating stock groups of coho salmon. Interior stocks, especially those in the upper Nahlin and Hackett Rivers, that make long and arduous migrations and stocks that inhabit systems with migration barriers were likely to show genetic divergence because of reduced probability of gene flow and the presence of unusual selection pressures.

Interpretation of results of outlier analyses depends on whether sampled stocks are considered representative of the range of variation present in the region. Nine stocks had distinctive characteristics based on outlier analyses (see fig. 16 for approximate locations). Relatively extensive data sets were available for the following stocks:

- Redoubt Lake—High MFWA differences between males and females (0.3 year, based on 7 years of sampling and over 1,500 aged individuals).
- Tsiu River—Unusually large escapement magnitude (mean survey estimate exceeds 22,000 across 26 years of sampling).

The following stocks show distinctive characteristics based on limited sampling. These results should be considered preliminary.

- Salt Chuck, George Inlet—Early run timing based on escapement survey dates.
- Falls Lake—Early run timing based on mean dates at the weir.
- Pavlof Lake—Early run timing based on escapement survey dates and small body size of age 1.1 and 2.1 females.
- Port Banks (Plotnikof Lake)—Early run timing based on escapement survey dates.
- Eagle River—High proportion of age 2.1 males in escapements.
- Klukshu River—High proportions of age 1.1 males and females in escapements and correspondingly low proportions of age 2.1 individuals.
- Tsiu River—Large MFWA differences between males and females.
- Tsiu-Tsivat River system—Large escapements.

Based on anecdotal reports the following stocks may have distinctive characteristics:

- Hasselborg River, Ford Arm Lake, Kadake Creek—Coho salmon rear in saltwater rather than freshwater habitats and apparently attain high growth rates.
- Lucky Cove, Reflection Lake, Hamilton and Ward Creeks—Early run timing to systems with partial migration barriers.
- Karta River—Early and prolonged run timing; possibly two stocks present.

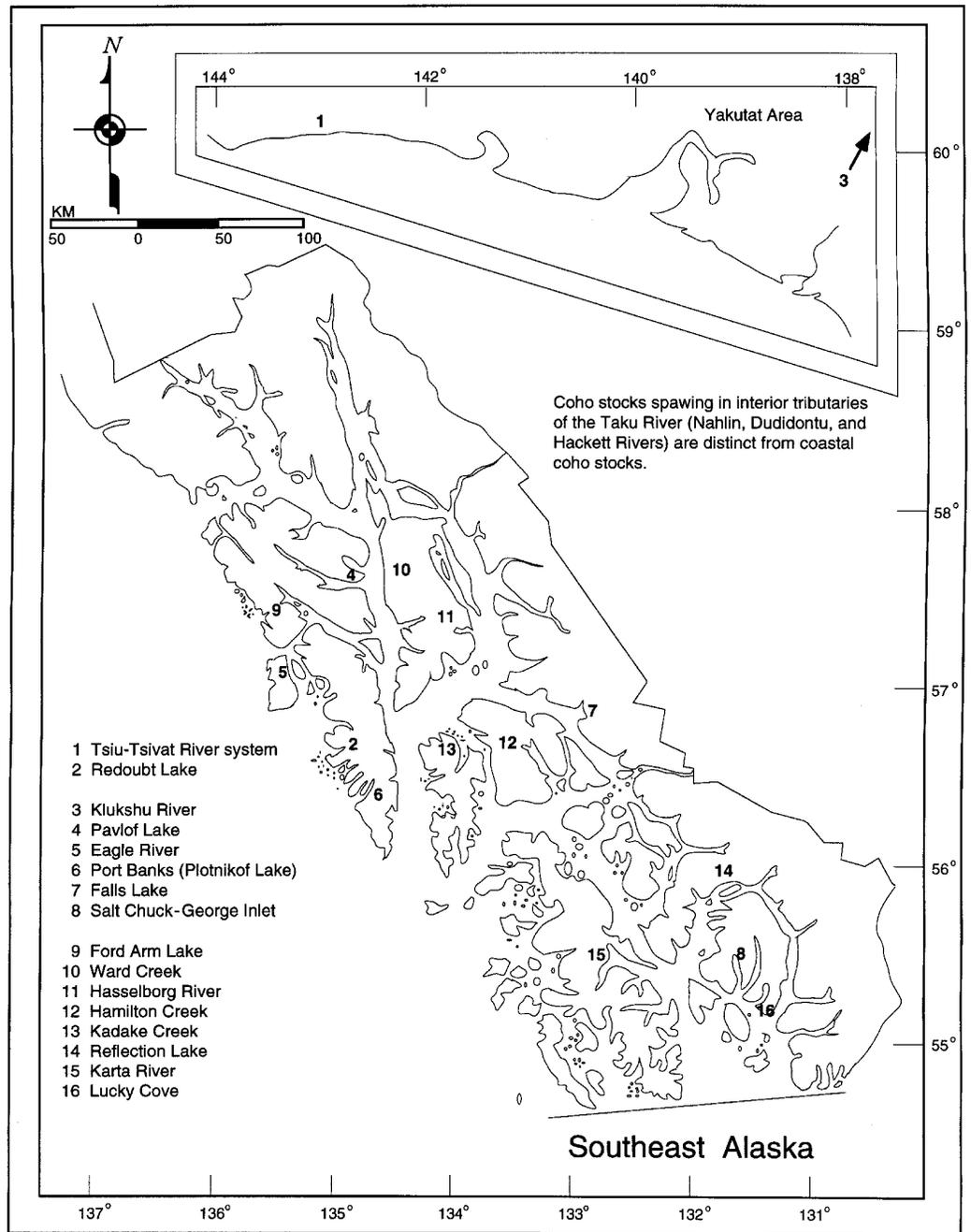


Figure 16—Approximate geographic locations in the study area of coho salmon stocks exhibiting distinctive characteristics. Stocks 1 and 2 were sampled relatively thoroughly. Stocks 3 to 8 were represented by limited samples (results are preliminary). Anecdotal reports suggested stocks 9 to 16 may have distinctive characteristics, but few or no quantitative data were available for these stocks. Stocks that spawn in interior tributaries of the Taku River have low MFWAs, sex ratio bias favoring males with virtually no jacks present, and low survival rates compared to coastal stocks.

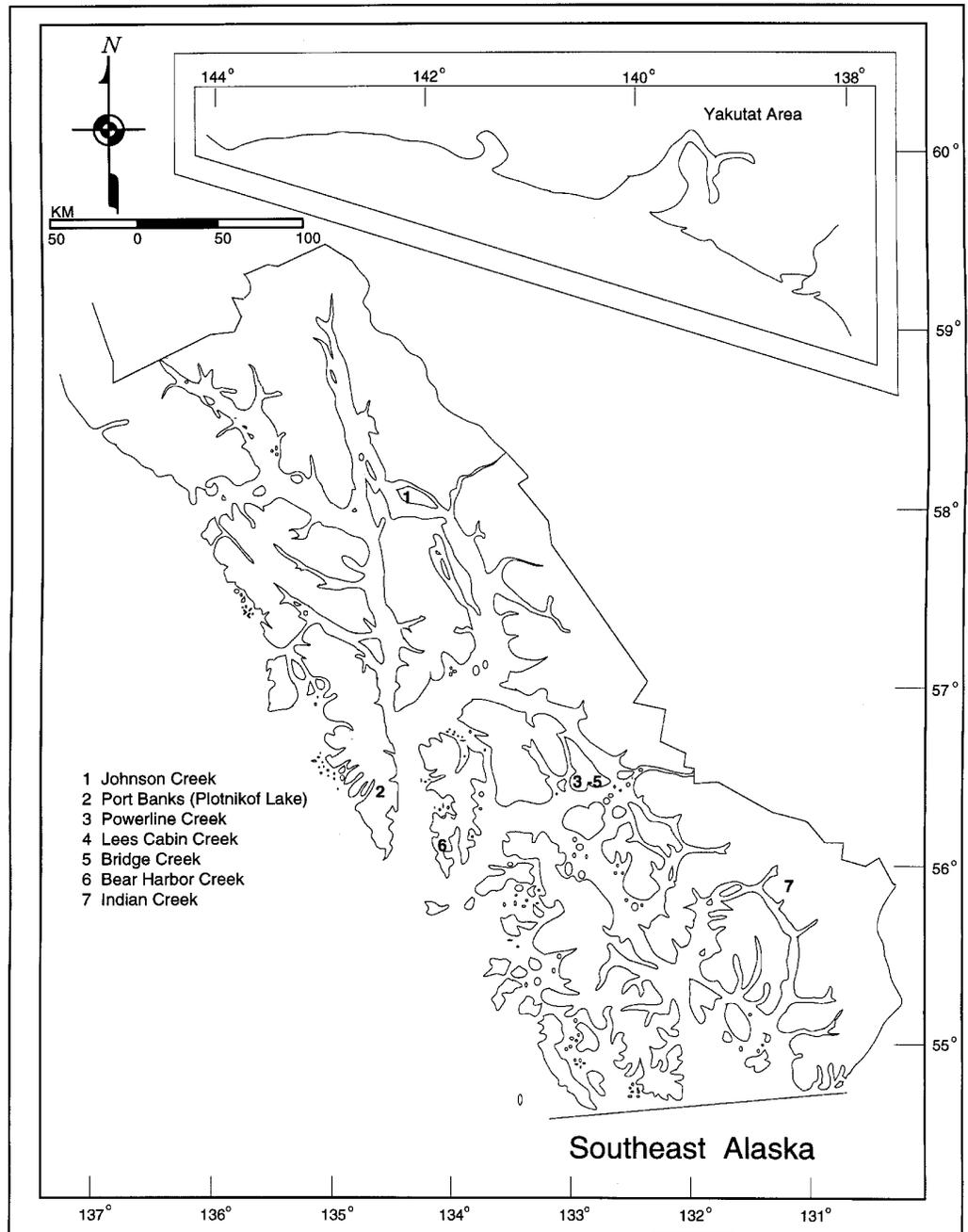


Figure 17—Approximate geographic locations in the study area of coho stocks with significantly declining escapement trends.

Seven of 129 (5.4 percent) stocks evaluated showed significant declines (see fig. 17 for approximate locations). Six of seven declining stocks inhabit streams, and the only declining lake stock (Plotnikof Lake) has distinctive run timing. In four cases, a combination of suspected factors may be responsible for declines, and in three cases, possible causative factors are unknown. No clear relation exists between water quality and population status, but many stocks in impaired or suspected water bodies have not been adequately surveyed to permit analysis of escapement trends, or insufficient postimpact surveys have been conducted to detect an effect.

Escapement survey data for coho salmon were more unreliable for determining trends in abundance than data for other species, thereby increasing the possibility that significant declines may be either generated or hidden by inconsistent surveys.

Existing data suggested the wild coho salmon resource in the region is in stable condition. Lack of sufficient information is the most pervasive risk factor threatening sustainable management of coho salmon stocks in the region. Additional risk factors include habitat disruption of watersheds associated with natural resource extraction and urbanization, and the potentially negative effects of increasing artificial enhancement on wild stocks. Wild coho salmon stocks have proven to be resilient in the face of high levels of exploitation, when high-quality spawning and rearing habitat are available. The effects of habitat degradation, artificial enhancement, and overexploitation are synergistic and can lead to rapid decline of productivity of wild stocks, as they did in the Pacific Northwest.

Acknowledgments

D. Aho, J. Carol, J. Christner, F. Cole, J. Franzel, G. Killinger, R. Sainz, and V. Starostka provided helpful information regarding the interpretation of escapement surveys and the history of enhancement projects. Statistical advice and technical assistance were provided by D. Bachman, K. Frangos, and T. Max. The ADF&G documents that provided nearly all the biological data for this report were provided by G. Karcz Alexander, G. Gunstrom, M. Harris, S. McGhee, and K. Savikko. C. Casipit, R. Dunlap, and V. Starostka supported the work in various and sometimes extraordinary ways. Incisive review of a previous draft by J.H. Clark greatly improved this work, as did the input and advice of J. Seeb. S. Elliott, R. Josephson, and A. Schmidt gave generously of their time and insights about coho salmon biology and management. We appreciate the guidance provided by L. Talley and S. Johnson on the ADF&G's Integrated Fishery Database and for retrieving indispensable information we requested from that database. We are especially grateful to L. Shaul for his thoughtful and thorough review of a previous draft and for sharing his expertise on coho salmon in southeast Alaska.

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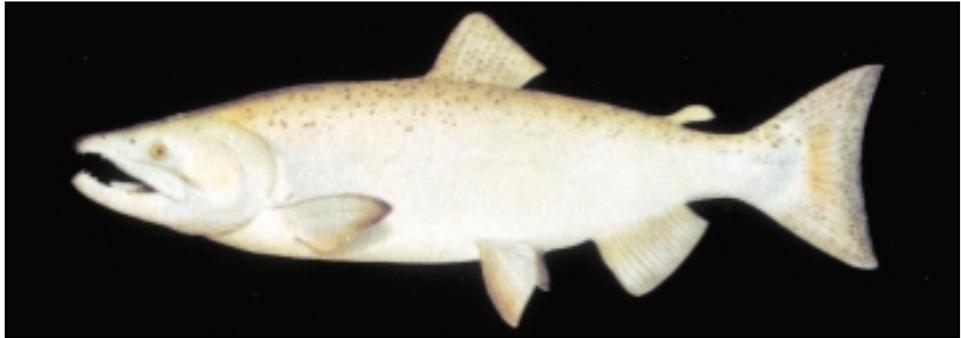
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Chinook Salmon (*Oncorhynchus tshawytscha*)¹

Abstract

Stocks of chinook salmon (*Oncorhynchus tshawytscha*) that spawn in southeast Alaska and adjoining areas of British Columbia and the Yukon Territory are valuable biological, commercial, and recreational resources. Stock-specific information on various biological characteristics including body length, run timing, age structure, and temporal trends in escapement was analyzed for geographic patterns and presence of distinctive stocks. Stocks from the southern portion of the region have larger mean body length, later run timing, and younger mean ages at maturation than northern stocks. Stocks having distinctive biological characteristics include the Situk River stock and nearby stocks from the Yakutat Forelands, the only ocean-type stocks in the region, and the King Salmon River stock, which spawns in an island drainage. Most stocks in the region have stable escapement trends, with 25 percent (15 stocks) showing significant increases, and 5 percent (3 stocks) showing significant declines from 1960 to 1993. Risk factors for chinook stocks in the region include habitat disruption from glacial advances, landslides, and human activities and potential overexploitation, especially of small stocks. Chinook stocks are well studied and monitored compared to coho salmon.

Keywords: Chinook salmon, *Oncorhynchus tshawytscha*, southeast Alaska, age distribution, run timing, body size, intraspecific diversity, population status.

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Introduction Life History

Chinook salmon are distributed throughout southeast Alaska, from the Keta and Marten Rivers in Misty Fjords National Monument to the Situk River on the Yakutat Forelands. Most are found in large mainland river systems, but four stocks occur in island systems: King Salmon River, Wheeler, and Greens Creeks on Admiralty Island, and in Carroll Creek on Revillagigedo Island, where the chinook salmon are from an introduced stock. Most stocks are found from the Stikine River south. Chinook spawning populations range from less than 100 in many watersheds to more than 50,000 fish on the Taku River (McPherson and others 1996, 1997; Pahlke and Bernard 1996). Most spawning populations in southeast Alaska consist of less than 1,000 individuals (based on recent escapement counts). Larger populations are found in tributaries of large transboundary rivers, the Taku, Stikine, and Alsek Rivers.

Most juvenile chinook salmon in southeast Alaska rear in freshwater habitats for a year or more after emergence before emigrating to sea ("stream-type" stocks). In contrast, "ocean-type" juvenile chinook salmon emigrate from fresh water soon after emergence or after a freshwater feeding period of 2 to 3 months. Ocean-type life history patterns are more common in chinook stocks of coastal rivers south of 56° N. lat. (Taylor 1990). Stream-type chinook salmon also tend to have (1) more extensive oceanic migrations than ocean-type chinook; (2) return migrations to natal spawning streams that occur in spring and summer, several months before spawning, compared to the fall return timing of ocean-type chinook; and (3) the occasional occurrence of males that mature precociously without ever going to sea (Healey 1991). Considerable variation exists, however, within these life history characteristics; for example, the chinook salmon stock in the Situk River near Yakutat has ocean-type juvenile emigration timing, but stream-type return and spawning timing² (Johnson and others 1992b).

Most chinook salmon in southeast Alaska return to spawn after 3 or 4 years in the ocean (i.e., x.3 or x.4). The proportion of jacks or males that mature at ages x.1 and x.2 differs greatly among stocks, sometimes exceeding 50 percent of all males (e.g., Hard and others 1985). The typical size of age 1.3 and 1.4 spawners in southeast Alaska is about 850 mm, mid-eye-to-fork length. Males usually outnumber females in current spawning populations, in part owing to the number of jacks. Females generally mature at older ages. Most spawning occurs in clearwater tributaries of large, glacial rivers. For most chinook populations in the region, peak spawning occurs from the last week in July to late August. In general, stocks in southern southeast Alaska spawn later than stocks in northern southeast Alaska. This trend reflects the pattern found throughout the geographic range of chinook salmon in which spawning occurs earlier at more northerly latitudes (Healey 1991).

In a review of the early life history of chinook salmon, Healey (1991) reports that eggs hatch in 7 to 9 weeks and alevins overwinter in the spawning redds. Emergence from the gravel occurs in spring, and fry attain fork lengths between 50 and 70 mm by October. Chinook juveniles tend to rear in areas with faster current, such as channel edges, including mainstem channels. The highest densities of rearing juveniles are found in braided areas, especially near rootwads or other large woody debris. Fry overwinter in close association with the stream substrate or dense cover. Fry resume a more active existence in early spring, and develop into smolt by late spring. Smolt typically emigrate from fresh water from early April to mid-June in most systems.

² Personal communication. 1996. P. Kissner, fisheries biologist (retired), Alaska Department of Fish and Game, 802 3d Street, Douglas, AK 99824.

Estuaries are important rearing areas for juvenile ocean-type chinook salmon (Levy and Northcote 1982). Ocean-type juveniles often rear in estuaries for several months (Healey 1991, Pearcy 1992), but stream-type juveniles in the Pacific Northwest typically spend a brief period near the estuary mouth before moving offshore (Healey 1991). Use of estuarine habitats by chinook salmon in southeast Alaska has not been well investigated. Likewise, little is known about the early marine distribution of juvenile chinook salmon from southeast Alaska, largely because of their low abundance relative to other species (about 1 percent of total seine catches; Jaenicke and Celewycz 1994).

Oceanic migration patterns of specific chinook salmon stocks are not well known (Healey 1991). In southeast Alaska, data from coded-wire tagging indicate that some chinook from southern southeast Alaska stocks (Chickamin and Unuk Rivers) as well as fish from Chilkat and King Salmon Rivers in northern southeast Alaska remain in near-shore waters for extended periods, possibly for the duration of their marine existence³ (Mecum and Kissner 1989, Pahlke and Mecum 1990). Most chinook salmon from the Taku and Stikine River systems appear to move quickly through the near-shore waters and into the Gulf of Alaska (Hubartt and Kissner 1987). Migratory pathways of returning fish moving through inside waters can differ within drainages; for example, two different migratory paths are followed by chinook salmon returning to the Taku drainage. The pathway used by most fish is through Icy Strait, and then south past Juneau to Taku Inlet. The second pathway, used by fewer fish, passes around the southern tip of Baranof Island and proceeds north through Frederick Sound and Stephens Passage to the Taku River (Kissner and Hubartt 1986).

Chinook salmon show latitudinal trends in biological characteristics (Healey 1991), and chinook salmon in the southern portion of their range have life history differences associated with freshwater migration distance. Based on these differences, we compared (1) northern and southern stock groups from the study region to look for latitudinal patterns of variation in biological characteristics, and (2) coastal (outside) and interior stocks to look for variation patterns associated with migration distance.

Management

Before the 1970s, chinook fisheries in the region were not closely managed (ADF&G 1992). The current phase of chinook salmon management began in the mid-1970s, when most chinook stocks in the region were considered depressed relative to historical abundance levels (ADF&G 1981). The ADF&G imposed restrictions on terminal and near-terminal gill-net fisheries for chinook salmon, closed coho salmon troll fisheries that intercepted large numbers of chinook salmon, and established size limits on chinook salmon caught in sport fisheries (ADF&G 1992). In 1981, the ADF&G began an expanded 15-year (three chinook life cycles) rebuilding program for all transboundary river systems as well as for the Keta, Blossom, King Salmon, and Situk Rivers (ADF&G 1992). An important component of this program was the establishment of regionwide catch ceilings for all gear types. These ceilings were largely responsible for the relative consistency of commercial harvests of chinook salmon during the last decade (fig. 18). The purpose of the rebuilding program was to achieve higher spawning escapements by 1995. Escapement goals were established in 1981 and set at the historical escapement count. Insufficient data were available for spawner-recruit analyses, thereby precluding calculation of optimum escapement levels.

³ Personal communication. 1996. S. McPherson, fisheries biologist, Alaska Department of Fish and Game, 802 3d Street, Douglas, AK 99824.

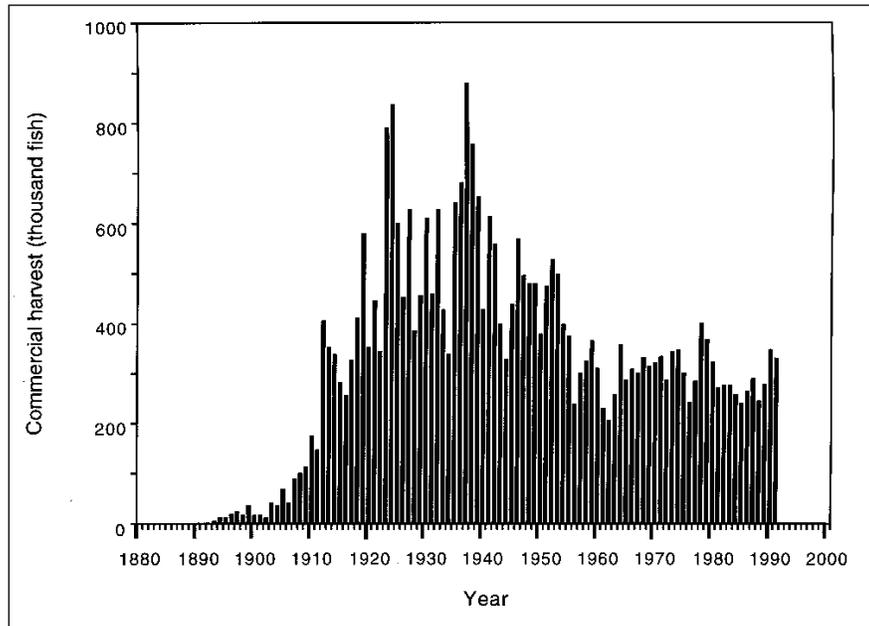


Figure 18—Annual commercial harvest of chinook salmon in southeast Alaska, 1893 to 1991 (data from Rigby and others 1991).

The rebuilding program begun in 1981 was incorporated into the U.S./Canada Pacific Salmon Treaty, ratified in 1985, that established the legislative basis for recent management of chinook salmon. A primary goal of the treaty was to rebuild depressed natural chinook stocks throughout the eastern Pacific range of the species over a 15-year period, or by 1998 (ADF&G 1992). The treaty established annual all-gear catch ceilings that could be exceeded by “add-ons” of hatchery produced chinook (Denton and Holland 1986).

Of the 11 index stocks in southeast Alaska used to monitor the success of the rebuilding program, Andrew and King Creeks and Situk, Chilkat, and Stikine Rivers have consistently exceeded escapement goals. Several stocks in southern southeast Alaska (Unuk, Chickamin, and Blossom River stocks) initially responded well to the rebuilding program but have declined since 1987. Mixed results have been observed for the Alsek, King Salmon, and Keta Rivers. The Blossom and Chickamin Rivers have had escapements below goals in recent years (McPherson and Carlile 1997, Pahlke 1991a).

For operational purposes, the ADF&G has divided chinook systems in southeast Alaska into three categories based on the estimated magnitude of total returns (Kissner 1977). Minor systems have total returns of less than 1,500 individuals, medium systems have total returns between 1,500 and 10,000 individuals, and major systems have more than 10,000 individuals returning (on average). These categories and their associated population estimates are based on complete drainages rather than individual tributaries. Thirty-four systems are categorized in this system: 22 minor, 9 medium, and 3 major (table 12). Management research in the region is directed toward refining escapement estimation and gathering information on the population biology of stocks useful in spawner-recruit analyses and determination of optimal escapement goals.

Table 12—Location of spawning streams and types of data available for chinook salmon stocks in the study region

Stream		Location			Coastal or interior	North or south	ADF&G mgmt. class	Data ^c
Number	Name	N. latitude ^a	W. longitude ^a	VCU ^b				
101-30-030	Keta River	55°20'11"	130°28'24"	842K	C	S	Medium ^d	B, E
101-30-060	Marten River	55°09'30"	130°31'47"	838K			Minor	E
101-45-078	Carroll Creek	55°39'04"	131°21'23"	744K			Established?	B, E
101-55-200	Wilson River	55°24'09"	130°36'25"	817K			Minor	E
101-55-040	Blossom River	55°24'10"	130°36'22"	815K & 818K	C	S	^d	B, E
101-60-015	Rudyerd Creek ^e	55°39'47"	130°38'17"	802K & 798K			Minor	
101-60-030	Big Goat Creek ^f	55°45'00"	130°40'00"	802K			Minor	E
101-71-028	Walker Creek ^e	55°59'29"	131°50'32"	724K			Minor	
101-71-040	Chickamin River	55°49'26"	130°55'20"	793K & 794K	C	S	Medium ^d	B, E
101-71-04A	Barrier Creek	55°51'13"	130°37'50"	794K & 797K	C	S	Medium	B, E
101-71-04B	Butler Creek ^f	56°03'00"	130°45'00"	795K	C	S	Medium	B, E
101-71-04C	Clear Falls Creek ^f	55°59'00"	130°40'00"	795K				E
101-71-04H	Humpy Creek	55°50'55"	130°52'21"	793K				B, E
101-71-04I	Indian Creek	55°59'26"	130°39'19"	796K	C	S		B, E
101-71-04K	King Creek	55°50'28"	130°50'59"	793K				B, E
101-71-04L	Leduc River	55°54'23"	130°47'13"	794K & 795K				E
101-71-04S	South Fork	55°52'32"	130°44'23"	796K	C	S		B, E
101-75-005	Herman Creek ^{g,f}	55°59'00"	131°18'00"	730K			Minor	
101-75-010	Grant Creek	56°02'21"	131°12'45"	782K & 783K			Minor	E
101-75-015	Eulachon River	56°05'08"	131°05'17"	786K	C	S		B, E
101-75-050	Klahini River	56°03'17"	131°02'54"	790K			Minor	E
101-75-030	Unuk River	56°04'38"	131°04'31"	786K			Medium ^d	
101-75-30C	Clear Creek ^f	56°07'	130°57'	786K	C	S		B, E
101-75-30G	Gene's Lake	56°12'	130°52'	786K	C	S		B, E
	Creek ^f							
101-75-30K	Kerr Creek ^f	56°10'	130°55'	Canada				E
101-75-30L	Lake Creek	56°08'03"	130°58'03"	786K & 789K				E
101-75-30Q	Cripple Creek	56°16'06"	130°47'47"	788K	C	S		B, E
101-75-30S	Sawmill Slough			786K				E
107-20-001	Anan Creek ^g	56°10'47"	131°53'09"	522S				
107-40-024	Aaron Creek ^f	56°22'	131°55'	503S			Minor	E
107-40-025	Oerns Creek	56°22'45"	131°57'57"	503S				
107-40-047	Tom Lake Creek	56°13'10"	131°40'21"	510S			Minor	E
107-40-049	Harding River	56°12'18"	131°37'08"	511S	C	S	Medium	B, E
107-40-052	Bradfield River, North Fork	56°14'06"	131°27'16"	514S			Medium	E
107-40-053	Bradfield River, East Fork	56°13'58"	131°30'06"	517S				E
107-40-055	Eagle River (Bradfield)	56°09'18"	131°35'13"	519S			Minor	E
108-40-015	Stikine River	56°38'20"	132°19'29"	493S			Major ^d	B, E
108-40-010	North Arm Creek	56°41'06"	132°18'19"	493S				B, E
108-40-016	Kikahe River	56°38'43"	131°53'49"	500S				E
108-40-017	Goat Creek	56°39'58"	131°58'12"	495S				E
108-40-020	Andrew Creek	56°40'13"	132°15'04"	498S	C	S	^d	B, E
108-40-024	Government Creek	56°38'43"	132°17'07"	497S				E
108-40-13A	West of Hot Springs ^f	56°41'	132°06'					E
108-40-080	Shakes Creek	56°42'49"	132°06'17"	495S				B, E
108-70-011	Katete River			Canada				E
108-80-100	Tahltan River			Canada	I	N		B, E

Table 12—Location of spawning streams and types of data available for chinook salmon stocks in the study region (continued)

Stream		Location			Coastal or interior	North or south	ADF&G mgmt. class	Data ^e
Number	Name	N. latitude ^a	W. longitude ^a	VCU ^b				
108-80-115	Beatty Creek			Canada				E
108-80-120	Little Tahltan River			Canada	I	N		B, E
108-60-030	Muddy River ^o	56°54'15"	132°49'41"	489S			Minor	
110-14-007	Farragut River	57°09'42"	133°08'46"	90S	C	N	Minor	B, E
110-32-009	Chuck River	57°34'42"	133°21'00"	69C			Minor	E
111-17-010	King Salmon River	58°02'36"	134°20'18"	142C	C	N	Minor ^d	B, E
111-32-032	Taku River	58°25'32"	133°58'25"	41C & 46C			Major ^d	B, E
111-32-210	King Salmon Creek			Canada				
111-32-220	Nakina River			Canada	I	N		B, E
111-32-240	Kowatua Creek			Canada	I	N		B, E
111-32-254	Little Tatsamenie Lake ^f	58°25'	132°20'	Canada	I	N		B, E
111-32-255	Tatsamenie River			Canada	I	N		B, E
111-32-260	Hackett River			Canada	I	N		B
111-32-270	Nahlin River ^f	58°48'	132°01'	Canada	I	N		B, E
111-32-275	Tseta Creek			Canada	I	N		B, E
111-32-280	Dudidontu River ^f	58°47'	132°03'	Canada	I	N		B, E
112-16-030	Wheeler Creek ^f	58°03'	134°47'	146C				
112-65-024	Greens Creek ^f	58°05'	134°45'	144C				
115-32-025	Chilkat River	59°13'33"	135°30'54"	NA			Medium ^d	B, E
115-32-046	Klehini River ^f	59°24'	135°58'	NA				B
115-32-054	Big Boulder Creek	59°25'43"	136°11'37"	NA				E
115-32-055	Little Boulder Creek	59°25'27"	136°07'55"	NA				E
115-32-064	Kellsall River	59°31'53"	136°02'03"	NA				B
115-32-301	Stonehouse Creek			Canada				E
115-32-068	Tahini River	59°36'57"	135°59'03"	NA	C	N		B, E
182-10-010	Doame River ^{o,f}	59°03'	138°17'	National Park			Minor	
182-20-010	East Alsek River	59°05'43"	138°25'37"	National Park			Minor	
182-30-010	Alsek River	59°09'58"	138°33'21"	National Park			Major ^d	B
182-30-020	Klukshu River			Canada				B, E
182-30-042	Tatshenshini River			Canada				B
182-30-043	Takhanni River			Canada				E
182-30-045	Goat Creek			Canada				E
182-30-050	Blanchard River			Canada				E
182-40-010	Akwe River	59°16'59"	139°02'50"	379C			Minor	E
182-50-010	Italio River ^o	59°19'49"	139°14'21"	379 & 380C			Minor	
182-60-010	Dangerous River ^{o,f}	59°23'	139°17'	377C			Minor	
182-70-010	Situk River	59°26'47"	139°33'58"	366C	C	N	Medium ^d	B, E
182-80-010	Lost River ^o	59°27'11"	139°36'33"	367C			Minor	
183-50-010	Ankau Creek ^{o,f}	59°30'	139°45'	369C			Minor	

NA = not available.

^a Latitude and longitude reported for river mouths.

^b VCU = USDA, Forest Service value comparison unit; approximately equivalent to a watershed. K = Ketchikan Area; S = Stikine Area; and C = Chatham Area.

^c Data types included in this review: B = biological characteristics, E = escapement survey counts.

^d Index system for management.

^e Small escapements reported, but no evidence of successful spawning.

^f Approximate latitude and longitude interpolated from topographic maps.

Sources: ADF&G 1992, Kissner 1977, Pahlke 1991a.

Most chinook salmon in southeast Alaska are harvested in mixed-stock fisheries. The mixed-stock commercial harvest in southeast Alaska may include fish from other regions; e.g., an estimated 57.9 percent of all chinook salmon harvested in 1987 were of non-Alaska origin (Olsen 1992). Chinook salmon from British Columbia south of Dixon Entrance are taken most frequently in inside waters, and chinook from the Pacific Northwest are caught in outside waters. For chinook salmon originating in rivers that flow through southeast Alaska, differences in migratory pattern have important consequences for the exposure of different stocks to troll and drift gill-net fisheries, the fisheries that account for most of the southeast Alaska catch of chinook salmon (ADF&G 1992). Stocks from southern southeast Alaska that are exposed to fisheries for extended periods have exploitation rates that range from 16 percent for the Unuk stock to 40 to 60 percent for the Chickamin stock, with a high of 65 percent calculated for age 1.3 fish from the Chickamin River caught in 1989⁴ (McPherson and Carlile 1997). Since the mid-1970s, when the start of the troll season was delayed, exploitation rates on the chinook stocks in the Taku and Stikine drainages (which move offshore quickly) have been less than 10 to 20 percent (see footnote 3). These stocks have been exposed to increasing exploitation by sport fisheries in recent years, but the effect of these fisheries is believed to be small compared to the effects of a directed commercial troll fishery (see footnote 3).

Recreational fisheries for chinook salmon are growing rapidly throughout southeast Alaska. From 1977 to 1984, the estimated average annual sport catch of chinook salmon was about 20,300 fish (ADF&G 1992). The estimated sport harvests in 1990 and 1991 were 51,200 and 68,400, respectively (ADF&G 1992). In these years, recreational fisheries took about 20 percent of the all-gear catch ceilings instituted under the Pacific Salmon Treaty. About 60 percent of the sport catch taken from 1977 to 1989 occurred in the Ketchikan and Juneau areas. In 1990, that declined to 45 percent as sport fisheries expanded in Petersburg-Wrangell, Sitka, and other areas (ADF&G 1992). Management of recreational fisheries is becoming an increasingly important component of overall chinook salmon management across southeast Alaska.

Enhancement

Development of ocean-type chinook runs was the goal of early enhancement efforts that involved transfers of chinook salmon eggs into Alaska from Washington and Oregon (Roppel 1982). This goal was apparently motivated by the expectation that ocean-type chinook would be able to use the abundant small-stream habitats found throughout southeast Alaska. The failure of these transplants was thought to be due to the low productivity of Alaska streams. Greater stream productivity at lower latitudes may permit the short freshwater residence of ocean-type chinook salmon (Taylor 1990). Hatchery production of ocean-type chinook salmon began in southeast Alaska in 1923 at the Ketchikan territorial hatchery, near the current site of the

⁴ Recent studies have confirmed that chinook populations in southeast Alaska differ in extent of ocean migration: Stikine, Taku, Asek, and Situk River stocks, as well as other Yakutat Foreland stocks, migrate quickly to outside waters and spend most of their ocean life in the Gulf of Alaska; the remainder of stocks spend most of their ocean life in coastal waters. We have not conducted analyses comparing characteristics of stock groups exhibiting these different ocean life patterns.

Deer Mountain hatchery on Ketchikan Creek. In 1923, nearly 1 million chinook fry were released into Ketchikan Creek (Roppel 1982). Half of the eggs hatched to produce these fry were from the Columbia River, and the other half were from unknown sites in Oregon (Roppel 1982). The chinook program at the Ketchikan territorial hatchery continued until 1927, with nearly 2 million fry released each year. After the initial shipment from Oregon, all subsequent transferred eggs were derived from stocks in Washington (Roppel 1982). Because funding for the territorial hatchery program was terminated in 1927, little information exists on returns from these early enhancement activities on Ketchikan Creek.

The next significant attempt to establish ocean-type chinook production occurred in the early 1950s with transfers of eyed chinook eggs from Washington that were planted in two streams near Juneau (Parker and Kirkness 1950). From 1950 to 1953, four shipments of eyed chinook eggs from Soos Creek, Washington (and possibly other sources), were planted in Montana and Spring Creeks near Juneau, resulting in a total transfer of at least 160,000 eggs (the number of eggs in the final shipment is unknown; Roppel 1982). As was the case with operations at the Ketchikan territorial hatchery, no systematically collected data are available on returns from these efforts.

Deer Mountain hatchery in Ketchikan began chinook operations in 1955 with another attempt to establish ocean-type runs with eggs from Soos Creek, Washington. After releasing over 200,000 fry hatched from Soos Creek eggs during 4 years, sufficient returns to the hatchery occurred in 1960 to continue the program with egg-takes at the hatchery (Roppel 1982). This program continued until 1967. No subsequent transfers of ocean-type eggs were pursued.

Egg transfers for chinook brood stock ended in the 1960s for several reasons: (1) low return rates from hatchery releases; (2) the possibility of importing infectious hematopoietic necrosis virus (IHNV), which is common in chinook from Washington and Oregon but is not present in native chinook stocks in southeast Alaska; and (3) concerns about potentially negative genetic effects of cultured fish from distant sources on native stocks. Infection of local wild stocks with IHNV as a result of egg transfers seemingly did not occur. The genetic effects of all early egg transfers on native stocks are unknown. Although straying rates of the transferred fish were probably high (Quinn 1993, Reisenbichler 1988), the probability of successful spawning and recruitment were probably low owing to differences in migration and spawning timing, rearing ecology, and a variety of other life history characteristics.

The current phase of enhancement for chinook salmon, which began in 1975 with a program to establish a chinook salmon brood stock from southeast Alaska, was another response to the depressed status of southeast Alaska chinook stocks as well as other stocks harvested incidentally in southeast Alaska. Chinook eggs were taken from the Unuk, Chickamin, Stikine (Andrew Creek), King Salmon, and Taku drainages (Moberly and Kaill 1977). Unuk and Chickamin River eggs were cultured separately at the Little Port Walter research hatchery, and eggs from the other sources were cultured at the Crystal Lake hatchery on Mitkof Island; most of these eggs were from the Andrew Creek chinook stock. Other hatcheries were located at Deer Mountain,

Table 13—Hatchery programs producing chinook salmon in southeast Alaska^a

Hatchery	Management	Location	Brood stock sources	Release sites	Annual egg-take goal
Whitman Lake	SSRAA ^b	Herring Bay, George Inlet, South Revillagigedo Island	Chickamin River	Whitman Lake Neets Bay Carroll Inlet Earl West Cove	3,000,000
Deer Mountain	Ketchikan Indian Corp.	Ketchikan	Unuk River	Ketchikan Creek Thorne Bay Big Salt Lake	133,000
Neets Bay	SSRAA ^b	Neets Creek, Neets Bay, North Revillagigedo Island	Chickamin River Unuk River before 1994	Neets Bay	1,500,000
Bell Island ^c	American Aquaculture Corp.	Bell Island, West Behm Canal	Unuk River	Bell Island Creek	
Port Armstrong ^d	Armstrong-Keta, Inc.	Jetty Lake, South Baranof Island	Unuk River (1985-91) King Salmon River Farragut River	Armstrong Bay	1,100,000
Crystal Lake	ADF&G ^e	Crystal Lake, Blind Slough, Mitkof Island	Andrew Creek	Crystal Creek Ohmer Creek Earl West Cove Medvejje Creek	2,500,000 to 4,000,000
Little Port Walter	U.S. Dept. of Commerce, NMFS	Little Port Walter, Sashin Creek, South Baranof Island	Farragut River Chickamin River Unuk River King Salmon River	Farragut River Little Port Walter Port Armstrong Gastineau Channel	
Snettisham	ADF&G ^e	Speel Arm, Port Snettisham	Andrew Creek Situk River	Speel Arm	No longer producing chinook salmon
			King Salmon River	Auke Creek Fish Creek (Douglas Island) Montana Creek Sheep Creek (Juneau) Redoubt Lake Gastineau Channel Indian River (Tenakee) Little Port Walter	
DIPAC ^f	Douglas Island Pink and Chum, Inc.	Salmon and Sheep Creeks, Gastineau Channel, Juneau	Unuk River Andrew Creek King Salmon River	Port Armstrong Gastineau Channel Sheep Creek Fish Creek (Douglas Island) Auke Creek Medvejje Creek	700,000
			Tahini River Big Boulder Creek	Tahini River Big Boulder Creek	

^a Tamgas hatchery (Annette Island, Unuk River brood stock), Hidden Falls hatchery (northeast Baranof Island, Tahini River brood stock) and Medvejje hatchery (Sitka, Andrew Creek brood stock) also have chinook salmon production programs.

^b SSRAA = Southern Southeast Regional Aquaculture Association.

^c This program is relatively small and is currently in the brood stock development stage.

^d A brood stock change to either King Salmon River, or possibly Farragut River, is anticipated in 1995.

^e ADF&G = Alaska Department of Fish and Game.

^f In transition to King Salmon River brood stock.

Source: Information primarily from hatchery management plans provided by S. McGhee, ADF&G Division of Commercial Fisheries, 1255 West 8th Street, Juneau, AK 99802.

Neets Bay, and Whitman Lake. After several years of relatively small releases, the hatchery program for chinook salmon grew quickly in the early 1980s and achieved a peak release of 9 million age-1 smolts in 1988. With the advent of catch ceilings for wild chinook associated with signing of the Pacific Salmon Treaty in 1985, hatchery chinook were expected to play an important role in compensating for reduced harvest of wild fish. One goal of the hatchery chinook program was to add 100,000 chinook salmon to the troll catch (ADF&G 1992). In 1991, 79,546 hatchery-produced chinook salmon were caught in southeast Alaska (ADF&G 1992). Most hatchery production programs for chinook salmon that were ongoing in 1994 are summarized in table 13.

The chinook salmon plan for southeast Alaska (Holland and others 1983) identified numerous sites with potential for structural enhancements, lake and stream stocking projects, or rehabilitation programs for chinook salmon. Relatively few of these enhancement activities have occurred in the region. The following summary is not a comprehensive list, but rather a representative sample of habitat enhancement projects throughout the region. Carroll Creek has been stocked with chinook fry (Chickamin River origin) from various hatcheries since 1982. A small run also was established in the Chilkoot River (see footnote 3). Chinook fry or smolts of Andrew Creek origin have been released at Ohmer Creek and at numerous locations in the Juneau area (future releases in the Juneau area probably will be of King Salmon River origin). The NMFS experimentally stocked chinook fry into Larry and Tranquil Lakes (both have barriers to anadromous migrations). Although the experiment produced chinook salmon, it was not as successful as coho salmon production. Fry outplant programs have been conducted in the Farragut, Harding, and Tahini Rivers. Chinook salmon were stocked in Indian River, Tenakee Inlet in 1986, 1989, and 1993 (Killinger 1994). Upstream access is blocked by a barrier falls; a spawning population therefore was not established. Big Boulder Creek was stocked with fry outplants, and an incubation box was installed at the creek following habitat disruptions associated with bridge building and road repair (see Parry and others 1993).

Enhancement efforts for chinook salmon have declined since the late 1980s, and in recent years, nearly all state-run enhancement programs have been terminated or transferred to private, nonprofit hatcheries. Brood stocks derived from the King Salmon, Unuk, and Chickamin Rivers and Andrew Creek currently dominate hatchery production throughout the region. Although a large amount of straying has not been observed among some rivers, such as the Taku, Stikine, Chilkoot, and Situk, release of these brood stocks throughout southeast Alaska may have increased gene flow among chinook stocks.

Stock Discrimination

Differences in morphology and scale patterns have not proven particularly effective for separating southeast Alaska chinook stocks. Rowland (1963) was unsuccessful in finding morphologic characteristics that permitted reliable identifications. Attempts to employ scale analysis permitted separation of Alaska versus non-Alaska fish but were unsuccessful for individual river systems owing to overlap in circuli counts (Kissner 1977, Van Alen 1988). Biochemical and genetic techniques have not yielded appreciably better results. Mitochondrial DNA analysis of chinook from south-central Alaska and British Columbia revealed the presence of regional mitochondrial

maternal lines, but overall sequence divergence among populations was less than 1 percent (Wilson and others 1987). Electrophoretic techniques have been useful for separating chinook stocks over broad geographic areas (Gall and others 1992). Gharrett and others (1987) found, however, that low levels of allozyme variability among Alaska stocks limited the resolution of this technique. In 1989, additional tissue samples were collected from southeast Alaska populations for genetic stock identification by using a more comprehensive selection of allozymes (Pahlke and Mecum 1990); but analysis of these samples was not complete as of 1994.⁵ Recent studies of chinook stocks in the Snake and Klamath Rivers in the Pacific Northwest demonstrate that analysis of additional polymorphic loci can greatly enhance the ability of electrophoresis to resolve genetic differences between stocks (Utter and others 1992). In view of this result, Utter and others (1992) recommend a cautious interpretation of electrophoretic data that do not identify genetic differences between stocks that have little potential for interbreeding. Their work suggests that further analysis of existing samples from southeast Alaska stocks may detect genetic divergence where previously none had been found.

Methods

Using data up to 1991, we subdivided the 34 chinook systems designated by the ADF&G to the level of tributaries within drainage systems. This subdivision yielded 85 reported or known chinook stocks in southeast Alaska and in transboundary systems of adjoining areas of British Columbia and the Yukon Territory (table 12). Of the 85 stocks, we found at least a single element of biological data, usually escapement counts, for 70. Of these 70 stocks, 39 had data sufficient to permit their inclusion in analyses of biological variables other than escapement. We sought to identify stocks with distinctive biological characteristics from the subsample of 39 stocks. Most of the 39 stocks for which data were available were from tributaries of major systems, with large, commercially significant, returns. Only 7 of 22 minor systems were included in our analyses.

We conducted our analyses primarily on data from escapement sampling of returning adults. Limited young of the year (YOY) and smolt fork-length data also were evaluated. Eight chinook salmon stocks in the region were sampled for biological characteristics at weirs (including the Nakina carcass weir).

Data Analysis Procedures

Methods used for obtaining, analyzing, and evaluating data for chinook stocks corresponded to those presented in the "General Introduction," with minor modifications as follows. Stocks were included in variance component analysis on the basis of having at least 4 years of data on adult mid-eye-to-fork length with at least 10 individuals sampled of each sex. For evaluations of run timing, we used mean dates calculated from peak escapement surveys rather than the peak spawning dates reported by Kissner (1982) and Mecum and Kissner (1989). These measures of run timing were very strongly correlated ($r = 0.83$, $P < 0.001$), and our index based on survey dates could be calculated for a larger number of stocks. Run-timing statistics also were calculated for seven stocks enumerated at weirs (excluding the Nakina carcass weir). Our evaluation of temporal variation in sex ratios included six chinook stocks with the

⁵ Personal communication. 1996. C. Noll, fishery biologist, National Marine Fisheries Service, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801.

largest numbers of individuals sampled for length or age for the most years. Two of these six, the Cripple Creek and Tahini River stocks, were not sampled at a weir or fishwheel; therefore, more sources of sampling bias may have affected sex ratio estimates in these stocks.

Compared to other species of Pacific salmon in the region, relatively long time-series of escapement surveys are available for most chinook stocks in the region; however, the types of spawning habitats used by chinook salmon are very difficult to survey accurately for escapements. Although continuing research is refining escapement estimation procedures (e.g., Johnson and others 1992a), existing escapement survey data provided only an index of actual abundance levels. In the absence of more reliable data, we used these to compare the interannual variability of abundance and distribution of the escapement survey analysis (Olsen 1992). Trends identified from these analyses should be interpreted cautiously.

We used multivariate analysis of variance (MANOVA) to look for geographic patterns in biological characteristics of chinook stock groups. Based on patterns present in other species, we included two geographic comparisons: (1) coastal versus interior, and (2) northern versus southern stocks. Dependent variables in the complete model were adult mid-eye-to-fork length and mean saltwater age (MSWA) for both sexes, sexual dimorphism in mid-eye-to-fork length, MSWA sexual differences, and mean survey index dates. To determine which characteristics contributed the greatest effects to the complete MANOVA, we conducted post hoc analyses that included only one type of biological data (e.g., mid-eye-to-fork length variables alone). Significance tests for these analyses used the approach based on greatest characteristic roots described by Harris (1985). Samples from the mainstem Taku and Stikine Rivers were excluded from analysis because fishwheels selectively catch smaller fish. Interior stocks were defined as those that experience a more continental climate because they spawn in tributaries of the Stikine, Taku, and Alsek Rivers that are north and east of the Coast Mountains. The mouth of the Stikine River was used as the boundary between northern and southern stock groups. Stocks in these groups have different oceanic migration patterns (see footnote 4) and experience small differences in freshwater climatic regimes. Stocks that spawn in interior tributaries of the Stikine River were considered northern stocks in our analyses (see table 12).

Because insufficient data were available to include YOY fork lengths and mean migration dates and variances at weirs in MANOVA analyses, we used graphic methods to look for geographic patterns in these characteristics.

Results

Geographic Patterns

The complete model that included all dependent variables (mid-eye-to-fork length, MSWA, mean survey index date, and sexual dimorphism) was significant (Roy's maximum root F-ratio, $P = 0.04$) when both coastal-versus-interior and north-versus-south effects were included. The interaction effect could not be tested because interior stocks are not present in the southern half of the region. The coastal-versus-interior effect alone was not significant (Roy's maximum root, $P = 0.34$). Examining the contributions of separate biological characteristics to the overall difference between northern and southern stocks, we found that differences in body lengths were the strongest contributors (Roy's maximum root, $F = 10.56$, $F_{crit.} = 5.1$, $P < 0.01$), with

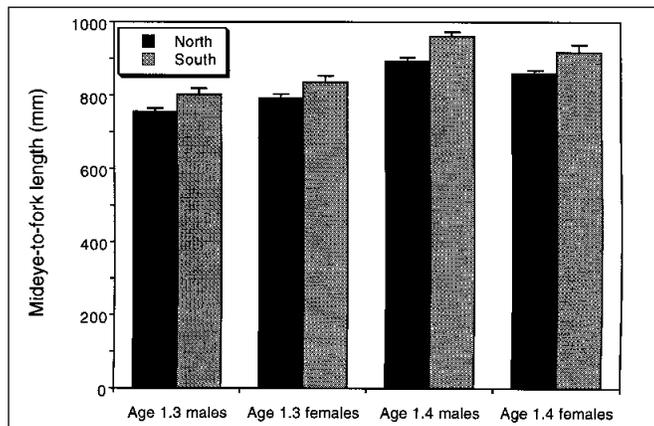


Figure 19—Mid-eye-to-fork lengths of adult chinook salmon from escapements by stock group, sex, and age class. Sample sizes were 12 and 15 for the southern and northern stock groups, respectively. Height of columns indicates grand mean for all stocks in that group across all sample years. Error bars give standard errors. See text for MANOVA results. Stock-specific length summaries are presented in table 14.

southern stocks having greater body lengths in all four age and sex classes included in the analysis (fig. 19). Southern stocks also tended to have lower MSWAs, less age difference between the sexes, and later survey index dates.

Graphic analysis of geographic patterns in chinook salmon fry (YOY) and smolt fork lengths, and mean dates of return migration and duration of return migration, showed no clear trends.

Body Length

The chinook salmon YOY in the Situk and Tahini Rivers appeared to be larger than others in southeast Alaska, based on outlier analysis of fork lengths (fig. 20). The number of stocks sampled and number of samples taken from each stock were small. We attempted to standardize the comparison of different stocks by using fork lengths measured in October, but for the Situk River, only August fork lengths were available. The mean fork length of the YOY in the Situk River in August exceeded the mean October fork lengths of other stocks in the region, indicating the ocean-type juvenile growth pattern of this stock.

Mean mid-eye-to-fork lengths showed considerable variation for all age and sex classes (table 14), but no stocks in the region had mean body lengths for any age or sex class that were outliers. Data for male and female mid-eye-to-fork length were analyzed separately because significant differences were observed between the sexes in adult body size (paired t-test: age 1.3, $P = 0.002$; age 1.4, $P = 0.0001$). Age 1.3 males, on average, were smaller than same-age females, but age 1.4 males were larger than age 1.4 females. Male and female body sizes within a stock were weakly correlated for the 1.3 age class ($r = 0.11$, $P = 0.39$) but strongly correlated for age class 1.4 ($r = 0.63$, $P < 0.001$). Three stocks showed distinctive patterns of sexual

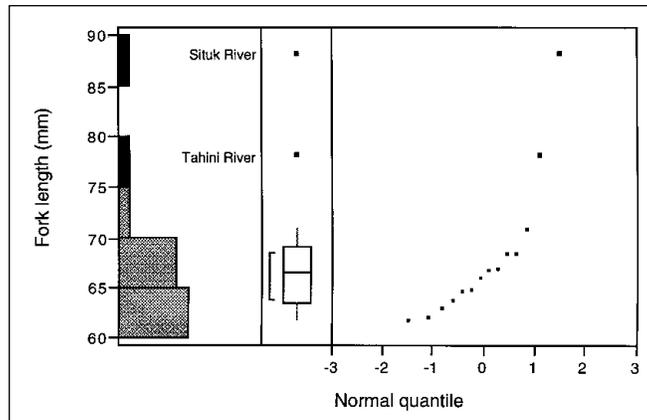


Figure 20—Frequency distribution, outlier plot, and normal quantile plot for October fork lengths of chinook salmon young of the year (YOY) from 14 stocks (Situk River lengths were measured in August). The YOY from the Situk and Tahini River stocks were distinctively large. This distribution was significantly nonnormal by the Wilks test ($P = 0.002$) but became acceptably normal ($P = 0.82$) when the Situk and Tahini points were removed.

dimorphism: Keta River, Barrier Creek, and Indian Creek (fig. 21), but this was based on small samples sizes of 31, 35, and 36 fish, respectively. In the Keta River stock, age 1.3 females were over 150 mm smaller than same-age males, contrary to the general trend in the region, but the mean mid-eye-to-fork length of age 1.3 females in Barrier Creek stock were larger than males by 146 mm. The 1.4 age class females in the Keta River stock did not contradict the prevailing pattern of dimorphism and were over 200 mm smaller than 1.4 males (fig. 21B). In contrast, the Indian Creek age 1.4 females were 31 mm larger than males, a pattern of dimorphism opposite the one prevailing among most stocks.

Variance-component analysis indicated that over 90 percent of total variation in male body length, but only 45 percent of female body length variation, were attributable to differences among individuals within the three stocks evaluated (table 15). Among females, variation among stocks accounted for 53 percent of the total variation observed, suggesting a higher level of stock-specific specialization in female chinook than in males (and considerably higher than all other species of Pacific salmon analyzed by this method). Interannual variation within stocks accounted for a small proportion of overall variance and was twice as great in males (5.6 percent) as in females (2.2 percent).

Adult body sizes of southeast Alaska chinook stocks have tended to decrease through time. Analyses were conducted separately on mid-eye-to-fork lengths of 1.3 and 1.4 age-class males and females (table 16). All regression slopes for males and half of the slopes for females were negative. Only the Cripple Creek age 1.3 males yielded a significantly negative regression ($P < 0.05$). The mean rate of decline for all sex and age classes (mean of the regression coefficients) was -4.22 mm/year. The high standard deviation (6.65) associated with this mean reflected the high variability and small number of stocks included in this analysis. Cripple Creek, Nahlin River, and Tahini River chinook salmon were the only stocks with enough years of data to analyze. These stocks had the longest series of length data available, but even these series were short (≤ 7 records).

Table 14—Summary of mean mideye-to-fork lengths (in millimeters) from chinook salmon escapement samples

Stream		Males					Females					Sexual dimorphism age classes		
		No.	Age classes					No.	Age classes					
Number	Name	No.	1.1	1.2	1.3	1.4	1.5	No.	1.2	1.3	1.4	1.5	1.3 ^a	1.4 ^b
101-30-030	Keta River	6		610.0	860.0	942.5		25		707.5	742.4		-152.5	200.1
101-55-040	Blossom River	26		752.7	853.8	950.7		24	930.0	811.3	919.0		-42.5	31.7
101-71-040	Chickamin River	77	427.0	587.1	794.7	922.0	976.0	144	760.0	843.8	924.5	939.0	49.1	-2.5
101-71-04A	Barrier Creek	24	430.0	552.5	734.5	990.0		11		880.0	943.8		145.5	46.2
101-71-04B	Butler Creek	37	375.6	610.0	788.6	943.3		44		831.0	897.5		42.4	45.8
101-71-04I	Indian Creek	18	405.0	609.0	835.0	955.0		18		851.0	986.0		16.0	-31.0
101-71-04K	South Fork	112	400.0	590.0	788.0	1,002.0		70		876.0	954.0	963.0	88.0	48.0
101-75-015	Eulachon River	100	397.1	616.1	788.3	963.4	1,070.0	127		849.3	942.6	930.0	61.0	20.8
101-75-30C	Clear Creek	144	393.0	593.1	808.1	943.8		93	861.4	922.7	980.0	53.3	21.1	
101-75-30G	Gene's Lake Creek	206	379.8	590.3	730.5	922.5		117	740.0	814.5	915.6	1,022.5	84.0	6.9
101-75-30Q	Cripple Creek	881	359.1	574.7	791.0	963.7	945.0	608	717.5	828.3	914.7	946.5	37.3	49.0
107-40-049	Harding River	16		702.9	851.4	1,030.0		9		875.0	951.7		23.6	78.3
108-70-002	Stikine River ^c	96	374.5	510.0	723.2	863.6	705.0	29	528.7	797.8	824.0		74.6	39.6
108-40-020	Andrew Creek ^d	375	356.9	540.4	701.1	859.2	905.0	282	688.0	783.9	852.5	857.2	82.8	6.7
108-80-100	Tahltan River	91	397.7	490.3	793.9	922.5		126	738.0	773.2	859.0	913.0	-20.7	63.5
108-80-120	Little Tahltan River ^d	451	362.9	501.9	766.7	903.3	897.0	533	711.6	797.2	866.6	936.3	30.5	36.7
110-14-007	Farragut River	113	599.0	569.5	768.5	941.4	983.2	39	710.0	825.6	889.1	900.4	57.1	52.3
111-17-010	King Salmon River ^d	140	455.0	604.6	753.7	892.3	890.0	119	620.0	809.9	871.6	893.2	56.2	20.7
111-32-032	Taku River ^e	1,646	371.5	529.6	737.1	841.4	972.0	881	583.1	756.0	841.4	877.8	18.9	0.0
111-32-220	Nakina River ^d	5,896	334.6	515.2	722.7	883.0	953.5	2,168	737.5	775.6	849.7	892.1	52.9	33.3
111-32-240	Kowatua Creek	776	354.3	558.8	753.8	888.7	945.0	317		785.3	867.5	900.2	31.5	21.2
111-32-254	Little Tatsamenie Lake ^d	591	349.8	567.8	747.1	870.7	981.0	288	534.7	752.1	841.0	926.0	5.0	29.7
111-32-255	Tatsamenie River	534	344.0	558.8	752.2	859.4	937.0	288	662.1	771.9	843.4	897.0	19.7	16.0
111-32-260	Hackett River ^d	108	372.1	531.0	739.0	882.5		25	691.9	776.0	858.8	886.3	37.0	23.7
111-32-270	Nahlin River	825	369.3	578.5	757.8	871.3	951.2	896	647.0	759.2	842.8	896.5	1.4	28.5
111-32-275	Tseta Creek	52	555.0	656.7	768.0	909.8		61	650.0	813.5	842.6	930.0	45.5	67.2
111-32-280	Dudidontu River	47	375.0	567.5	770.9	922.8	910.0	45		776.0	852.4		5.1	70.4
115-32-068	Tahini River ^e	610	423.2	636.0	767.6	914.4	914.0	151	670.0	842.0	893.0	960.0	74.4	21.4
182-70-010	Situk River	20		643.3	765.0	861.0		37	680.0	845.0	871.0		80.0	-10.0
Total mean			398.5	584.4	772.8	917.8	933.4		684.2	809.3	882.1	922.4	36.5	35.7
Total SE			12.3	10.8	7.5	8.7	18.8		20.4	7.9	9.4	8.8	9.7	7.5
Total CV			15.6	10.0	5.3	5.2	8.2		13.1	5.3	5.8	4.3	7,143.8	113.6

^a Age 1.3 sexual dimorphism calculated as (female - male).

^b Age 1.4 sexual dimorphism calculated as (male - female).

^c Samples primarily from fishwheels.

^d Samples primarily from a weir; Nakina River has a carcass weir.

^e Samples primarily from gill nets.

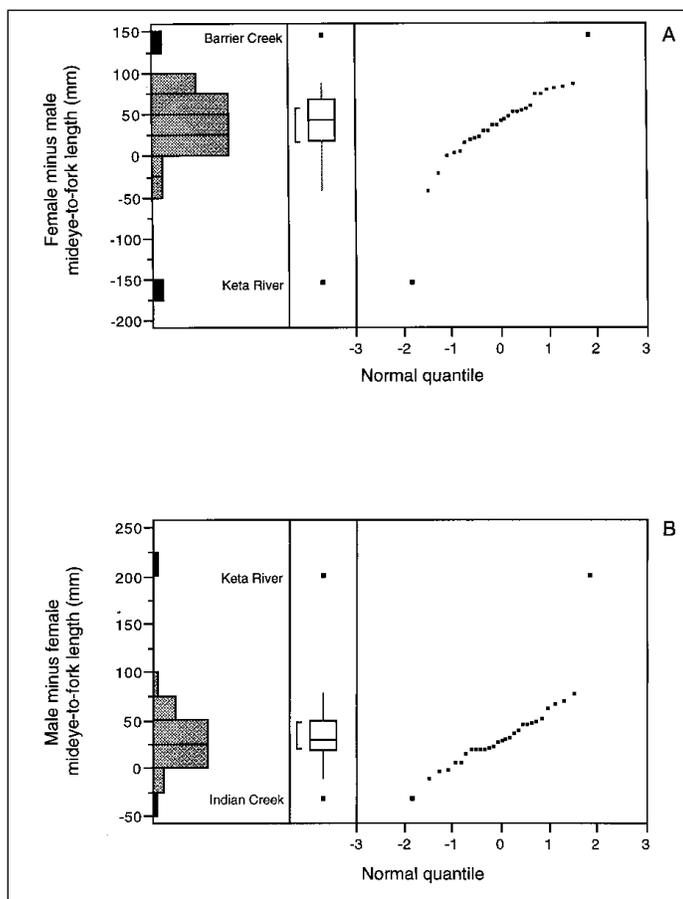


Figure 21—Frequency distributions, outlier plots, and normal quantile plots for sexual dimorphism in mid-eye-to-fork lengths of (A) age class 1.3, N = 27, and (B) age class 1.4, N = 27. Note that age 1.3 females are typically larger than males, but age 1.4 males are typically larger than females. In the Keta River stock, females in both age classes were distinctively smaller than males. Age 1.3 males from Barrier Creek were distinctively smaller than females, and age 1.4 females from Indian Creek were distinctively larger than males. Both distributions were significantly nonnormal by the Wilks test but became acceptably normal when the outliers were removed. Data are presented in table 14.

Timing

The mean date for chinook stocks to return to weirs seems to be consistent among years (McGregor and Clark 1989, 1990; Olsen 1992; Pahlke 1991a; Van Alen and Olsen 1986; Van Alen and others 1987, 1990; see footnote 6). The largest coefficient of variation (CV) for mean date at a weir was 3.77 percent for 16 years of sampling on the Klukshu River. The variances associated with these mean dates differed greatly, indicating large interannual differences in the duration of runs; CVs ranged from 25 to 112 percent. Regression analysis revealed no trends across years in run duration.

⁶ Alaska Department of Fish and Game, unpublished data. On file with: Alaska Department of Fish and Game, 802 3d Street, Douglas, AK 99824.

Table 15—Variance component analysis of age 1.3 chinook salmon mideye-to-fork lengths from escapement samples^{a,b}

Source of variation	Degrees of freedom	Type 1 sum of squares	F-test	Error term	Expected mean square	Variance component	Percentage of total
Males							
Total	804	3,633,999.5			4,519.90	4,618.32	100
Stocks	2	125,278.99	3.36	Years	62,639.49	145.25	3.15
Years	9	168,009.88	4.43	Error	18,667.76	260.32	5.64
Error	793	3,340,710.7			4,212.75	4,212.75	91.22
Females							
Total	656	2,136,977.6			3,257.59	4,325.72	100
Stocks	2	832,829.74	64.28	Years	416,414.87	2,299.66	53.16
Years	9	58,300.18	3.35	Error	6,477.80	94.51	2.18
Error	645	1,245,847.70			1,931.55	1,931.55	44.65

^a Variance components computed from means, standard errors, and sample sizes.

^b Stocks included in the analysis:

101-75-30Q Cripple Creek
 111-32-270 Nahlin River
 115-32-068 Tahini River

Table 16—Regression analyses of trends across years in mideye-to-fork lengths for chinook salmon escapement samples^a

Stream			Regression					
Number	Name	Sex	Age	No. years sampled	R-squared	Slope	P-value	Sig-nificance ^a
101-75-30Q	Cripple Creek	M	1.3	6	0.67	-16.66	0.02<P<0.05	*
		M	1.4	6	0.27	-6.45	0.2<P<0.4	NS
		F	1.3	5	0.28	2.92	0.2<P<0.4	NS
		F	1.4	6	0.09	4.17	0.5<P<0.9	NS
111-32-270	Nahlin River	M	1.3	7	0.41	-11.33	0.1<P<0.2	NS
		F	1.3	7	0.05	-3.95	0.5<P<0.9	NS
115-32-068	Tahini River	M	1.3	7	0.14	-0.86	0.4<P<0.5	NS
		M	1.4	7	0.19	-8.32	0.2<P<0.4	NS
		F	1.3	7	0.07	-3.60	0.5<P<0.9	NS
		F	1.4	7	0.13	1.91	0.4<P<0.5	NS

* = 0.05 > P > 0.01; NS = not statistically significant.

^a All samples taken from 1982 to 1990.

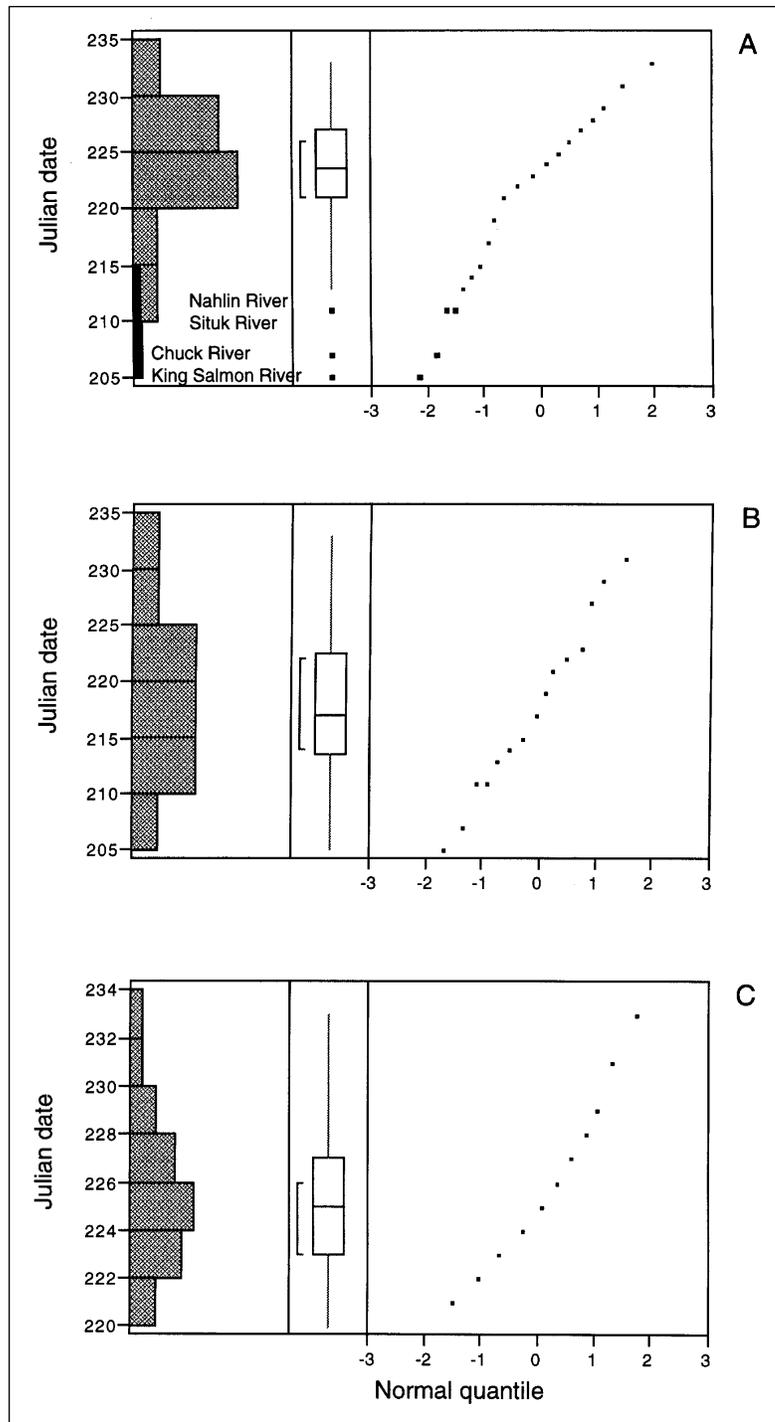


Figure 22—Frequency distributions, outlier plots, and normal quantile plots for index dates based on the timing of peak escapement survey counts. **(A)** When all stocks (N = 58) in the region were evaluated together, the stocks from the King Salmon, Chuck, Situk, and Nahlin Rivers had distinctively early run timing. When northern (panel B, N = 21) and southern (panel C, N = 37) stock groups were evaluated independently, no stocks had distinctive run timing.

The grand mean survey index date for all stocks in the region was 11 August. The grand means for northern and southern stock groups were 7 August and 14 August, respectively. Outlier analysis of index dates for all stocks combined indicated that the Chuck, Nahlin, King Salmon, and Situk River stocks had earlier run timing but not necessarily spawning time than other stocks (fig. 22A). The Nahlin River was the only interior stock in this group. Separate outlier analysis of northern and southern stock groups found no stocks with distinctive index dates (fig. 22B and C).

Demography

Geographic distribution—Of more than 85 identified stocks in southeast Alaska, chinook salmon from King Salmon River, Wheeler Creek, and Greens Creek on Admiralty Island and Carroll Creek on Revillagigedo Island were the only stocks found in island drainages. All were smaller watersheds than those used by chinook salmon in mainland systems. The small drainage of the island systems seemed to limit the size of these populations, which increases both demographic risk and potential for rapid evolutionary divergence. For example, Kissner (1975) reports that the King Salmon River stock begins to mature in salt water rather than in the river, a characteristic not found in other southeast Alaska stocks. No biological data were available for either the Wheeler or Greens Creek stocks. The population size of the Wheeler Creek stock was considered to be very small.^{7,8} The Carroll Creek stock is considered to be an introduced stock.⁹ If any native fish are present, the integrity of the wild stock is further compromised by stocking of Chickamin River fry and high straying rates of chinook from the Deer Mountain hatchery.

Escapement—Trends in escapement from 1960 to 1993 were evaluated for 59 chinook salmon stocks with more than 7 years of escapement records. The Little Tatsamenie Lake stock was the only one evaluated by weir counts. Escapement estimates from both surveys and weirs were available for five stocks. Of all stocks analyzed, 15 (25 percent) were increasing significantly and three (5 percent; North Arm Creek, Big Boulder Creek, and King Salmon River) were declining significantly (table 17). Because the 1962 count of 800 fish for North Arm Creek seemed to be anomalous, we reanalyzed the escapement trend for this stock, but excluded this count. The result of this reanalysis was a marginally nonsignificant decline ($P = 0.065$). The King Salmon River stock showed a significant decline based on weir counts (9 years) but was stable based on intensive surveys (24 years). Increasing stocks were clustered in the Boca de Quadra and in the interior tributaries of the Taku River. No stocks in the region have distinctively large escapements based on outlier analysis of mean escapement estimates.

⁷ Personal communication. 1996. M. Laker, fisheries biologist/ecologist, U.S. Department of Agriculture, Forest Service, Tongass National Forest, Admiralty National Monument, 8461 Old Dairy Road, Juneau, AK 99801.

⁸ Personal communication. 1996. A. Wertheimer, fishery biologist, National Marine Fisheries Service, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801.

⁹ Personal communication. 1996. K. Pahlke, fisheries biologist, Alaska Department of Fish and Game, 802 3d Street, Douglas, AK 99824.

Table 17—Results of regression analysis on escapement survey estimates of chinook salmon abundance from 1960 to 1993

Stream		Regression								
Number	Name	No. of survey years	Mean escapement	Slope	SE slope	Change	R-squared	Test statistic	Probability value	Trend
<i>Percent</i>										
101-30-030	Keta River	25	389.16	22.67	5.63	5.83	0.41	4.03	P<0.001	+++
101-30-060	Marten River	18	123.17	8.25	2.75	6.70	0.36	3.00	0.001<P<0.01	++
101-45-078	Carroll Creek	12	211.58	38.64	14.50	18.26	0.42	2.67	0.02<P<0.05	+
101-71-004	Chickamin River	14	371.86	47.10	9.28	12.67	0.68	5.08	P<0.001	+++
101-71-04K	King Creek	22	164.09	6.94	3.10	4.23	0.20	2.24	0.02<P<0.05	+
101-75-30C	Clear Creek-Unuk River	15	87.20	6.93	3.05	7.95	0.28	2.28	0.02<P<0.05	+
107-40-053	Bradfield River East Fork	12	129.92	13.83	4.60	10.65	0.48	3.01	0.01<P<0.02	+
108-40-010	North Arm Creek	22	109.23	-7.72	3.06	-7.06	0.24	-2.53	0.01<P<0.02	-
108-40-020	Andrews Creek	29	341.66	15.67	4.54	4.59	0.31	3.45	0.001<P<0.01	+
108-80-120	Little Tahltan River	21	1,791.86	93.60	24.17	5.22	0.44	3.87	0.001<P<0.01	++
111-32-255	Tatsamenie River	24	694.67	43.67	6.29	6.29	0.69	6.95	P<0.001	+++
111-32-270	Nahlin River	28	885.71	44.23	10.98	4.99	0.38	4.03	P<0.001	+++
111-32-275	Tseta Creek	22	199.55	7.82	2.78	3.92	0.28	2.81	0.01<P<0.02	+
111-32-280	Dudidontu River	26	295.62	16.48	5.71	5.57	0.26	2.89	0.001<P<0.01	++
115-32-054	Big Boulder Creek	20	102.15	-5.72	1.81	-5.60	0.36	-3.17	0.001<P<0.01	—
182-30-020	Klukshu River (Canada)	15	506.40	31.95	10.74	6.31	0.40	2.97	0.01<P<0.02	+
182-30-050	Blanchard Creek (Canada)	9	237.56	27.08	8.84	11.40	0.57	3.06	0.01<P<0.02	+
Systems with weirs:										
111-17-010	King Salmon River	9	262.11	-18.47	7.44	-7.04	0.47	-2.48	0.02<P<0.05	-
Total stocks analyzed		59								
Total stocks increasing significantly		15	25.0%							
Total stocks decreasing significantly ^a		3	5.0%							

+ = increasing trend with 0.05 > P > 0.01; ++ = increasing trend with 0.01 > P > 0.001; +++ = increasing trend with 0.001 > P; - = decreasing trend with 0.05 > P > 0.01; and — = decreasing trend with 0.01 > P > 0.001.

^a The King Salmon River shows no decline based on survey counts and a significant decline based on weir counts.

Age structure—Age structure of chinook escapements was evaluated in terms of MSWA and proportions of individuals in each age and sex class (table 18). Jacks were excluded from MSWA analysis because sampling effort was consistent neither among stocks nor among years within stocks (see footnote 9). Outlier analyses were conducted separately on males and females because females have significantly higher MSWAs than males (paired t-test, P < 0.001). No stocks in the region were distinctive based on outlier analysis of MSWA for either sex.

Sampling for age structure has been conducted on the Nakina and Klukshu Rivers for enough years to permit regression analysis of trends in MSWA across years. Both males and females in the Nakina River showed significant trends of increasing MSWA across years, while both sexes of the Klukshu River stock showed nonsignificant trends of decline in MSWA (table 19).

Table 18—Summary of age distributions of chinook salmon escapement samples^{a b}

Stream		Males					Females						
		Age classes					Age classes						
Number	Name	1.1	1.2	1.3	1.4	1.5	1.2	1.3	1.4	1.5			
		No.	-----Percent-----					No.	-----Percent-----				
101-30-030	Keta River	7	0	14	57	29	0	10	0	30	70	0	
101-55-040	Blossom River	28	0	43	32	25	0	24	4	50	42	0	
101-71-040	Chickamin River	77	11	17	45	23	4	144	1	31	62	5	
101-71-04A	Barrier Creek	24	4	33	42	21	0	11	0	64	36	0	
101-71-04B	Butler Creek	37	46	16	30	8	0	45	0	76	24	0	
101-71-04I	Indian Creek	18	6	44	39	11	0	18	0	61	39	0	
101-71-04K	South Fork	113	19	49	28	4	0	70	0	49	49	3	
101-75-015	Eulachon River	101	18	27	37	17	1	127	0	46	52	2	
	Unuk River drainage												
101-75-30C	Clear Creek	145	32	41	19	9	0	93	0	38	61	1	
101-75-30G	Gene's Lake Creek	208	47	34	14	4	0	119	3	56	39	2	
101-75-30Q	Cripple Creek	884	27	46	19	8	0	608	0	42	56	0	
108-70-002	Stikine River	74	19	57	12	11	1	22	18	41	41	0	
108-40-020	Andrew Creek	170	16	65	14	2	0	14	0	29	57	14	
108-80-080	Shakes Creek	23	13	13	57	13	0	26	19	62	19	0	
108-80-100	Tahltan River	14	14	7	57	21	0	24	8	75	17	0	
108-80-120	Little Tahltan River	600	11	20	27	42	1	722	1	36	60	2	
110-14-007	Farragut River	114	11	18	35	27	4	40	3	30	55	13	
111-17-010	King Salmon River	140	1	30	43	26	1	119	3	10	79	8	
111-32-032	Taku River	1,653	22	42	24	9	0	883	11	49	35	3	
111-32-220	Nakina River	43,676	37	40	16	7	0	10,832	0	38	61	1	
111-32-240	Kowatua Creek	767	19	18	34	22	3	316	0	26	69	4	
111-32-254	Little Tatsamenie Lake	542	15	30	43	9	1	251	3	63	31	2	
111-32-255	Tatsamenie River	536	24	22	30	22	1	291	7	26	69	1	
111-32-260	Hackett River	110	28	24	25	24	0	25	4	24	68	4	
111-32-270	Nahlin River	1,156	5	25	43	24	2	1,085	1	40	55	1	
111-32-275	Tseta Creek	53	2	11	43	19	0	61	2	44	38	3	
111-32-280	Dudidontu River	42	2	24	36	36	2	42	0	48	52	0	
115-32-068	Tahini River	616	4	31	49	15	1	156	0	33	61	2	
182-30-020	Klukshu River	1,330	1	20	57	22	0	967	2	77	21	0	
182-70-010	Situk River	18	0	11	6	50	0	33	0	3	67	0	
	Total mean		15.1	29.1	33.8	18.7	0.7		3.0	43.2	49.5	2.4	
	Total SE		2.5	2.7	2.6	2.1	0.2		0.9	3.4	3.1	0.7	
	Total CV		88.7	50.4	43.1	61.3	161.2		168.4	42.5	34.3	152.0	

^a Percentages may not add to 100 because rare age classes have been omitted and because of rounding.

^b Summary statistics calculated from untransformed percentages.

A high proportion of jacks was observed for many populations. Eleven stocks had 50 percent or more of male escapement samples consisting of age 1.1 and 1.2 males, including three of four stocks in the Unuk River drainage. Andrew Creek had the highest proportion of jacks (81 percent) from only 1 year of sampling. Two stocks had male age distributions dominated by age 1.1 males (Genes Lake Creek, 47 per-

Table 19—Regression analyses of trends across years in mean saltwater age of chinook salmon stocks

Stream				Regression			
Number	Name	Sex	No. years sampled	R-squared	Slope	P-value	Trend
111-32-220	Nakina River	M	19	0.21	0.006	0.05	+
		F	19	0.36	0.01	0.01	++
182-30-020	Klukshu River	M	13	0.16	-0.02	0.18	NS
		F	13	0.08	-0.02	0.33	NS

+ = increasing trend with $0.05 > P > 0.01$; ++ = increasing trend with $0.01 > P > 0.001$; and NS = not statistically significant.

cent; Butler Creek, 46 percent). Female age distributions were not strongly skewed toward younger age classes (table 18). Nonetheless, two stocks had greater than 15 percent of their average female escapement consisting of age 1.2 individuals (Shakes Creek, 19 percent; Stikine River, 18 percent).

Sex ratio—Most observations of sex ratios were from small samples often taken during short periods in the run or from observations during stream surveys. Samples taken at weirs or fishwheels are considered to be least biased but were available from only eight stocks. Tahini River samples, taken by gill net, may not be comparable to weir and foot survey samples from other stocks.

Of 30 stocks evaluated, 18 had sex ratios favoring males (table 20); however, 21 of 30 stocks had less than 50 percent males in the 1.3 and 1.4 age classes, which suggested that for those stocks having more males, the increased number was due to jacks. Four stocks had total sex ratios greater than or equal to four males for every female (Nakina River, Kowatua Creek, and Hackett River in the Taku drainage and the Tahini River in the Chilkat drainage). The skewed sex ratios also were present in Kowatua Creek and Farragut, Hackett, and Tahini River stocks when only the 1.3 and 1.4 age classes were considered. All data from Hackett River and some from Kowatua Creek were collected at weirs.

Both overall sex ratios and sex ratios of 1.3 and 1.4 age classes differed among years within stocks. For stocks sampled for several years at weirs or fishwheels, the coefficient of variation among years for sex ratio (expressed as a percentage of males) ranged from a low of 9 percent for the King Salmon River to a high of 25 percent for the Little Tahltan River (table 20). For the combined 1.3 and 1.4 age classes, the range was higher, from 17.4 percent to 29 percent for the King Salmon and Taku Rivers, respectively. Only the Nakina River stock had a data set spanning enough years to test for temporal trends in sex ratio. Although no consistent trend was apparent in the Nakina River sex ratio, available data suggested cyclic fluctuations with about a 5-year period (fig. 23).

Genetic Surveys

The most complete survey of biochemical or genetic characteristics of chinook salmon to date is by Gharrett and others (1987), who used gel electrophoresis to examine variation in 28 loci among chinook salmon from 13 drainages throughout Alaska. They examined stocks from the Unuk, Farragut, Stikine (mainstem), Little Tahltan, King Salmon, Taku (mainstem), Nakina, Nahlin, and Tahini Rivers and

Table 20—Sex ratios of chinook salmon escapement samples^a

Stream			Complete sample ^b			1.3 age class			1.4 age class			1.3 & 1.4 combined		
Number	Name	Sampling years	No.	Per-cent male	Ratio	No.	Per-cent male	Ratio	No.	Per-cent male	Ratio	No.	Per-cent male	Ratio
101-30-030	Keta River	1982, 84	31	19	1:4.26	13	23	1:3.35	17	12	1:7.33	30	18	1:4.71
101-55-040	Blossom River	1985	52	54	1:0.85	21	43	1:1.33	17	41	1:1.44	38	42	1:1.38
101-71-040	Chickamin River	1985, 89	221	35	1:1.86	79	44	1:1.27	106	16	1:5.25	185	30	1:2.33
101-71-04A	Barrier Creek	1986	35	69	1:0.45	17	59	1:0.69	9	56	1:0.79	26	58	1:0.74
101-71-04B	Butler Creek	1986, 87	82	45	1:1.22	45	24	1:3.17	14	21	1:3.76	59	23	1:3.35
101-71-04I	Indian Creek	1987	36	50	1:1.00	18	39	1:1.56	9	22	1:3.55	27	31	1:2.28
101-71-04S	Chickamin River (South Fork)	1987	183	62	1:0.61	66	48	1:1.08	39	3	1:6.70	105	31	1:2.28
101-75-015	Eulachon River	1986, 87, 89	228	44	1:1.27	96	39	1:1.56	84	21	1:3.76	180	30	1:2.33
101-75-30C	Clear Creek	1986, 87, 89	238	61	1:0.64	62	44	1:1.27	70	19	1:4.26	132	32	1:2.17
101-75-30G	Genes Lake Creek	1984-87, 89	327	64	1:0.56	97	31	1:2.23	56	16	1:5.25	153	24	1:3.17
101-75-30Q	Cripple Creek	1984-87, 89	1,492	59	1:0.69	422	39	1:1.56	412	17	1:4.88	834	28	1:2.57
108-40-015	Stikine River	1982-85	125	77	1:0.30	21	52	1:0.92	25	56	1:0.79	46	54	1:0.85
108-40-020	Andrew Creek	1982-84	657	57	1:0.75	158	50	1:1.00	284	33	1:2.03	442	42	1:1.41
108-80-080	Shakes Creek	1983	49	47	1:1.13	29	45	1:1.22	8	38	1:1.63	37	42	1:1.41
108-80-100	Tahltan River	1982-84	217	42	1:1.38	51	45	1:1.22	148	40	1:1.50	199	43	1:1.35
108-80-120	Little Tahltan River	1982-87	1,496	45	1:1.22	407	47	1:1.13	858	33	1:2.03	1,265	40	1:1.50
110-14-007	Farragut River	1983-85	154	74	1:0.35	52	77	1:0.30	53	58	1:0.72	105	68	1:0.47
111-17-010	King Salmon River	1983-87	259	54	1:0.85	72	83	1:0.20	130	28	1:2.57	202	56	1:0.80
111-32-032	Taku River	1983-87, 89, 90	2,536	65	1:0.65	826	48	1:1.08	457	32	1:2.13	1,283	42	1:1.38
111-32-220	Nakina River	1956-59, 73-81, 83-87, 89	5,450	80	1:0.25	1,115	70	1:0.43	9,516	31	1:2.23	2,066	51	1:0.96
111-32-240	Kowatua Creek	1983, 89, 90	1,083	80	1:0.25	345	76	1:0.31	387	44	1:1.27	732	59	1:0.69
111-32-254	Little Tatsamenie Lake	1985, 89	879	67	1:0.49	455	59	1:0.69	146	38	1:1.63	601	49	1:1.00
111-32-255	Tatsamenie River	1983-85	827	65	1:0.54	236	68	1:0.47	320	38	1:1.63	556	50	1:2.03
111-32-260	Hackett River	1985-86	135	81	1:0.23	33	82	1:0.22	43	60	1:0.67	76	71	1:0.41
111-32-270	Nahlin River	1983-86, 88, 89	2,241	52	1:0.92	924	53	1:0.89	882	32	1:2.13	1,806	43	1:1.35
111-32-280	Dudidontu River	1990	84	50	1:1.00	35	43	1:1.33	37	41	1:1.44	72	42	1:1.41
111-32-275	Tseta Creek	1983, 89	114	46	1:1.17	50	46	1:1.17	33	30	1:2.33	83	38	1:1.63
115-32-068	Tahini River	1983-87, 89-90	772	80	1:0.25	353	85	1:0.18	185	49	1:1.04	538	67	1:0.49
182-30-020	Klukshu River	1983, 85-87	802	47	1:1.13	543	40	1:1.50	173	48	1:1.08	716	44	1:1.27
182-70-010	Situk River	1985, 88	57	35	1:1.86	4	50	1:1.00	31	29	1:2.45	35	40	1:1.53

^a Complete sample size includes all age classes for all years.

^b Data derived from escapement age or length samples; the larger of these samples is presented here.

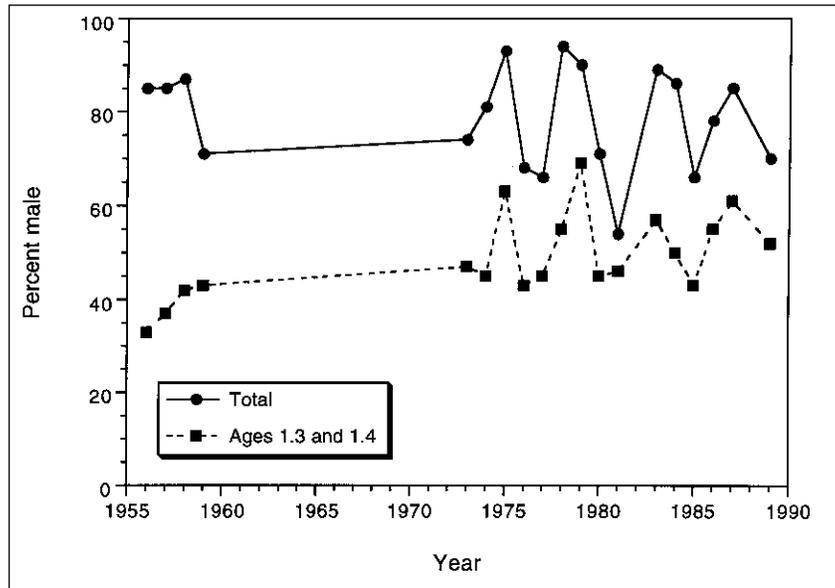


Figure 23—Temporal variation in sex ratio of the Nakina River stock, which has the longest time series in the region. Data were collected at a carcass weir. Both total sex ratio and the sex ratio of combined nonprecocious age classes appear to oscillate with a frequency of about 5 years. The causes and consequences of this apparent pattern are unknown.

Andrew and King Salmon (Taku drainage) Creeks from southeast Alaska. The stocks from southeast Alaska showed greater genetic divergence than stocks from western Alaska. The Tahini River stock was most divergent from other stocks in southeast Alaska, and based on cluster analysis, branched from stocks from southern British Columbia and Washington (Gharrett and others 1987). Significant allelic heterogeneity also was found between the Andrew Creek stock in the lower Stikine and the Little Tahltan stock in the upper Stikine, indicating that genetic divergence had occurred within the Stikine drainage (Gharrett and others 1987). No significant temporal heterogeneity was found within stocks among years.

Anecdotal Reports

Anecdotal reports about chinook stocks deal primarily with the historic presence of chinook stocks that are currently of unknown status and potentially distinctive characteristics of chinook stocks in addition to those evaluated above. Most anecdotal reports are from brief mentions of chinook stocks in unpublished reports or from discussions with fisheries biologists. Possible extinctions of chinook populations have been reported for the Muddy, Nakwasina, and Black Rivers and for Big Goose and Greens Creeks (Holland and others 1983). All these, except the Muddy River, are island drainages. Recent surveys of Greens Creek indicate that a few wild chinook have recolonized and spawned successfully in this drainage (see footnote 8). Chinook salmon were consistently counted at the USBF weir on Anan Creek from

¹⁰ Personal communication. 1996. W. Heard, program manager, National Marine Fisheries Service, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801.

¹¹ Personal communication. 1996. A. Moles, fishery biologist, National Marine Fisheries Service, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801.

1925 to 1932 (Rosier and others 1965). The mean escapement of chinook salmon during this period was 62 fish. We found no subsequent surveys or records of chinook salmon in this system. Two Alaska populations are infected with IHNV, the Situk and the Karluk River stocks.^{10 11} The Situk chinook also have been reported to have particularly red spawning coloration (see footnote 2). King Salmon River chinook return to the river in ripe condition and spawn soon after entering fresh water and may spawn in tidally influenced areas (see footnote 2).

Discussion

Northern and southern stock groups show the clearest differences in biological characteristics of chinook salmon in southeast Alaska. These groups differ most strongly in body length, but they also differ in MSWA, run timing, and oceanic migration patterns. Differences between mainland and island drainages may be important also; but data on biological characteristics of island stocks are available only from the King Salmon River. This stock has early run timing and also has the unusual characteristics of arriving at fresh water in nearly ripe condition and spawning in tidally influenced portions of the river (Kissner 1975; see footnote 2). Both characteristics are unusual for chinook salmon. If the unusual characteristics of the King Salmon River stock represent heritable responses to environmental factors found in an island drainage, then this island stock, as well as others, may represent valuable elements of genetic diversity in the region.

The chinook salmon stocks in the Yakutat Forelands, which include the Situk, Akwe, and Italo Rivers, are probably the most distinctive stocks in the region owing to the large proportion of smolts that emigrate at age-0. Chinook salmon in southeast Alaska are predominantly stream-type stocks having a small proportion of individuals that emigrate as age-0 smolts (based on readings of adult scales). Up to 98 percent of Situk smolts emigrate from fresh water in the same year as emergence occurs (Johnson and others 1992b). The chinook stock in the Deshka River in south-central Alaska is the only other Alaska population in which a large proportion of juveniles outmigrate at age-0 (Delaney and others 1982); however, in the Deshka system emigrating juveniles may rear for a year in the mainstem Susitna River (see footnote 2). Early emergence and a long growing season are the environmental factors likely enabling Situk chinook to reach a size adequate for adaptation to seawater as age-0 fish. Taylor (1990) suggests that geographic differences in "growth opportunity" drove the disruptive selection that led to the development of stream- and ocean-type life histories. Outlier analysis of YOY fork lengths indicated that Situk River YOY were distinctively large. The Situk stock was also unusual in having (1) an ocean-type juvenile life history pattern and stream-type run and spawning timing (Johnson and others 1992b), (2) endemic infection with IHNV (see footnotes 10 and 11), and (3) spawning coloration of a deeper, brighter red than the norm (see footnote 2). The presence of IHNV may be a consequence of spawning in unusually close association with large numbers of sockeye salmon, which generally carry this virus (see footnote 2). Bright red coloration is not characteristic of ocean-type stocks and may represent a specialized local adaptation of the Situk stock.

Biological and demographic data for most small populations of chinook salmon are limited, and several of these small populations are geographically isolated. Even though the economic significance of small stocks may not be large, some of their distinct characteristics, such as those of the King Salmon River stock, may represent genetic divergence from larger mainland stocks, but this is speculative at present.

Evaluation of Results

Body length—Chinook stocks from the southern region had greater body lengths than stocks in the northern region, but this result does not correspond to a general latitudinal trend throughout the range of chinook salmon in North America (Roni and Quinn 1995). Among North American stocks of chinook salmon, only the body lengths of age 1.3 males were negatively correlated with latitude, but no latitudinal trends were apparent for other age and sex classes (Roni and Quinn 1995). When population mean lengths that included all age classes were evaluated, a positive correlation between length and latitude was present for females, but no relation was apparent for males (Roni and Quinn 1995). Those authors also found significant negative relations between body size and migration distance for some age and sex classes, but this was not consistent.

The regional pattern of body lengths we observed may reflect differences in marine migration patterns and the combined influences of latitude and freshwater migration distance. Southern stocks spend more time during their ocean life in near-shore waters, which tend to be more productive but where fish may have greater risk of predation than in the Gulf of Alaska where northern interior-spawning stocks spend most of their ocean life. These factors may contribute to more rapid growth in southern stocks (in addition to greater body length, southern stocks have lower MSWAs for both sexes, which suggests that rate of growth is more rapid). Following from the hypothesized association between migration pattern and body size, if freshwater mortality rates are similar, we predict that spawner-recruit ratios in southern stocks should tend to be lower than in northern stocks that have a less “risky” marine life history. We could not investigate statistically the interaction of latitude and migration distance because all southern stocks have short coastal migrations. However, interaction effects may be important because the majority of northern stocks in our analyses spawned in interior drainages.

Differences in lengths occurred between male and female chinook but lengths of each sex were generally correlated within stocks. This relation may be a result of selection by environmental factors for certain optimal body sizes in different habitats (Taylor and McPhail 1985). Some environmental selection pressures on body size, such as migration length and stream gradient, should operate similarly for both sexes.

Sexual dimorphism during marine residence reverses between the 1.3 and 1.4 age classes; age 1.3 females are 37 mm longer than males, but age 1.4 males are 36 mm longer than females on average. The pattern of length dimorphism is consistent among most stocks in the region, as is the tendency for higher proportions of males to return at age 1.3 rather than at age 1.4. Males and females feeding in the ocean may have different size or condition thresholds that trigger the onset of maturation and return migration. Female thresholds may be higher because females produce more energetically expensive gametes than males, high fecundity is required to have any probability of successful reproduction, and female fecundity is correlated with body size. Females with slow growth that do not achieve the required threshold for return at age 1.3 remain at sea for an additional year of feeding. The growth increment achieved by these females during the additional ocean year may be less than that achieved by males owing to higher investment of energy in eggs. In combination, these factors suggest that the tradeoffs between the fitness benefits of increased

size and the risks of mortality imposed by an additional year at sea are different for age 1.3 and 1.4 male and female chinook salmon. The selective mechanisms underlying these differences are likely to include the potential for males, but not females, to pursue noncompetitive reproductive strategies and the advantages of large female body size in terms of redd construction and defense (see Healey and Heard 1984).

Variance component analysis indicated that female chinook salmon show a higher level of stock-specific variation in body length than any other species of Pacific salmon in the region. Only three stocks were included in this analysis, which raises the possibility that stocks with an unrepresentative level of divergence were included. However, results for male chinook do not support this explanation because a very low level of among stock variation was found for males. An evolutionary explanation for the observed pattern is that spawning females face stronger selection for local adaptation in body size owing to habitat characteristics affecting successful redd construction, such as substrate particle size, average scour depth, and the need to defend the redd from excavation by other females. Local adaptation in body length has occurred in about 20 generations (roughly 100 years) among several chinook salmon stocks in New Zealand descended from a common founder stock (Quinn and Unwin 1993). These authors did not evaluate male and female lengths independently, however.

The YOY fork lengths of the Situk River stock and the juvenile fork lengths of Tahini River stock (Chilkat drainage) were larger than other stocks. The YOY from the Tahini River had a mean fork length of 73.4 mm based on samples collected from early August to early October 1990, but presmolts measured in the mainstem Chilkat in April 1990 had a mean fork length of 67.4 mm (Pahlke 1991b). The 95-percent confidence intervals for both samples do not overlap. The Tahini River provides spawning habitat for about 33 percent of the total Chilkat chinook run (Johnson and others 1992a). The Kelsall River, the other major source of Chilkat smolts (54 percent of the Chilkat run), also produces large YOY (1990 mean of 70.3 mm). Because these two stocks should contribute the majority of smolts sampled in the lower Chilkat, we would not expect the mean body size of presmolts caught in the mainstem Chilkat in spring to be smaller than that of those captured during the previous fall. Other than sampling error, possible explanations include (1) Tahini and Kelsall juveniles may not have begun outmigrating and may not have been present in the mainstem Chilkat during presmolt sampling (see footnote 2), (2) a large interannual variation in juvenile growth rates (Pahlke 1991b), and (3) some part of the largest Tahini River chinook juveniles may migrate into Lynn Canal without spending a winter in fresh water. The accepted size at which juvenile chinook can tolerate seawater is 70 mm (Weisbart 1967). This speculative possibility is circumstantially supported by the genetic similarity of Chilkat chinook to ocean-type stocks in Washington (Gharrett and others 1987), but it is not supported by the physical characteristics of Tahini River YOY or by age data from returning individuals; however, Johnson and others (1992b) question the reliability of scale aging data for detecting age-0 chinook smolts.

Timing—Chinook salmon in northern latitudes tend to spawn earlier than those in southern latitudes (Healey 1991). Chinook stocks in southeast Alaska conformed to this trend. Stocks in northern southeast Alaska had a mean survey index date that was about a week earlier than stocks in southern southeast Alaska. Across the

region, peak escapement counts for chinook salmon typically occurred from the last week in July to late August. Earlier spawning may be related to water temperature and egg and embryo development time, with longer development time required in increasingly cold environments.

The low level of variation among years in mean dates of migration past weirs may be related to stable temperature regimes of larger watersheds. The influence of temperature regime on run timing is likely through incubation and development schedules of eggs (Brannon 1987). Miller and Brannon (1982) propose a general model of salmonid life history evolution that suggests temperature regimes may be responsible for ecological isolation of stocks. In accord with this model, Burger and others (1985) hypothesize that strong selection generated by predictable thermal regimes has critically adjusted timing of spawning runs in the Kenai River drainage. If the riverine habitats used for spawning by chinook salmon in southeast Alaska also have relatively low levels of interannual variation in temperature regime, then consistent thermal regimes could indirectly select for consistent run timing that optimizes timing of hatching or emergence. Time of hatching may be critical if redds are consistently at risk of flood or ice scour; late-hatching eggs suffer increased mortality because redds are disrupted before the alevins can burrow more deeply into the gravel. As do other species of Pacific salmon, chinook salmon show plasticity in development rate in response to temperature changes (Beacham and Murray 1990), but the relative amount of plasticity present among different species is not known.

Demography

Escapement—Analysis of escapement trends showed that 25 percent of all chinook stocks evaluated were increasing, but many stocks may have been depleted before 1960, the earliest date for which stock-specific escapement data were available. As a result, population estimates after 1960 may not provide a sound biological basis for evaluating historical abundance. A result that indicates no significant change from 1960 to 1993 may reflect either a healthy, stable population or a persistently depressed population. The trends for many stocks appear to be either bell- or U-shaped, but data series were too short to permit nonlinear analysis of trends. The stocks in the Blossom River and several tributaries in the Chickamin system showed pronounced bell-shaped escapement patterns.

North Arm Creek (Stikine drainage), Big Boulder Creek (Chilkat drainage), and King Salmon River were the only three stocks showing significantly declining trends. North Arm and Big Boulder stocks were represented by at least 20 years of surveys between 1960 and 1993, but because of inconsistencies among years in survey methods, timing, and distance, data quality for both systems was rated as fair. For the King Salmon River, data from 24 escapement survey counts were considered good, and yielded a stable regression outcome; 9 years of weir counts from 1983 to 1991 indicated a significant decline. Because data from weir counts are generally more reliable than data from helicopter surveys, and because of the distinctive nature of the King Salmon River stock, we considered this stock to have a significant decline. Possible causes of declines in the North Arm Creek are unknown. Potentially adverse impacts on the Big Boulder stock included hydrologic changes in the adjoining Klehini River and road-building activities, which temporarily disrupted spawning gravel (Mecum and Kissner 1989). The combination of adverse natural conditions and human-caused disturbance may have contributed to the decline of this stock. The Big Boulder stock historically has shown high variability in escapement

counts. The high variation may reflect a combination of environmental instability and the tendency of spawners to arrive in groups that have a brief residence time in this short, swift tributary (see footnote 3). Ongoing enhancement efforts in the form of fry outplants and a streamside incubation box may help to rebuild this stock. Decline in the King Salmon River stock may be associated with weir operations, including egg takes, as well as increased sport catches.

Age structure—Although age structure of chinook stocks was based on small sample sizes and inconsistent sampling methods, some general patterns were apparent. For nearly all stocks in the region, male MSWA was less than female MSWA, if age classes 1.1 and 1.2 were excluded from the analysis. Significant differences between the nonjack MSWA of males and females probably reflects differences in life-history tradeoffs, as discussed above.

For the two stocks with long-time series of age data, regression analysis did not reveal any consistent trends in MSWA across years, but decreasing size and age trends are documented for chinook salmon caught in southeast Alaska troll fisheries (Ricker 1980, 1981) and sport fisheries (Fagen 1988).

Sex ratio—Overall escapement sex ratios are expected to favor males in chinook salmon because jacks should survive better than adult females.¹² One cause of differential mortality may be selective removal by fisheries governed by a minimum total length limit, such as the 28-inch (about 700-mm) limit for southeast Alaska commercial troll, terminal gill-net, and sport fisheries. The effects and importance of this artificial selection on sex ratios are unknown because the sex ratio of fish caught in commercial and sport fisheries is not known, and the effects of size-selective fisheries on populations often are not straightforward (see Miller and Kapuscinski 1994).

Differential mortality associated with differing maturation patterns cannot account for male-biased sex ratios in specific nonprecocious age classes. The sex ratio of age 1.3 and 1.4 individuals from escapements was strongly biased in favor of males in the Farragut River, Hackett River, Kowatua Creek, and Tahini River in northern southeast Alaska. These uneven sex ratios may be the result of biased sampling procedures (see footnotes 2 and 9). For example, estimates derived from “carcass weirs” that capture moribund fish drifting downstream tend to be biased toward males (McPherson and others 1997).

Holtby and Healey (1990) propose that male-biased sex ratios in salmonid populations may be the result of increased susceptibility of females to predation. Holtby and Healey (1990) suggest that differential female mortality for coho salmon is a consequence of more risky foraging tactics necessitated by sex-specific constraints on reproductive size. Fishing mortality also may contribute to biases in age-specific escapement sex ratios, but the relation between susceptibility to natural predation and susceptibility to fisheries is unclear.

¹² Personal communication. 1996. D. Eggers, chief fisheries scientist, Alaska Department of Fish and Game, 1255 W. 8th Street, Juneau, AK 99801.

Fecundity—In general, chinook are characterized by high levels of variation in fecundity at both intrapopulation and interpopulation levels (Healey and Heard 1984), but few data were available for stocks from southeast Alaska. The data available for southeast Alaska stocks agreed with the overall positive relation between fecundity and latitude plotted by Healey (1991). This relation reflects the generally higher fecundity of stream-type stocks relative to ocean-type stocks.

Several important aspects of chinook life history were identified through anecdotal reports; presence and prevalence of parasites, spawning behavior, freshwater rearing ecology, ocean distribution, straying patterns, and flesh color could not be reviewed at a stock-specific level because of a lack of information. Although these observations could be useful for identifying distinctive stocks, they have not been examined systematically to determine their significance to the freshwater ecology and evolutionary biology of chinook stocks.

Conceptual Issues

Decreasing body size and age—Decreasing body size and an increase in the number of jacks may be interrelated, and these two characteristics may have genetic and evolutionary consequences. Decreasing size and age may be the result of increasing exploitation rates. Using data from the southeast Alaska troll fishery, Ricker (1980) found a significant decrease in weight of chinook ($r = -0.560$, $P < 0.05$, yielding a mean rate of decrease of 0.14 kg/yr) between 1960 and 1974. Ricker evaluates a series of alternative hypotheses for this decline and argues that artificial selection by fisheries, especially troll fisheries, changed the genetic basis for maturation of chinook at older ages, which results in an earlier maturation and a reduction in adult size. Intense artificial selection in past decades, especially by gill nets targeting large fish, may have changed the equilibrium ratios of jack- and adult-type spawners in many of southeast Alaska's chinook stocks (see Gross 1991; Kissner 1975, 1976). Ongoing low levels of artificial selection may be sufficient to maintain these altered age-structure equilibria, thereby counteracting natural selection favoring preexploitation ratios.

Because some southeast Alaska chinook stocks may spend long periods of their ocean life in near-shore waters, they are susceptible to fisheries for extended times. No accurate estimates of exploitation rates of chinook in southeast Alaska are available for years before the current rebuilding program. Since the mid-1970s, exploitation rates on chinook stocks from southeast Alaska have typically been less than 40 percent, although exploitation estimates for some stocks from southern southeast Alaska have occasionally been as high as 69 percent (Pahlke and Mecum 1990). The results of our regression analyses indicated that a trend toward decreasing size may be occurring in several southeast Alaska stocks, but only one stock showed a significant trend (Cripple Creek, a Unuk River stock that may spend extended periods in coastal waters). Our analyses were conducted on short time-series, and all data were collected subsequent to the rebuilding program that represented a relaxation of artificial selection from fisheries. Fagen (1988), using more extensive datasets and more sophisticated analytical techniques, also found declining trends in chinook body size in two of four southeast Alaska sport fisheries.

In southeast Alaska, high rates of jacks occur in many stocks (Hard and others 1985, Kissner 1975). Experimental crosses of chinook salmon from the Elk River hatchery in Oregon demonstrated high heritability of age of maturity in this stock, (estimates of heritability [h^2] ranged from 0.49 to 0.57 for males and 0.39 to 0.41 for females;

Hankin and others 1993). Hankin and others (1993) tentatively propose that the heritable mechanism underlying variation in age at maturity is variation in minimum threshold sizes necessary to trigger maturation. Wild populations of chinook salmon introduced to New Zealand have diverged in age at maturity, both among and within drainages, in roughly 20 generations, indicating relatively rapid response to environmental selection pressures (Quinn and Unwin 1993). Thus, increases in the proportion of jacks in a population also could contribute to size declines in all age classes by reducing the frequency in the population of alleles that contribute to larger size thresholds for maturation.

The biological significance of declining body size and increasing numbers of jacks may lie in their effects on reproductive success (Roni and Quinn 1995). In coho salmon, there is a positive correlation between female body size and redd depth (van den Berghe and Gross 1984). Redd depth may be locally adjusted by selection imposed by redd superimposition or scouring from floods (Hankin and McKelvey 1985), and smaller body sizes could lead to higher egg losses. In chum salmon, a strong positive relation exists between adult body size and survival of juveniles (Helle 1979). Although no comparable data are available for chinook salmon, the possibility of a similar relation may exist for chinook. If this is the case, then the decline in adult chinook body size may decrease reproductive success.

Increased proportions of jacks also may have consequences in mate selection and productivity. Baxter (1991) found that larger male chinook salmon have greater spawning success than small males, and that female chinook salmon display significantly more courting behavior to equal-sized or larger males and more aggressive behavior toward smaller males. In three other studies investigating patterns of mate selection in Pacific salmon, one each for sockeye (Hanson and Smith 1967), chum (Schroder 1981), and pink salmon (Keenleyside and Dupuis 1988), spawning females preferred to mate with males of similar or larger body size. In chum salmon, redd construction by females was prolonged when males were smaller than females (Schroder 1981). Females also might express their preference in the number of eggs laid in a spawning bout (Brown 1981). A net decline in productivity of a population could result from female spawning with less preferred males, but female mate-choice behavior may select for large body size, counteracting artificial selection by fisheries that favors small body size (Baxter 1991).

Precocious parr—The occurrence of precocious parr has been reported for the Nahlin River stock, a headwater tributary of the Taku River¹³ (also see footnote 2). These fish were less than 100 mm in fork length and expressed milt when handled for tagging purposes. The occurrence of this form of extremely precocious maturation has been documented previously in stream-type stocks in headwater tributaries (Burck 1967, Foote and others 1991, Gebhards 1960, Rich 1920, Robertson 1957, Taylor 1989). Fifty-six percent of hatchery-reared chinook salmon from the Nicola River (British Columbia) matured as parr (Foote and others 1991). Taylor (1989) raised juvenile chinook salmon from several British Columbia stocks in a common laboratory environment and found that stocks that spawned in interior drainages showed a higher propensity for precocious maturation than coastal stocks, suggesting a genetic component to this trait.

¹³ Personal communication. 1996. L. Shaul, fisheries biologist, Alaska Department of Fish and Game, 802 3d Street, Douglas, AK 99824.

Maturing parr had more rapid rates of overall weight gain in early spring than nonmaturing fish, but this pattern reversed in late spring when the precocious parr began to show a rapid increase in gonad weight (Foote and others 1991). Gonad weight of precocious males in July accounted for 8 percent of average body weight, compared to 0.005 percent for nonmaturing males (Foote and others 1991). Furthermore, precocious parr showed declining seawater adaptability during spring when nonmaturing individuals were reaching the peak of their seawater tolerance (Foote and others 1991), but experiments were not continued to determine if precocious parr regained their ability to adapt to seawater. Gebhards (1960) suggested that precocious parr in an Idaho population emigrated to sea the year after achieving sexual maturity. In Atlantic salmon, some precocious parr reabsorb gonadal tissue and migrate to sea the year after initial maturation and later return as full-sized adults (Lundqvist and others 1988). Chinook salmon are semelparous, however, and Kissner (see footnote 2) has noted dead precocious parr during spawning ground surveys of the Nahlin River. The high proportion of body weight devoted to gonads and low adaptability to seawater of chinook precocious parr suggest these individuals probably never go to sea. The proportion of males in the Nahlin stock that mature as precocious parr, their contribution to reproduction, and the proportion of other stocks in southeast Alaska in which this maturation pattern occurs are unknown.

Risk Factors

Relative to other species of Pacific salmon in the region, the large body size, small population size, and restricted habitat-use characteristics of chinook salmon render them more susceptible to endangerment or local extinction. In the Pacific Northwest, 64 populations of chinook salmon are considered at risk of extinction, more than any other species (Nehlsen and others 1991). From the perspective of managing chinook salmon diversity in southeast Alaska, a risk for minor chinook stocks in the region is a general lack of information. Some of these small populations have highly variable escapements and are subject to exploitation in mixed-stock fisheries. These populations, when faced with additional factors that generally reduce survival rates, such as declining ocean productivity, may suffer disproportionately severe declines in abundance. Because the status of some of these populations is not monitored regularly, declines could go unnoticed for several years, thereby increasing the probability that stochastic events could extirpate these small stocks. In southeast Alaska, the lack of human disturbance in most watersheds that support chinook salmon provides a margin of safety.

Habitat Factors

Thermal regimes, silt loads, and flood intensity of rivers may be the most significant habitat features affecting chinook salmon productivity. The thermal environment of spawning areas may play an important role in the local adaptation of Pacific salmon stocks (Burger and others 1985, Miller and Brannon 1982, Taylor 1990). Changes to thermal regimes may alter development and fry emergence times, which in turn may adversely affect fry survival (Burger and others 1985). Increased water temperatures also can contribute to rapid progression of infections and higher than average mortality rates from disease (Fryer and Pilcher 1974). Increased siltation may reduce pool depths and fill interstitial spaces in gravel, which will reduce both living space and invertebrate production. Hillman and others (1987) found significantly higher densities of juvenile chinook in areas where cobble substrate was added to a streambed heavily embedded with fine sediment. Lloyd and others (1987) review the generally negative effects of increasing turbidity, which is correlated with suspended sediments, on all life history stages of salmonids in Alaska waters. Rapid siltation from natural processes has changed the structure of Dry Bay in recent decades (Gmelch 1982).

These changes may have reduced the capacity of the lower Alsek and Dry Bay to serve as rearing habitat for juvenile chinook (Mecum and Kissner 1989). Floods can have both positive and negative effects on salmon habitats. Negative effects include scouring spawning gravels and creating debris jams that can impede salmon migration, while benefits can include the creation of new rearing or overwintering habitat (Swanston 1991). Few debris jams are actual blocks to migration and more often contribute to habitat complexity and increase rearing habitat (Bisson and others 1987).

Landslides can be of natural origin or the result of management activities (i.e., road failure, logging) and move inorganic (sediment) and organic material into rivers and streams. Obvious negative effects include increased siltation and, in extreme cases, blocks to migration. Both the Dudidontu River in the Taku drainage and the Little Tahltan River in the Stikine drainage have experienced serious blockages from landslides in the last 30 years. Both blockages cleared and chinook populations recovered, but recovery depended on downstream recruitment or recruitment from subbasins within the larger watersheds. In smaller watersheds, such as the King Salmon River, the consequences of a blockage from a landslide, either natural or human-caused, may be more severe and threaten the existence of the stock.

At various points during the Pleistocene, glaciers blocked large rivers in Alaska, and about 10,000 years BP, the Copper River was blocked by a glacier (Ferrians and Nichols 1955). More recently, the Hubbard Glacier has had the potential to dam Russell Fjord, which would inundate the present Situk River basin and dramatically alter the physical characteristics of the river (Thedinga and others 1993). Although the actual effects are mostly speculative, the changes likely would reduce the area of spawning and rearing habitat (Thedinga and others 1993). These changes would alter the demographic structure of the chinook population in the Situk River basin. Glacial movements that could block the main channels of the Taku and Alsek Rivers also represent potential risk factors to the many chinook salmon populations in those drainages.

Logging and mining are the human activities having the most widespread potential for adversely affecting temperature regimes, silt loads, and flood intensity of habitats used by chinook salmon in the region. The effects on aquatic environments are reviewed by Chamberlin and others (1991), Meehan (1991), and Nelson and others (1991). Anecdotal reports suggest that aggressive logging in the Bradfield River drainage during the 1950s may have contributed to a temporary decline in chinook stocks in this drainage.¹⁴¹⁵ Illegal fishing practices also may have been a contributing factor¹⁶ (Moberly and Kaill 1977).

¹⁴ Personal communication. 1996. F. Everest, research fisheries biologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; located at Tongass-Chatham Area, 204 Siginaka Way, Sitka, AK 99835.

¹⁵ Personal communication. 1996. C. Casipit, regional fisheries program leader, U.S. Department of Agriculture, Forest Service, Tongass National Forest, Regional Office, P.O. Box 21628, Juneau, AK 99801.

¹⁶ Personal communication. 1996. A. Kimbell, forest supervisor, U.S. Department of Agriculture, Forest Service, Tongass National Forest, Stikine Area, P.O. Box 309, Petersburg, AK 99833.

Fishing Pressure

Chinook salmon have high economic value in both commercial and sport fisheries, which tend to be mixed-stock fisheries in southeast Alaska. The economic value of chinook to the commercial fishery and their popularity in the sport fishery creates a high demand that can lead to overexploitation, particularly for stocks with small escapements, such as those in King Salmon River on Admiralty Island, in mixed-stock fisheries. Since 1985, all-gear catch ceilings have been regulated by the US/Canada Pacific Salmon Treaty, and escapement goals have been set by ADF&G as part of their program to rebuild chinook salmon stocks. The result has been exploitation rates on the major index streams that range from 10 to 24 percent for the Unuk River to 40 to 65 percent for the Situk River stocks (Pahlke 1995; see footnote 9). Although these studies address larger and more economically important stocks, smaller runs are assumed to follow the same patterns of exploitation.

Migration pathways and marine residence patterns can affect exploitation rates. Stocks exposed to both sport and commercial fisheries for prolonged periods, such as those in southern southeast Alaska, have an increased potential for overexploitation. The greatest potential risk is to small stocks, which are neither monitored nor consistently sampled. These stocks may require stock-specific protective measures or enhancement programs.

Overexploitation risks posed by enhancement activities for chinook salmon result primarily from having hatcheries and release sites along the migration pathways of wild stocks. The hatchery add-on provision, which allows ceilings on the annual allowable catch imposed by the Pacific Salmon Treaty to be exceeded by harvesting fish produced through enhancement activities (Denton and Holland 1986), may be a possible risk factor, if hatchery fish are not readily identified in the fishery.

Conclusions

About 85 chinook salmon stocks in the region occur in large river habitats in mainland drainages. All but the Situk River and Yakutat Foreland stocks have stream-type life histories. The Situk River is small and its chinook salmon stock has an ocean-type juvenile rearing life history but stream-type adult migration and spawning timing. Currently only three wild stocks occur in island drainages, and these are found on north Admiralty Island (Wheeler and Greens Creeks and King Salmon River). The Carroll Creek stock on Revillagigedo Island was established through stocking. Island populations tend to be small. The largest chinook salmon stocks spawn in interior clearwater tributaries of the Stikine, Taku, and Alsek Rivers.

Analyses of biological characteristics were based on a sample of 32 stocks from major and medium producing drainages and 7 stocks from smaller producing drainages. Thirty stocks were represented by samples of adult lengths and ages, and 58 stocks had adult migration timing indices. The group of chinook stocks found south of the Stikine River had greater mid-eye-to-fork lengths, lower MSWA, and later run-timing index dates than the group of stocks from northern southeast Alaska. Variance-component analysis indicated that over 90 percent of total variation in male body length, but only 45 percent of female body length variation, was attributable to differences among individuals within the three stocks evaluated. Among females, variation among stocks accounted for 53 percent of the total variation observed, thereby suggesting a higher level of stock-specific specialization in female chinook than in any other species of Pacific salmon analyzed by this method. Adult body sizes of southeast Alaska chinook stocks have tended to decrease through time.

Run-timing statistics from weirs indicated that chinook stocks are generally consistent among years in mean date of return, another unusual characteristic among species of Pacific salmon in the region. Several stocks in the region seemed to have high proportions of jacks or few females in escapements, but these results may have been artifacts of biased sampling. Tagging returns indicated that some stocks from the Chickamin and Unuk Rivers in the south, Andrew Creek in the Stikine watershed, and King Salmon and Chilkat Rivers in the north may spend prolonged periods of their ocean life in near-shore waters (see footnote 4).

The following stocks had distinctive characteristics based on the most reliable data (see fig. 24 for approximate locations):

- Situk River (and Yakutat Foreland rivers)—Ocean-type juvenile life history (Johnson and others 1992b), and early-run timing; also the only stock in the region infected with IHNV. Anecdotal reports of unusual spawning coloration. Potentially threatened by flooding from Russel Fjord.
- King Salmon River—Inhabits an island drainage and has distinctively early run timing. Anecdotal reports that this stock enters fresh water in ripe condition and that some spawning occurs in tidally influenced areas.
- Wheeler and Greens Creeks—Not well studied, but inhabit island drainages.
- Tahini River—Unusual allozyme frequencies indicating a relation with chinook stocks from southern British Columbia and Washington. Limited data suggest this stock produces distinctively large YOY and that this stock may feed for prolonged periods in Lynn Canal and Icy Strait.

The following stocks showed distinctive characteristics based on limited sampling. These results should be considered preliminary:

- Keta River—Unusual pattern of sexual dimorphism based on small samples.
- Barrier Creek—Extreme level of sexual dimorphism in age 1.3 individuals.
- Indian Creek (Chickamin River)—Extreme level of sexual dimorphism in age 1.4 individuals.
- Chuck River—Early run timing (based on index dates) at the regional level, but not distinctive within the northern stock group.
- Nahlin River—Early run timing (based on index dates) at the regional level, but not distinctive within the northern stock group.

Escapement survey estimates of abundance were made from 59 stocks. Of the 59 stocks analyzed for escapement trends, 15 (25 percent) were increasing significantly and 3 (5 percent; North Arm Creek, Big Boulder Creek, and King Salmon River) were declining significantly (see fig. 25 for approximate geographic locations). The apparent decline in the North Arm Creek stock may have been the result of an erroneously high count in 1962. The King Salmon River stock showed a significant decline based on weir counts but was stable based on surveys. Increasing stocks were clustered in the Boca de Quadra and in the Taku River drainage. Available data indicated that the status of chinook stocks in the region is generally stable or increasing. Historical levels of abundance are not well known, however, and anecdotal reports suggest that as many as four small stocks may have been extirpated.

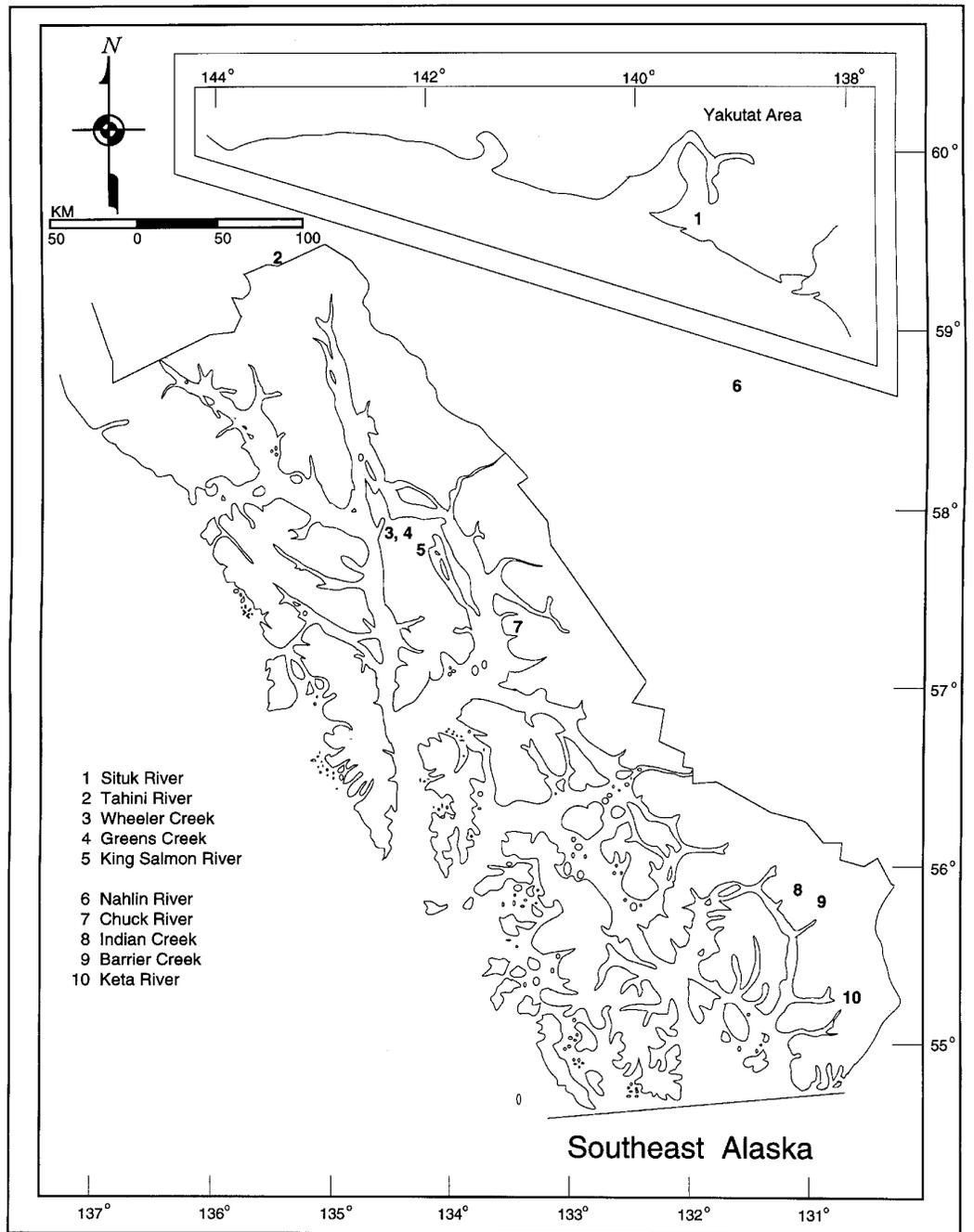


Figure 24—Approximate geographic locations in the study area of chinook salmon stocks that have distinctive characteristics. Stocks 1 through 5 were considered to have distinctive characteristics based on relatively reliable data. The distinctive nature of characteristics of stocks 6 through 10 were detected based on limited samples and data should be considered preliminary. The Nahlin and Chuck Rivers have distinctive run timing at the regional level but not within the northern stock group.

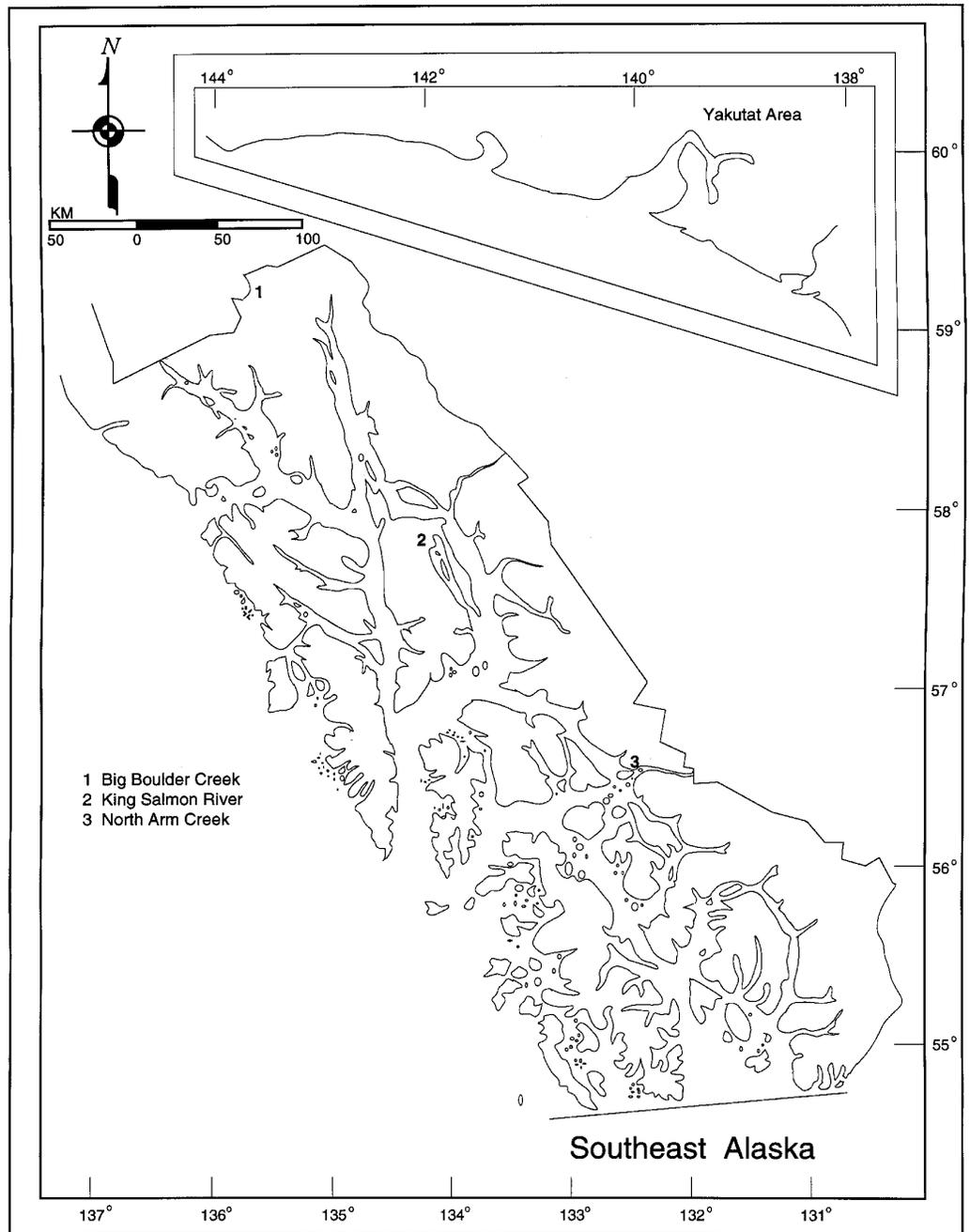


Figure 25—Approximate geographic locations in the study area of chinook stocks that have significantly declining escapement trends.

In comparison to stocks elsewhere in the Pacific Northwest, chinook stocks in southeast Alaska do not face serious risks so long as pristine habitats are maintained and conservative harvest strategies are pursued. Increasing human populations will increase habitat disruption and pressure to harvest more fish; overexploitation is a potential risk. Overexploitation could result from a combination of factors, including (1) lack of adequate information about population dynamics leading to management uncertainty about sustainable catch levels, (2) rapid and unpredictable growth of sport fisheries that complicates management and could exacerbate allocation conflicts among gear groups, and (3) interception of wild stocks mixed with hatchery returns. Natural risk factors include glacial advances and major landslides that may block large river systems. Such events have occurred in the recent (10,000 years) geological past, but stocks have repopulated areas under natural conditions. Recovery depends on adjacent stocks and long time intervals.

Acknowledgments

R. Armstong, H. Jaenicke, C. Riley, and G. Snyder provided helpful suggestions and supported this project in its early stages. G. Karcz Alexander, G. Gunstrom, M. Harris, and R. Johnson supplied ADF&G documents that were the foundation of this report. Information retrieval from various sources was facilitated by R. Betit, P. DeSloover, L. Erbs, P. Johnson, and L. Petershoare. L. Talley and S. Johnson retrieved essential data from the ADF&G Integrated Fisheries Database. D. Eggers, A. Gharrett, W. Heard, R. Medel, J. Seeb, V. Starostka, P. Sucanek, A. Wertheimer, and B. Wright shared their insights and expertise, which greatly enhanced this report. J.H. Clark's review of an early draft led to significant revisions of this manuscript and a more refined approach to the project. S. Marshall provided access to the vast information resources of the ADF&G and criticism that helped to sharpen our focus. We are especially grateful to P. Kissner, K. Pahlke, and S. McPherson who reviewed, and improved, early drafts of this manuscript, contributed unpublished data, and offered many ideas and insights based on their experience studying chinook salmon.

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Sockeye Salmon (*Oncorhynchus nerka*)

Abstract

We reviewed patterns of intraspecific variation in the biological characteristics of 85 sockeye salmon (*Oncorhynchus nerka*) stocks sampled from the roughly 200 stocks present in southeast Alaska and adjacent areas of British Columbia and the Yukon Territory. Escapement trends were evaluated for 107 stocks. Most stocks in the region had lake-type life histories, but 24 stocks also showed either river- or sea-type life history patterns. Fourteen sockeye salmon stocks (16.5 percent) had distinctive characteristics based on comparatively good data. This high proportion of distinctive sockeye stocks, relative to other species reviewed, may reflect reduced gene flow, high phenotypic plasticity, or more thorough sampling. Sixteen additional stocks may have unusual characteristics based on limited sampling (10) or anecdotal reports (6). Three stocks also have unusual allozyme frequencies. Most stocks in the region have stable escapement trends, with 4 percent (4 stocks) showing significant increases, and 7.5 percent (8 stocks) showing significant declines from 1960 to 1992. Risk factors for sockeye salmon include lack of information about small stocks and the possibility that the high commercial value of this species may promote enhancement of fisheries programs that are detrimental to wild stocks.

Keywords: Sockeye salmon, *Oncorhynchus nerka*, southeast Alaska, age distribution, run timing, body size, sexual selection, intraspecific diversity, population status.

Introduction

The available data for the sockeye salmon stocks in southeast Alaska stocks were used to identify patterns of intraspecific variation, stocks with distinctive characteristics, and trends in stock abundance. More than 200 sockeye salmon stocks occur in southeast Alaska, including 31 that spawn in Canadian waters. Escapement-index data were available for 97 stocks and biological data for 85 stocks. This database, assembled for management purposes, was more comprehensive than those available for other Pacific salmon species in the region. Sockeye salmon displayed considerable variation in all biological variables evaluated.

Life History

Sockeye salmon are able to exploit a broad range of habitat types. They typically spawn in rivers or streams associated with lakes, or sometimes along lake shores. About 70 percent of the sockeye populations we reviewed spawned in areas with lakes. They usually spend 1 to 3 years in lakes as juveniles (lake-type), but some rear for a short period (1 to 2 months) in rivers and estuaries and then migrate to the

ocean (sea-type). Sea-type individuals that emigrate without overwintering in fresh water do not develop a freshwater annulus on their scales (often referred to as “zero-check”). A few river-type sockeye spawn in rivers and streams without lakes and rear in the river (Wood and others 1987). In the Taku River, 55 percent of mainstem fish spawned in side-channel habitats. A smaller percentage spawned in slough and tributary habitats (Eiler and others 1992). In all habitats, areas of upwelling groundwater are preferred for spawning (Foerster 1968, Lorenz and Eiler 1989).

Most sockeye stocks in southeast Alaska are lake-type fish and most juveniles rear in lakes for 1 year, with a smaller proportion spending 2 years in fresh water before smolting. Few individuals of any stock remain in fresh water for 3 years. Several stocks in southeast Alaska either rear in rivers or migrate as zero-check fish. These stocks include mainstem spawners in the Stikine, Taku, Lace-Gilkey, and Chilkat drainages and several stocks in the Yakutat region, of which the largest is from the East Alsek River. Fry from river-type stocks that overwinter in fresh water typically rear in sloughs, off-channel pools, beaver ponds, or tributaries to the main river where spawning occurs (Heifetz and others 1987, McPherson and others 1990). Sea-type sockeye often rear in estuarine habitats where warmer temperatures and abundant food contribute to rapid growth (Birtwell and others 1987).

Most sockeye salmon return to near-shore marine waters of southeast Alaska in June and July. Mean dates of freshwater migration usually are from late July through early to mid-August. No pattern of latitudinal variation in run timing is apparent in the region. Spawning typically occurs in August and September but is known to continue until as late as March in some systems (McPherson and others 1990). Systematic data on time of spawning were not available for most southeast Alaska stocks. Stream temperature, which can vary considerably over a local area, is likely to have a strong influence on time of migration (Brannon 1987).

Surveys of genetic differentiation among populations of sockeye salmon indicate great precision in homing behavior in this species (Varnavskaya and others 1994). Subpopulations within lake systems often show significant genetic heterogeneity: the greatest differentiation is associated with run timing and spawning habitat (Varnavskaya and others 1994). These genetic results are supported by tagging and parasite-prevalence studies (Quinn and others 1987), as well as studies of spawning-site selection (Hendry and others 1995).

The incubation period for sockeye salmon eggs varies widely, depending on water temperature (Burgner 1991). For most southeast Alaska stocks, eggs overwinter in the gravel, and hatching and emergence occur in spring. Timing of emergence generally coincides with the onset of spring zooplankton blooms in the lacustrine rearing habitat (Godin 1982).

Smolt emigration timing for sockeye stocks is not well studied in southeast Alaska. Like most other life history characteristics of sockeye salmon, existing data indicate emigration timing is highly variable. In the Naha River, emigration historically occurred in late May and early June (Chamberlain 1907). Emigration from Chilkat and Chilkoat Lakes typically occurred in June (Bergander 1988). Emigration of smolts from the Stikine River is completed before the end of May (Wood and others 1987), while emigration of Taku River sockeye smolts peaked in June (Meehan and

Siniff 1962), but zero-check fish emigrated about 1 month later (Murphy and others 1989). In contrast, zero-check sockeye were found in the estuary of the Situk River from April to July, and age 1.x and 2.x smolts were present only in May and June (Heifetz and others 1989). Mean body size of smolts at the time of emigration also is highly variable. The fork length of most sockeye salmon smolt from southeast Alaska ranges from 60 to 120 mm.

Sockeye salmon from southeast Alaska stocks typically spend 2 to 3 years in salt water before returning to fresh water to spawn. After leaving inshore waters, they migrate in a generally northwesterly direction (Burgner 1991). No stock-specific information on oceanic migration is available. Generalized models of oceanic distribution suggest that southeast Alaska sockeye undertake circular annual migrations in the Gulf of Alaska north of about 46° N. lat. (Burgner 1991). Return migrations generally follow a reverse direction, but some stocks on the outer coast appear to return directly from the open ocean rather than follow the coastline south (Hoffman and others 1984). Migration through inside waters tends to be relatively direct, although exceptions to this pattern are known to occur. For example, some southern stocks migrate south to Dixon Entrance before returning north through Clarence Strait to mainland spawning areas (Hoffman 1987, Hoffman and others 1984).

The body length of returning adult sockeye differs significantly by sex, but no general geographic or temporal trends in body length or weight are apparent. Throughout southeast Alaska, the mean mid-eye-to-fork length of age 1.3 males in escapements is 577 mm, and the mean length of females is 556 mm (paired t-test, N = 77 stocks, $t = -16.24$, $P < 0.001$). Estimates of mean body weights of commercially harvested sockeye salmon in southeast Alaska from 1958 to 1985 differ considerably but not consistently in any direction (Marshall and Quinn 1988). Sex-specific body-weight data for commercially caught sockeye salmon are not available.

The age structure of sockeye runs typically changes during the season, particularly in large returns with prolonged run timing. Fish with higher freshwater ages (2.x) and lower saltwater ages (x.2) tend to return later in runs (McGregor and others 1991, McPherson and McGregor 1986, McPherson and others 1990). The river- and sea-type stocks in both the Stikine and Taku Rivers increase in proportional abundance late in both runs (Jensen and Frank 1989, McGregor and Jones 1989). The abundance of precociously maturing males (jacks) also tends to increase later in runs (McGregor and Jones 1989).

Jacks are present in most sockeye stocks, but the relative abundance of jacks is generally unknown, because they are small and difficult to capture and sample proportionately. In 1982, the highest proportion of jacks reported for any system where fish were sampled at a weir was 1.42 percent (Salmon Bay Lake). Where sampling was conducted with beach seines or by carcass collection, 10 systems had more than 10 percent jacks in the sample, with a maximum of 45.2 percent jacks in Petersburg Lake (McGregor 1983). Jacks dominated escapements to Klawock and Kutlaku Lakes in 1990,¹ and fishwheel catches on the Taku River in 1988 and 1989 consisted

¹ McPherson, S.A.; Rowse, M.L. 1992. Abundance, age, sex, and size of sockeye salmon catches and escapements in southeast Alaska in 1990. 53 p. Unpublished report. On file with: USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 2770 Sherwood Lane, Juneau, AK 99801.

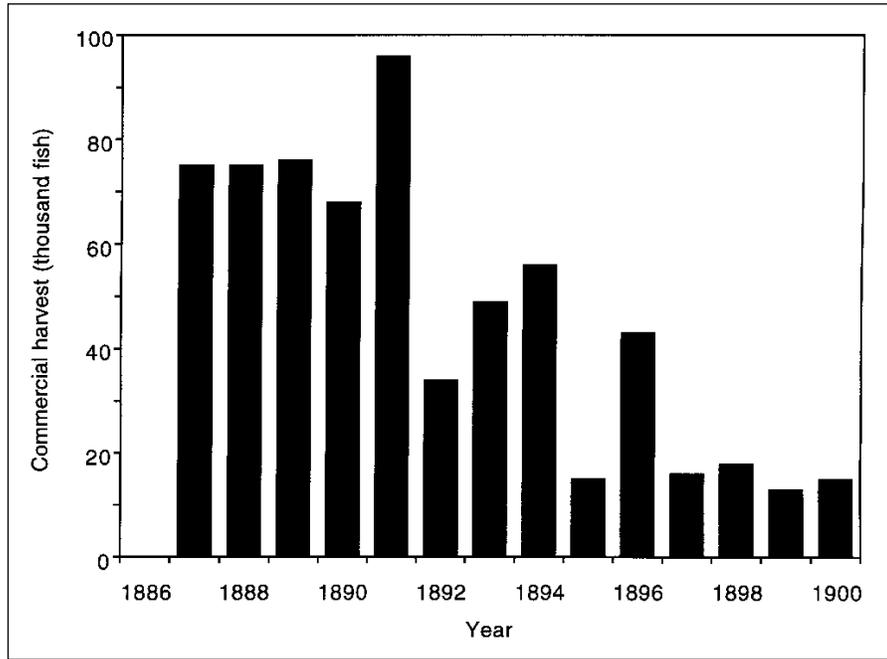


Figure 26—Sockeye harvest from the Naha River, 1887-1900 (data from Chamberlain 1907).

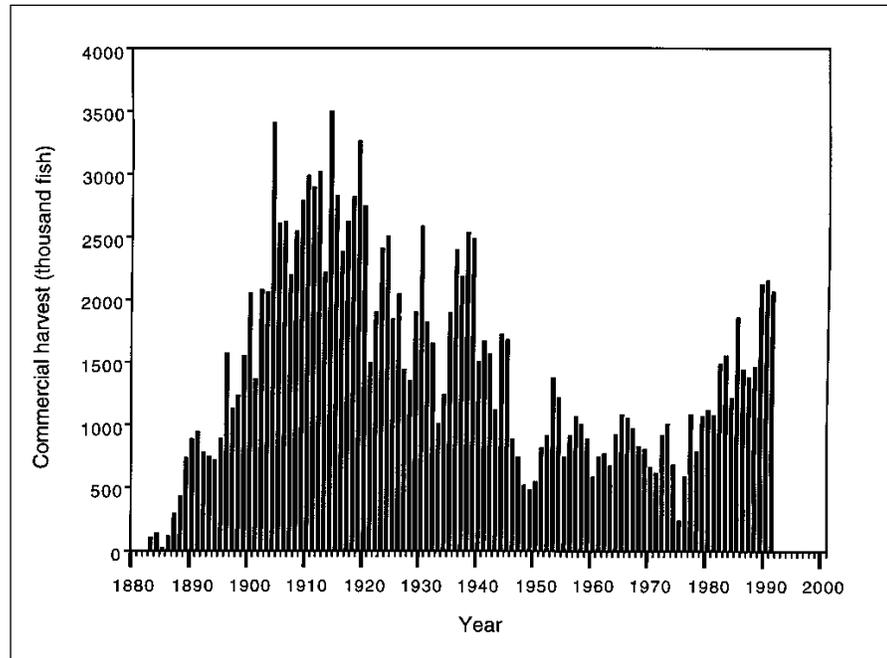


Figure 27—Annual commercial harvest of sockeye salmon in southeast Alaska, 1880-1991 (data from Rigby and others 1991).

of 6.8 percent and 3.4 percent jacks, respectively (McGregor and others 1991). Controversy persists regarding whether the proportion of jacks in escapements is most strongly influenced by inheritance or environmental factors.

Management History

Sockeye salmon stocks have the longest history of intense commercial exploitation of all anadromous salmonid species in southeast Alaska. Sockeye salmon were harvested by aboriginal populations in the region. Hewes (1957, cited in Cooley 1963) conservatively estimated the annual harvest of sockeye salmon at 2 267 962 kg. Commercial catches by Russian fishermen are believed to have begun at Redoubt Lake between 1812 and 1818.² Redoubt Lake, along with Whale Bay and Gut Bay, were among the first locations reported “denuded” of salmon by stream-fencing practices (Moser 1899, Tingle 1897). The first annual record of sockeye commercial harvest by U.S. fishermen was 108,000 fish harvested in 1883 (Rigby and others 1991), the year a saltworks was constructed in the outlet lagoon of the Naha River (Roppel 1982). By 1889, 12 canneries operated throughout southeast Alaska (Bean 1889), and the recorded commercial catch had increased to 738,000 sockeye. During this period of commercial expansion, the destructive use of barricades and malicious competition among canneries led to growing concern that some stocks in southeast Alaska had been “fatally over fished” (Cobb and Kutchin 1907). Chamberlain (1907) reported stock-specific harvests before 1900 from the Naha River system and adjacent streams. The record from the Naha River is most complete and illustrates early patterns of over-exploitation (fig. 26). Severe depletion of runs during this period typically led to relocation of fishing effort, which allowed subsequent recovery of overexploited stocks. The questionable accuracy of records and differences between past and current fishing strategies make it difficult to estimate and compare the size of past runs to recent run size in these heavily exploited streams.

The maximum commercial harvest of sockeye salmon from southeast Alaska was about 3,500,000 fish taken in 1914. Harvest declined steadily after that, to a minimum decade average of 642,000 fish per year during the 1970s—a harvest roughly equivalent to that obtained by the relatively undeveloped fishery of 1889 (fig. 27; Rigby and others 1991). Commercial harvest rebounded sharply during the 1980s, averaging over 1,200,000 fish per year. This increasing trend has continued in the 1990s with harvests exceeding 2,000,000 fish annually. Favorable ocean conditions in recent years have probably contributed to increasing harvests.

Current Management

Because sockeye populations tend to fluctuate greatly in run strength, and because mixed-stock exploitation prevails, the preferred management approach for sockeye stocks is the use of escapement goals. Insufficient information is available, however, to permit formal escapement goals to be set for all commercially exploited stocks in the region. Most small stocks are fundamentally unmanaged. Sockeye salmon management in regulatory districts 101, 104, 106, and 111 and the Asek River (fisheries that catch transboundary or Canadian stocks) is governed by the U.S./Canada Pacific Salmon Treaty, which sets harvest limits and allocates catch proportions (Ingledue 1987). Scale-pattern analysis is currently being used to separate stocks harvested in these districts and in Lynn Canal. Improved stock-separation technology has enhanced inseason management and compliance with treaty requirements. Inseason management decisions are based mainly on abundance as a function of time during

² Personal communication. 1996. R.H. DeArmond, historian. Sitka Pioneer's Home, 120 Katlian Avenue, Sitka, AK 99835.

migration of stocks through fisheries. Selective time and area closures have proven effective management tools for achieving escapement goals in areas where stocks can be readily separated (e.g., Lynn Canal). The only remaining interception fisheries for sockeye salmon in the region are the district 104 purse seine fishery off Noyes Island and the district 101 gill-net fishery off Tree Point (Pacific Salmon Commission 1991). Both fisheries intercept sockeye bound for spawning streams in southeast Alaska and British Columbia—especially the Nass and Skeena River systems.

Drift gill nets and purse seines take roughly equal proportions of the commercial harvest of sockeye salmon in southeast Alaska. Sport fisheries take a small proportion of the total regional catch but are concentrated on stocks near roads, such as Windfall Lake on the Juneau road system. Subsistence harvest also is a small proportion of the total regional harvest, but a few stocks are harvested relatively intensively for this use (e.g., Karta and Klawock Rivers; Sarkar, Hetta, Sitkoh, and Kanalku Lakes). Substantial inriver catches are taken from the Stikine and Taku Rivers; the mean harvests in these systems from 1979 to 1994 were 22,229 and 19,079 fish, respectively (Pacific Salmon Commission 1997). Differing numbers of sockeye salmon are harvested in pink salmon purse-seine fisheries. The incidental catch of sockeye salmon in the pink salmon purse-seine fishery differs annually, but 60,488 fish were caught in 1990 (see footnote 1). The magnitude of the incidental catch of sockeye salmon is related to the strength of the pink salmon run and fishing pressure on pink salmon (McPherson and McGregor 1986). Limiting early-season fishing for pink salmon has controlled the incidental take of sockeye salmon (Ingledue 1987).

Southern southeast Alaska districts have contributed about 70 percent of the total regional harvest in recent years (McPherson and McGregor 1986; also see footnote 1). District 104 consistently harvests the most fish, but up to 84 percent of this harvest can be fish destined for the Skeena and Nass systems in Canada (see footnote 1). Although most of the harvest is taken from southern stocks, fewer data are available for those stocks than for northern ones.

Current estimates of exploitation rates were available for only a few stocks in the region. The mean estimated exploitation rate for all these stocks combined for 1985 to 1989 was 66 percent. This estimate does not include Canadian interception of southern stocks or incidental, sport, or subsistence catches. Wild sockeye salmon stocks in southeast Alaska have shown great resilience in the face of intense exploitation for over a century. Undoubtedly this resilience depends on the presence of high-quality spawning and rearing habitats. Recent increases in commercial harvest can be sustained only if the quality of freshwater habitats is maintained.

Enhancement

Between 1901 and 1906, a law required commercial fisheries operators to establish hatcheries that would produce at least four times the number of adult sockeye harvested (Roppel 1982). The few hatcheries that were constructed seldom produced fry in the required 4-to-1 ratio. In one example cited by Roppel (1982), two hatcheries operated by the Alaska Packers Association released 52,500,000 fry and caught 16,587,097 adults, a ratio of 3:1. From 1892 through 1933, six hatcheries operated for various lengths of time in southern southeast Alaska. In 1933, the last of these hatcheries was closed by the commissioner of fisheries, Frank T. Bell, who stated, "The salmon will reproduce naturally if a sufficient number are allowed to reach their spawning grounds. If we find that any district is threatened with depletion, we will

restrict the gear or the fishing period and permit it to build up by natural propagation rather than try to do it artificially” (as cited in Roppel 1982). Renewed interest in hatcheries revived during the 1950s, and a hatchery at Deer Mountain near Ketchikan was constructed. Significant production of sockeye salmon occurs currently at the Beaver Falls, Klawock, and Snettisham hatcheries.

Brood stock for the early sockeye salmon hatcheries in southeast Alaska were generally taken from the stream where the hatchery was located. This tended to preserve to some degree the genetic integrity of the hatchery stock, but eggs and fry from the early hatcheries were outplanted to various locations, some of which are reported by Roppel (1982). Barren lakes were common targets for stocking of sockeye eggs and fry. Introduction of fry to barren lakes continued through the 1950s up to the present and often was accompanied by the construction of a fish ladder to provide access to the lake.

Hatcheries are a part of current enhancement efforts for sockeye salmon in southeast Alaska, but other methods include lake fertilization, construction of fish ladders, fry stocking, and remote releases of fry, presmolts, and smolts. Lake fertilization is intended to increase the primary productivity of lakes in which sockeye production is thought to be “forage-limited” (Koenings and others 1989). In some instances, growth and production of sockeye salmon increased. Fertilization at McDonald Lake was followed by an estimated increase in production from 84,000 to over 300,000 returning adults (Zadina and others 1995). Smolt size in Falls and Redoubt Lakes increased significantly after fertilization (Burkett and others 1989), but fertilization had little effect on sockeye smolts in Hugh Smith Lake (Burkett and others 1989).

Sockeye fry from Beaver Falls and Klawock hatcheries were stocked in Salmon Lake, Hugh Smith Lake, and Klawock River from eggs taken from their respective nursery areas. Fertilized eggs from the Tahltan, Speel, Crescent, Sweetheart, Little Trapper, Little Tatsamenie, and Chilkat Lakes were incubated in the Snettisham hatchery and returned to their sources in northern southeast Alaska. Fry from the Beaver Falls hatchery of McDonald Lake brood stock have been stocked in George Inlet, Virginia Lake, Margaret Lake, and Shrimp Bay. Hugh Smith Lake brood stock incubated at Beaver Falls was used to stock the Bakewell-Badger Lakes system after fishpass reconstruction (Bibb 1987). Sockeye production at the Klawock hatchery is directed toward enhancing the depressed Klawock River stock. The Snettisham hatchery is used primarily for incubation of sockeye eggs for fry plants in several lakes in southeast Alaska and British Columbia. Snettisham hatchery is also developing brood stock from Speel Lake for smolt releases near the hatchery.

Methods

Stock Discrimination

Simpson (1969) estimated that 128 systems in southeast Alaska produce sockeye salmon, including 14 systems in the Yakutat region. More recent reports from the ADF&G put the total count of sockeye-producing systems at about 114 (e.g., Bergander 1989). Baker and others (1996) identified 206 spawning aggregates in the region. Based on the criterion of escapement survey counts of at least 20 fish, we found about 230 systems supporting sockeye salmon in southeast Alaska and adjacent areas of British Columbia and the Yukon Territory.

Geographic location (watershed) and run timing provide the most direct approach for defining sockeye stocks and describing intraspecific diversity and for identifying populations with distinctive biological characteristics. Several other stock-separation methods have been successfully applied to manage sockeye salmon fisheries in southeast Alaska. Scale-pattern analysis (Marshall and others 1987), prevalence of the brain parasite *Myxobolus neurobius* (Moles and others 1990), and egg diameter (Craig 1985, Lynch and others 1990) have been used to determine the origin of fish caught in mixed-stock fisheries. Genetic stock identification based on allozyme frequencies suggests the presence of subpopulation structure within several sampled populations (Guthrie and others 1994). The objectives of most of these efforts were to identify stocks originating from a specific watershed and to provide a method to determine catch-and-escapement goals. In addition, results from these methods may be used to identify potential gene flow or isolation among stocks and differences in environmental characteristics of rearing habitats.

Data Analysis Procedures

Escapement sampling provided most of the data for our analysis of adult length, population age structure, and adult migratory timing. More information is available for large sockeye stocks than for small stocks. Methods used to identify trends in stock abundance and distinctive stocks followed those described in the "General Introduction." Grand means from all sample years were used for most analyses of biological characteristics. The number of stocks compared for each characteristic differed, because of limitations in the availability and quality of data.

The variance-component analysis of adult fork lengths was based on 15 stocks with at least 6 years of sampling and a sample size of at least 15 individuals of each sex in the 1.3 age class, the only age class evaluated. Similar selection criteria were used to include stocks in all analyses of temporal trends. Temporal trends were analyzed only for age classes with the largest sample size.

Postorbit-to-hypural (POH) plate lengths, used in many Canadian stocks, were converted to mideye-to-fork lengths (MEF) by using the conversion equations provided in the source document. Equations were not provided for the 1984 sample from Little Trapper Lake and the 1985 sample from the Klukshu River, and the lengths were converted with the following equations:

for Little Trapper Lake—

$$\text{MEF} = (1.0877 \times \text{POH}) + 23.83 ,$$

and for Klukshu River—

$$\text{MEF} = (1.097 \times \text{POH}) + 23.039 .$$

The former was derived from length-conversion equations for 1986 to 1990. The Klukshu River sample was converted by using a generalized equation for converting lengths of ocean-caught sockeye salmon in southeast Alaska (Pahlke 1989b).

Migratory timing characteristics were evaluated for 28 stocks with daily weir counts and 97 stocks for which our run-timing index (defined in “General Introduction”) could be calculated. Seventeen of the systems with weirs also were included in the run-timing index sample. Most survey counts of sockeye salmon in southeast Alaska are made during surveys directed at pink salmon, and these may be too early to identify migration peaks for sockeye stocks. The timing index calculated from these data provided only comparative differences in timing among sockeye salmon stocks. We did not compile any information on emigration timing of sockeye smolts. We compared run-timing characteristics of stocks from island, mainland, coastal, and interim drainages to look for geographic patterns. Only stocks monitored at weirs were included in this comparison.

Mean freshwater age (MFWA), mean saltwater age (MSWA), and proportions of escapements in each age and sex class were analyzed for 79 sockeye stocks. Two major factors influenced the interpretation of sockeye age data. (1) The growth rate of juvenile sockeye was density dependent in many lakes, which can lead to cycles of weak and strong brood years. In southeast Alaska, these cycles seemed to have a period of about 5 years; therefore, MFWA calculations based on less than 5 return years may be influenced by weak or strong brood years.^{3 4} (2) Changes in run composition through the season complicate the evaluation of the age structure and sex ratio (McPherson and McGregor 1986). The typical method of collecting age data from escapements consists of a single, brief sampling visit to each run. This sampling regime cannot detect seasonal shifts in age structure or sex ratio. Although short-term sampling may be adequate for small stocks with relatively brief runs, serious bias can result from a few days of sampling from large stocks with protracted runs (see footnotes 3 and 4). The most reliable age-structure and sex-ratio data come from stocks sampled throughout their runs at weirs. Interannual variation in MFWA and MSWA and sex ratios were examined only for stocks sampled at weirs. Sex ratios were derived from samples taken for age-structure analysis.

River- and sea-type life histories were identified in 24 stocks from accounts in the literature or by the presence of at least 10 percent zero-check individuals of each sex in the x.3 age class. For analyses of biological characteristics, we combined the river- and sea-type stocks into a single group (river-sea-type) and evaluated them separately from the lake-type stocks. Although all three life history patterns occur in the Situk River (Thedinga and others 1993), we treated this as a lake-type stock. Samples taken at the Taku fishwheel were analyzed as river–sea-type, although this undoubtedly was a mixture of lake- and river-sea-type fish.

Results

Body Length

Adult body-length data from escapements of 84 stocks showed significant differences between body lengths of males from lake- versus river-sea-type stocks, but not between females of each type of stock (table 21). Therefore, outlier analyses of body length were conducted separately for males of each type of stock, but stock types were pooled for females. Five stocks (Essowah Lake, Julian, Coffee, Chuunk Mountain, and Honakta Sloughs) were not included in body-length analyses, because sample sizes were too small ($N \leq 60$ fish).

³ Personal communication. 1996. M. Haddix, limnologist, Alaska Department of Fish and Game, 2030 Sea Level Drive, Suite 215, Ketchikan, AK 99901.

⁴ Personal communication. 1996. T. Zadina, fisheries biologist, Alaska Department of Fish and Game, 2030 Sea Level Drive, Suite 215, Ketchikan, AK 99901.

Table 21—Mid-eye-to-fork length comparisons between lake-type and river-sea-type sockeye salmon stocks, and between age 1.3 and 2.3 lake-type sockeye salmon

Age and sex class	t-value	P-value	Lake-type			River-sea-type		
			Mean	SD ^a	N	Mean	SD ^a	N
Age 1.2 females	0.43	0.67	492.6	16.68	46	490.3	16.48	13
Age 1.2 males	3.68	<0.01	485.3	24.96	47	462.7	17.39	20
Age 1.3 males	3.01	<0.01	572.5	20.86	54	587.1	15.32	23
Age 1.3 females	0.97	0.34	554.3	19.57	54	558.8	16.32	23
Age 1.2 sexual dimorphism	2.54	0.01	-6.5	21.39	46	-22.	15.75	13
Age 1.3 sexual dimorphism	3.63	<0.01	18.2	11.91	54	28.3	8.80	23
Age 1.3 vs. 0.3 dimorphism	3.52	<0.01	18.2	11.91	54	29.0	13.55	24

Comparisons of lake-type age classes								
	t-value	P-value	Age 1.3			Age 2.3		
			Mean	SD ^a	N	Mean	SD ^a	N
Age 1.3 vs. 2.3 males	0.37	0.71	572.5	20.9	54	570.3	24.7	44
Age 1.3 vs. 2.3 females	2.79	0.07	554.3	19.6	54	551.1	21.1	43

^a SD = standard deviation.

Both types of sockeye stocks showed significant levels of sexual dimorphism in all age classes tested (table 21), but the direction of the difference was not consistent. Males were larger than females in the 1.3 and 2.3 age classes, but females were larger than males in the 1.2 age class (fig. 28). Differences between males and females were greater in river-sea-type stocks than lake-type stocks in the 1.3 age class (table 21). Furthermore, age 0.3 fish from river-sea-type stocks were significantly more dimorphic in body length than age 1.3 fish from lake-type stocks (table 21). Outlier analysis for degree of sexual dimorphism therefore was conducted separately on lake- and river-sea-type stocks. Although significant sexual dimorphism exists, male and female body lengths were highly correlated throughout the region (fig. 28). Freshwater age did not have a significant effect on adult body length (males, $T = 0.37$, $P = 0.71$ NS; females, $T = 2.79$, $P = 0.07$ NS), but age 1.3 individuals tended to be larger than age 2.3 individuals (table 21).

Adult body length increased over time in four of the 32 stocks tested (table 22). The specific stocks and age classes were (1) Petersburg Lake age 1.3 females, but not males; (2) Thoms Lake age 2.3 males and females; (3) Speel Lake age 1.3 males; and (4) Crescent Lake age 1.3 males. Sample sizes have been small in recent years from both Petersburg and Thoms Lakes. Speel and Crescent Lakes have weirs, and large samples of body lengths for age 1.3 individuals were available. Regression coefficients were positive in 45 of 64 tests (70 percent), suggesting a weak trend of increasing body size with time throughout the region. Our database did not contain sufficient recent data to detect any changes in body size in systems where lake fertilization has occurred.

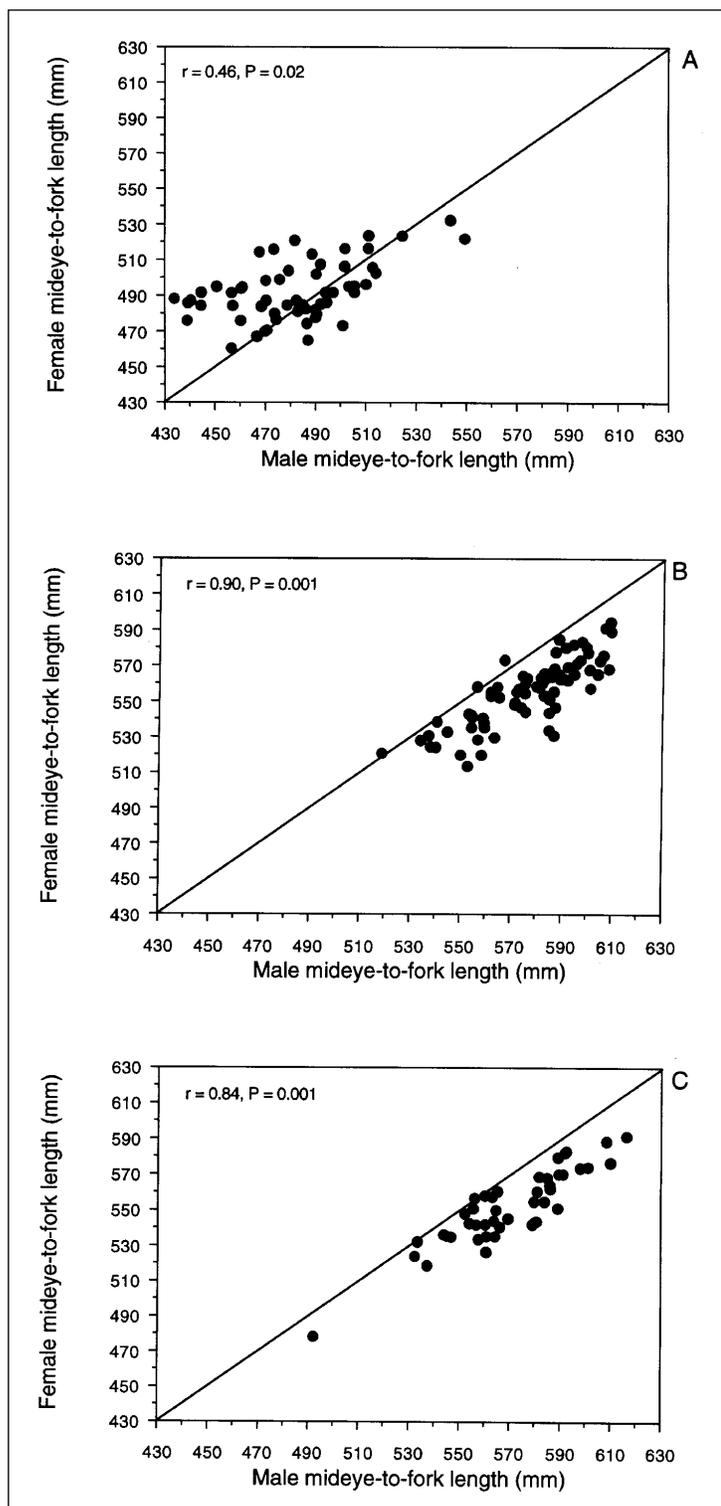


Figure 28—Male versus female sockeye salmon mid-eye-to-fork lengths: (A) age 1.2, N = 58, (B) age 1.3, N = 77, (C) age 2.3, N = 46. Each point represents mean lengths for one stock. Means calculated for escapement samples across all years. Diagonal line represents equal lengths for both sexes.

Table 22—Regression analysis of trends across years in mideye-to-fork lengths from sockeye salmon escapements

Stream		Males					Females		
Number	Name	Age class	No. years sampled	R-squared	Slope	P-value ^a	R-squared	Slope	P-value ^a
101-30-075	Hugh Smith Lake	1.3	8	0.01	1.35	0.5<P<0.9	0.22	1.09	0.2<P<0.4
101-80-068	McDonald Lake	1.3	8	0.15	2.66	0.2<P<0.4	0.06	1.16	0.5<P<0.9
101-90-050	Naha River	1.3	8	0.12	3.23	0.2<P<0.4	0.11	2.74	0.4<P<0.5
101-90-084	Helm Lake	1.2	7	0.26	2.87	0.2<P<0.4	0.01	0.45	0.5<P<0.9
102-30-067	Kegan Lake	1.3	8	0.01	1.01	0.5<P<0.9	0.00	-0.28	P>0.9
102-60-087	Karta River	1.3	8	0.10	2.43	0.4<P<0.5	0.08	1.06	0.5<P<0.9
103-15-027	Klakas Lake	1.3	7	0.01	0.63	0.5<P<0.9	0.42	-3.96	0.1<P<0.2
103-25-047	Hetta Lake	1.3	7	0.02	1.19	0.5<P<0.9	0.01	0.42	0.5<P<0.9
103-60-047	Klawock Lake	1.3	6	0.03	1.29	0.5<P<0.9	0.02	0.65	0.5<P<0.9
103-90-014	Sarkar Lake	2.2	7	0.01	1.04	0.5<P<0.9	0.14	-3.83	0.4<P<0.5
106-30-051	Luck Lake	1.3	7	0.00	0.03	P>0.9	0.01	-1.17	0.05<P<0.9
106-41-010	Salmon Bay Lake	1.3	8	0.08	2.24	0.4<P<0.5	0.00	0.27	0.5<P<0.9
106-41-030	Red Bay Lake	1.3	7	0.19	1.69	0.2<P<0.4	0.01	-0.26	0.5<P<0.9
106-44-060	Petersburg Lake	1.3	8	0.03	1.42	0.5<P<0.9	0.57	8.89	0.02<P<0.05 *
107-30-030	Thoms Lake	2.3	8	0.54	5.28	0.02<P<0.05*	0.58	3.72	0.02<P<0.05 *
109-20-013	Falls Lake	1.3	6	0.02	-0.43	0.5<P<0.9	0.01	-0.30	0.5<P<0.9
109-52-035	Kutlaku Lake	1.3	8	0.06	-1.03	0.5<P<0.9	0.09	1.41	0.4<P<0.5
109-62-013	Alecks Lake	1.3	6	0.03	1.10	0.5<P<0.9	0.01	0.41	0.5<P<0.9
111-32-032	Taku River	1.3	7	0.48	2.13	0.05<P<0.1	0.36	1.81	0.1<P<0.2
111-32-235	Kuthai Lake	1.3	7	0.07	-2.81	0.5<P<0.9	0.05	-1.93	0.5<P<0.9
111-32-245	Little Trapper Lake	1.3	8	0.25	-4.45	0.2<P<0.4	0.21	-4.35	0.2<P<0.4
111-32-254	Little Tatsamenie Lake	1.3	6	0.31	-8.62	0.2<P<0.4	0.28	-8.18	0.2<P<0.4
111-33-034	Speel Lake	1.3	8	0.66	4.92	0.01<P<0.02**	0.44	4.64	0.5<P<0.1
111-35-007	Crescent Lake	1.3	8	0.76	6.19	0.001<P<0.01***	0.30	3.78	0.1<P<0.2
111-50-042	Auke Lake	2.3	8	0.38	2.04	0.1<P<0.2	0.40	2.91	0.05<P<0.1
111-50-056	Steep Creek	1.3	8	0.03	-1.06	0.5<P<0.9	0.02	-0.68	0.5<P<0.9
113-41-043	Redoubt Lake	2.2	8	0.09	1.56	0.4<P<0.5	0.06	0.84	0.5<P<0.9
113-73-003	Ford Arm Lake	1.3	8	0.11	2.54	0.4<P<0.5	0.00	0.16	P>0.9
115-32-025	Chilkat River	0.3	7	0.00	-0.14	P>0.9	0.05	0.95	0.5<P<0.9
115-32-032	Chilkat Lake	2.3	8	0.00	-0.03	P>0.9	0.00	-0.01	P>0.9
115-33-020	Chilkoot Lake	1.3	8	0.14	0.79	0.2<P<0.4	0.29	1.34	0.1<P<0.2
182-20-010	East Alsek River	0.3	6	0.35	3.33	0.2<P<0.4	0.44	3.07	0.1<P<0.2

^a* = 0.05 > P > 0.01; ** = 0.01 > P > 0.001; and *** = P < 0.001.

Table 23—Variance component analysis of age 1.3 sockeye salmon mideye-to-fork lengths from escapements^{a, b}

Source of variation	Degrees of freedom	Type 1 sum of squares	F-test	Error term	Expected mean square	Variance component	Percentage of total
Males							
Total	31,972	55,076,640			1,722.65	1,741.92	
Stocks	14	5,452,334	7.17	Years	389,452.42	144.07	8.27
Years	90	4,887,491	38.68	Error	54,305.45	194.04	11.14
Error	31,868	44,736,816			1,403.82	1,403.82	80.59
Females							
Total	34,218	42,045,441			1,228.75	1,254.26	
Stocks	14	8,998,098	13.99	Years	642,721.28	254.10	20.26
Years	90	4,135,193	54.21	Error	45,946.59	152.64	12.17
Error	34,114	28,912,150			847.52	847.52	67.57

^a Variance components computed from means, standard errors, and sample sizes.

^b Stocks included in the analysis:

101-30-075	Hugh Smith Lake	111-33-034	Speel Lake	106-41-010	Salmon Bay Lake
101-80-068	McDonald Lake	111-35-007	Crescent Lake	109-52-035	Kutlaku Lake
101-90-050	Naha River	111-50-056	Steep Creek	111-32-245	Little Trapper Lake
102-30-067	Kegan Lake	113-41-043	Redoubt Lake	115-32-032	Chilkat Lake
102-60-087	Karta River	113-73-003	Ford Arm Lake	115-33-020	Chilkoot Lake

Variance-component analysis of lake-type stocks indicated that nearly 81 percent of total variation in male body length was attributable to variation among individuals within stocks, and 8 percent was accounted for by differences among stocks (table 23). Females were less variable within stocks (68 percent) and more variable among stocks (20 percent). Interannual variation within stocks was about equal for both sexes (males 11 percent, females 12 percent). No river-sea-type stocks were included in this analysis, because of the requirement for balanced data and relatively large samples of age 1.3 individuals. Given the highly variable nature of the rearing habitats used by river-sea-type stocks, these stocks also may have high levels of within-stock variance in body length.

Adults in all age-sex classes from both the Karta and Naha Rivers were near or at the top of their respective size distributions. Age 1.2 males in the Karta system are larger than other stocks in the group (fig. 29A). The Karta River on Prince of Wales Island and the Naha River on Revillagigedo Island both drain large, low-gradient watersheds containing numerous lakes. Insufficient information is available to determine if smolts from these populations are particularly large. No other stocks had distinctive adult body size.

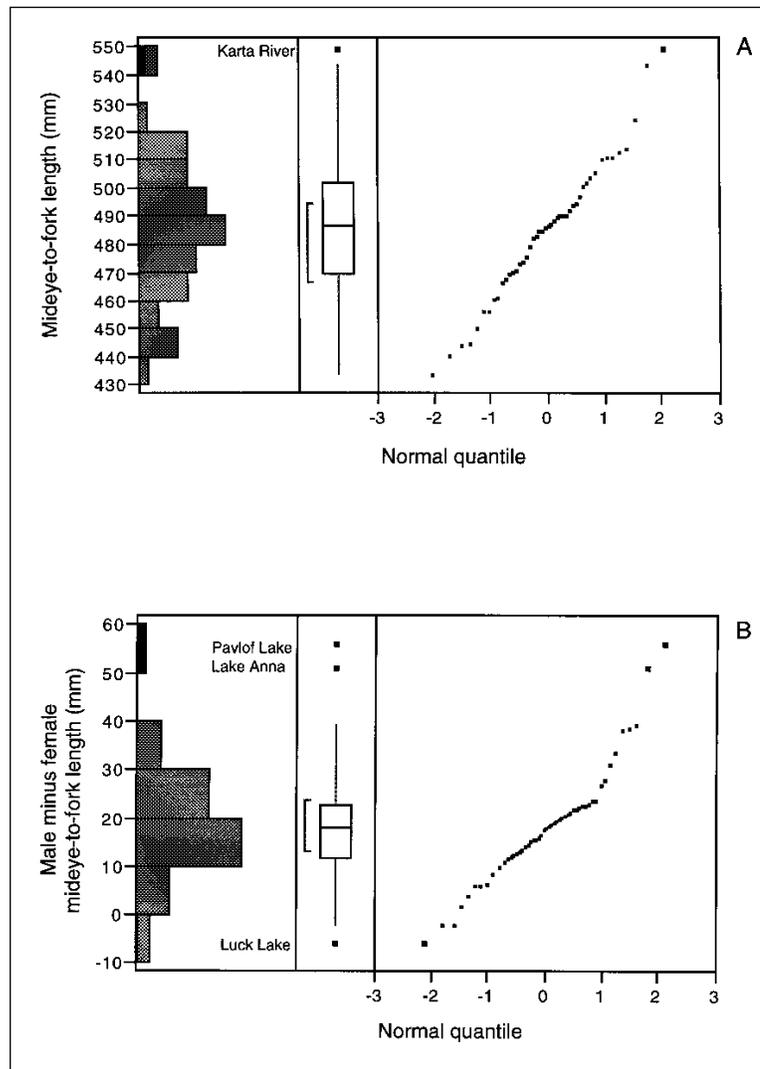


Figure 29—Frequency distributions, outlier plots, and normal quantile plots for **(A)** mid-eye-to-fork lengths of age 1.2 males from lake-type stocks, N = 47, and **(B)** sexual dimorphism of age 1.3 individuals from lake-type stocks, N = 55. Age 1.2 males in the Karta River stock are distinctively large. In the Pavlof and Lake Anna stocks, males are distinctively larger than females, and in Luck Lake females average nearly 6 mm longer than males in mid-eye-to-fork length.

The sockeye stock that spawns in Benzeman Lake and is harvested in Necker Bay has long been recognized as consisting of unusually small individuals (Moser 1899). Body lengths of fish caught in Necker Bay are the smallest of all sampled commercial fisheries (McPherson and McGregor 1986). The commercial sockeye harvest from Necker Bay is dominated by age 2.2 individuals (McGregor and others 1984, McPherson and McGregor 1986). No data were available from escapements regarding body lengths in this stock.

Differences in the body lengths between age 1.3 males and females in the Pavlof, Anna, and Luck Lake stocks were greater than those observed for the other stocks (fig. 29B). Males in the Pavlof and Lake Anna populations averaged 56 and 51 mm greater in mid-eye-to-fork length, respectively, than females. The Pavlof Lake result was based on a sample of 27 males and 35 females from a single year, and the Lake Anna sample consisted of 47 males and 26 females. In contrast, Luck Lake females were larger (average 6 mm) than males in a sample size of 123 males and 416 females during a 7-year period. No outliers were found for river-sea-type stocks.

Timing

The grand mean date of adult freshwater migration for 30 stocks inhabiting systems monitored with weirs or fishwheels was 7 August. The mean date of migration for individual stocks ranged from 4 July to 3 September. Interior stocks tended to have later mean migration dates (Kruskal-Wallis test, $P = 0.11$ NS; table 24), which was expected, given that most weirs were located near outlets of nursery lakes, far from the sea. No relation existed between the mean date of migration and body length of age 1.3 sockeye ($N = 25$ stocks; males, $r = 0.12$, $P = 0.56$; females, $r = 0.06$, $P = 0.79$).

Table 24—Run timing summary statistics by habitat for sockeye salmon stocks monitored with weirs or fishwheels

Habitats	Mean date			Variance (duration)			Escapement		
	N (stocks)	Mean (Julian date)	Mean CV	N (stocks)	Mean (days squared)	Mean CV	N (stocks)	Mean (no. of fish)	Mean CV
			<i>Percent</i>			<i>Percent</i>			<i>Percent</i>
Island	10	212.1	4.4	10	222.1	54.2	11	17,407	74.3
Coastal	10	217.1	3.1	10	259.8	43.6	10	35,964	60.0
Interior	7	229.1	2.0	7	120.0	48.9	7	9,139	51.4

Variance in migration timing is an index of run duration, because it reflects the dispersion of the migratory time-density function at the weir (Mundy 1984). Actual run duration was more protracted than estimates at weirs show, because weirs frequently were not operated for the full duration of runs. Variance (days squared) ranged from 30.75 for the Nakina River stock to 752.26 for the Chilkat Lake stock. Interior stocks had more compact run timing than island or coastal-mainland stocks (table 24). Run duration and mean escapement count were weakly correlated ($N = 25$, $r = 0.33$, $P = 0.1$). Based on a comparison of coefficients of variation, run duration and escapement magnitude were more variable among years than was the mean migration date. Coefficients of variation for mean migration date ranged from 1 to 8 percent, and coefficients of variation for variance (run duration) and escapement ranged from 10 to 80 percent and 10 to 140 percent, respectively. No geographic pattern was apparent in the degree of variability of these characteristics.

Historic and current weir counts were available for Klawock and Redoubt Lakes, but only Klawock Lake was sampled for enough years to permit comparison of timing characteristics between the historic and current periods. The mean date of migration was significantly earlier (Wilcoxon test, $P = 0.001$) and the duration of migration was

significantly greater than they are currently (Wilcoxon test, $P = 0.03$). Differences in mean date of migration may be partially attributed to significantly larger historic runs (Wilcoxon test on mean escapements, $P = 0.001$), because mean date of migration and escapement count were correlated in this stock ($r = 0.58$, $P = 0.01$). Run duration and escapement magnitude were not strongly correlated ($r = 0.38$, $P = 0.12$).

Thirteen sockeye stocks in the region had sufficiently long series of weir counts to permit evaluation of contemporary trends across years in mean date of migration (table 25). Three of these 13 stocks showed significant changes in mean migration date. Both Klawock River and Chilkat Lake stocks had trends toward later run timing,

Table 25—Regression analyses of trends across years in sockeye salmon mean migration dates for stocks counted at weirs

Stream				Regression		
Number	Name	No. years sampled	Years	R-squared	Slope	P-value ^a
103-60-047	Klawock Lake	10	1968-88	0.72	1.66	0.001<P<0.01**
106-41-010	Salmon Bay Lake	10	1965-88	0.14	0.41	0.2<P<0.4
108-80-110	Tahltan Lake	32	1959-91	0.22	-0.48	0.001<P<0.01**
109-20-013	Falls Lake	9	1981-89	0.02	0.55	0.5<P<0.9
111-32-245	Little Trapper Lake	9	1983-91	0.00	0.07	P>0.9
111-32-254	Little Tatsamenie Lake	7	1985-91	0.36	1.00	0.1<P<0.2
111-33-034	Speel Lake	10	1983-92	0.27	-0.68	0.1<P<0.2
111-35-007	Crescent Lake	12	1977-92	0.21	0.60	0.1<P<0.2
113-41-043	Redoubt Lake	11	1982-92	0.05	0.35	0.5<P<0.9
115-32-032	Chilkat Lake	26	1967-92	0.27	0.95	0.001<P<0.01**
115-33-020	Chilkoot Lake	17	1976-92	0.03	0.30	0.5<P<0.9
182-30-020	Klukshu Lake	16	1976-91	0.08	0.47	0.2<P<0.4
182-70-010	Situk River	14	1971-92	0.03	0.13	0.5<P<0.9

^a** = 0.01 > P > 0.001.

and the Tahltan Lake stock showed a trend toward earlier run timing. The mean index (peak number of fish counted) date for the 97 stocks evaluated was 21 August, about 2 weeks later than the grand mean migration date for systems with weirs. For the 17 stocks for which weir mean date and timing-index date could be calculated, the mean difference between calculated values was 15.59 days (SE = 3.33, range -13 to 33), with index dates generally being later than weir dates. At Redfish and Redoubt Lakes, weir mean dates were later than index dates by 13 and 5 days, respectively. At Falls Lake the dates were the same. One explanation for these discrepancies is that all three systems are very near salt water, and the short length of visible stream led to unreliable abundance estimates from surveys.

No stocks showed distinctive timing characteristics. Run duration of the Chilkat Lake stock was much more protracted than for other stocks in the region, but this difference did not meet the outlier criterion. Five other stocks also had relatively protracted runs; Klukshu, Sitkoh, Kegan, Hugh Smith, and Chilkoot Lakes. The Klukshu Lake stock was unusual among these because it is the only interior stock, and interior stocks tend to have relatively compact runs.

Table 26—Sockeye salmon stocks with significantly declining escapement trends

Stream		Location			Data quality rating	Possible factors
Number	Name	VCU ^a	General	Land use ^b		
103-11-017	Hunter Bay	699K	Prince of Wales	Wilderness	Fair	Unknown
103-15-027	Klakas Lake	687K	Prince of Wales	Wilderness	Fair	Unknown
105-43-002	Lake Creek- Shiple Bay	541K	Kosciusko Island	LUD II (legislated) FS cabin	Fair	Unknown
109-20-007	Gut Bay	332C	Baranof (south)	Wilderness	Fair	Unknown
111-50-042	Auke Lake	29C	Auke Bay, Juneau	LUD III Private	Good	Habitat degradation; hatchery manipulations; gravel mining
112-50-010	Pavlof River	218C	Chichagof	LUD III Timber harvest	Good	Habitat degradation; fish pass effects (?)
113-52-004	Hanus Bay	295C	Baranof	LUD II FS cabin and trail	Fair	Unknown
115-32-060	Mosquito Lake	NA	Haines	Private and State (campground)	Fair	Habitat degradation; sport harvest (?)

NA = not available.

^a VCU = USDA, Forest Service value comparison unit; approximately equivalent to a watershed; K = Ketchikan Area; and C = Chatham Area.

^b LUD = Land use designation:

LUD II = roadless areas

LUD III = multiple use

LUD IV = intensive resource use (especially logging)

Demography

Escapement—Escapement trends for the period 1960 through 1992 could be evaluated for 107 stocks: 14 (13 percent) showed significant trends. Four stocks were increasing significantly and 10 were declining significantly (table 26). No geographic pattern was apparent for either the increasing or declining stocks. The significant declines detected for the Shiple Bay-Lake Creek, Auke Lake, and Pavlof Lake stocks are of particular note, given the distinctive characteristics of these populations (see “Age Structure,” below). Declines detected in the Sitkoh Lake and Situk River populations were probably attributable, respectively, to inappropriately early surveys and a reduced escapement goal. When surveys conducted before 15 August were omitted from the Sitkoh Lake analysis, the decline became nonsignificant. The decline in escapements to the Situk River probably resulted, in part, from the increase in exploitation rate that followed a reduction of the management escapement goal in 1987 for this system from 80,000-100,000 to 40,000-55,000 fish (McPherson and others 1987). The Sitkoh and Situk stocks were not included in the list of declining stocks.

Both weir counts and survey counts were available for seven stocks, allowing a limited comparison of these data types. In five of seven cases, both data types yielded regression lines of escapement trends with slopes of the same sign. Falls and Redoubt Lakes both had negative slopes, based on aerial survey counts, and positive slopes, based on weir counts, but the aerial survey counts were unreliable for the short outlet streams from these deep lakes. The Situk stock showed a significant decline based on weir counts but a nonsignificant decline based on survey counts. This difference is probably due to the low degree of overlap in the timing of survey (1960 to 1975) and weir (1971 to 1992) counts.

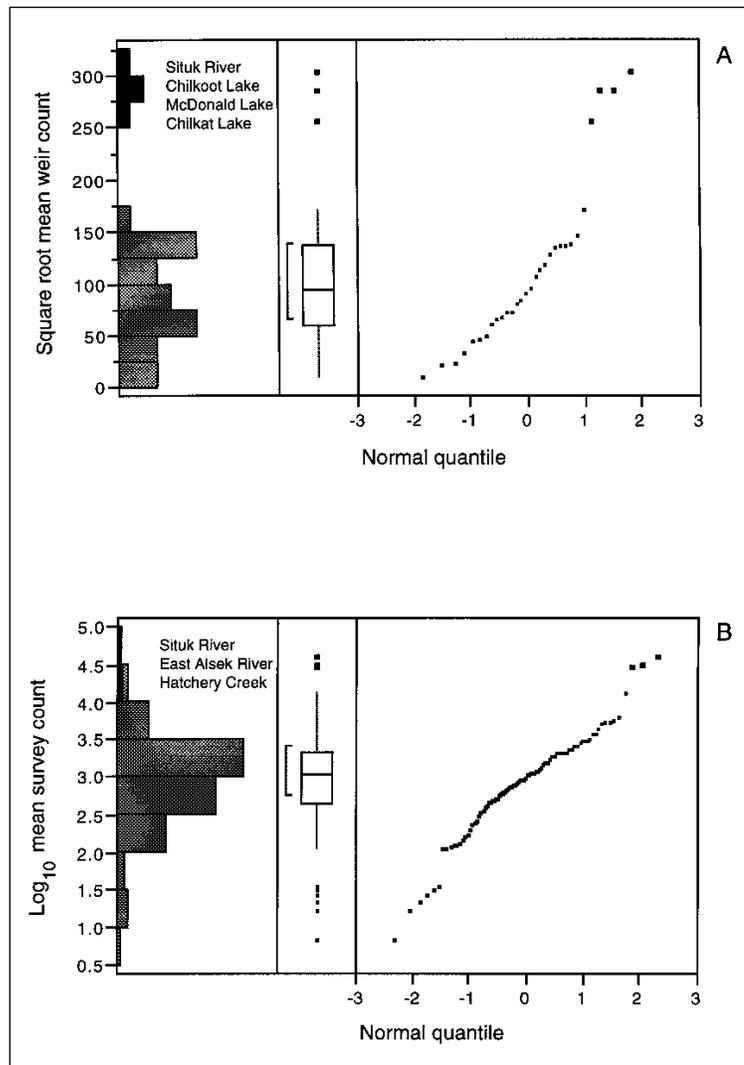


Figure 30—Frequency distributions, outlier plots, and normal quantile plots for mean escapement magnitude of (A) stocks enumerated at weirs, N = 30, and (B) stocks included in escapement surveys, N = 97. All named stocks are distinctively large. Hatchery Creek is an inlet stream to McDonald Lake.

McDonald, Chilkat, and Chilkoot Lakes, and the Situk River, which were monitored with weirs, had large sockeye populations (fig. 30A). Among stocks for which escapement survey counts were available, the Situk and East Alsek Rivers and Hatchery Creek (McDonald Lake) stocks also had particularly large runs (fig. 30B). Total run size for the East Alsek River stock has been estimated to be as high as 180,000 sockeye.⁵ The East Alsek stock was also the only large stock in the region in which the zero-check life history pattern predominated.

⁵ Personal communication. 1996. F. Bergander, fisheries biologist, Alaska Department of Fish and Game, 802 3d Street, Douglas, AK 99824.

Table 27—Sockeye salmon stocks in impaired or suspected water bodies

Stream		Location		Pollutant source types ^b	Comments
Number	Name	VCU ^a	General		
Impaired water bodies					
101-47-015	Ward Cove	749K	Ketchikan	IN, DO Debris	Small run; maximum count of 290 fish in 1982
Suspected water bodies					
102-70-058	Thorne Bay	586K	Thorne Bay	IN, UR, SE, SM	Only 3 escapement surveys conducted: 200 fish in 1963, 2 fish in 1979, 10 fish in 1982
111-50-052	Montana Creek	27C	Juneau	UR	Only 3 escapement surveys conducted: 210 fish in 1983, 10 fish in 1989, 2 fish in 1992
113-72-002	Klag Bay	271C	Klag Bay	Metals MI, TA	Moderate sized run; maximum count of 6,000 fish in 1976; no significant population trend
115-33-020	Lutak Inlet	NA	Haines	As, PAH	Large population; mean annual weir escapement count of 81,538 fish, from 1976 to 1992. No significant population trend

NA = not available

^a VCU = USDA, Forest Service value comparison unit; approximately equivalent to a watershed; K = Ketchikan Area; and C = Chatham Area.

^b Pollutant source types:

As = Arsenic

DO = Dissolved oxygen

IN = Industrial

Source: ADEC 1992

MI = Mining

PAH = Poly aromatic hydrocarbons

SE = Sewage discharge

SM = Streambank or shoreline modification

TA = Tailings

UR = Urban runoff

Water quality and demographic status—Ward Cove is the only “impaired” water body inhabited by a sockeye population; four additional “suspected” water bodies contain sockeye populations (Alaska Department of Environmental Conservation 1992) (table 27). Ward Cove, Montana Creek, and Thorne Bay contain small populations, with maximum escapement counts of less than 300 individuals. The Klag Bay population was of intermediate size with a maximum escapement survey count of 6,000 fish in 1976 and a mean survey count of 1,597 fish (based on 24 surveys between 1962 and 1992) but no significant temporal trend in population size. The Ward Creek stock, surveyed eight times between 1975 and 1989, did not show a significant population trend. Both the Thorne Bay and Montana Creek stocks have been surveyed only three times at intermittent intervals. Incidental observations of sockeye spawning at various locations in the Thorne River drainage suggested annual escapements may have been as high as 5,000 fish for 1983 to 1993.⁶ Catch reports from the subsistence fishery on the Thorne River ranged between 6 and 131 fish for the same period (see footnote 6). The last survey for Thorne Bay counted 10 fish in 1982.

⁶ Personal communication. 1996. E. Johnston, staff officer, USDA Forest Service, Tongass National Forest, Thorne Bay Ranger District, P.O. Box 1, Thorne Bay, AK 99919.

The largest stock using a suspected water body is the Chilkoot Lake stock. Lutak Inlet is listed as a suspected water body and serves as a secondary rearing area for Chilkoot Lake sockeye smolts (McPherson 1990). Chilkoot Lake sockeye smolts emigrate at comparatively small sizes (65 to 75 mm; McPherson 1990). The time spent rearing in Lutak Inlet therefore may be critical to the relatively high productivity of this stock (McPherson 1990). The Chilkoot Lake sockeye stock is one of the largest southeast Alaska stocks.

Age structure—Age structure data were available for the same 84 stocks for which body-length data were available. Male and female MFWA were correlated within sockeye stocks (fig. 31A). However, MFWA differed among stocks over a wide range, extending from 0.01 to over 2 years. The grand mean MFWA for the region was 1.07 years. A relatively large number of river-sea-type stocks with low MFWA occurred in the Yakutat area, the northern-most area included in this review. River-sea-type stocks do not occur south of the Stikine River.

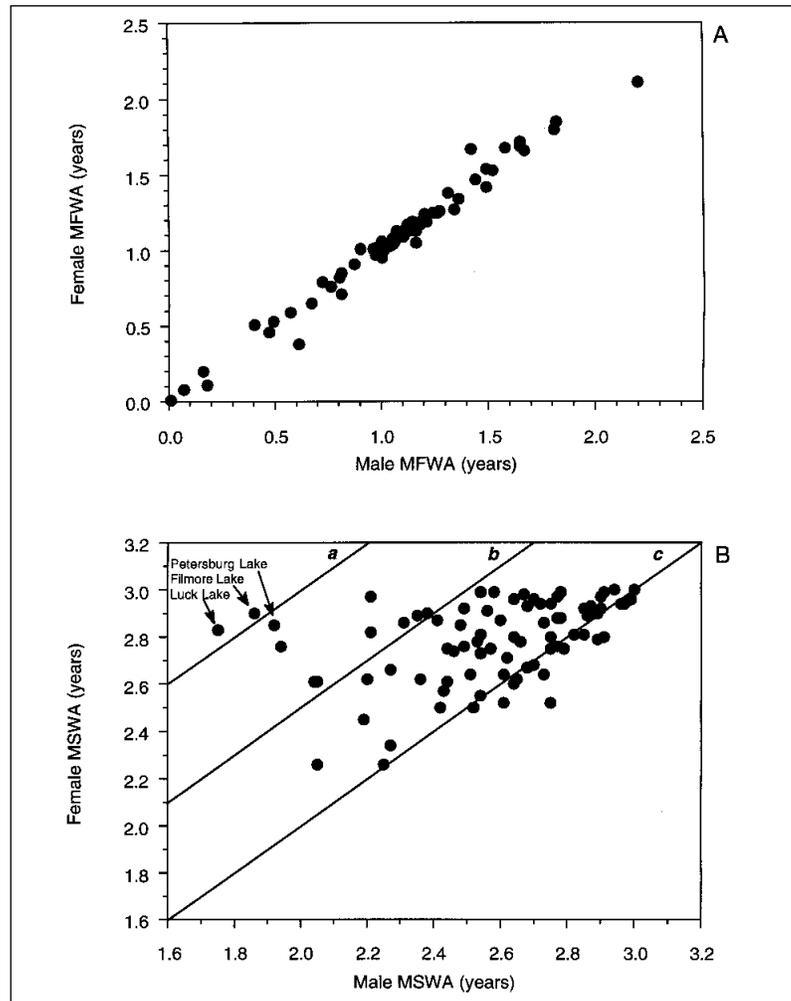


Figure 31—Relation between the age structures of males and females in sockeye stocks: (A) mean freshwater age (MFWA), N = 79, and (B) mean saltwater age (MSWA), N = 79. Line (c) indicates equal male and female MSWA; line (b), a difference of 6 months between male and female MSWA; and line (a) a 1-year difference in MSWA. Fillmore, Luck, and Petersburg Lakes have high proportions of returning jacks, resulting in low male MSWA.

Table 28—Regression analyses of trends across years in mean freshwater age (MFWA) and mean saltwater age (MSWA) of sockeye salmon stocks^a

Stream		No. years sampled	MFWA						MSWA					
Number	Name		Males			Females			Males			Females		
			R-squared	Slope	P-value	R-squared	Slope	P-value	R-squared	Slope	P-value	R-squared	Slope	P-value
101-30-075	Hugh Smith Lake	9	0.03	-0.01	0.5<P<0.9	0.07	-0.01	0.5<P<0.9	0.01	0.01	0.5<P<0.9	0.00	-0.00	P>0.9
102-60-087	Karta River	6	0.07	0.01	0.5<P<0.9	0.30	0.01	0.2<P<0.4	0.31	-0.05	0.2<P<0.4	0.38	-0.05	0.1<P<0.2
106-41-010	Salmon Bay Lake	6	0.00	-0.00	P>0.9	0.37	-0.01	0.1<P<0.2	0.07	-0.03	0.5<P<0.9	0.27	-0.07	0.2<P<0.4
108-80-110	Tahltan Lake	8	0.65	0.01	0.01<P<0.02 *	0.75	0.02	0.001<P<0.01 **	0.09	-0.01	0.5<P<0.9	0.15	-0.03	0.2<P<0.4
109-20-013	Falls Lake	7	0.30	-0.06	0.2<P<0.4	0.13	-0.03	0.4<P<0.5	0.30	-0.06	0.2<P<0.4	0.22	0.03	0.2<P<0.4
111-32-245	Little Trapper Lake	6	0.40	0.02	0.1<P<0.2	0.50	0.03	0.1<P<0.2	0.29	-0.02	0.2<P<0.4	0.11	-0.01	0.5<P<0.9
111-33-034	Speel Lake	7	0.25	0.01	0.2<P<0.4	0.56	0.01	0.5<P<0.1	0.10	0.02	0.4<P<0.5	0.00	-0.00	0.5<P<0.9
111-35-007	Crescent Lake	7	0.59	0.02	0.02<P<0.05 *	0.02	0.00	0.5<P<0.9	0.20	0.06	0.2<P<0.4	0.20	0.02	0.2<P<0.4
111-50-042	Auke Lake	8	0.14	-0.01	0.2<P<0.4	0.02	-0.01	0.5<P<0.9	0.03	-0.03	0.5<P<0.9	0.01	-0.01	0.5<P<0.9
113-41-043	Redoubt Lake	8	0.26	0.04	0.2<P<0.4	0.24	0.04	0.2<P<0.4	0.37	-0.05	0.1<P<0.2	0.55	-0.05	0.02<P<0.05*
115-32-032	Chilkat Lake	9	0.01	0.01	0.5<P<0.9	0.02	0.01	0.5<P<0.9	0.06	0.02	0.5<P<0.9	0.04	0.01	0.5<P<0.9
115-33-020	Chilkoot Lake	9	0.52	0.03	0.02<P<0.05 *	0.40	0.03	0.05<P<0.1	0.05	0.00	0.5<P<0.9	0.38	0.01	0.05<P<0.1
182-30-020	Klukshu Lake	6	0.12	0.01	0.4<P<0.5	0.00	-0.00	P>0.9	0.24	-0.03	0.2<P<0.4	0.60	-0.22	0.05<P<0.1
182-70-010	Situk River	6	0.28	-0.04	0.2<P<0.4	0.02	-0.01	0.5<P<0.9	0.43	0.06	0.1<P<0.2	0.00	-0.00	P>0.9

* = 0.05 > P > 0.01; ** = 0.01 > P > 0.001.

Tahltan, Crescent, and Chilkoot Lake stocks showed significant trends of increasing male MFWA of the 14 stocks with 6 or more years of data (table 28). Despite the tight correlation between male and female MFWA (fig. 31A), only Tahltan Lake females showed a significantly increasing trend. Females in the Crescent and Chilkoot stocks had increasing MFWAs, but the increases were not statistically significant.

Shiple Lake sockeye had a higher MFWA for both sexes than all other lake-type stocks (fig. 32, A and B). Most Shiple Lake sockeye spend at least 2 years in fresh water before emigrating to the ocean, but only 197 fish sampled over 2 years were in the sample. No river–sea-type stocks (N = 24) had a distinctive MFWA. The Hasselborg, East Alsek, Akwe, and Ahrnklin River stocks exhibited MFWAs ≤ 0.20 years, which suggests that large proportions of these populations were zero-check individuals. The Hasselborg and Ahrnklin stocks both were sampled for age composition for only 1 year (1989 and 1987, respectively).

Four lake-type stocks have distinctive levels of sexual difference in MFWA; in Christina and Kah Sheets Lakes, females spent more time in fresh water than did males, and in Shiple Lake and Buschmann Creek the opposite pattern was present (fig. 32C). Among these four populations, the Kah Sheets sample had 415 fish sampled over 5 years, but the others had less than 2 years of data. Two river–sea-type stocks, Chum Salmon Slough (Taku River) and Lost River, also had distinctive levels of MFWA difference (fig. 32D). Although Chum Salmon Slough has been sampled for only 2 years, in both cases females spent less time in fresh water than did males.

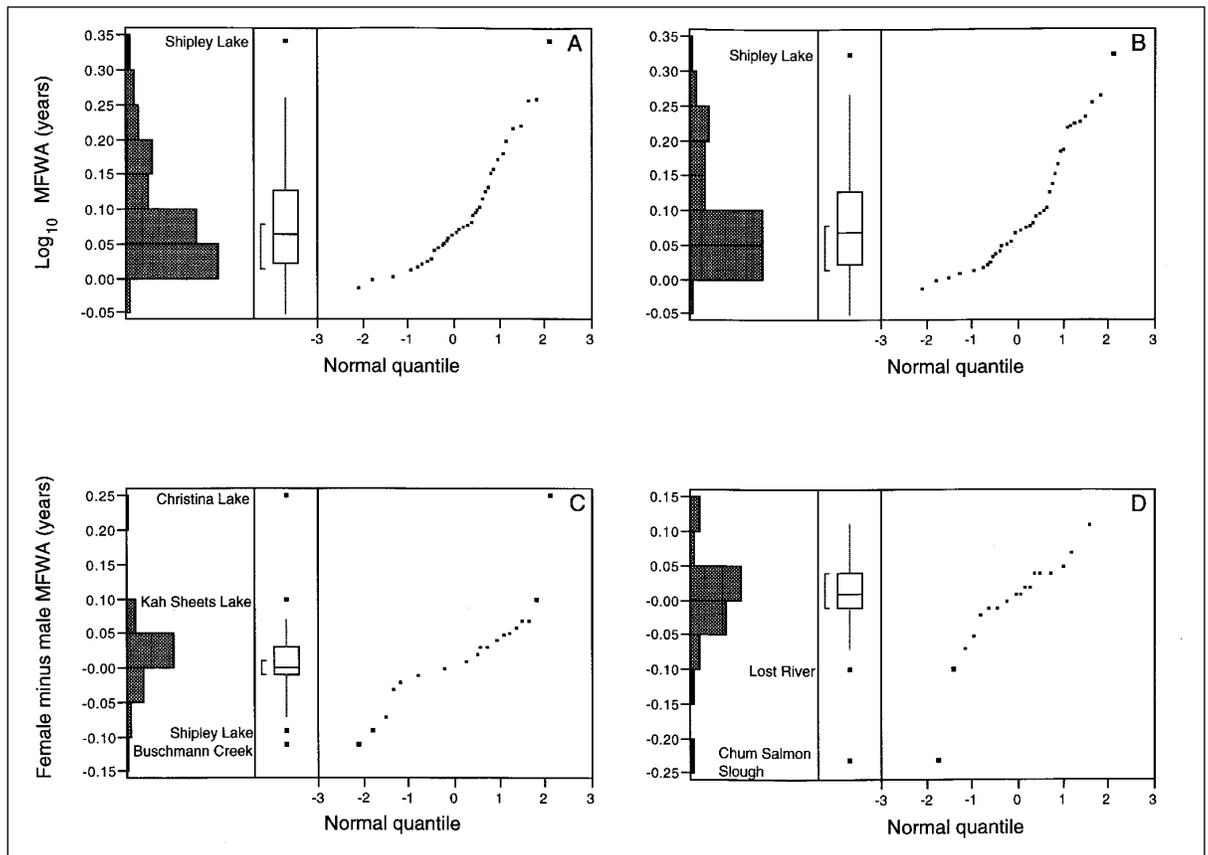


Figure 32—Frequency distributions, outlier plots, and normal quantile plots for mean freshwater age (MFWA) characteristics. **(A)** Lake-type males and **(B)** lake-type females. Shipley Lake males and females spend an average of 2.2 and 2.1 years in fresh water prior to emigration; both distinctively high MFWAs. Despite transformation these distributions were very nonnormal; $N = 55$. **(C)** Lake-type and **(D)** river–sea-type sexual differences in MFWA. All named stocks in (C) and (D) had distinctive

The annual variation of MFWA was high in the Falls Lake stock. Male MFWA ranged from 1.12 for the 1988 return to 1.86 for the 1984 return, and female MFWA ranged from 1.10 in 1988 to 1.93 in 1985. Falls Lake was fertilized from 1983 to 1985 (Burkett and others 1989), but data were not collected in enough years to determine if MFWA was highly variable before lake fertilization. Studies of Falls Lake in 1981 and 1982, before fertilization, found 40 percent and 83 percent, respectively, of age 2.0 smolts emigrating from this system (Koenings and others 1984). The extended rearing period was probably the result of forage limitations (Koenings and others 1984), and successful enhancement of lake productivity could account for the decrease in MFWA seen recently. Alternatively, high interannual variation in age structure could reflect run-strength cycles and the overlap of weak and strong brood years. Outlier analysis was not conducted on degree of interannual variation because only 14 stocks had sufficient data for inclusion.

The same set of stocks was used to evaluate MSWA. Sex-specific MSWA and MFWA were negatively correlated, significantly so for females (females, $r = -0.47$, $P < 0.001$; males, $r = -0.15$, $P = 0.17$). Because males return to spawn precociously at a much higher frequency than females, male and female MSWAs were not tightly correlated (fig. 31B). Distinctive levels of sexual differences in MSWA were present in Fillmore, Luck, and Petersburg Lakes (fig. 31B), but the Fillmore Lake stock was sampled for only 2 years. In the extreme cases of the Fillmore and Luck Lake stocks, female MSWAs were a year older than for males. High proportions (45 percent and 29 percent) of age 1.1 males in the escapement of these stocks may account for the difference between male and female MSWA. Escapement samples with > 20 percent jacks occurred in Trumpeter, Kutlaku, and Ford Arm Lake stocks, but these lakes also had high proportions of x.3 males or x.2 females, which reduced the overall difference in MSWA between males and females. Because age structure results involving jacks may have been strongly influenced by sampling methodology, these results should be interpreted cautiously.

The MSWA of females in 26 of 79 stocks ranged from 2.9 to 3.0, indicating very few females returned precociously. Bakewell and Leask Lake females had the lowest MSWAs, although Leask Lake was sampled only 1 or a few days each season. Bakewell Lake stock, which was established from stocked fry, was sampled throughout the course of its run, but for only 2 years. In both of these cases, the low female MSWA was attributable to high proportions of 2-ocean-year fish (age classes 1.2, 2.2, and 3.2). Assuming that 2-ocean-year females were large enough to be sampled proportionately, the low MSWA of these stocks may reflect distinctive maturation characteristics.

Year-to-year variation in MSWA was about the same as in MFWA, with no apparent relation between year-to-year variation in MSWA and MFWA. Mean saltwater age differed more for males than females in 11 of the 14 stocks. Redoubt Lake was the only stock showing a significant temporal trend in MSWA; female MSWA was decreasing significantly (table 28). Male MSWA was also decreasing in this stock but not significantly.

Outlier analyses of proportions of individuals in major age classes provided results similar to the MFWA and MSWA analyses. Because the separate age-class approach was more fine-grained, this technique identified a few additional stocks with unusual age-structure characteristics (figs. 33 and 34). Among lake-type stocks, Bakewell Lake had distinctively high proportions of age 1.2 males and females, Leask Lake had higher proportions of age 2.2 males and females than all other stocks, and Shipley and Auke Lakes had distinctively high proportions of age 2.3 females. Among river-sea-type stocks, the East Alsek and Lost Rivers had distinctively high proportions of 0.2 females, and the Ahrnklin River had higher proportions of 0.3 males (fig. 34).

Sex ratio—Sockeye stocks did not show the wide range of sex ratios seen in chinook and coho salmon stocks. Sex ratios (expressed as a percentage of males) for entire populations (all age classes) ranged from 0.37 for the Ford Arm Lake stock to 0.68 for the Hackett River stock (weir-sampled populations, throughout their runs; $N = 25$; fig. 35). These sex-ratio estimates typically did not account accurately for jacks. The sex ratios of the predominant age classes of these stocks had a similar range,

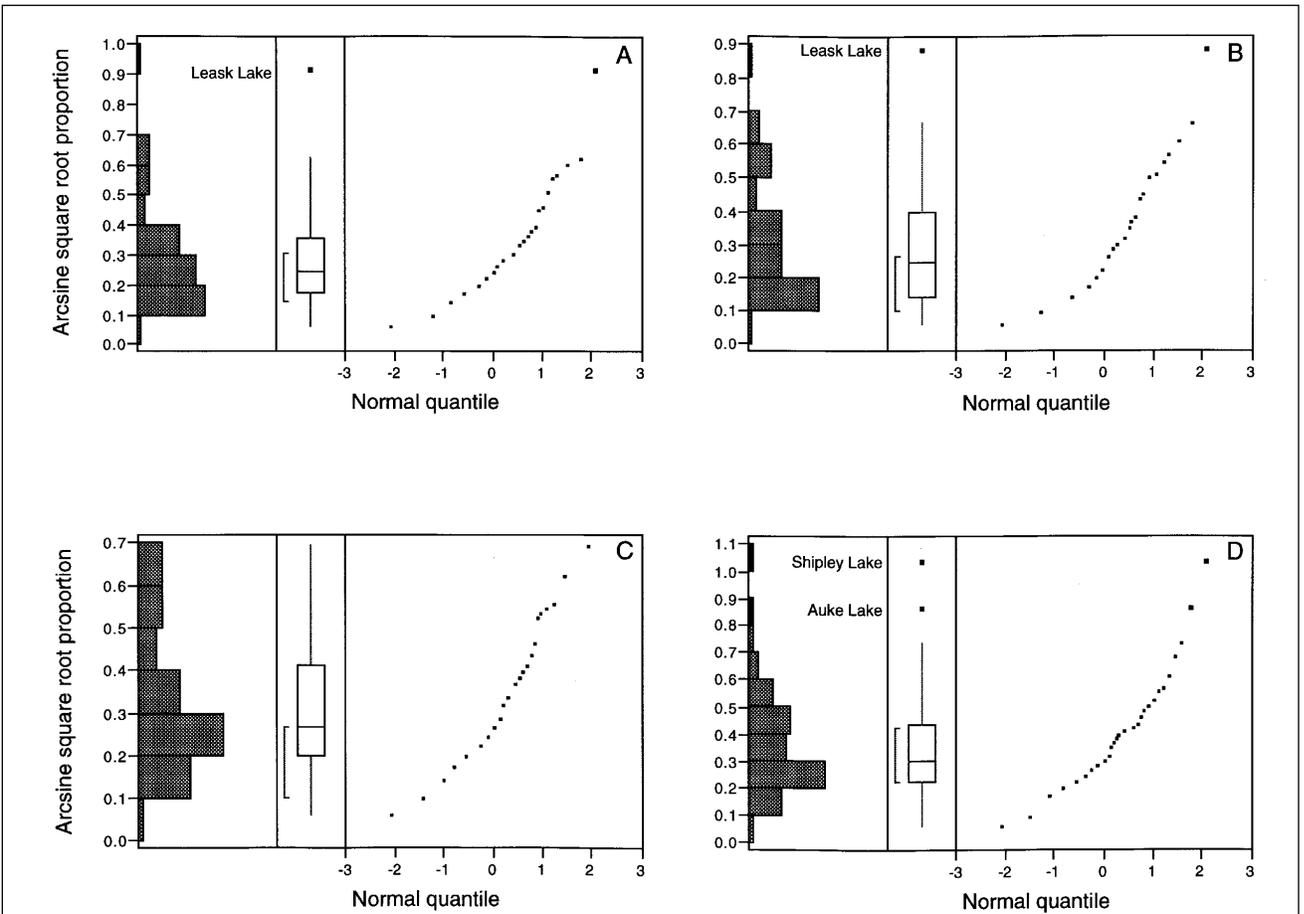


Figure 33—Frequency distributions, outlier plots, and normal quantile plots for proportions of individuals by age and sex classes in lake-type escapements. N = 51 for (A) age 2.2 males, (B) age 2.2 females, and (D) age 2.3 females; N=53 for (C) age 2.3 males. All distributions are very nonnormal despite transformation. All named stocks have distinctively high proportions of age 2.x individuals in escapements. Auke and Leask Lakes are represented by relatively large samples.

from 0.25 for Ford Arm Lake to 0.68 for Hackett River. The Hackett River stock was the only river-sea-type stock included in the evaluation of sex ratios, so whether a sex ratio skewed in favor of males was a general characteristic of zero-check stocks is unknown. The distribution of sex ratios for stocks in the region demonstrates that population sex ratios cluster near 1:1 (fig. 35). A similar pattern holds for the sex ratio of predominant age classes within populations.

The Hackett and Karta River systems had distinctive sex ratios in which males predominate, and the Ford Arm Lake sex ratio was skewed in favor of females (fig. 35).

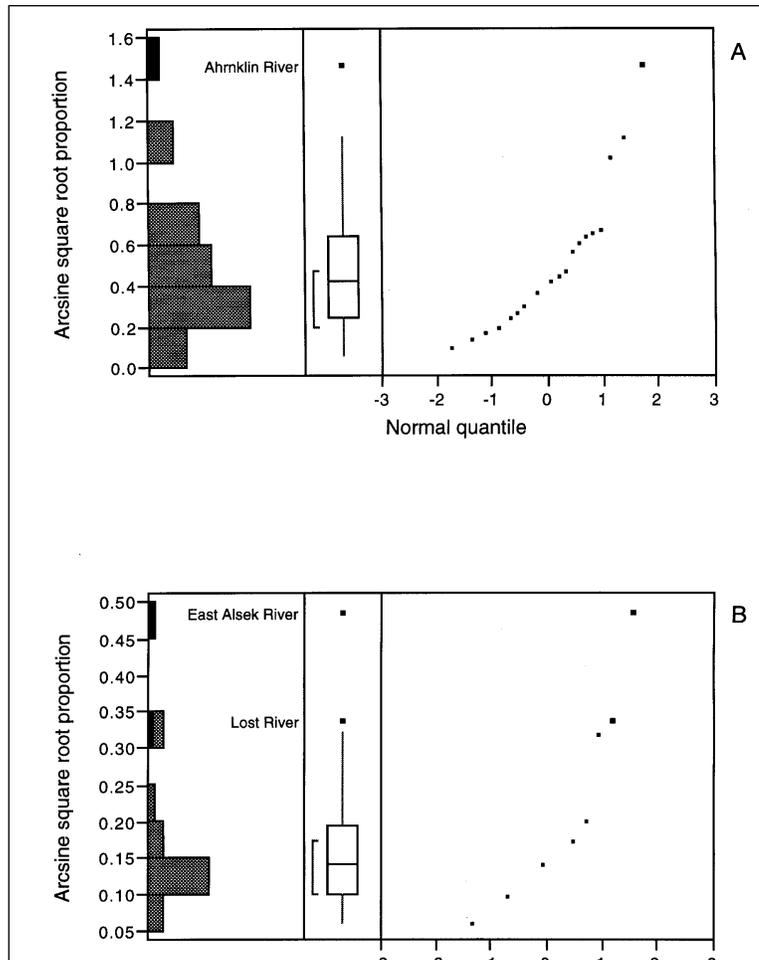


Figure 34—Frequency distributions, outlier plots, and normal quantile plots for proportions of individuals by age and sex classes in river-sea-type escapements: **(A)** age 0.3 males, N = 22; **(B)** age 0.2 females, N = 16. Both distributions are nonnormal despite transformation. Named stocks have distinctively high proportions of the respective age and sex classes in escapements. Samples from the East Alsek and Lost Rivers are relatively large.

Genetic Surveys

A survey of electrophoretic diversity of 52 sockeye populations throughout the region identified three geographic groupings that differed in allele frequencies (Guthrie and others 1994). These groups corresponded to the southern inside waters, the far southeastern islands including Prince of Wales Island, and inside waters of northern and central southeast Alaska. Two further groups, northern coastal and northern island, may exist but require additional sampling to confirm (Guthrie and others 1994). Analysis of stock groupings by migration entry routes yielded significant differences in total heterogeneity among entry route groups, but F-tests comparing heterogeneity within and among entry routes were not significant ($P = 0.10$; Guthrie and others 1994). Rearing habitat (i.e., lake versus river-sea) did not affect the underlying geographic patterns of genetic divergence (Guthrie and others 1994, Wood and others 1994).

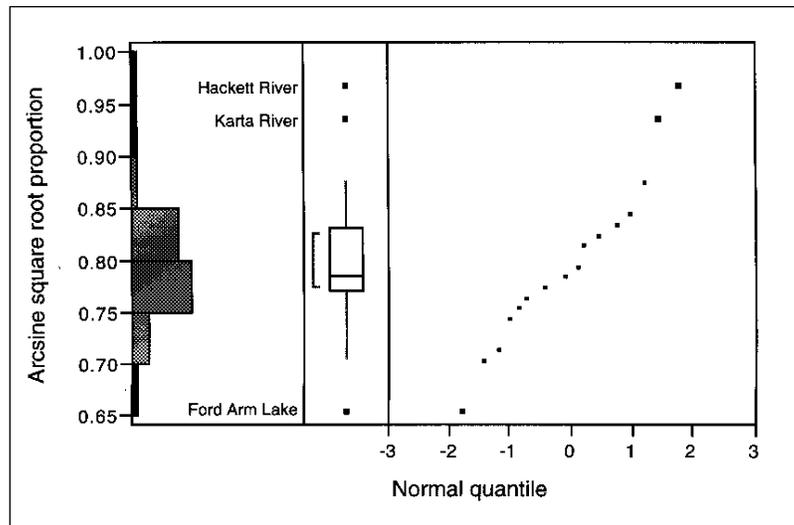


Figure 35—Frequency distribution, outlier plot, and normal quantile plot for proportion of males in escapements. Named stocks all have distinctive sex ratios, and all are represented by large samples collected at weirs.

Principal-component analysis and neighbor-joining trees suggested that the Tahltan and Sitkoh Lake stocks have unusual allele frequencies. Several other stocks diverged to a lesser degree (Shiple Creek, Galea Lake, and Juneau area stocks may have been influenced by the egg transfer from Afognak Lake). In their survey of British Columbia sockeye stocks, Wood and others (1994) found that fish from the Stikine and Taku drainages cluster with those from the Nass and Skeena Rivers to the south. The Klukshu Lake stock from the Alsek River drainage clustered with southern river stocks including the Fraser and Columbia (Wood and others 1994).

Six locations showed temporal heterogeneity in allele frequencies (McDonald Lake, Karta River, Salmon Bay Lake, Yehring Creek, Tatsamenie Lake, and the Chilkat drainage), thereby suggesting genetic substructure in these populations.

Anecdotal Reports

Seven stocks may have distinctive biological characteristics, but they were not included in the analyses because data were limited either in quantity or quality or the spawning location was uncertain.

- Excursion Inlet—Purse seine harvest is dominated by age 2.3 fish (McGregor and McPherson 1986). The predominance of this age class suggests a particularly high MFWA. Spawning location is unknown.
- Redfish Bay—Harvest is dominated by age 2.3 fish (McGregor 1983, McGregor and McPherson 1986). Again, the predominance of this age class suggests a particularly high MFWA. There has been a long exploitation history (Roppel 1982). Current management is based on annual determination of run strength in the bay and a limited purse seine fishery is allowed if adequate fish are present (see footnote 5).
- Essowah Lakes—Fish of small body size.⁷ Data from 1 year of sampling do not support this contention.

⁷ Personal communication. 1996. P. Peyton, consultant, P.O. Box 22871, Juneau, AK 99802.

- Kanalku Lake—Small body size and early migration timing.⁸ A fish pass constructed in the early 1970s was destroyed by high water within a few years of installation (Bibb 1987).
- Virginia Lake—May have small body size or low MSWA associated with flow limiting barriers (see footnotes 3 and 4). Fish passes, lake fertilization, and fry stocking have occurred at Virginia Lake, beginning in 1989 (Parry and others 1993).
- Mahoney Creek—May have small body size or low MSWA associated with flow limiting barriers (see footnotes 3 and 4).
- Kook Lake—Outlet stream passes underground in karst topography; some spawning occurs within the cave.⁹

Among river–sea-type stocks, the Hasselborg River stock deserves comment. This stock is thought to consist entirely of stream spawners, with juveniles rearing in a salt chuck rather than a freshwater lake.¹⁰ The Hasselborg River stock is also noteworthy in being located in a small clearwater stream on Admiralty Island while all other river–sea-type stocks are located on the mainland. Outside southeast Alaska, zero-check sockeye stocks are typically found in large glacial mainland systems (Wood and others 1987).

Discussion Evaluation of Results

Body length—The Speel and Crescent Lake stocks were the only stocks showing well-defined changes in body size; both stocks are increasing significantly in body length. Both stocks were considered to be depressed, relative to their former abundance, and were the object of time and area closures designed to allow rebuilding (McGregor 1985). Despite these restrictions, exploitation rates on these stocks have remained at about 55 percent, the mean estimated exploitation rate for 1983 to 1989 (Jensen and others 1990, McGregor and Jones 1989). The reduction in exploitation rates of these stocks or a partial shift from gill-net to purse-seine harvest may have contributed to an increase in the body size of fish in escapements (McPherson and McGregor 1986). Older and larger fish are known to be harvested differentially in gill-net fisheries (Jensen 1991, McGregor 1986, McPherson 1989). Increasing male size in the Speel and Crescent Lake stocks may have been the result of reduced selective removal of large fish.

There was a weak regionwide trend of increasing body length, particularly in males. Mathisen (1962) and Simpson (1969) suggest that large male sockeye are selectively harvested by gill nets in comparison to females. The switch to purse-seine harvesting may have accounted for the increase in the size of males.

⁸ Personal communication. 1996. M. Laker, fisheries biologist/ecologist, USDA Forest Service, Tongass National Forest, Admiralty National Monument, 8461 Old Dairy Road, Juneau, AK 99801.

⁹ Personal communication. 1996. V. Starostka, fishery and wildlife staff assistant, USDA Forest Service, Tongass National Forest, Chatham Area, 204 Siginaka Way, Stika, AK 99835.

¹⁰ Personal communication. 1996. S. McPherson, fisheries biologist, Alaska Department of Fish and Game, 801 3d Street, Douglas, AK 99824.

Alternatively, favorable ocean conditions in recent years may have contributed to the increases in male body length. There is some evidence of recent high ocean productivity (Brodeur and Ware 1993), but the interacting effects of ocean productivity and density-dependent competition on body size is unclear and possibly variable (McKinnell 1995; Peterman 1984, 1985; Rogers and Ruggerone 1993).

Timing—Interior stocks in southeast Alaska and in the Copper River (Merritt and Roberson 1986) have more compact runs than coastal stocks. Several factors may contribute to this pattern. The coastal climate is generally less variable than the continental climate of the interior, which may reduce the intensity of selection for precise timing of spawning, emergence, and emigration. Compact run timing also may be associated with compact emergence timing, possibly keyed to food resources or flow conditions. Flow rates also can contribute to compact run timing by creating temporary velocity blocks to spawner migrations. An example is on the Stikine River for stocks spawning in Tahltan Lake, an interior spawning area more than 300 km from saltwater (Richardson and Johnston 1966). The Tahltan Lake stock has compact run timing compared to other stocks in the area (Jensen and Frank 1988); however, results from Stikine River test fisheries indicate that the Tahltan Lake stock also has more compact run timing through nearshore waters than non-Tahltan stocks (coastal and interior) (Jensen and Frank 1988). Thus, both flow conditions and adaptive factors may contribute to compact run timing in the Tahltan Lake stock.

Analysis of trends in the mean migration dates of 13 stocks revealed that the two stocks with the longest data series, Tahltan and Chilkat Lakes, had significant changes in their mean migration dates. The Tahltan Lake stock is returning progressively earlier and the Chilkat Lake stock is returning progressively later. Fisheries probably selectively remove later fish in the Tahltan Lake stock, because this stock migrates through existing fisheries earlier than other stocks in its region (Jensen and Frank 1988). In contrast, fisheries are likely to remove early returning fish from the Chilkat run, because that run is later than other Lynn Canal runs. The Chilkat run has two distinct run segments, however; the later migration date may be due to strengthening of the later run segment relative to the early segment. The data were consistent with expectations based on fisheries effects, but other factors also may be influencing timing trends of the Chilkat stock.

The duration of the Chilkat run was longer than that of any other stock. Two distinct populations may be present in Chilkat Lake (Guthrie and others 1994, McPherson 1990). Currently, the late stock tends to be more abundant than the early stock. McPherson (1990) describes the spawning time of the early stock as extending from 15 July to 31 August and the late stock from 1 September to 15 February. The late return of the late stock is the primary cause of the extended run duration to Chilkat Lake. Both early and late stocks spawn along lake beaches as well as tributary streams. Juveniles resulting from late spawning are believed to emerge late and consequently show a 2.x or even a 3.x life history pattern. This difference in rearing time was reflected in the age structure of returning adults. The early component of the run to Chilkat Lake consists primarily of 1.x fish, and the late portion of the run consists primarily of 2.x fish.

Causes of potential divergence among stocks in Chilkat Lake are unknown, but two possible explanations are presented: (1) fisheries practices may selectively remove the central portion of the run, thereby imposing disruptive selection on run timing; and (2) flow reversals between Chilkat Lake and the Tsirku River may separate the stocks. When lake levels are low, or during high river flow conditions, river water from the Tsirku flows into Chilkat Lake; this flow reversal occurs regularly and is considered normal (Bergander and others 1988). Fish do not enter the lake during flow reversals. If flow reversals occur consistently and are sufficiently prolonged, they may impose a substantial gap in the migratory timing of fish into Chilkat Lake. Differences in run timing may in turn serve to reproductively isolate early and late populations to the degree necessary for genetic divergence. Prolonged flow reversals could have the effect of retarding the phenology of late-spawned juveniles and account for the higher proportion of age 2.x individuals in the late stock. In addition, unrecorded stocking or fry transfers cannot be excluded.

Chilkoot Lake also had relatively prolonged run timing. This lake also is believed to be inhabited by two distinct sockeye populations (McPherson 1990). Early and late migrating stocks in Chilkoot Lake overlap to a greater extent than the two stocks in Chilkat Lake; the spawning dates of the early and late stocks were defined by McPherson (1990) as 1 July to 15 August and 1 August to 15 October, respectively. The early stock spawns primarily in small tributaries and the later stock spawns in the mainstem of the Chilkoot River and on lake beaches (McPherson 1990). Both stocks in Chilkoot Lake are dominated by age 1.x individuals, with smolts leaving the lake at a comparatively small size (see footnote 10). The late stock is more abundant than the early stock, as is the case in Chilkat Lake.

The presence of two stocks in Chilkoot Lake may be the result of a transfer of 2 million eggs from Chilkat Lake in 1917 (Roppel 1982). Alternatively, natural colonization of Chilkoot Lake by sockeye from Chilkat Lake is certainly possible, given the proximity of these systems in upper Lynn Canal. The late runs in the two lakes differ in duration of spawning, location of spawning, duration of freshwater rearing period, and size at outmigration. Bimodal run timing also could be due to fisheries practices or habitat segregation.

Hugh Smith and Kegan Lakes are other locations having prolonged migrations and some indications, not statistically significant, of genetic divergence within the population (Guthrie and others 1994). No transfers of eggs from other stocks are known to have occurred to either of these stocks. Escapements to Hugh Smith Lake in some years show bimodality in run timing (Bergander 1972). Two streams are the primary spawning locations for Hugh Smith Lake sockeye; Cobb Creek spawners have compact run timing, and Buschmann Creek spawners have protracted run timing (see footnotes 3 and 4). Historically, very heavy fishing pressure (Kutchin 1903, cited in Roppel 1982) may have reduced the population to a few fish. In addition, hatchery operations and lake fertilization (Peltz and Koenings 1989, Roppel 1982) may have influenced run timing. Hatchery-incubated fry were stocked in Hugh Smith Lake from 1986 through 1992 in numbers ranging from 250,000 to 1,480,800 (see footnotes 3 and 4). The potential effects of enhancement activities on run timing have been demonstrated by recent fry plants: fry hatched from eggs taken from Buschmann Creek during a brief segment of the run were replanted into Hugh Smith Lake, and corresponding changes in run timing were noted (see footnotes 3 and 4).

Among interior stocks in the Taku River, the Little Tatsamenie Lake system stock has protracted run timing past the Canyon Island fish wheel (McGregor and others 1991). This stock also shows genetic heterogeneity (Guthrie and others 1994), providing another example of a potential association between run duration and genetic structure of sockeye populations. The run duration of the Klukshu Lake stock is over twice that of any other interior stock and, like other stocks with prolonged runs, is likely to exhibit within-population heterogeneity in allozyme frequencies.

Demography, declining stocks—The eight stocks having significant population declines showed no apparent patterns in terms of geographic location or stock size. Five of these stocks were found in systems having minimal known human impacts on spawning habitats (Hunter Bay, Klakas Lake, Lake Creek-Shipley Bay, Gut Bay, and Situk River). Declines in these stocks may be due to natural variability, changes in the capability of the habitat to support sockeye salmon, or changes in harvest patterns.

Three declining stocks were found in systems with differing degrees of human impacts on spawning habitats. The Auke Lake stock is monitored at a weir. Pavlof Lake stocks are counted during foot surveys, and those at Mosquito Lake have changed from foot surveys to boat survey to fixed wing aerial surveys.

Among causes thought to be responsible for the decline of the Auke Lake stock are (1) alteration of spawning habitat, including gravel removal from and road building near Lake Creek, the primary spawning tributary; (2) limnological changes caused by wastewater effluent entering the lake; and (3) experimental manipulations, which involved smolt trapping and ensuing high smolt mortality (Taylor 1987). A drought in summer 1993 caused the outlet stream to Auke Lake to dry up, and sockeye were mechanically transported to Auke Lake for part of the run. Low water also led to spawning in suboptimal habitats. These factors may contribute to further declines in the Auke Lake stock. Sport-fishing restrictions have been instituted in Auke Bay to protect returning sockeye.

If counts completed by the USFWS from 1953 to 1959 are included in the regression analysis for the Pavlof Lake stock, the decline becomes nonsignificant ($0.1 < P < 0.2$); however, historical escapements up to 50,000 sockeye were reported before 1900 (Moser 1902, cited in Bibb 1987). A step-pool fishway was completed in 1935 to circumvent a 4.3-m waterfall at tidewater. This fishway was replaced with a more effective fish pass in 1974; an additional fish pass was added at a 2.8-m falls above Pavlof Lake in 1987.¹¹ Increased competition with other salmonids due to access provided by these fishways, heavy subsistence harvest, and changes in habitat quality due to road building and timber harvest may be contributing factors to sockeye population decline in this system.

The mean escapement survey count was 119 sockeye salmon for Mosquito Lake. Habitat degradation, caused by residential development around the lake, and the potential for high sport harvest as a result of easy lake access are possible contributors to the decline of this stock.

¹¹ Personal communication. 1996. C. James, biological technician, USDA Forest Service, Tongass National Forest, Hoonah Ranger District, P.O. Box 135, Hoonah, AK 99829.

Escapement magnitude—McDonald Lake is the only exceptionally large sockeye stock remaining in the southern half of southeast Alaska. It also has been extensively manipulated. Nutrients have been added to the lake in recent years. Eggs and fry were stocked from Afognak (Litnik) Lake decades ago (Roppel 1982). In addition, hatchery operations, predator control, releases of brook trout, lake fertilization (Burkett and others 1989), and heavy harvests (Roppel 1982) may have modified stock composition.

Harvest of sockeye salmon in the East Alsek system have increased dramatically in recent years, from an average of 13,798 fish in 1960-79 to 83,532 fish in 1980-88, which probably reflects expansion of the stock, as well as an increase in fishing effort (Rowse 1990). In contrast to the McDonald Lake stock, the East Alsek stock does not have a long history of manipulation and exploitation but was exposed to substantial recent changes in stream-channel morphology. Migration of the Alsek River channel and ground-water upwelling through gravel deposits resulted in the formation of the East Alsek River in the 1960s (McPherson 1987). The East Alsek River is relatively short (about 12 km), is of low gradient, and has no available lake for rearing habitat, which may account for the high incidence of zero-check individuals. The high proportion of gill-net harvest of this stock may be contributing to the high proportion of age 0.2 fish in escapements. The East Alsek River currently supports the largest sockeye fishery in the Yakutat region (Pahlke 1989a, Rowse 1990).

Age structure—Exploitation rates on older and larger fish tend to be higher (e.g., Jensen 1991, McGregor 1986, McPherson 1989), and the expected effect of selective removal of large fish by gill nets is a decrease in age in escapements. In general, fish harvested by purse seine tend to be younger and more variable in age than fish taken by gill net (McPherson and McGregor 1986). The only significant trends in age structure we found were for increasing age, which may reflect an increasing trend in the proportion of the catch taken by purse seines. Other factors that might contribute to the weak trend of increasing age are ocean conditions favorable to growth in recent years and dramatic differences in the recruitment strength of certain year-classes (see footnote 1). If the progeny of a very strong year-class were to dominate returns for several years, this would result in a progressive increase in age for a stock over the course of a 5- to 10-year time series.

The MFWA of sockeye in Shipley, Auke, and Leask Lakes was greater than other stocks in southeast Alaska (figs. 32 and 33). The estimate of MFWA of the Shipley Lake came from a small sample in only 2 years. A hatchery operated for 1 year, 1903, at Shipley Lake and 1,700,000 fry were planted in the lake during this year (Roppel 1982). Presumably the fry planted were the result of eggs being taken from Shipley Lake. Auke Lake sockeye showed a high proportion of age 2.3 individuals in escapements. More than 5 million sockeye eggs were transferred from Afognak Lake to Auke Lake in 1922 (Roppel 1982), but this transfer is unlikely to explain the unusual age structure, because age 2.3 individuals made up less than 15 percent of escapements to Afognak Lake from 1985 to 1989 (White and others 1990). Furthermore, survival of the transferred eggs is thought to have been very low (Roppel 1982). Leask Lake had an exceptionally high proportion of age 2.2 individuals in escapements. Usually only a small segment of the run was sampled each year and the sample dates differed among years, but high proportions of age 2.2 individuals were found in samples from all years.

The Leask Lake sockeye stock had a relatively low female M_{SWA}, compared to other lake stocks in the region (in addition to having a high M_{FWA}). Abbreviated ocean residence by the Leask Lake stock may be associated with a small barrier to migration that is negotiable only by smaller fish (see footnotes 3 and 4). For sockeye salmon, returning after 2 ocean years may be functionally equivalent to the early season returns seen in coho salmon that inhabit locations with flow barriers. Early returns are not associated with particularly rapid ocean growth: 2-ocean-year females from Leask Lake return at sizes similar to those of 2-ocean-year females from other stocks.

The decreasing trend in M_{SWA} in the Redoubt Lake stock may be related to lake fertilization. A significant increase in smolt size has occurred since fertilization of this lake began in 1984 (Burkett and others 1989), and larger smolts tend to spend less time in the ocean (Bradford and Peterman 1987; but see also Koenings and others 1993). Hyatt and Stockner (1985) suggest that less time in the ocean reduces exposure to marine predators and may increase marine survival, which in combination with the predator-avoidance advantages of larger smolts, may contribute to a positive relation between smolt size and marine survival. When lake-fertilization programs increase the number of returning fish, body size often decreases (Hyatt and Stockner 1985), but this trend was not evident at Redoubt Lake. Although the number of sockeye returning to Redoubt Lake is increasing nearly significantly, body-length data from 1982 to 1989 showed no significant trend in body size for age 2.2 individuals (table 22).

Sex ratio—The sex ratio tends to be close to 1:1 for most sockeye salmon stocks. This may be the result of nonselective purse-seine harvests that do not differentially remove larger (male) sockeye. Only Speel and Crescent Lakes showed high levels of interannual variation in sex ratio, for unknown reasons. At Crescent Lake this variation might be due to fish escaping through the weir, which would prevent proportional sampling (see footnote 5).

The comparisons used to identify distinctive sockeye stocks were regionwide in scope. The geographic framework was based on political boundaries rather than biological criteria. Analysis of genetic divergence among sockeye populations indicated that genetic variability within the region clusters into three geographically definable groups.¹² The process of identifying distinctive stocks therefore might be more appropriately conducted at smaller geographic scale of these genetic groups. As techniques for genetic characterization of populations improve, and additional data allow refinement of methods used to discriminate phenotypically distinctive stocks, comparative analyses at smaller scales should be considered. Large drainage basins that contain numerous sockeye populations, such as the Taku River basin, constitute a biologically meaningful lower limit of geographic scale for conducting the sort of comparative phenotypic analyses presented here.

Conceptual Issues

Sexual selection—Sexual selection in Pacific salmon has not been well studied, despite several life history attributes that render these species particularly suitable subjects for studies of reproductive behavior and the evolution of sexual dimorphism (Quinn and Foote 1994). The intense competition associated with semelparity and a relatively short peak spawning season, facilitate the determination of factors that may

¹² Personal communication. 1996. C. Guthrie, fishery biologist, National Marine Fisheries Service, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801.

be responsible for differences in morphology and reproductive behavior (Quinn and Foote 1994). Among Pacific salmon, sockeye are noted for high levels of sexual dimorphism and particularly bright spawning coloration.

The typical pattern of age 1.3 and 2.3 males being larger than females may be the result of competition among males for access to females. Large size may provide an advantage in this competition (Hanson and Smith 1967, Quinn and Foote 1994; but see Healey 1987; Holtby and Healey 1986, 1990; Schroder 1981). The greater level of sexual dimorphism found in river-sea-type stocks suggests that sexual selection may be more intense in these stocks. Competition for access to females could be intensified by a high level of synchronization in spawning or by sex ratios biased in favor of males (e.g., Schroder 1982). Increased sexual dimorphism also could result from relaxation of selection for large body size on females (if spawning habitat is not limited) or intensified selection by abiotic factors for reduced female size (Fleming and Gross 1989, Healey 1987).

The strong correlation between length and fecundity in females may constrain possible female body lengths to a more narrow range than that for male body lengths. These constraints could produce the observed pattern of female sockeye salmon having a higher level of stock-specificity in body length than males, as seen in our variance component analysis. Male body size may be subject to a more complicated suite of selection pressures that has the net effect of increasing variability. For instance, sexual selection may favor larger body size in males that pursue a competitive reproductive strategy, but the potential for successfully pursuing alternate reproductive strategies, such as returning as jacks, could maintain genetic diversity for small size (Gross 1985, 1991).

Body size and shape, especially hump size, were good predictors of male breeding success among beach-spawners in Iliamna Lake (Quinn and Foote 1994). Lake spawners are most likely to show the greatest hump development, and perhaps the least length dimorphism, compared to river or stream spawners. Energetic costs associated with increased hump size may limit development of this characteristic in river spawners, especially those using interior rivers. Increased length dimorphism in river-sea-type stocks may be permitted by reduced energetic investment in hump development. In stream spawners, bear predation as well as water depth and current are likely to limit hump development (Quinn and Foote 1994).

Sea-type sockeye stocks, and life history evolution—Phylogenetic relationships among sockeye, pink, and chum salmon are subject to debate. Evidence from studies of morphology (Smith and Stearley 1989), biochemistry (Utter and others 1973), and nuclear DNA support a sister group relationship between sockeye and pink salmon. Life history (Smith and Stearley 1989) and mtDNA (Thomas and others 1986) data support a sister group relationship between pink and chum salmon. One derived life-history characteristic used to support the close relationship between pink and chum salmon is the reduced freshwater phase, with juveniles ready to emigrate as they emerge from the gravel (Smith and Stearley 1989). This capacity can be viewed as the current endpoint in an evolutionary trend toward decreasing reliance on freshwater spawning and rearing habitats. Studies of zero-check sockeye in the Situk River indicate that some sockeye begin moving to estuarine environments at a

small size (about 50 mm in fork length) and the timing of emigration for some sockeye in these populations is similar to that of pink and chum stocks in the system (Heifetz and others 1989, Thedinga and others 1993). This work suggests that the emigration behavior of sea-type sockeye is intermediate between that of the pink-chum group and the chinook-coho group. Information on the emigration behavior of other sea-type sockeye stocks is needed to determine the usefulness of this characteristic for testing phylogenetic hypotheses. The relatively numerous sea-type sockeye stocks found in southeast Alaska could be useful in this context.

The East Alsek River stock could provide an opportunity for investigating the pace of adaptation for freshwater rearing period. The East Alsek River separated from the mainstem Alsek during the 1960s. The main Alsek River is not known to have a large sea-type component in its sockeye population (McBride and Bernard 1984; Rowse 1990). The development of a large sea-type stock in the East Alsek may have resulted from (1) colonization of the East Alsek River by the relatively rare sea-type fish from the Alsek River stock preadapted to the novel conditions encountered in the East Alsek; (2) colonization by strays from nearby systems with similar habitat characteristics and dominated by sockeye stocks with sea-type life histories; (3) a rapid, environmentally induced (phenotypic) shift in life history by lake- or river-type colonists from the Alsek River; or (4) an extremely rapid adaptive (genotypic) shift in life history. Genetic techniques that permit relatively fine-grained discrimination of stocks may permit a test of these hypotheses by helping to determine the source or sources of East Alsek River colonists.

Most sea-type stocks occur in morphologically active river systems, with shifting channels and high sediment loads. Many river systems in southeast Alaska have active glaciers and may have been blocked by recent movement of these glaciers (e.g., Ferrans and Nichols 1955). As a result, access to lake spawning and rearing areas may have been blocked, thereby leaving no alternative for fry except for a sea-type life history. Landslides also can block access to upstream lakes, and sea-type sockeye observed in the Fraser River by Birtwell and others (1987) may be the result of the landslide that occurred at Hell's Gate in 1913 (Foerster 1968). River blockages also contribute to the development of strictly freshwater populations of sockeye (kokanee).

Parasites—At least 42 different species of parasites and numerous bacterial and viral pathogens infect sockeye salmon (Margolis 1963, cited in Foerster 1968). Most work on the parasitology of sockeye salmon has been on using parasites for stock separation or to investigate aspects of life history, such as migratory behavior (Konovalov 1995, Quinn and others 1987). In a recent review of sockeye life history, Burgner (1991) refers to parasites only in terms of prespawning mortalities in Fraser River runs and as a possible factor in Skeena River population cycles. Relatively little research has been conducted on the effects of parasites on the ecology and population dynamics of sockeye stocks, despite their potential importance. Garnick and Margolis (1990), for example, report that helminth parasites may have detrimental effects on the ability of sockeye smolts to orient properly. Detrimental effects of parasites are generally more severe in juvenile life stages, but these critical stages are the least studied.

In southeast Alaska, the presence of *Myxobolus neurobius* has been widely investigated as a biological marker for separating stocks (Moles 1987, Moles and others 1990), but the pathology caused by this parasite is not well understood. The pathology of infectious hematopoietic necrosis virus (IHNV) is better studied, because of its detrimental effects on hatchery production of sockeye (Saft and Pratt 1986). The effects of this nearly ubiquitous virus on wild stocks in southeast Alaska are unknown. Epizootic outbreaks of this virus have been reported from British Columbia (e.g., Williams and Amend 1976). Because of the usefulness of parasites in sockeye stock separation, more information is available on the parasites of sockeye stocks than for stocks of other Pacific salmon in the region. This parasite-distribution information sets the stage for studies of the ecological and evolutionary effects of parasites on sockeye populations. *Myxobolus neurobius*, for example, was found in all sampled populations in southeast Alaska except Steep Creek, Chilkat, and Chilkoot Lakes (Moles 1987), but why these populations are not parasitized is unknown. Experimental infections can be used to determine if absence of certain parasites indicates resistance or lack of exposure. Parasite resistance is a component of intraspecific diversity with important ramifications for enhancement programs.

Variation in run strength and cyclic patterns—Sockeye salmon runs are highly variable and often show little relation between escapement and recruitment (Foerster 1968). Eggers and Rogers (1987) ascribe fluctuations to compensatory fishing, but Walters and Woodey (1992) suggest that cyclic fluctuations are natural. Numerous factors in both freshwater and saltwater environments probably contribute to fluctuations in run size, but one of the goals of management is to maintain constant "optimum" escapement numbers to major sockeye salmon producing systems. The ecological effects of modifying cyclical escapements of sockeye salmon are largely unknown.

Long-term ecological consequences of sockeye salmon cycles include effects on nutrient budgets, predator-prey interactions, juvenile salmonid survival and growth, and zooplankton populations. Large escapements of sockeye salmon deliver nutrient pulses to stream and lake ecosystems (Kline and others 1990, 1993; Mathisen 1972; Richey and others 1975), which increases productivity of the aquatic ecosystem. Large populations of sockeye fry are capable of overgrazing their zooplankton forage base (Koenings and Burkett 1987), and size-selective predation by juvenile sockeye salmon can alter zooplankton population structure (Stockner 1987). Density-dependent effects decrease juvenile sockeye salmon growth and increase freshwater residence time, resulting in higher predation rates by juvenile coho salmon or other species that prey on sockeye fry (Ruggerone and Rogers 1992).

Risk Factors

Although few sockeye stocks in southeast Alaska seem to be declining, several potential risk factors exist, including fishing pressure, enhancement activities, and habitat degradation. None seems to offer immediate threats to most stocks in southeast Alaska, but risk to smaller stocks or localized stocks may be greater than for other larger stocks that are more closely monitored.

Risks from fishing pressure derive from overexploitation and harvest of mixed stocks. Sockeye salmon are among the most economically valuable of salmon species harvested in the region, which can lead to increased harvest demands. Consequently, managers are likely to face increasing pressure from fishers to increase quotas,

decrease escapement goals, or produce more fish. Mixed-stock management increases the vulnerability of small stocks (e.g., Hilborn 1985). Escapements of small stocks often are not well monitored and management of them often is lumped with larger stocks. Subsistence fishing on localized sockeye stocks may be substantial and harvest rates can be difficult to manage.

Lake fertilization is one of the more common enhancement efforts to increase sockeye salmon production. Although lake fertilization can increase the number of sockeye salmon available for harvest, potential risks include overexploitation of natural stocks mixed with artificially enhanced stocks, changes in biological characteristics of stocks, and changes in ecosystem dynamics resulting from increased sockeye fry numbers and lake productivity.

Fertilization tends to be successful in increasing the harvestable biomass of sockeye stocks. When fertilization increases the number of sockeye salmon, the fishery usually expands, which can lead to overharvest of other stocks with lower productivity that pass through the fishery (see Hilborn 1985). The most obvious management remedy is to increase harvest effort on the harvest area nearest the enhanced stock. If fertilization is discontinued, the new harvest levels must be established to avoid overexploiting stocks producing at prefertilization levels. Although fertilization may increase the number of harvestable fish, the size of returning fish decreased in some Canadian populations after fertilization (Hyatt and Stockner 1985). Lake fertilization may produce responses in zooplankton populations and lake ecology similar to those suggested during cyclic patterns of sockeye escapement, such as changes in zooplankton species composition and cyclic patterns of zooplankton productivity.

Stocks in particular habitats or locations may be vulnerable to habitat alterations, either natural or human-caused. Sockeye stocks with high proportions of stream spawners may have more variable productivity than stocks dominated by lake spawners. The Auke Lake stock, for example, has a high proportion of stream spawners and unstable fry production, caused by fall freshets that scour redds and low winter flows that leave redds without enough water (Taylor 1987). Urban development around Lake Creek, the primary spawning area of the Auke Lake stock, contributes to increased sediment load to the spawning area. Stream-spawning sockeye stocks are more likely than lake spawners to be adversely affected by land-use activities that disrupt the hydrology and flow regimes of watersheds or increase sediment loads.

The potential for the Hubbard Glacier to block Russell Fjord and divert its water through the channel of the Situk River is a unique risk factor. Most sea-type sockeye that spawn in the Situk system use the Old Situk River, the channel that would be most heavily affected by flooding (Thedinga and others 1993). Furthermore, the Old Situk channel provides important winter habitat for river-type sockeye in the Situk system (Thedinga and others 1993). New habitat would be created following the flow alterations, but habitats and population would be unstable for an unknown period of time.

Conclusions

About 200 populations of sockeye salmon are relatively evenly distributed throughout the study region. At least 7 years of escapement data are available for 97 of these stocks, and data on biological characteristics are available from at least 1 year of sampling for 85 stocks. Most stocks in the region have a lake-type life history, but at least 24 stocks have relatively large proportions of individuals that have either a river- or sea-type life history, including most stocks on the Yakutat forelands.

Age 1.3 individuals tended to be larger than age 2.3 individuals, indicating that the extra year in fresh water does not lead to larger adult size. Body size of sockeye salmon showed a generally increasing trend, in contrast to the decreasing trends present in other species of Pacific salmon in the region. Run timing of interior stocks was significantly more compact than timing of island or coastal-mainland stocks.

Surveys of electrophoretic allele frequencies indicated strong geographic patterning, and at least three geographic clusters have been recognized (southern inside, south-eastern island, and inside north and central).

A larger proportion of sockeye stocks have distinctive characteristics than do other species of Pacific salmon evaluated. This may reflect a combination of higher level of homing fidelity attributed to sockeye salmon, which reduces gene flow among populations, high levels of phenotypic plasticity in response to differing environmental conditions, or the superior quantity and quality of data available for sockeye stocks.

The following stocks had distinctive biological characteristics, based on relatively large samples (see fig. 36 for approximate geographic locations):

- Leask Lake—high proportions of age 2.2 individuals of both sexes in escapements.
- McDonald Lake (Hatchery Creek)—large population size (possibly artificially maintained by lake fertilization); high proportion of stream spawners; possibly two stocks present.
- Karta River—distinctively large age 1.2 males. This stock is near or at the top of the size distribution for all other sex and age classes. Sex ratio skewed in favor of males.
- Luck Lake—reverse sexual size difference, and high level of sexual difference in MSWA (high jack proportion).
- Kah Sheets Lake—high level of sexual difference in MFWA (females remain in fresh water longer).
- Petersburg Lake—high level of sexual difference in MSWA (high proportion of jacks).
- Hackett River—river-type stock with a sex ratio skewed toward males.
- Auke Lake—high proportions of age 2.3 females in escapements; also a declining population.
- Ford Arm Lake—lake-type stock with a sex ratio skewed toward females.
- Chilkat Lake—large population size; two separate stocks probably present; prolonged run duration.
- Chilkoot Lake—large population size; two separate stocks probably present.
- East Alsek River—high proportion of age 0.2 individuals in escapements of this distinctively large sea-type stock (mean escapements > 30,000 fish).

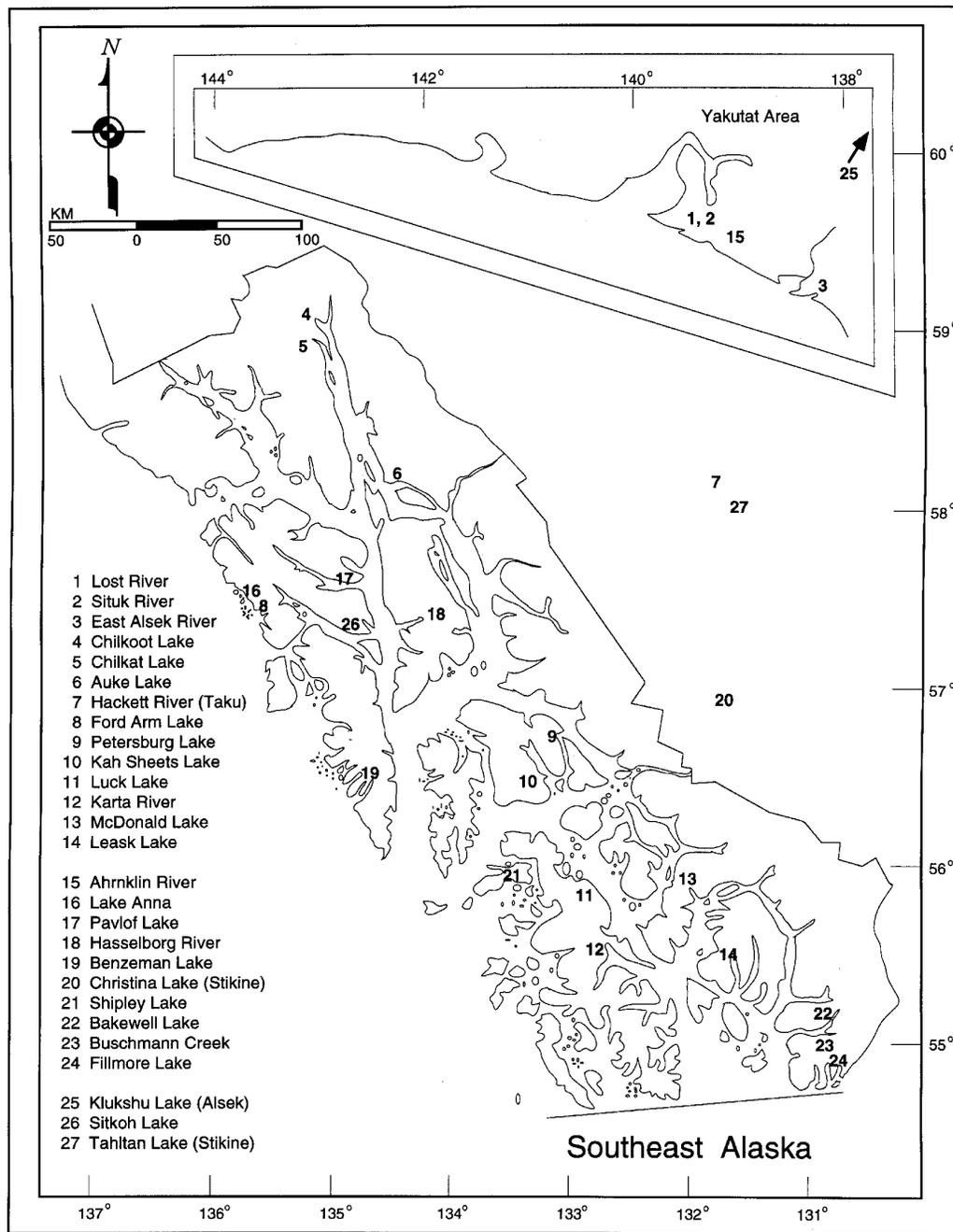


Figure 36—Approximate geographic locations in the study area of sockeye salmon stocks that have distinctive characteristics. Stocks 1 to 14 have been sampled relatively thoroughly. Stocks 15 to 24 are preliminary results based on limited samples. Stocks 25 to 27 have distinctive allele frequencies based on surveys by Guthrie and others (1994) and Wood and others (1994).

- Situk River—large population size; lake-, river-, and sea-type life histories all in the same system.
- Lost River—high level of sexual difference in MFWA (males remain in fresh water longer); high proportion of age 0.2 females in escapements.

The following stocks show distinctive characteristics based on limited sampling (these results are preliminary):

- Fillmore Lake—large sexual difference in MSWA (high proportion of jacks).
- Buschmann Creek—large sexual difference in MFWA.
- Bakewell Lake—high proportion of age 1.2 individuals of both sexes; an artificial population.
- Shipley Lake—high MFWA, high proportions of age 2.3 females in escapements; large sexual difference in MFWA; also a declining population.
- Christina Lake—large sexual difference in MFWA.
- Pavlof Lake—large sexual difference in body length of age 1.3 individuals; also a declining population.
- Hasselborg River—zero-check life history predominates; only island stock having this life-history pattern; stream spawning with juveniles rearing in salt chuck.
- Lake Anna—large sexual difference in body length of age 1.3 individuals.
- Benzeman Lake-Necker Bay—small adult body size (in harvest); age 2.2 and 2.3 fish predominate (in harvest).
- Ahrnklin River—high proportion of age 0.3 males.

The following stocks have unusual electrophoretic allozyme frequencies, based on existing surveys:

- Tahltan Lake—interior lake in the Stikine River drainage; this stock also may produce smaller eggs than other Stikine stocks (Craig 1985).
- Sitkoh Lake—only Chichagof Island stock included in the analysis.
- Klukshu Lake—interior lake in the Alsek River drainage; clusters with southern British Columbia stocks.

Based on anecdotal reports the following stocks may have distinctive characteristics:

- Excursion Inlet—purse-seine harvest in the inlet dominated by age 2.3 fish; the predominance of this age class suggests a particularly high MFWA; spawning location unknown.
- Redfish Bay—harvest dominated by age 2.3 fish; the predominance of this age class suggests a particularly high MFWA.
- Kanalku Lake—small body size and early migration timing.
- Mahoney Creek—may have small body size or low MSWA associated with flow-limiting barrier.
- Virginia Lake—possible small body size or low MSWA associated with historic barrier; effects of fish pass and intensive enhancement activities on native population unknown.
- Kook Lake—karst topography, cave spawning.

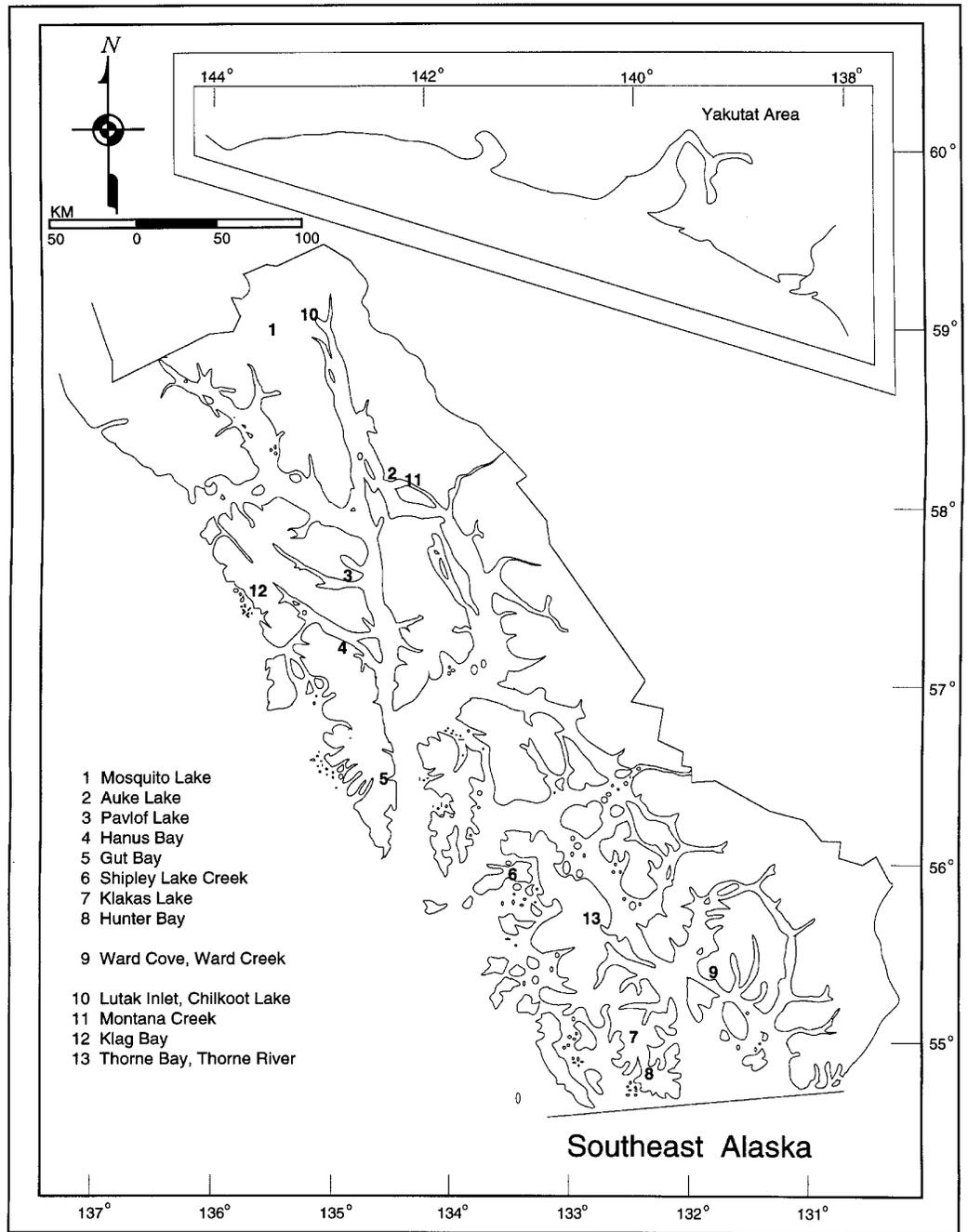


Figure 37—Approximate geographic locations in the study area of sockeye stocks with significantly declining escapement trends (stocks 1 to 8), or that inhabit “impaired” (Ward Cove, stock 9) or “suspected” water bodies (stocks 10 to 13).

Significantly declining escapement trends were found for eight sockeye salmon populations (8 percent of those evaluated; see fig. 37 for approximate geographic locations). Only two of the eight stocks were represented by relatively good data. Distinctive characteristics were present in three of the declining populations. Five declining populations were in relatively undisturbed watersheds. Of the six sockeye stocks inhabiting impaired or suspected water bodies, four were surveyed enough times to permit evaluation of population trends; three were stable, and one (Auke Lake) was declining significantly. Lutak Inlet, a suspected water body, may serve as a rearing area for the distinctively large and commercially important Chilkoot Lake stock.

The overall status of sockeye populations in southeast Alaska is good, but potential risks include (1) increased demand for this commercially valuable species; (2) over-exploitation of small, artificially enhanced, or weak stocks in mixed-stock fisheries; (3) heavy and poorly monitored subsistence harvests; and (4) lack of adequate information about small populations.

Acknowledgments

L. Talley and S. Johnson provided professional assistance in accessing the information contained in the ADF&G Integrated Fishery Database. G. Gunstrom, M. Harris, S. McPherson, and K. Savikko provided ADF&G documents that were the foundation of this report, and J. Helle provided important documents from the Pacific Salmon Commission and the National Marine Fisheries Service. S. Marshall provided both access to the information resources of the ADF&G and criticism that improved this project. F. Bergander and S. McPherson shared their insights and expertise regarding sockeye salmon biology. J. Christner, J. Franzel, E. Johnston, R. Medel, and V. Starostka commented on specific aspects of a previous draft. Both the content and format of this report were improved by the input provided by F. Bergander and P. Porter. Special thanks to M. Haddix and T. Zadina for their thorough review of a previous draft.

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Pink Salmon (*Oncorhynchus gorbuscha*)

Abstract

There are over 6,000 populations of pink salmon in southeast Alaska (odd- and even-year lines in over 3,000 streams). Stock groups in northern and southern parts of southeast Alaska (separated at Sumner Strait) differ in migratory pathways and rarely interbreed. Because of these patterns of temporal and spatial separation, outlier analyses of biological characteristics were conducted separately on southern even-, southern odd-, northern even-, and northern odd-year stock groups. Adult run timing and escapement magnitude are the only biological data available for many stocks of pink salmon. Nineteen southern populations have distinctively early run timing. Seven streams across the region show large differences in timing between even- and odd-year lines, suggesting alternate responses by each line to the same freshwater environment. Exceptionally large escapements occur in eight populations, but only two locations have large escapements of both lines. One population is unique in the region for traveling far upstream to spawn in the interior. Most pink salmon populations in the region that can be analyzed have stable escapement trends, with 18 percent (240 populations) showing significant increases, and 1.6 percent (21 populations) showing significant declines from 1960 to 1993.

Keywords: Pink salmon, *Oncorhynchus gorbuscha*, southeast Alaska, run timing, population status, intraspecific diversity.

Introduction

Pink salmon inhabit rivers north of 40° N. lat. around the Pacific Rim of Asia and North America. Spawning generally occurs in the lower reaches of coastal rivers, and pink salmon rarely ascend beyond 500 km from the sea (Neave 1966). A substantial portion of spawning, up to 74 percent in regions such as Prince William Sound, takes place in intertidal areas (Noerenberg 1963). Intertidal spawning is indicative of the general pattern of pink salmon life history, which deemphasizes reliance on fresh-water habitat. Pink salmon fry begin migrating to sea within hours of emergence, and most fry spend less than a week in fresh water. This life history pattern may have originated in the small, unproductive streams in far northerly regions during interglacial times (Miller and Brannon 1982). Pink salmon also are characterized by a simplified, and virtually fixed, 2-year life span. Eggs are deposited in redds from July to October and hatch during winter; fry emerge and immediately migrate to salt water in early spring. After about 16 months at sea, adults return to

spawn and die (Sheridan 1962). Two consequences of this accelerated life history are that even- and odd-year lines are reproductively isolated, and pink salmon are distinguished from other Pacific salmon by their small adult size (averaging 1 to 2.5 kg) (Heard 1991).

Southeast Alaska is near the center of the North American distribution of pink salmon; consequently, populations are numerous, well distributed, and often large. Pink salmon inhabit over 3,000 streams in the region (ADF&G, Habitat Division 1994), and at least 200 of these populations have mean escapements in excess of 10,000 individuals. Pink salmon are the most abundant of the five species of Pacific salmon in the region, with total catches exceeding 30 million annually during the early 1990s (Hofmeister 1994). Pink salmon tend to inhabit smaller streams, with occasional large populations in large rivers (Heard 1991). The only large transboundary population of pink salmon in the study area is in the Taku River drainage, where spawning occurs primarily in the Nakina River (McGregor and Clark 1990). In contrast to Prince William Sound, less than 20 percent of pink salmon spawning is estimated to occur in the intertidal zone in southeast Alaska.

We reviewed information on 650 even-year and 684 odd-year runs of pink salmon in southeast Alaska. Even- and odd-year lines inhabiting the same stream were treated separately, because they are reproductively isolated. Estimates of run timing and of escapement magnitude, both based on stream surveys or weir counts, were the basis of virtually all evaluations and analyses presented here. Data available for other biological characteristics, such as body size, were inadequate to permit worthwhile comparisons at the population level of analysis. These characteristics are discussed in this "Introduction" in an effort to describe basic pink salmon biology and trends present in southeast Alaska. More general reviews of pink salmon biology are available (Bonar and others 1989, Heard 1991, Raleigh and Nelson 1985), including one focused on southeast Alaska (Alexandersdottir 1987). Furthermore, the extensive body of literature on pink salmon biology has been compiled recently into an electronic bibliography (Johnson and others 1994).

Spawning and Freshwater Life History

Pink salmon stocks in southeast Alaska often are divided into stock groups based on the geographic location of spawning streams or on run timing. Sumner Strait serves as the approximate boundary between the geographically defined northern and southern groups. Pink salmon that spawn in streams of northern southeast Alaska generally enter through Icy Strait or northern Chatham Strait; southern populations move to inside waters through Dixon Entrance and Sumner Strait. Tagging studies indicate that, after adults move inshore, very little intermingling occurs between pink salmon from each geographic area (reviewed in Hoffman and others 1984). Timing of peak spawning is used to separate pink salmon populations into early (before 15 August), middle (15 August-15 September), and late (after 15 September) stock groups (Royce 1962, Sheridan 1962). Run-timing groups are generally believed to be determined by the temperature regime of spawning streams; early run timing is typical of populations that spawn in cooler streams. Pink salmon in southeast Alaska spawn in water temperatures ranging from 7 to 18 °C (Sheridan 1962). Because mainland streams throughout the region tend to be cooler than island streams, run-timing groups show some degree of geographic separation along a mainland-island axis. Much overlap and many exceptions to this temperature-based run-timing pattern occur, however. The large population in the Wilson River, for example, has

waves of spawning that correspond to all three timing segments (Hofmeister and Dangel 1989). Historically, the overall pattern of run timing in the region may have been earlier, but artificial selection by fisheries that removed early portions of runs is thought to have caused a change in run timing, particularly for runs with intermediate timing (Alexandersdottir 1987, Alexandersdottir and Mathisen 1982). Timing of spawning in odd-year Auke Creek pink salmon is moderately heritable (males $h^2 = 0.2 \pm 0.16$ SE; females $h^2 = 0.4 \pm 0.20$ SE) (Smoker and others 1991), thereby confirming that this trait can respond readily to selection. Both the northern and southern stock groups have populations that fall into all three run-timing categories, but in accord with trends in water temperature, northern populations tend to have earlier run timing than southern populations (Heard 1991). Both even- and odd-year lines conform to similar stock grouping patterns based on geography and run timing.

Males generally return to spawning streams before females, but by the time runs are completed, the overall sex ratio generally approaches 1:1 (Dangel and Jones 1988, Heard 1991, Hofmeister and Dangel 1989). The spawning period for pink salmon populations typically lasts from 1 to 1.5 months. Within this spawning period, runs often are subdivided into early and late components (Taylor 1980). The factors responsible for the origin of these timing components are unclear, but segregation may be maintained, once established, by shock-induced mortality of eggs of early spawners resulting from redd superimposition by later spawners (Joyce 1986). Pink salmon eggs are susceptible to mortality due to mechanical shock for 15 to 30 days (depending on water temperatures) after deposition (Joyce 1986). This period corresponds roughly to the time interval between early and late spawning peaks.

Stream life is an important variable in pink salmon reproductive success because, for females, successful defense of a redd may limit egg losses due to superimposition and, for males, extended stream life can provide additional spawning opportunities. Stream life was highly variable among streams, years in the same stream, stream segments, and timing segments of the run (table 29).

Table 29—Duration of pink salmon stream-life in southeast Alaska

Stream name	Year	Mean stream life ^a	Range (individual fish or weekly mean)	Source
-----Days-----				
Salmon Creek	1983	15	4.0 - 38	Thomason and Jones 1984
Starrigavan Creek	1983	30	6 - 55	Thomason and Jones 1984
Kadashan Creek	1986	12.4	10.6 - 12.7 ^b	Dangel and Jones 1988

^a Mean number of days between tagging and recovery, weighted by the number of fish recovered.

^b Range of mean stream life values computed weekly throughout the spawning season.

One consistent finding in stream-life studies is that stream life decreases as the run proceeds (Dangel and Jones 1988, Helle and others 1964, Thomason and Jones 1984). Of the many environmental variables suggested as potential causes of differences in duration of stream life, current velocity is likely to be most important; swift currents impose the greatest energetic demands on spawning and holding fish, thereby resulting in shorter stream life (Heard 1991). Predation rates, particularly by bears, also can affect mean stream life (Dangel and Jones 1988).

Pink salmon prefer spawning habitat with shallower riffles and more rapid flow than habitats preferred by other Pacific salmon. The two critical habitat variables for spawning are water depth and current velocity (Semko 1954, cited in Heard 1991). Preferred water depths are in the range of 20 to 25 cm, with virtually all redds between 10 and 140 cm (reviewed in Heard 1991). Average current velocities above redds range from 30 to 140 cm/second with averages between 60 and 80 cm/second (reviewed in Heard 1991). Although other species of Pacific salmon rely on upwelling groundwater to deliver oxygen to developing eggs and alevins, pink salmon rely more heavily on penetration of surface water into the gravel (Kobayashi 1968, Semko 1954, both cited in Heard 1991). None of the studies reviewed by Heard (1991) was based on data collected in southeast Alaska; however, the studies reviewed covered nearly the entire geographic distribution of pink salmon and therefore the values provided are likely to apply to most populations in southeast Alaska.

Egg and alevin mortality may drive pink salmon population dynamics. Pink salmon catches in southeast Alaska cycle with a periodicity of about 20 years, apparently tracking cyclic changes in sea surface and winter air temperatures (Hofmeister 1994): low catches correspond with periods of low temperatures. Very cold temperatures in late fall or early winter, before eggs hatch, can cause mortality when ice formation reduces intergravel flow (Reiser and Bjornn 1979). Once eggs have hatched, alevins can burrow deeply into gravel to escape freezing, but unusually severe winter cold may increase alevin mortality.

Timing of emigration is another factor influencing juvenile survivorship. Fry emergence and emigration tend to be highly synchronous. Coordinated emigration may be favored by predator swamping or other antipredator benefits to individuals of being in a group. Emergence and migration take place almost entirely at night (Sheridan 1962), and bright moonlight inhibits migration (Pritchard 1944, cited in Heard 1991), suggesting that visually oriented predators have been an important force of natural selection shaping migratory behavior. Migration timing is thought to coincide with optimal "windows of opportunity" in the saltwater environment (Miller and Brannon 1982, Smoker and others 1991). For pink salmon stocks these windows may be defined by onset of zooplankton blooms that provide forage for fry, optimal saltwater temperature for growth, or avoidance of predators (Percy 1992, Sheridan 1962). Selection favoring appropriate timing of emigration may be stronger for pink and chum salmon, because these species rely more heavily on plankton than do other anadromous species such as coho salmon (Percy 1992). Strong selection to optimize the emigration timing could lead to differentiation among stocks in response to thermal characteristics of natal streams (Beacham and Murray 1986, Heard 1991).

Warm stream temperatures can result in early emigration of pink salmon fry, causing fry to arrive in salt water before plankton blooms. This sort of inappropriate timing is thought to result in poor adult returns in southern southeast Alaska (Hofmeister and others 1988). Few data are available regarding the timing of emigration for populations in southeast Alaska. The date by which 50 percent emigration had occurred from Sunny Creek (Prince of Wales Island) ranged from 21 April to 26 May for the odd-year line, and from 2 May to 24 May for the even-year line (Hofmeister and others 1988).

Mortality resulting from emigration timing “errors” are a manifestation of fluctuating selection pressures imposed by a changeable environment. This fluctuating selection can preserve genetic variation in characters exposed to selection, or it can favor genotypes with appropriate reaction norms (Stearns 1992). Variation maintained by fluctuating selection may be critical to long-term stock productivity in a changeable environment (Smoker and others 1991). Maintenance of genetic variation does not preclude local adaptation. Theoretical work suggests that if environmental variation among spawning sites is greater than temporal variation within sites, then differences in environmental selection pressures along a gradient can result in local adaptation (Lynch and Gabriel 1987). In pink salmon, local adaptations to thermal regimes can occur within segments of a stream. Hebert (1994) found that differences in developmental rate compensate for differences in spawning timing of different run components in Auke Creek. Individuals in the late component of the run show heritable developmental acceleration that enables eggs to hatch with about 15 percent fewer thermal units than the early spawning component in this stream (Hebert 1994, Joyce 1986).

Marine Life History

The early marine stage of the life cycle may represent a critical period profoundly influencing return rates. Parker (1962, 1968) examined mortality schedules for pink salmon and estimated that the highest mortality rates occur during the first 40 days in the coastal ocean. Predation by coho salmon smolts may be a significant cause of pink salmon mortality in the near-shore environment, particularly when the abundance of pink salmon fry is low (Hargreaves and LeBrasseur 1985, Hofmeister and others 1988).

Schooling and rapid growth may be considered additional elements of a predator avoidance strategy in the early life history of pink salmon. Once in the marine environment, pink salmon fry form large schools and either forage along shorelines and in estuaries for several weeks (Bailey and others 1975, Healey 1967) or move relatively rapidly out to sea (Healey 1967, Neave 1966). Growth rate of pink salmon fry during early marine life in Tenakee Inlet was 0.30 mm/day in length, and 15.3 mg/day in weight (Hofmeister and others 1988). These rates are somewhat lower than Parker's (1964) estimate of 0.87 mm/day for Bella Coola River fry and perhaps reflect differences in marine productivity. Though the Tenakee Inlet rates are slower, the observed 6-percent/day increase in weight is still an impressively rapid growth rate.

Marine migration routes and chronology for southeast Alaska pink salmon (both adults and juveniles) are fairly well studied. Major offshore migrations of juvenile pink salmon occur through the straits of southeast Alaska in July and August (Martin 1966). In general, the area of the north Pacific traversed by pink salmon from southeast Alaska extends from about 44° N. lat. off the coasts of Oregon and Washington,

north and west to the south coast of the Alaska Peninsula (Takagi and others 1981). During the first summer at sea, migration proceeds in a generally northwesterly direction along the Alaska coast, followed by a southeasterly migration across the open sea between 44° N. lat. and 50° N. lat. during fall and winter (Takagi and others 1981). In the second spring and summer at sea, pink salmon follow various migratory pathways that bring them back to the coastal waters of southeast Alaska (Takagi and others 1981). Tagging studies have revealed many details of the inshore migrations of pink salmon to fishing districts in the region (Hoffman 1982, Hoffman and others 1984). For most districts, returning pink salmon enter through at least two different straits and often follow indirect paths to their natal streams (Hoffman 1982, Hoffman and others 1984). Highly mixed-stock fisheries are one consequence of this complicated migratory pattern in southeast Alaska.

In many areas throughout their range, pink salmon abundance fluctuates dramatically between even- and odd-year lines (Ricker 1962). Many hypotheses have been offered to explain the origin and maintenance of line dominance, and it is likely that the phenomenon results from the interaction of several factors (Ricker 1962); for example, density-independent mortality due to severe climatic conditions may initiate line dominance that is subsequently preserved by compensatory mortality. At present in southeast Alaska, no clear pattern of line dominance is apparent in either the northern or southern region. Line dominance at smaller spatial scales is possible, but it is not well documented.

In British Columbia, in conjunction with a general pattern of odd-year dominance, odd-year pink salmon tend to be larger than even-year fish (Ricker 1962). Based on the weight data compiled by Marshall and Quinn (1988), odd-year pink salmon also are significantly larger than even-year fish in southeast Alaska ($t = 2.26$, $P = 0.03$). This difference in weight may be attributable either to genetic differences in growth rate or differences in ocean productivity in the areas used by each line (Ricker 1962). Body size of pink salmon also tends to increase with decreasing latitude (Heard 1991).

Body size decreased significantly through time in both even- and odd-year lines in British Columbia (McAllister and others 1992, Ricker 1981). Ricker (1981) attributes this decline in size to the selectivity of gill net and troll gear for larger fish, resulting in artificial selection that favors individuals with heritable small size characteristics; however, alternative hypotheses such as changes in oceanographic conditions (Healey 1986), increased competition (Healey 1986), or selective depletion of stocks with large mean body size (Nelson and Soulé 1987) could not be rigorously tested (McAllister and others 1992). Linear regression analysis of trends in pink salmon body size using the weight estimates of Marshall and Quinn (1988) revealed a significant decline in body size in both even- and odd-year lines across years (fig. 38; even, $N = 35$, $R^2 = 0.20$, $T = -2.86$, $P = 0.01$; odd, $N = 36$, $R^2 = 0.28$, $T = -3.6$, $P < 0.01$). Because most pink salmon in southeast Alaska currently are harvested with purse-seine gear, which is considered nonselective, the observed decline in body size may be due to other factors, such as persistent effects of historical selection including high-seas drift netting, ongoing weak gear selection, or any of the alternative hypotheses given above (e.g., see Ishida and others [1993] on chum size declines). This result also may reflect the negative relation between pink salmon run strength and body size of individuals (Heard 1991), given that run strength generally increased from 1916 to 1984.

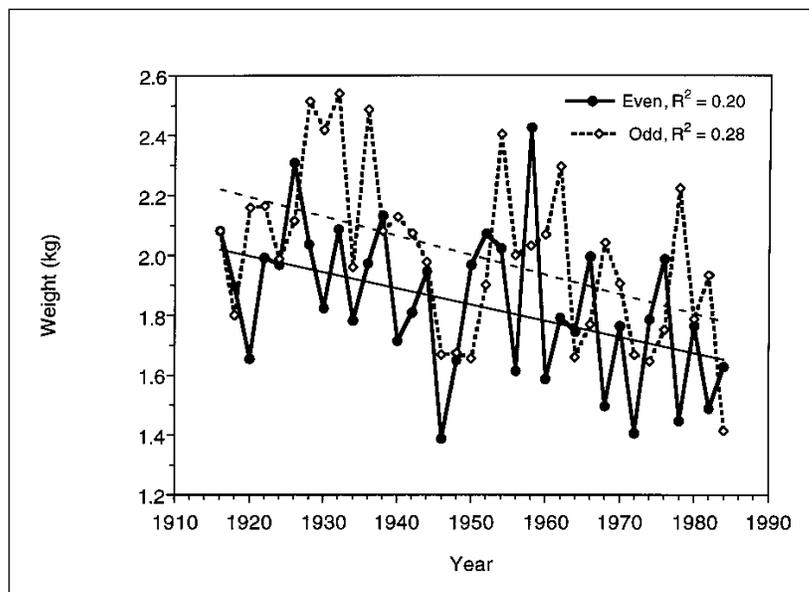


Figure 38—Trends in body weight for pink salmon harvested commercially in southeast Alaska, 1915-85. Linear regression, even years, $N = 35$, $R^2 = 0.20$, $T = -2.86$, $P = 0.01$; odd years, $N = 36$, $R^2 = 0.28$, $T = -3.6$, $P < 0.01$. See Marshall and Quinn (1988) for details of data compilation methods.

Management History

Commercial fisheries for pink salmon were started in southeast Alaska with the construction in 1878 of salmon canneries at Klawock and at Turner's Point in Sitka (Bean 1887). Although these facilities were built primarily for processing sockeye salmon, the destructive fishing practices, such as stream barricades, used to catch sockeye for the canneries undoubtedly had detrimental effects on pink salmon populations. Stream barricades were first outlawed and periods closed to fishing were established by the Alaska Salmon Act of 1896 (Royce 1962). The USBF first recorded pink salmon commercial catch data for the 1889 season, when a total catch of 92,000 fish was recorded. Subsequently, a continuous record of regional catch data has been maintained for each year through the present (Rigby and others 1991; see fig. 39).

The pink salmon industry grew slowly from its inception until 1910 and then expanded rapidly from 1910 to 1920, as sockeye populations near canneries were depleted (Vaughan 1942). Salmon traps were the principle gear type used during this period, and the number of traps operated expanded from 57 in 1908 to 472 in 1920 (Alexandersdottir 1987). Economic conditions prompted severe curtailment of commercial fishing effort in 1921 and 1922, and again from 1931 to 1933 (Vaughan 1942). During the intervening period, rebuilding of the fishery was slowed by passage of the White Act in 1924, which required 50 percent of annual returns be allowed to spawn and established numerous closed areas in southeast Alaska (Royce 1962). This law reflected increasing concern about the management of salmon fisheries in Alaska and was accompanied by an increase in the number of enforcement personnel hired. The White Act was never applied to pink salmon, however, and because it was typically impossible to attribute catches to particular streams, the regulation was generally unenforceable (Royce 1962).

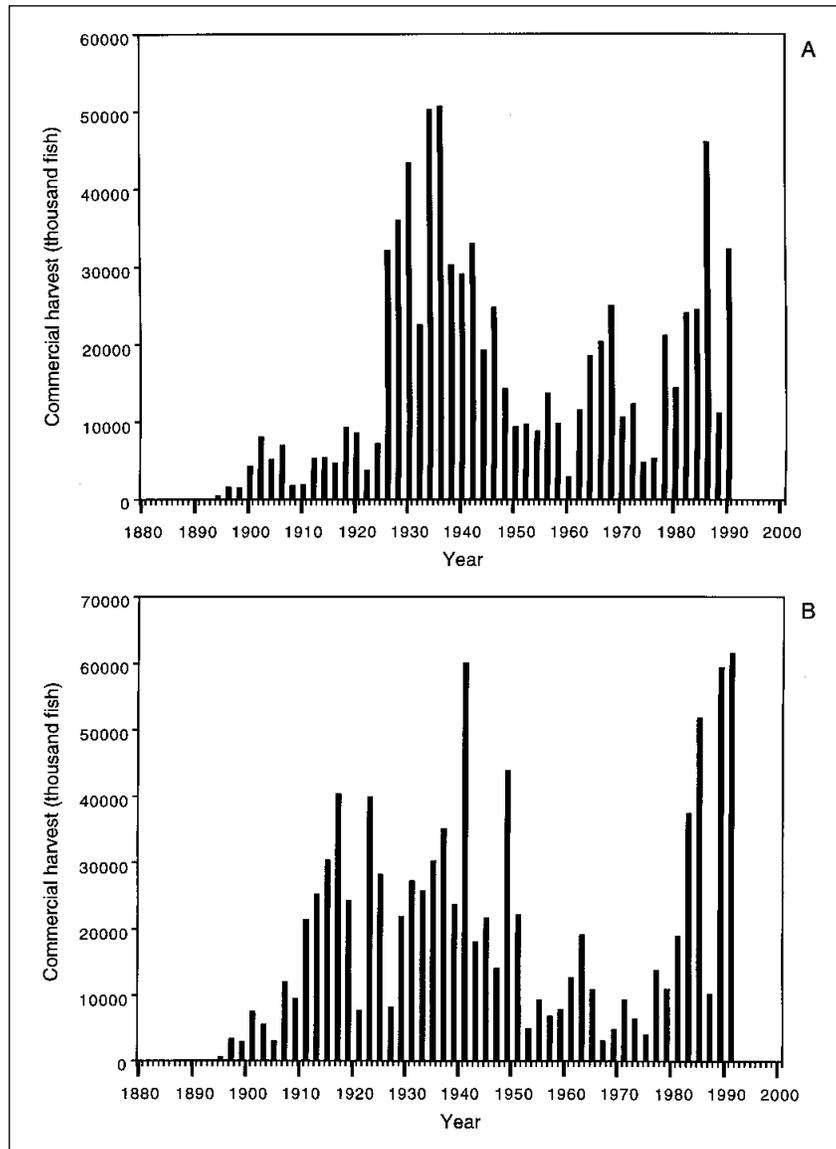


Figure 39—Annual commercial harvest of pink salmon in southeast Alaska: **(A)** even years, 1892-1990; and **(B)** odd years, 1893-1991 (data from Rigby and others 1991).

Catches during the 1930s and 1940s were high but showed a steadily declining trend, which suggests a gradual decline in productivity or overexploitation, or both. This decline in catches occurred despite an increase in fishing effort (Alexandersdottir and Mathisen 1982). Salmon traps were discouraged during this time in favor of seines and gill nets. Throughout this period, enforcement efforts by the USFWS in southeast Alaska declined¹ (Royce 1962). Nearly three decades of relatively meager catches and escapements followed.

¹ Personal communication. 1996. K. Hofmeister, fisheries biologist, Alaska Department of Fish and Game, 802 3d Street, Douglas, AK 99824.

The State of Alaska assumed responsibility for fisheries management in 1960. The management strategy adopted by the state was based on obtaining constant (optimal) escapements. Attainment of this goal was monitored by surveys of selected streams throughout the region. Estimation of optimal escapement is a complex and imprecise process, and estimates gradually were adjusted upward as pink salmon catches remained depressed. During the 1970s, the ADF&G began a rebuilding program based on increasing escapements throughout the region. This rebuilding program and favorable oceanic conditions (Lawson 1993, Percy 1992; see footnote 1) contributed to average commercial catches in the 1980s that exceeded catches in any prior decade (Rigby and others 1991; see fig. 39). This trend has continued, with commercial catches of pink salmon during the early 1990s reaching record high levels.

Current Management

Current management of the pink salmon fishery is based on attempting to obtain optimal escapements to index streams throughout the region. Recent analyses of the relation between brood-year escapement index and catch of pink salmon indicates that the optimum escapement index for the region is at least 12 million fish (Hofmeister 1994). The regional escapement index is the sum of indices for each district. District escapement indices are calculated by summing the highest escapement count made for each stream surveyed in the district and adjusting for the number of index streams not surveyed during that season. The number of index streams in each district is defined as all streams for which an escapement count was available at least once from 1960 to the brood year of the returning run. Adjustment for unsurveyed streams involves multiplying the number of streams not surveyed by the average escapement count for all streams within that district having a peak escapement count of less than 10,000 pink salmon. To complete the district index, the adjustment is simply added to the sum of counts from surveyed streams. Roughly 700 streams are surveyed annually, the majority of which are in southern districts. This level of survey effort represents about a 50-percent sample of index streams and a 25-percent sample of all pink salmon populations in the region. The regional escapement index is not designed to provide an estimate of total escapement to the region (Hofmeister 1994); however, the design of the index does provide an easy means for monitoring attainment of escapement goals at the district level.

In recent years, most districts have consistently achieved escapement goals while supporting record catches. Districts 105-108, in the southern part of southeast Alaska, are exceptions to this pattern, consistently failing since 1988 to meet escapement goals (Hofmeister and Dangel 1989, Hofmeister and others 1988, Pacific Salmon Commission 1991). Whether this represents a problem of stock decline (perhaps due to interceptions in districts 102 and 104 [Hofmeister and others 1988]) or unrealistically high escapement goals is unclear.

Preseason forecasting and inseason management are important components of the current sustained-yield strategy for pink salmon. A tremendous amount of management research effort has been invested to generate models that reliably predict pink salmon run strength (e.g., Hoffman 1963; Hofmeister and Dangel 1989; Jones and Dangel 1981, 1985; Jones and others 1988). These efforts have been valuable in terms of learning about the influence of environmental factors on freshwater survivorship. To date these models have had mixed predictive success, however. Potentially high variability in marine survival may reduce the accuracy of forecasts derived from models built around freshwater variables (see Hofmeister and Dangel 1989).

Inseason assessment of run strength is accomplished by combining data from harvest, sex composition of the catch, and escapement surveys in multiple regression models developed from historical data (Pacific Salmon Commission 1991). Inseason assessments of run strength have been effectively implemented through delegation of authority for time and area closures to district managers.

Proportions of the total catch taken by different gear types differ considerably by district throughout the region, but in general the purse seine fleet catches over 85 percent of the total pink salmon taken in southern southeast Alaska. The gillnet fishery takes the next largest proportion (about 5 to 10 percent) followed by the troll fleet (1 to 10 percent) (Pacific Salmon Commission 1991).

Enhancement

Hatchery production of pink salmon in southeast Alaska has never been extensive. The Fortmann hatchery (1901 to 1927) on the Naha River system, and the Yes Bay hatchery (1905 to 1933) near McDonald Lake were the first hatcheries to produce pink salmon in the region (Roppel 1982). Pink salmon also have been produced at Ketchikan Creek since 1924, with releases occurring at Ketchikan Creek and in salt-water ponds off Gravina and Duke Islands (Roppel 1982). The Ketchikan Creek hatchery was the only early facility devoted to enhancement of pink salmon in the region. The contribution of these early enhancement efforts to commercial harvests cannot be determined. Operations at these early hatcheries led to transfers of eggs among several sites in the region. Fry from eggs taken from Fish Creek (Thorne Arm), Ward Cove, and Lucky Cove were released at Ketchikan Creek or the Duke Island ponds. Eggs from Ketchikan Creek and Smeaton Bay were moved to Yes Bay, and eggs from Eva Lake were planted by A.J. Sprague of the Territorial Fish Commission in Portage Bay, Cascade Bay Lakes, Saginaw Bay, Tebenkof Bay, Hamilton River, and Johns Harbor (Roppel 1982). The success of these transfers is unknown. Sprague also transferred eggs from Chilkat Lake to Chilkoot Lake from 1917 to 1920, which apparently did yield some returns (Roppel 1982). During the same period, Sprague made numerous poorly documented transfers of pink salmon eggs from several streams (including Anan Creek) to streams in the Juneau area (including Auke Creek), Douglas and Admiralty Island streams, and Lake Baranof (Roppel 1982). Little is known of the outcome of these numerous transfers.

Small-scale hatcheries on Sashin Creek and Auke Creek have been operated by the NMFS to conduct research on pink salmon ecology, population biology, and genetics. One transfer associated with these hatcheries involved moving adult pink salmon from Bear Harbor on Kuiu Island to Sashin Creek in an attempt to replace the even-year line at Sashin Creek that had been experimentally eradicated (Smedley and McNeil 1966). The purpose of this experiment was to determine the feasibility of establishing pink salmon populations in new locations by transplanting adults (Smedley and McNeil 1966). Although the transplant was successful, the technique of moving adults never achieved widespread application. The Sashin and Auke Creek hatcheries continue to make considerable contributions to our understanding of pink salmon biology, although they are not large contributors to commercial fisheries.

Currently, pink salmon are produced on a large scale by (1) Burnett Inlet hatchery on Etolin Island in southern southeast Alaska, (2) Armstrong-Keta hatchery on southern Baranof Island, and (3) Douglas Island Pink and Chum (DIPAC) hatchery near Juneau. Burnett Inlet brood stock was derived from McHenry Inlet, Mosman Inlet,

Black Bear Creek, and Anan Creek. Release sites are at the hatchery and in Anita Bay. Brood stock for Armstrong-Keta was derived from Lovers and Coras Coves and Sashin Creek. Releases occur at the hatchery. Brood stock for DIPAC is derived from Fish Creek (Douglas Island) and Kadashan Creek stocks. Pink salmon from DIPAC are released near the hatchery in Gastineau Channel. Production from these hatcheries make important contributions to local fisheries but a relatively minor contribution (<10 percent) to the total commercial catch of pink salmon throughout the region. We did not attempt to document the operations of several small-scale pink salmon hatcheries in the region.

The localized nature of pink salmon enhancement in southeast Alaska has minimized the sorts of conservation problems developing for wild stocks in Prince William Sound (see Geiger 1994). Given the importance to effective management of inseason run-strength assessments, large hatchery returns, if indistinguishable from wild fish, can lead to overexploitation of wild stocks (Pacific Salmon Commission 1991). The prevailing cautious policy toward enhancement and new technological developments for marking hatchery fish, such as thermally induced otolith marks (Hagen and Munk 1994) and genetic markers (Utter and Ryman 1993), may reduce conflicts between hatchery programs and conservation of wild stocks. These new developments in marking technology cannot reduce high straying rates among hatchery fish, but they do provide a means for identifying these strays. Surveys of streams along Gastineau Channel have revealed that up to 70 percent of fish sampled from escapements were DIPAC strays with thermally marked otoliths.²

Installation of fish passes and other enhancement activities in the region have been reviewed by Bibb (1987) and Parry and others (1993). The only enhancement project directed explicitly at pink salmon was the fish pass at Anan Creek; however, pink salmon undoubtedly have benefited from projects undertaken for other species (see Bibb 1987, Sullivan 1980).

Methods Stock Discrimination

A large body of data indicates distinct genetic separation between even- and odd-year pink salmon stocks inhabiting the same stream (e.g., Aspinwall 1974). Consequently, we evaluated even- and odd-year lines separately.

Within the odd- and even-year runs, the definition of a stock is complicated by an unknown degree of straying among streams. A fairly widespread perception exists that pink salmon tend to stray more often, and more widely, than other species of Pacific salmon (Quinn 1984), but few data are available to support this. To the contrary, both tagging and biochemical evidence suggest generally low straying rates among pink salmon populations (reviewed in Heard 1991). Since Heard's review, Gharrett and others³ (1993) report that genetically marked pink salmon spawning in Auke Creek show exceedingly precise homing, resulting in genetic infrastructure within the spawning area of this small stream. In contrast, coded-wire-tagged wild and hatchery pink salmon from Prince William Sound showed high straying rates; for example, 53 percent of wild fish marked at Herring Creek were recovered in 14

² Personal communication. 1996. E. Volk, Douglas Island Pink and Chum, 2697 Channel Drive, Juneau, AK 99824.

³ Gharrett, A.J.; Lane, S.; McGregor, A.J.; Taylor, S.G. 1993. Use of a genetic marker to examine genetic interaction among subpopulations of pink salmon (*Oncorhynchus gorbuscha*). Unpublished document. On file with: University of Alaska Southeast, 11120 Glacier Highway, Juneau, AK 99801.

different streams up to 38 km away (Sharp and others 1994). Studies of homing and straying are susceptible to many confounding factors, such as the effects of (1) marking procedures on homing behavior, (2) run strength, (3) spawning location (e.g., intertidal vs. upstream), and (4) environmental variation, such as oil contamination in Prince William Sound. Nonetheless, the bulk of available data support the generalization offered by Ricker (1962) that straying “probably rarely exceeds 10% for indigenous stocks.”

Genetic surveys of pink salmon in 16 streams in both southern and northern southeast Alaska (McGregor 1983) and 19 streams in southern southeast Alaska found high overall levels of genetic similarity among populations that precluded local-scale geographic discrimination of stocks.⁴ At a larger geographic scale, populations from western Prince of Wales, adjacent to the Gulf of Alaska, were found to differ significantly from populations originating from streams flowing into the inside waters of southeast Alaska. If straying is infrequent, then the lack of local geographic divergence may reflect relatively recent founding of these populations. Furthermore, the close proximity of streams suitable for pink salmon in southeast Alaska may promote gene flow, and many relatively small populations may make low levels of gene flow sufficient to prevent divergence at allozyme loci.

The divergence between western Prince of Wales populations and inside populations may be a consequence of colonization from different glacial refugia (see Kondzela and others 1994). The hypothesis of colonization from alternative glacial refugia also has been invoked as a possible explanation for the dramatic genetic differences between even- and odd-year lines of pink salmon (Aspinwall 1974).

As described above, for management purposes only two large stock groups of pink salmon are recognized in the study area; the northern and southern groups divide approximately along Sumner Strait (Smedley and Seibel 1967). This division corresponds to management districts 101-108 in the southern group, and districts 109-115, 182, and 183 in the northern group.

Stock groups of pink salmon may contain more fine-grained geographic separation. For instance, Alexandersdottir and Mathisen (1982) recognized 16 stocks in their classification for southeast Alaska based on geographical location, spawning time, and migration route. In addition, intertidal spawners and upstream spawners in the same stream have been considered separate stocks owing to differences in timing, physical and chemical environment, and line dominance (Royce 1962). In view of the ongoing controversy, for operational purposes we defined individual stocks of pink salmon based on geographic location (i.e., spawning streams), as was done throughout this paper.

⁴ Personal communication. 1996. A. Gharrett, professor of fisheries, University of Alaska Southeast, 210 Anderson Building, 11120 Glacier Highway, Juneau, AK 99801. Preliminary results from: Gharrett, A.J.; Wilson, R.B.; Baker, B.M. [and others]. 1990. Preliminary report on genetic diversity of southern southeast Alaskan pink salmon populations. NWAFC Proc. Rep. 909-03. Auke Bay, AK: National Marine Fisheries Service, Alaska Fisheries Science Center. 50 p.

Data Analysis Procedures

Because the types of data on biological characteristics of pink salmon populations were limited, analyses in this paper were confined to timing characteristics, geography, escapement magnitude, escapement trends, and water quality. These analyses were conducted on data collected from escapement surveys and daily weir counts and were compiled into computerized data files by the ADF&G, Division of Commercial Fisheries. The ADF&G escapement survey database for pink salmon is very extensive, and readers interested in detailed records for particular locations should contact the Southeast Regional Office of ADF&G in Douglas, AK. No data from catches were included in our analyses. Weir counts for pink salmon collected historically by the USBF also were not included in this paper.

We conducted analyses of timing and escapement characteristics on a sample of 650 even-year and 684 odd-year pink salmon stocks. This sample represented over 20 percent of the approximately 6,000 even- and odd-year lines present in the region. These stocks were well distributed throughout the region, and for many stocks the data collection period extended over 30 years (from 1960 to 1992). All stocks included in our analyses were represented in the ADF&G database by at least 7 years of survey data.

Run-timing analyses are based on the timing index described in the "General Introduction." The usefulness of this index is enhanced for many pink salmon populations by multiple surveys per year, which permit fine resolution of the date when peak abundance of spawners occurred. Because of the many stocks for which timing indices could be calculated, and the low number of stocks for which daily weir counts were available for evaluating run timing, our analyses of run timing relied on index dates.

Data were available to calculate run-timing statistics for 27 of 45 even-year pink salmon stocks enumerated at weirs and 26 of 42 odd-year populations. Most of these weirs were operated primarily for other species with counts of pink salmon made incidentally. The numerous possible sources of bias associated with these data rendered them unsuitable for detailed analysis of run timing. Weirs at Sashin, Auke, and Kadashan Creeks targeted pink salmon and yielded more complete and reliable data.

Our estimate of escapement magnitude was calculated by taking the largest escapement survey estimate from each year and computing the mean of these maxima. Survey counts were not expanded to estimate total escapement.

We analyzed the effects of geographic region (northern or southern) and line (even or odd) on timing index and escapement magnitude by using a fixed-effects ANOVA model (Beacham and Murray 1988);

$$Y_{ijk} + \mu + R_i + L_j + RL_{ij} + e_{ijk} ,$$

where

Y_{ijk} = observed timing index or escapement,

μ = mean,

R_i = region, and

L_j = line.

Results Timing

The regression procedures described in the "General Introduction" were used to evaluate escapement trends for pink salmon populations. Even- and odd-year lines were evaluated separately, meaning that escapement surveys had to be conducted over a span of 14 years before a population could be included in the analysis.

At systems with weirs, even- and odd-year lines showed a similar range of grand mean freshwater migration dates. These dates ranged, for even-year stocks, from 2 August for Kadashan East, to 10 September for Sashin Creek. Among odd-year lines, Sashin Creek again showed relatively late run timing with a grand mean freshwater migration date (based on data from 1935 to 1963) of 4 September. The Kadashan East pink salmon population was relatively early with a grand mean date of 30 July.

Kadashan Creek stocks showed no trends across years in migration timing for even- or odd-year lines, but historical data (1935-63) from the odd-year line at Sashin Creek showed a nearly significant trend ($0.05 < P < 0.1$) toward earlier run timing. This trend becomes less strong if the datum from 1987 (the only value we obtained for recent years) was included in the analysis. Experimental manipulations at Sashin and Auke Creeks and hatchery operations at Auke Creek may have altered natural run timing patterns.

Even-year runs were later than odd-year runs at both Kadashan River sites and at Sashin Creek, but the difference in mean migration date was significant only at Sashin Creek (paired t-test, $N = 15$, $P = 0.01$). The East and West Kadashan Creek stocks did not differ in run timing ($N = 9$, $P = 0.3$). The most that can be inferred from these analyses is a suggestion of the range of run timing in the region. Clearly, these limited data from weirs were insufficient for evaluating regional patterns of pink salmon run timing.

Pink salmon migration timing in the Taku River is about a month earlier than other runs in northern southeast Alaska. The calculated mean migration dates from samples taken at the Canyon Island fishwheel ranged from an early date of 18 July in 1989 to the latest date of 27 July in 1986 (McGregor and others 1991). These dates suggest that both even- and odd-year pink salmon from the Taku River have particularly early run timing relative to other stocks in the region. The primary spawning area of Taku River pink salmon is in the clearwater reach of the Nakina River (McGregor and others 1991), nearly 100 km upstream from Taku Inlet. The early run timing of this stock is probably related to the exceptionally long freshwater migration these fish undertake.

Analysis of timing index dates revealed highly significant effects of both region ($F = 116.12$, $P < 0.01$) and line ($F = 76.37$, $P < 0.01$), but no significant interaction effects. Tukey pairwise comparisons indicated that all comparisons except one were highly significant ($P < 0.01$); the only nonsignificant difference was between even-year northern stocks and odd-year southern stocks ($P = 0.48$). Within both regions, odd-year lines had significantly earlier index dates than even-year lines. The difference was about 4 days in both regions (table 30). The variance of index dates was significantly heterogeneous among the four stock groups (F_{\max} test, $P < 0.05$; Sokal and Rohlf 1981), with southern stock groups showing less variability in timing than northern groups for both even- and odd-year runs. The variances of even- and odd-

Table 30—Descriptive statistics for pink salmon run-timing index, summarized by region and line

Statistic	South		North	
	Even years	Odd years	Even years	Odd years
N ^a	359	367	291	317
Mean (Julian day)	237.5	233.4	232.5	228.7
Variance	59.7	46.1	87.2	79.3
SD ^b	7.7	6.8	9.3	8.9
Minimum	215	212	206	207
Maximum	256	254	253	251

^aN = number.

^bSD = standard deviation.

year lines within regions were quite similar (table 30). The observed heterogeneity in variance probably did not adversely affect the results of ANOVA, because significance tests in ANOVA are relatively robust with regard to deviations from the assumption of equal variances (Sokal and Rohlf 1981).

Within each stock group defined by the ANOVA (southern even, southern odd, northern even, and northern odd), we plotted frequency distributions to look for outliers (fig. 40). Eleven populations in the southern even early group and two populations in the southern odd, early group had distinctly early run timing (table 31). Four odd-year late populations in the southern region had conspicuously late run timing (table 31). No clear timing outliers were present in either line in the northern region. The frequency distributions for the northern region were relatively flat and suggested bimodality or multimodality, which probably accounts for the lack of apparent outliers (fig. 40).

The validity of the early index dates from southern southeast Alaska is suspect, because of the possible influences of early surveys for chinook or sockeye salmon in some of these systems (noted in table 31); however, not all systems with early runs of chinook and sockeye also yielded early timing indices for pink salmon, and some of the stocks with early index dates are found in streams that do not support populations of these other species (e.g., Swift Creek, Valentine Creek).

The mean date of the run-timing index was earlier for odd-year lines than for even-year lines, and this pattern also was conspicuous within a number of particular streams. Nineteen locations in northern southeast Alaska had odd-year lines with a timing index more than 10 days earlier than even-year lines (table 32); Indian River (Sitka), Wheeler Creek (Admiralty), Phonograph Creek (Chichagof), and Althorp Creek (Chichagof) were outliers from the distribution (table 32, fig. 41).

Patterns of run-timing index within a stream did not always conform to the pattern of stock group means. Even-year lines had earlier timing indices, by at least a week (table 32), than odd-year lines in six streams in the southern part of southeast Alaska. Two of these streams (Clear and Grant Creeks in the Chickamin River drainage) had timing-index differences that were outliers from the overall distribution (fig. 41), with

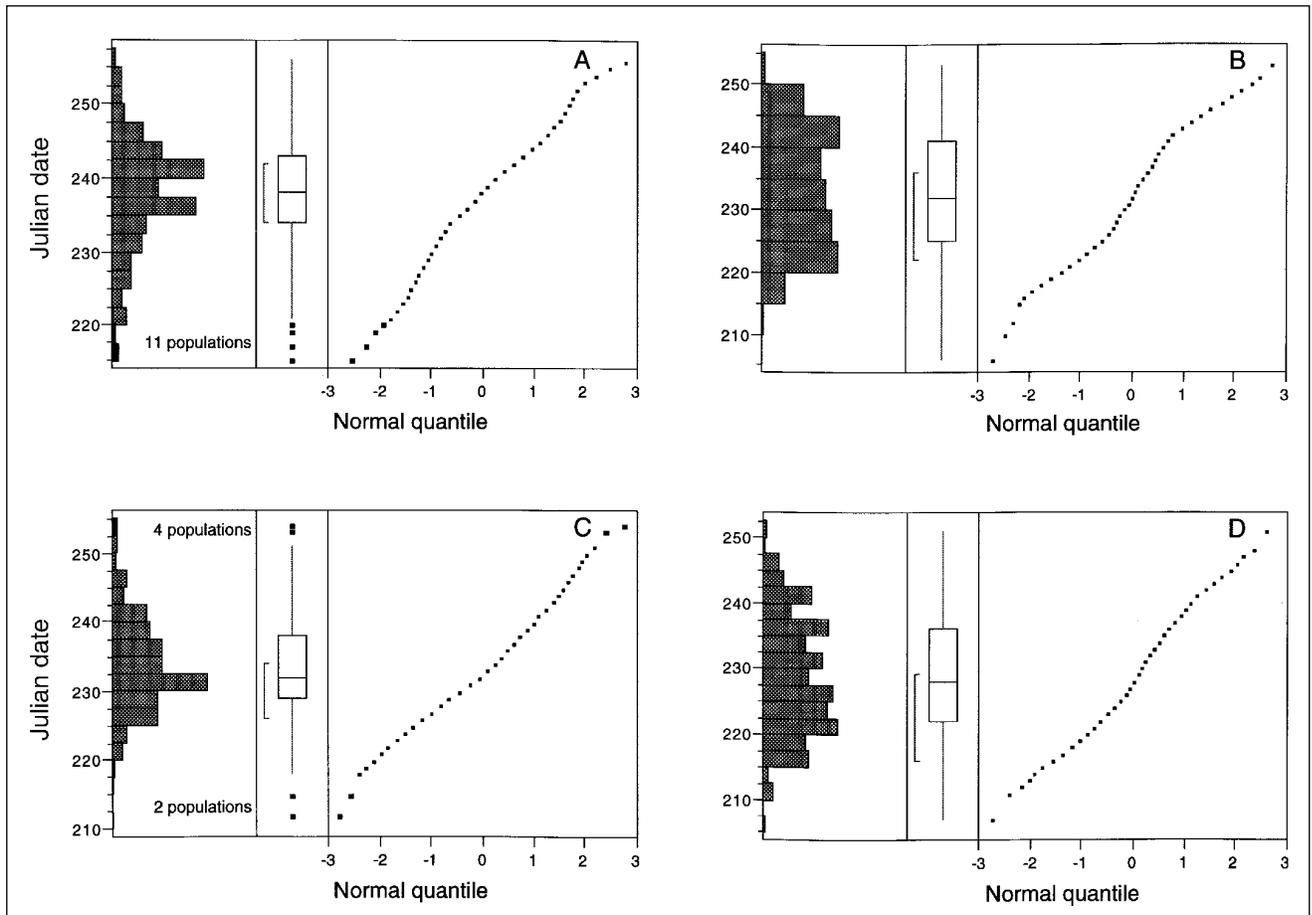


Figure 40—Frequency distributions, outlier plots, and normal quantile plots for run-timing index dates plotted by line and region: **(A)** even-year lines, southern region, N = 359; **(B)** even-year lines, northern region, N = 291; **(C)** odd-year lines, southern region, N = 367; and **(D)** odd-year lines, northern region, N = 317. See table 31 for specific stocks in the tails of each distribution.

even-year returns occurring 13 and 9 days earlier than odd-year returns. In the northern part of southeast Alaska, Lake Kathleen Creek (Admiralty Island) was conspicuous in having an even-year index date that preceded the odd-year date by 25 days (fig. 41).

Demography

The geographic distribution of stocks, escapement magnitude, and escapement trends were the variables we evaluated to characterize pink salmon demographics. We also reviewed the effects of diminished water quality on pink salmon escapements. Age structure and sex ratio could not be evaluated owing to a lack of data (see Olson and McNeil [1967] and Vallion and others [1981] for sex-ratio data from Sashin Creek). The age composition of all stocks was assumed to be entirely 0.1, although rare deviations from this pattern, in duration of both freshwater (Heard 1991) and saltwater residence (Anas 1959, Foster and others 1981), are known from other regions.

Table 31—Pink salmon stocks with early or late run timing, based on index date and evaluated by region and line

Stream		Survey					
Number	Name	Mean Julian date	Mean date	Number of years	First year	Last year	Mean escape-ment
Southern southeast, even-year lines, early stocks							
• 101-11-100	Swift Creek	215	03-Aug	7	64	90	381.4
• 101-60-025	Valentine Creek	215	03-Aug	13	64	92	17,517.7
• 101-71-04C	Clear Creek	215	03-Aug	12	66	92	3,125.0
• 101-71-028	Walker Creek	217	05-Aug	17	60	92	23,176.5
• 101-75-010	Grant Creek ^a	217	06-Aug	16	60	92	21,360.3
• 101-71-025	Walker Cove Lower Head	219	07-Aug	10	70	92	9,700.8
• 101-71-063	Portage Creek	219	07-Aug	17	60	92	30,027.3
• 101-75-080	Robinson Creek	219	07-Aug	7	72	88	5,300.0
• 101-71-04K	King Creek ^a	220	08-Aug	17	60	92	28,399.9
• 101-75-015	Eulachon River ^a	220	08-Aug	17	60	92	18,739.6
• 101-75-050	Klahini River ^a	220	08-Aug	17	60	92	16,391.5
101-30-030	Keta River ^a	221	09-Aug	17	60	92	93,394.1
101-60-016	Rudyard Creek	221	09-Aug	16	60	92	9,089.0
Southern southeast, even-year lines, late stocks							
101-23-094	Crab Bay	256	13-Sep	7	64	92	2,735.7
102-60-087	Karta River	255	12-Sep	15	60	92	53,785.0
105-43-001	Shiple Bay North Head	255	12-Sep	7	68	86	1,075.9
102-30-065	Kugel Creek	254	11-Sep	12	68	92	6,259.3
102-30-067	Kegan Cove	254	11-Sep	12	64	92	11,206.4
103-40-067	Coco Harbor Head	254	11-Sep	12	64	92	3,480.1
102-40-015	Kitkun Bay Southeast Side	253	10-Sep	9	66	92	1,447.2
102-40-060	Lagoon Creek	253	10-Sep	17	60	93	26,320.6
103-60-047	Klawock River	253	10-Sep	12	60	92	112,345.8
106-10-030	Eagle Chuck Luck Lake	253	10-Sep	16	62	92	36,426.8
106-10-034	Luck Creek Luck Lake	252	09-Sep	7	78	92	1,551.9
103-21-018	Keete Inlet North Arm Head	252	09-Sep	17	60	86	1,741.2
101-23-087	Kwain Bay	252	09-Sep	8	64	92	2,956.3
102-30-017	Johnson Cove Creek	251	08-Sep	14	62	92	7,167.3
102-40-047	West of Disappearance	251	08-Sep	10	72	92	4,460.0
102-40-011	Lancaster Cove East	250	07-Sep	7	72	90	5,464.3
106-30-080	108 Creek Whale Pass	250	07-Sep	13	60	92	78,781.5
106-30-082	Squaw Creek Whale Pass	250	07-Sep	14	66	92	8,608.9

Table 31—Pink salmon stocks with early or late run timing, based on index date and evaluated by region and line (continued)

Stream		Survey					
Number	Name	Mean Julian date	Mean date	Number of years	First year	Last year	Mean escape-ment
Southern southeast, odd-year lines, early stocks							
• 101-60-025	Valentine Creek	212	31-Jul	11	73	93	18,038.2
• 101-75-080	Robinson Creek	215	03-Aug	13	73	93	27,069.2
101-30-030	Keta River ^a	218	06-Aug	17	61	93	47,126.5
Southern southeast, odd-year lines, late stocks							
• 106-30-080	108 Creek Whale Pass	254	11-Sep	13	61	93	70,143.1
• 102-60-087	Karta River	253	10-Sep	14	61	93	28,402.6
• 103-60-047	Klawock River	253	10-Sep	13	61	93	120,560.8
• 106-10-030	Eagle Creek Luck Lake	253	10-Sep	17	61	93	41,427.6
102-30-041	Frederick Creek	251	08-Sep	13	67	93	12,716.9
103-30-040	Grace Harbor Creek	251	08-Sep	13	73	93	3,279.1
101-47-025	Ketchikan Creek	250	07-Sep	7	75	89	11,738.4
102-40-011	Lancaster Cove East	250	07-Sep	9	67	93	5,598.9
103-21-018	Keete Inlet North Arm Head	250	07-Sep	8	61	81	2,712.5
101-41-067	Nadzaheen Creek	249	06-Sep	13	61	87	10,695.2
103-30-043	Vesta Bay	248	05-Sep	12	65	93	626.6
106-10-010	Ratz Harbor Creek	248	05-Sep	16	61	93	16,696.6
Northern southeast, even-year lines, early stocks							
112-42-025	Kadashan Creek	206	25-Jul	7	60	92	33,004.6
112-48-023	West Bay Head Creek	210	29-Jul	10	62	92	6,941.2
112-47-010	Long Head Bay	212	31-Jul	16	62	92	32,158.2
Northern southeast, even-year lines, late stocks							
113-41-019	Indian River, Sitka	253	10-Sep	11	62	90	3,417.6
113-44-005	Katlial Bay South Fork	251	08-Sep	16	60	92	8,509.4
113-43-002	Nakwasina River	260	07-Sep	14	60	92	6,628.6
112-17-026	Lake Florence Creek	249	06-Sep	14	60	92	13,119.3
112-73-017	Hood Bay South Arm Head North	249	06-Sep	9	64	92	1,008.6
113-62-006	Sukoi Inlet West Side	249	06-Sep	13	62	90	3,719.2
109-62-012	Elena Bay Head	248	05-Sep	14	62	92	3,171.6
109-62-018	Goose Trap Creek	248	06-Sep	13	66	92	6,160.4
113-65-005	Fish Bay South Side Head	248	05-Sep	14	60	92	2,535.7

Table 31—Pink salmon stocks with early or late run timing, based on index date and evaluated by region and line (continued)

Stream		Survey					
Number	Name	Mean Julian date	Mean date	Number of years	First year	Last year	Mean escapement
Northern southeast, even-year lines, late stocks							
109-52-035	Kutlaku Creek	247	04-Sep	16	62	92	11,820.0
109-62-024	Petrof Bay West Head	247	04-Sep	15	62	92	3,755.5
112-17-050	Thayer Creek	247	04-Sep	16	60	92	4,272.3
113-66-002	East of Kane Island	247	04-Sep	7	64	78	2,928.6
114-25-012	East Homeshore Creek	247	04-Sep	9	66	92	2,536.7
Northern southeast, odd-year lines, early stocks							
112-16-030	Wheeler Creek	207	26-Jul	17	61	93	18,967.6
112-42-025	Kadashan Creek	211	30-Jul	7	61	93	57,857.1
112-48-019	Little Goose Creek	211	30-Jul	10	73	93	4,495.0
111-17-010	King Salmon River	212	31-Jul	13	61	93	18,205.0
114-23-080	Goose Creek	212	31-Jul	9	65	93	1,903.9
112-48-015	Big Goose Creek	213	01-Aug	17	61	93	26,785.3
Northern southeast, odd-year lines, late stocks							
112-48-035	Tenakee Inlet Head	215	03-Aug	16	61	93	12,701.9
112-67-060	Kanalku Lake Creek	251	08-Sep	9	69	93	6,433.3
113-44-005	Katlial Bay South Fork	251	08-Sep	17	61	93	51,458.8
113-41-011	Port Krestof Sound	248	05-Sep	7	63	91	428.6
109-45-013	Salt Chuck-Security	247	04-Sep	17	61	93	7,587.2
109-62-018	Goose Trap Creek	247	04-Sep	11	65	93	5,048.9
114-25-012	East Homeshore Creel	247	04-Sep	8	69	91	2,043.8
109-62-012	Elena Bay Head	246	03-Sep	14	61	93	3,859.9
109-62-013	Alecks Creek	245	02-Sep	17	61	93	28,163.2
109-62-020	Petrof Bay Southeast Head	245	02-Sep	16	61	93	3,069.3
112-12-025	Kook Lake Outlet	245	02-Sep	13	61	93	6,511.9
113-62-006	Sukoi Inlet West	245	02-Sep	15	63	93	6,200.0

• = outlier.

^a Index date may be affected by early season escapement surveys targeting chinook salmon in which pink salmon are counted incidentally.

Table 32—Pink salmon streams with large timing differences between even and odd-year lines

Stream		Number of survey years			
Number	Name	Timing difference ^a	Even	Odd	Mean escapement
<i>Days</i>					
Southern southeast, negative differences					
• 101-71-04C	Clear Creek	-13	12	7	3,125.0
• 101-75-010	Grant Creek	-9	16	16	21,360.3
103-30-040	Grace Harbor Creek	-8	13	13	4,911.5
105-10-010	North of Louise Cove	-8	11	11	1,992.0
103-80-056	Inside St. Phillips Island	-7	11	14	7,590.9
108-60-003	Bear Creek Frederick Sound	-7	10	9	4,569.4
Southern southeast, positive differences					
102-30-067	Kegan Cove	15	12	16	11,206.4
103-60-011	Shinaku Inlet North Side	16	7	7	9,070.0
102-60-068	Kina Creek	14	12	13	10,490.8
102-60-038	Dog Salmon Creek	13	13	15	4,448.5
102-60-082	Harris River	13	17	16	74,168.3
103-11-035	Little Datzkoo Head	13	10	8	2,611.5
102-30-040	Moir South Arm Head Southwest	13	8	10	13,131.3
102-40-015	Kitkun Bay Southeast Side	12	9	14	1,447.2
103-11-041	Datzkoo Harbor Head	12	11	9	5,268.5
103-15-023	Klakas Right Head	12	17	17	33,751.2
103-60-037	Big Salt Lake Southwest Side	12	7	8	5,522.1
106-22-014	Burnett Inlet Northeast Head	12	7	8	186.3
101-30-095	Vixen Bay Head	11	13	15	5,354.8
101-45-094	Spit Creek	11	8	11	4,324.8
102-30-089	Miller Lake Creek	11	10	10	5,530.0
102-60-042	Cabin Creek Polk Inlet	11	10	13	5,565.0
103-90-028	Slow Creek	11	9	7	6,522.2
105-10-019	Kathleen Creek	11	12	12	8,600.6
107-40-055	Eagle River Bradfield	11	17	17	42,573.5
Northern southeast, negative differences					
• 112-17-012	Lake Kathleen Creek	-25	15	16	5,825.7
112-80-028	Chaik Bay Creek	-6	17	17	20,195.4
109-42-030	Kadake Creek	-5	17	16	18,884.7
110-22-004	Amber Creek North Arm Pybus	-5	17	17	14,667.9
110-34-010	Walter Island Creek	-5	8	7	615.5
112-42-025	Kadashan Creek	-5	7	7	33,004.6
112-67-060	Kanalku Lake Creek	-5	11	9	2,322.7
113-41-042	Kizhuchia Creek Red Bay	-5	10	13	1,622.0

Table 32—Pink salmon streams with large timing differences between even- and odd-year lines

Stream		Timing difference ^a	Number of survey years		
Number	Name		Even	Odd	Mean escapement
<i>Days</i>					
Northern southeast, positive differences					
• 113-41-019	Indian River, Sitka	30	11	13	3,417.6
• 112-16-030	Wheeler Creek	17	16	17	3,601.6
• 113-95-004	Phonograph Creek Lisianski Inlet	16	12	16	833.3
• 114-50-020	Althorp Creek	16	17	17	6,855.9
109-52-008	Rowan Bay East Head	15	17	17	9,123.5
113-54-007	Rodman Creek	14	17	17	29,805.9
109-20-007	Gut Bay Head	13	11	10	2,131.8
112-12-046	Gypsum Creek	13	14	14	950.2
113-57-005	Patterson Bay West Head	13	17	17	24,247.1
113-96-002	Saltery River Stag	13	17	17	6,900.0
109-52-050	Pillar Bay Southwest Side	12	8	11	1,123.8
113-95-006	Lisianski River	12	17	16	12,894.1
114-40-035	Trail River	12	17	16	3,251.5
109-52-055	Kwatahein Creek Pillar	11	10	14	3,255.2
112-12-034	North of Basket Bay	11	17	16	5,292.5
112-17-050	Thayer Creek	11	16	17	4,272.3
113-42-002	Limit Creek Nakwasina Point	11	15	16	3,857.5
113-58-002	Hoonah Sound North Arm West	11	15	16	4,317.1
113-81-011	Black River	11	16	17	6,375.0

• = outlier

^a Timing difference calculated as (even index date) - (odd index date).

Geographic distribution—The Nakina River pink salmon stock is unique among stocks in southeast Alaska in having a freshwater migration that extends up to 100 km. We do not know of any other transboundary pink salmon stocks in the region that ascend this far into fresh water.

Pink salmon stocks appeared to be sparsely distributed in Lynn Canal and along the northern outer coast, but this appearance may reflect a lack of data on the relatively small pink salmon populations found in these areas. Within this context, the pink salmon stock in the Situk River was unusual, because of its large mean escapements (see table 33 and next section).

Escapement magnitude—Escapement magnitude differed significantly between regions ($F = 13.9$, $P < 0.01$) but not between lines. Tukey (1977) pairwise comparisons indicated that southern even- and odd-year lines had significantly greater mean escapements than the northern even-year line (table 34).

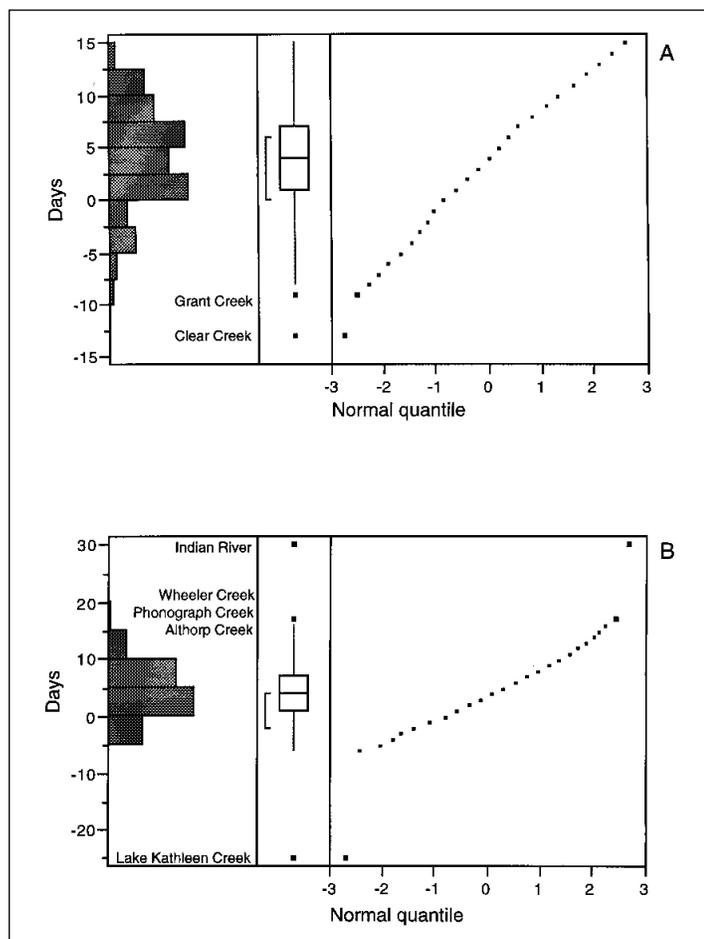


Figure 41—Frequency distributions, outlier plots, and normal quantile plots for differences in run-timing index between even- and odd-year lines for the (A) southern (N = 323) and (B) northern (N = 275) regions. Difference calculated as mean even-year index date minus mean odd-year index date. See table 32 for summary data for stocks occupying the tails of the distributions.

Distinctively large mean escapements occur in six drainages in the southern region and only one (Chuck River, even years only) in the northern region (table 33; fig. 42). Only the Wilson River and Anan Creek in the southern region have distinctively large runs of both lines. Not surprisingly, these large escapements occur in relatively large drainages on the mainland or on Prince of Wales Island (fig. 43). Taku River pink salmon escapement, estimated by using mark-recapture methods, indicated that this system is a major pink salmon producer in northern southeast Alaska (McGregor and Clark 1990). Estimated abundance ranges from 340,000 to nearly 500,000, depending on the recovery data included in the analysis (McGregor and others 1991). It was not included in the outlier analysis because a different method was used.

Table 33—Pink salmon stocks with large mean escapements

Stream		Mean escapement	Maximum number of fish	Number of years surveyed
Number	Name			
Even-year lines, southern region				
101-30-083	Humpback Creek	107,259	300,000	17
• 101-55-020	Wilson River	183,686	660,000	17
103-60-047	Klawock River	112,346	350,000	12
• 107-20-015	Anan Creek	157,439	338,000	17
Even-year lines, northern region				
• 110-32-009	Chuck River Windham Bay	86,047	259,000	17
110-34-008	Sanborn Creek	63,266	125,000	17
182-70-010	Situk River	62,000	175,000	9
Odd-year lines, southern region				
• 101-30-083	Humpback Creek	102,165	295,000	17
• 101-55-020	Wilson River	158,719	388,000	17
• 103-21-008	Nutkwa Creek	102,468	202,000	17
• 103-60-047	Klawock River	120,561	350,000	13
• 103-90-030	Staney Creek	101,247	310,000	17
• 107-20-015	Anan Creek	157,439	338,000	17
Odd-year lines, northern region				
109-20-016	Red Bluff Bay South Head	77,063	195,000	16
110-32-009	Chuck River Windham Bay	72,474	209,000	17
110-34-003	Rusty River	60,741	229,000	11
110-34-008	Sanborn Creek	61,420	153,950	17
111-32-220	Nakina River	96,978	750,000	9
113-64-001	Deep Bay Head	74,235	150,000	17
113-95-006	Lisianski River	78,988	220,000	16

• = outlier.

Differences in magnitude of the largest stocks are indicative of the general differences in population size between southern and northern regions. For example, the odd-year line of the Nakina River stock had a mean escapement estimate of about 100,000 fish, which was the highest estimate for any stock in the northern region. The Wilson River and Anan Creek stocks were the largest in the southern region and both have mean escapement estimates over 150,000 fish.

Escapement trends—The great majority of pink salmon stocks analyzed have stable escapements across years, and among stocks showing significant changes, increasing trends were far more common than decreasing trends. Among even-year lines, 115 stocks showed a significant trend, with 101 stocks (15.5 percent) increasing significantly and 14 (2.2 percent) decreasing significantly. The pattern was similar for odd-year stocks but with an even more pronounced increasing trend; 147 stocks

Table 34—Descriptive statistics for pink salmon escapement estimates summarized by region, and even and odd years

Statistic	South		North	
	Even years	Odd years	Even years	Odd years
N ^a	359	367	291	317
Mean (survey count)	13,406.3	13,013.4	8,296.5	10,952.0
Variance	431,647,000.0	418,203,000.0	126,119,000.0	198,073,000.0
SD ^b	20,776.1	20,450.0	11,230.0	14,073.8
Minimum	159.5	60.7	118.6	298.6
Maximum	183,685.9	159,684.1	86,047.0	96,977.8

^aN = number.

^bSD = standard deviation.

(21.5 percent) showed a significant trend, with 140 (20.5 percent) increasing significantly and only 7 (1 percent) decreasing significantly. Only one stream, Thetis Bay—southwest head, showed significant declines of both lines (table 35 and fig. 44). In systems with weirs, only five even-year stocks were evaluated and one was increasing significantly. This was the Sashin Creek stock, which was recovering from the eradication and transplant experiment (Smedley and McNeil 1966). Weir counts from six odd-year stocks were sufficient for analysis, and three of these were increasing significantly.

The only geographic pattern apparent among declining stocks was a cluster of three even-year stocks in Seymour Canal (fig. 44). This set of three included Pack Creek, a popular brown bear observation site. Pack Creek and Windfall Creek were both represented by relatively good data sets; both were surveyed more than once annually for all 17 even years from 1960 to 1992. Only seven surveys were available for the last significantly declining stock, in an unnamed creek opposite south Tiedeman Island (111-14-038). Two additional stocks in Seymour Canal showed nearly significant declines ($0.05 < P < 0.1$), and 10 of 11 even-year stocks had negative slopes. This general pattern was not present in Seymour Canal in the odd-year line.

Water Quality

The large number of pink salmon stocks in the region assures that many will be found in impaired and suspected water bodies (table 36). Ten water bodies classified as “impaired” by the Alaska Department of Environmental Conservation are inhabited by stocks of pink salmon (table 36). Only five of these water bodies were surveyed for pink salmon escapement with sufficient regularity to permit escapement-trend analysis. Three of these five showed significantly increasing trends in escapement, and the remaining two were stable. Salmon Creek (Juneau) is one of the significantly increasing stocks, and this likely is due to hatchery operations (the DIPAC Gastineau Channel hatchery is at the mouth of Salmon Creek and uses the creek as its water source).

Twenty-five pink salmon populations were found in suspected water bodies (table 36). None of the 25 showed a significant decline. Seven stocks (28 percent) increased significantly.

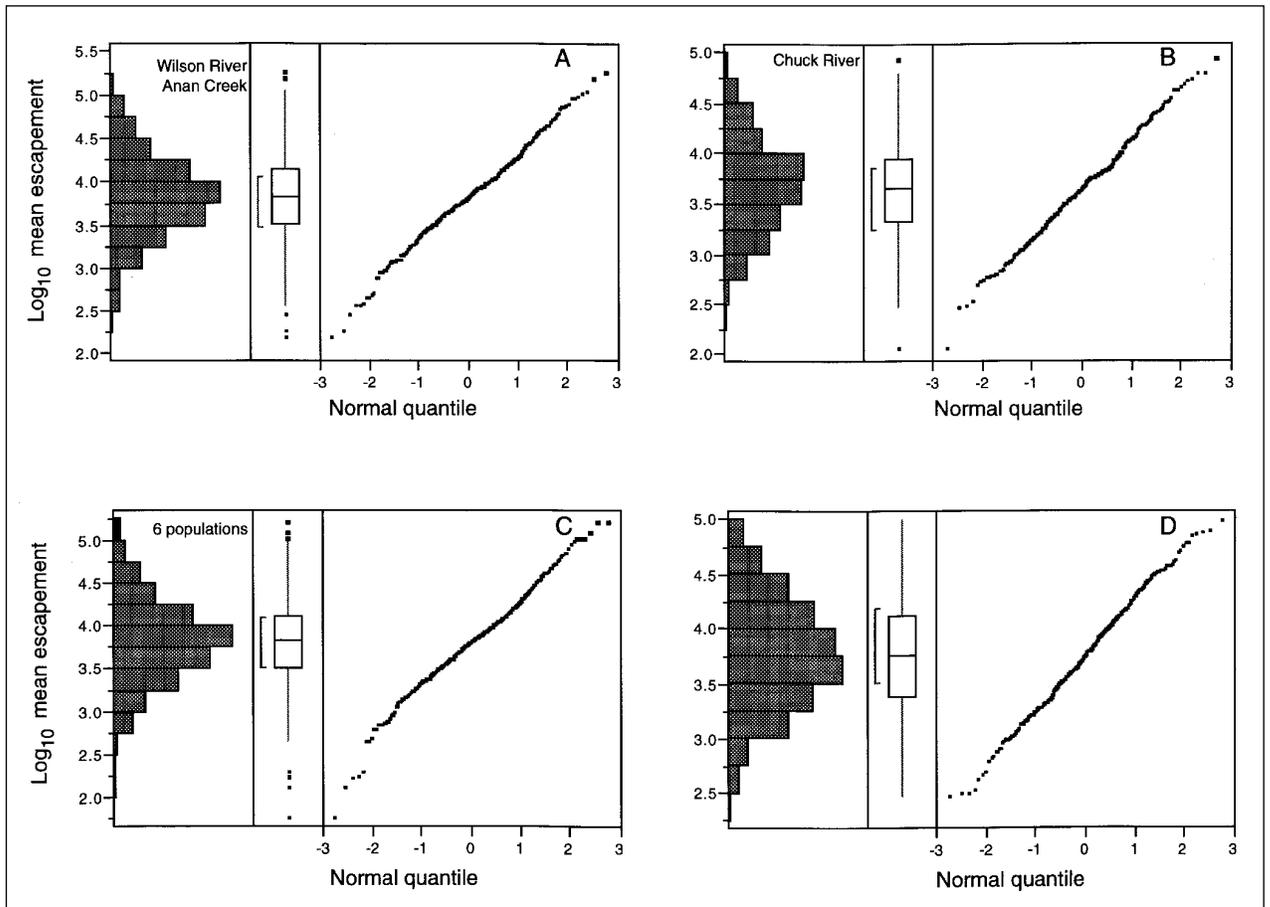


Figure 42—Frequency distributions, outlier plots, and normal quantile plots of mean pink salmon escapement magnitude based on escapement surveys, by line and region. Panel letters and sample sizes as in fig. 40. Table 33 presents summary data for specific stocks with large escapements.

Genetic Surveys

At this time, only preliminary surveys of allozyme frequencies have been conducted on pink salmon stocks in southeast Alaska. McGregor (1983) surveyed 12 streams in northern southeast Alaska and four in southern southeast Alaska, and Gharrett and others reported on 19 populations in southern southeast Alaska (see footnote 4). Significant differences in allele frequencies are present between northern and southern regions (McGregor 1983), but both surveys found that differences within regions were small. Among the stocks surveyed in the southern region, Anan Creek and Black Bear Creek differed from all others in cluster analyses. Because of the limited extent of the survey, results of additional analyses are necessary to confirm the genetic distinctiveness of these populations.

Table 35—Pink salmon stocks with significantly declining escapement trends

Stream		Location			Data quality rating	Possible factors
Number	Name	VCU ^a	General	Land use ^b		
Even-year lines						
101-15-012	Halibut Bay Northwest Head	846K	Misty Fiords National Monument	Wilderness	Good	Unknown
103-11-035	Little Datzkoo Head	663K	Dall Island	LUD IV	Poor	Unknown
107-20-020	Canoe Pass West Side	474S	Etolin Island	Wilderness	Fair	Unknown
107-20-071	Fools Inlet Head East	480S	Wrangell Island	LUD IV	Fair	Habitat? 380 ha logged 1953-90
107-30-070	Snake Creek, Olive Cove	469S	Etolin Island	LUD IV, state land	Good	Habitat? 186 ha logged 1941-80
108-40-007	Stikine North Arm Mouth	492S	Stikine River	Wilderness	Poor	Unknown
109-30-017	Curtiss Creek	181C	Admiralty Island	Wilderness	Fair	Unknown
109-62-030	Thetis Bay Southwest Head	407S	Kuiu Island	Wilderness	Fair	Unknown
109-62-036	Neal Creek	406S	Kuiu Island	Wilderness	Fair	Unknown
110-11-003	Twelvemile Creek, Frederick Sound	446S	Kupreanof Island	LUD III	Good	Unknown
111-14-038	Opposite South Tiedeman	140C	Admiralty Island	Wilderness	Poor	Unknown
111-15-020	Windfall Creek	151C	Admiralty Island	Wilderness	Good	Unknown
111-15-030	Pack Creek	152C	Admiralty Island	Wilderness	Good	Unknown
112-50-032	Bay Head Creek	243C	Chichagof Island	LUD IV	Fair	Unknown
Odd-year lines						
101-43-029	Pop Creek	756K	Revillagigedo Island	LUD III	Poor	Habitat? 472 ha logged 1955-81
101-90-060	Wolf Creek	743K	Revillagigedo Island	LUD III	Poor	Unknown
106-22-14B	Burnett Inlet Southeast Head	468S	Etolin Island	LUD III	Poor	Hatchery effects?
109-62-030	Thetis Bay Southwest Head	407S	Kuiu Island	Wilderness	Good	Unknown
112-17-025	Lake Florence Creek	150C	Admiralty Island	Wilderness; native corp.	Good	Habitat? Timber harvest
114-23-035	Chicken Creek Icy Strait	196C	Chichagof Island	LUD IV	Fair	Unknown
114-31-009	Gartina Creek	205C	Chichagof Island	LUD IV; native corp.	Poor	Habitat?

^a VCU = USDA Forest Service value comparison unit; approximately equivalent to a watershed; K = Ketchikan Area; S = Stikine Area; and C = Chatham Area.

^b LUD = land use designations:

LUD III = multiple use

LUD IV = intensive resource use (especially logging)

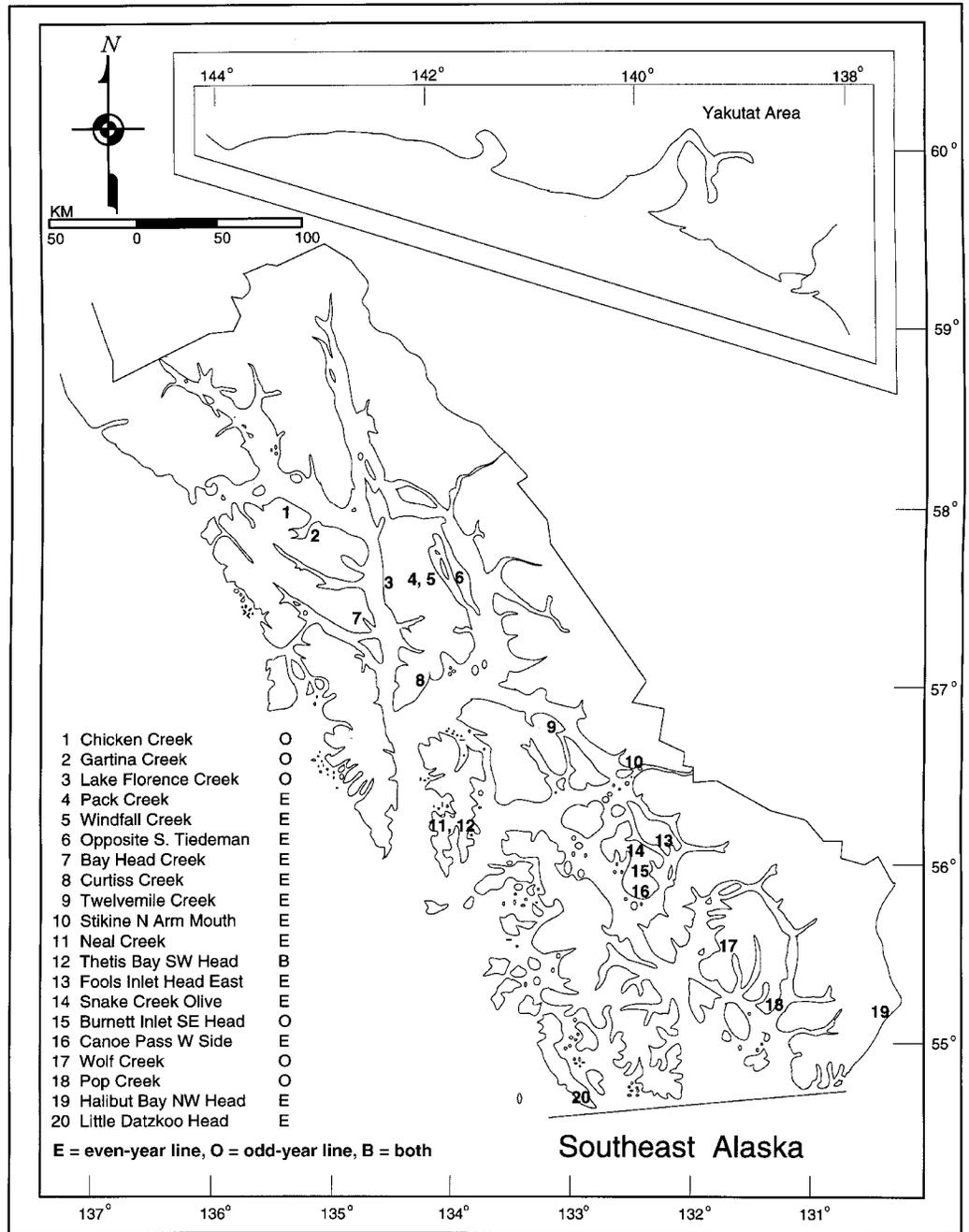


Figure 44—Approximate locations of southeast Alaska pink salmon stocks with significantly declining escapements; see table 35 for summary data including possible factors contributing to apparent declines.

Table 36—Pink salmon stocks in impaired or suspected water bodies

Stream		Location		Pollutant sources ^b	Comments
Number	Name	VCU ^a	General		
Impaired water bodies					
101-45-038	Salt Chuck George Inlet	747K	Carroll Inlet	TH, RC	Even-year runs increasing significantly Odd-year runs show no significant trend
101-47-015	Ward Cove	749K	Ketchikan	IN, DO, Debris	Even years—3 surveys from 1982-88, max. 3,277 fish, min. 390 fish Odd years—3 surveys from 1981-89, max. 905 fish, min. 27 fish
109-52-007	Rowan Bay	402S	Kuiu Island	TH	Even-year runs increasing significantly Odd-year runs increasing significantly
110-33-009	Hobart Bay	75C	Near Juneau	TH, IN, SM, RC	Even years—only 1 survey, 30 fish in 1986 Odd years—2 surveys, 16 fish in 1971, 4,200 fish in 1991
111-40-010	Lemon Creek	32C	Juneau	UR, PP, MI LF, SM, GM	Odd years only—2 surveys, 11 fish in 1981, 80 fish in 1985
111-40-012	Vanderbilt Creek	32C	Juneau	UR, GM, LF	Even years—only 1 survey, 941 fish in 1990 Odd years—only 1 survey, 2 fish in 1983, survey too late
111-40-015	Salmon Creek	32C	Juneau	UR, DDE, PCB	Even- and odd-year runs both increasing significantly Hatchery operation; status of wild stock unknown
111-40-089	Lawson Creek	33C	Douglas	UR, RD, CH, SM	Even years—5 surveys from 1968-92, highly variable Odd years—10 surveys from 1969-93, no significant trend
113-41-017	Granite Creek	311C	Sitka	UR, GM	Even years—7 surveys from 1978-92, no significant trend Odd years—5 surveys from 1981-91, max. 7,000 fish, min. 500 fish
113-41-028	Bear Creek Silver Bay	318C	Sitka	IN, DO, Debris	Even years—3 surveys, 0 fish in 1978, 76 fish in 1980, 2,500 fish in 1990 Odd years—4 surveys, max. 8,000 fish, min. 1,000 fish
Suspected water bodies					
101-45-024	White River	748K	Ketchikan	TH	Even-year runs increasing significantly Odd-year runs show no significant trend
101-47-017	Carlanna Creek	750K	Ketchikan	UR, IN, SE	Odd years only—210 fish in 1969, 34 fish in 1977, 491 fish in 1979
101-47-025	Ketchikan Creek	751K	Ketchikan	UR, IN, SE	Even and odd years—a moderate-sized run showing no significant trend
102-40-033	Dora Lake Creek	677K	Prince of Wales	TH	Even years—5 surveys from 1966-86, max. 13,000 fish, min. 0 fish Odd years—6 surveys from 1963-93, max. 6.825 fish, min. 0 fish

Table 36—Pink salmon stocks in impaired or suspected water bodies (continued)

Stream		Location		Pollutant sources ^b	Comments
Number	Name	VCU ^a	General		
102-40-035	Dora Bay West	677K	Prince of Wales	TH	Even years—1 survey in 1986, 13,000 fish Odd years—3 surveys, 4,965 fish in 1985, 2,000 fish in 1987, 100 fish in 1993
102-70-058	Thorne Bay	588K	Prince of Wales	IN, UR, SE, SM	Even years—no significant trend Odd years—increasing significantly
103-60-029	Steelhead Creek	595K	Prince of Wales	TH, RD	Even years—14 surveys 1960-92; no significant trend Odd years—increasing significantly
103-60-059	Port St. Nicholas Creek	NA	Craig	TH, UR	Even years—no significant trend Odd years—increasing significantly
103-90-030	Staney Creek	588K	Prince of Wales	TH	Even years—no significant trend Odd years—increasing significantly
106-44-001	Hammer Slough	447S	Petersburg	UR, SE	Even years—1 survey in 1984, 10 fish Odd years—2 surveys, 6 fish in 1983, 20 fish in 1985
111-40-007	Switzer Creek	32C	Juneau	UR, DDT	Odd years—3 surveys; max. 45 fish in 1991 Possible hatchery strays
111-50-035	Auke Nu Creek	27C	Juneau	UR	Even years—2 surveys, 25 fish in 1968, 2 fish in 1988 Odd years—2 surveys, 1,828 fish in 1983, 42 fish in 1987
111-50-037	Wadleigh Creek	27C	Juneau	UR, SE	Even years—8 surveys, 1968-92, no significant trend Odd years—5 surveys 1983-93, max. 2,000 fish in 1985, min. 50 fish in 1993
111-50-042	Auke Creek	27C	Juneau	HA, UR, SE, PP, LD, RE	Even and odd years—no significant trend Research and hatchery effects
111-50-052	Montana Creek	27C	Juneau	UR	Even years—2 surveys, both < 20 fish Odd years—mean escapement 346 fish, no significant trend
112-13-006	False Bay	210C	Chichagof Island	TH	Even years—no significant trend Odd years—increasing significantly
112-42-016	Corner Bay	236C	Tenakee Inlet	TH	Even and odd years—no significant trend Fish pass present
112-65-015	Hawk Inlet Head	128C	Hawk Inlet	Metals	Even years—6 surveys from 1970-92, max. 2,000 fish in 1990, min. 100 fish in 1974 No odd-year surveys
112-65-025	Greens Creek	144C	Admiralty Island	PP	Even years—increasing significantly Odd years—no significant trend
113-41-012	Sitka Harbor (Indian River)	311C	Sitka	UR, HA, PP, STP	Even and odd years—no significant trend
113-41-021	Sawmill Creek	318C	Sitka	LF	Odd-year surveys only—4 surveys, max. 8,000 fish in 1985, min. 1,000 fish in 1979
113-54-007	Rodman Creek	292C	North of Sitka	TH	Even and odd years—no significant trend
113-72-002	Klag Bay	271C	Klag Bay	Metals, MI, TA	Even years—6 surveys, range 0-500 fish Odd years—9 surveys 1961-91, no significant trend

Table 36—Pink salmon stocks in impaired or suspected water bodies (continued)

Stream		Location		Pollutant sources ^b	Comments
Number	Name	VCU ^a	General		
114-32-036	Eight Fathom Bight Creek	202C	Chichagof Island	TH	Odd years only—2 surveys, 250 fish in 1965, 40 fish in 1969
115-33-020	Lutak Inlet	NA	Haines	As, PAH	Possibly an established population

^a VCU = USDA Forest Service value comparison unit; approximately equivalent to a watershed; K = Ketchikan Area; S = Stikine Area; and C = Chatham Area.

^b Pollutant source types:

As = arsenic	LD = land development	RE = recreation
CH = channelized stream	LF = landfill	SE = sewage discharge
DDE = dichlorodiphenylchloroethane	MI = mining	SM = streambank or shoreline modification
DDT = dichlorodiphenyltrichloroethane	PAH = poly-aromatic hydrocarbons	TA = tailings
DO = dissolved oxygen	PCB = polychlorinated biphenyls	TH = timber harvest
GM = gravel mining	PP = petroleum products	UR = urban runoff
HA = harbor	RC = road construction	
IN = industrial	RD = road runoff	

Sources: Alaska Department of Fish and Game computerized escapement files. Available from: Alaska Department of Fish and Game, 802 3d Street, Douglas, AK 99824; ADEC 1992.

Discussion Evaluation of Results

Timing—Large differences occurred in the run timing of even- and odd-year lines returning to certain streams in the region. The relation between these line differences in spawning timing and fry emigration timing is unknown. Spawn-timing differences of a similar magnitude have been reported previously (Aro and Shepard 1967, Skud 1958), but the mechanisms underlying these within-stream differences have not been investigated. These mechanisms are of interest because both lines are exposed to similar selective environments in fresh water, and timing differences can be viewed as alternative solutions to the problem of reproducing successfully in a particular environment. In our survey, all streams showing large between-line timing differences were on or near the outer coast, except for Lake Kathleen Creek on the west side of Admiralty Island.

Another outcome of our analysis of run timing was that odd-year lines in both southern and northern regions were typically earlier than even-year lines. This result provided additional circumstantial support for the consistent finding that differences between even- and odd-year lines are greater than differences within lines over large geographic areas (Beacham and others 1985). The causes of pervasive differences between even- and odd-year lines are unknown, but hypotheses include (1) founding of even- and odd-year lines from genetically divergent stocks dispersing from different glacial refugia; (2) heritable differences in development, growth, and maturation rate preserved as coadapted complexes; and (3) heritable differences in migration route (possibly due to item (1), above).

Stocks occupying the tails of the timing distribution for each analysis group are good candidates for biochemical tests of genetic divergence. Analysis of run timing at a fine geographic scale might reveal stocks temporally isolated from others in their area. If water temperature is a critical variable determining run timing (Sheridan 1962), then stocks from systems in karst terrain or with large lakes that buffer temperature fluctuations are likely to diverge in timing from nearby systems lacking these

attributes. For example, 108 Creek (Whale Pass) is in an area of low-relief karst terrain on Prince of Wales Island and had exceptionally late run timing, and four north-facing drainages in Tenakee Inlet (including Kadashan Creek, noted for its cold water temperatures) had very early run timing (table 31).

Escapement magnitude—Escapement magnitude results from habitat characteristics, such as the size of the available spawning habitat (see Swanston and others 1977) and spawning productivity per unit area, as well as ocean conditions and the size of the harvest. Nonetheless, as population size increases, the intensity of natural selection necessary to counteract genetic drift or the homogenizing effects of gene flow declines, and genetic differentiation among populations in response to selection can occur more readily (Chakraborty and Leimar 1987, Wehrhahn and Powell 1987). Reduced gene flow due to spatial isolation can further enhance the potential for divergence of large populations. Pink salmon stocks spawning in large rivers in British Columbia have diverged morphologically from populations in smaller rivers; they generally have proportionately larger heads, thicker caudal peduncles, and larger fins than those spawning in small rivers (Beacham and others 1988).

We identified large breeding populations of pink salmon in eight locations in southeast Alaska, including the Taku River. The Taku River stock is estimated to have an annual escapement of 350,000 to 500,000 fish (McGregor and others 1991), most of them bound for the Nakina River spawning grounds far upstream. The Nakina River population has the characteristics associated with high potential for genetic divergence: it is large, it is isolated from gene flow by the distance of freshwater migration, and its spawning environment (in the interior) may impose selection pressures different from those on the coast.

Managers have sometimes attempted to increase escapement size by installing fish passes to bypass migration barriers and increase access to spawning areas. For example, the Anan Creek stock was estimated to support historical harvests of 2 to 3 million and still have escapements of several hundred thousand, making this one of the world's largest pink salmon-producing systems (see footnote 1). Mean escapements for even- and odd-year lines during USBF weir operations (1925-32) were 253,413 and 285,210 fish, respectively (Rosier and others 1965). The ADF&G installed a fish pass in 1967 to circumvent a waterfall in the tidal area that was a velocity barrier to pink salmon migration during periods of high water flow (Bibb 1987). Washouts and other problems prevented proper function of the fish pass, and in winter 1975-76, the fish pass was removed. High water in 1976 prompted an airlift of 129,000 pink salmon over the falls. In 1977, a replacement fish ladder was installed by the ADF&G and USDA Forest Service. This ladder was supposed to provide access in all flow conditions and increase pink salmon escapements to numbers nearer the estimated optimal escapement value of 320,000 fish (USDA, n.d., cited in Bibb 1987). Thorough analyses of the success of this project have not been conducted. Based on escapement-survey counts, we found no significant difference in escapements among the periods before fish pass construction (1960-66), during attempted installation (1967-77), and after construction of the ladder (1978-93) (Kruskal-Wallis, even-years, $N = 16$, airlift year excluded, $P = 0.62$; odd-years, $N = 17$, $P = 0.59$). Comparison of only before and after samples also yielded no significant differences (Wilcoxon, even-years, $N = 12$, $P = 0.47$; odd-years, $N = 14$, $P =$

0.99). Subsequent to fish pass construction, even-year mean annual escapement survey counts declined by over 20,000, and in odd years, survey counts increased by over 10,000 fish. The fish pass has had no clear effect, positive or negative, on Anan Creek pink salmon escapements.

Escapement trends—Over 18 percent of pink salmon stocks evaluated had significantly increasing trends. In contrast, the number of pink salmon stocks in the region showing declining escapement trends was exceptionally small (21 of 1,334 stocks analyzed, or less than 2 percent). The probability is high of obtaining this many declining stocks purely by chance, even if all stocks were in fact stable or increasing. Using a different method for evaluating trends, Baker and others (1996) found nearly 40 percent increasing and 3 percent declining or precipitously declining pink salmon spawning aggregates in the region. The predominantly positive trend in pink salmon escapements reflects ADF&G's successful implementation of efforts to rebuild pink salmon stocks by increasing escapements. The success of this program was assisted by generally favorable ocean conditions and winter temperatures from 1980 through 1990 (Hofmeister 1994). Another factor contributing to success of the rebuilding effort possibly was the generally pristine quality of spawning habitat in the region.

Ten of the declining stocks are in designated wilderness areas. Of the 11 stocks in locations where commodity extraction or other potentially disruptive land uses are possible, five locations have not had any development activities. Though the number of stocks involved is small, the pattern suggests that fishing pressure may be the most important factor contributing to declines. Twice as many stocks are declining in even years as in odd years. Given that even-year lines tend to be lower in abundance than odd-year lines, even-year lines may experience proportionately heavier fishing mortality. Three even-year stocks are declining in Seymour Canal, and data quality is good for two of these stocks: Pack Creek and Windfall Creek. The high value of Pack Creek as a brown bear observation venue increases the significance of the decline at this location and suggests an attempt should be made to determine factors contributing to the decline (such as the impact of bear predation and possible disruption of spawning associated with bear-viewing activities). Of the 35 pink salmon stocks spawning in water bodies designated as "impaired" or "suspected" by ADEC (1992) and with adequate data to permit analysis of escapement trends, none is declining and 10 show a significant increase. This surprising result suggests pink salmon are relatively resilient in regard to diminished water quality, especially pollution resulting from urban development (the most frequently cited source of pollution).

The general lack of data on biological characteristics of pink salmon and the lack of an accepted biological basis for stock discrimination at more refined geographic scales than northern and southern regions were pervasive difficulties that hindered our efforts to identify distinctive stocks and evaluate population status. Two pink salmon systems in southeast Alaska, Sashin and Auke Creeks, are very well studied. We considered these populations to have particular scientific value owing to the long-term databases available from each. Throughout the natural sciences, detailed long-term databases are gaining recognition as invaluable resources because they permit thorough analysis of variation and cyclic trends. But for virtually all the remaining stocks in the region, relatively little is known about their biology.

Conceptual Issues

Two central issues in pink salmon biology are the definition of stocks and the degree to which local adaptation occurs in quantitative traits. One insight provided by the work of Gharrett, Smoker, and coworkers is that, although between-stock variation in allozyme frequencies measured electrophoretically is often limited, variation in quantitative traits, such as life history characteristics, is nonetheless present and potentially critical to the long-term fitness of salmon populations (reviewed in Smoker and others 1991). Related to the issue of local adaptation are the matters of straying and gene flow. High rates of straying in Prince William Sound relative to other locations may reflect recent geologic instability in the sound. The earthquake of 27 March 1964 produced widespread habitat disruption (Noerenberg and Ossiander 1964). Much of this disruption occurred in the intertidal zone of streams, and Prince William Sound is noted for having a large proportion of intertidal spawners (Noerenberg 1963, Roys 1971). A high level of straying was likely among returning pink salmon that found natal streams no longer accessible. Given the general similarity of the intertidal spawning environment, this straying was likely to result in successful gene flow. Fifteen generations may not be an adequate amount of time for straying rates to return to an equilibrium level after such a significant disruption (see footnote 3). Furthermore, the relative lack of specific homing cues in the intertidal environment may tend to increase background straying rates (Baker and others 1996).

The degree of ecological interaction among different species of Pacific salmon deserves additional attention. Currently, predator-prey interactions are somewhat better understood than competitive or mutualistic interactions; for example, coho salmon smolts are known to be major predators on pink salmon fry, but chinook salmon smolts caught in similar locations consume very few pink salmon (Hofmeister and others 1988). Coho smolts also are known to preferentially prey on pink salmon fry even when chum fry are more abundant (Hargreaves and LeBrasseur 1985, Jones and others 1988).

Interspecific competition is believed to play a significant role in driving abundance cycles between pink and chum salmon (reviewed in Salo 1991), but experimental tests of this hypothesis have not been conducted. Pink and chum salmon are likely to compete while spawning, as fry in the early marine environment (Gallagher 1979, cited in Salo 1991), and possibly during the ocean feeding stage (Beacham and Starr 1982). In areas where strong line dominance occurs in pink salmon, chum salmon adjust their maturation schedule to spawn in greater numbers in years when pink salmon are less abundant (Gallagher 1979, cited in Salo 1991). The competitive interaction between these species may have evolutionary implications for both, given that fluctuations in abundance and age at maturity (in chum salmon) are probably partly heritable (Smoker 1984). On a per-stream basis, the degree of habitat and temporal segregation between pink and chum salmon in both freshwater and marine environments is not well investigated. Likewise, little is known about the potential for chum salmon to benefit from the presence of pink salmon, or if pink salmon function as a sort of predator shield, both as fry in the marine environment and as adults in the spawning stream (Dangel and Jones 1988). Widespread sympatric populations of pink and chum salmon in streams in southeast Alaska make it a promising area for investigating interspecific interactions.

In southeast Alaska, considerable overlap in habitat use also occurs between pink and sockeye salmon. Interactions between these species have not been studied. The fertilizing effect of pink salmon carcasses (Kline and others 1990, 1993) could have positive effects if pink salmon spawn above lakes used by rearing juvenile sockeye. Large numbers of decaying pink salmon carcasses also could have negative effects if decomposition decreases dissolved oxygen content in sockeye rearing lakes.

A fascinating and persistent question in pink salmon biology is, What factors are responsible for line dominance? Line dominance is not apparent currently in southeast Alaska but has occurred historically in the southern region. The methods used to collect data on pink salmon abundance and drainage patterns in a region may determine how easily dominance can be detected. Dominance may be more readily detected in areas where relatively few separate populations are taken in a fishery, especially if the majority of the catch is derived from a few very productive systems. In these areas, once dominance is established in the major regional stock, this pattern will be clearly reflected in catch statistics. This situation does not pertain to southeast Alaska where there is a large number of small populations. Ricker (1962) suggests that line dominance is the result of a variety of different factors, many operating locally. In southeast Alaska, alternative factors may operate on different local stock groups, resulting in no net dominance of one line at the geographic scale for which catch data are typically analyzed (i.e., northern and southern regions). Evaluating this hypothesis requires reliable catch and escapement data for groups of adjacent populations. If dominance occurs at a local scale in southeast Alaska, and if dominance is maintained by compensatory predation or interspecific competition between pink and chum salmon, management efforts to maintain large populations of both lines may be futile (Ricker 1962). Understanding scale and underlying mechanisms would enable management strategies to be tailored to particular biological circumstances.

The final issue of considerable biological and practical interest is whether or not overescapement is an important factor affecting pink salmon returns, and what magnitude of escapement results in diminishing returns. The conflicting hypotheses regarding this issue are (1) very large escapements lead to both thorough seeding of marginal habitats and thorough cleaning of spawning gravels, ultimately resulting in increased recruitment; or (2) very high spawner densities lead to increased aggression among spawners, higher egg losses due to redd superimposition, and density-dependent reductions in fry survival, possibly by exceeding the carrying capacity of the near-shore environment. In southeast Alaska, the 1985 and 1986 brood-year escapement indices exceeded the estimated optimal escapement of 12 million fish and these high escapements produced very low returns in both 1987 and 1988 (Hofmeister 1994). This small sample suggests overescapement may be reached at about 15 million fish (Hofmeister 1994). Although it is unlikely that an adaptive management experiment will be conducted intentionally to determine what magnitude of escapement is excessive (see McAllister and others 1992), such an experiment at a management-district scale could provide very useful information. The basis of current escapement goals is not well documented (Pacific Salmon Commission 1991).

Risk Factors

The low number of declining stocks in the region indicated that pink salmon populations are not currently jeopardized by imminent risk factors. The following list contains some factors we consider potentially important, given the continuation of current biological and economic trends. Heard (1991) reviews natural risk factors affecting pink salmon populations. We focus on human-caused risks.

1. Escapement-goal management for pink salmon is certainly more appropriate than fixed quotas, given the tremendous variation in abundance of pink salmon across years. The application of escapement-goal management also has some potential pitfalls. One pitfall associated with pink salmon is a consequence of strong run-timing segregation by sex, with males preceding females. If fishing is deferred until late in the run, females may be harvested disproportionately, adversely unbalancing the sex ratio of escapements (Hofmeister and Dangel 1989). Sex-ratio data from weirs on the Naha River, Hugh Smith Lake, and Karta River from 1986 to 1988 all show a predominance of males; catches in the districts where these systems are found contain a predominance of females (Hofmeister and Dangel 1989). This risk factor is most severe for stocks with intermediate run timing (see Alexandersdottir and Mathisen 1982). The ADF&G uses inseason sex-ratio data to direct fishing effort at entire runs rather than only early or late segments; however, the scale of harvest control may not be sufficiently precise to alleviate sex-ratio bias in the catch.

The effects of a sex ratio favoring males on stock productivity are not known, but the obvious expectation is that productivity would decline when the sex ratio becomes too biased. Besides the simple reduction in numbers of eggs deposited, productivity declines could result from intensification of competition among males for access to females. Male pink salmon are very aggressive at the spawning ground and competition among males is extreme (Heard 1991, Keenleyside and Dupuis 1988). Increased competitive interactions among large males might increase the spawning success of small, femalelike males. If femalelike morphology in males has a genetic basis, a decline over time in male body sizes could result (Gross 1985, 1991).

2. Although the survey of many index streams in the region suggests that management of pink salmon occurs at a relatively fine geographic scale, management decisions ultimately are based on attainment of district-wide escapement goals. It is possible that, at the district level, escapement goals can be exceeded while some populations disappear. In essence, smaller or less productive populations can be overexploited as fisheries grow and develop based on larger or more productive populations with similar migratory pathways or spawning destinations. The economic and political momentum of large fisheries on productive stocks make them difficult to slow or divert, leading to the potential depletion or extirpation of weak stocks. The capacity of small or less productive populations to persist in a changing environment also may be compromised indirectly, if overexploitation reduces genetic variability (Gharrett and Smoker 1993). If small pink salmon populations are reduced or eliminated, wildlife populations relying on the pink salmon resource could be adversely affected, and removal of salmon may compromise the integrity of entire vertebrate communities (Willson and Halupka 1995). The significance of this risk factor depends on the degree to which pink salmon stocks are genetically isolated and geographically distinct. At this time, it is completely unclear if the geographic scale of management districts corresponds to the biological reality of pink salmon metapopulations.

3. Prespawning mortality of pink salmon in southeast Alaska is primarily caused by low water flows and large numbers of spawners, resulting in hypoxic conditions (Davidson 1933, cited in Heard 1991; Heard 1991; Murphy 1985; Pentec Environmental, Inc. 1991). Historical surveys revealed 76 streams with prespawning mortalities from 1949 to 1989 (see footnote 5, cited in Pentec Environmental, Inc. 1991), but undocumented die-offs are believed to be more common (Murphy 1985). The summers of 1992 and 1993 were particularly warm and dry in southeast Alaska and numerous fish kills occurred during these years, particularly on Prince of Wales Island.⁵ Prespawning mortality tends to occur in small drainages in low-elevation terrain with little buffering capacity in the form of lakes or ponds, or in confined intertidal systems with restricted tidal exchange (Pentec Environmental, Inc. 1991). The former type of drainage also is favored for logging activities, which tend to increase stream temperatures (reviewed by Beschta and others 1987), decrease dissolved oxygen in surface as well as intragravel water (Chamberlin and others 1991), and in some situations, decrease stream flow (Hicks and others 1991). These effects are all more pronounced in small drainages, and retention of forested buffers along streams tends to decrease them. Consequently, appropriate timber management practices are necessary to minimize logging impacts on prespawning mortality. Prespawning mortality events tend not to remove large portions of spawning populations (Murphy 1985), but logging can reduce the climatic buffering capacity of streams sufficiently to increase the frequency of die-off events. Repeated die-offs could have cumulative effects on population sizes.

4. Decreases in body size may have negative consequences on pink salmon productivity. Body size of pink salmon in southeast Alaska shows a significant decline across years. Decreases in female body size may decrease egg number or size, or both, and survival of eggs, alevins, and fry (Bilton 1973, cited in McAllister and others 1992). In coho salmon, larger females obtain better redd sites, dig deeper redds that are less susceptible to scour, and defend their redd longer and more successfully, thereby reducing the frequency of redd superimposition (van den Berghe and Gross 1989). If similar patterns apply to pink salmon, then decreasing body size can diminish stock productivity. Given that payment for catches is made by weight, not number, the obvious result of declining body size is increasing pressure to take larger numbers of fish. This may not be an important issue if small body size continues to be associated with strong runs.

5. Although wild coho salmon consume more pink salmon fry than do hatchery-reared coho (Hofmeister and Dangel 1989), the very large numbers of coho smolts that can be released by hatcheries make them a potential threat to nearby pink salmon populations. This potential risk factor is easily addressed by delaying hatchery releases until after pink salmon fry move offshore (Hofmeister and others 1988).

⁵ Gibbons, D. 1989. Alaska working group on cooperative forestry/fisheries research annual report for 1989. Unpublished report. On file with: U.S. Department of Agriculture, Forest Service, Wildlife and Fisheries, P.O. Box 21682, Juneau, AK 99802.

⁶ Personal communication. 1996. Brenda Wright, fisheries biologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 2770 Sherwood Lane, Juneau, AK

Another risk associated with hatchery production of pink salmon in southeast Alaska relates to the effects of hatchery returns on inseason management. Brood stock from the DIPAC hatchery was derived in part from the Kadashan River, a stock with relatively early run timing. Burnett Inlet hatchery is developing Anan Creek brood stock; Anan Creek pink salmon also have relatively early run timing for their area. Development of fisheries on these hatchery returns has the potential to increase exploitation rates on nearby wild stocks with early timing, such as the Taku River stock. Furthermore, if the problem of disproportionate catch of females is addressed by shifting the basis of management more toward fishery performance and away from escapement goals, then hatchery fish can confound determination of natural stock run strength (Pacific Salmon Commission 1991). Large, early returns of hatchery fish could provide an erroneous impression of a strong run, if the hatchery fish are not distinguishable from wild populations. This risk factor can be easily minimized by requiring that hatchery fish be marked, and new, more efficient marking techniques are being developed.

Conclusions Distinctive Stocks

Pink salmon are immensely abundant in southeast Alaska, with populations inhabiting over 3,000 streams. Because even- and odd-year lines are reproductively isolated by the 2-year life cycle of pink salmon, over 6,000 separate populations are present in the region. Spatial and temporal factors have been used to characterize these populations into stock groups. Both even- and odd-year lines are divided into northern and southern stock groups based on differences in migratory pathways and apparent lack of mingling across the boundary at Sumner Strait. Within the northern and southern regions, pink salmon stock groups also have been characterized by migratory timing (early, middle, and late spawning groups). Spawning timing is related to stream temperature regime; therefore, stock groups defined by spawning timing also show rough geographic separation, with early stocks concentrated on the mainland and late stocks on the outer islands. Genetic data distinguished two geographic stock groups within the southern half of the region: inland and Prince of Wales groups. No widespread genetic surveys of pink salmon in southeast Alaska have been completed. Additional genetic and biological data from pink salmon escapees would be useful to define more clearly the spatial and temporal boundaries of pink salmon stocks. Existing data suggested that stock separation may occur at scales ranging from within streams, to groups of populations separated by hundreds of kilometers of shoreline. The spatial extent of stocks probably differs among areas, with finer grain separation in areas of higher habitat heterogeneity and temporal stability. Except for the populations in Sashin and Auke Creeks, relatively little is known about the biological characteristics of individual pink salmon populations in southeast Alaska. Spawning timing and population size were the only biological characteristics for which large databases exist that include populations throughout the region.

Spawning timing—Based on analysis of index dates, 12 even-year, and 2 odd-year southern-region populations have distinctively early run timing (see fig. 45 for approximate geographic location). Four odd-year southern populations have distinctively late run timing. No populations in the northern region have distinctive timing, probably because the histograms for this region suggest broader bimodality than those for the southern region. The Taku River stock appears to be conspicuously early in its run timing, but the relation between mean date of migration calculated at a fishwheel and our timing index was unclear. Differences in spawning timing can limit gene flow.

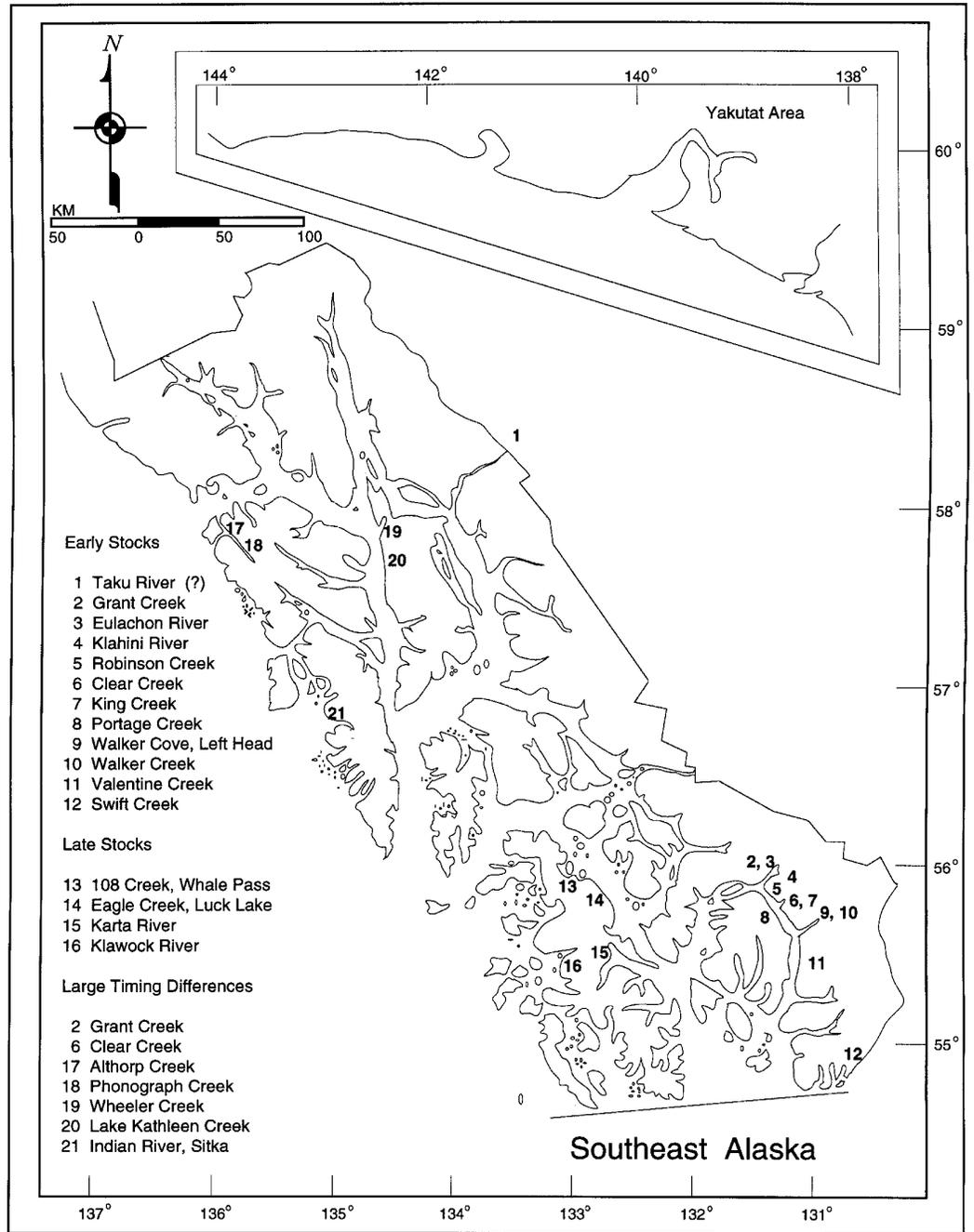


Figure 45—Approximate location of southeast Alaska pink salmon stocks, with timing index dates, that are outliers from the overall distribution for their line and region, and stocks with timing differences between lines that are outliers. The Taku River stock is included based on run timing calculated from fishwheel captures.

Timing differences—Two southern-region streams, and five northern-region streams showed exceptional differences in timing between even- and odd-year lines, possibly indicating alternate responses to similar selective environments by each line.

Large escapements—Six southern-region streams and two northern-region streams had exceptionally large escapements. Wilson River and Anan Creek in the southern region had large escapements in both even and odd years. Large populations may be important contributors to fisheries and may diverge genetically, if the rate of gene flow is not great enough to overcome the change in allele frequencies due to selection. Based on a preliminary allozyme survey, the Anan Creek population is genetically divergent from other populations sampled in southern southeast Alaska (see footnote 4).

Geographic location—We did not compile data on spawning migration length for pink salmon populations throughout the region, but the pink salmon population that spawns in the Nakina River is the only population traversing the coastal climate and spawning in an area with a more continental climatic regime. Isolation by distance and different selection pressures could contribute to genetic divergence of this population.

Special scientific value—The extraordinary amount of research conducted at Sashin and Auke Creeks has resulted in a wealth of information about pink salmon biology at these sites, as well as invaluable long-term databases. Insufficient information was available from other pink salmon populations in the region to know if the Sashin and Auke Creek populations are biologically unique. The study of pink salmon populations at these locations has made, and will continue to make, significant contributions to our understanding of this species.

Declining Escapement Trend

Only seven of 21 declining stocks were represented by relatively good data. Factors responsible for declines of well-surveyed stocks are generally unknown. Habitat disruption in the form of timber harvest has occurred in the watersheds of Snake Creek and Lake Florence Creek.

Water Quality

Existing data indicated that diminished water quality does not have a clear negative effect on pink salmon escapements. These data are scant, and additional monitoring of populations inhabiting impaired water bodies is recommended. Ten pink salmon populations were found in impaired water bodies.

Risk Factors

The low percentage (about 2 percent) of declining pink salmon stocks in the region indicated that pink salmon populations are not generally at risk in the region at the present time. Factors that could contribute to future declines include sex-biased catches that lead to a predominance of males in escapements, prespawning mortality, egg and alevin mortality associated with changed hydrologic and thermal regimes of streams in logged watersheds, and an ongoing decline in pink salmon body size that could reduce productivity.

Acknowledgments

The cooperation of L. Talley and S. Johnson greatly facilitated access to the information contained in the ADF&G Integrated Fishery Database, without which this report would have been impossible. G. Gunstrom, M. Harris, and K. Savikko provided essential ADF&G documents. S. Marshall provided both access to the information resources of the ADF&G and criticism that improved this project. Lengthy conversations with B. Heard, K. Hofmeister, and H. Jaenicke introduced us to the important

issues in pink salmon biology and the pink salmon literature for southeast Alaska. W. Smoker provided copies of unpublished theses of K. Hebert and P. Goddard. D. Aho provided useful comments on an earlier draft. Special thanks to A.J. Gharrett and A. Wertheimer for their conversations, reviews, and moral support, all of which improved this manuscript.

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Chum Salmon (*Oncorhynchus keta*)

Abstract

Chum salmon (*Oncorhynchus keta*) inhabit over 3,000 streams throughout southeast Alaska. This review contains run-timing indices and escapement-trend evaluations for over 400 of these populations and analysis of additional biological characteristics for 46 populations. Throughout the region, summer chum salmon populations spawn primarily in mainland or northern-island drainages, and fall populations spawn primarily in southern-island drainages. At the subregional scale, genetic analysis of populations in southern southeast Alaska has revealed three geographic groups that may reflect historical colonization patterns. Differences in migratory pathways that reduce gene flow among groups may have preserved these differences. Four chum salmon stocks have distinctive characteristics based on reliable data, including the Chilkat River stock, which has late run timing and large population size and is an important resource for wildlife. Twelve additional stocks may have unusual biological characteristics based on limited sampling (seven) or anecdotal reports (five). Twelve populations (2.8 percent) of chum salmon had escapement trends that were increasing significantly, and 41 populations (9.5 percent) had declining escapement trends, a higher proportion than any other species surveyed. Risk factors that may contribute to declines in chum salmon abundance include inadequate understanding of chum salmon population biology, logging practices that result in increased sediment loads in spawning streams, and large-scale enhancement activities that may contribute to over exploitation of wild stocks.

Keywords: Chum salmon, *Oncorhynchus keta*, southeast Alaska, run timing, body size, intraspecific diversity, population status.

Introduction

Chum salmon inhabit the widest geographic range of all the Pacific salmon. In North America, they were found from the Sacramento River in central California to the Mackenzie and Anderson Rivers on the Arctic coast of Canada's Northwest Territories (Bakkala 1970). Chum salmon inhabit over 3,000 streams throughout southeast Alaska, and additional chum salmon populations are still being identified. Chum salmon stocks are distributed more densely and evenly in southern southeast Alaska than in northern southeast Alaska. Except for the East Alsek and Itallo Rivers, relatively few chum salmon populations occur in the Yakutat region. Transboundary chum salmon populations occur only in the Stikine and Taku Rivers in southeast

Alaska. We reviewed information for more than 400 chum salmon populations in southeast Alaska, primarily evaluations of population status and run timing based on escapement surveys. Information on biological characteristics is presented for 46 populations.

Life History

Chum salmon populations in southeast Alaska are separated into two types that are commonly referred to as "summer" and "fall" run populations after the designations for Asian chum salmon by Berg (1934, cited in Salo 1991). Except for differences in run timing, these populations do not show the same set of correlated characteristics that Berg used to define these types (Salo 1991). Summer chum salmon in southeast Alaska are typically characterized as having larger body size and older age composition. Summer chum salmon spawn from July to September and are found primarily in northern southeast Alaska. Fall chum salmon spawn from September to November and predominate in southern southeast Alaska, especially in Prince of Wales Island drainages. Exceptions to this general pattern include large fall chum salmon populations in the Chilkat, Excursion, and Taku Rivers in northern southeast Alaska (several small runs as well; McGregor and Marshall 1982) and large summer runs in the Tombstone and Keta Rivers, Hidden Inlet, and Fish Creek (Hyder) in southern southeast Alaska. Both types of chum salmon runs are found in some streams. For both summer and fall chum salmon, migratory timing differs by sex, age, and body size; males tend to precede females (Clark and McGregor 1983), older fish tend to precede younger fish, and larger fish in a given age class are generally found in the early portion of runs (Dangel and others 1977).

Throughout their range, chum salmon typically spawn in the lower 200 km of rivers, sometimes using the intertidal zone. Exceptions to this pattern occur, such as populations that ascend the Yukon River over 2500 km to spawn. The inability or reluctance of chum salmon to surmount barriers (including some fish ladders) is a characteristic that limits upstream migration and determines the suitability of streams as spawning habitat (Hale and others 1985). Like most other salmonid species, chum salmon prefer to spawn in locations where upwelling occurs or just above areas of turbulent flow (Salo 1991). A wide range of temperatures, water velocities, and substrates are acceptable (Hale and others 1985).

Eggs incubate in redds for 50 to 130 days, depending on water temperature (Bakkala 1970), and emergence occurs from February through May (Jones and others 1988; Koerner 1988, 1989, 1990). Late-running stocks often select spawning areas with relatively warm winter temperatures. The relation among spawning timing, water temperature, and emigration timing probably reflects evolutionary synchronization of these events with "windows of opportunity," such as near-shore plankton blooms, that maximize fry survival (Holtby and others 1989, Miller and Brannon 1982). Mortality of eggs and alevins is high; only 10 percent of eggs typically survive to emergence (Hunter 1959). Some controversy exists over whether all newly emerged juveniles immediately begin emigration to saltwater or if some remain to feed in freshwater for several weeks or months (Holtby and others 1989, Mason 1974, Salo 1991). No data are available from southeast Alaska to address this issue. Downstream migration of fry occurs primarily at night (Hale and others 1985, Koerner 1990). During the day fry remain near the gravel. Approximate mean dates of emigration are available for only three stocks in southeast Alaska; roughly 8 April for Fish Creek (Hyder, early segment

of run missed; Koerner 1988, 1989, 1990) and 2 May for Kadashan Creek (early part of run missed; Jones and others 1985), both of which are summer stocks, and 13 May for Sunny Creek, a fall stock near Ketchikan (Hofmeister 1990). Fry from all three locations average just under 40 mm in length at emigration (see refs. above).

Chum salmon smolts typically remain in estuaries for 1 to several months where they feed extensively and grow rapidly (Healey 1980, Mason 1974). Movement offshore typically occurs when inshore food resources begin to decline and fry are large enough to feed on larger prey and avoid predators (Salo 1991). Studies in southeast Alaska indicate early marine predation on chum salmon smolts by coho smolts is not nearly as intense as coho predation on pink salmon (Hofmeister and others 1988, Jones and others 1988). Chum salmon may in fact benefit from the presence of pink salmon, because coho selectively prey on pink salmon fry (Hargreaves and LeBrasseur 1985).

Increasing evidence indicates chum salmon occupy a unique trophic position in the ocean environment, relative to other salmon species. Chum salmon apparently feed predominantly on gelatinous zooplankton (Welch and Parsons 1993), while other salmon species are primarily piscivorous.

Little is known about stock-specific oceanic migration patterns of chum salmon from southeast Alaska, especially in the northern half of the region. Returning adults typically move inshore in early July, peak in late July, and decrease rapidly in August. Annual variation in this pattern is not well studied. District 101-11 near the mouth of Portland Canal has been identified as an important mixing area for returning chum salmon, including stocks from as far north as District 106—northeastern Prince of Wales Island (Pacific Salmon Commission 1987). An extensive juvenile marking program in Fish Creek (Hyder) should provide information on the migratory pathways and harvest patterns of this stock (Koerner 1990).

Chum salmon spawning populations consist of age 0.2, 0.3, and 0.4 individuals. On average, chum salmon from southeast Alaska typically spend about 3 years in salt water before returning to spawn (grand mean saltwater age [MSWA] = 3.24 years); however, there is considerable variation about this mean within seasons, among years, and among populations. In many systems in northern southeast Alaska, age 0.4 fish consistently dominate escapements. Males and females differ little in mean age in escapements. Precociously maturing males apparently are rare among chum salmon populations in southeast Alaska. No age 0.1 chum salmon of either sex have been reported for systems studied in the region.

Over broad geographic areas, the body size of chum salmon decreases with increasing latitude (Salo 1991). Although the largest chum salmon in southeast Alaska are found in the southern area, near Portland Canal, the overall trend is not readily apparent throughout the region. Male chum salmon tend to be significantly larger than females (regional mean male length for age 0.3 individuals = 641 mm, mean female length = 618 mm). Body size tends to increase with age for both sexes.

Considerable interest exists in apparent temporal trends of decreasing size and increasing age in chum salmon. This pattern has been found for both wild and hatchery stocks in North America and Asia^{1 2} (Helle 1993, Ishida and others 1993, Ricker 1980). The causes and consequences of this trend are unclear. Density-dependent effects in the ocean have been suggested as one possible cause (Ishida and others 1993). Selective harvest may have contributed directly to increasing age and indirectly, through selection for slow growth rates, to the general trend of decreasing size (Ricker 1980). Whatever the cause of the observed trends may be, because reproductive success in chum salmon is positively related to body size in some stocks (Helle 1989; but see Ricker 1980), a potential consequence of decreasing body size is decreased productivity.

No chum salmon populations in southeast Alaska are noted for having distinct patterns of interannual variation in life-history characteristics and abundance. In other geographic areas where these oscillations occur, they are thought to result from competition between juvenile chum salmon and pink salmon for zooplankton resources, in conjunction with pronounced even- and odd-year cycles of pink salmon abundance (Salo 1991). When pink salmon are abundant, chum salmon are not and vice versa. Cycles of chum salmon abundance are not apparent in southeast Alaska, perhaps because pink salmon in the region have not shown pronounced cycles in recent times (Hofmeister and others 1988).

Management

The first recorded commercial catch of chum salmon in southeast Alaska occurred in 1896 when 2,938 fish were reported caught (Rich and Ball 1933, cited in Clark and Weller 1986). Commercial harvest increased during the next two decades, peaking in 1918 when 9.35 million chum salmon were harvested (Clark and Weller 1986). Catches remained at a high level until the early 1950s, when a substantial decline occurred. Poor harvests persisted for nearly three decades; the average annual harvest from 1971 to 1980 was 1.43 million fish. In the mid-1980s, a modest increase began, with the average annual harvest for 1986-90 reaching 2.76 million fish (Rigby and others 1991; fig. 46).

An important factor associated with the decline in harvest has been a reduction in directed fisheries for chum salmon. Currently in southeast Alaska, significant fisheries directed primarily at wild-stock chum salmon occur only for summer and fall chum salmon in the Tree Point-Portland Canal area, and for fall chum salmon in Icy Strait-Lynn Canal and district 102 (southeastern Prince of Wales Island). Small directed fisheries for chum salmon occur in districts 105 and 111. The majority of chum salmon are harvested incidentally in purse-seine fisheries for pink salmon, and the number of chum salmon harvested is related to the duration of pink salmon fishing periods (Clark and Weller 1986). Chum salmon also are harvested incidentally in fisheries for sockeye (early season) and coho salmon (late season). More than 60 percent of chum salmon are harvested by purse seine, about 30 percent are caught by gill net, and the remainder are taken in troll, trap, sport, and subsistence fisheries.

¹ Personal communication. B. Bachen, Northern Southeast Regional Aquaculture Association, 1308 Sawmill Creek Boulevard, Sitka, AK 99835.

² Personal communication. 1996. K. Hofmeister, fisheries biologist, Alaska Department of Fish and Game, 802 3d Street, Douglas, AK 99824.

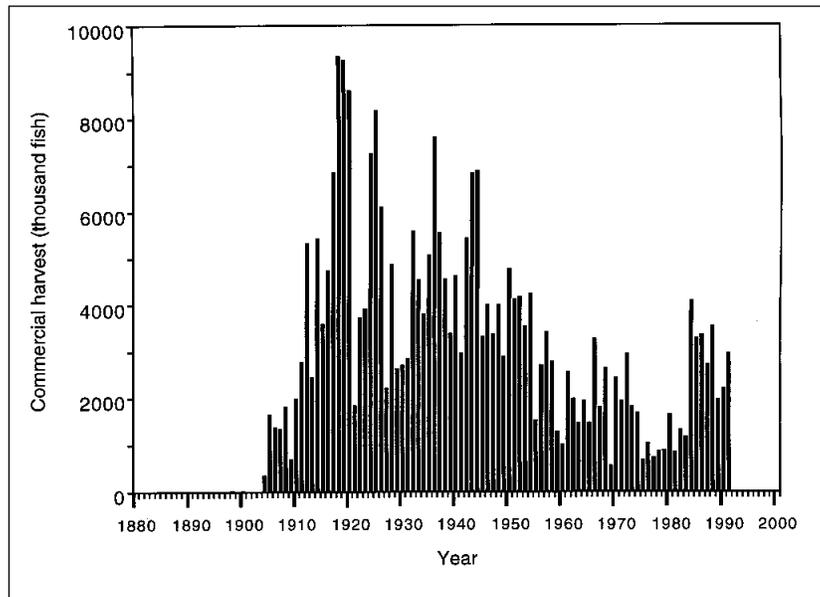


Figure 46—Annual commercial harvest of chum salmon in southeast Alaska, 1890-1991 (data from Rigby and others 1991).

Escapement surveys are the primary management tool for chum salmon. The accuracy of these surveys is compromised, however, by the need to count the more numerous pink salmon present in most of the streams where chum salmon spawn. Fixed escapement goals have been established only for Fish Creek (Hyder) and Disappearance Creek, both in southern southeast Alaska. Achievement of these goals has been monitored through escapement surveys and weir counts. Few weirs in the region are operated explicitly for the enumeration and sampling of chum salmon populations. Because few fisheries are directed toward chum salmon, few management research efforts are directed toward this species.

A significant proportion of the catch in recent years has been attributable to hatchery production (e.g., Neets Bay and Whitman Lake hatcheries contribute over 192,000 chum salmon annually to the Tree Point harvest [Pacific Salmon Commission 1991], and Hidden Falls hatchery alone contributed 725,000 fish in 1992 [see footnote 1]). Large returns to hatcheries have required an increasing number of special time and area openings to harvest them (Clark and Weller 1986). The need for these openings and the presence of large numbers of unmarked hatchery fish have complicated, and in some cases confounded, the management of wild-stock fisheries (Pacific Salmon Commission 1987).

Chum salmon stocks of southern southeast Alaska and northern British Columbia, particularly those in Portland Canal, have been designated as stocks of special concern by the U.S./Canada Pacific Salmon Treaty (Annex IV, Chapter 2). The stocks located on the Canadian side of Portland Canal are of greatest concern, because they collapsed in the mid-1970s and have not recovered. Summer chum salmon runs throughout the boundary region are depressed, relative to their historical abun-

dance (Pacific Salmon Commission 1991). Boca de Quadra fisheries have been closed frequently in the past 25 years because of weak runs (Pacific Salmon Commission 1991).

Methods

Stock Discrimination

The limited development of tools to discriminate among stocks of chum salmon has limited the implementation of stock-specific management strategies. Both scale-pattern analysis (McGregor and Marshall 1982) and allozyme surveys (Davis and Olito 1982; Kondzela and others 1989, 1994) can be used as effective stock separation tools for chum salmon, but neither technique has been broadly applied throughout the region.

The “special concern” status of populations in the boundary region has motivated extensive genetic surveys (Kondzela and others 1989, 1994). Consequently, the genetic relationships among chum salmon populations in southern southeast Alaska are relatively well understood compared to those of other salmon species in the region. Chum salmon populations in the boundary region cluster into six geographically defined groups, three of which are in southeast Alaska (Kondzela and others 1994). These three groups can be roughly described as central southeast (north of Sumner Strait), Prince of Wales Island area, and southern southeast east of Clarence Strait. The divergence of the Prince of Wales stock group may reflect the presence of glacial refugia on this island (Kondzela and others 1994; also see “Conceptual Issues” below).

The stocks sampled for genetic analysis overlap little with stocks sampled for other biological characteristics, thereby preventing us from determining if phenotypic characteristics follow similar geographic clustering patterns as allozyme frequencies, or if stocks exhibiting unusual phenotypes are also genotypically divergent.

Data Analysis Procedures

Data from escapement surveys and sampling were used for the analyses presented in this report. Adult body length data were converted to mid-eye-to-fork lengths by using equations in Pahlke (1989). Ten stocks were included in a variance-component analysis of adult fork lengths (table 37). These stocks were selected by the criteria of having at least 5 years of sampling with samples of at least 15 individuals of each sex in the 0.3 age class. The years sampled were not the same for all stocks. No other age classes were analyzed by the variance-component procedure because insufficient data were available. Stocks with at least 6 years of sampling were selected for inclusion in analyses of temporal trends in body length and age at return.

The methods described in the “General Introduction” were used to calculate the timing of peak escapement. Because chum salmon surveys are typically ancillary to pink salmon surveys, they may not reflect true timing for chum salmon. Escapement survey data and daily weir count data were taken from computerized files maintained by the ADF&G, Division of Commercial Fisheries.

The age structure of chum salmon stocks was evaluated in terms of M_{SWA} and the proportions of escapement samples in each age and sex class. Because the age structure and sex ratio of chum salmon runs vary during the spawning season, evaluations of these characteristics based on “snapshot” samples from runs may be biased. Weirs that remain in operation for the full duration of runs provide the best

Table 37—Variance component analysis of chum salmon mideye-to-fork lengths^{a,b}

Source of variation	Degrees of freedom	Type 1 sum of squares	F-test	Error term	Expected mean square	Variance component ^c	Percentage of total
Males							
Total	7,187	11,937,581.86			1,661.00	1,717.65	100.00
Stocks	9	3,147,533.40	12.16	Years	349,725.93	438.69	25.54
Years	40	1,150,283.38	26.87	Error	28,757.08	208.66	12.15
Error	7,138	7,630,765.08			1,070.29	1,070.29	62.31
Females							
Total	7,004	10,099,223.55			1,441.92	1,492.35	100.00
Stocks	9	2,801,248.56	9.14	Years	311,249.84	382.11	25.60
Years	40	1,362,032.22	39.9	Error	34,050.81	256.76	17.21
Error	6,955	5,935,942.77			853.48	853.48	57.19

^a Body lengths of age 0.3 fish from escapements.

^b Stocks included in the analysis and years when sampling occurred:

101-15-085	Fish Creek-Hyder	1973-77
102-40-043	Disappearance Creek	1973, 1975-77, 1984
111-50-052	Montana Creek	1982-85, 1988
112-42-025	Kadashan Creek	1976-77, 1982-84
114-27-030	Spasski Creek	1984-88
114-80-020	Excursion River	1975-76, 1982-84
115-32-025	Chilkat River	1974-76, 1982-83
115-32-046	Klehini River	1976, 1982-85
115-32-048	Herman Creek	1982-85, 1987
182-20-010	East Alsek River	1983-87

^c Variance components computed from means, standard errors, and sample sizes.

opportunity for sampling throughout the run and for providing accurate data on age composition and sex ratio. Sampling for age and sex at weirs is limited to only five streams in the region, and sampling was incomplete for at least two of these sites because the weir was pulled before the run was complete.

Biological characteristics of summer and fall chum salmon populations were not analyzed separately because they form a continuum in the region and are difficult to separate. Characteristics of stocks spawning in island versus mainland drainages were compared with a t-test or Wilcoxon tests.

Biological data other than run timing or escapement magnitude were available for only 46 of the 3,000 known populations. Most data were from stocks that spawn north of Sumner Strait and the Stikine River, although most chum salmon stocks in the region are found south of Sumner Strait. Many data sets were collected while eggs were taken for hatchery production or incubation boxes or during development of spawning channels. Long-term data sets were available only for the Fish Creek

Table 38—Regression results for trends in chum salmon mideye-to-fork length^a

Stream number	Name	No. of years sampled	Years	Males				Females			
				R-squared	Slope	P-value	Significance	R-squared	Slope	P-value	Significance
101-15-085	Fish Creek-Hyder	6	1972-77	0.08	1.21	0.50<P<0.9	NS	0.11	2.07	0.50<P<0.9	NS
115-32-025	Chilkat River	8	1972-84	0.13	-1.87	0.20<P<0.4	NS	0.18	-2.71	0.20<P<0.4	NS
115-32-046	Klehini River	8	1972-88	0.41	1.40	0.05<P<0.1	NS	0.00	0.05	P>0.9	NS
115-32-048	Herman Creek	8	1982-90	0.52	-3.33	0.02<P<0.05	*	0.60	-4.33	0.02<P<0.05	*
182-20-010	East Alsek River	7	1959-87	0.12	-0.41	0.40<P<0.5	NS	0.50	-1.08	0.05<P<0.1	NS

NS = not statistically significant; * = 0.05 > P > 0.01.

^a Body lengths of age class 0.3 fish.

(Hyder), Disappearance Creek, Kadashan Creek, and Chilkat River stocks; all are among the largest stocks in the region. Most of the biological information available is not representative of the majority of chum salmon populations found in the region. In their 1987 report, the Northern Boundary Technical Committee of the Pacific Salmon Commission (1987) described the situation succinctly: “Our knowledge of chum stocks is minimal.”

Results Adult Body Length

Adequate samples of adult lengths from escapements were available from 46 wild stocks. Age 0.3 and 0.4 adult lengths differed significantly by sex and age (two-way ANOVA, sex, $F = 59.5$, $P < 0.001$; age, $F = 71.0$, $P < 0.001$). Age 0.4 males were largest and age 0.3 females smallest.

Both age 0.3 and 0.4 males showed nearly significant differences in body length between island and mainland spawning populations; mainland spawners were larger (age 0.3, $t = 1.95$, $P = 0.06$; age 0.4, $t = 1.88$, $P = 0.07$). For females, the same overall pattern was present, and for age 0.4 females the difference in body length was significant (age 0.3, $t = 1.27$, $P = 0.21$ NS; age 0.4, $t = 2.10$, $P = 0.04$).

Variance-component analysis indicated that over 62 percent of total variation in male body length is attributable to variation among individuals within stocks, and 25.5 percent is accounted for by differences among stocks (table 37). Females were less variable among individuals (57 percent), but interannual variation was higher (17 percent versus 12 percent for males).

Five stocks were analyzed to determine if temporal trends in adult body length were present. Only one stock, Herman Creek (Chilkat) showed a significant trend, with both males and females decreasing in size (table 38). The lack of significant results for the other stocks may be due in part to the few years for which data were available. More detailed analyses of changes in body size of chum salmon have revealed a distinct downward inflection point beginning in the mid-1980s.³ Compared to Herman Creek, all other stocks analyzed had fewer post-1985 samples.

³ Personal communication. 1996. J. Helle, fishery biologist, National Marine Fisheries Service, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801.

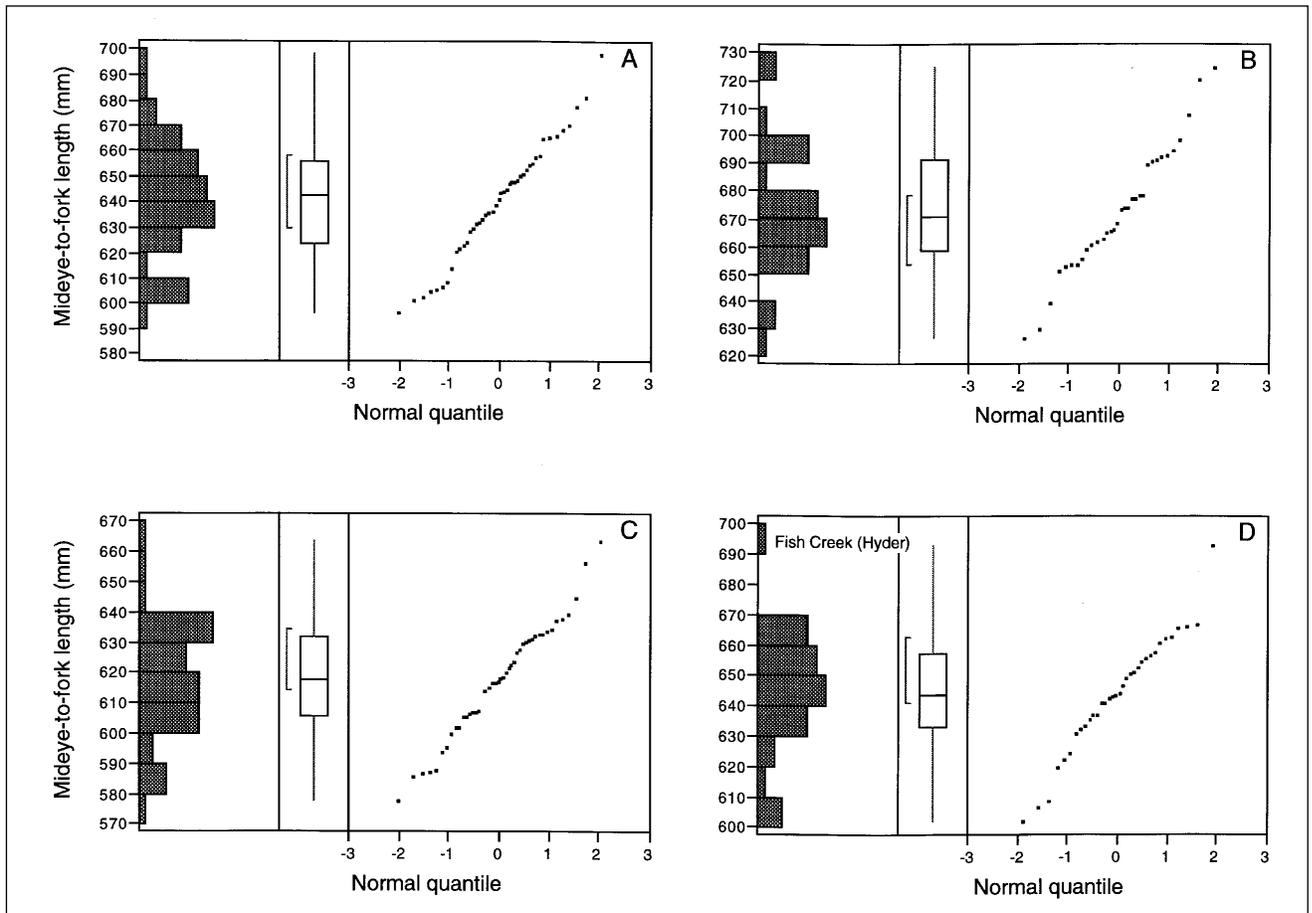


Figure 47—Frequency distributions, outlier plots, and normal quantile plots for chum salmon mean mideye-to-fork lengths: **(A)** age 0.3 males, N = 46; **(B)** age 0.4 males, N = 46; **(C)** age 0.3 females, N = 34; and **(D)** age 0.4 females, N = 34. Mean lengths calculated for escapements from all years sampled. No outliers are present.

No chum salmon stock in the region was distinct in terms of body size. Age 0.4 female chum salmon from Fish Creek (Hyder) were over 20 mm longer, on average, than females from other stocks in the region, but the distribution of body sizes was relatively even and the Fish Creek population was not an outlier (fig. 47).

The West Bay Head stock showed a distinctive level of sexual dimorphism in body size, with age 0.4 males averaging more than 70 mm longer in mideye-to-fork length (fig. 48B), but this result was based on a small sample from a single year. The Port Camden stocks were the only populations in which females were distinctively larger than same-age males but, again, the sample was limited (fig. 48).

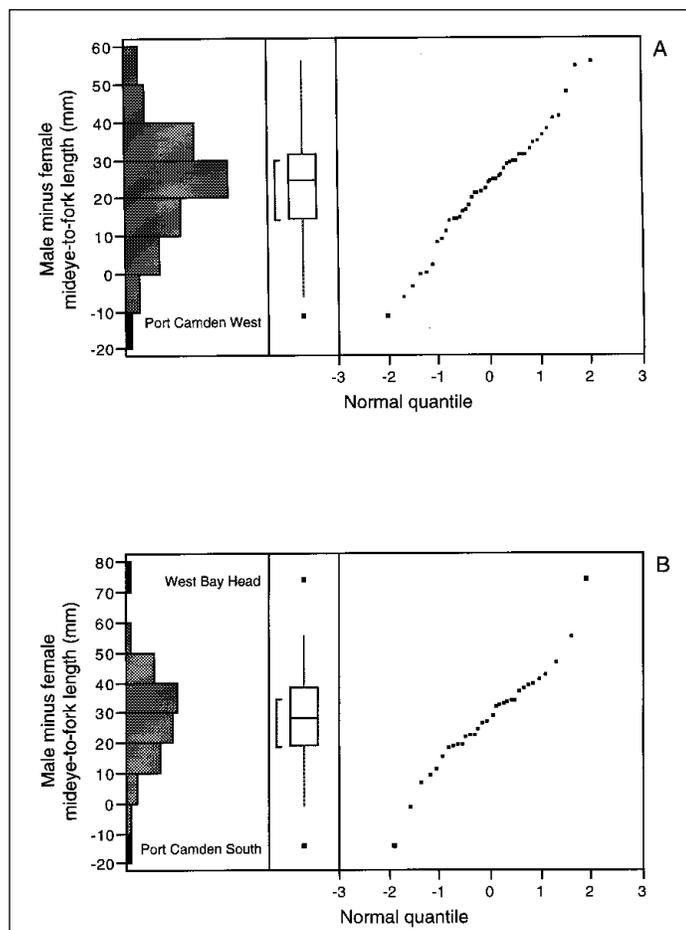


Figure 48—Frequency distributions, outlier plots, and normal quantile plots for sexual dimorphism in chum salmon body length by age class. Sexual dimorphism in body length calculated as male minus female mid-eye-to-fork lengths: (A) age 0.3, N = 46, and (B) age 0.4, N = 46. Means calculated for escapement samples from all years. Port Camden and West Bay Head stocks are outliers, but these stocks were sampled for only one year.

Table 39—Summary statistics for chum salmon run timing

Statistic	Weir counts ^a	Survey index		
		Total	Mainland	Island
Number of stocks	9	428	17	23
Mean (Julian day)	214.6	234	246.1	227.6
Variance	123.4	313.7	976.4	375.7
Standard deviation	11.8	17.7	31.3	19.4
Minimum	200	200	211	200
Maximum	238	306	306	265

^a Systems with at least 4 years of data.

Timing

Ten streams had weir data that could be used to calculate mean dates and duration of freshwater migrations. In most streams, however, the weir was removed before the chum salmon run was complete. The longest temporal data sets were from two streams in the Kadashan River drainage—east and west (Tonolite Creek) branches of the Kadashan River, which had more than 18 years of escapement counts. No change or trend in mean date of migration past the weir was detected for either branch during the sample period, from 1969 through 1988. No other data sets were sufficiently long to permit analysis of trends in mean date through time. The mean dates of migration were 26 July for the east branch and 25 July for the west branch (standard error was 1.1 for both); mean run duration for both branches was about 2 months for runs averaging 12,000 and 16,000 fish, respectively.

The mean of run-timing indices calculated for 428 stocks in the region was 21 August, with the range extending from 19 July to 2 November (table 39). The west branch of Kadashan Creek had the earliest index date, 19 July, which precedes the mean weir migration date by nearly a week. This pattern suggested that the index date underestimates the date of peak spawning; however, because weir mean date and index date can be compared in only one system, no conclusions were possible.

The run-timing index of island stocks was significantly earlier than for mainland stocks ($N = 40$, $t = 2.15$, $P = 0.04$; table 39). This comparison included only stocks for which body-length data were available and the result therefore was strongly influenced by the large number of late-spawning stocks in the Chilkat drainage included in the analysis, as well as the dearth of fall-type stocks from the islands of southern south-east Alaska. Based on an index date of 2 November, the timing of peak spawning of the Chilkat River stock is considerably later than other stocks in the region (fig. 49). Two other stocks in the Chilkat drainage, Porcupine Creek and Herman Creek, as well as the Taku River and one of its tributaries, Fish Creek, all have relatively late run timing. Peak survey counts occur in the second week in October in these systems.

Demography

Counts from escapement surveys and weirs, age structure, and sex ratio were the data types we evaluated to examine the demographic characteristics of chum salmon populations. Age structure and sex ratio were included in our analysis but were based on a small, nonrandom sample of the chum salmon stocks. Adequate age structure and sex-ratio data can be obtained only by sampling many individuals throughout the spawning season.

Escapement—Escapement trends for 1960 through 1993 were evaluated for 433 chum salmon stocks in the region. Twelve of these stocks showed a significantly increasing trend in escapement, and 41 were declining significantly. A cluster of five increasing stocks was found in Cholmondeley Sound. The remainder were scattered throughout the region. Clusters of declining stocks were located on Prince of Wales Island, in Petrof Bay on Kuiu Island, and in Seymour Canal on Admiralty Island (see table 40). Seven declining stocks spawn in Chichagof Island streams.

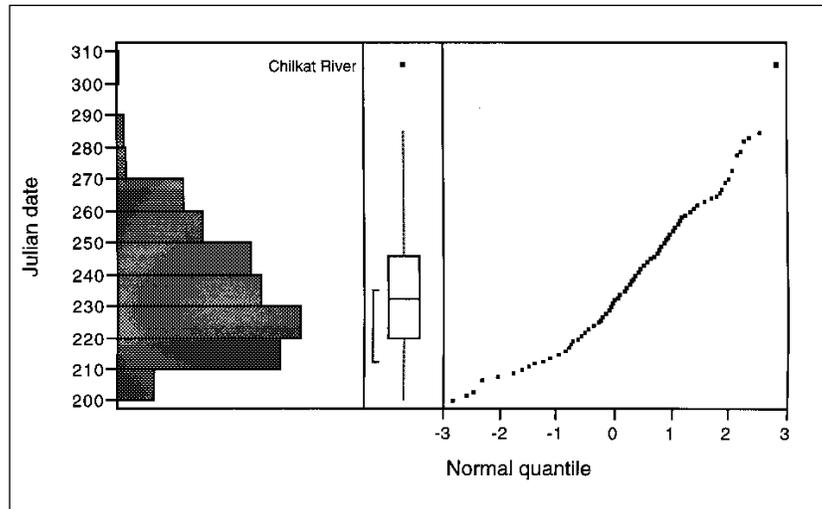


Figure 49—Frequency distribution, outlier plot, and normal quantile plot for run timing index calculated from timing of escapement surveys, N = 428. The Chilkat River stock has exceptionally late run timing.

Some stocks in the region showed considerable declines in abundance, but available data were not appropriate or sufficient for regression analysis. For example, Eagle Creek, the outlet of Luck Lake on Prince of Wales Island, was the site of a USBF weir from 1928 to 1931. During the 4 years of weir operation, the mean chum salmon count was 17,853 fish. This stream has not been surveyed regularly since large-scale timber harvest occurred in the drainage in 1969, but the mean count of chum salmon from four surveys conducted in 1967-68 and 1981-82 was 99 fish. These recent surveys were conducted at times corresponding to historical peaks in the run.

We reviewed USFWS escapement surveys conducted from 1925 to 1960, in an attempt to identify additional stocks that show conspicuous changes in abundance (table 41). The survey methods and reporting during these early surveys cannot be rigorously compared to later surveys; therefore, these stocks were not included in our list of stocks showing a significant decline. Nonetheless, these stocks have shown sufficient changes in abundance that we suspect the differences are unlikely to be caused entirely by differences in sampling methods. Two examples are Grace Creek where mean escapement count was 3,413 fish before 1957 and 1,255 after 1964, and Nutkwa Creek with mean escapement of 11,145 before 1955 and 318 after 1961 (table 41). Data were not available for either stream after 1985.

Sheep Creek near Juneau had a small native population of chum salmon before hatchery development (Huizer and others 1970a). The fate of this wild stock in the presence of large hatchery returns is unknown, but it is possible that the wild stock has been extirpated (see footnote 3). Similarly, the effects of hatchery operations on nearby native populations of chum salmon in Kowee, Salmon, and Peterson Creeks near Juneau are unknown. The brood stock used to produce the fry released into creeks in the Juneau area was an amalgam derived from at least four populations in the region, including Kadashan, Sawmill, Montana, and Salmon Creeks.

Table 40—Chum salmon stocks with significantly declining escapement trends

Stream		Location			Data quality rating	Possible factors
Number	Name	VCU ^a	General	Land use ^b		
101-11-101	Hidden Inlet	850K	Misty Fiords National Monument	Wilderness	Good	Unknown (harvest)
101-71-026	Walker Cove River Head	799K	Misty Fiords National Monument	Wilderness	Fair	Unknown (harvest)
101-90-039	Margeruite Creek	738K	Revillagigedo Island	LUD IV	Fair	Habitat degradation; fish pass
102-60-072	Twelvemile Creek	621K	Prince of Wales Uskabd	LUD IV	Fair	Habitat degradation
103-62-013	Shinaku Creek	594K	Prince of Wales Island	LUD IV	Fair	Unknown (hatchery)
103-90-027	Gutchie Creek	571K	Prince of Wales Island	LUD IV	Fair	Habitat degradation
103-90-030	Staney Creek	588K	Prince of Wales Island	LUD IV	Fair	Habitat degradation
103-90-042	Shaheen Creek	589K	Prince of Wales Island	LUD IV	Fair	Habitat degradation
105-10-032	Kell Bay Creek	411S	Kuiu Island	LUD III	Good	Unknown
105-42-010	Wolf Creek North El Capitan	536K	Prince of Wales Island	LUD IV	Fair	Habitat degradation
106-44-031	Crystal Creek	451S	Mitkof Island	LUD III	Good	Hatchery?
107-10-020	Vixen Inlet Creek	720K	Cleveland Peninsula	LUD IV	Fair	Unknown
107-10-070	Kudays Creek South Etolin	473S	Etolin Island	Wilderness	Fair	Unknown
107-10-072	South Etolin Island East	473S	Etolin Island	Wilderness	Good	Unknown
107-40-047	Tom Lake Creek	510S	Bradfield Canal	LUD IV	Good	Unknown
109-30-001	Woewodski Harbor	180C	Admiralty Island	Wilderness	Fair	Unknown
109-62-020	Petrof Bay Southeast Head	407S	Kuiu Island	Wilderness	Good	Unknown
109-62-024	Petrof Bay West Head	407S	Kuiu Island	Wilderness	Good	Unknown
109-62-028	William Creek Thetis East	407S	Kuiu Island	Wilderness	Good	Unknown
111-12-005	Pleasant Bay Creek	168C	Admiralty Island (Seymour Canal)	Wilderness	Good	Unknown
111-13-010	Mole River	156C	Admiralty Island (Seymour Canal)	Wilderness	Good	Unknown
111-15-024	Windfall Harbor West Side	151C	Admiralty Island (Seymour Canal)	Wilderness	Good	Unknown
111-15-030	Pack Creek	152C	Admiralty Island (Seymour Canal)	Wilderness	Good	Unknown
111-16-035	Swan Cove South Creek	152C	Admiralty Island (Seymour Canal)	Wilderness	Good	Unknown
111-16-040	Swan Cove Creek	152C	Admiralty Island (Seymour Canal)	Wilderness	Good	Unknown
111-17-010	King Salmon River	143C	Admiralty Island (Seymour Canal)	Wilderness	Good	Unknown
111-17-028	Portage Creek	135C	Admiralty Island (Seymour Canal)	Wilderness	Fair	Unknown

Table 40—Chum salmon stocks with significantly declining escapement trends (continued)

Stream		Location			Data quality rating	Possible factors
Number	Name	VCU ^a	General	Land use ^b		
111-35-020	Sweetheart Creek	57C	Snettisham	LUD III	Poor	Hatchery effects
112-42-008	Indian River- (?)	220C	Chichagof Island	LUD III	Fair	Habitat degradation
112-43-012	Tenakee Crab Bay Head	233C	(Tenakee Inlet) Chichagof Island	LUD IV	Good	harvest Habitat degradation;
112-45-032	Eaton Creek	230C	(Tenakee Inlet) Chichagof Island	LUD IV	Fair	harvest Habitat degradation;
112-50-030	Freshwater Creek	215C	(Tenakee Inlet) Chichagof Island	LUD IV	Good	harvest Habitat degradation;
113-53-003	Saook Bay West Head	294C	Baranof Island (NE)	LUD IV	Fair	harvest Habitat degradation;
113-57-005	Patterson Bay West Head	283C	Chichagof Island (S)	LUD II	Fair	Unknown
113-58-003	Granite Creek North Arm	284C	Chichagof Island (S)	Wilderness	Fair	Unknown
113-62-005	Krestof Sound Sukoi South 2	303C	Kruzof Island	LUD III	Poor	Unknown
114-25-035	West Swanson Creek	118C	Pt. Couverden	LUD III	Good	Habitat degradation
114-27-030	Spasski Creek	207C	Chichagof Island (NE)	Native Land	Good	Habitat degradation
114-80-020	Excursion River	NA	Glacier Bay National Park	National Park	Good	Harvest
115-10-065	Beardslee River	107C	Lynn Canal	LUD III	Fair	Unknown
115-20-052	Sawmill Creek	17C	Lynn Canal	LUD II	Good	Unknown
	Berners Bay		(Berners Bay)			(egg take?)

^a VCU = USDA, Forest Service value comparison unit; approximately equivalent to a watershed. K = Ketchikan Area; S = Stikine Area; and C = Chatham Area.

^b LUD = Land use designation:

LUD II = roadless areas

LUD III = multiple use

LUD IV = intensive resource use (especially logging)

The Chilkat River run of chum salmon is the largest chum salmon population in the region, with a mean survey estimate of over 54,000 fish (fig. 50). Returns of this population have been depressed in recent years (see footnote 2). The next largest run, based on escapement surveys, spawns in the Harding River and has a mean count of nearly 16,000 fish. Disappearance Creek is the largest chum salmon population monitored at a weir with a mean escapement count of 26,336. This is a minimum estimate of the true mean because, in later years, the weir on Disappearance Creek was removed once the management escapement goal of 30,000 fish was reached.

Table 41—Comparison of historical and current survey counts for selected chum salmon stocks

Stream		Historical surveys ^a		Current surveys		VCU number ^b	Land use	Comments
Number	Name	Year	Count	Year	Count			
101-71-050	Grace Creek	1947	3,000	1964	4,000	776K	Wilderness	Many surveys per year for historical counts improve data quality. "Grace Creek is a very productive salmon stream for its size. During recent years of low relative abundance, its production has been better than other streams in Behm Canal." (Martin 1959).
		1949	5,300	1972	100			
		1950	9,000	1983	36			
		1951	1,800	1985	886			
		1952	950					
		1953	1,080					
		1954	2,500					
		1955	1,500					
		1956	6,000					
		1957	<u>3,000</u>					
Mean			<u>3,413</u>		<u>1,255.5</u>			
101-80-003	Cow Creek	1949	6,000	12 counts		781K	Wilderness	Located at the apex of Behm Canal. Site of Fisheries Research Institute studies begun in 1948.
		1950	1,900	1964-85				
		1951	1,800					
		1952	805					
		1953	<u>420</u>					
Mean			<u>2,185</u>		140			
102-30-089	Miller Lake Creek	1940	3,000	1985	600	682K	LUD IV Native corporation	
		1942	4,000					
		1947	700					
		1948	4,000					
		1953	2,000					
		1956	4,500					
		1957	<u>9,000</u>					
Mean			<u>3,885.7</u>		600			
102-60-080	Indian Creek	1948	120	No recent counts		622K	State LUD IV	Extensive timber harvest 1959-65. Small run may have been extirpated.
		1949	106					
		1950	10					
		1951	485					
		1952	42					
		1953	20					
		1956	60					
		1957	22					
		1958	0					
		1959	0					
		1960	<u>0</u>					
Mean			<u>78.6</u>					
103-21-008	Nutmka Creek	1929	8,500	1961	86	K27a	Native corporation LUD IV	
		1931	18,763	1962	24			
		1944	6,500	1966	1,000			
		1945	5,000	1972	700			
		1946	20,000	1973	400			
		1948	25,000	1984	6			
		1949	400	1985	16			
		1955	<u>5,000</u>					
Mean			<u>11,145.4</u>		<u>318.9</u>			

Table 41—Comparison of historical and current survey counts for selected chum salmon stocks (continued)

Stream		Historical surveys ^a		Current surveys		VCU number ^b	Land use	Comments
Number	Name	Year	Count	Year	Count			
103-25-015	Deer Creek	1940	3,000	10 years 1960-85		673K	Native corporation	Recent surveys too early.
		1943	8,000					
		1944	16,000					
		1945	21,000					
		1947	22,500					
		1948	20,000					
		1949	1,450					
Mean			13,135.7		304.1			
105-42-005	Calder Creek	1930	27,516	28 years 1961-93		531K	LUD IV	Both weir and survey counts during historic period. Moderate timber harvest during 1970s.
		1931	17,125					
		1951	20,400					
		1952	2,270					
		1953	3,100					
		1955	650					
		1956	10,000					
		1957	20,000					
		1958	17,500					
Mean			13,173.4		1,007.6			
106-30-080	108 Whale Pass	1929	5,728	1972	0	538K	LUD IV	Also called Big Creek, this stream flows underground for about 100 m. Extensive timber harvest 1966-89. Recent surveys too early.
		1930	7,542	1981	5			
		1931	68,617	1984	1			
		1961	8,215	1993	100			
		1962	1,357					
		1963	723					
		1964	981					
Mean			13,309		26.5			
106-10-030	Eagle Creek Luck Lake	1928	1,982	1967	300	581K	LUD IV	Historic weir counts of chums incomplete. Extensive timber harvest beginning in 1969.
		1929	5,066	1968	1			
		1930	23,224	1981	24			
		1931	50,772	1982	72			
Mean			20,261		99.3			
109-42-030	Kadake Creek	13 years 1940-59		15 years 1962-93		421S	LUD IV	Extensive timber harvest beginning in 1965.
Mean			8,390		372.1			

^a USBF or USFWS weir present.

^b VCU = USDA, Forest Service value comparison unit; approximately equivalent to a watershed. K = Ketchikan Area; S = Stikine Area; and C = Chatham Area.

Sources for historical data: Martin 1959, Orrell and Klinkhart 1963, Orrell and others 1963, Rosier and others 1965.

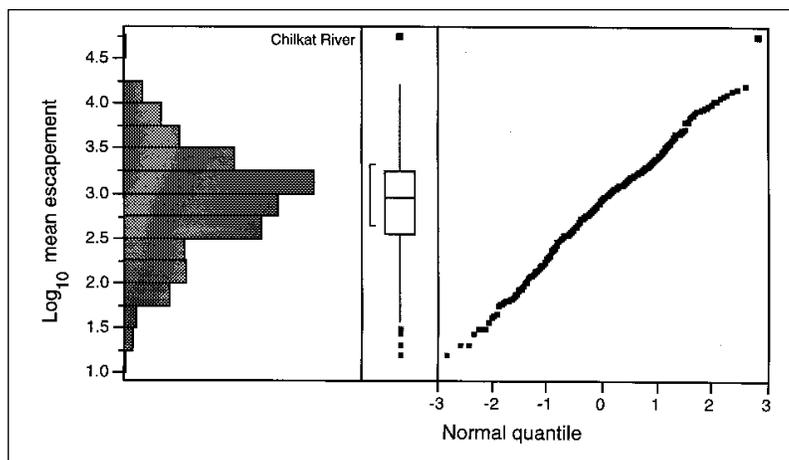


Figure 50—Frequency distribution, outlier plot, and normal quantile plot for mean chum salmon escapement magnitude based on escapement survey counts, N = 428. The Chilkat River stock has exceptionally large runs for the region.

Age structure—We included 46 stocks in our evaluation of escapement age composition (table 42). Age structure was evaluated both in terms of MSWA and proportions of individuals found in each sex and age class (table 42, fig. 51). No geographic trend in MSWA was apparent. Island and mainland stocks did not differ significantly in MSWA (males, $t = 1.13$, $P = 0.27$ NS; females, $t = -1.52$, $P = 0.13$ NS), but for both sexes the trend was for island stocks to be older. Male MSWA ranged from 2.65 years (East Alsek River) to 3.65 years (an unnamed creek near Snettisham), and female MSWA ranged from 2.71 (East Alsek River) to 3.68 (Gartina Creek). The only stock showing a distinctive age structure was the East Alsek River, which had an unusually low MSWA (fig. 52A) because of a high proportion of age 0.2 spawners. Throughout the region, male and female MSWA were highly correlated within stocks ($r = 0.95$, $P < 0.001$). The Nakwasina River and Gravel Creek stocks were unusual in showing different MSWA between male and female fish (fig. 52B). In the Nakwasina River females were older than males (fig. 52B), and in Gravel Creek males were older. These results were based on limited sampling from 2 and 3 years, respectively.

Significant temporal trends in MSWA were apparent only in the Herman Creek and East Alsek stocks (table 43). In the Herman Creek stock, only females showed a significant increase in MSWA with time, but the male trend was nearly significant ($0.05 < P < 0.1$). Both sexes showed a significant increase in the East Alsek stock, due largely to samples from 1959 and 1962 that had an exceptionally high proportion of age 0.2 fish. Age sampling of this stock was not resumed until 1982, and no subsequent samples have shown such a high proportion of age 0.2 fish. The exceptional 1959 sample has been attributed to an extraordinarily weak year class in 1955 (Mattson and Thorsteinson 1976). These authors offer no explanation for this weak year class, or for the recurrence of the unusual age-composition pattern in 1962. Results of these analyses of temporal trends must be considered preliminary, given the few samples for each stock and the caveats regarding representative sampling of age distributions provided above.

Table 42—Summary of chum salmon age distributions and mean saltwater ages (MSWA)

Stream		Males						Females					
Number	Name	Sample size ^a	0.2	0.3	0.4	0.5	MSWA ^b	Sample size ^a	0.2	0.3	0.4	0.5	MSWA ^b
				<i>Percent</i>			<i>Years</i>			<i>Percent</i>			<i>Years</i>
101-15-085	Fish Creek (Hyder)	1,194	10	78	11		3.01	1,210	8	80	11		3.03
101-15-090	Marx Creek (Hyder)	68	3	81	16		3.13	110	5	81	14		3.08
101-90-029	Traitors Creek	154	5	90	6		3.01	190	2	93	4		3.02
102-40-043	Disappearance Creek	1,413	17	69	14	<1	2.97	1,129	13	69	17	<1	3.05
108-70-002	Stikine River (Kakwan)	478	5	83	12		3.06	255	7	84	10		3.03
108-70-00?	Stikine (Great Glacier)	105	2	86	11	1	3.11	59		85	14	2	3.17
109-43-006	Port Camden West Head	68		43	53	4	3.62	105		40	59	1	3.61
109-43-008	Port Camden	105		75	24	1	3.26	42		67	33		3.33
109-45-01?	Security Bay	31	16	84			2.84	55	9	89	2		2.93
110-14-007	Farragut River	39	3	77	21		3.18	9		89	11		3.11
111-32-032	Taku River	2,372	<1	78	21	<1	3.21	1,872	<1	78	21	<1	3.21
111-33-010	Prospect Creek Speel	25		96	4		3.04	23	4	83	13		3.09
111-33-020	Crater Creek	128	1	56	42	1	3.43	96	2	57	40	1	3.40
111-33-025	Gravel Creek	114	6	60	34		3.28	90	4	77	19		3.14
111-34-010	(not named)	40		35	65		3.65	58		36	64		3.64
111-40-065	Middle Point Creek	176	1	97	2		3.01	196	2	97	2		3.00
111-41-005	Admiralty Creek	95	3	92	5		3.02	171	3	92	5		3.02
111-50-052	Montana Creek	974	3	43	52	2	3.53	1,086	2	44	52	1	3.53
111-50-069	Fish Creek (Douglas Island)	692	<1	44	55	1	3.57	632	<1	49	48	2	3.52
111-90-005	Limestone Inlet	141	1	74	24		3.23	160	1	78	21		3.19
112-21-005	Clear River-Kelp Bay	261	3	73	24		3.21	253	2	75	24		3.22
112-42-025	Kadashan Creek	914	6	57	36	1	3.32	969	2	54	44	1	3.43
112-42-025	Kadashan West	246	2	33	65	1	3.64	233	1	36	62	<1	3.61
112-48-023	West Bay Head Creek	208	<1	88	11		3.11	271		86	14		3.14
112-80-028	Chaik Bay Creek	529	3	88	9		3.06	511	3	87	10		3.06
113-41-032	Salmon Lake	172	6	54	35	5	3.38	153	6	48	45	1	3.41
113-41-040	Sandy Cove	216	<1	93	6		3.06	350	<1	91	8		3.08
113-43-002	Nakwasina River	348	1	78	16	4	3.24	366	1	54	28	17	3.61
113-44-005	Katlina Bay South Fork	391	4	85	11		3.07	365	2	82	15		3.13
113-72-005	Sister Lake	172	5	94	1		2.96	198	4	96	1		2.97
113-81-011	Black River	79	9	80	11		3.03	65	9	68	23		3.14
114-27-030	Spasski Creek	849	<1	51	47	2	3.50	902	<1	43	55	1	3.57
114-31-009	Gartina Creek	769	1	44	53	2	3.56	982	1	33	65	1	3.68

Table 42—Summary of chum salmon age distributions and mean saltwater ages (MSWA) (continued)

Stream		Males						Females					
Number	Name	Sample size ^a	0.2	0.3	0.4	0.5	MSWA ^b	Sample size ^a	0.2	0.3	0.4	0.5	MSWA ^b
		<i>Percent</i>						<i>Years</i>					
114-31-013	Game Creek	424		42	55	3	3.60	413	<1	39	58	3	3.63
114-33-023	Neka River	451	1	87	12	<1	3.12	455	<1	86	13	<1	3.13
114-34-010	Humpback Creek	281	1	67	32	1	3.33	445	1	65	33	1	3.34
114-80-020	Excursion Inlet	1,185	3	78	17	2	3.19	1,124	2	70	25	3	3.27
115-20-020	Lace River (Berners Bay)	99	3	89	8		3.05	115	1	82	17		3.17
115-20-052	Sawmill Creek (Berners Bay)	226	1	81	15	2	3.19	174	1	76	21	2	3.24
115-32-025	Chilkat River	1,382	8	79	13	<1	3.05	1,061	5	82	13		3.09
115-32-046	Klehini River	1,922	5	79	17	<1	3.12	1,937	2	76	22	<1	3.20
115-32-048	Herman Creek	1,144	4	73	22	1	3.19	1,327	2	74	24	<1	3.23
115-32-048S	Spawning Channel	685	8	77	14	<1	3.07	416	6	74	20		3.13
115-32-057	31 Mile Creek	374	1	53	44	2	3.46	324	1	44	52	2	3.56
115-32-059	25 Mile Creek	94	2	76	22		3.20	110	2	66	30	2	3.32
182-20-010	East Alsek River	1,317	44	48	9		2.65	1,465	37	54	9		2.71
Total stocks							46						46
Total mean		503.3					3.21	489.8					3.24
Total SE		80.4					0.03	74.9					0.03
Total median			3	77.5	16.5				2	74.5	21		

^a Cumulative sample size for all years.

^b MSWA may not equal value expected based on percentages because MSWA is calculated from numbers of individuals in each age class, not percentages, and because of rounding.

The historical samples from the East Alsek decreased the grand MSWA of this stock enough that it appeared to be distinct from other populations in the region (fig. 51A). No other chum salmon stocks were unusual in either MSWA or the proportions of individuals found in each age class.

Sex ratio—While male chum salmon predominate early in runs and females late, the overall ratio of males to females for the entire spawning season is believed to balance near 1:1 (Bakkala 1970). To minimize the effects of sample timing on results, only cumulative sex ratios for all sampling years were evaluated (table 44). The cumulative sex ratios of chum salmon populations in southeast Alaska ranged from 1:1.8 to 1:0.23 (males:females) (fig. 53). Like most sex-ratio values that deviated appreciably from 1:1, the distinctive values from the Port Camden West and Farragut River stocks resulted from relatively small samples or samples from single years, or both, and may not represent the true sex ratio of these populations. The sex ratios of the majority age classes in escapements were similar to those of entire populations, largely because the number of age classes found in chum salmon populations was low (table 44).

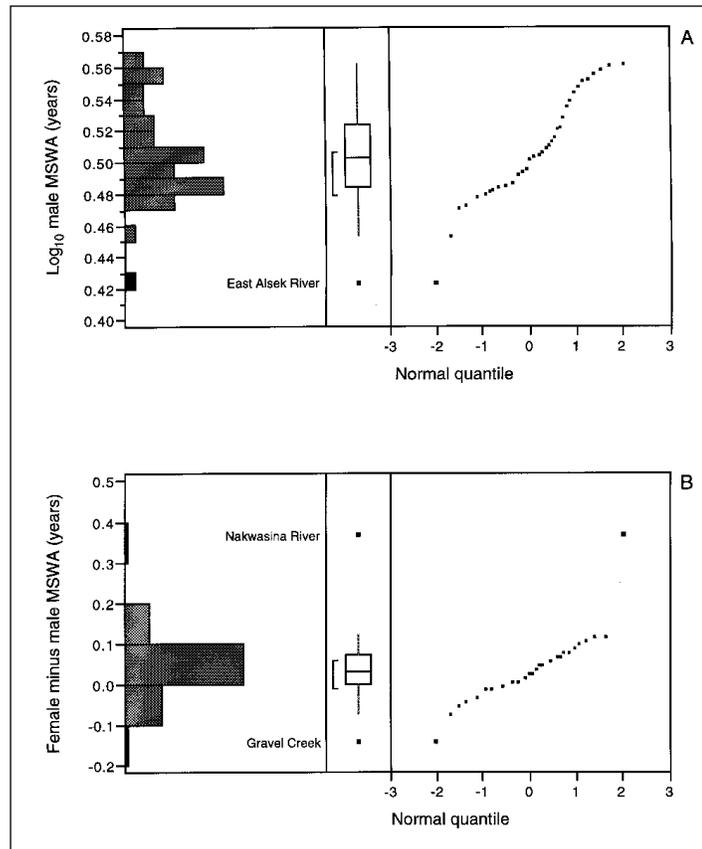


Figure 51—Frequency distributions, outlier plots, and normal quantile plots for **(A)** male mean saltwater age (MSWA), and **(B)** sexual differences in MSWA. For both plots, $N = 46$. **(A)** The East Alsek River stock has a distinctly low male MSWA. **(B)** Females in the Nakwasina River stock are markedly older than males, but sampling is limited to one year. Gravel Creek females are distinctly younger than males, but again sampling is limited to 204 individuals in three years.

Water Quality

Given the large number of chum salmon stocks found in the region, it is not surprising that many are in impaired and suspected water bodies (table 45). Eight stocks inhabit water bodies considered impaired by the Alaska Department of Environmental Conservation (1992). Only one of these populations is surveyed regularly (Rodman Creek), and this population shows no significant trend in abundance. Eighteen chum salmon populations are found in suspected water bodies. One of these populations, Stoney Creek, shows a significant decline in number of fish based on escapement survey counts. Eleven of the populations in suspected water bodies had fewer than 20 survey years from 1960 to 1993, indicating that they are not surveyed regularly; five populations were surveyed fewer than seven times and could not be analyzed for trends in abundance.

Genetic Surveys

Three chum populations analyzed by Kondzela and others (1989, 1994) show unusual genetic characteristics. The Port Real Marina stock from Prince of Wales Island shows greater genetic affinity to Queen Charlotte Island stocks than do other Prince of Wales Island stocks. Lover's Cove Creek chum salmon from south Baranof Island

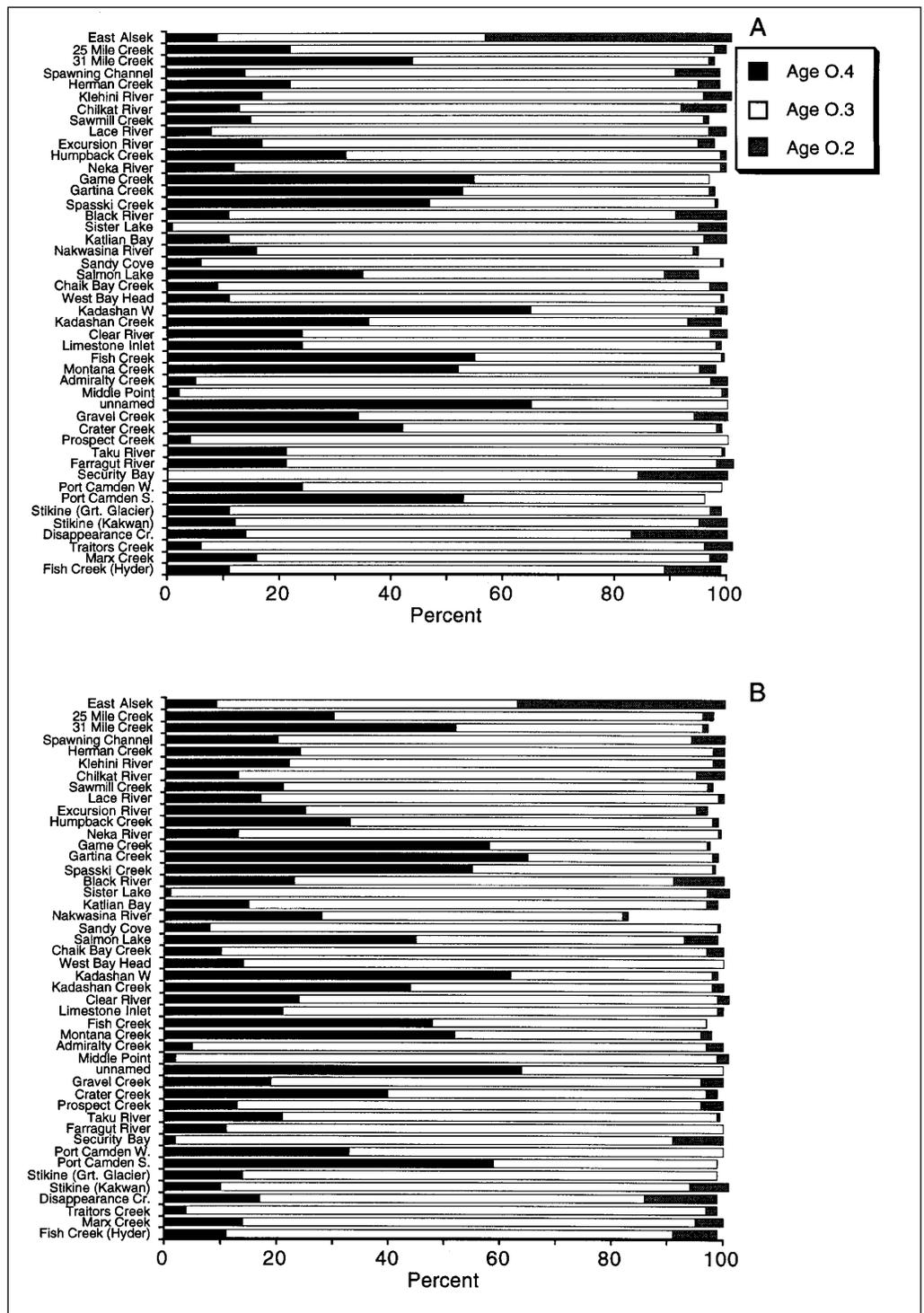


Figure 52—Age composition of 46 chum salmon stocks in the region: **(A)** male age distributions, and **(B)** female age distributions. Percentages do not sum to 100 in many cases because rare age classes (0.5, 0.6) are not included. Note the high proportion of age 0.2 individuals in the East Asek River stock.

Table 43—Regression analysis for trends across years in chum salmon mean saltwater ages (MSWA)

Stream		No. of years sampled	Years	Males				Females			
Number	Name			R-squared	Slope	P-value	Significance	R-squared	Slope	P-value	Significance
101-15-085	Fish Creek-Hyder	6	1972-77	0.18	-0.06	0.4<P<0.5	NS	0.18	-0.06	0.4<P<0.5	NS
102-40-043	Disappearance Creek	6	1973-84	0.15	0.04	0.4<P<0.5	NS	0.16	0.04	0.4<P<0.5	NS
112-42-025E	Kadashan Creek	6	1976-85	0.00	-0.00	P>0.9	NS	0.02	-0.01	P>0.9	NS
114-80-020	Excursion Inlet	6	1975-84	0.09	0.03	0.5<P<0.9	NS	0.05	0.02	0.5<P<0.9	NS
115-32-025	Chilkat River	8	1972-84	0.01	0.00	0.5<P<0.9	NS	0.00	0.00	0.5<P<0.9	NS
115-32-046	Klehini River	8	1972-88	0.20	0.01	0.2<P<0.4	NS	0.42	0.02	0.05<P<0.1	NS
115-32-048	Herman Creek	8	1982-90	0.48	0.03	0.05<P<0.1	NS	0.71	0.04	0.01<P<0.001	**
182-20-010	East Alsek River	8	1959-87	0.94	0.04	P<0.001	***	0.94	0.04	P<0.001	***

NS = not statistically significant; ** = 0.01 > P > 0.001; and *** = P < 0.001.

are distinct from all other central-southeast Alaska stocks, but no other Baranof Island stocks were sampled. The chum salmon population in Herman Creek (Chilkat River drainage) is divergent from other stocks in the northern area, showing genetic similarity to stocks in central British Columbia. The Herman Creek stock also is the only population with significant interannual heterogeneity, indicating the possibility of subpopulation genetic structure in this stock.

Anecdotal Reports

Several chum salmon stocks may be distinctive or occupy unusual habitats but have no quantitative data. J. Helle (see footnote 3) has suggested that the chum salmon stocks in Disappearance and Lagoon Creeks should be considered unique in productivity per unit area. Disappearance Creek is a stream in karst topography that originates in two limestone caves. The Tombstone River and Hidden Inlet stocks, like the Fish Creek (Hyder) stock, are summer populations with highly protracted escapement timing that extends from June to October (Pacific Salmon Commission 1991). The Tombstone River stock also may have fish with an exceptionally large body size (see footnote 3). Kook Lake Creek passes underground and fish swim through caves in karst terrain to reach spawning areas, with some spawning occurring in the cave reaches.⁴

Discussion Evaluation of Results

Biological information on chum salmon stocks is generally inadequate to assess patterns of variation and to identify distinctive populations throughout the region. Adult length, run-timing index, and demographic characteristics of escapements were the only biological variables that could be analyzed for 46 populations out of over 3,000 in the region, and data for many of these populations were limited. Virtually no information was available about migratory behavior, juvenile life-stage characteristics, and stock-recruitment relations, as well as other factors useful for fisheries management

⁴ Personal communication. V. Starostka, fishery and wildlife staff assistant, U.S. Department of Agriculture, Forest Service, Tongass National Forest, Chatham Area, 204 Siginaka Way, Sitka, AK 99835.

Table 44—Sex ratios of chum salmon stocks

Stream		Entire sample				Age class 0.3 or 0.4 ^b			
		Sample size		Proportion	Sex ratio	Sample size		Proportion	Sex ratio
Number	Name	Males	Females	male	male:female ^a	Males	Females	male	male:female ^a
101-15-085	Fish Creek-Hyder	1,194	1,210	0.50	1:1.01	936	972	0.49	1:1.04
101-15-090	Marx Creek-Hyder	68	110	0.38	1:1.62	55	89	0.38	1:1.62
101-90-029	Traitors Creek	154	190	0.45	1:1.23	138	177	0.44	1:1.28
102-40-043	Disappearance Creek	1,413	1,129	0.56	1:0.80	968	779	0.55	1:0.80
108-70-002	Stikine River-Kakwan	478	255	0.65	1:0.53	397	213	0.65	1:0.54
108-70-00?	Stikine-Great Glacier	105	59	0.64	1:0.56	90	50	0.64	1:0.56
109-43-006	Port Camden South Head	68	105	0.39	1:1.54	29	42	0.41	1:1.45
109-43-008	Port Camden West Head	105	42	0.71	1:0.40	79	28	0.74	1:0.35
109-45-01?	Security Bay	31	55	0.36	1:1.77	26	49	0.35	1:1.88
110-14-007	Farragut River	39	9	0.81	1:0.23	30	8	0.79	1:0.27
111-32-032	Taku River	2,372	1,872	0.56	1:0.79	1,855	1,469	0.56	1:0.79
111-33-010	Prospect Creek Speel	25	23	0.52	1:0.92	24	19	0.56	1:0.79
111-33-020	Crater Creek	128	96	0.57	1:0.75	72	55	0.57	1:0.76
111-33-025	Gravel Creek	114	90	0.56	1:0.79	68	69	0.50	1:1.01
111-34-010	(not named)	40	58	0.41	1:1.45	14	21	0.40	1:1.50
111-40-065	Middle Point Creek	176	196	0.47	1:1.11	171	190	0.47	1:1.11
111-41-005	Admiralty Creek	95	171	0.36	1:1.80	87	158	0.36	1:1.82
111-50-052	Montana Creek	974	1,086	0.47	1:1.11	422	481	0.47	1:1.14
111-50-069	Fish Creek (Douglas Island)	692	632	0.52	1:0.91	303	312	0.49	1:1.03
111-90-005	Limestone Inlet	141	160	0.47	1:1.13	105	125	0.46	1:1.19
112-21-005	Clear River-Kelp Bay	261	253	0.51	1:0.97	190	189	0.50	1:0.99
112-42-025	Kadashan Creek	914	969	0.49	1:1.04	521	519	0.50	1:0.99
112-42-025W	Kadashan West ^b	246	233	0.51	1:0.95	159	144	0.52	1:0.91
112-48-023	West Bay Head Creek	208	271	0.43	1:1.30	184	234	0.44	1:1.27
112-80-028	Chaik Bay Creek	529	511	0.51	1:0.97	468	446	0.51	1:0.95
113-41-032	Salmon Lake	172	153	0.53	1:0.89	93	74	0.56	1:0.80
113-41-040	Sandy Cove	216	350	0.38	1:1.62	201	320	0.39	1:1.59
113-43-002	Nakwasina River	348	366	0.49	1:1.05	273	197	0.58	1:0.72
113-44-005	Katlian Bay South Fork	391	365	0.52	1:0.93	332	300	0.53	1:0.90
113-72-005	Sister Lake	171	198	0.46	1:1.16	161	190	0.46	1:1.18
113-81-011	Black River	79	65	0.55	1:0.82	63	44	0.59	1:0.70
114-27-030	Spasski Creek ^b	849	902	0.48	1:1.06	402	499	0.45	1:1.24
114-31-009	Gartina Creek ^b	769	982	0.44	1:1.28	409	642	0.39	1:1.57
114-31-013	Game Creek ^b	424	413	0.51	1:0.97	234	239	0.49	1:1.02
114-33-023	Neka River	451	455	0.50	1:1.01	393	392	0.50	1:1.00
114-34-010	Humpback Creek	281	445	0.39	1:1.58	187	290	0.39	1:1.55
114-80-020	Excursion Inlet	1,185	1,124	0.51	1:0.95	928	791	0.54	1:0.85

Table 44—Sex ratios of chum salmon stocks

Stream	Entire sample				Age class 0.3 or 0.4 ^b				
	Sample size		Proportion		Sample size		Proportion		
Number	Name	Males	Females	male	Sex ratio male:female ^a	Males	Females	male	Sex ratio male:female ^a
115-20-020	Lace River (Berners Bay)	99	115	0.46	1:1.16	88	94	0.48	1:1.07
115-20-052	Sawmill Creek (Berners Bay)	226	174	0.57	1:0.77	184	132	0.58	1:0.72
115-32-025	Chilkat River	1,382	1,061	0.57	1:0.77	1,092	868	0.56	1:0.79
115-32-046	Klehini River	1,922	1,937	0.50	1:1.01	1,509	1,472	0.51	1:0.98
115-32-048	Herman Creek	1,144	1,327	0.46	1:1.16	840	979	0.46	1:1.17
115-32-048S	Spawning Channel	685	416	0.62	1:0.61	529	308	0.63	1:0.58
115-32-057	31 Mile Creek	374	324	0.54	1:0.87	200	144	0.58	1:0.72
115-32-059	25 Mile Creek	94	110	0.46	1:1.17	71	73	0.49	1:1.03
182-20-010	East Alsek River	1,317	1,465	0.47	1:1.11	626	792	0.44	1:1.27
N				46				46	
Minimum				0.36				0.35	
Maximum				0.81				0.79	
Median				0.50				0.50	

^a Male component of ratio standardized to 1 for comparative purposes.

^b Data for the age class that predominates in escapements are presented. Stocks in which the 0.4 age class predominates are noted.

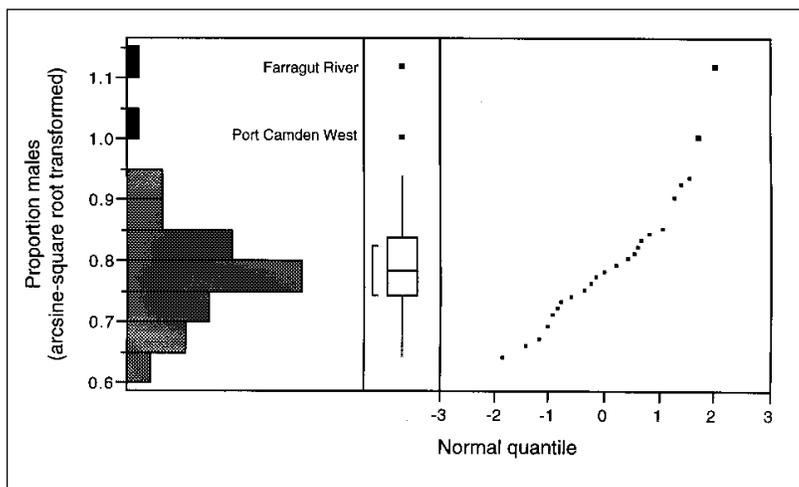


Figure 53—Frequency distribution, outlier plot, and normal quantile plot for sex ratio (expressed as the proportion of males) of chum salmon escapements. Mean sex ratios for all age classes for all years of sampling are presented. Outliers from the distribution are based on small samples from single years and may not be representative of the true escapement sex ratios of these populations. Data are presented in table 44.

Table 45—Chum salmon stocks in impaired or suspected water bodies

Stream		Location		Pollutant source types ^b	Comments
Number	Name	VCU ^a	General		
Impaired water bodies					
101-45-038	Salt Chuck-George Inlet	747K	Carroll Inlet	TH, RC	3 years of surveys: 860 fish in 1972.
101-47-015	Ward Cove	749K	Ketchikan	IN, DO, Debris	6 years of escapement surveys, 1981-88. Maximum count, 341 fish in 1984, minimum count, 2 fish in 1988.
109-52-007	Rowan Bay	402S	Kuiu Island	TH	Moderate sized run, mean escapement of 1,064 fish. No population trend with 24 survey years, 1962-93.
110-33-009	Hobart Bay	75C	Near Juneau	TH, IN, SM, RC	Only 1 survey; 1,950 fish in 1991.
111-40-010	Lemon Creek	32C	Juneau	UR, PP, MI, LF, SM, GM	6 survey years from 1968-89; highly variable.
111-40-015	Salmon Creek	32C	Juneau	UR, DDE, PCB	Hatchery operation; status of wild stock unknown.
111-40-089	Lawson Creek	32C	Douglas	UR, RD, CH, SM	5 survey years; considerable increase in 1990 and 1991.
113-41-028	Bear Creek Silver Bay	318C	Sitka	IN, DO, Debris	5 survey years; highly variable.
Suspected water bodies					
101-45-024	White River	748K	Ketchikan	TH	Moderate sized stock, mean escapement 1,026 fish. Nonsignificant declining trend, 12 survey years.
102-70-058	Thorne Bay	588K	Thorne Bay	IN, UR, SE, SM	Four survey years; 1,500 fish in 1961, less than 100 fish from 1982-86.
103-60-059	Point St. Nicholas Creek	NA	Craig	TH, UR	Moderate sized stock; mean escapement 1,000 fish. Nonsignificant decline, 16 survey years, 1960-92.
103-90-030	Staney Creek	588K	Prince of Wales	TH	Highly significant decline.
111-40-007	Switzer Creek	32C	Juneau	UR, DDT	Small stock; mean survey count of 84 fish. No population trend, 18 survey years.
111-50-037	Wadleigh Creek	27C	Juneau	UR, SE	Small stock; mean survey count of 44 fish. No population trend with 9 survey years.
111-50-042	Auke Creek	27C	Juneau	HA, UR, SE, PP, LD, RE	Small population with hatchery effects.
111-50-052	Montana Creek	27C	Juneau	UR	Moderate sized stock; mean survey count 664 fish. Nonsignificant increasing trend, 20 survey years.
112-13-006	False Bay	210C	NE Chichagof Island	TH	Small run; no population trend, 14 years surveyed.
112-42-016	Corner Bay	236C	Tenakee Inlet	TH	Small stock; nonsignificant decline with 26 survey years (1960-92); fish pass present.

Table 45—Chum salmon stocks in impaired or suspected water bodies

Stream		Location		Pollutant source types ^b	Comments
Number	Name	VCU ^a	General		
112-65-015	Hawk Inlet Head	128C	Hawk Inlet	Metals	Moderate sized stock; mean survey count 605 fish. No population trend with 12 survey years.
112-65-025	Greens Creek	144C	Admiralty Island	PP	Moderate sized stock; mean escapement 2,188 fish. No population trend with 31 survey years (1960-93).
113-41-012	Sitka Harbor (Indian River)	311C	Sitka	UR, HA, PP, STP	6 survey years; highly variable.
113-54-007	Rodman Creek	292C	North of Sitka	TH	Moderate sized stock; mean survey count 2,293 fish. No population trend, 23 survey years.
113-72-002	Klag Bay	271C	Klag Bay	Metals, MI, TA	One survey in 1973; 4,000 fish.
114-32-036	Eight Fathom Bight Creek	202C	Chichagof Island	TH	5 survey years 1963-78; highly variable.
115-20-007	Johnson Creek	16C	Berners Bay	TA	One survey in 1974; 50 fish.
115-33-020	Lutak Inlet	NA	Haines	As, PAH	Mean annual weir escapement count of 421 fish from 1976 to 1993.

^a VCU = USDA, Forest Service value comparison unit; approximately equivalent to a watershed. K = Ketchikan Area; S = Stikine Area; and C = Chatham Area.

^b Pollutant source types:

As = Arsenic	IN = Industrial	RD = Road runoff
CH = Channelized stream	LD = Land development	RE = recreation
DDE = Dichlorodiphenylchloroethane	LF = Landfill	SE = Sewage discharge
DDT = Dichlorodiphenyltrichloroethane	MI = Mining	SM = Streambank or shoreline modification
DO = Dissolved oxygen	PAH = Poly-aromatic hydrocarbons	TH = Timber harvest
GM = Gravel mining	PCB = Polychlorinated biphenyls	TA = Tailings
HA = Harbor	PP = Petroleum products	UR = Urban runoff
	RC = Road construction	

Source: ADEC 1992.

and the identification of potentially distinctive stocks. The inadequacy of existing data was exacerbated by the geographic distribution and timing of data collection for the baseline. Most information on chum salmon populations is for northern southeast Alaska, while the majority of stocks are in southern southeast Alaska. Most biological data were collected from the late 1970s to the late 1980s during a period of improving ocean survival. Ocean survival rates of hatchery stocks reached unprecedented highs during this period (from a typical expectation of 2 to 3 percent, ocean survival has increased up to 16 percent at Medvejie Creek and 8 percent for 1980 brood at Hidden Falls [see footnote 1]), and survival of wild stocks probably increased as well. The short duration of the data set (< 15 years) and improved ocean survival may overestimate long-term stock conditions.

Body length—Chum salmon showed pronounced sexual size dimorphism; males were larger than females in all age classes. The consistency of this pattern (fig. 47) suggests that sexual selection favoring large size in males is a general characteristic of chum salmon populations (Schroder 1981). Older fish also were larger, but the increment between successive age classes decreased with increasing age, indicating diminishing returns for prolonged ocean life. Differences in body size between island and mainland stocks may be due to factors that include run timing, egg size, and the physical characteristics of drainages (Beacham and Murray 1987).

Several potential factors have been implicated to explain decreasing body size including oceanic density-dependence, selective fisheries effects, and changes in physical characteristics of the ocean environment (Helle 1993, Ishida and others 1993, Kaeriyama 1989, Ricker 1980). The prevailing hypothesis offered to explain the decline is based on the presence of density-dependent limitation of growth in the ocean (Kaeriyama 1989). Perhaps the gelatinous planktonic forms fed on by chum salmon (Welch and Parsons 1993) are more prone to concentration in the marine environment by abiotic factors than the piscine prey of other salmon species. Spatial concentration of prey can intensify intraspecific competition for food resources. Furthermore, large-scale enhancement operations, in both Japan and the west, have contributed enormous numbers of fish having relatively homogeneous genetic characteristics to the ocean population of chum salmon. If these enhanced stocks move *en masse* to relatively circumscribed areas, determined in part by inherited migratory routes, the opportunity for local resource depletion is also increased. Ishida and others (1993) calculate that density-dependent effects could account only for about 35 percent of variability in chum salmon body weight. Other factors undoubtedly are involved. Selection by fisheries against large individuals is unlikely to be a pervasive factor, because most chum salmon are harvested with seine gear, which does not selectively remove large individuals. In British Columbia (Ricker 1980) and southeast Alaska (Clark and others 1984), age 0.2 fish are more common in harvests than in escapements, thereby suggesting that fisheries are selectively removing small individuals. Ricker (1980) argues that this pattern of harvest may effectively select against rapid growth rate and thereby contribute to declines in both age and size. Increased sedimentation of streams selects against larger fry (Scrivener and Brownlee 1989), and this mortality factor also could contribute to selection for reduced growth rate. Changes in ocean temperature may be yet another factor contributing to the observed changes (Ricker 1980). Our inability to detect trends in body size through time for several stocks may be due to lack of recent data. Estimated body weights of chum salmon harvested commercially in southeast Alaska from 1958 to 1985 (Marshall and Quinn 1988) do not show a declining trend, and this result also is possibly due to a lack of estimates from recent years. Body weights of several Asian chum salmon populations are decreasing (Ishida and others 1993), but the one Canadian population (Fraser River) included in the Ishida study did not show a decreasing trend in characters correlated with body weight.

Variance-component analysis of chum salmon body lengths indicated a greater proportion of variability among populations and less variability within populations than was shown by other species of Pacific salmon (see other chapters in this paper). This result suggested an increased level of local body-size adaptation in chum salmon. Chum salmon stocks in British Columbia showed a high level of local adaptation in morphology as well as other characteristics, such as meristic counts, egg size,

and development pattern (Beacham and Murray 1987). Substrate grain size and variability of flow regime are two environmental factors that may have important selective consequences for body size in chum salmon (Beacham and Murray 1987; see footnote 3).

The presence of local adaptations within stocks suggests that straying between stocks is limited. The few existing studies of marked individuals indicate that the straying rate of wild fish is low (Salo 1991). Geographic distance among stocks is correlated with genetic distance between stocks (Davis and Olito 1982, Kijima and Fujio 1982, Scribner and others 1998). Some hatchery stocks of chum salmon show considerable local straying (McNair 1985).

Helle (1984) notes the large size of chum salmon spawning in Fish Creek near Hyder. Although this stock is among the largest in each sex and age category we analyzed, it is not an outlier; however, our analysis was based on mid-eye-to-fork lengths and not weights. Stock-specific weight data were not available for other stocks in the region.

Timing—Run timing is a central component of local adaptation of chum salmon stocks in other regions (Beacham and Murray 1987, Miller and Brannon 1982). In British Columbia, timing of spawning had a marked effect on fry emergence timing and age of maturity. Within geographic areas, early-spawning stocks have later times of fry emergence and higher proportions of older chum salmon than late-spawning stocks (Beacham and Murray 1987). Early spawning is associated with cold water systems (Holtby and others 1989). Cold water temperatures retard development and increase the development time of egg and alevins.

In southeast Alaska, Kadashan River has the earliest run timing of any system surveyed, and winter water temperatures in this system are consistently below 1°C (see footnote 1). The Kadashan River stock also showed relatively compact run timing despite its considerable size. This suggests a relation between water temperatures, which affect embryo and alevin development, and run duration. We are unaware of any discussion in the literature of a relation between compact run timing and cold incubation temperatures. A compact early run may result from a combination of opposing selection pressures; developmental delays imposed by cold water on eggs and alevins would favor early spawning so fry can emigrate at an appropriate time to take advantage of high marine productivity, but delaying adult entry into fresh water as much as possible would provide the benefit of more time to feed in the marine environment resulting in larger body size and higher fecundity.

In contrast, the Fish Creek (Hyder) stock has a protracted run duration and some spawning occurs in warm upwelling areas (see footnote 3). Availability of these spawning habitats, which permit more rapid development, could contribute to a more protracted run duration.

The effects of warm upwelling water in spawning areas on mean date of return migration are more apparent than effects on run duration. The timing of the Chilkat run, which occurs in October and November, is probably influenced by warm upwelling water (Bugliosi 1988). We suspect that the late runs in Porcupine Creek and in the Taku River drainage also may be associated with warm upwelling water.

Local timing adaptations of salmon populations can have important consequences for wildlife species that prey on salmon (Willson and Halupka 1995). The late timing and large magnitude of the Chilkat River chum salmon run attracts aggregations of bald eagles exceeding 3,000 individuals, the largest aggregation of bald eagles in the world (Hansen and others 1986). The strength of the late chum run in the Chilkat may influence the reproductive success of bald eagles over a wide geographic area (Hansen 1987).

Daily weir counts are available from USFWS weirs operated for various years between 1929 and 1966 at Keete Inlet (103-21-018), Klawock River, Staney Creek (Orrell and others 1963), Kook Lake, and Hood Bay (112-73-024) (Huizer and others 1970b). At all these locations, counts showed distinctly bimodal run timing suggesting that both summer and fall chum runs may be present. Favorite Creek (112-67-080) in Kootznahoo Inlet is also reported to have both summer and fall runs, but no supporting data are available (Huizer and others 1970b). Throughout the region, the frequency of sympatric runs of summer and fall chum in the same stream is unknown, but maintenance of clear timing differences suggests reproductive isolation and possible genetic differences between early and late spawners.

Demography, declining stocks—Relatively good survey data were available for 9 of the 12 chum salmon stocks in the region that showed a significant increase in abundance, and for 21 of the 41 declining stocks (table 40). Of the 21 declining stocks with the best data, 14 spawned in drainages with minimal human disturbance to habitat (wilderness areas, roadless areas, and national parks and preserves). Eight of these spawning streams empty into Seymour Canal on Admiralty Island. The relatively large number of declining populations in this area is a source of concern, and the causes of decline are unknown. Declines in areas where timber harvests have occurred were not surprising in view of results from the Carnation Creek experimental watershed, which demonstrated the sensitivity of chum salmon to increased sedimentation (Scrivener and Brownlee 1989).

Age structure—The frequency distributions of male and female MSWAs for the region appeared to be bimodal, with a primary peak at about 3.1 years and a secondary peak near 3.5 years (fig. 52A). All stocks in the secondary peak were from northern southeast Alaska, but too few summer stocks have been sampled from southern southeast Alaska to determine if older fish are restricted to northern areas. Older age is generally considered a characteristic of summer chum, which are more widely found in northern southeast Alaska.

As was the case for temporal changes in length, detection of temporal changes in MSWA was inhibited by insufficient data. Only the Herman Creek and East Alsek stocks showed significant changes in age (both increasing). This result paralleled the results of other investigators, who have found trends of increasing age and decreasing lengths in a wide range of chum salmon stocks (Ishida and others 1993, Ricker 1980; see footnote 3).

Conceptual Issues

Chum salmon from the Queen Charlotte Islands form two distinct stock groups, based on genetic analysis (Kondzela and others 1994). Allele frequencies in both groups diverge from those of mainland British Columbia populations. This pattern of genetic divergence is consistent with geologic evidence indicating that the Queen

Charlotte Islands were ice free during the height of the Wisconsin glaciation (Warner and others 1982). Divergence between the mainland and island populations also suggests that postglacial colonization of mainland streams tended to occur from mainland source populations rather than from island populations. Similarly, the allele frequencies of chum salmon stocks from Prince of Wales Island are distinct when compared to those from stocks inhabiting the area east of Clarence Strait, which suggests that a similar pattern of glacial refugia and subsequent colonization occurred in southeast Alaska. This interpretation is supported by geologic and botanic evidence indicating that portions of Prince of Wales Island were ice free during the most recent glacial maxima.^{5 6}

We agree with Kondzela and others (1994) that further genetic surveys of stocks in northern southeast Alaska could improve understanding of postglacial colonization patterns. Based on allozyme analysis of chinook salmon throughout Alaska, Gharrett and others (1987) suggest that some similarities between Yukon River and southeast Alaskan chinook could be due to colonization via headwater capture of the Taku and Stikine Rivers. Because chum salmon also currently spawn near the headwaters of the Yukon River and may have persisted in the Bering refugium during glacial periods, colonization of northern southeast Alaska by chum salmon could have followed a similar route.

Risk Factors

As was found for the other salmon species reviewed in this paper, a relatively small proportion (9.5 percent) of chum salmon stocks we evaluated had declining escape-trends. This was, however, the highest percentage for any species in the region. Several factors may be contributing to these declines and have the potential to cause further declines in chum salmon abundance and diversity throughout southeast Alaska. We do not consider the following list complete, but it contains those factors that are most pervasive and therefore have the potential to affect large numbers of chum salmon populations.

1. Benign neglect may be the most insidious threat to chum populations in southeast Alaska. Stock-specific information is limited for chum populations on the biological characteristics critical to effective management, such as stock-recruit relations, exploitation rates, or migratory timing and pathways. The current low level of research and monitoring effort probably reflects the low economic interest in chum salmon, relative to other salmon species in the region. Because few fisheries are directed at chum salmon, management effort is correspondingly reduced. Although few fisheries are directed at chum salmon, large numbers of them are being harvested incidentally in fisheries for sockeye, pink, and coho salmon. This high proportion of incidental harvest increases the potential for unsustainable harvest of particular stocks that overlap in route and timing with very productive runs of other species, and it increases the likelihood of artificial selection through fishery effects, because management decisions are not made with regard for the migratory timing or productivity

⁵ Personal communication. 1996. J. Baichtal, geologist, U.S. Department of Agriculture, Forest Service, Tongass National Forest, Thorne Bay Ranger District, P.O. Box 19001, Thorne Bay, AK 99919.

⁶ Personal communication. 1996. A. Harris (retired), U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 2770 Sherwood Lane, Juneau, AK 99801.

of chum salmon populations. Without monitoring, the status of populations could decline to crisis levels before notice is taken. Even if monitoring indicated severe declines in chum salmon populations, the great economic value of fisheries for other species severely limit the possibility of attempting to protect weak chum salmon stocks with time and area closures.

The threat posed by benign neglect is exacerbated by the unrepresentative nature of existing baseline data. Most baseline information is for large chum salmon populations, the majority of which are in northern southeast Alaska, but the majority of chum salmon populations are small and found in southern southeast Alaska streams. Furthermore, most baseline data for chum salmon populations in the region have been collected during a period of favorable ocean conditions. A downturn in ocean conditions is highly probable; only the time of its onset is uncertain. If current political and policy trends continue, it seems unlikely that large amounts of additional baseline information on chum salmon will be collected. Reductions in weir operations and other field monitoring programs suggest that the ADF&G is choosing to devote less of its dwindling financial and personnel resources to data collection and more to management of existing data. In our opinion, a lack of economic incentive and insufficient funding of management research are contributing to a tenuous management situation for chum salmon in southeast Alaska.

2. Chum salmon are sensitive to changes in streams that result from timber harvest, such as changes in flow dynamics, increased temperature, and increased sediment loads (Holtby and others 1989, Murphy 1985, Scrivener and Brownlee 1989). Several declining populations in the region are in areas of intensive timber harvest. Proper implementation of improved land-management programs may reduce the magnitude of this threat. The extensive scale of planned timber-harvest activities in some areas are nonetheless likely to contribute to further declines of chum salmon populations.

3. Chum salmon enhancement projects tend to be large in scale. A few hatcheries in the region can produce enormous numbers of chum salmon fry and correspondingly large returns of mostly unmarked adults, which cannot be identified as hatchery fish in mixed stock fisheries. For those relying on harvest statistics to assess the health of a fish resource, the success of enhancement efforts has the potential to obscure widespread declines in wild stocks. The confused perceptions resulting from simultaneously increasing harvests (of hatchery-produced fish) and declining wild stocks can delay development of the consensus necessary to take action to protect relatively unproductive stocks. This represents a particular threat to chum salmon stocks, given the management situation described above.

At a local level, the detrimental effects of large-scale enhancement efforts on wild stocks have been reviewed by numerous authors (e.g., Goodman 1990). A few wild stocks of chum salmon have probably experienced some of these detrimental effects, and at least one (Sheep Creek) may have been extirpated. Further development of large-scale hatchery production should be critically evaluated, and the potential use of hatcheries to augment weak stocks should be explored (Kapusinski and Jacobson 1987).

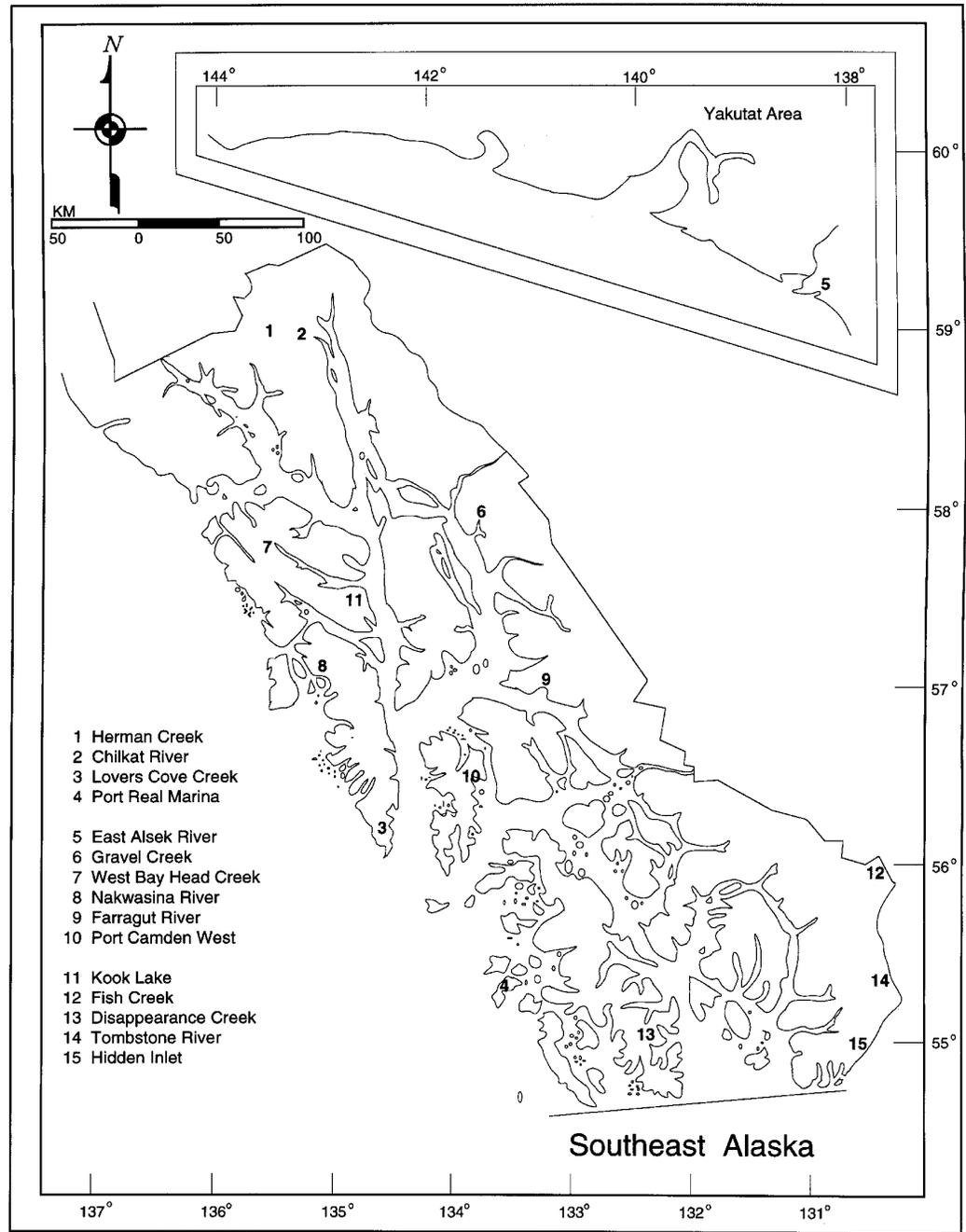


Figure 54—Approximate geographic location of southeast Alaska chum salmon stocks with distinctive biological characteristics.

4. Little information is available on the degree to which roe-stripping of chum salmon occurs in southeast Alaska. The relatively high value of chum salmon roe relative to whole fish may provide incentive for roe-stripping. Underreported or unreported catches of chum salmon associated with roe-stripping could contribute to population declines.

Conclusions

At the regional level, chum salmon diversity in southeast Alaska can be characterized along the axes of run timing (summer and fall runs) and island-versus-mainland spawning locations. Both axes may be correlated with water-temperature regime during egg incubation. At the subregional level, genetic analysis of chum salmon populations in southern southeast Alaska cluster into geographically defined groupings. The three genetically defined groups identified to date are Prince of Wales Island area, inside areas east of Clarence Strait and south of Sumner Strait, and central-southeast Alaska from Sumner Strait to Frederick Sound. These geographic clusters may reflect historical colonization patterns and may be preserved by differences in migratory pathways that reduce gene flow among groups. We expect that similar genetic analyses for chum salmon populations in northern southeast Alaska will reveal a similar geographic pattern. Based on our analyses conducted at the level of individual populations, and on studies of genetic characteristics, the following chum salmon stocks have distinctive characteristics (see fig. 54 for approximate geographic locations):

- Chilkat River stock has late run timing, large population size, and is an important resource for wildlife.
- Herman Creek stock has a genetic affinity to populations in central British Columbia and may exhibit subpopulation genetic structure; significant declines in size and age were detected in this stock.
- Port Real Marina stock has a genetic affinity to Queen Charlotte Island stocks, as well as other Prince of Wales Island stocks.
- Lover's Cove Creek stock has unusual allele frequencies, but no other stocks in its geographic area were sampled; further genetic sampling of northern southeast Alaska stocks is required.

The following stocks showed distinctive characteristics based on limited sampling. These results need to be confirmed.

- East Alsek River stock has a high proportion of age 0.2 spawners in some years and low MSWA.
- Port Camden females are larger than same-age males—a sexual size-difference that is the reverse of most other stocks in the region.
- West Bay Head Creek stock appears to have an extreme sexual size-difference in age 0.4 fish; males are over 70 mm longer than females in mid-eye-to-fork length.
- Nakwasina River stock appears to have an extreme sexual difference in MSWA; female MSWA is over 3 months greater than male's.
- Gravel Creek stock appears to have sexual size-difference in MSWA with females younger than males—the reverse of most stocks in the region.
- Farragut River stock appears to have sex ratio skewed in favor of males.
- Port Camden West stocks appear to have sex ratio skewed in favor of males.

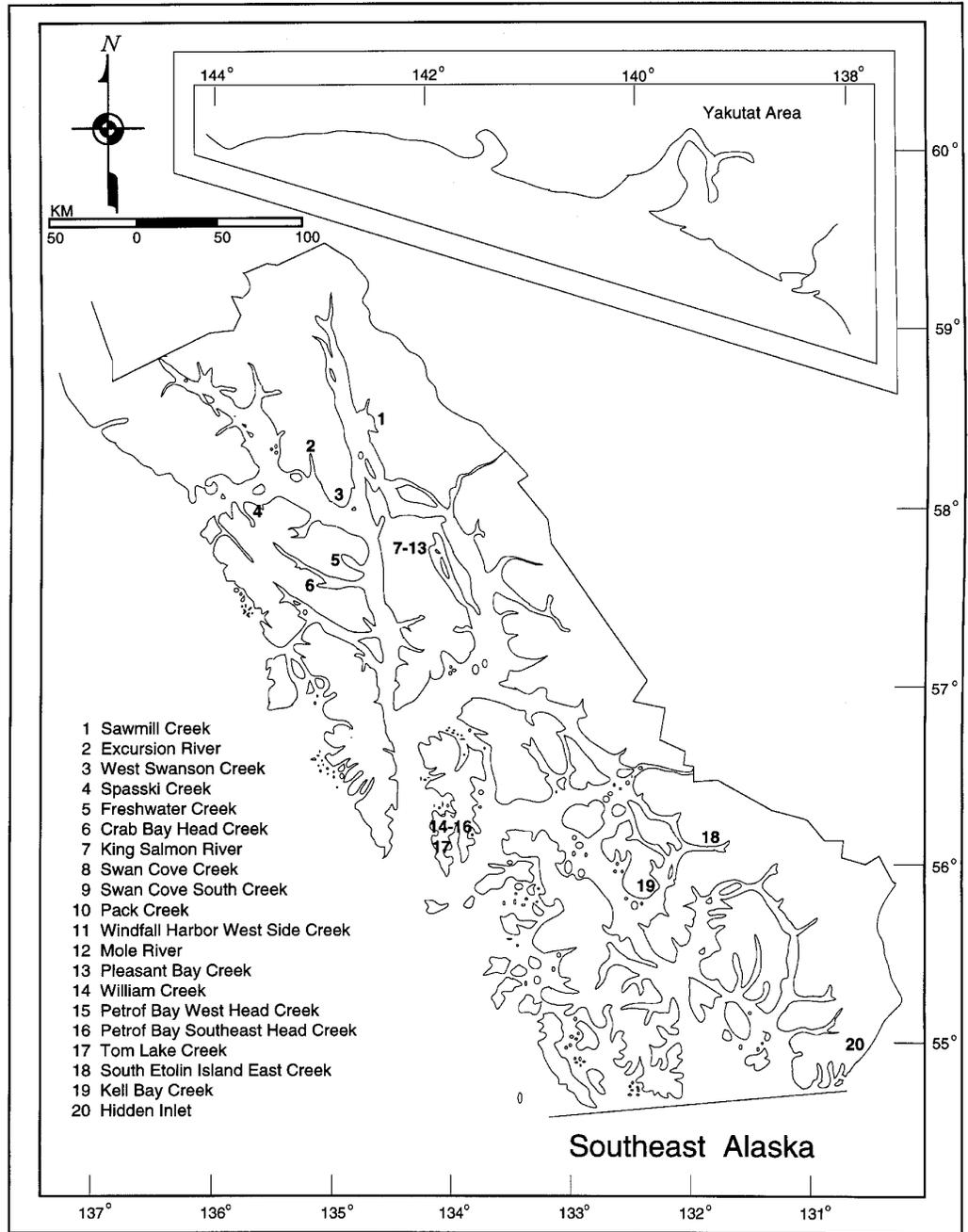


Figure 55—Approximate geographic location of southeast Alaska chum salmon stocks with significantly declining escapements and relatively high-quality escapement survey data.

Based on anecdotal reports and professional judgment, the following stocks may have distinctive characteristics. Lack of adequate comparative data prevented evaluation of these reports.

- Fish Creek (Hyder) stock has prolonged run duration and large body size.
- Hidden Inlet stock has prolonged run duration.
- Tombstone River stock has prolonged run duration and potentially large body size.
- Disappearance Creek stock has high productivity per unit area and large population size.
- Kook Lake stock swims through karst caves to reach spawning grounds, and some fish spawn in cave reaches.

Eight chum salmon populations are found in impaired water bodies and 18 spawn in or migrate through suspected water bodies, but only one of these shows a significant decline in escapement.

A higher proportion of chum salmon stocks have declining escapement trends than stocks of other species surveyed. Forty-one stocks (9.5 percent) show significant declines, and 21 of these stocks have relatively good escapement data (table 40). Declining stocks are clustered in Seymour Canal on Prince of Wales Island and the Petrof Bay area of Kuiu Island (fig. 55). Risk factors that may be contributing to these declines, and that have the greatest potential to cause future declines, include minimal management research leading to inadequate understanding of chum salmon biology, logging practices resulting in increased sediment loads, and large-scale enhancement activities possibly contributing to overexploitation of wild stocks.

Acknowledgments

The assistance of S. Johnson and L. Talley in accessing the ADF&G Integrated Fisheries Database was indispensable. G. Gunstrom, M. Harris, and K. Savikko provided ADF&G documents that were the foundation of this report, and J. Helle provided documents from the Pacific Salmon Commission and the National Marine Fisheries Service. S. Marshall provided both access to the information resources of the ADF&G and criticism that improved this project. In-depth discussions with B. Bachen, J. Helle, and K. Hofmeister provided a wealth of insights about chum salmon biology and management. B. Lorenz and V. Starostka commented on specific aspects of a previous draft. K. Kondzela's careful review greatly improved this manuscript.

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English Equivalents

When you know:	Multiply by:	To find:
Millimeters (mm)	0.04	Inches
Centimeters (cm)	0.39	Inches
Meters (m)	3.28	Feet
Kilometers (km)	0.62	Miles
Milligrams (mg)	0.000035	Ounces
Kilograms (kg)	2.21	Pounds
Hectares (ha)	2.47	Acres
Celsius (°C)	$(^{\circ}\text{C} \times 1.8) + 32$	Fahrenheit

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