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MIGRATORY TIMING OF SALMON IN ALASKA WITH AN ANNOTATED BIBLIOGRAPHY ON MIGRATORY BEHAVIOR OF RELEVANCE TO FISHERIES RESEARCH

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INTRODUCTION

The search for a common theme which unites the management of the commercial fisheries for adult salmon across the thousands of miles of coastline between Kotzebue Sound and Dixon Entrance is now focused on migratory timing. Migratory timing is abundance as a function of time in a fixed geographic reference frame. The "fixed geographic reference frame" is most often a commercial fishing district, some of which have been established in Alaska for thirty years, or more.

The problem of sharp fluctuations in annual abundance which occur in the Pacific salmons has led to the use of the proportion of total abundance as a function of time, the migratory time density. The migratory time density of a stock in one locale is usually less variable from year to year than the corresponding migratory timing. Indeed it is the regularity of the time densities of salmon migrations which offers hope for standardizing some of the harvest control procedures for all adult salmon fisheries.

The present purposes are: 1) to deliver a brief history of migratory timing research within the context of commercial fisheries management, and particularly of harvest control, 2) to describe standard methods for the description of migratory timing behavior, 3) to discuss the migratory timing of salmon in Alaska as recorded in the predominately unpublished literature records, and 4) to provide a partially annotated bibliography of published and unpublished work to serve as an entry point for fisheries research in migratory timing.

The motivation for studying migratory timing is the need for high precision information in harvest control situations. The ultimate challenge in commercial marine fisheries management is the proper division of a biological population into two categories; dead and alive. All of the multi-disciplinary efforts which are focused to determine the proper level of harvest count for little if the fishing operation cannot be directed to achieve the specified harvest level. Unfortunately, research on the design and implementation of harvest control methods which are capable of achieving any specified level of harvest are usually subordinate to the determination of the "right" level of harvest such as the maximum sustainable yield (MSY), the total allowable catch (TAC), or the optimum sustainable yield (OSY) and derivatives. An accurate knowledge of migratory timing and its sources of variability counts among the most powerful tools available for precision harvest control.

Nowhere is the need for precision harvest control more evident than in the white hot atmosphere of the Alaskan salmon fisheries. Harvest events which require a year to develop, and longer to interpret, in many of the world's major commercial fisheries, are condensed to a span of four weeks, or less, in the fisheries for adult salmon on the shores of the eastern Bering Sea and Gulf of Alaska. At the pinnacle of intensity in Alaskan salmon fisheries is Bristol Bay where annual migrations in excess of 70 thousand metric tons of sockeye salmon have passed through the harvest areas in less than four weeks. At the peak of the migration, a period of three to four days, the harvest control authority may be compelled to decide the fate of U.S. $5 million worth of salmon every 12 hours. The consequences of a decision cannot be reversed, for once the salmon escape the harvest districts, they are lost to the fishery, and harvested fish will never contribute

progeny to future fisheries. The search fo precision harvest control is of critical economic and biologic concern.

The regularity of the timing of Pacific salmon migrations had been established by the results of commercial fisheries long before scientific inquiry was launched. Basic biological knowledge of the life cycle, mode of reproduction, and critical habitat had to be addressed before more subtle attributes could be studied. One of the first published critical accounts of migratory timing in Pacific salmon concerned pink salmon in Southeastern Alaska (Davidson et al. 1943). Migratory behavior was considered to be a genetic phenomenon whose expression could be modified by environmental factors, and that interpretation has not been altered by any subsequent work. One of Davidson's co-authors, Elizabeth Vaughan, subsequently published two papers (1947, 1954) which should be regarded as the foundation of the quantitative analysis of migratory timing behavior. Vaughan (1954) suggested characterizing pink salmon migrations by a generalized probability density function, which is essentially the approach derived and implemented independently by Mundy (1979).

The dominant source of critical evidence on migratory timing in Pacific salmon is the work of the International Pacific Salmon Fishing Commission (IPSFC) (Killick 1955; Gilhousen 1960; Henry 1961). Evidence based on tagging and scale pattern recognition demonstrated that timing of Fraser River sockeye salmon was unique to each stock and that the timing relation between stocks was preserved over hundreds of miles in marine and fresh waters. Other investigators of note during this period include W.F. Thompson (1940; 1945; 1951; 1960), M.B. Schaefer (1951), L.A. Royal (1953), W. Sheridan (1962), D. Bevan (1962), and D. Narver (1963).

Although the distinction is somewhat arbitrary, 1965 marks the beginning of transition from the definition of basic biological knowledge toward the application of that knowledge in the Pacific salmon fisheries. (While the IPSFC had been using timing information for some time in 1965, it cannot be considered as representative of the management of salmon on the Pacific Rim). Authors such as Royce (1965), Paulik et al. (1967), Mathisen and Berg (1968), Dahlberg (1968), Bevan and Lechner (1970), Rothschild and Balsiger (1971), Lord (1973), Roberson and Fridgen (1974), Walters and Buckingham (1975), and Mobrand (1977) each had the concept of utilizing migratory timing, often including some quantitative measure of migratory timing, in fisheries management.

Notable among the fisheries biologists who work outside the realm of salmonids are Saila (1972, 1980) and Leggett (1972, 1977, 1978). The analysis of the time series of monthly CPUE of New Zealand rock lobster (Saila et al. 1980) is of considerable interest. Saila has an established record of research in the quantitative description of migratory behavior. In his review of the ecology of migration, Leggett (1977) successfully combines concerns relevant to fisheries management with the theory and research of general ecology.

METHODS

Elementary

Mathematical descriptions of the standard methods of describing and using, migratory timing information are provided under ADVANCED METHODS. A simplified description is provided here, but the use of mathematics ultimately is not to be avoided.

The basic data, catch and effort by fishing period, are familiar to fisheries biologists. The use of these data to construct a frequency distribution of time (see Sokal and Rohlf, 1969, Box 4.3, p. 60) may also be familiar to many, but the computation and interpretation of a mean, variance and measures of skewness and kurtosis for timing data are usually alien to fisheries workers. The computation of the mean date of the migration (see ADVANCED METHODS) is identical to the computation of the mean of the birth weights of male Chinese illustrated by Sokal and Rohlf (1969). The computations of the variance, skewness, and kurtosis of the migratory time density are almost the same as the computation of those values illustrated by Sokal and Rohlf above (see Box 6.2 for skewness and kurtosis). The class marks are dates, coded as integers, 1,2,3,...and the frequency of each date is the catch or CPUE for that date.

The computational methods normally employed for length, weight, and other common types of fisheries data are not recommended here (other than to aid understanding) because other methods better serve to emphasize key concepts of time which are crucial to harvest control operations.

The catch or CPUE of a single life history stage of a population which is moving in a single direction through a harvest area will be called n_i, where i denotes the time period (day, week or month) of the observation . The n_i's constitute the migratory timing of the population in the harvest area. Calculate the migratory time density by dividing each n_i by the total catch or CPUE for the season, $\sum_{i=1}^{\ell} n_i$, where ℓ is the number of time periods fished. The time density is f_i; therefore,

$$f_i = n_i / \sum_{i=1}^{\ell} n_i \qquad (1)$$

The mean of the migratory time density is estimated

$$\bar{t} = \sum_{i=1}^{\ell} i \cdot f_i \qquad (2)$$

and the variance is estimated

$$S^2 = \sum_{i=1}^{\ell} (1-\bar{t})^2 \, f_i \qquad (3)$$

Example: A season is divided into five time intervals, i = 1, 2, ..., 5. The following catches are obtained:

i	n_i	$f(i)$
1	0	0
2	5	0.25
3	10	0.50
4	5	0.25
5	0	0
	$\Sigma n_i = 20$	

$$\bar{t} = (1)(0) + (2)(0.25) + (3)(0.50) + (4)(0.25) + (5)(0)$$

$$= \quad 0.50 \quad + \quad 1.50 \quad + \quad 1.00$$

$$\bar{t} = 3.00$$

$$S^2 = (1-3)^2\ (0) + (2-3)^2\ (0.25) + (3-3)^2\ (0.50) + (4-3)^2\ (0.25) + (5-3)^2\ (0)$$

$$= 0 + 0.25 + 0 + 0.25 + 0$$

$$= 0.50$$

The migratory time density of a single year based only on catch is not very satisfactory for describing migratory behavior or for use in harvest control. The fishery may not cover every day of the migration or the fishery may start late or early. The best image of migratory behavior, when only catch data are available is to average the migratory time densities across years:

$$\bar{f}_i = \frac{1}{m} \sum_{j=i}^{m} f_{ij} \tag{4}$$

where f_{ij} is the proportion of catch on the ith time interval in the jth year (season) for m many seasons.

It is frequently necessary to discuss the relative timing of a migration; is the run on time or not? The confidence interval about the grand mean of migratory timing, $\bar{\bar{t}}$, is used here,

$$\bar{\bar{t}} = \frac{1}{m} \sum_{j=i}^{m} \bar{t}_j \tag{5}$$

which is the arithmetic mean of the annual mean date of migratory timing. The $(1-\alpha)\%$ confidence interval is found as in Sokal and Rohlf (here Students - t is denoted "b" to avoid confusion),

$$\bar{\bar{t}} \pm b_{\alpha,\ m-1}(S^2_{\bar{\bar{t}}}/m)^{\frac{1}{2}} ,$$

where the estimate of the variance of the grand mean of migratory timing

$$S^2_{\bar{\bar{t}}} = \{ \sum_{j=1}^{m} \bar{t}_j^2 - \frac{(\sum_{j=1}^{m} \bar{t}_j)^2}{m} \} \frac{1}{m-1} \quad . \tag{6}$$

For example, the value of Students - t at $\alpha = 0.05$ and $m-1$ degrees of freedom is multiplied into the standard error of the grand mean, and this quantity is added and subtracted from the grand mean to define a 95% confidence interval.

If an annual mean date of migration falls below $\bar{\bar{t}} - b_{\alpha,\ m-1}(S^2_{\bar{\bar{t}}}/m)^{\frac{1}{2}}$ the migration is early and if $\bar{t}_j$ is greater than the upper bound on the 95% CI, the migration is late.

Note that the variance of the migratory time density given above is an "uncorrected variance," but for Alaskan salmon fisheries the difference between a corrected variance and an uncorrected variance is negligible. The average migratory time density, f_i, was calculated by Mundy (1979) by adding catches plus escapements, not proportions, on time intervals across years (equation 6, p. 27). Such a procedure weights years of high abundance (catch) unequally against years of low abundance. Since there is no apparent relation between abundance and migratory timing over a wide range of abundances, the procedures of averaging proportions is preferred.

No assumptions regarding the form of the migratory time densities is made. Many possibilities (normal, logistic, inverse gaussian) have been investigated, however the preceding methods are flexible and adaptable to the fisheries for adult salmon in Alaska because they are distribution free. The use of Students-t to place a confidence interval on the grand mean is justified by the Central Limit Theorem and borne out by experience.

Advanced

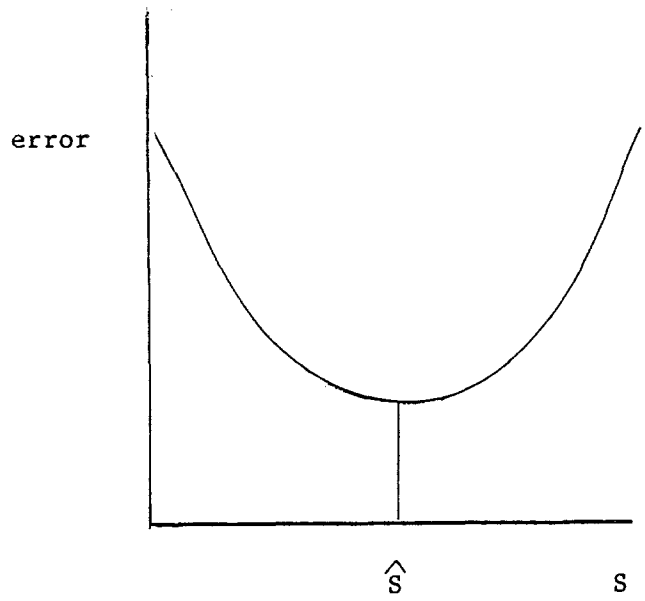
The use of models of migratory behavior in the harvest control of Pacific salmon, and in other commercially exploited organisms which exhibit large interannual fluctuations in abundance (see Babcock 1982), may have been inhibited by the unsuccessful (and unpublished) application of various models to numerical data. The introduction of models of the cumulative proportion of the migration as a function of time was an important step in understanding the potential of a knowledge of migratory behavior in harvest control.

The preceding discussion has assumed that the current catch or CPUE of a time interval will be compared to some measure of historical performance to guide a harvest control decision. As previously discussed for sockeye salmon in Bristol Bay, the objective of any active harvest control decision is to further the goal of attaining a fixed level of harvest, a quota (TAC), or the complement of a catch quota, the escapement goal.

Historical performance is provided in the form of numbers between zero and one. Observations of CPUE and commercial catch must be converted to proportions of total, in order to compare observaton to expectation. The conversion is accompanied by dividing each observation by a scaling factor which converts the numerical observation to a proportion of total. Let E be expectation, zero $< E \leq 1$, O be observation and S be a scaling factor. The scaling factor is total annual catch or CPUE. The objective is to select S so that differences between expectation and observation will be minimized where

$$\text{error}(t) = \sum_{i=1}^{t} (E_i - O_i/S)^2 \tag{7}$$

expresses the difference between observation and expectation. Equation 1 is an upward opening parabola which expresses error as a function the value of S, the scaling factor.



The value of s for which error is minimized is found by taking the first partial derivative of equation 1 with respect to s, setting the first derivative equal to zero and solving for s.

$$\text{error}(t) = \Sigma\ (E^2 - 2EO/S + O^2/S^2)$$

$$\frac{\partial\ \text{error}}{\partial\ S_t} = \Sigma\ (2EO - 2O^2/S)$$

Setting $\frac{\partial\ \text{error}}{\partial\ S}$ equal to zero, then

$$\text{zero} = 2\Sigma\ EO - 2/S(\Sigma\ O^2)$$

$$\Sigma\ EO = \Sigma\ O^2/S$$

$$S = \Sigma\ O^2/\Sigma\ EO$$

Assuming that the migration is on time, the best estimate of the scaling factor on day t is,

$$S_t = \sum_{i=1}^{t} O_i^2 \Big/ \sum_{i=1}^{t} E_i O_i \tag{8}$$

The data of many fisheries indicate that the salmon migrations can be early or late by several days. Since there may be no way to determine the location of the mean of the migration before the start of the migration, the procedure is to examine the value of the error function associated with comparing $Y(t)$ to $O(t+\ell)$ where $-3 \leqq \ell \leqq 3$. The value "3" is used to denote a range of observed mean dates of migration. For ℓ = zero, the sum of squares formula is the same as equation 8A. In general,

$$\min_{\ell} \left[\min_{S} (\Sigma\ (E_i - [O_{i+\ell}/S])^2 \right] \tag{8A}$$

for $i \geqq 6$, $-3 \leqq \ell \leqq 3$, expresses the concept that the minimum sum of square identifies the best choice of s for shifts of the observed values relative to the model values, ℓ = 3, -2, ..., 3 whenever six or more observations have accumulated. (The choice of six is arbitrary, since the sum of squares minimum value will be zero for three or fewer observations. In simulation studies (Mundy 1979) equation 8A did not yield reliable information on the "earliness" or "lateness" of the migration until 50% of the observations had accumulated.

MOMENTS OF MIGRATORY TIME DENSITIES

The moments of a migratory time density which are of interest in the interpretation of migratory behavior are the same as the moments of a random variable which are of

special interest in statistics (see Freund and Walpole 1980, pp. 137-141). The biological interpretation and practical utility of each moment may vary from one population or locality to the next, but the computational procedure remains the same.

The center of the time density, the central date or time period of the migration, is the mean. The mean is the first moment about the origin of the random variable, time. It is estimated for our purposes by $\bar{t}$;

$$\bar{t} = \sum_{t=1}^{\ell} t \cdot f_t \tag{2}$$

where $f_t = n_t/N$ and n_t is abundance (or some quantity which is proportional to abundance) on time interval t, and $N = \sum_{t=1}^{\ell} n_t$. In many salmonid migrations, the mean will occur near the median (50% point).

The variance of the migration, the second moment about the mean, measures the dispersion of the migration through time. For fixed time intervals, a large variance accompanies an even distribution of the migration among the time intervals, while a small variance indicates the concentration of the migration on one, or a few, time intervals. The variance is estimated

$$S^2 = \sum_{t=1}^{\ell} (t - \bar{t})^2 \cdot f_t \tag{3}$$

The square foot of S^2, S, is called the standard deviation.

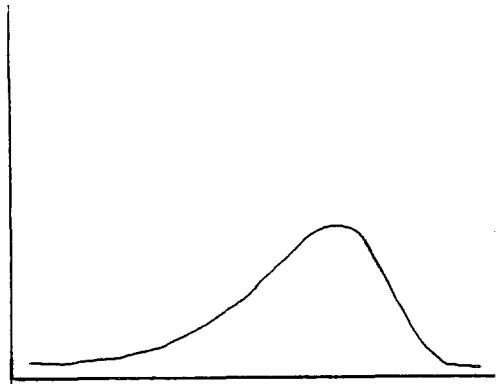
Other moments about the mean are used in conjunction with the variance to measure the symmetry (skewness) of the time density. The third moment about the mean

$$U_3 = \sum_{t=1}^{\ell} (t - \bar{t})^3 \cdot f_t \tag{9}$$

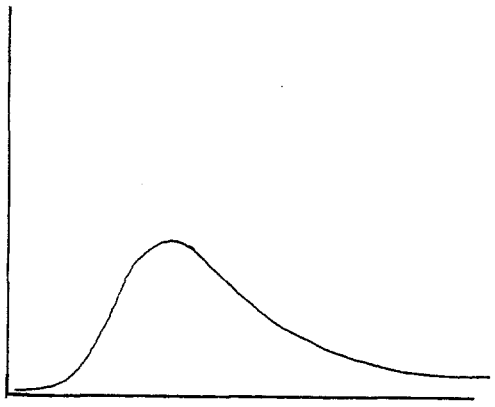
is divided by the cube of the standard deviation to yield a_3, the statistics of symmetry. (a_3 is known as g_1 when it is estimated by simple random sampling of a random variable having the normal distribution).

$$a_3 = U_3/S^3 \tag{9A}$$

When the time density is drawn out to the left, it is negatively skewed (a_3 is negative) when



attenuated to the right (a_3 is positive) it is positively skewed.



The fourth moment about the mean,

$$U_4 = \sum_{t=1}^{\ell} (t - \bar{t})^4 f_t \tag{10}$$

is divided by s^4, the fourth power of the standard deviation to measure kurtosis

$$a_4 = U_4/S^4 \tag{10A}$$

(a_4 is designated g_2 under the above circumstances in which a_3 is designated g_1). A sharply peaked time density is designated leptokurtic (a_4 is positive), while a flat time density is platykurtic (a_4 is negative).

The purpose of calculating the moments of a time density are: 1) to quantify the single year and 2) to allow comparisons between years. As long as the time unit remains unchanged, the annual magnitudes of $\bar{t}$, s^2, a_3, and a_4 are directly comparable. In the case of the mean, $\bar{t}$, it is safe to assume the behavior of a normally distributed random variable. Early, average, and late timing may be objectively

determined by comparing the behavior of an annual mean to the distribution of the grand mean of all years (see Mundy 1982).

Between year fluctuations in S^2, a_3, and a_4 provide information on the stability of the shape of the time density. Widely fluctuating values of S^2, a_3, and a_4 from salmonid populations usually mean faulty data due to inadequate sample size, or censorship and/or truncation. Censorship is usually due to a very small number of fishing periods or sampling occasions during the time span of the migration. Truncation occurs when the fishery (or sampling) starts after the initiation of the migration, or ceases before the end of the migration. The term "widely fluctuating" is subjective and it must be evaluated individually for each population or location.

Fluctuations in all of the statistics discussed above could also be due to genetic and environmental factors (see Mundy 1982). The relative importance of genetics and physical factors in determining migratory timing appear to fluctuate from population to population. One of the key contributions of the time density approach to data analysis lies in its ability to contribute to understanding the causes of variability in migratory timing.

TIMING

The primary sources of timing information are the commercial catch and effort data of the annual management report (AMR) for each area. There are many other sources of timing information which are difficult to locate without substantial knowledge on the management and research program in every area of Alaska. Some sources of data, such as the Informational Leaflet series, receive wide distribution. Other sources, such as Anadromous Fish Act Completion Reports, are obscure.

Some sources have undoubtedly been overlooked, but these will be included in future editions if brought to the attention of the author. The common names of fishes follow American Fisheries Society Special Publication No. 12 (1980). The annual management reports are not listed as primary data sources, even though this is assumed.

COMMENTARY

Kotzebue

Primary commercial target species: Chum salmon
Other target species: Chinook and pink salmon

Primary data sources: Bird and Bigler (1982)

Timing information on chum salmon is well developed and it is used to forecast yield. All timing information is based on catch in the commercial fishery. Test fishing and sonar counts are available (Noatak River) for timing study. Emergency order fishing periods are announced between 10 July - 1 August, weekly periods are allowed between 1 August - 31 August, and the fishery is closed after 31 August.

Norton Sound

Primary commercial target species: Pink and chum salmon
Other target species: Coho and chinook

Primary data sources: Gaudet and Schaefer (1982)

Interception of stocks bound for other areas may diminish reliability of timing data. Season is closed on 31 August each year, opens on 15 June. Two 48-hour periods are fished each week, subject to emergency order closure. Data are for 1978 and 1979 only based on catch of sample set gill nets and commercial CPUE in the area of the sample nets. Information on direction and movement from tagging may help to determine applicability of commercial catch to timing studies. Unit of effort for CPUE not defined. The authors were not able to find any separation of stocks based on timing.

Yukon

Commercial target species: Chinook and chum salmon

Primary data sources: Mundy (1982), Brady (1982), Buklis (1981 and 1982)

Chinook timing information is well developed in Yukon delta area. Test fisheries and historical commercial catch produce a good image of the migration in the lower river. Chum salmon have only recently been a primary target species hence the record of reliable information is about ten years. Problems of variable effort and gill net selectivity occur as a result of the simultaneous occurrence of the summer race of chum and chinook in the lower river. The fall race of chum may have more reliable timing information on the Upper Yukon (see Buklis). The measure of CPUE is the boat hour in the commercial fishery and the fathom hour in the test fishery.

Bristol Bay

Primary target species: Sockeye salmon
Other species: Pink, chinook, coho, and chum

Primary data sources: Mundy (1979), Brannian (1982)

Additional timing data are available from an offshore test fishery at Port Moller (sockeye and chum), and test fisheries in the Kvichak, Igushik, Egegik, and Ugashik Rivers (sockeye only). An offshore test fishery at the mouth of Nushagak Bay was fished in 1980 and 1981. Test fishing projects date to 1960 (Seibel 1965), although not all projects have operated every year.

Analysis of sockeye scale pattern variables (Van Alen 1982) found significant differences with respect to timing in Nushagak Bay. Stock biology efforts are essential in Bristol Bay since differential abundance of stocks can make timing information based on commercial catches difficult to interpret.

Bristol Bay is of special interest in timing studies since sockeye catches and escapements can be combined to produce a time series of total abundance in the fishing districts. The catch and escapement data are not recorded in the same

area (spatial reference frame). Hence the timing of escapement must be adjusted to that of catch or vice versa. In the study of sockeye timing of Mundy (1979), the average time between peak catch and peak escapement given by Royce (1965) was used; Igushik; 5 days, Wood; 3 days, Nuyakuk; 8 days, Kvichak; 7 days, Naknek; 4 days, Egegik; 7 days, and Ugashik; 9 days. (Togiak was not included by Mundy). Brannian (1982) estimated a lag time for each year 1967-1980 (except 1970) at Togiak based on arguments derived from estimating catchability as the ratio of catch to the product of catch plus tagged escapement and effort. In varying the lag time on escapement (time from estuary to counting tower), a new estimate of catchability results at each lag time. The catchability coefficient with the minimum coefficient of variation was chosen to designate the appropriate lag time. Lag times for Togiak varied from 7 to 14 days with a mode of 11 days. The modal value of Brannian corresponded to the peak-to-peak average value of Royce (1965).

The concept of lag time is also critical in the use of timing data from Port Moller. The timing of the migration in the fishing districts is previewed in the test fishery four to eleven days before the fish reach Bristol Bay (Mundy and Mathisen 1981). Similar reasoning has been applied to match test catches in the lower reaches of the rivers to escapement counts at towers near the origins of the rivers (Yuen, various).

Species other than sockeye are important commercially but particularly on the west side of Bristol Bay in Togiak and Nushagak fishing districts. Hornberger and Mathisen (1981) calculated migratory timing by averaging the cumulative proportions of fish present in the fishing district during each time period. The lag time for escapements was basically determined by the peak-to-peak method of Royce for each year. The mean values (1959-1979) of sockeye lag times were 2.6 days for the Wood River, 6.4 days for the Igushik River and 11.3 days for the Nuyakuk River. Pink salmon require an average of 9.8 days to ascend the Nuyakuk River (1949-1979). For chinook, chum, and coho salmon, the migratory timing is based solely on commercial catch data.

Chignik

Primary target species: Sockeye salmon

Primary data sources: Dahlberg (1968); Dahlberg and Lechner (1968); Phinney and Lechner (1969)

Chignik represents one of the earliest applications of a quantitative definition of migratory timing to harvest control in a commercial fishery. Between 1962 and 1966 Dahlberg participated in, and conducted, tagging studies to define the average timing of all sockeye in the fishery, and to identify the timing of the two major stocks: Chignik Lake and Black Lake. Dahlberg used the information on rates of migration of tagged individuals to combine catch and escapement. The time series of total abundance for each stock and the combined stocks was then used to estimate the parameters of three logistic models. The logistic models specify expected cumulative proportion of the migration as a function of time.

Kodiak

Primary target species: Pink and sockeye salmon

Primary data sources: Bevan et al. (1982), and Bevan et al. (1979), Bevan and Lechner (1970).

Migratory timing based on commercial catch is well developed. Kodiak is remarkable in that forecasts of annual abundance of pink salmon are given as a time series, whereas in all other Alaskan salmon fisheries pre-season forecasts of abundance consist of point estimates with no reference to timing. Timing information are stratified by odd and even-year in recognition of the different populations of pink salmon which spawn in alternate years.

Cook Inlet

Primary target species: Sockeye salmon
Other species: Chum, coho, pink, and chinook salmon

Primary data sources: Waltemyer et al. (1981), Cross et al. (1981 and 1982), Davis (1970)

Migratory timing information is well developed only for sockeye in Upper Cook Inlet. Some timing information for pink salmon is available in Davis (1970). Migratory timing information relating to the migration as a whole (the sum of the production of three major river systems , Kenai, Kasilof, Susitna, and two lesser rivers, Crescent River and Fish Creek) is based upon total abundance information. Escapement data are moved back in time by 3 days for the Kenai and Kasilof Rivers, 6 days for the Susitna, and 10 days for the Crescent River in the case of the historical data of Waltemyer et al. (1981).

A finer division of stocks is accomplished by Cross et al. (1981) on the basis of a catch allocation derived from scale pattern analysis. Migratory timing by river system in the reference frame of the fishery is accomplished by moving back escapement in time to the catch of the various districts of Upper Cook Inlet (Waltemyer considers all districts combined to be a single reference frame). The salmon transit time from the fishing district to the four points of escapement enumeration are estimated separately; 7-11 days for Susitna, 2-4 days for the Kenai, 1-4 days for the Kasilof, and 10-14 days for the Crescent (Cross et al. 1982). The catch allocation ability provided by the stock biology studies greatly increases the potential for precision in the harvest control of sockeye in Upper Cook Inlet.

Pink salmon timing data for four even-years 1962, 1964, 1966, 1968 based on commercial catches in 6 seine and gill net districts from Lower and Upper Cook Inlet are available (Davis 1970).

Timing data on sockeye salmon is also supplied by a test fishery at the southern boundary of Upper Cook Inlet (Waltemyer et al. 1981). Timing of species other than sockeye salmon remains to be rigorously defined and analyzed.

Prince William Sound

Primary target species: Pink, chum, sockeye, coho, and chinook salmon

Primary data sources: Roberson and Fridgen (1974), Roberson et al. (1978)(1983)

Timing information is well developed for sockeye salmon from the Copper River and timing information has been used in harvest control operations since about 1973.

Timing information based on catch per unit effort data from the Copper River flats area, an average CPUE by week from 1966-1972, are presented by Roberson and Fridgen (1974). Note that weekly CPUE was averaged across years, not weekly proportion. Timing is expressed as percentage of total catch by week.

Stock identification by means of tagging has also provided data for the evaluation of timing information by spawning stock (Merritt and Roberson 1983). New scale pattern analysis studies of sockeye salmon are also being undertaken.

A study to evaluate timing of pink salmon by district is now being conducted by Mundy et al., Old Dominion University, Norfolk, Virginia 23508.

Southeastern Alaska

Primary target species: Pink salmon
Other species: Sockeye, coho, chum, and chinook salmon

Primary data sources: Alexandersdottir and Mathisen (1982)

Migratory timing information is now becoming well developed for pink salmon, as is the study of migratory timing of salmon in Alaska. Some of the first scientific inquiries into migratory timing were based on observations of pink salmon in Southeastern Alaska (Davidson et al. 1943). The work of Alexandersdottir and Mathisen is based on trap catch data during 4 periods (1) start to 1924, (2) 1925-1940, (3) 1941-1944, (4) 1945-end of operations. Selected traps from 7 locations provided data from varying periods: 1. Icy Strait II (1916-1950), 2. Icy Strait II (1916-1950), 3. Chatham Strait (Frederick Sound) (1936-1950), 4. Sumner Strait (1936-1950), 5. Prince of Wales Island (Northern West Coast) (1924-1947), 6. Prince of Wales Island (Southern West Coast) (1922-1947), and 7. Revillagigedo Channel (1914-1948). The relation of the time scale to calendar time is 15 June = Day 1.

Further timing information on pink salmon is contained in the tagging studies summarized by Hoffman (1982). Tagging studies on pink salmon in Southeastern Alaska date to 1924.

A brief description of sockeye salmon migratory timing in Lynn Canal is presented in Marshall et al. (1982). Migratory timing based on all available catch and escapement records for sockeye in Lynn Canal is under development by Barth et al. at Old Dominion University, Norfolk, Virginia 23508.

Migratory timing of adult coho salmon (and juveniles also) originating from the Taku, Berners, and Chilkat Rivers based on tagging studies (fluorescent pigment) is presented by Gray et al. (1978). Some potential applications of migratory timing to harvest control are discussed.

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*There are qualitative and quantitative differences in the food of different age groups which are evidently caused by the dominant position of some fish and the subordinate position of others. Something similar also features in the diurnal feeding rhythm of fish of different ages.

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