Stock Identification of Fraser River Sockeye Salmon: Methodology and Management Application

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Steve Cox-Rogers

October, 1993

Pacific Salmon Commission
Technical Report No. 5

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ABSTRACT

The Pacific Salmon Commission uses scale-pattern analysis to identify Fraser River sockeye salmon (*Oncorhynchus nerka*) stocks in mixed-stock fisheries from Puget Sound northward to southeastern Alaska. Scale-pattern analysis relies on growth differences between stocks that are reflected in the patterns of circuli recorded on their scales. Discriminant function analyses of scale-pattern features are used to distinguish among the various Fraser River sockeye salmon stocks, and to classify fishery mixtures according to probable stocks of origin. Additional information such as run-timing, age composition, and length data, are used to refine and enhance the analyses. The detailed application of the technique, for both in-season and post-season management purposes, is described.

INTRODUCTION

The Pacific Salmon Commission (and, prior to 1986, the International Pacific Salmon Fisheries Commission) uses scale-pattern analysis (SPA) to identify Fraser River sockeye salmon stocks harvested in fisheries along the Pacific coast of North America from Washington State northward to southeastern Alaska (Figure 1). The Pacific Salmon Commission, under the terms of the Pacific Salmon Treaty (1985), has the overall responsibility for allocating the catch of Fraser River sockeye salmon between Canada and the United States. As the fleets participating in the major interception fisheries are highly mobile and efficient, intensive in-season management of the fisheries is required to ensure that annual escapement, international allocation, and domestic allocation objectives are met.

The Fraser River Panel of the Pacific Salmon Commission is responsible for the in-season management of fisheries that target on Fraser River sockeye salmon in the Panel Area. Scientific work required by the Fraser River Panel to fulfil its management responsibilities is conducted by Pacific Salmon Commission staff. Stock identification is an integral part of the overall management process and is conducted by Pacific Salmon Commission staff. Estimates of stock composition are used by the Fraser River Panel to assess stock-specific timing and abundance patterns as the stocks pass through the various fisheries and enter the Fraser River. As well, daily and weekly updates of stock composition are used by the Fraser River Panel to modify or change fisheries so that specific harvest and escapement goals can be achieved.

The major Fraser River sockeye salmon stocks are characterized by inter-annual variation on a 4-year cycle with one large (dominant), one moderate (sub-dominant), and two low (off-cycle) production years (Woodey 1987). The annual migration is composed of six to ten major stocks and various minor stocks that pass through the migratory areas from mid-June through September. The individual stocks are associated with particular rearing lakes in the Fraser River watershed (Table 1). In general, stocks that spawn farther upstream tend to pass through the fishery areas earlier. The many bulletins and annual reports of the International Pacific Salmon Fisheries Commission document extensive studies of the biology of Fraser River sockeye salmon (Killick 1955, Killick and Clemens 1963, Henry 1961).

Various techniques are available for distinguishing salmon stocks in fishery mixtures. Mark and recapture methods have long been employed by many agencies (Ihssen et al. 1981), however, they are logistically difficult and can be costly to implement on an annual basis. The alternative to tagging is to use naturally occurring variation in one or more biological attributes ("markers") that are known to differ among stocks. For example, many salmon stocks can be identified because of stock-specific genetic differences (Beacham et al. 1987), morphometric differences (Winans 1984), and parasitic differences (Bailey and Margolis 1987). Perhaps the most widely applied biological attribute for estimating salmonid stock compositions, however, has been the use of scale-pattern growth differences (Henry 1961, Ihssen et al. 1981, Marshall et al. 1987). Scale-pattern analysis is particularly useful because, unlike other methods, scales are easy to collect, do not require extensive preparation or preservation, and may be analyzed to provide estimates of stock composition within hours of being sampled.

Since the signing of the Pacific Salmon Treaty in 1985, changes to fisheries in both Canada and the United States have increased the complexity of Fraser River sockeye salmon management. To meet annual escapement goals while fulfilling international and domestic allocation objectives, the Pacific Salmon Commission has updated its stock identification program by replacing more traditional univariate scale-pattern techniques with multivariate methodologies. In the Methods

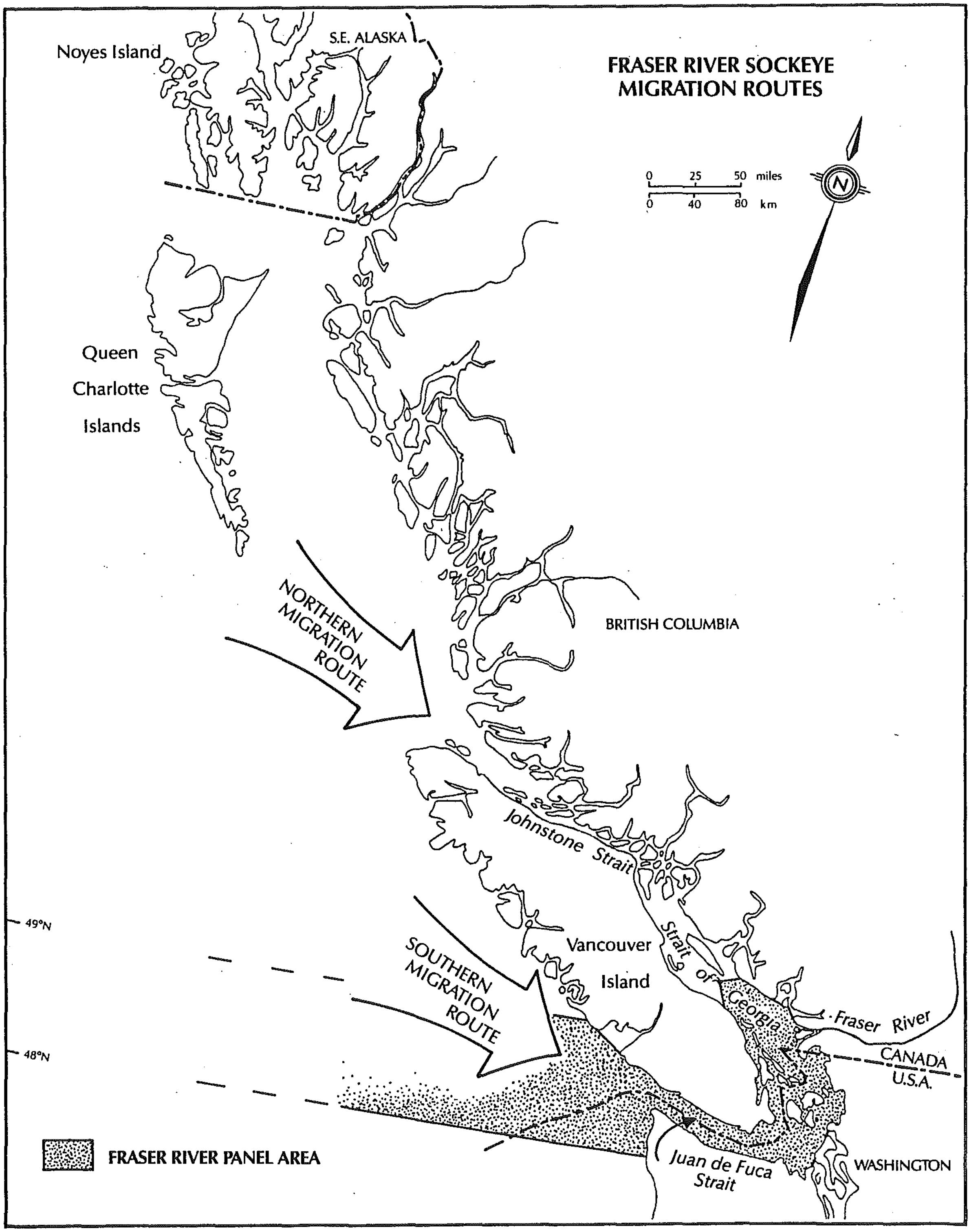


Figure 1. Coastal migration routes of Fraser River sockeye salmon.

Table 1. Rearing lakes and associated sockeye stocks in the Fraser River Watershed.

Rearing Lake	Streams
Pitt Lake	Pitt River
Chilliwack Lake	Chilliwack Lake Dolly Varden Creek
Cultus Lake	Cultus Lake
Nahatlatch Lakes	Nahatlatch Lakes Nahatlatch River
Harrison & Lillooet Lakes	Big Silver Creek Birkenhead River Green River Railroad Creek Weaver Creek
Seton & Anderson Lakes	Gates Creek Portage Creek
Shuswap & Adams Lakes (Early Runs)	Anstey Creek Eagle River Momich/Cayenne Creek Scotch Creek Seymour River Upper Adams River
Mara, Mable & Shuswap Lakes (Late Runs)	Eagle River Little River Lower Adams River Lower Shuswap River Middle Shuswap River Scotch Creek Seymour River Shuswap Lake South Thompson River Wap Creek
Kamloops & N. Barriere Lakes (North Thompson Drainage)	Barriere River Fennell Creek Harper Creek North Thompson River Raft River
Chilko & Taseko Lakes	Chilko River North End Chilko Lake South End Chilko Lake Taseko Lake
Quesnel Lake	Lower Horsefly River Lower McKinley Creek Mitchell River Upper Horsefly River Upper McKinley Creek
Takla & Trembleur Lakes (Early Runs)	Ankwill Creek Bivouak Creek Blackwater Creek Blanchette Creek Crow Creek Driftwood River Dust Creek Felix Creek Fleming Creek Forfar Creek Forsythe Creek French Creek Frypan Creek Gluskie Creek Hooker Creek Hudson's Bay Creek Kazchek Creek Kynock Creek Leo Creek Lion Creek McDougal Creek Narrows Creek Paula Creek Point Creek Porter Creek Rossette Creek Sakiniche River Sandpoint Creek Shale Creek 5 Mile Creek 15 Mile Creek 25 Mile Creek
Trembleur & Stuart Lakes (Late Runs)	Kazchek Creek Kuzkwa Creek Middle River Pinchi Creek Sakiniche Creek Tachie River
Francois & Fraser Lakes	Endako River Nadina River Nechako River Nithi River Ormonde Creek Stellako River
Bowron Lake	Bowron River Indianpoint Creek Swift Creek
Non-Lake Rearing	Harrison River Widgeon Slough

section of this report, we describe the multivariate scale-pattern method now being used by the Pacific Salmon Commission to identify Fraser River sockeye salmon stocks in mixed-stock fisheries in Fraser River Panel and Non-Panel waters. In the Management Application section, we outline how the scale-pattern method has been applied with respect to in-season and post-season analyses, and describe how additional information such as run timing, age composition, and fish length is used to enhance stock resolution.

SCALE-PATTERN ANALYSIS: METHODS

Scale-pattern analysis is the comparison of stock-specific variations in the widths and numbers of circuli found in the freshwater and marine growth zones of scales. Scale patterns reflect variations in growth that develop while stocks are spatially isolated, such as during juvenile residence in lakes or streams, or during certain phases of marine residence. It is also possible that genetic differences between stocks play a role in observed scale pattern differences. In using scale patterns to identify stocks in fishery mixtures, scale samples from each of the contributing stocks (baseline standards) must first be collected. Baseline standards for Fraser River sockeye salmon are usually assembled from present-year or prior cycle-year spawning ground collections, or from terminal areas where stock mixing is known to be minimal. Once the baseline standards have been selected the scales are analyzed, and statistical decision rules for separating the stocks are established. The decision rules are then applied to scale samples collected from mixed-stock fisheries to generate proportional estimates of each stock present.

The scale-patterns used for stock identification of Fraser River sockeye salmon occur on the anterior portion of individual scales. Sockeye salmon scales form when the fry are 30-40mm long (Clutter and Whitesel 1956). As the fish grow in body size, corresponding radial scale growth takes place. The scales consist of lower transparent basal plates and a mineralized upper layer. During scale growth, new basal plates are formed under existing plates and hyalodentine ridges (circuli) are deposited on the margins between adjoining plates. The circuli appear under magnification as partially concentric rings which radiate outward from the scale focus. Seasonal changes in growth rate are reflected by changes in circulus spacing, and by the number of circuli formed. Recurring bands of narrowly spaced circuli (annuli) denote the cessation of annual growth.

Two distinct zones of scale growth are discernable on adult sockeye salmon scales: an inner freshwater zone, consisting of thin, narrowly spaced circuli, and an outer marine zone, consisting of thick, widely spaced circuli (Figure 2). A third scale zone, the marginal increment or "plus-growth" zone, is often present on sockeye salmon scales, and lies between the freshwater and marine scale zones. Circuli in the plus-growth zone are of intermediate size and form just prior to, or soon after, ocean entry.

Circuli counts in the freshwater and plus-growth scale zones, as well as distance measures within these zones, are presently used to identify Fraser River sockeye salmon stocks. Dr. C.H. Gilbert, in the early 1900's, first recognised that the freshwater scale patterns of Fraser River sockeye salmon stocks differ (Henry 1961). In examining the freshwater portions of their scales, Gilbert noted that certain stocks exhibited high circuli counts to the first freshwater annulus, while other stocks exhibited low circuli counts to the first freshwater annulus. Gilbert attributed the among-stock differences to variable rearing conditions in the nursery lakes, and postulated that the differences could be used to identify the stocks in mixed-stock fisheries. Several studies have confirmed that the freshwater scale growth of Fraser River sockeye salmon is indeed stock-

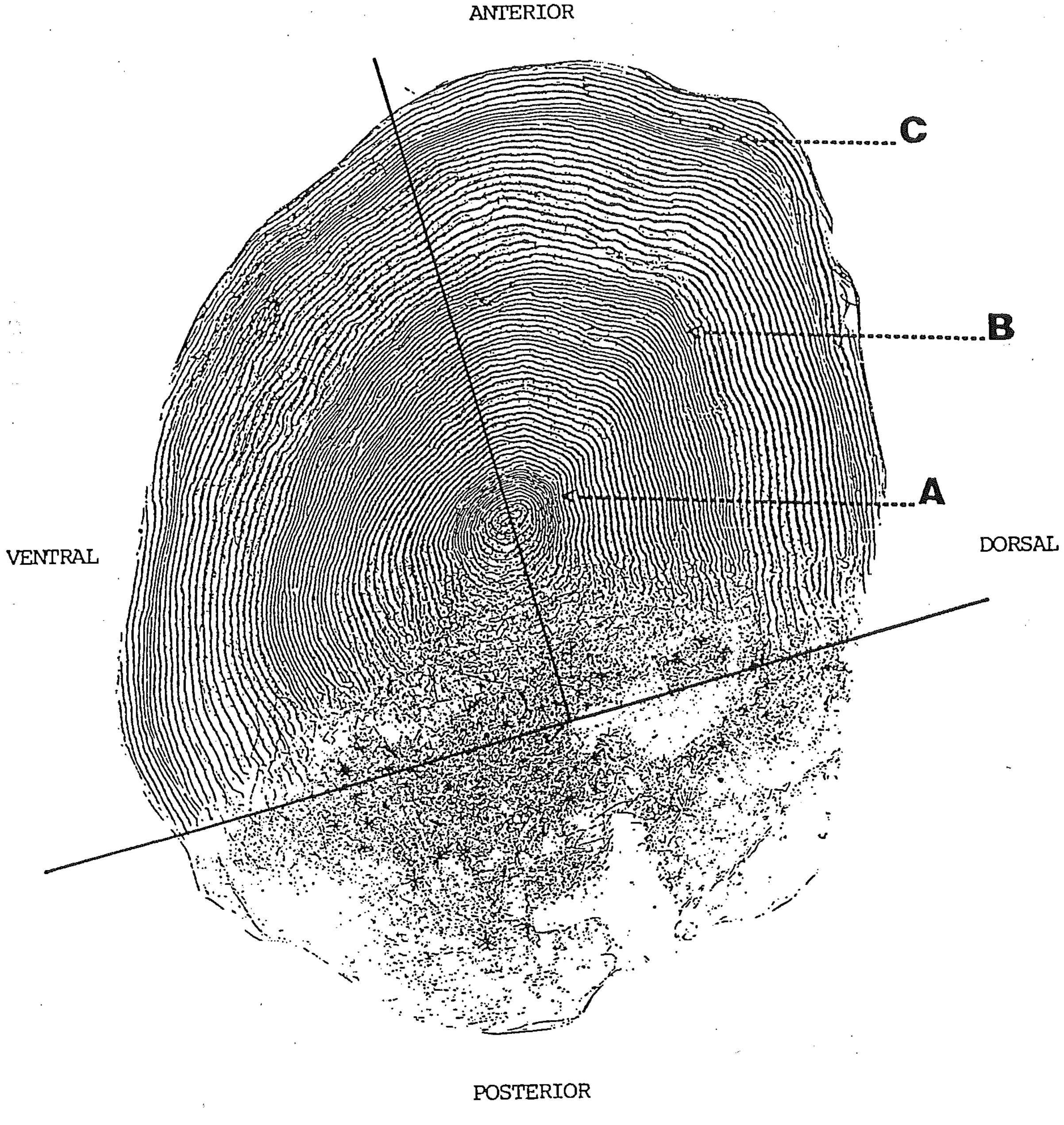


Figure 2. Scale of age 4_2 Fraser River sockeye salmon showing the 20° ventral measurement axis used for data extraction, the first lacustrine annulus (A), the first marine annulus (B), and the second marine annulus (C).

specific, can vary annually, and is influenced by both lake productivity and juvenile rearing density (Clutter and Whitesel 1956, Goodlad et al. 1974).

Henry (1961), building on earlier work conducted by Clutter and Whitesel (1956) and Hamilton (1947), developed a univariate procedure for separating Fraser River sockeye salmon stocks using freshwater circuli counts. The univariate procedure, known as "triangulation", was used by the International Pacific Salmon Fisheries Commission and the Pacific Salmon Commission for identification of Fraser River sockeye salmon in commercial catches until 1986. The triangulation method compared circuli frequencies among baseline stocks with those sampled from mixed-stock fisheries. Using graphs, the circuli frequency distributions for each stock were successively superimposed over the circuli frequency distributions from mixed-stock samples. The mixture curves were then integrated by hand to calculate the proportions of each stock present. Henry (1961) provides a detailed account of the method, and explains its application to fisheries management.

Although Henry's (1961) method performs adequately for simple situations, the technique becomes limited when more than four or five stock assemblages are considered. In the late 1970's, and through the mid-1980's, the International Pacific Salmon Fisheries Commission began to develop multivariate discriminant analysis of scale pattern features as a replacement for Henry's triangulation methodology (Cook and Guthrie 1986). Discriminant analysis, which considers multiple variables to distinguish groups, offers increased resolution compared to univariate methods. Multivariate scale-pattern analysis formally replaced Henry's triangulation methodology in 1987, and now forms the basis of the Pacific Salmon Commission's stock identification program for sockeye salmon.

SCALE COLLECTION

Scale samples from spawning grounds within the Fraser River watershed and from mixed-stock fisheries in Fraser River Panel and Non-Panel Area waters are collected following the methodology of Clutter and Whitesel (1956). A single scale is removed from the left side of each sockeye salmon from the preferred area, which is two scale rows above the lateral line on a diagonal extending from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin. Scales from the preferred area are used for stock identification because a) scales form first in this region, and b) scales from the preferred area exhibit more uniform growth compared to scales from other parts of the body. Clutter and Whitesel (1956) present a detailed review of the factors influencing scale growth in sockeye salmon.

Two sampling programs for scale collection are initiated by the Pacific Salmon Commission staff each year: 1) spawning ground (baseline) scale sampling conducted by Canadian Department of Fisheries and Oceans staff, and 2) commercial fishery and test fishery (mixture) scale sampling conducted by Pacific Salmon Commission staff in both Fraser River Panel and Non-Panel Area waters.

Spawning ground scale samples are randomly selected from fresh-dead adult sockeye salmon during the course of assessment operations each fall. Sample size requirements for each stock are determined, using standard statistical techniques, as the number necessary for estimating mean circuli counts to the freshwater annulus within a one circulus confidence interval. For most stocks, this number falls somewhere between 100 and 400 fish per stock (equal males and females) depending upon historical estimates of variance. The expected age composition structure is also used in setting stock-specific sample sizes, as larger samples are required for those stocks exhibiting complex age structures. Single-period samples are collected for stocks with compressed spawning times and simple age structures. Three-period samples, collected ten days before, during, and ten days after peak die-off, are required for stocks with protracted spawning and complex age structure. Jack sockeye salmon (age 3_2 and 4_3) are sampled as they occur, to a maximum of 460 samples for those stocks producing large numbers of jacks. Matching otoliths are collected for aging purposes for most stocks, as resorption of a portion of the marine scale zone makes the aging of spawning ground scales difficult. Matching sex and post-orbital to hypural plate lengths and standard lengths (snout to hypural plate) are collected for all samples.

Commercial fishery scale sampling is area specific for fisheries occurring in Fraser River Panel and Non-Panel Area waters, and consists of both adult and jack sampling operations. In a typical year, the sampling of commercial fisheries begins in late June and continues through to the end of September or early October. To assess the catch of Fraser River sockeye salmon in commercial fisheries, the Pacific Salmon Commission funds programs that allow for the sampling of northern- and southern-area coastal fisheries from Alaska, British Columbia, and Washington State. Commission staff routinely sample commercial sockeye landings at canneries in Bellingham, Blaine, Vancouver, Steveston, Port Renfrew, Ucluelet, Winter Harbour, Port Hardy and Prince Rupert. In addition, at the request of the Pacific Salmon Commission, the Alaska Department of Fish and Game conducts a comprehensive sampling program which provides estimates of Fraser River sockeye catch in the Alaska District 104 fishery.

Random samples of up to 360 scales are obtained from fish collectors or packers from catch areas of interest. The origin of the catch from each collector is confirmed with the vessel captain as to area and gear type to avoid mis-representative samples being obtained. In some fisheries it is necessary to sample from individual vessel off-loads, a less desirable procedure. In these instances a maximum of 60 samples per boat are obtained, with four to six individual boats being sampled. This provides a for a greater chance of obtaining a representative sample from the catch area and gear type of interest.

Separate samples are obtained for each gear type actively fishing during a scheduled opening. This requires the sampling of as many as 12 or more commercial fisheries each week through the period of active commercial fishing. All samples are obtained prior to any quality sorting (high-grading) which may occur in the fish plant. For adult samples, 240 to 360 scales are sampled, often with matching data on sex, weight, and post-orbital/fork length. As well, 120 scale samples per day are collected from Pacific Salmon Commission and Canadian Department of Fisheries and Oceans test fisheries operating in Fraser River Panel and Non-Panel Area waters throughout the season. Through the period of active in-season management, in excess of 30,000 scales are aged and digitized in preparation for stock assessments using discriminant function analysis. For jack samples, sub-samples of total sockeye landings are counted and for any jack sockeye encountered in a sub-sample a scale and a post-orbital/fork length measurement are obtained. Sample sizes of between 115 to 230 jacks per fishery are obtained if jack availability allows. Sample size guidelines for stock identification mixture samples are discussed later in this paper.

SCALE PROCESSING

All spawning ground and commercial fishery scale samples are forwarded to the Pacific Salmon Commission laboratory for mounting and processing. The scales are cleaned and acetate impressions of the original scales are made using the procedures outlined in Clutter and Whitesel (1956). A computer database is maintained in the scale laboratory for cataloguing purposes, which contains the specific parameters and variables measured for each scale. The Pacific Salmon Commission scale database is in ASCII format and is complete back to the early 1950's.

Once mounted, the scale impressions are projected at 100X to 250X magnification for aging and data extraction. The projection assemblies consist of two Neo-Promar projection microscopes and light tables similar to those described by Ryan and Christie (1976). Ages are assigned to each scale by visual observation and are recorded in Gilbert-Rich notation (Clutter and Whitesel 1956). Nine age classes are typically seen in Fraser River sockeye salmon (ages 4_2, 5_2, 5_3, 6_3, 6_2, 4_3, 3_2, 4_1 and 3_1), although age 4_2 and 5_2 fish account for 70%-95% and 5%-25% of the annual production, respectively.

Circuli counts in the freshwater and plus-growth scale zones are currently obtained from the projected scale images by eye. Distance measurements to successive circuli within these zones are recorded using a Calcomp 28240 digitizing tablet mounted within the light table surface. All scale data are extracted at 247 power magnification along a common axis extending through the scale focus 20° ventral to the posterior-anterior scale axis (Figure 2). All distance measurements are made from the focus to the outer edge of each circulus. The criteria for identifying annuli, false checks, plus-growth, and circuli follow Clutter and Whitesel (1956) and Tanaka et al (1969). Scale reading is conducted by two experienced scale analysts, who are regularly monitored to ensure consistent reading and interpretation of variables.

STATISTICAL METHODS

Discriminant function analysis is the statistical technique used to distinguish among the baseline standards, and to classify fishery mixtures to their probable stocks of origin. We use linear discriminant function analysis, as opposed to non-parametric quadratic or polynomial discriminant function analysis, because a) linear analyses have proven to be useful in numerous applications involving scale data (Ihssen et al. 1981), b) computer programs for linear discriminant analysis are readily available and c) our scale data generally conform to the assumptions required for linear discriminant analysis.

Discriminant functions are linear combinations of variables that maximize among-stock variance relative to within-stock variance. The objective of discriminant analysis is to weight and combine the variables such that the baseline standards being analyzed become as statistically distinct as possible. The assumptions of linear discriminant analysis are a) the variable system being used is multivariate normal, b) the variance-covariance matrices are homogeneous among the stocks, and c) the stocks being investigated are discrete and identifiable. Multivariate analysis of variance is used to test for significant differences among stock means prior to analysis.

The scale data for each baseline standard are recorded in a matrix where each row contains the data vector for each fish. Geometrically, the array of p correlated random variables (X_1,X_2,X_3,....X_p) measured for each fish k (k=1,2,3,...n_i) from each stock i describes the proximity of each fish about the stock mean vector, or centroid. Discriminant analysis reduces the variable vectors for each fish to single scores (canonical variables, L) using linear combinations of the original variables weighted according to their contribution to among-stock discrimination. The discriminant functions for i stocks using j variables (j=1,2...p) measured over k cases (k=1,2,...n_i) are of the form:

$$L_i = (\beta_1 Z_1) + (\beta_2 Z_2) + \ldots(\beta_p Z_p) \tag{1}$$

where L is the discriminant score on function i, the β_p's are standardized weighting coefficients representing the contribution of each variable p to discrimination along function i, and the Z's are standardized values of the p discriminating variables used in the analysis. The number of discriminant functions calculated, for any given analysis, is equal to the number of variables (p) in the analysis, or one less than the number of stocks used, whichever is less.

An empirical measure of how well the baseline standards can be distinguished from each other is obtained by classifying the fish of known origin, from each stock, back to their stocks of most probable origin using the developed classification rules. As the actual origin of each fish is already known, the trial classification provides an assessment of how well a particular discrimination model is able to distinguish among the stocks.

The elements of the classification matrix (C) report the number of fish from baseline stock j classified to baseline stock i by the classification rules. Expressed as a percentage, the diagonal elements of C report the probability of correct classification for each stock, while the off-diagonal elements report the probabilities of mis-classification for each stock. The mean estimated rate of correct classification, calculated along the diagonal, provides an indication of overall stock resolution and model performance. The classification matrix for i stocks (i=1,2,3...n) is of the form:

$$C = \begin{array}{cc} \text{FROM STOCK} & \\ \begin{bmatrix} c_{11} & c_{12} & \cdot & \cdot & c_{1n} \\ c_{21} & c_{22} & \cdot & \cdot & c_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ c_{n1} & c_{n2} & \cdot & \cdot & c_{nn} \end{bmatrix} & \text{TO STOCK} \end{array}$$

We use Lachenbruch's (1975) jack-knifing procedure to reduce the bias in calculating the elements of C, given that the same fish are used to calculate both the discriminant functions and the classification matrix. Here, the first fish is removed from the analysis, the discriminant and classification functions are re-calculated, and the fish removed is then classified to probable stock of origin using the classification functions. The procedure is then repeated for each subsequent fish, and the results are tallied.

The stock composition of commercial fishery samples is estimated using the developed models. Based upon their scale-variable vectors, each fish in a particular mixture sample is classified to the stock to which it is most similar. The result is a series of first-order point estimates for the stocks estimated to be present in the mixture. The first-order estimates, however, do not take into account the classification error rates associated with distinguishing among the baseline standards (eg. the off-diagonal elements of the classification matrix). To correct for this bias, Worlund and Fredin (1962) developed linear equations which adjust the initial point-estimates for errors in distinguishing among the baseline standards. Cook and Lord (1978) extend the procedure to multiple stocks using matrix algebra. Using Cook and Lord's notation, the classification accuracy of each discrimination model is again the square matrix C. R is a column vector $(r_1,r_2,r_3,\ldots r_i)$ where r_i is the proportion of the mixture sample initially allocated to stock

i. The column vector U $(u_1,u_2,u_3...u_i)$, where u_i is the actual proportion of stock i in the mixture, is related to r_i through a series of simultaneous equations:

$$CU=R \tag{2}$$

e.g.,

$$\begin{array}{cccc} \begin{bmatrix} c_{11} & c_{12} & \cdot & \cdot & c_{1n} \\ c_{21} & c_{22} & \cdot & \cdot & c_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ c_{n1} & c_{n2} & \cdot & \cdot & c_{nn} \end{bmatrix} & \begin{bmatrix} u_1 \\ u_2 \\ \cdot \\ \cdot \\ u_i \end{bmatrix} & = & \begin{bmatrix} r_1 \\ r_2 \\ \cdot \\ \cdot \\ r_i \end{bmatrix} \\ \begin{array}{c}\text{Classification}\\ \text{Matrix}\end{array} & \begin{array}{c}\text{Actual}\\ \text{Estimate}\end{array} & & \begin{array}{c}\text{Initial}\\ \text{Estimate}\end{array} \end{array}$$

and so:

$$U=C^{-1}R \tag{3}$$

Equation (3) is termed the classification matrix correction procedure (Cook and Lord 1978). However, it too can be biased in that the elements of U can be positive, zero, or negative depending upon the proportions of each stock initially estimated to be present in the mixture. To avoid negative values, we use Cook's (1983) constrained corrected classification modification to equation (3), rather than simply eliminating stocks with negative point-estimates and re-running the models to calculate non-negative U. Simulation studies have shown that the constrained estimator performs well in practice (Cook 1983, Millar 1990), and provides valid confidence intervals for stocks occurring in zero proportions. For all model runs, we calculate simultaneous 90% confidence intervals about the corrected point-estimates U using the variance formulae of Pella and Robertson (1979). Our discriminant function programs are written in APL and are implemented on a 386 microcomputer.

The criteria we use for selecting which scale variables to use in our discriminant models follows Habbema and Hermans (1977). Variables are chosen to maximize the mean estimated rate of correct classification for a given discrimination model. This is achieved by selecting uncorrelated variables with high F-scores in one-way analyses of variance (ANOVA), and which appear to satisfy the general distributional assumptions of discriminant analysis. As a guide, we set the minimum acceptable level of mean classification accuracy, for any discrimination model, as being halfway between random allocation and 100%. For example, for a two stock model the minimum acceptable mean classification accuracy is 75%, for a three stock model 67% is the minimum acceptable level and for a four stock model 62.5% is the minimum acceptable level.

ACCURACY AND PRECISION

The goal of our discrimination modelling is to ensure that the point estimates generated for fishery mixtures are as accurate and precise as possible. We have found, as have others (Cook 1983, Millar 1990), that point-estimate accuracy can be maintained if the bias correction procedure of Cook and Lord (1978) is used. Point-estimate bias can be large when similar stocks differ greatly in abundance (Millar 1987); without bias-correction, stocks present in low proportions tend to be overestimated while stocks in high proportions tend to be underestimated. We find this especially noticeable when using discrimination models that perform poorly (eg., those with low mean classification accuracies). Without bias-correction, the use of such estimates would be questionable.

Point-estimate precision is less controllable in most situations, and is influenced by three interacting features of the analysis: 1) the accuracy of the classification matrix, which reflects the degree of stock separation possible, 2) the sample size of each baseline standard used to construct and evaluate the classification matrix, and 3) the sample size of the fishery mixture being analyzed (Pella and Robertson 1979). It is important for fishery managers to know how changes to these three factors affect point-estimate precision for Fraser River sockeye salmon.

To examine the problem, we applied a probable range of classification accuracies, baseline sample sizes, and mixture sample sizes to hypothetical three-stock and five-stock classification problems. The classification matrices tested were symmetric along the diagonal, and an equal proportion of each mixture was assigned to each stock (R=U). The effect of different sample sizes and classification accuracies on precision was assessed by calculating simultaneous 90% confidence intervals, in percentage units, about the final point estimates by using a spreadsheet version of Pella and Robertson's (1979) formulae. The mean classification accuracies we tested for the three-stock and the five-stock simulations were 60%, 70%, 80%, and 90%, respectively. The sample sizes tested were 25, 50, 75, 100, 150, 200, 300, 500, and 1000 for each mixture sample and for each baseline standard, respectively.

Tables 2 and 3 summarize the effects of changing baseline and mixture sample sizes on 90% confidence interval widths for the three-stock and five-stock simulations tested with 60%, 70%, 80%, and 90% mean classification accuracies. Although a limited range of models was tested, some general trends were apparent. For both models, increasing both the baseline and the mixture sample sizes resulted in increased precision, decreasing the widths of the 90% confidence intervals (Tables 2 and 3). For any mean classification accuracy, changes to mixture sample size had a greater effect on achievable precision than did changes to baseline sample size. For mixture sample sizes, large increases in achievable precision were observed up to sample sizes of about 300. Changes to baseline sample size beyond 100 to 150 resulted in minor changes to achievable precision, especially for the models with already high (80-90%) mean classification accuracy. The greatest changes in achievable precision, brought about by changes in baseline sample size, were for sample sizes less than 100.

Classification accuracy was the most important factor in determining achievable precision: the widths of the 90% confidence intervals became markedly smaller as mean classification accuracies increased. As well, changes to mixture and baseline sample sizes had a smaller affect on changing the widths of the 90% confidence intervals as classification accuracy increased.

The number of stocks in a particular model should theoretically have no significant affect on achievable precision if mixture and baseline sample sizes are reasonably large (eg.>150). Thus, the results of the limited number of models examined will generally apply to more complex scenarios involving more stocks. However in practice, classification accuracies typically deteriorate when numerous stocks are considered. In fact, it is difficult to maintain high classification accuracies for complex models, simply because of increasing stock similarity. Under such conditions, three avenues for maintaining classification accuracy can be considered: 1) similar stocks which co-migrate can be pooled into stock groups, 2) additional information, such as run-timing, can be used to guide the inclusion and exclusion of similar stocks during model development such that the number of similar stocks included in any given model is minimized,

Table 2. 90% confidence interval widths, in percentages, for various combinations of baseline mixture sample sizes for a hypothetical three-stock classification based model, with stocks present in equal proportions, using mean classification accuracies of 60%, 70%, 80%, and 90%. (ie: in a model with a mean classification accuracy of 80%, a mixture sample size of 200, a baseline sample size of 150, and an estimated stock proportion of 33.3%, the confidence interval width of 22.6% represents a range around the point estimate from 29.3 to 36.7).

Baseline Sample Size	Mixture Sample Size								
	25	50	75	100	150	200	300	500	1000
	60% Mean Accuracy								
25	114.3%	89.3%	79.2%	73.6%	67.6%	64.3%	60.9%	58.1%	55.8%
50	107.9%	80.9%	69.5%	63.1%	56.0%	52.0%	47.8%	44.1%	41.1%
75	105.7%	77.9%	66.0%	59.2%	51.5%	47.2%	42.5%	38.3%	34.8%
100	104.5%	76.3%	64.2%	57.2%	49.2%	44.6%	39.6%	35.0%	31.2%
150	103.4%	74.8%	62.3%	55.1%	46.7%	41.9%	36.4%	31.4%	27.1%
200	102.9%	73.9%	61.4%	54.0%	45.4%	40.4%	34.8%	29.5%	24.8%
300	102.3%	73.1%	60.4%	52.9%	44.0%	38.9%	33.0%	27.4%	22.2%
	70% Mean Accuracy								
25	81.6%	62.9%	55.3%	51.1%	46.4%	44.0%	41.3%	39.0%	37.3%
50	77.7%	57.7%	49.3%	44.5%	39.1%	36.1%	32.8%	29.9%	27.6%
75	76.3%	55.9%	47.1%	42.1%	36.3%	33.1%	29.5%	26.2%	23.5%
100	75.6%	54.9%	46.0%	40.8%	34.9%	31.5%	27.7%	24.2%	21.2%
150	74.9%	54.0%	44.9%	39.5%	33.3%	29.8%	25.7%	21.9%	18.6%
200	74.6%	53.5%	44.3%	38.8%	32.5%	28.9%	24.7%	20.7%	17.1%
300	74.2%	53.0%	43.7%	38.2%	31.7%	27.9%	23.6%	19.4%	15.5%
	80% Mean Accuracy								
25	62.5%	47.3%	50.0%	37.4%	33.5%	31.4%	29.1%	27.1%	25.5%
50	60.2%	44.2%	37.4%	33.4%	29.0%	26.5%	23.7%	21.2%	19.2%
75	59.3%	43.1%	36.1%	32.0%	27.3%	24.6%	21.6%	18.9%	16.5%
100	59.0%	42.5%	35.4%	31.2%	26.4%	23.6%	20.5%	17.6%	15.0%
150	58.6%	42.0%	34.7%	30.5%	25.5%	22.6%	19.3%	16.2%	13.3%
200	58.4%	41.7%	34.4%	30.1%	25.0%	22.1%	18.7%	15.4%	12.4%
300	58.2%	41.4%	34.0%	29.7%	24.6%	21.6%	18.0%	14.6%	11.4%
	90% Mean Accuracy								
25	49.7%	36.6%	31.0%	27.8%	24.2%	22.2%	20.0%	18.0%	16.3%
50	48.7%	35.2%	29.3%	25.9%	21.9%	19.7%	17.1%	14.8%	12.7%
75	48.3%	34.7%	28.7%	25.2%	21.1%	18.8%	16.1%	13.5%	11.2%
100	48.1%	34.4%	28.4%	24.9%	20.7%	18.3%	15.5%	12.9%	10.4%
150	47.9%	34.2%	28.1%	24.5%	20.3%	17.8%	15.0%	12.2%	9.6%
200	47.8%	34.0%	27.9%	24.3%	20.1%	17.6%	14.7%	11.8%	9.1%
300	47.7%	33.9%	27.8%	24.1%	19.9%	17.3%	14.3%	11.4%	8.6%

Table 3. 90% confidence interval widths, in percentages, for various combinations of baseline mixture sample sizes for a hypothetical five-stock classification based model, with stocks present in equal proportions, using mean classification accuracies of 60%, 70%, 80%, and 90%. (ie: in a model with a mean classification accuracy of 80%, a mixture sample size of 200, a baseline sample size of 150, and an estimated stock proportion of 20%, the confidence interval width of 22.2% represents a range around the point estimate from 17.8 to 22.2).

Baseline Sample Size	Mixture Sample Size								
	25	50	75	100	150	200	300	500	1000
	60% Mean Accuracy								
25	95.7%	72.0%	62.1%	56.5%	50.2%	46.8%	43.1%	39.9%	37.3%
50	92.5%	67.7%	57.0%	50.9%	43.9%	39.9%	35.5%	31.6%	28.2%
75	91.5%	66.2%	55.3%	48.9%	41.5%	37.3%	32.6%	28.2%	24.4%
100	90.9%	65.4%	54.4%	47.9%	40.3%	36.0%	31.0%	26.4%	22.3%
150	90.4%	64.7%	53.4%	46.8%	39.1%	34.6%	29.4%	24.4%	19.9%
200	90.0%	64.3%	52.9%	46.3%	38.4%	33.8%	28.5%	23.4%	18.7%
300	89.8%	63.9%	52.5%	45.7%	37.8%	33.1%	27.6%	22.3%	17.2%
	70% Mean Accuracy								
25	75.6%	56.3%	48.2%	43.5%	38.3%	35.5%	32.3%	29.6%	27.4%
50	73.5%	53.5%	44.8%	39.8%	34.1%	30.8%	27.1%	23.8%	20.9%
75	72.8%	52.5%	43.6%	38.5%	32.5%	29.1%	25.1%	21.5%	18.3%
100	72.4%	52.0%	43.1%	37.8%	31.7%	28.2%	24.1%	20.3%	16.8%
150	72.1%	51.5%	42.5%	37.1%	30.9%	27.2%	23.0%	18.9%	15.2%
200	71.9%	51.2%	42.2%	36.8%	30.5%	26.7%	22.4%	18.2%	14.3%
300	71.8%	51.0%	41.8%	36.4%	30.0%	26.3%	21.8%	17.5%	13.4%
	80% Mean Accuracy								
25	62.1%	45.6%	38.6%	34.5%	29.9%	27.4%	24.6%	22.1%	19.9%
50	60.8%	43.9%	36.5%	32.3%	27.3%	24.4%	21.2%	18.2%	15.6%
75	60.4%	43.2%	35.8%	31.4%	26.3%	23.4%	20.0%	16.7%	13.8%
100	60.2%	43.0%	35.5%	31.0%	25.8%	22.8%	19.3%	15.9%	12.9%
150	59.9%	42.7%	35.1%	30.6%	25.3%	22.2%	18.6%	15.1%	11.8%
200	59.8%	42.5%	34.9%	30.4%	25.1%	21.9%	18.3%	14.7%	11.3%
300	59.7%	42.4%	34.7%	30.2%	24.8%	21.6%	17.9%	14.2%	10.7%
	90% Mean Accuracy								
25	52.2%	37.7%	31.4%	27.8%	23.6%	21.1%	18.4%	15.7%	13.7%
50	51.6%	36.9%	30.5%	26.7%	22.2%	19.6%	16.6%	13.8%	11.2%
75	51.4%	36.6%	30.1%	26.3%	21.8%	19.1%	16.0%	13.1%	10.3%
100	51.3%	36.5%	30.0%	26.1%	21.5%	18.9%	15.7%	12.7%	9.8%
150	51.2%	36.4%	36.3%	25.9%	21.3%	18.6%	15.4%	12.3%	9.2%
200	51.1%	36.3%	29.7%	25.7%	21.2%	18.5%	15.2%	12.1%	8.9%
300	51.0%	36.2%	29.6%	25.6%	21.1%	18.3%	15.0%	11.8%	8.7%

and 3) additional variables can be found to better separate similar stocks. Our approach to this problem is outlined in more detail in the section on "Application of Stock Specific Timing Data".

What level of precision is required for stock composition estimates for Fraser River sockeye salmon? Precision levels of ± 10% are desirable (J. Woodey, PSC, pers. comm.) for most management purposes. For a five stock-group analysis, and using realistic baseline sample sizes of 150 fish per stock, this level of precision would theoretically require mixture sample sizes of approximately 1000+ per age class for a 60% accurate model, 300-500 for a 70% accurate model, 200-300 for an 80% accurate model, and 150-200 for a 90% accurate model. This assumes that stocks occur in proportion to their abundance and that sampling is random. Presently, mixture sample sizes collected by the Pacific Salmon Commission are 240 per fishery, which results in 150-200 fish with readable scales for the dominant 4_2 age class. The five stock-group discrimination models we now build would typically have classification accuracies of between 60%-80%. Working within these guidelines, we expect 90% confidence limits about our point estimates to be approximately ± 18%-20% for a 60% accurate model, to ± 11%-13% for an 80% accurate model. Further increases in precision will require either improvements to classification accuracy or taking larger mixture sample sizes. Both of these aspects are being investigated.

SCALE-PATTERN ANALYSIS: APPLICATIONS

In this section we review historical run timing data for Fraser River sockeye salmon from the following data sources: tagging studies, spawning ground arrival-timing studies, and commercial scale data. We then describe how these data are used to construct migrational timing curves for individual stocks. Next, we outline the methodologies used by the Pacific Salmon Commission in conducting in-season and post-season racial analyses. Finally, we describe how we use additional data, such as age composition and fish length, in our stock identification programs.

These supplemental data sources are important because they improve the resolution of the analysis. Some Fraser River sockeye stocks share similar scale characteristics and consequently are not identifiable as discrete stocks in discriminant function models. By incorporating information on age composition and fish length in our stock identification assessments, we increase the number of resolvable stock groups. In addition, by incorporating run timing into our analyses, we can reduce the number of stock groups under active consideration in each sample being analyzed, thereby increasing model classification accuracies.

REVIEW OF RUN TIMING AND SPEED OF TRAVEL

Henry (1961), in his developmental work on applications of scale-pattern analysis to salmon management, discussed the importance of run timing as information ancillary to data derived from freshwater scale parameters. Both the timing of individual stocks migrating through commercial waters, and the speed of migration of stocks between areas, were recognized as important information by the International Pacific Salmon Fisheries Commission. Data sources for stock-specific timing include: marine tagging studies, spawning ground arrival curves, weir counts and stock-specific peak catch data from the Pacific Salmon Commission's historical database. Migration speeds have been estimated from tagging studies and by tracking daily abundances between adjacent areas using commercial and test catch data.

Tagging Data

Marine tagging studies were conducted by the International Pacific Salmon Fisheries Commission between 1938 and 1948. Verhoeven and Davidoff (1962) presented a detailed examination of the results of the tagging operations. In Table 4 we present the average travel time, as summarized by Verhoeven and Davidoff (1962), for sockeye stocks to pass through adjacent fishing areas on their homeward spawning migration. For management purposes Fraser River sockeye stocks are grouped into early-summer, mid-summer and late-run components, based upon historical run-timing data (Table 5).

The speed of migration calculated from tagging studies was influenced by tagging-induced stress which causes tagged fish to migrate more slowly than untagged fish. In addition, summer-run stocks in some years exhibit short term delay behaviour off the mouth of the Fraser River, lasting from 1 to 7 days or more (IPSFC, unpublished data). The average passage times presented in Table 4 include both types of delay behaviour.

Taking into account the tagging-induced delay behaviour, and corroborating the adjusted speed of migration estimates with migration data derived from scale based assumptions (described later), reliable estimates of migration timing between areas can be made. Summer-run stocks migrate more quickly through migratory areas outside of Georgia Strait than do late run stocks. A typical summer-run migration pattern is approximately 3 days from Area 20 to Area 7, 1 day from Area 7 to Area 7A, and from 2-3 days from Area 7A to Area 29D (Figure 3).

Late-run stocks delay for substantial periods of time in the Strait of Georgia before initiating their upstream spawning migration. This delay can last from 2 to 6 weeks for individual fish (Gilhousen 1960).

The agents which cause variations in the annual migration timing of sockeye stocks act during the period of ocean residency. Gilhousen (1960) discussed two types of timing differences: 1) the apparent effect of population size on the time of marine migration, with large runs of individual stocks having slightly later-than-average timing of on-shore arrival, and 2) larger deviations in timing that affect most co-migrating stocks, which are likely the result of variable oceanic conditions. For example, Blackbourn (1987) has shown that sea surface temperatures in the central Gulf of Alaska are positively correlated with differences in the annual return timing for a number of Fraser River sockeye stocks; Thomson et al. (1992) have shown that Fraser River sockeye return timing is influenced by annual changes in offshore ocean currents. Ocean currents and temperature may be two among many oceanographic factors that affect sockeye return timing.

Spawning Ground Arrival Data

The chronological order of Fraser River sockeye salmon stocks is maintained during their migration through marine areas and up the Fraser River to their spawning sites (Killick 1955). This allows migration speeds to be estimated, using the peaks and valleys in local abundances caused by fishery openings and closures, to track the passage of co-migrating groups of fish. This procedure breaks down for late-run stocks which delay in the Strait of Georgia. It is not always possible to relate dates of peak occurrence in the terminal areas to dates in outside areas due to uncertainty over the length of delay and the potential breakdown in the chronological order of early-, mid- and late-timed components of delaying stocks.

Table 4. Average passage times (days) for early-summer and mid-summer stocks of Fraser River sockeye salmon through adjacent fishery areas. Data are from Verhoeven and Davidoff (1962) who report that the data are a summary of the most likely migration times of marine-tagged sockeye in terms of days out to certain recovery areas in the commercial fisheries.

	Tagging Area				
Recovery Area	**Sooke**	**Salmon Banks**	**Lummi Island**	**Sand-Heads**	**Johnstone Straits**
Salmon Banks (Area 7)	2				
Point Roberts (Area 7A)	3-4	2-3	2		
Mouth of Fraser (Area 29)	4-5	3-7	3-6	2-3	8
North Arm & New Westminster (Area 29B)	4-7	6-10	3-6	2-7	9
Above Bridge (Area 29D)	4-11	7 +	6-13	3-7	12

Table 5. Management based timing classification of Fraser River sockeye stocks.

Fraser River Sockeye Salmon Stocks	
Run	**Stock**
Early Stuart	Early Stuart
Early Summer	Bowron River
	Fennell Creek
	Raft River
	Pitt River
	Gates Creek
	Nadina River
	Scotch Creek
	Seymour River
	Chilko Lake
	Miscellaneous Stocks
Mid Summer	Horsefly River
	Late Stuart
	Chilko River
	Stellako River
	Birkenhead River
	Miscellaneous Stocks
Late	Adams River
	Lower Shuswap River
	Weaver Creek
	Portage Creek
	Harrison River
	Cultus Lake
	Miscellaneous Stocks

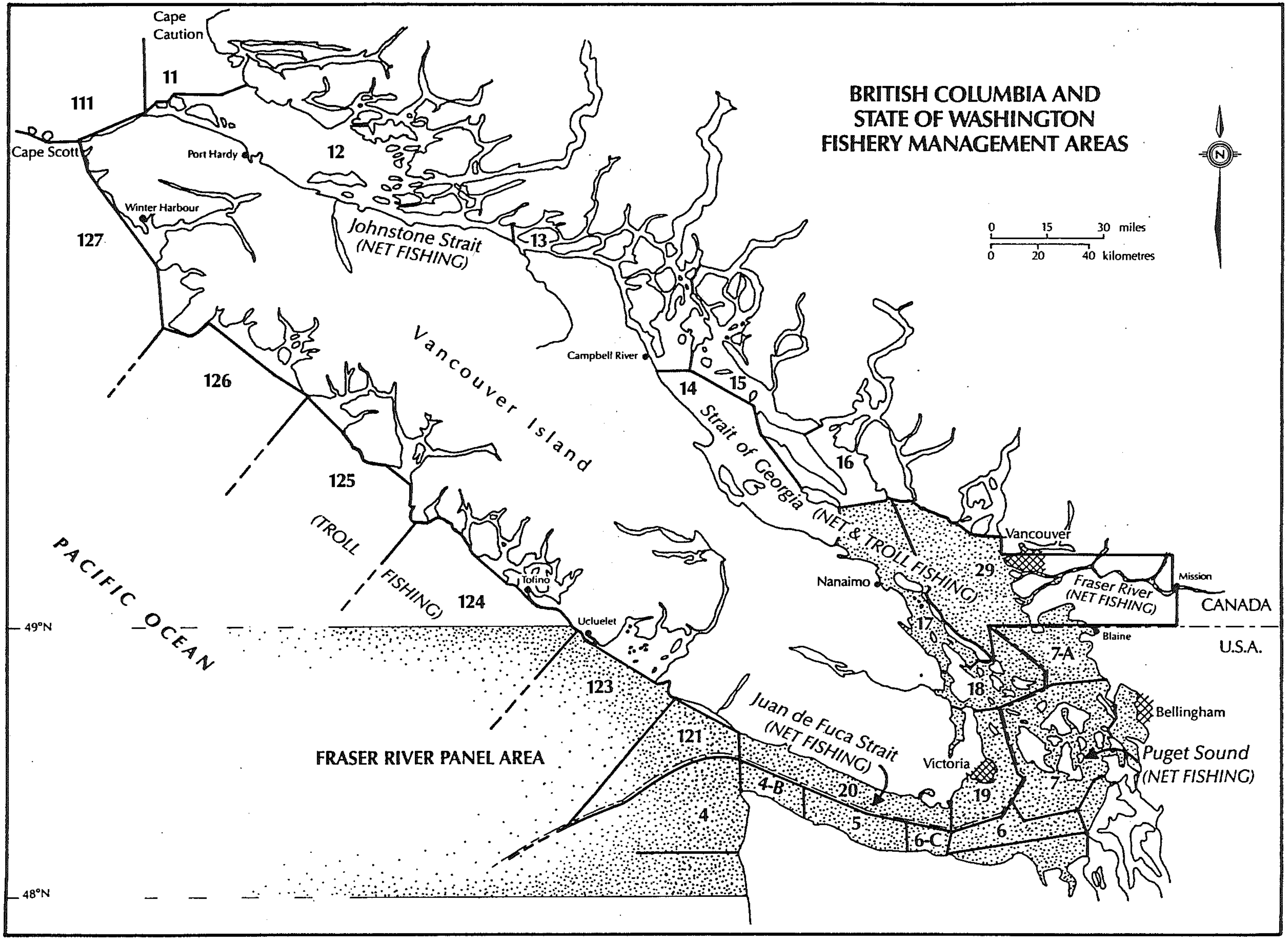


Figure 3. Southern British Columbia and northern Washington State fishery management areas through which Fraser River sockeye salmon migrate.

Killick (1955), used tagging data and ancillary spawning ground arrival information including visual counts, weirs, and Indian food fishery catch data, to document the estimated dates of passage at New Westminster for five stocks, and the dates of passage at Hells Gate for six stocks. Verhoeven and Davidoff (1962) documented migration timing for nine Fraser River stocks using data derived from tagging within the Fraser River drainage at Harrison Bay, Hell's Gate, and Bridge River Rapids. The recovery of tagged fish from Indian fishing sites, and from spawning ground recoveries, provided valuable data on estimated times of passage for the individual stocks. Spawning ground arrival timing and daily catch data from the Indian food fishery continue to be useful information sources for estimating timing-by-stock for post-season stock identification analyses.

Scale Data

For many years, stock-specific timing has been determined directly from scale analysis. For this to be possible, one of two conditions must be met: 1) the return strength of an individual run must be large relative to other co-migrating stocks so that a characteristic scale pattern is readily identifiable, or 2) the scale pattern of the stock must be unique relative to the scale patterns of other co-migrating stocks (Henry 1961). Using scale samples from daily commercial catches, Henry (1961) applied scale-pattern analysis to derive dates of peak racial abundances, and periods of presence for individual stocks, near the San Juan Islands in United States waters. The timing data show consistent trends, with individual stocks migrating sequentially from outside migratory areas (Sooke) to the lower Fraser River (New Westminster) and upstream towards their natal spawning areas.

The historical database of the Pacific Salmon Commission contains stock- and area-specific timing records which span approximately 40 years. For minor stocks there may be substantial errors associated with estimates of peak timing by area. However, for dominant stocks, and for stocks exhibiting unique scale pattern traits in specific years, accurate estimates of peak timing in individual commercial fishing areas can be determined.

Since stock-specific migrational timing curves approximate a normal distribution, Henry (1961) recommended using normal curves to adjust daily catches, and to fill in gaps in daily catch data. This technique provides estimates of stock-specific peak abundances in an area and reduces the potential bias caused by using daily catch estimates to calculate peak dates of passage in commercial fishing areas. Potential biases include: changes in stock availability over time, changes in weekly fishing intensity, gear selectivity bias when data from one gear type are applied to other gear types, and the possibility that the peak abundance of a stock in an area will occur when the commercial fishery is closed. In recent years this latter concern is more significant because the annual number of days fishing have been reduced in response to increasing fleet efficiencies and changing escapement goals.

To update the historical run-timing data for individual Fraser River sockeye salmon stocks, we conducted a computer search of the Pacific Salmon Commission's racial database. For individual stocks of interest, the dates of the three largest catches were identified for all available areas and years. We restricted the search to the 4_2 age class, since age 4_2 production generally accounts for 70-95% of the annual Fraser River sockeye production.

To estimate the date of the peak numerical abundance of a stock, the weighted average of the dates of the three largest catches for each stock-area combination was calculated:

$$\text{Estimated Peak Date} = (3D_1 + 2D_2 + D_3) / 6$$

where D_1 = the date of the largest catch
D_2 = the date of the second largest catch
D_3 = the date of the third largest catch

While more sophisticated weighting procedures can be developed, such as weighting by CPUE data or actual catches, this method has the advantage of using weighting factors that are unaffected by changes in stock availability and/or fishing intensity. An example of the procedure used is outlined below:

Weighted Average Peak Date For Stock "S" in Area "A" = 25/6 = August 4

Date	Fishery In Area "A"	Catch of Stock "S"	Ranking	Weighted Date
August 1	Yes	50,000		
August 2	Yes	85,000	D_1	6
August 3	No			
August 4	No			
August 5	No			
August 6	Yes	70,000	D_2	12
August 7	Yes	60,000	D_3	7
August 8	Yes	30,000		
				25

To limit potential errors in identifying stock-specific peak dates through the use of the method outlined above, Pacific Salmon Commission records were searched to identify periods of extended fishery closures, either due to management actions or strikes. Where data gaps occurred during periods when specific stocks were expected to be near their peak of migration no estimate of peak migration date for that area was made. The most complete data records were from Area 7 (Salmon Banks) and from Area 29B (lower Fraser River). Area 20 had many data gaps for both early-summer and summer-run stocks. To obtain stock-specific Area 20 timing estimates in years where Area 20 data gaps occurred, Area 7 peak dates were used with a three-day time lag. Wherever possible, we calculated peak migration dates for individual stocks directly from the area of interest. Future Pacific Salmon Commission work plans will incorporate run reconstruction modelling techniques to evaluate historical catch distributions and peak timing dates for dominant stocks. This will provide a more rigorous evaluation of historical timing trends in Fraser River sockeye stocks.

Stock-specific racial data were not available from Johnstone Strait prior to 1962. Consequently, the calculation of peak timing was limited to the years from 1963 to present. Since there were fewer years of data available for Johnstone Strait fisheries, the peak timing data are less complete than for Areas 20, 7 and 29B. In addition, because catch data from Johnstone Strait are available only in week-ending format, the peak timing was calculated by week-ending period.

Many Fraser River sockeye salmon stocks exhibit a four year cycle with one year of large abundance (dominant cycle year), one year with a smaller abundance (sub-dominant year) and two years with low production (off-cycle years). Since there is evidence that run size influences run timing (Gilhousen 1960), the historical racial data were analyzed in four separate cycle years (Table 6). This table presents the mean peak timing date by area and its associated standard error in days, along with the duration of passage for each stock. The duration of passage information was derived from historical data presented by Verhoeven and Davidoff (1962) and Henry (1961).

In addition, in Table 7 we summarize the overall mean timing date by stock as calculated from the Pacific Salmon Commission's historical data base in Areas 20 and 29. Blackbourn (1987) suggests that sea surface temperature, and perhaps other environmental variables, are involved in observed inter-annual differences in run timing. For this reason the pooled-year timing data from Table 7 may be more representative than the cycle-year timing data presented in Table 6. Also presented in Table 7, for comparative purposes, are the mean timing dates calculated by Verhoeven and Davidoff (1962), Henry (1961), and Blackbourn (1987). Generally, the stock-specific, cycle-year peak timing dates presented in Table 7 are similar to the dates reported by the authors mentioned above.

Possible biases exist when using tagging data to estimate migratory durations of specific stocks through fishing areas. The effect of tagging on individual fish, and problems associated with estimating run timing and duration from tagging studies are discussed by Verhoeven and Davidoff (1962). However, despite possible shortcomings in the historical tagging and racial data, they provide the best estimate currently available of the duration of stock-specific migration through a migratory area. Revised estimates of the duration and shape of stock-specific migrational timing curves will be produced in the future through detailed assessments of the historical database using run reconstruction methodologies.

The database allows the speed of migration to be calculated for stocks migrating between Area 20 and Area 29. This information is summarized in Table 8. Differences between median dates of the observed peak dates by cycle year were used to estimate the average speed of migration by stock. Stocks for which data are available for a minimum of three of the four cycle years, show consistent trends in their speed of travel: early-timed stocks migrate more quickly than later-timed stocks, even within the summer-run grouping. For example, early-timed stocks (Early Stuart, Bowron, Nadina and Seymour) migrate between Area 20 and Area 29 in 5-6 days, compared to summer-run stocks (Chilko and Stellako) which travel the same distance in 6-8 days. The Birkenhead stock delays in some years, taking an average of 10 days to migrate from Area 20 to Area 29. Late-run stocks (Adams, Weaver and Cultus) delay for extended periods in the Strait of Georgia: they average 30-38 days to migrate from Area 20 to the lower Fraser River.

USE OF STOCK-SPECIFIC TIMING DATA

In-Season Racial Analysis

The International Pacific Salmon Fisheries Commission, and more recently the Pacific Salmon Commission, have employed an intensive in-season management regime to achieve the domestic and international catch allocation goals and escapement objectives for Fraser River sockeye stocks. Fishery managers rely on the rapid acquisition and analysis of data from commercial fisheries, test fisheries, and escapement estimates to make informed decisions on appropriate weekly balances between catch and escapement of Fraser River sockeye stocks (Woodey 1987).

As part of the stock identification program, weekly scale samples and other biological data such as fish length and weight are obtained from commercial fishery catches by each major gear

Table 6. Peak estimated times of passage for Fraser River sockeye salmon based upon scale pattern analysis for individual cycle years. The mean peak dates (+/- S.E.) for the cycle are reported. Also reported for each stock is the average duration of the run in days, obtained from Verhoeven and Davidoff (1962) and Henry (1961).

Stock	Mean Date of Passage (Peak, S.E.)					Duration of run
	Area 12	Area 20	Area 7	Area 7A	Area 29B	
1984 Cycle						
	(n=3)	(n=7)	(n=7)	(n=7)	(n=7)	(days)
Early Stuart	Jul-10 (n/a)	Jul-1 (1.1)	Jul-2 (n/a)	Jul-4 (n/a)	Jul-7 (0.7)	32.0
Bowron	Jul-21 (n/a)	Jul-21 (1.2)	Jul-24 (1.1)	Jul-24 (1.3)	Jul-27 (1.0)	29.0
Nadina	Jul-23 (1.7)	Jul-20 (0.8)	Jul-23 (0.8)	Jul-24 (1.2)	Jul-26 (2.0)	34.0
Pitt	Jul-26 (1.2)	Jul-23 (0.9)	Jul-27 (1.2)	Jul-27 (1.0)	(n/a) (n/a)	26.0
Chilko	Aug-7 (3.3)	Aug-2 (1.4)	Aug-5 (1.3)	Aug-6 (0.8)	Aug-8 (2.0)	40.0
Stellako	Aug-4 (2.7)	Aug-1 (0.9)	Aug-4 (0.9)	Aug-5 (0.5)	Aug-9 (1.1)	41.0
Birkenhead	Aug-10 (2.1)	Aug-7 (1.3)	Aug-8 (1.5)	Aug-9 (1.7)	Aug-17 (0.5)	41.0
Weaver	Aug-12 (1.7)	Aug-8 (1.0)	Aug-10 (1.5)	Aug-11 (1.1)	Sep-29 (7.1)	46.0
Cultus	Aug-19 (n/a)	Aug-15 (3.0)	Aug-18 (2.9)	Aug-20 (3.4)	Sep-18 (4.0)	46.0
1985 Cycle						
	(n=4)	(n=8)	(n=8)	(n=8)	(n=8)	(days)
Early Stuart	Jul-5 (1.7)	Jul-3 (1.3)	Jul-7 (0.7)	Jul-8 (2.2)	Jul-8 (1.5)	32.0
Nadina	Jul-24 (2.7)	Jul-18 (2.0)	Jul-22 (1.6)	Jul-23 (1.3)	Jul-24 (2.8)	34.0
Horsefly	Aug-5 (4.2)	Jul-25 (2.1)	Jul-30 (2.7)	Aug-1 (2.9)	Aug-4 (3.3)	32.0
Chilko	Aug-2 (2.2)	Jul-27 (1.5)	Jul-30 (1.9)	Jul-31 (1.8)	Aug-4 (2.4)	40.0
Late Stuart	Aug-4 (1.9)	Jul-26 (1.1)	Jul-30 (1.4)	Aug-1 (1.8)	Aug-5 (1.4)	34.0
Stellako	Aug-9 (3.4)	Aug-1 (1.9)	Aug-3 (2.0)	Aug-4 (1.4)	Aug-6 (1.7)	41.0
Birkenhead	Aug-13 (2.1)	Aug-12 (2.7)	Aug-12 (2.1)	Aug-14 (1.9)	Aug-19 (2.1)	41.0
Weaver	Aug-17 (2.4)	Aug-15 (2.0)	Aug-15 (2.4)	Aug-17 (1.7)	Sep-26 (3.4)	46.0
1986 Cycle						
		(n=6)	(n=6)	(n=6)	(n=6)	(days)
Early Stuart	(n/a) (n/a)	Jul-4 (1.1)	(n/a) (n/a)	(n/a) (n/a)	Jul-10 (1.1)	32.0
Bowron	(n/a) (n/a)	Jul-21 (3.3)	Jul-25 (1.8)	Jul-26 (1.8)	Jul-27 (3.3)	29.0
Nadina	(n/a) (n/a)	Jul-26 (2.5)	Jul-26 (1.4)	Jul-29 (1.4)	Jul-30 (1.7)	34.0
Pitt	(n/a) (n/a)	Jul-23 (2.1)	Jul-26 (1.3)	Jul-28 (1.6)	Jul-29 (2.3)	26.0
Seymour	(n/a) (n/a)	Jul-29 (1.4)	Jul-30 (0.9)	Aug-1 (1.2)	Aug-4 (1.4)	28.0
Chilko	(n/a) (n/a)	Jul-30 (1.2)	Jul-31 (1.1)	Aug-3 (0.9)	Aug-5 (1.2)	40.0
Late Stuart	(n/a) (n/a)	Jul-31 (n/a)	Aug-3 (n/a)	Aug-3 (n/a)	Aug-13 (n/a)	34.0
Stellako	(n/a) (n/a)	Aug-4 (2.0)	Aug-7 (1.9)	Aug-7 (2.2)	Aug-12 (2.6)	41.0
Birkenhead	(n/a) (n/a)	Aug-9 (2.1)	Aug-12 (3.3)	Aug-11 (4.6)	Aug-20 (3.5)	41.0
Weaver	(n/a) (n/a)	Aug-19 (2.9)	Aug-19 (3.3)	Aug-24 (3.2)	Sep-10 (4.5)	46.0
Adams	(n/a) (n/a)	Aug-19 (3.5)	Aug-24 (1.7)	Aug-26 (2.5)	Sep-18 (4.5)	50.0
Cultus	(n/a) (n/a)	Aug-18 (2.8)	Aug-24 (1.0)	Aug-27 (1.6)	Sep-18 (4.6)	46.0
1987 Cycle						
	(n=3)	(n=7)	(n=7)	(n=7)	(n=7)	(days)
Early Stuart	Jul-11 (2.4)	Jul-7 (1.8)	Jul-8 (2.4)	Jul-10 (2.0)	Jul-8 (1.9)	32.0
Bowron	Jul-21 (0.4)	Jul-21 (1.4)	Jul-23 (1.8)	Jul-24 (2.0)	Jul-28 (0.8)	29.0
Nadina	Jul-24 (1.3)	Jul-21 (0.8)	Jul-24 (1.0)	Jul-26 (0.8)	Jul-28 (0.8)	34.0
Pitt	Jul-21 (n/a)	Jul-23 (2.6)	Jul-26 (2.8)	Jul-27 (2.3)	Aug-1 (2.5)	26.0
Seymour	Jul-28 (3.0)	Jul-28 (1.3)	Aug-1 (1.2)	Aug-2 (1.7)	Aug-3 (1.4)	28.0
Chilko	Aug-3 (3.2)	Jul-30 (1.8)	Jul-31 (1.7)	Aug-2 (1.6)	Aug-4 (1.7)	40.0
Stellako	Aug-2 (3.1)	Jul-31 (2.1)	Aug-1 (1.5)	Aug-4 (1.5)	Aug-9 (1.5)	41.0
Birkenhead	Aug-12 (3.9)	Aug-10 (1.9)	Aug-12 (1.8)	Aug-13 (1.9)	Aug-20 (2.3)	41.0
Weaver	Aug-24 (2.8)	Aug-15 (2.2)	Aug-19 (2.9)	Aug-20 (2.0)	Sep-11 (3.4)	46.0
Adams	Aug-20 (2.3)	Aug-13 (1.9)	Aug-17 (2.5)	Aug-19 (2.6)	Sep-16 (3.4)	50.0
Cultus	Aug-24 (3.5)	Aug-16 (2.0)	Aug-19 (3.9)	Aug-22 (4.0)	Sep-22 (6.8)	46.0

Table 7. Estimated peak times of passage for major Fraser River sockeye stocks through Areas 20 and 29, as calculated by Verhoeven and Davidoff (1962), Henry (1961), Blackbourn (1987) and the PSC's historical data base. The estimated run timing of late run stocks in the lower Fraser River is unreliable in some years (*) due to possible errors in calculating their arrival timing resulting from unpredictable delays in Georgia Strait. This is particularly true when fishery openings were not scheduled at regular intervals during the period of late run upstream migration.

	Estimated Peak Migration Dates					
Stock	Verhoeven & Davidoff	Henry	Blackbourn	PSC	n (yrs)	S.E. (days)
	Area 20					
Early Stuart	Jul-10	Jul-4	Jul-3	Jul-4	17	0.81
Bowron	Jul-18	Jul-18		Jul-21	16	1.22
Nadina	n/a	n/a		Jul-20	18	1.04
Pitt	Jul-28	Jul-20	Jul-23	Jul-23	17	1.07
Seymour	Aug-3	Aug-1		Jul-28	11	0.95
Horsefly	Jul-24	Jul-26	Jul-28	Jul-25	8	2.10
Chilko	Aug-2	Jul-31	Jul-31	Jul-30	27	0.91
Late Stuart	Aug-1	Aug-1		Jul-27	10	1.12
Stellako	Aug-4	Aug-2	Aug-3	Aug-1	25	0.93
Birkenhead	Aug-21	Aug-8		Aug-9	27	1.14
Weaver	Aug-22	Aug-14	Aug-15	Aug-14	24	1.26
Adams	Aug-27	Aug-20	Aug-23 (Dominant) Aug-14 (Sub-Dom.)	Aug-18	12	2.07
Cultus	N/A	N/A		Aug-16	16	1.58
	Area 29					
Early Stuart	Jul-16	Jul-10		Jul-9	17	0.77
Bowron	Jul-24	Jul-24		Jul-27	16	1.14
Nadina	n/a	n/a		Jul-26	18	1.19
Pitt	Aug-3	Jul-26		Jul-30	10	1.73
Seymour	Aug-10	Aug-8		Aug-3	11	1.04
Horsefly	Jul-31	Aug-2		Aug-4	8	3.31
Chilko	Aug-9	Aug-7		Aug-5	27	1.06
Late Stuart	Aug-8	Aug-8		Aug-6	10	1.51
Stellako	Aug-11	Aug-9		Aug-9	26	0.94
Birkenhead	Aug-28	Aug-15		Aug-19	27	1.11
Weaver	n/a	n/a		Sep-21*	21	2.87
Adams	n/a	n/a		Sep-17*	10	2.88
Cultus	n/a	n/a		Sep-19*	13	3.05

Table 8. Speed of migration for major Fraser River sockeye salmon stocks from Area 20 to Area 29, as calculated from the PSC's historical data base.

	Migration Time from Area 20 to Area 29	
Stock	**Range (Days)**	**Mean (Days)**
Early Stuart	1 - 6	4.5
Bowron	6 - 7	6.3
Nadina	4 - 7	5.8
Seymour	6	6.0
Chilko	5 - 8	6.3
Stellako	5 - 9	7.5
Birkenhead	7 - 11	9.5
Weaver	22 - 52	35.8
Adams	28 - 31	29.5
Cultus	31 - 37	34.0

type that potentially intercepts Fraser River sockeye salmon. In addition, multiple samples are taken each week from Pacific Salmon Commission-sponsored test fisheries to monitor changes in stock composition in key areas. For example, daily assessments of stock composition in test fisheries conducted in the Fraser River are applied to daily gross escapement estimates, to provide managers with daily estimates of escapement by stock grouping.

The procedure used by the Pacific Salmon Commission to conduct in-season racial analyses of commercial and test fishery scale samples is outlined in Figure 4. Within-year standards are unavailable during the summer management period. Therefore, stock-specific baseline standards for use in in-season discriminant function models are developed from two sources:

1) scales from prior year spawning ground returns of 3_2's are used as standards in the age 4_2 models, and age 4_2 adults from the prior year are used as standards for the age 5_2 models.

2) data for the same age class in previous years are used as baseline standards if prior-year data are lacking.

Once the baseline standards are constructed, centroid relationships among the major stocks are plotted using the best discriminating variables. Stocks with similar scale patterns tend to cluster together, while stocks with dissimilar scale growth remain distinct (Figure 4, Step 1). An example of the in-season centroid plots calculated for 1988 is presented in Figure 5. Stocks that have highly overlapped centroid relationships are termed "problem clusters".

Because the number of stocks that can be individually resolved with discriminant analysis techniques depends on the number of statistically distinct "groups" being used, problem stocks within clusters must either be omitted a priori from the analysis, or pooled into stock groups and treated as one. We use a combination of a priori stock selection, grouping of stocks, and forecast abundances to guide the choice of which individual stocks to include in our discrimination models.

The historical timing curves are used to guide decisions on whether stocks with similar scale characters can be kept separate based on timing differences (Figure 4, Step 2). The timing curve for each stock is weighted using pre-season forecasts of production provided by the Canadian Department of Fisheries and Oceans (Figure 4, Step 3). Historical patterns of abundance may also be considered. The result is a migrational timing curve for each stock (Figure 4, Step 4). The final decision on the stock groups to be used for in-season management is then made and in-season discriminant function models are constructed (Figure 4, Step 5). In addition, when the data are available during the in-season management period, migrational timing curves are updated using revised estimates of run size and timing.

Historical stock group timing data is a valuable guide during in-season scale-pattern analysis. For example, if the migrational timing curve for a particular stock group indicates it should be present in excess of 5% of the total sockeye abundance in a given area on a given date, then that stock group is included in the discriminant function analysis model. The model is run and the stock group is allocated a proportion for the sample in question (Figure 4, Step 6). If the migrational timing curve indicates the stock group should contribute 5% or less in the sample under consideration, then the stock group is removed from the model. While the 5% threshold acts as a general guide, it is not followed rigidly (especially when performing in-season analyses) because the migrational timing curves cannot take into account unusual run-timing occurrences

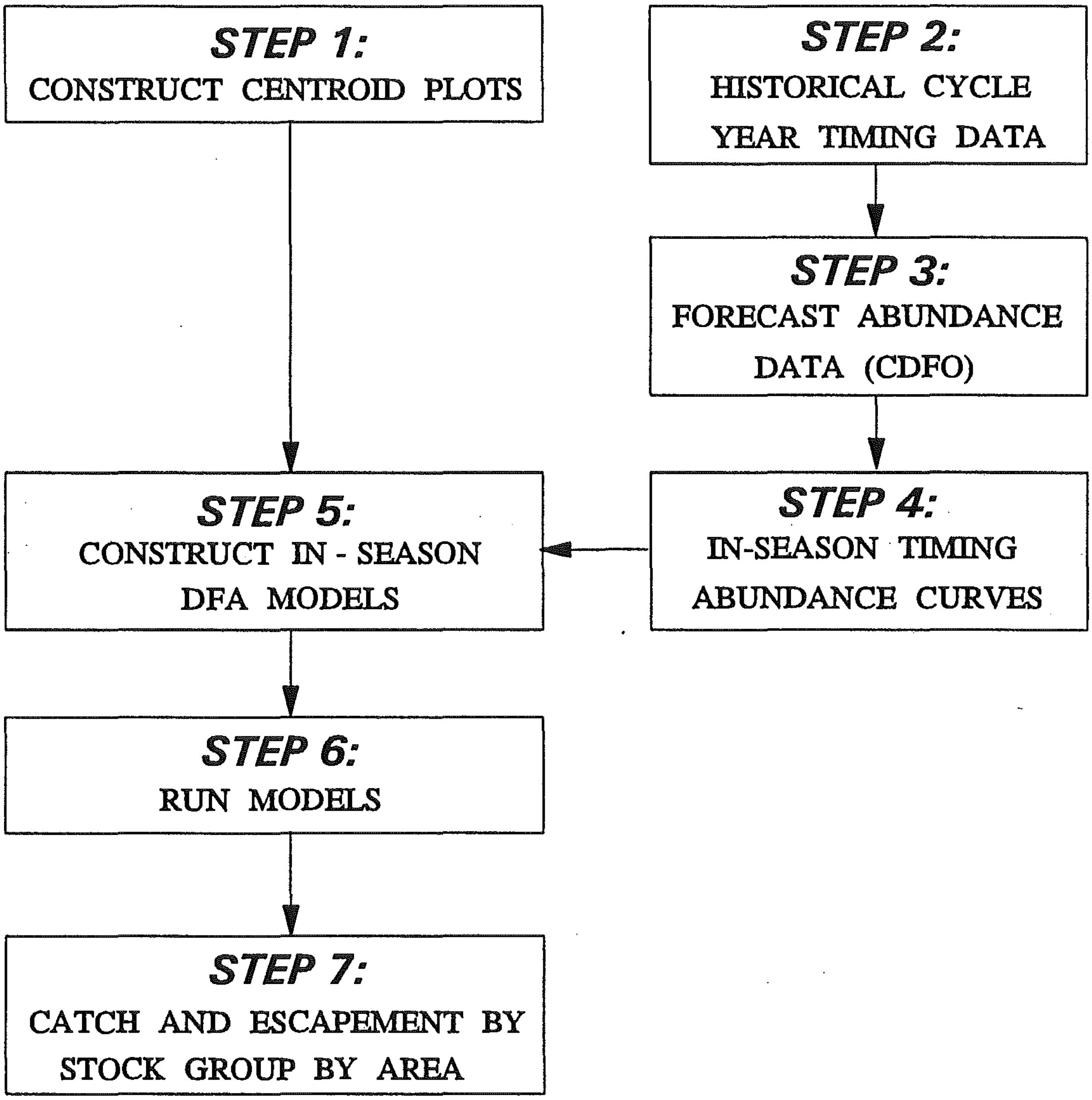
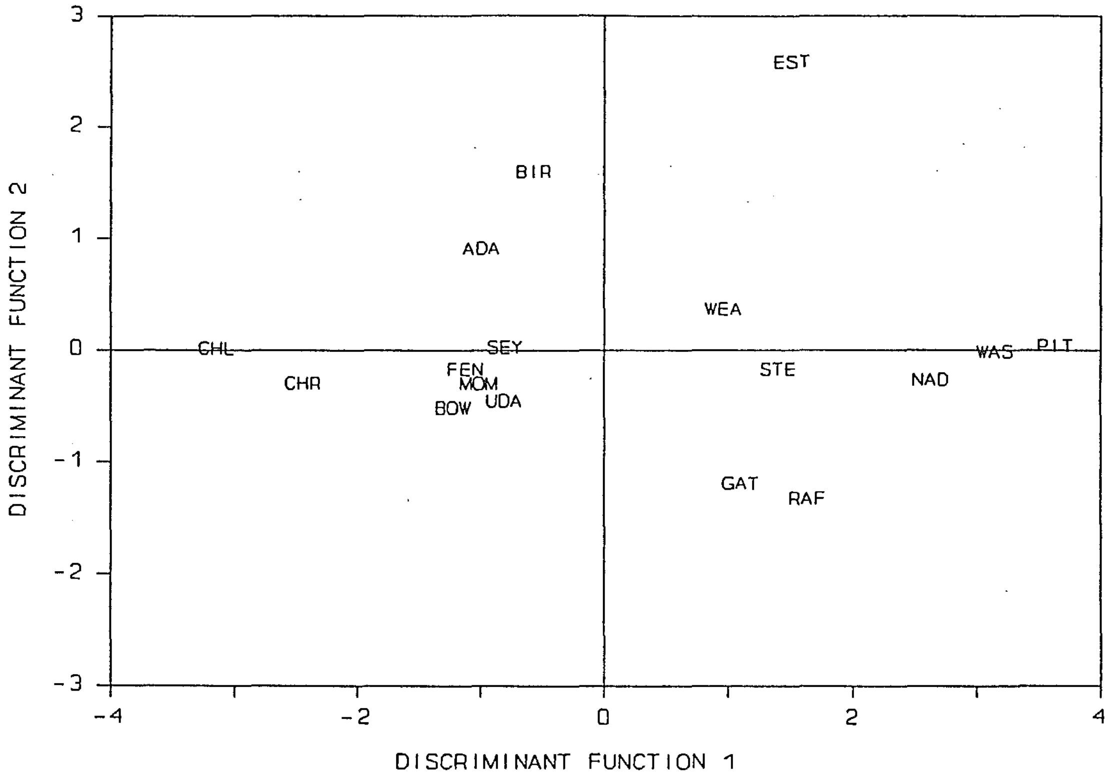


Figure 4. In-season application of discriminant function analysis models for racial analysis of Fraser River sockeye salmon by stock group, area, and gear.



FUNCTION 1 = 0.32(COUNT) - 0.01(PLUS) + 0.74(DISTANCE)

FUNCTION 2 = 0.23(COUNT) + 1.08(PLUS) + 0.18(DISTANCE)

STOCK KEY

ADA = LOWER ADAMS RIVER
BIR = BIRKENHEAD RIVER
BOW = BOWRON RIVER
CHL = CHILKO LAKE
CHR = CHILKO RIVER
EST = STUART LAKE SYSTEM
FEN = FENNELL CREEK
GAT = GATES CREEK
MOM = MOMICH RIVER

NAD = NADINA RIVER
PIT = PITT RIVER
RAF = RAFT RIVER
SEY = SEYMOUR RIVER
STE = STELLAKO RIVER
UDA = UPPER ADAMS RIVER
WAS = LAKE WASHINGTON
WEA = WEAVER CREEK

Figure 5. Spatial distribution of mean discriminant scores for age 4_2 Fraser River and Lake Washington sockeye salmon used for in-season baseline standards in 1988. The three variables used to discriminate between the stocks were 1) circuli count to the first freshwater annulus (count), 2) circuli count in the plus-growth zone (plus), and 3) distance to the first freshwater annulus (distance).

or run sizes greatly different than pre-season forecasts. To avoid making a decision to incorrectly exclude a stock group from a model run, each sample is analyzed with and without the stock group in question and results are compared with previous days' analyses. This approach limits the number of stock groups being analyzed by the model, and generally increases the classification accuracy.

Each week through the management season, discriminant function analyses are conducted on commercial and test fishery samples from a broad range of areas. These analyses, along with production data, enable Pacific Salmon Commission staff to assess the in-season run timing and return strength of the major Fraser River sockeye salmon stocks. Escapement goals for each stock group are monitored and fishing plans are developed which address stock-specific escapement and catch requirements. In addition, when the discriminant function analyses are applied to in-season estimates of commercial catch, then daily updates of catch by stock group, area, and user group are tabulated (Figure 4, Step 7).

Future improvements to the in-season racial analysis program are expected. Investigations are being conducted into methods of improving the representativeness of baseline standards used in the in-season discriminant function models. This is of particular concern when insufficient numbers of prior year age 3_2's are available to form standards for returning age 4_2 stocks. Also, the ability to accurately forecast stock-specific return timing would assist in decisions about which stocks to include in discriminant function models at various junctures through the fishing season. Blackbourn (1987) uses a temperature displacement model to account for annual variations in run timing for seven Fraser River sockeye salmon stocks. While this model has had some predictive success, it is likely that many factors work in concert to influence variations in the annual timing of specific stocks. Until a better understanding of the causal factors involved in annual variations in run timing is obtained, the historical migrational timing curves will be important tools in the in-season racial analysis program.

Post-Season Racial Analysis

Each year, the in-season racial analyses are subjected to a post-season re-evaluation. This process is critical in finalizing estimates of stock-specific production data, as well as international and domestic catch allocations. The steps involved in the post-season racial analysis are depicted in Figure 6.

Final catch data are obtained for Panel and non-Panel Area waters in Canada and the United States, and catch files are constructed for all areas where Fraser River sockeye salmon are intercepted (Figure 6, Step 1). The Canadian catch data are obtained from Canada Department of Fisheries and Oceans; the United States catch data are obtained from the Washington Department of Fisheries and the Alaska Department of Fish and Game. Preliminary ticket/sales slip data on catches are generally available by May of the year following the fishing season of interest. Final catch data may not be completed for two years.

The in-season discriminant function models are restructured using revised baseline standards collected from actual spawning ground escapements in the year being analyzed. With the revised scale data, and in some cases with the addition of age- and sex-specific length data, new models are developed (Figure 6, Step 2).

Stock-specific peak timing dates for catch areas of interest are estimated from in-season peak catch data derived from commercial fisheries, timing of minor age-classes, spawning ground

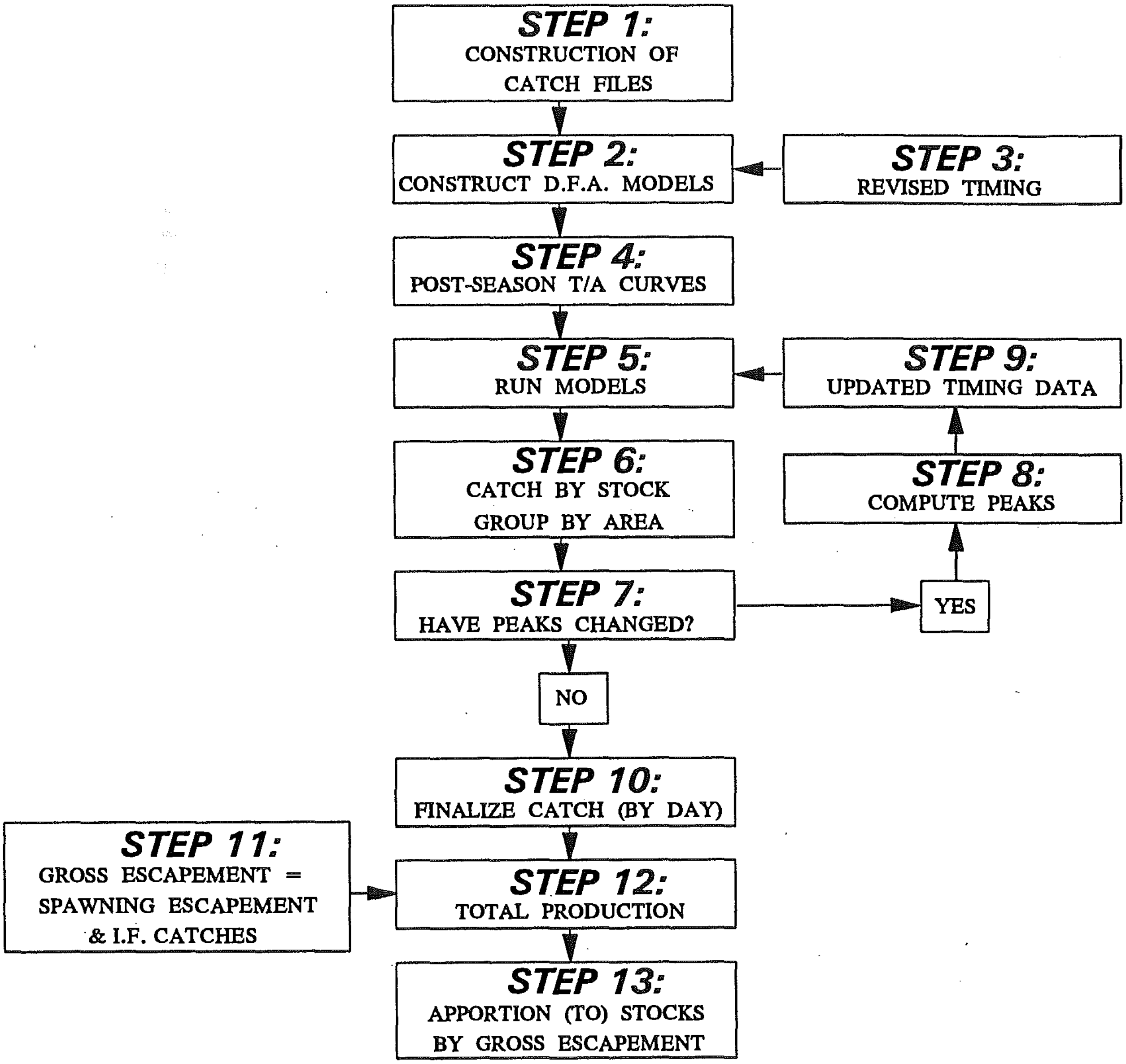


Figure 6. Post-season application of discriminant function analysis models for racial analysis of Fraser River sockeye salmon by stock, area, and gear.

arrival curves, Indian food fishery catches, and daily escapement estimates by stock. These timing data replace the historical timing data used for the in-season analysis (Figure 6, Step 3). The revised timing estimates are used in conjunction with preliminary estimates of production by stock and historical migratory duration data to create post-season migrational timing curves (Figure 6, Step 4). As discussed previously, when dealing with problem stocks within clusters, the migrational timing curves are used as a guide to assist in determining which stocks to group together and which to keep separate. An expected contribution rate of 5% is the criterion used to include or exclude a stock group in the discrimination models. As is the case when conducting in-season analyses, the 5% stock inclusion rule is used as a guide. Since relative stock specific contribution rates in fisheries can at times vary unexpectedly, commercial and test fishery scale samples are often analyzed both with and without stock groups which are expected to be present in proportions below 5%. By comparing the results of these analyses with similar analyses performed on adjacent days, unexpected changes in stock composition can be identified.

If post-season analyses have established the peak dates of occurrence for a particular stock, or group of stocks, as earlier or later than the historical mean date, then Steps 3 and 4 result in the migrational timing curve being adjusted in the appropriate direction. This in turn influences the decision on the appropriate model to run for the sample of interest. The periodic short delay of individual summer-run stocks in the Strait of Georgia, and the annual delay of late-run stocks, necessitates the use of area-specific migrational timing curves in the post-season analysis. Final discriminant function analysis models are now constructed, and appropriate models are selected and run for individual commercial and test fishery samples (Figure 6, Step 5).

The application of the various discriminant function models to area-specific commercial and test fishery catch data generate estimates of catch by stock group by area (Figure 6, Step 6). As was the case for the in-season analysis, the approach outlined above will result in stock contribution estimates for stocks through most of their migration in a fishing area. However, it does not account for the very early- and late-timed components of the stock. Gilhousen (1960), points out that the typical migrational timing curve of a Fraser sockeye run has a distinct peak with long tails extending to either side. The migrational timing curves are used to assign percentages to stock groups before and after they have been excluded from the discriminant function models (i.e. when stocks are present in proportions below 5%).

The peak date of occurrence of each stock group, and its seasonal catch, in each statistical catch area is then re-assessed. If the estimate of the date of peak catch has changed, then the migrational timing curves are recalculated (Figure 6, Steps 7,8,9) and the catch by stock by area is reassessed (Figure 6, Steps 5,6,7). In statistical areas where the intermittent nature of fisheries does not permit a reliable peak timing date to be established, peak timing data from adjacent areas or back-dated Area 29 timing estimates are used.

Once revised estimates of catch by stock group by area have been calculated, the catch data for all areas is finalized (Figure 6, Step 10). This involves assigning racial estimates for catches where no direct sample is available. For each area where Fraser River sockeye salmon have been intercepted, the daily catch is broken down by age class and by stock. Catches for each gear type are estimated separately. Where data gaps exist in the commercial scale sampling database, a detailed interpolation routine is developed. If the data gap within an area is less than or equal to seven days, the interpolation is performed between adjacent racial percentages for each age class and stock, within the area of interest. If the data gap exceeds seven days, then racial data are transferred from the closest adjacent area with a common gear type, using an appropriate time-lag adjustment. This detailed assessment of daily catch, by stock, by user group, is extremely important in that it is utilized in numerous stock monitoring analyses conducted by the Pacific Salmon Commission.

To generate final estimates of production by stock group, estimates of spawning escapements and Indian fishery catches are added to the final commercial catch data (Figure 6, Steps 11,12). Stock-specific net escapement data are provided by the Canadian Department of Fisheries and Oceans. Weekly catch data by area from the Indian fishery are also provided by Canada. The weekly catches from the Indian fishery are allocated to their component stocks by the Pacific Salmon Commission, using a combination of racial analysis and run reconstruction methodologies.

Minor stocks are initially grouped with more abundant co-migrating stocks. Production estimates for each minor stock present in the stock group are most often derived by assuming a catch in each statistical area that is proportional to the gross escapement of the individual stocks relative to the entire group (Figure 6, Step 13). For example, the total commercial catch for a stock grouping, comprising stock A and stock B, may have been estimated to be 500,000. If the gross escapement (net escapement plus Fraser River Indian catch) of stock A is estimated to be 100,000, and the gross escapement of stock B is estimated to be 50,000, then the commercial catch of stock A and B are assumed to be 333,000 and 167,000 respectively.

Although it is not a preferred option, on some occasions it is necessary to combine individual stocks with different timing behaviour in the same stock group. When this occurs biases may be introduced if the commercial catch for individual stocks within a group are assigned simply on the basis of proportional gross escapement. For example, for the hypothetical stock grouping discussed above where the commercial catch is 500,000, the commercial exploitation rate on stock A may be significantly greater than stock B if it has a peak timing two weeks later than stock B. If the peak timing of the two stocks can be independently verified, either through spawning ground passage counts, terminal Indian fishery catches, or through the use of unique scale patterns in the non-4_2 age-class for either stock, then separate migrational timing curves are developed for stocks A an B. These migrational timing curves are then used to estimate the commercial catch for each stock. Since the migrational timing curves take into account both the proportional differences in gross escapement between the two stocks, and the relative timing differences, they should provide a less biased means of dividing the commercial catch of 500,000 between the two stocks.

ACCESSORY DATA USED TO REFINE THE RACIAL ANALYSIS

Age Composition

As discussed in the section on post-season analysis, age composition estimates are made for all major commercial and test fishing samples collected in a given season. Application of age composition estimates to the daily catch estimates by area and to daily gross escapement estimates, generate estimates of stock production by age class. For Fraser River sockeye salmon stocks, post-season racial analyses are normally conducted only on the 4_2, 5_2, 5_3, and 3_2 age classes. The production of other age classes is normally not large enough to allow for detailed scale-pattern analysis. Production is assigned to these minor age classes based on timing and spawning ground escapement estimates using procedures similar to those used for minor stocks.

Identification of the stock group composition of age 5_2 and 5_3 sockeye can be useful in the identification of co-migrating age 4_2 sockeye from the same stocks. This can be particularly important during in-season management periods when age 4_2 scale-pattern analysis for the stock of interest is uncertain. Examples are the use of age 5_2's to identify the Pitt River stock and age 5_3's to identify the presence of Chilko and Birkenhead sockeye in mixed-stock fisheries.

Under the Pacific Salmon Treaty, the Pacific Salmon Commission is responsible for identifying Fraser River sockeye salmon stocks wherever they are caught. Age composition has proven to be a useful tool, along with scale traits and length data, in identifying the Fraser River sockeye salmon catch in northern British Columbia and southeastern Alaska fishery catches.

Sockeye salmon stocks originating in streams from northern British Columbia and southeastern Alaska tend to have more complex age structures than do most Fraser River sockeye salmon stocks. An increase of Fraser River sockeye salmon catches in northern area waters can often be detected by aging representative scale samples from these catches. The presence of Fraser River sockeye salmon in northern area catches can have important in-season management implications.

Fish Length

Fish length as a stock identification variable has limited utility during the in-season management period due to the unpredictability of inter-annual variability in fish lengths (Pacific Salmon Commission, unpublished data). Until an accurate method is developed to forecast the stock-specific mean lengths before the season, length cannot be used in the majority of our stock identification models. However, length frequencies are often examined in-season and are useful in detecting stocks that are significantly larger or smaller than co-migrating stocks.

Once post-season spawning ground standards are obtained, length data can be utilized as an independent variable in discriminant function models. Sample sizes must be large enough to allow for age- and sex-specific analysis due to length differences between sexes for any given stock. To compare spawning ground lengths to those collected from commercial fisheries, post-orbital:hypural plate measurements are taken from the spawning grounds, and post-orbital:fork length measurements are taken from commercial fishery samples. These measures eliminate concerns about sexual-dimorphic maturation changes that occur as sockeye migrate from the ocean to the spawning grounds, and that can limit the utility of length as a stock identification variable. Pacific Salmon Commission staff use conversion factors (unpublished data) to allow spawning ground post-orbital:hypural plate lengths to be converted to post-orbital:fork length measurements for use in stock identification analyses of commercial fishery catches. Although length has not been used extensively in past post-season racial analyses, its importance will likely increase in future years.

Age- and sex-specific length data have been powerful variables in stock identification models developed to identify Fraser River sockeye salmon catches in northern area waters. Length is useful in separating Alaskan and northern British Columbian stocks from Fraser stocks because Alaskan and Skeena River stocks have significantly smaller age 4_2 male and female lengths than do Fraser River stocks.

In-season Fraser River standards, including lengths, are derived from mixed-stock commercial samples that are identified as being of 100% Fraser origin, taken from south coast fisheries in Johnstone Strait (Areas 12 and 13) and in Juan de Fuca Strait (Area 20). Terminal area catches are used to construct Skeena and Nass River standards and historical data are used to create in-season standards for Alaskan streams. In the 1989 to 1992 seasons, Fraser stocks were successfully identified in-season in northern area waters using discriminant function models which incorporated length data.

FUTURE WORK

Future improvements in the application of discriminant function analysis techniques may include incorporation of additional freshwater scale variables and assessments of marine growth scale parameters. The inclusion of sockeye length measurements as an independent variable in the post-season analysis is expected to increase stock resolution in the future. Research will continue into incorporating lengths in in-season analysis. However, before this can be achieved a method must be developed which accounts for the inter-annual variability observed in stock-specific length data. Other stock separation variables which may be included in future discriminant function analysis programs include data on parasite incidence, genetic and morphometric traits. In addition, work is currently in progress to examine the relative merits of using discriminant function analysis versus maximum likelihood estimation techniques.

Further refinements in stock-specific timing estimates will be implemented as developments proceed. Additional work is required on assessing stock-specific cycle-year migrational timing curves. The duration (in days) that individual stocks are present in major fishing areas will be examined. Currently, the historical tagging data of Verhoeven and Davidoff (1962) and the historical racial analyses of Henry (1961) are used to assign speed of migration values to individual stocks. These values will be re-assessed and revised as necessary using a variety of data, including spawning ground arrival curves, Indian food fishery catches, daily gross escapement estimates at Mission and the Pacific Salmon Commission's racial database.

Tagging programs could be conducted to provide valuable, independent assessments on stock-specific run timing and migratory behaviour, particularly for stocks which have been rebuilt since the 1940's. While such programs would provide valuable information, the funding requirements would be high and it may be necessary to use indirect assessment methodologies to evaluate timing and behaviour patterns.

SUMMARY

The Pacific Salmon Commission uses scale-pattern analysis to identify stock groups in mixed-stock fisheries which potentially intercept Fraser River sockeye stocks. The fisheries of interest take place from Washington State, through coastal British Columbia waters, and into southeastern Alaska. The successful application of scale pattern analysis in in-season and post-season fishery evaluations requires both the assemblage of baseline standards each year and the sampling of the commercial fisheries which are intercepting Fraser River sockeye salmon. Scale processing is done throughout the season, on a real time basis, by the Pacific Salmon Commission scale lab.

Prior to 1987 a univariate scale analysis technique was used in the stock identification program; however, since that time, discriminant function analysis has been used to distinguish among baseline standards and assign racial composition estimates to fisheries of interest. A bias correction procedure is used to increase the accuracy of stock group point estimates generated from individual fishery samples. The current technique, which is a four variable discriminant function analysis, has been successfully applied in recent years. In evaluations of classification accuracy and precision, we have found that minimum discriminant function model classification accuracies of 70 to 80% are required for five stock models to achieve the levels of precision needed for in-season management decision making. These levels have been achieved in recent years.

In conjunction with scale data, the Pacific Salmon Commission uses information on age composition and fish length, in addition to historical data on run timing and speed of travel to increase the number of resolvable stock groups and to improve the overall accuracy of the stock identification program results. The accessory data are derived from historical timing studies, spawning ground arrival data, and the analysis of the Pacific Salmon Commission historical scale database. The methods used in both the in-season and the post-season racial analysis programs are described, as is the application of the accessory data which are used to supplement the scale data.

In future years further refinements to the Pacific Salmon Commission's stock identification program can be expected. Additional stock separation variables will be examined for inclusion in the discriminant function analyses. However, the methodology outlined above provides managers with reliable estimates of stock-specific production at a reasonable cost. In-season, these estimates are produced quickly, allowing them to be incorporated into the management process. Commercial fisheries are sampled and scale analysis results are available to fishery managers within 24 to 48 hours of the close of the fishery. Refinements during the post-season analyses incorporate data which are unavailable during the in-season management period.

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