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ASSESSMENT OF THE UPSTREAM LIMIT OF MULTIPLE STOCK MIXING OF SOCKEYE SALMON STOCKS WITHIN THE LOWER NUSHAGAK RIVER, ALASKA

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ABSTRACT

Management of sockeye salmon *(Oncorhynchus nerka)* fisheries are usually based upon assessments of individual or conglomerate stocks. These assessments are usually accomplished by estimating the number of salmon which have escaped the fishery and entered their parent stream. However, the lower reaches of a river may contain salmon from several stocks. Therefore, it is necessary to know how far upstream non-natal stocks occur before designing a program to sample or enumerate the escapement of a particular stock. A study was undertaken to determine the upstream limit of the Wood River sockeye salmon stock in the lower Nushagak River, Alaska. Five sampling stations were chosen in the study area, which was 52 km of the lower Nushagak River above the mouth of the Wood River. Sockeye salmon were captured daily by gillnets at each of the stations throughout the 1978 run. Sex and length were recorded and scale samples were collected from each salmon. Live fish were tagged and released. Data from tag recoveries, age class composition, and scale pattern analysis were used to assess the percentage of Wood River stock which occurred at each station. Tagging data indicated that some fish captured in the study area did return to spawn within the Wood River drainage. Age composition data and scale pattern analysis indicated that the percentage of Wood River salmon decreased as upstream distance increased. Salmon from the Wood River stock were estimated to occur as far as 55.4 km upstream from the mouth of the Wood River.

KEY WORDS: Sockeye salmon, *Oncorhynchus nerka*, escapement, stock separation.

INTRODUCTION

The management of sockeye salmon *(Oncorhynchus nerka)* fisheries is based on production and exploitation of individual stocks. The term stock has been defined as a group of fish which to a substantial degree do not interbreed with any other group spawning in a different place or time (Ricker 1972, 1975). A stock is a genetically discreet group and should be managed as such. In reality, it is often difficult to identify what segment of a sockeye salmon population is a discreet spawning group. A particular river drainage may contain several discreet spawning groups, yet for practical reasons, the entire river population must be managed as a single unit. In this paper, I will refer to a stock as a manageable group of sockeye salmon which migrate to and spawn within a single river drainage.

One strategy for managing a sockeye salmon stock is to allow a terminal fishery on mature adults during their migration to the spawning grounds. Fishery boundaries are established to intercept the salmon in coastal bays and estuaries prior to entering their natal streams. The outside boundary of a fishery is established to avoid interception of other stocks which are not migrating to the particular bay or estuary. The inside boundary is established at or near the outlets of the freshwater stream flowing into the fishing zone. Harvest is regulated to allow an optimal number of salmon to escape capture and migrate to the spawning ground. Those fish which are surplus to the escapement goal are harvested prior to entering freshwater. The management of a terminal fishery is simplest if only one stock is intercepted by the fishery, but many terminal sockeye salmon fisheries intercept multiple stocks. The best management strategy for such mixed stock fisheries requires optimizing the escapement of all the component stocks.

Realization of this management scheme requires that the number of fish which have escaped the fishery be known or estimated as the run progresses. Fish weirs, counting towers, and sonar counters are the most common methods of enumerating a salmon run as it progresses past a single point in the migration route to the spawning grounds (Cousens et al. 1982).

An effective escapement enumeration project must meet the following criteria listed below:

1) The count or estimate must be complete. All individuals of the target stocks which have escaped the fishery must be enumerated or estimated.

2) The count or estimate should be timely. The escapement should be enumerated or estimated as soon as practical after it escapes the fishery.

3) The count or estimate must be unique. Each individual must be enumerated or estimated only once.

4) Once an individual is enumerated or estimated it must not return downstream to the fishery and be captured.

5) Only individuals from the target stock may be enumerated or estimated.

The first two criteria are best met by an enumeration project at the inside fishery boundary. All salmon which spawn within the stream would be counted as they moved past the enumeration site and the escapement count would be immediately available to the manager. The final three criteria are best met by an enumeration project upstream from the fishery boundary. Tidal currents and the tendency of sockeye salmon to mill about during their transition from saltwater to freshwater may cause the salmon to pass the fishing boundary and/or the enumeration site more than once. Such fish will be susceptible to capture and/or enumeration more than once. Salmon which are not members of the target stock may be washed by or stray past the enumeration site, making them susceptible to being falsely counted. Other factors such as the physical properties of the river (depth, velocity, turbidity, number of channels, etc.) must be taken into consideration when choosing an escapement enumeration site. The final choice will of necessity be a compromise between competing factors.

This paper addresses the problem of determining how far upstream non-natal fish occur within a river or stream. This problem must be considered before selecting an escapement enumeration site.

Salmon are known to imprint upon the organic odors of their parent stream during the transformation from parr to smolt (Ricker 1972; Hasler and Scholz 1983). Upon returning to local waters, after one or more years at sea, adult salmon follow this bouquet of odors to their natal spawning grounds (Hasler and Wisby 1951; Hasler 1966; Foerster 1968; Harden-Jones 1968; Hara 1970; Hasler and Scholz 1983). However, salmon do not home without error. Studies have suggested that "overshooting" or bypassing the natal stream is a common occurrence (Hasler and Scholz 1983). Salmon which have made a mistake and swum past their parent stream or turned into another tributary, eventually recognize their error and backtrack downstream until they again pick up the odor of their natal stream. Other researchers have suggested that salmon exhibit rheotropic responses to the presence or absence of the odor of their natal stream (Ricker and Robertson 1935; Hasler 1966; DeLacy et al. 1969; Kleerekoper 1969; Hasler and Scholz 1983). When the odor of their natal stream is present adult salmon migrate upstream and when the odor is absent they migrate downstream.

There is little evidence in the literature to indicate how far upstream salmon will proceed prior to turning around and backtracking to find the lost odor. Pink salmon *(O. gorbuscha)* tagged at the mouth of what was assumed to be their natal streams were found to return to other streams (Jones and Thomason 1984). Sockeye salmon captured and tagged 9.7 km up the Igushik River, Nushagak Bay, Alaska were found to "flush" or backtrack out of the river and return to other streams to spawn (McBride 1978).

Background

The Nushagak River flows into Nushagak Bay, a portion of Bristol Bay, near Dillingham, Alaska (Figure 1). The Nushagak River drains a watershed of approximately 36,500 km^2, which includes three major tributaries. The three tributaries are the Wood River, Mulchatna River, and Nuyakuk River. They converge with the Nushagak River 15 km, 174 km, and 206 km, respectively, from its outlet in Nushagak Bay. The outlet boundary is defined to be Nushagak Point which is the inside fishing boundary. The Wood River watershed is 3,663 km^2 in size and

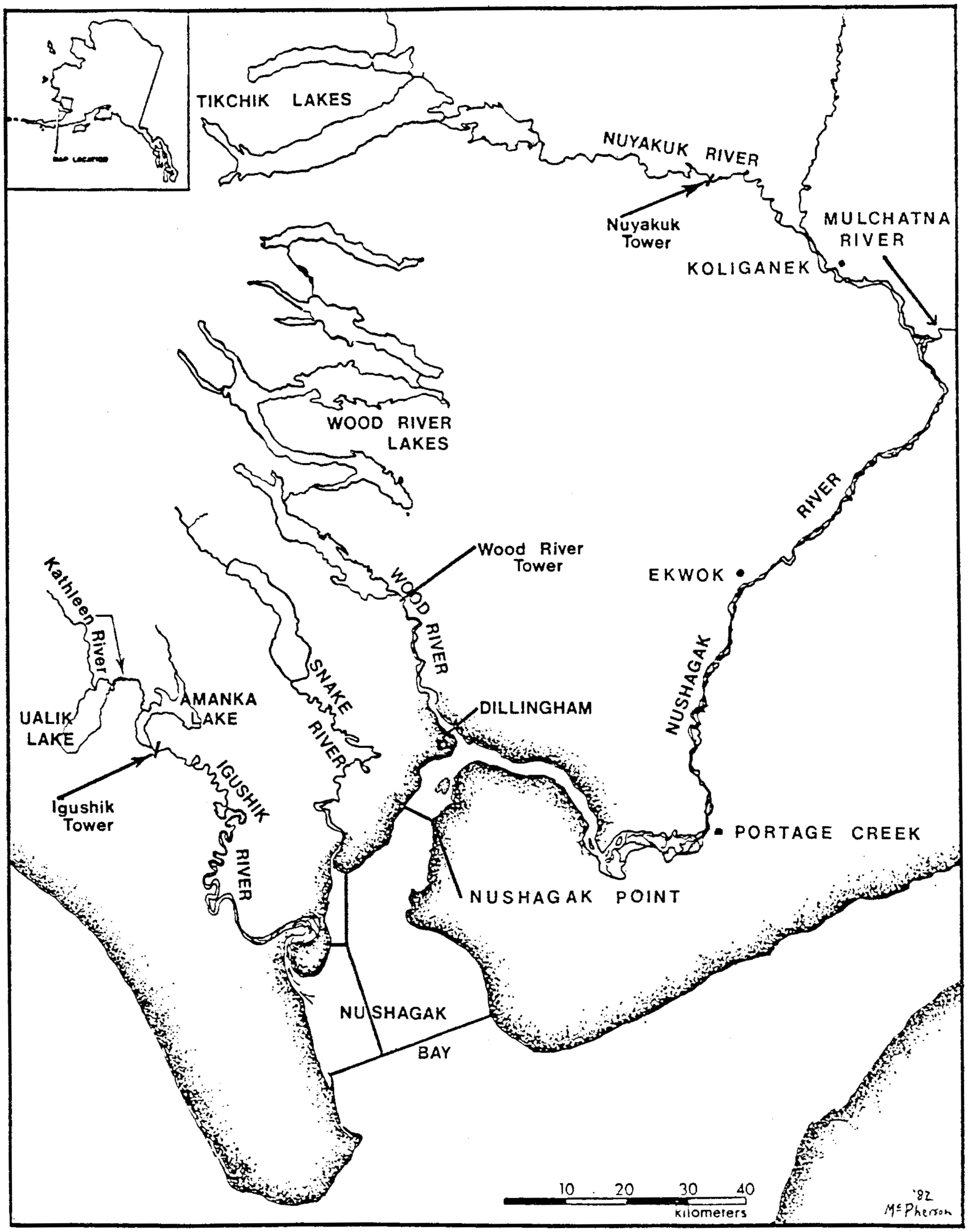

Figure 1. Map showing the Nushagak River drainage.

contains four large lakes totaling 425 km^2 in surface area. The Mulchatna River watershed is 11,132 km^2 but contains no large lakes. The Nuyakuk River watershed is 5,333 km^2 in size and contains five large lakes totaling 471 km^2 in surface area (U.S. Army Corps of Engineers 1957).

The Nushagak Bay commercial fishery is one of the largest and most valuable terminal salmon fisheries in Alaska. Significant numbers of all five North American Pacific salmon *(Oncorhynchus* sp.*)* are harvested by this gillnet fishery, but sockeye salmon have always been the most important species in both numbers and value (Middleton 1983). The sockeye salmon run returns to Nushagak Bay in late June and early July each year. The duration of the run is short with most of the salmon passing through the fishing district within a 10-day period (Middleton 1983).

Two major and two minor spawning stocks of sockeye salmon occur within the Nushagak River drainage. These stocks, designated by parent stream, are: Wood River, Nuyakuk River, Mulchatna River, and Nushagak River. I will refer to the combined Nuyakuk, Mulchatna, and main Nushagak River stocks as upper Nushagak River stocks. The escapement of sockeye salmon into the Wood River and Nuyakuk Rivers usually comprises greater than 95% of the total escapement to the Nushagak River drainage.

In 1946 the Fisheries Research Institute (FRI) of the University of Washington began spawning ground surveys in the Nushagak drainage (Thompson 1962; Gilbert 1968). Spawning ground surveys have been continued until present by both the FRI and the Alaska Department of Fish and Game (ADF&G) (Church 1963a,b; Church and Nelson 1963; Mathisen et al. 1963; Nelson 1964, 1966, 1967; Metsker 1967). Spawning ground surveys provide an index of escapement abundance and spawning distribution but not an accurate escapement enumeration.

During the 1950s counting towers were developed to enumerate salmon runs on a hourly basis as they passed a single point in their migration upstream to the spawning grounds (Straty 1960; Becker 1962; Thompson 1962; Seibel 1967). Salmon are visually counted from towers located on the stream banks as they swim past. Counts are made for 10 minutes out of each hour on both sides of the stream and expanded by a factor of six to estimate the total number of salmon which passed during the hour.

In 1953 a counting tower project was established on the Wood River, approximately 31 km from the inside fishery boundary, to enumerate the sockeye salmon escapement of the Wood River stock (Thompson 1962). In 1959 a second counting tower project was established in the Nushagak drainage to enumerate the sockeye salmon escapement of the Nuyakuk River stock (Gilbert 1968). This counting tower site is located on the Nuyakuk River approximately 200 km from the inside boundary of the fishery. These counting tower projects have continued to operate every year since they began. In 1966 a third counting tower was established on the main Nushagak River, downstream from its confluence with the Mulchatna River (Pennoyer 1967). The purpose of this project was to enumerate the sockeye salmon escapement into the upper Nushagak drainage. The escapement counts from the Nuyakuk counting tower could then be subtracted giving a combined escapement to the main Nushagak River and the Mulchatna River stocks. The Nushagak counting tower project was discontinued in 1975 because it had failed to produce reliable estimates (Randall and Yuen 1978). The problem was caused by poor visibility because of the turbidity of the water.

During the 1970s sonar was developed to count migrating adult salmon (Cousens et al. 1982). Sonar can be used for escapement enumeration in rivers too turbid for counting towers. In 1978 ADF&G obtained funds for sonar enumeration on the Nushagak River. The new enumeration project was to be located somewhere upstream the confluence with the Wood River and would solve two management problems related to the Nushagak fishery. First, the combined main Nushagak River and Mulchatna River sockeye salmon stocks could be accurately enumerated by subtraction of the Nuyakuk tower counts from the sonar counts. Secondly, a more timely estimate of the entire upper Nushagak River escapement would be possible for in-season management. The migration time for sockeye salmon from the fishing district to the Nuyakuk counting tower is estimated to be 10 to 12 days (Van Alen 1981). Therefore, by the time the first salmon were counted at the tower the commercial fishery was almost over.

The first step in establishing this new sonar enumeration project was to determine the best site location for the sonar counters. One factor that needed to be investigated was how far upstream sockeye salmon from the Wood River stock mixed with the upper Nushagak River stocks. During the summer of 1978 I conducted a research project to investigate this matter.

Objectives

The objectives of this study were as follows:

1) To determine if sockeye salmon from the Wood River stock occurred in the Nushagak River above the confluence with the Wood River, and

2) If the Wood River stock did occur in the lower Nushagak River, then determine how far upstream it occurred.

MATERIALS AND METHODS

I defined the study area to be the section of the Nushagak River from the mouth of the Wood River to the village of Portage Creek, 52.1 km upstream. The study area was chosen based on the assumption that this portion of the river would include the maximum possible range of straying by the Wood River stock. Additionally, ADF&G personnel desired to locate the sonar counters somewhere downstream from Portage Creek in order to achieve timely escapement estimates.

A wide range of tidal velocities and heights occurred within the study area. During a maximum high tide (7 m) the river current was completely reversed by the incoming tide in the lower 30 km of the study area. The river level rose, but the current was not reversed throughout the remainder of the study area. Tidal currents in the lower portion of the study area may have reached 4.5 m/sec in an upstream direction during incoming tides. Freshwater from the Wood River may have been pushed as far as 30 km up the lower Nushagak due to this tidal action.

Sampling Design

Five sampling stations were chosen within the study area (Figure 2). I chose the sampling stations with the assistance of a commercial salmon fisherman who had experience as a test fisherman for ADF&G in Nushagak Bay. We surveyed the study area by boat and chose the sampling stations from physical properties of the river (e.g., number of channels, flow pattern, tidal fluctuation, water depth, bank slope). The primary concern was to select places in which gillnets could be successfully fished to consistently capture migrating salmon. Equal spacing between stations was strived for but not possible. The distance from the mouth of the Wood River to each sampling station varied from 17.6 km to 52.1 km (Table 1).

Each station was to be sampled daily within 1 hour (plus or minus) of the highest high tide throughout the 1978 run. The highest run tide was chosen on the assumption that Wood River sockeye salmon would be most likely to occur in the study area at this time. The daily sample size for each station was to be as many salmon as could be captured in 30 minutes up to a maximum of 50 fish.

I used three techniques to evaluate the objectives of this study. Tagging salmon at the sampling stations with subsequent sightings at the counting towers provided data that were used to evaluate the relative abundance of the Wood River stock throughout the entire study area. These techniques were tagging, age composition analysis, and scale pattern analysis. The proportion of the age 4_2[1] age class was used to estimate the percentage of Wood River stock occurring at each sampling station. Likewise, an independent estimate of the percentage of Wood River stock occurring at each station was to be obtained from scale pattern analysis of the 5_2 age class. Together the age composition analysis and scale pattern analysis gave an indication of the extent of Wood River stock straying into the lower Nushagak River.

Capture and Field Sampling

Two field crews were responsible for the capture of sockeye salmon and the biological sampling portion of the study. One crew was stationed at Dillingham and sampled stations I and II. Another crew stationed at Portage Creek and sampled stations III, IV, and V. Both crews worked from skiffs. We attempted to fish each sampling station daily, at local high slack tide. Tide stage was determined from local tide books plus a correction factor established for each site by observing when local high slack tide occurred relative to book time.

We captured migrating sockeye salmon by fishing one or two 45.7 m set gillnets with 13.6 cm (stretched diameter) mesh. The nets were monitored continuously and salmon were removed as soon as possible to minimize mortality.

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[1] Gilbert-Rich formula for age designation - Total years of life at maturity (large type) - year of life at outmigration from freshwater (subscript).

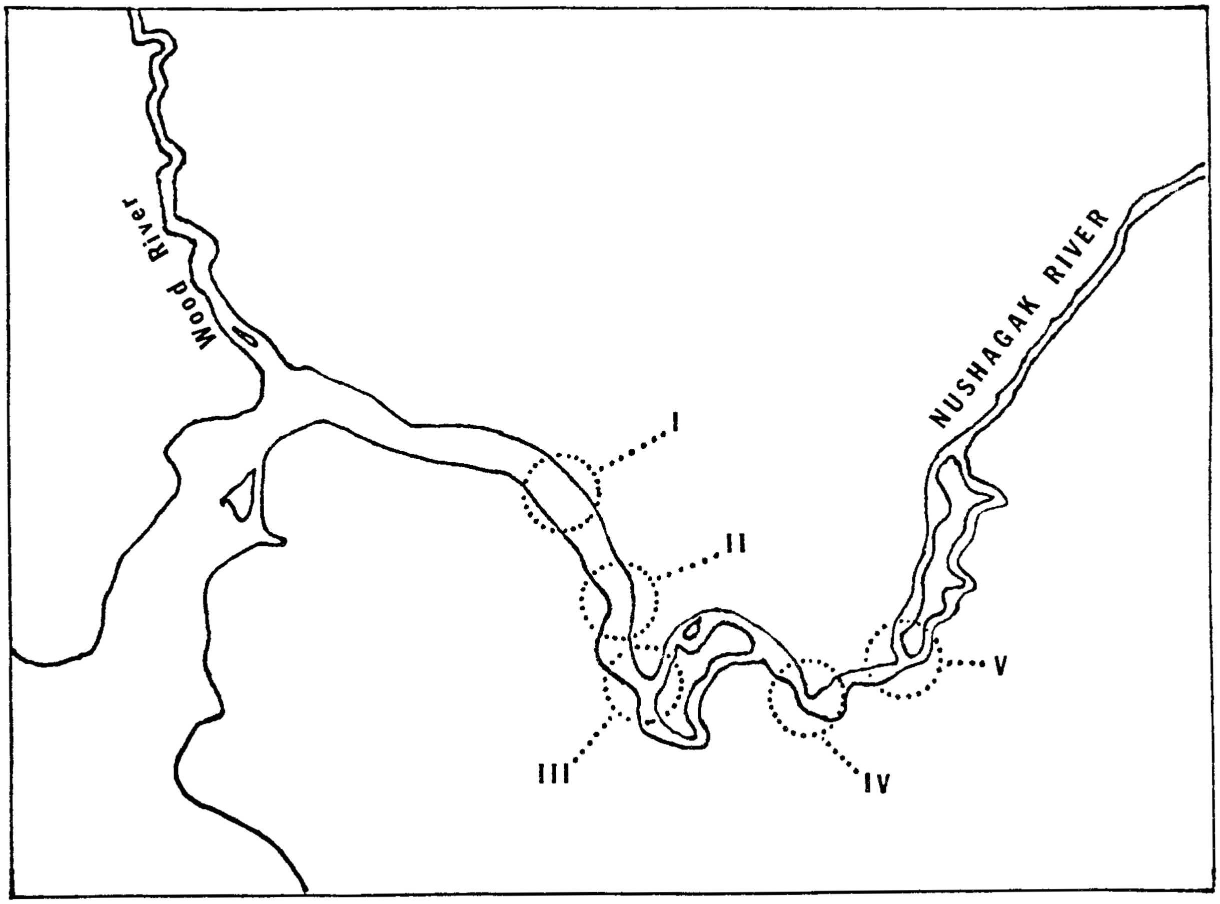

Figure 2. Map showing the location of the five sampling stations on the lower Nushagak River.

Table 1. Distance from the mouth of the Wood River up the Nushagak River to the five sampling stations.

Station	Distance upstream from mouth of Wood River (km)
I	17.6
II	25.1
III	30.8
IV	44.5
V	52.1

The sampling crews measured and recorded the mid-eye to fork length of each sockeye salmon captured on standard AWL (age-weight-length) forms. Sex was also recorded and four scales per salmon were taken and placed on gum cards corresponding to the AWL forms. All scales were taken from a preferred area on the left side of the body below the insertion of the dorsal fin and three rows above the lateral line (international North Pacific Fisheries Commission 1963). Standardization of body location was necessary because scale characteristics are known to vary between different body locations in Pacific salmon (Scarnecchia 1979).

Tagging

All sockeye salmon which were recovered alive from the gillnets were held in a holding tank to be tagged and released. Live fish were anesthetized using MS-222 prior to sampling and tagging. Numbered orange Floy tags were inserted through a 46 cm strip of pink surveyor's tape and then inserted into the fish just below the anterior end of the dorsal fin. The salmon were held until they recovered from the anesthetic and then released into a pool or eddy. Tagged salmon could be identified to station of release only if the Floy tag was recovered. Sightings of tagged fish would only identify the salmon to have been tagged somewhere in the study area.

Tagging fish sightings at the Wood River and Nuyakuk River counting towers were of primary concern. The tower crews were instructed to look for and report all tagged fish sighted. Likewise, all ADF&G personnel throughout the Bristol Bay region were instructed to be alert for tagged fish. All tag sightings and recoveries were reported on a standard form.

Age Class Analysis

Impressions of the scale surfaces were made on acetate cards (Clutter and Whitsel 1956). The impressions were then examined and aged with the aid of a microfiche reader by one other person experienced in aging Bristol Bay sockeye salmon and myself. The Gilbert and Rich (1927) salmon aging system was used to designate ages. The designated ages were compared and scales which were not aged the same were reviewed again by both people. Scales for which aging could not be agreed upon were discounted from further analysis (less than 1% of the total). I tabulated the age composition for each sample station by 4-day periods and across the entire run.

In 1978, the age structure of the Wood and Nuyakuk River escapements were estimated by ADF&G from scale samples collected from sockeye salmon captured by beach seine at the counting towers. ADF&G estimated the age structure of the combined Nushagak-Mulchatna stocks from spawning ground samples of previous brood years (Yuen and Nelson 1983). I weighted the Nuyakuk and Nushagak-Mulchatna age compositions by their respective escapement estimates to produce a combined age structure estimate for the sockeye stocks of the upper Nushagak River (Table 2). I present these data here in order to facilitate the explanation of the age composition analysis.

The two dominant age classes of the Nushagak River stocks are ages 4_2 and 5_2. In 1978 94.1% of the sockeye salmon escapement to the Nushagak River belonged to one of these age classes. However, the percentage of age 4_2 and 5_2 salmon

Table 2. Escapement and age composition estimates of the 1978 escapement of sockeye salmon to segments of the Nushagak River system.

Stock	Escapement	Percent age composition 4_2	5_2	5_3	6_2	6_3	Other
Wood River	2,267,238	76.0	20.3	1.0	0.4	0.5	1.8
Nuyakuk River	576,666	11.8	76.3	0.1	3.5	7.9	0.4
Nushagak-Mulchatna	87,000	6.4	69.4	4.9	3.9	15.4	0.0
Upper Nushagak River (Nuyakuk-Nushagak-Mulchatna)	663,666	11.1	75.4	0.7	3.6	8.9	0.3
Entire Nushagak River	2,930,904	61.3	32.8	0.9	1.1	2.4	1.5

Taken from Yuen and Nelson (1983).

varies dramatically between stocks. The Wood River escapement was estimated to contain 76.0% age 4_2 salmon while the remainder of the Nushagak stock contained 11.1% age 4_2 salmon. The relative composition was opposite for the 5_2 age class, the Wood River escapement contained only 20.3% of the 5_2 age class while the upper Nushagak River escapement contained 75.4% age 5_2 salmon. Since the magnitude for the Wood River escapement was much larger than the remainder of the Nushagak River escapement (2.3 million fish vs. 0.6 million fish), the 4_2 age class was the dominant age class entering the Nushagak River (61.3%). The proportion of age 4_2 fish in the mixed samples taken at the five sampling stations was used to estimate the percent Wood River stock occurring at each station.

The procedure for estimating the stock composition of a mixed sample from differences in the proportions of age classes was developed by Worland and Fredin (1962). I modified their notation to facilitate understanding of my application. The proportion of the age 4_2 salmon occurring within a mixed sample is a combination of the fraction of the Wood River stock occurring in the sample plus the fraction of the upper Nushagak River stocks, where these fractions are weighted by their respective age 4_2 proportions.

$$R_m = F_w P_w + F_n P_n \tag{1}$$

Where: R_m = proportion of age 4_2 salmon in the mixed sample.

F_w = fraction of Wood River stock in the mixed sample.

F_n = $(1 - F_w)$ = fraction of the upper Nushagak stocks in the sample.

P_w = proportion of age 4_2 salmon in the Wood River escapement.

P_n = proportion of age 4_2 salmon in the Nuyakuk River escapement.

Equation (1) may be solved for the fraction of Wood River stock in the mixed sample.

$$\hat{F}_w = \frac{R_m - P_n}{P_w - P_n} \tag{2}$$

The age 4_2 proportions of the 1978 run were substituted into equation (2) to give an estimation of the percent Wood River stock occurring in a mixed sample.

$$\hat{F}_w = \frac{R_m - .111}{.760 - .111} = \frac{R_m - .111}{.649} \tag{3}$$

This estimator was used to calculate the fraction of the Wood River stock which occurred at the five stations on the lower Nushagak River.

The approximate variance of equation (2) was also given by Worlund and Fredin (1962):

$$V(\hat{F}_W) = \left(\frac{1}{P_w - P_n}\right)^2 \left(\frac{1}{n}\right)\left[\hat{F}_w \hat{F}_n (P_w - P_n)^2 + \hat{F}_w (P_w (1 - P_w) - P_n (1 - P_n)) + P_n (1 - P_n)\right] \quad (4)$$

The age 4_2 proportions were substituted into equation (2) and the results were simplified to produce the following variance estimator for equation (3):

$$V(\hat{F}_w) = \frac{2.3742}{n}\left[\hat{F}_w (1 - \hat{F}_w) 0.42120 + \hat{F}_w (0.08372) + 0.098679\right] \quad (5)$$

This variance estimate was limited in that it is assumed that P_W and P_n were measured without error. Therefore, this variance estimate is known to be liberal (too small). Assuming $\hat{F}_W$ to be normally distributed a 90% confidence interval was constructed around $\hat{F}_W$ by the following equation:

$$\hat{F}_w - 1.96\sqrt{V(\hat{F}_w)} \text{ to } \hat{F}_w + 1.96\sqrt{V(\hat{F}_w)} \quad (6)$$

Equation (6) was used to estimate the approximate 90% confidence intervals of the fraction of Wood River stocks which occurred at each of the five stations on the lower Nushagak River.

Scale Pattern Analysis

The patterns of circuli on salmon scales reflect the growth history of the fish (Clutter and Whitesel 1956; Major and Craddock 1962; Bilton 1972; Bilton and Robins 1971a, b). If the growth history and thus the scale patterns of two or more stocks differ at one or more stages in their life history, then variables measured from scale patterns may be used to distinguish individual stocks. The technique is based upon measuring data from the scale patterns of "known" stock origin and using these data to develop a mathematical model to predict the stock origin.

Scale pattern analysis has been used to distinguish the continent of origin of Pacific salmon (Fukuhara et al. 1962, Amos et al. 1963; Dark and Landrum 1964; Mason 1966; Anas and Murai 1969; Tanaka et al. 1969; Mosher 1972; Major et al. 1975; and Cook 1982). The technique has also been used to distinguish between Canadian and United States stocks (Bilton 1970, 1972; Bilton and Messinger 1975;

and Marshall et al. 1984). Scale pattern data have also been used to distinguish between stocks in nearshore areas in Asia, Alaska, and Canada (Konovalof 1975; Cook and Lord 1978; Krasnowski and Bethe 1978; Bethe and Krasnowski 1979; Bethe et al. 1980; Cross et al. 1981; McGregor and Marshall 1982; McBride and Marshall 1983; Sharr 1983; McGregor et al. 1983; and Wilcock and McBride 1983).

The techniques used for measuring the scale character data from scale impressions are described by Krasnowski and Bethe (1978) and briefly outlined below. The scale impressions were projected at 100 power onto a SIGMA Model 01 fish scale digitizer[1]. The scale characteristics were measured along a single axis of the scale. The scale measurements consisted of the number of circuli and the incremental distance (.02 cm/increment) for each growth zone of the scale (Figure 3). Scale character measurements were only taken from the dominant 5_2 age class. Sample size precluded the use of scale pattern analysis for other age classes.

Scales collected from sockeye salmon captured at the Wood River and Nuyakuk River counting towers were used as samples of known stock origin. The data group from each known sample was randomly divided into a learning sample and a test sample. The learning samples were used to create a classification model using stepwise discriminant function analysis. The test samples were used to test the accuracy of the classification model.

Linear discriminant function analysis is based upon a set of orthogonal multivariate regressions which maximize the differences between data groups (stocks) by minimizing the overall variance of the data set (Fisher 1936). The stepwise linear-discriminant functions of the SPSS computer programs (Nie et al. 1978) were used to create the classification models. This program uses a stepwise multivariate regression procedure to select and weight those variables which best discriminate between the known data groups (Johnson and Wichern 1982). The learning samples were used to calculate an estimated variance-covariance matrix and a sum of squares and cross products matrix. These estimated parameters are then used in a least-squares technique to derive orthogonal discriminant functions which maximize the difference between group means. Classification boundaries, which denote a space of most probable occurrence for each group, are established along the discriminant functions. A data case is classified by determining in which group's space it lies and assigning it to that group. In this way a data case is assigned to the group to which it most probably belongs.

Once a classification model was established, its accuracy was estimated by classifiction of the test samples. The classification of the test samples produced a classification matrix or error matrix. This matrix is an unbiased estimate of the accuracy of the classification model because the test samples were not used when creating the model. The designations were then switched between the learning and test samples and the analysis was repeated creating and testing a second model.

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[1] The SIGMA Model 01 fish scale digitizer is marked by H & A Computer Services, 14401 - 31st NE, Suite K308, Bellevue, WA 98007.

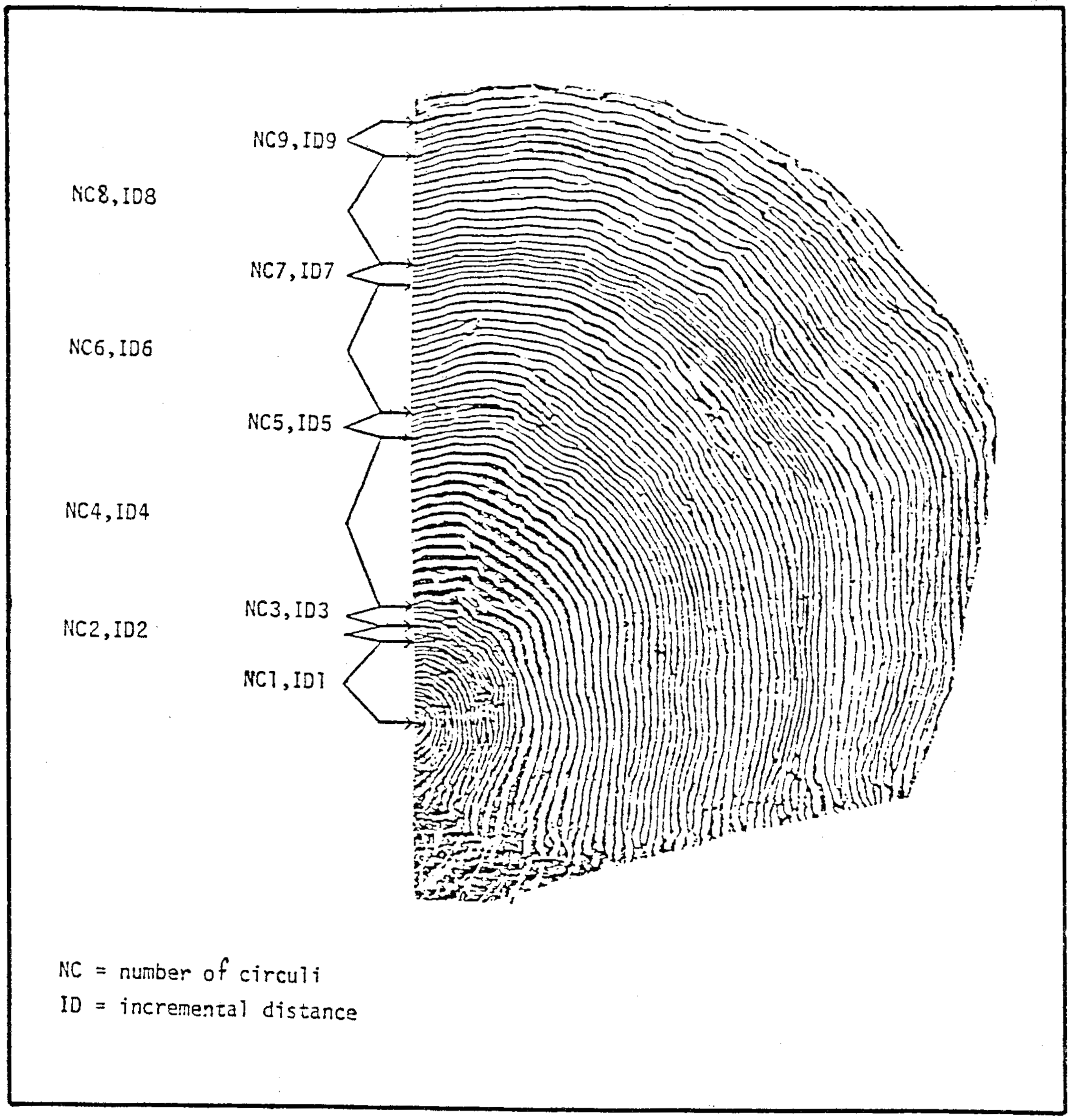

Figure 3. Diagram of measurements taken from age 5_2 sockeye salmon scales for scale pattern analysis.

Once the classification models were created and classification matrices estimated, data from the unknown samples collected at each of the five sampling stations were classified. The resulting percent composition of the unknown samples by stock were the first order estimates. Second order estimates of stock composition were then calculated by correcting the first order estimates by the appropriate classification matrix. The procedures for making this correction were first presented by Worlund and Fredin (1962), then modified and improved upon by Cook and Lord (1978) and Pella and Robertson (1979). Pella and Robertson's $\tilde{\theta}$ estimation formula was used because simulation studies indicated that this estimator had the least bias and the smallest variance of all the estimators studied.

The variance and confidence intervals of the second order estimates were calculated by the procedure described by Pella and Robertson (1979). This variance estimate takes into consideration the following two sources of variation: (1) the sampling variation in estimating the first order estimates, and (2) the sampling variation in estimating the classification matrix. Monte Carlo simulations have shown that this variance estimate is conservative (Cook 1982). The average of the two second order estimates is considered the best point estimate of percentage composition of the component stocks. A more detailed outline of the scale pattern analysis technique is given in Appendix A.

RESULTS

Sampling began on 24 June 1978 and continued until 11 July 1978. The numbers of sockeye salmon captured by station and date are listed in Table 3. A total of 1,802 sockeye salmon was captured and sampled. Rough water, due to storms, and mechanical problems prevented each station from being sampled every day. The height of the highest high tide varied from 5.4 m to 6.7 m during the sampling time frame. Small sample size and missing data precluded any comparison of stock composition by tide height.

Tagging

A total of 307 sockeye salmon was tagged and released within the study area (Table 4). While an effort was made to release as many tagged fish as possible, it turned out that 91% of the sockeye salmon tagged were captured and released at stations III, IV, and V. The reasons for this disproportionate distribution of tagged fish releases were as follows:

1) The crew sampling stations I and II consisted of only two people, opposed to a three-person crew sampling stations III, IV, and V, as processing fish was slower at stations I and II, and

2) Rougher water conditions existing at stations I and II resulted in slower picking of the gillnets which increased sockeye salmon mortality rate.

Forty tagged fish were sighted or recovered (Table 5). Sixteen tags were recovered from marked fish. Eleven tags equaling 68.7% of the tag recoveries were from sockeye salmon captured in the upper Nushagak River drainage. Three tags equaling 18.8% of the tag recoveries were from salmon captured in the Wood River

Table 3. Number of sockeye salmon captured at five sampling stations on the lower Nushagak River, 1978.

Date	Station I	II	III	IV	V	Total
June 24	*	*	*	*	9	9
25	11	26	1	6	14	58
26	14	8	10	7	15	54
27	13	11	5	6	1	36
28	157	40	10	4	17	228
29	*	*	30	5	10	45
30	*	*	33	17	21	71
July 1	24	32	*	38	42	136
2	*	*	*	42	11	53
3	8	*	27	*	24	59
4	*	*	51	*	59	110
5	77	33	48	30	52	240
6	71	5	57	*	62	195
7	39	27	16	46	35	163
8	76	*	*	15	8	99
9	99	*	19	8	10	136
10	*	*	20	*	41	61
11	*	*	49	*	*	49
Total	589	182	376	224	431	1,802

* No sampling effort on this date due to weather or mechanical problems.

Table 4. Number of sockeye salmon tagged and released at five sampling stations on the lower Nushagak River, 1978.

Date	Station I	II	III	IV	V	Total
June 24	*	*	*	*	3	3
25	2	1	0	4	4	11
26	4	4	0	2	1	11
27	0	0	1	2	3	6
28	0	1	3	0	0	4
29	*	*	0	0	0	0
30	*	*	1	0	0	1
July 1	11	5	*	4	1	21
2	*	*	*	45	8	53
3	0	*	26	*	18	44
4	*	*	30	*	23	53
5	0	0	21	20	3	44
6	0	0	17	*	0	17
7	0	0	0	0	0	0
8	1	*	*	0	0	1
9	0	*	0	0	0	0
10	*	*	12	*	0	12
11	*	*	7	*	19	26
Total	18	11	118	77	83	307

* No tag effort on this date due to weather or mechanical problems.

Table 5. Sighting and recoveries of sockeye salmon tagged in the lower Nushagak River, 1978.

Tagged Fish Sightings:

Date sighted	Number sighted	Location sighted	River drainage
July 6	1	Nuyakuk counting tower	Upper Nushagak River
July 7	1	"	"
July 8	2	"	"
July 9	2	"	"
July 10	4	"	"
July 11	1	"	"
July 12	4	"	"
July 13	2	"	"
July 15	1	"	"
July 18	1	"	"
Total	19		Upper Nushagak River
June 27	1	Wood River counting tower	Wood River
July 2	3	"	"
July 5	1	"	"
Total	5		Wood River

Tagged Fish Recoveries:

Date tagged	Station tagged	Date recovered	Location recovered	River drainage
June 26	IV	July 3	Ekwok village	Upper Nushagak River
July 4	V	July 11	"	"
July 6	III	Unknown	"	"
July 2	IV	July 15	Koliganek village	"
July 2	V	Unknown	"	"
July 3	III	July 15	"	"
July 3	III	Unknown	"	"
July 4	III	July 15	"	"
July 4	IV	Unknown	"	"
Unknown	Unknown	July 15	"	"
July 5	IV	July 13	Nuyakuk tower	"
Total	11			Upper Nushagak River
Unknown	Unknown	June 29	Wood River tower	Wood River
Unknown	Unknown	July 3	"	"
Unknown	Unknown	July 7	Agulowak River	"
Total	3			Wood River
June 24	V	July 7	Scandinavian Beach	Nushagak Bay
July 10	III	Aug. 8	Coffee Point	"
Total	2			Nushagak Bay

drainage. Two tags equaling 12.5% of the tag recoveries were from salmon captured in Nushagak Bay. Interpretation of these data are difficult because recovery effort was not quantifiable. Since the commercial gillnet fleet was fishing in Nushagak Bay, recapture effort must have been highest there. Only two tags were returned from Nushagak Bay indicating a small proportion of the sockeye salmon tagged in the study area return to the fishing district.

Twenty-one tagged fish were sighted, but not recovered, by the crews of the Wood River and Nuyakuk River counting towers during their ten-minute counting periods. These sightings were of interest because an equal effort was expended looking for tags at both places. Five tagged salmon were sighted at the Wood River counting tower while 19 tags were sighted at the Nuyakuk River tower. Of the 663,666 sockeye salmon which were estimated to have spawned in the upper Nushagak River (Nuyakuk, Nushagak, and Mulchatna stocks) only 576,666 sockeye salmon were estimated to have passed the Nuyakuk River tower (Table 2). Therefore, the number of tags sighted at the Nuyakuk River tower represent only 86.9% of the total which would have been sighted had the entire upper Nushagak River escapement run been enumerated from a tower. Thus a correction factor of 1.151 was applied to the 19 tags sighted at the Nuyakuk counting tower to produce an estimated 21.9 tags which would have been sighted had the entire upper Nushagak River sockeye salmon run been observed. Since observation effort was equal, the estimation can be made that 18.6% (5 of 26.9) of the tagged fish eventually returned to the Wood River drainage.

Age Class Analysis

The percentage age composition of the sockeye salmon captured at the five sampling stations for four time periods and across the entire run was calculated. Overall, the percentage of 4_2 age class represented 31.1%, 23.7%, 23.7%, 12.8%, and 15.5% at stations I through V, respectively (Table 6 to 10). The percentage of 4_2 age class declined and the percentage of the 5_2 age class increased from station I to station V. The overall age composition best represented the make-up of those sockeye salmon which occurred at each station because the sample sizes generally reflected catch per unit effort or abundance at each station. The estimates by time period are limited by sample size and missing data points.

The results of the age class method of stock allocation are presented in Table 11. These results indicate a decline in the percentage of Wood River stock from station I to station V. The highest estimate of the percentage of Wood River was 30.8% at station I, and the lowest estimate was 2.8% at station IV. These data indicate that the percentage of Wood River stock which occurred at stations I, II, III, and V were significantly greater than zero at an alpha level of 0.10. I plotted these estimates of percentage of Wood River stocks against river kilometer (Figure 4). A linear regression of these data yielded an R value of -0.93 and intercepts the X axis at 55.4 km. Thus indicating that fish from the Wood River stock were present in the study area and may have occurred as far as 55.4 km upstream. These data indicate that some sockeye salmon from the Wood River stock occurred throughout the study area.

It would not be appropriate to use age class analysis on time segments of the run because sampling at the counting towers indicated that the 4_2 age class percentage varied through time (Yuen and Nelson 1983). As might be expected the percentage of 4_2 age class increased through time at both counting towers while the opposite was true for the 5_2 age class.

Table 6. Sample size and percent age composition of the sockeye salmon captured at Station I of the lower Nushagak River, 1978.

Time period	Sample size	Percent age composition					Other
		4_2	5_2	5_3	6_2	6_3	
6/24 - 6/27	38	47.4	47.4	2.6	0.0	2.6	0.0
6/28 - 7/01	181	25.7	69.5	0.0	1.0	3.8	0.0
7/02 - 7/05	85	22.4	72.9	3.5	1.2	0.0	0.0
7/06 - 7/11	285	34.7	62.1	0.7	1.4	1.1	0.0
Overall[1]	589	31.1	65.0	1.0	1.0	1.9	0.0

[1] Overall represents age composition taken across the entire run, not the average age composition of the four time periods.

Table 7. Sample size and percent age composition of the sockeye salmon captured at Station II of the lower Nushagak River, 1978.

Time period	Sample size	Percent age composition					Other
		4_2	5_2	5_3	6_2	6_3	
6/24 - 6/27	45	51.2	46.6	2.2	0.0	0.0	0.0
6/28 - 7/01	72	15.3	80.5	0.0	1.4	1.4	1.4
7/02 - 7/05	33	27.3	69.6	0.0	3.1	0.0	0.0
7/06 - 7/11	32	9.4	90.6	0.0	0.0	0.0	0.0
Overall[1]	182	23.7	73.7	0.5	1.1	0.5	0.5

[1] Overall represents age composition taken across the entire run, not the average age composition of the four time periods.

Table 8. Sample size and percent age composition of the sockeye salmon captured at Station III of the lower Nushagak River, 1978.

Time period	Sample size	Percent age composition					Other
		4_2	5_2	5_3	6_2	6_3	
6/24 - 6/27	16	25.0	68.7	0.0	6.3	0.0	0.0
6/28 - 7/01	73	28.8	71.2	0.0	0.0	0.0	0.0
7/02 - 7/05	126	24.6	74.6	0.0	0.8	0.0	0.0
7/06 - 7/11	161	20.5	78.3	0.6	0.6	0.0	0.0
Overall[1]	376	23.7	75.2	0.3	0.8	0.0	0.0

[1] Overall represents age composition taken across the entire run, not the average age composition of the four time periods.

Table 9. Sample size and percent age composition of the sockeye salmon captured at Station IV of the lower Nushagak River, 1978.

Time period	Sample size	Percent age composition					Other
		4_2	5_2	5_3	6_2	6_3	
6/24 - 6/27	19	10.5	84.2	0.0	5.3	0.0	0.0
6/28 - 7/01	64	7.8	89.1	0.0	3.1	0.0	0.0
7/02 - 7/05	72	2.8	95.8	0.0	1.4	0.0	0.0
7/06 - 7/11	69	27.6	72.4	0.0	0.0	0.0	0.0
Overall[1]	224	12.8	85.4	0.0	1.8	0.0	0.0

[1] Overall represents age composition taken across the entire run, not the average age composition of the four periods.

Table 10. Sample size and percent age composition of the sockeye salmon captured at Station V of the lower Nushagak River, 1978.

Time period	Sample size	Percent age composition					Other
		4_2	5_2	5_3	6_2	6_3	
6/24 - 6/27	39	2.6	92.3	0.0	2.5	2.6	0.0
6/28 - 7/01	90	11.1	78.9	0.0	3.3	6.7	0.0
7/02 - 7/05	146	17.8	79.5	0.0	0.0	2.7	0.0
7/06 - 7/11	156	19.2	74.4	0.0	1.9	4.5	0.0
Overall[1]	431	15.5	78.4	0.0	1.9	4.2	0.0

[1] Overall represents age composition taken across the entire run, not the average age composition of the four time periods.

Table 11. Estimated percent of Wood River stock and other Nushagak stocks at five sampling stations in the lower Nushagak River in 1978 as allocated by age class analysis.

Station	Stock	Percent composition	90% confidence factor[1]
I	Wood River	30.8	4.8
	Other Nushagak	69.2	4.8
II	Wood River	19.3	8.0
	Other Nushagak	80.7	8.0
III	Wood River	19.4	5.5
	Other Nushagak	80.6	5.5
IV	Wood River	2.8	5.7
	Other Nushagak	97.2	5.7
V	Wood River	6.8	4.4
	Other Nushagak	93.2	4.4

[1] 90% confidence interval may be obtained by adding and subtracting this factor from the average. This confidence interval is known to be liberal.

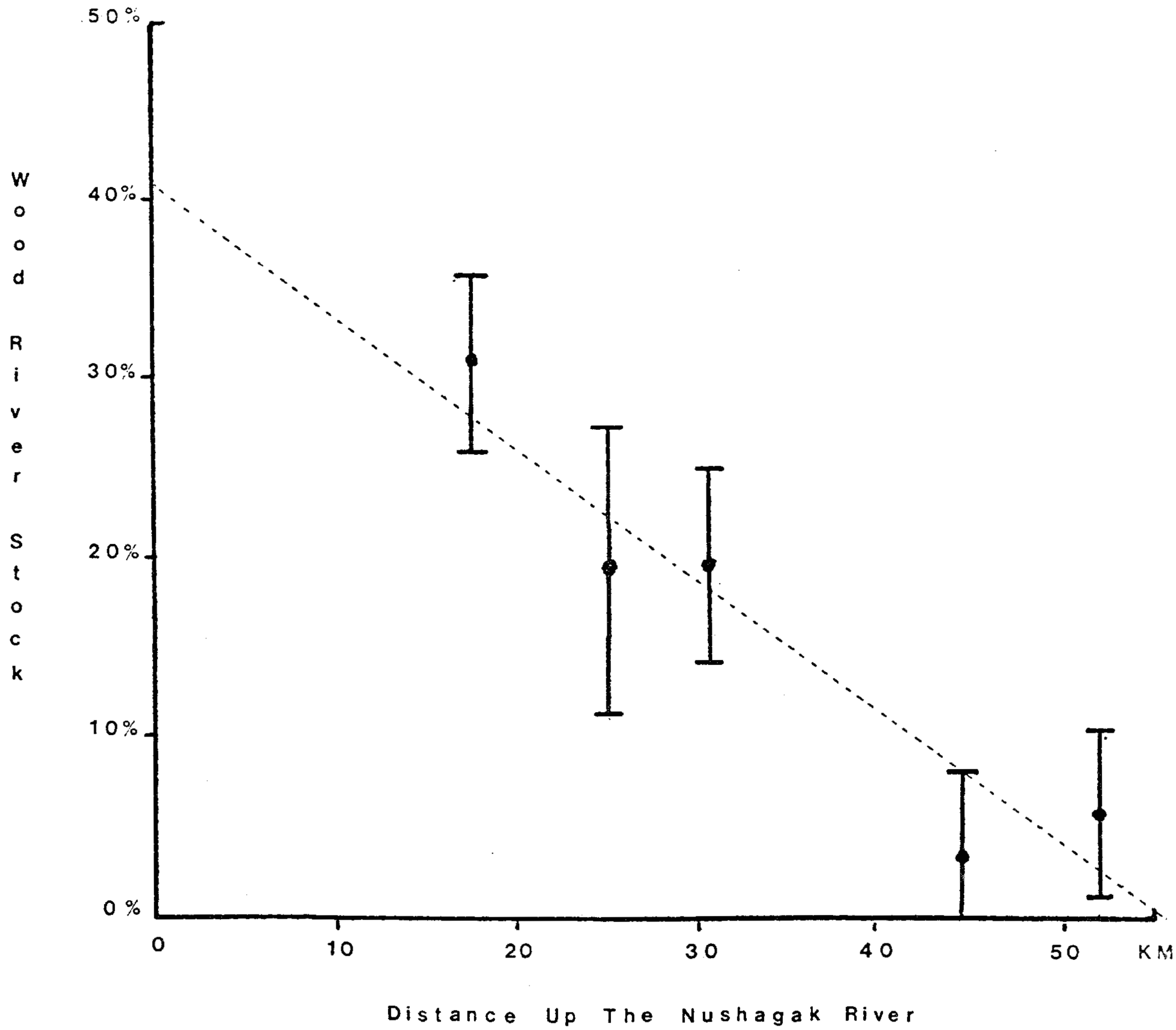

Figure 4. Plot of estimated percentage of Wood River stock, as allocated by age composition analysis, vs distance up the Nushagak River.

Scale Pattern Analysis

I constructed the "known" samples from the scale pattern data of sockeye salmon captured at the Wood River and Nuyakuk River counting towers. A sample of 150 age 5_2 scales was measured from each stock. Scale collections were taken from the spawning grounds of the Nushagak and Mulchatna Rivers but these scales were too resorbed to measure for scale pattern analysis. This bias will be discussed later. The known samples were randomly divided into learning and test samples, each of which contained data from 75 scales from each stock. The classification model was constructed using the stepwise linear discriminant function routine of the SPSS computer package. The classification model was then tested by classifying the test samples. The designations of the learning and test samples were then switched and the entire procedure was repeated. The resulting two classification matrices were estimates of the accuracy of these models. The first model classified 83.3% of the test samples correctly and the second model correctly classified 84.0% of the test samples (Table 12).

The average accuracy of the models was 83.7% or 33.7% better than would have been classified by chance alone.

The five most important variables in both models were from the following zones:

1) First summer's growth, freshwater,

2) Plus growth, growth of second summer prior to seaward migration,

3) Fourth winter's growth, growth during the final winter at sea,

4) First winter's growth, growth during the first winter in freshwater, and

5) Second winter's growth, growth during the first winter at sea.

One model might have chosen incremental distance of the zone while the other might have chosen number of circuli, but these measures were highly correlated and it was the zone of growth which was of most interest.

The number of the unknown samples taken at the five stations are listed in Table 13. Results of classifying the unknown samples of each station are presented in Table 14 along with the 90% confidence intervals of the estimates. The average of the two models yielded the best point estimate of the stock composition at each station. These data indicated that the percentage of Wood River stock which occurred at stations I, II, III, and IV were significantly greater than zero at an alpha level of 0.10. The largest estimate of the percentage Wood River salmon occurred at station II (34.7%) while the lowest estimate was at station V (7.4%) The percentage Wood River estimate was plotted against distance upstream from the confluence with the Wood River in Figure 5. A linear regression of these estimates yielded an R value of -0.603. This low R value indicated a decline in the percentage of Wood River stock with upstream distance, but a linear model was not adequate to predict how far upstream zero percent Wood River fish would have occurred.

Table 12. Classification matrices of the two classification models created to determine the percent of Wood River stocks at five stations on the lower Nushagak River in 1978.

Known stock origin	Classified stock origin # (%) Wood River	Nuyakuk River
Model 1		
Wood River	66 (88.0)	9 (12.0)
Nuyakuk River	16 (21.3)	59 (78.7)
Total	82 (54.7)	68 (45.3)
Overall accuracy	(83.4)	
Model 2		
Wood River	58 (77.3)	17 (22.7)
Nuyakuk River	7 (9.3)	68 (90.7)
Total	65 (43.3)	85 (56.7)
Overall accuracy	(84.0)	

Table 13. Sample sizes of the 5_2 age class scales measured for scale pattern analysis at the five stations on the lower Nushagak River in 1978.

Date	Station I	II	III	IV	V	Total
June 24	*	*	*	*	3	3
25	0	6	1	3	6	16
26	5	4	6	6	11	32
27	5	7	3	5	1	21
28	75	20	8	1	9	113
29	*	*	18	1	4	23
30	*	*	20	9	12	41
July 1	7	20	*	10	13	50
2	*	*	*	28	5	33
3	0	*	20	*	8	28
4	*	*	24	*	16	40
5	27	21	17	6	25	96
6	18	2	35	*	31	86
7	9	15	7	16	23	70
8	18	*	*	4	3	25
9	19	*	6	1	3	29
10	*	*	7	*	17	24
11	*	*	23	*	*	23
Total	183	95	195	90	190	753

* No samples were collected on these dates.

Table 14. Estimated percent of Wood River stock and Nuyakuk stock at five sampling stations in the lower Nushagak River in 1978 as allocated by scale pattern analysis.

Station	Stock	Percent composition			90% confidence factor[1]
		Model 1	Model 2	$\overline{X}$	
I	Wood River	15.9	27.7	21.8	11.6
	Nuyakuk River	84.1	72.3	78.2	11.6
II	Wood River	33.9	35.8	34.7	11.9
	Nuyakuk River	66.1	64.6	65.3	11.9
III	Wood River	11.4	29.2	20.3	11.7
	Nuyakuk River	88.6	70.8	79.7	11.7
IV	Wood River	10.8	39.7	25.2	14.4
	Nuyakuk River	89.1	60.3	74.7	14.4
V	Wood River	0.0	16.4	7.4	11.9
	Nuyakuk River	100.0	83.6	92.6	11.9

[1] 90% confidence interval may be obtained by adding and subtracting this factor from the average. This confidence interval is known to be conservative.

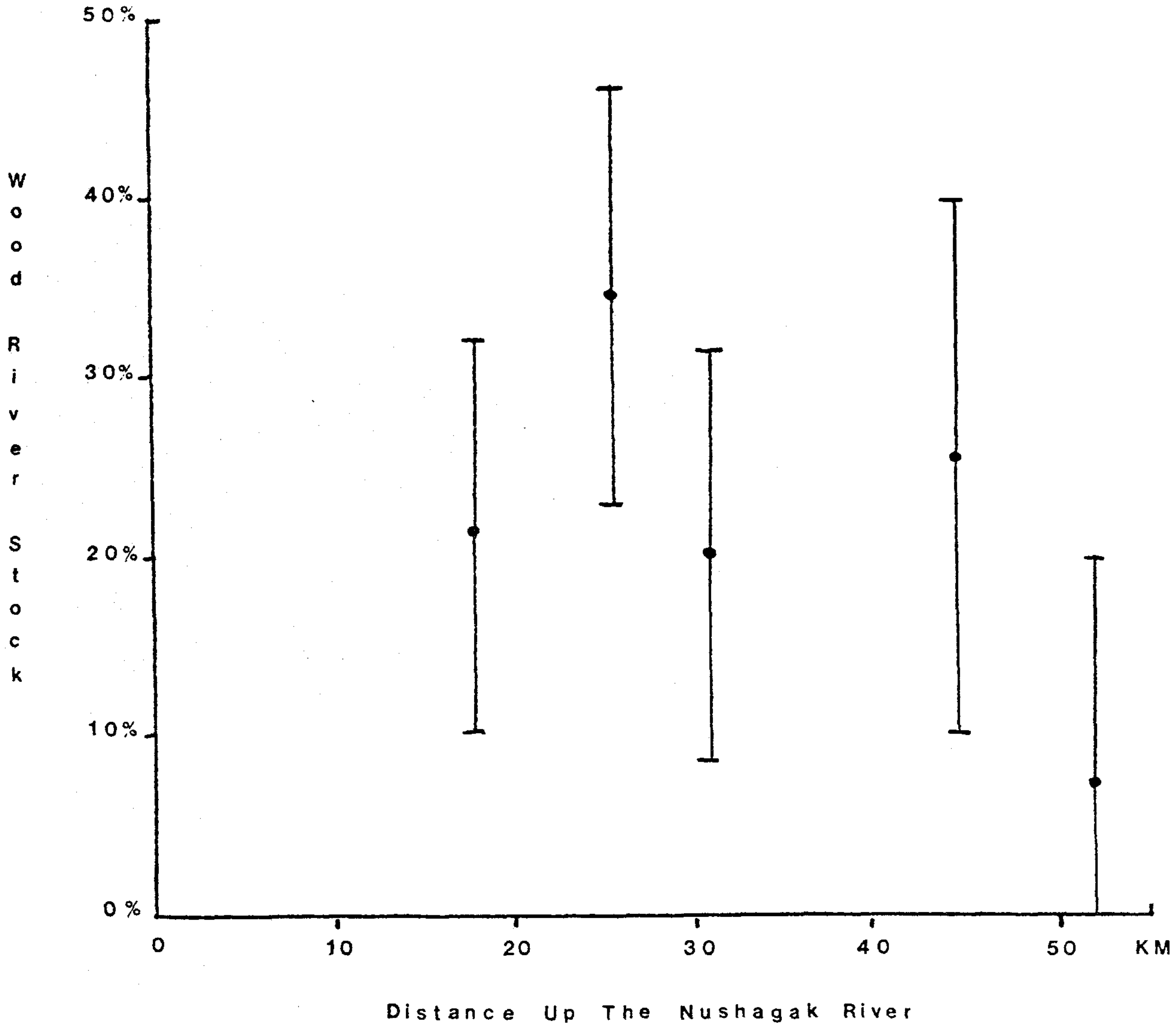

Figure 5. Plot of estimated percentage of Wood River stock, as allocated by scale pattern analysis, vs distance up the Nushagak River.

DISCUSSION

In this section I will discuss the limitations of each of the three approaches which I used to evaluate the objectives. I will point out how the study could be improved should it be carried out again. Finally, I will summarize the results and evaluate the objectives in light of these results.

The sampling scheme of this study could have been improved if an alternate capture gear were available. Gillnets are size selective, and may have biased the age composition of the mixed stock samples. I believe that beach seines would not have been an effective sampling gear in the lower Nushagak River due to the depth and velocity of the river. A series of stationary traps might have been the most effective means of sampling the run without bias in this river. The traps would have been fished most effectively during the flood tide when strays from the Wood River would be most likely to occur in the study area. Unless a trap were damaged, it would have fished continuously and missing data would not have been a problem. Sampling and tagging salmon from the holding pen of a trap would have been relatively easy and not so subject to the time constraints of the gillnet capture methodology. The drawback to traps is that they would have been expensive to build and would have required installation prior to the beginning of the run.

Tagging

The tagging portion of the study demonstrated that some sockeye salmon captured within the study area did return downstream and eventually migrated up the Wood River past the counting tower. Tagging may have affected the behavior of the fish, but I do not believe that tagging will induce a salmon to spawn in another stream.

This belief is supported by a study done by Ricker and Robertson (1935). They fin-clipped 100 sockeye salmon below a fish weir on Sweltzer Creek, British Columbia. Some marked fish did backtrack downstream and were observed in downstream tributaries. However, these fish ascended the tributaries no more than 0.4 km and eventually returned to Sweltzer Creek. Ricker and Robertson eventually recovered all 100 marked fish at the weir or on the spawning grounds. All of the recoveries were found in Sweltzer Creek. None of the salmon were induced to spawn in a non-natal stream by captured, handling, or mutilation.

The tagging data would have been more useful if the tags were released proportionate to the abundance and timing of the run and if different color streamers were used at each sampling station. Multiple colors of streamers were not available because of conflicts with other tagging studies occurring in Bristol Bay during 1978.

Age Class Analysis

The use of gillnet captured samples introduced an unknown bias into the age composition estimates, but the bias was constant throughout the study area. Therefore, the trend of a decreasing proportion of age 4_2 sockeye salmon with respect to distance upstream from the confluence of the Wood River remains unchanged.

The 13.6 cm (5-3/8 in) mesh gillnets selected for larger salmon of the older age classes. The estimates of the 4_2 age class were smaller than the actual percent-ages within the study area and the estimates of the percentage of Wood River stock were too low. If the gillnets captured only 90% of the actual 4_2 age salmon, relative to a 100% capture rate for age 5_2 salmon, then the age 4_2 bias was 10%. I calculated the estimates of the Wood River stock for age 4_2 biases of 10%, 20%, 30%, and 40% (Table 15). These data indicate that even if 40% of the age 4_2 sockeye salmon were lost from the gillnet, the percentage of Wood River salmon estimated increased by a maximum of 11.7% (station I). The linear trends change very little and still indicate that the Wood River stock occurred through the five sampling stations (Figure 6). It is my conclusion that gillnet bias did not seriously affect the results of interpretation of the age class composition analysis.

Scale Pattern Analysis

The scale pattern analysis was limited in two ways. The analysis only applied to salmon of the 5_2 age class and the results were biased by not including known samples from the Nushagak and Mulchatna sockeye salmon stocks. The 5_2 age class was most abundant throughout the study area and in the escapement to the upper Nushagak River drainages in 1978 while the age 4_2 age class was the most abundant age class in the Wood River stock (Table 2 and Tables 6 to 10). Therefore, the highest proportion of Wood River salmon would be expected to occur in the 4_2 age class. The omission of known samples of the Nushagak and Mulchatna stocks from the classification model was a more serious problem. Since 12.1% of the age 5_2 salmon which spawned in the upper Nushagak River drainage belonged to one of these two stocks, then up to 12.1% of the samples taken in the lower Nushagak River were misclassified by the model. If all sockeye which belonged to the Nushagak-Mulchatna stocks were classified as belonging to the Wood River stock then the estimates of the percentage of Wood River stock are 12.1% too high. If the opposite were true and all of the Nushagak-Mulchatna stocks were assigned to the Nuyakuk stock, then the estimates of the percentage of Wood River stock were 12.1% too low. Most likely, the bias was somewhere between these two cases. No matter what the actual level of the bias was, it was constant. Therefore, the trend of a decreasing proportion of the Wood River stock with respect to distance upstream from the confluence with the Wood River would remain unchanged. I feel that the two limitations of the scale pattern analysis were severe enough that the estimates of the percentage of Wood River salmon occurring at each station could not be themselves be used to determine the upstream limit of straying. However, the estimates of the percentage of Wood River stock at the five stations obtained by scale pattern analysis do agree closely with the estimates obtained by age class composition analysis (Figure 7). This suggests that the bias because of omission of the minor stocks from the classification model did not seriously alter the scale pattern analysis results.

Summary

The tagging data, age composition analysis, and scale pattern analysis all indicate that some Wood River sockeye salmon did occur in the study area during 1978. The first objective is then clearly resolved. Sockeye salmon from the Wood River stock do stray past the confluence of the Wood and Nushagak Rivers into the study area.

The age composition and scale pattern analysis both indicate a decling proportion of the Wood River stock with respect to distance upstream from the mouth of the

Table 15. Percentage of Wood River stock occurring at five stations in the lower Nushagak River as allocated by age composition analysis and adjusted for four levels of gillnet bias.

Station	Original estimate	Bias level[1] 10%	20%	30%	40%
I	30.8	34.0	37.0	39.8	42.5
II	19.3	22.0	24.6	27.1	29.5
III	19.4	22.1	24.7	27.2	29.5
IV	2.8	4.6	6.2	7.9	9.4
V	6.8	8.8	10.8	12.6	14.5

[1] Bias calculated as follows:

- Example for bias level of 20%.
- Station III: 89 salmon age 4_2, from 376 total samples.
- 89 salmon x 1.20 bias = 106.8 adjusted age 4_2 salmon.
- (106.8 - 89) + 376 = 393.8 adjusted total samples.
- $\frac{106.8 \text{ adj. age } 4_2}{393.8 \text{ adj. total}}$ = .271 adjusted proportion age 4_2.
- $\frac{.271 - .111}{.649}$ x 100% = 24.6% Wood River stock.

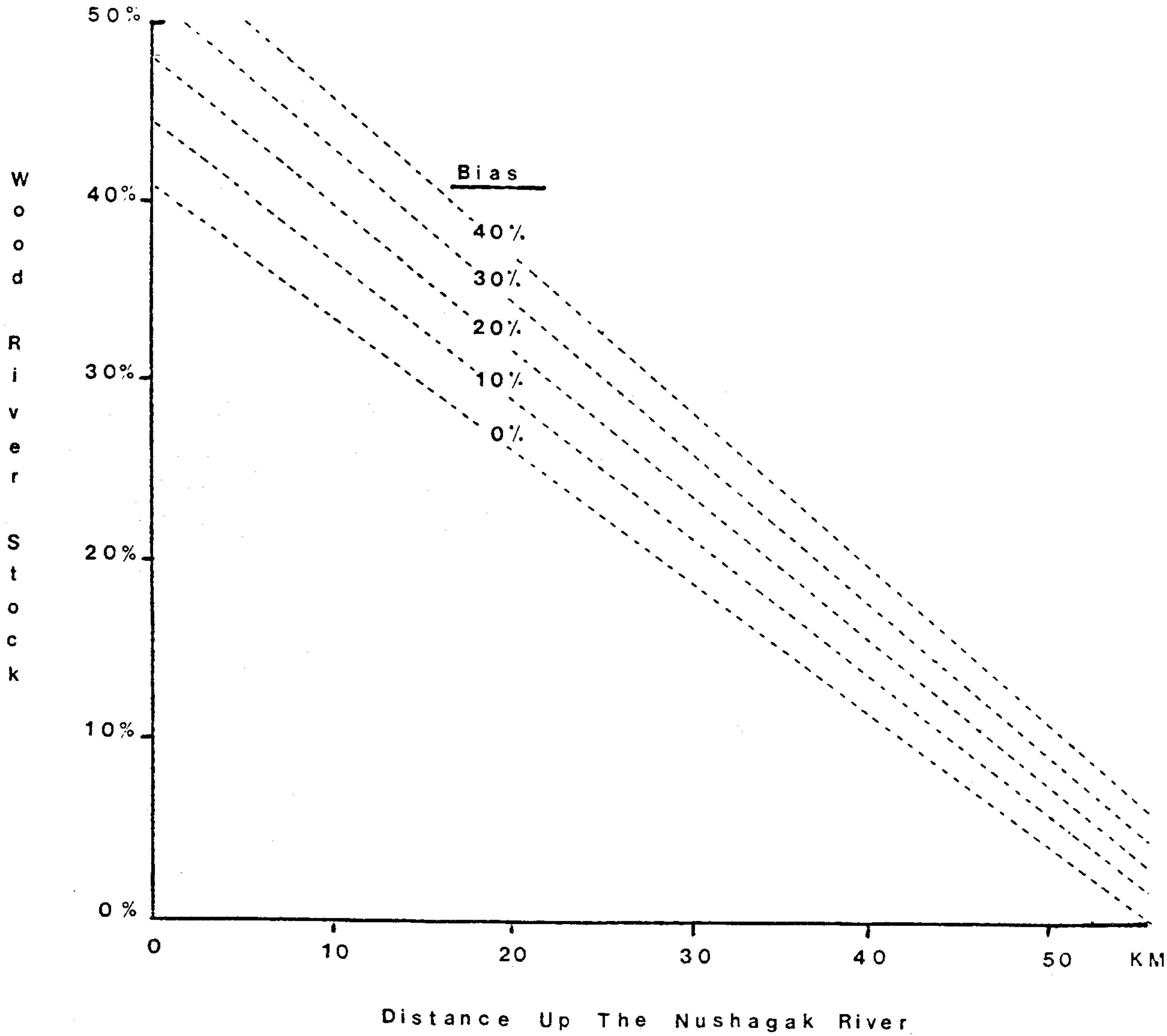

Figure 6. Effect of gillnet bias on estimates of the percentage of Wood River stock in the lower Nushagak River, as allocated by age composition.

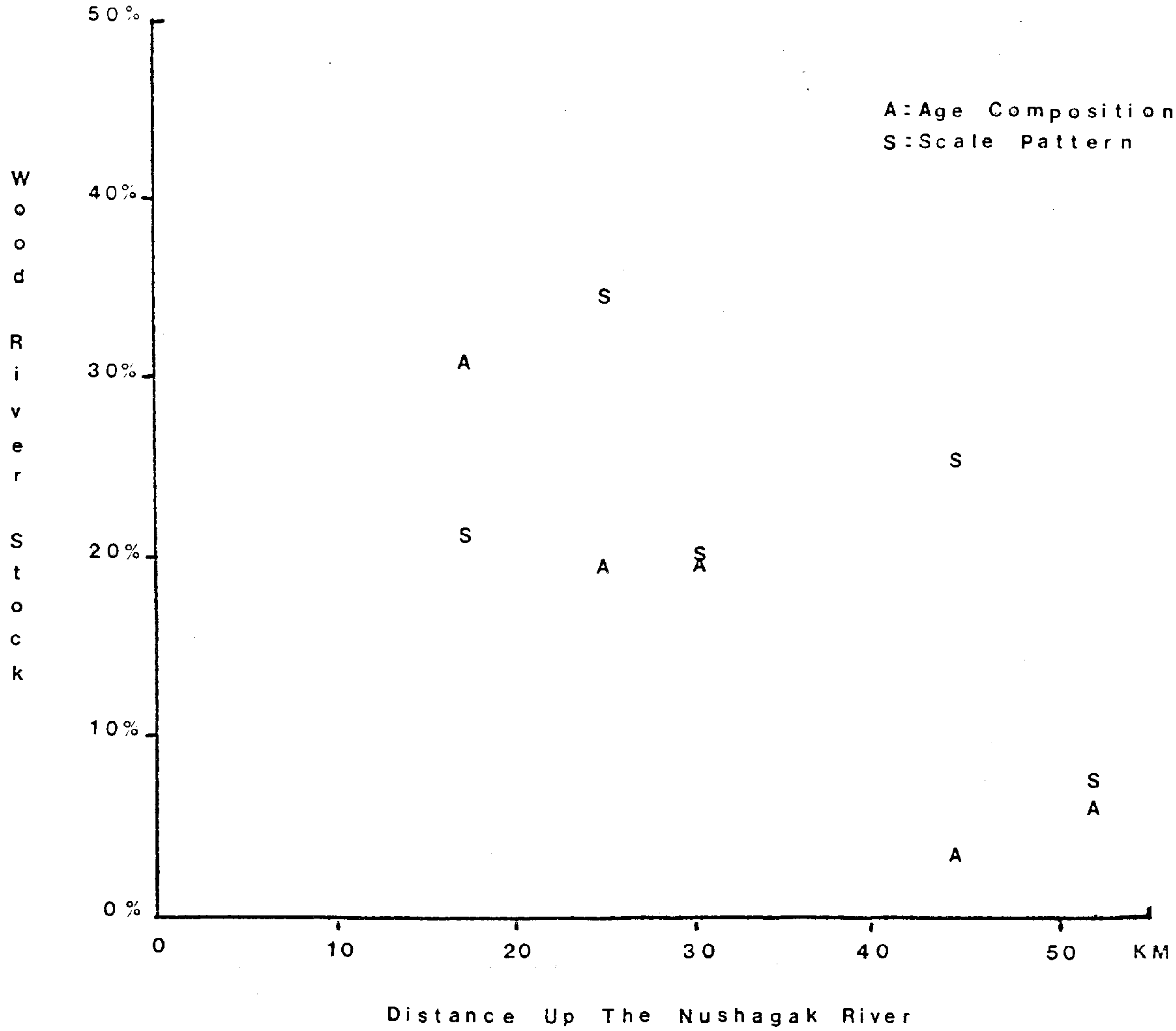

Figure 7. Comparison of the results of scale pattern analysis and age composition analysis in estimating the percentage of Wood River stock at the five stations on the lower Nushagak River.

Wood River. The exact percentage of Wood River stock at any single point along the river must vary with tide stage, stage of the run, and certainly between years. A precise estimate of the percentage of Wood River stock occurring at any point along the river is of little value. It is the trend that indicates the upstream limit of the occurrence of the Wood River stock.

The age class analysis trend indicated that some Wood River sockeye salmon occurred in lower Nushagak River as far as 55.4 km above the mouth of the Wood River. It is my conclusion that the sonar enumeration project should be located at least this far upstream. If the sonar project must be located downstream from this point, then it can be expected that some sockeye salmon of the Wood River stock will be enumerated.

The situation of non-natal salmon stocks occurring in the lower reaches of rivers is probably wide spread and should be considered in designing any escapement sampling or enumeration projects. The results of this investigation can not be applied directly to other situations but might be used as an example of the extent of straying which can occur. The methodology presented here could be applied to other situations to resolve similar objectives.

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LITERATURE CITED

Anas, R.E. and S. Murai. 1969. Use of scale characters and a discriminant function for classifying sockeye salmon *(Oncorhynchus nerka)* by continent of origin. Int. North Pac. Fish. Comm., Bull. 26:157-192.

Amos, M.H., R.E. Anas, and R.E. Pearson. 1963. Use of discriminant function in the morphological separation of Asian and North American races of salmon. *Oncorhynchus gorbuscha* (Walbaum). Int. North Pac. Fish. Comm., Bull. 11:73-100.

Becker, C.D. 1962. Estimating red salmon escapements by sample counts from observation towers. Fish. Bull. 61:355-369.

Bethe, M.L. and P.V. Krasnowski. 1979. Stock separation studies of Cook Inlet sockeye salmon based on scale pattern analysis, 1977. Alaska Department of Fish and Game, Informational Leaflet No. 180, 31 pp.

Bethe, M.L., P.V. Krasnowski, and S. Marshall. 1980. Origins of sockeye salmon in the upper Cook Inlet fishery 1978 based on scale pattern analysis. Alaska Department of Fish and Game, Informational Leaflet No. 186, 45 pp.

Bilton, H.T. 1970. Data and computations used in racial analysis of age 1.2 and 1.3 North American sockeye on the basis of their scale characters. Fish. Res. Bd. Can. Tech. Rpt. No. 223, 57 pp.

Bilton, H.T. 1972. Identification of major British Columbia and Alaska runs of even-year and odd-year pink salmon from scale characters. J. Fish. Res. Bd. Canada 29(3):295-301.

Bilton, H.T. and H.B. Messinger. 1975. Identification of major British Columbia and Alaska runs of age 1.2 and 1.3 sockeye from their scale characters. Int. North Pac. Fish. Comm., Bull. 32:109-129.

Bilton, H.T. and G.L. Robins. 1971a. Effects of starvation, feeding, and light period on circulus formation on scales of young sockeye salmon *(Oncorhynchus nerka)*. J. Fish. Res. Bd. Canada, 28(11):1749-1755.

Bilton, H.T. and G.L. Robins. 1971b. Response of young sockeye salmon *(Oncorhynchus nerka)* to prolonged periods of starvation. J. Fish. Res. Bd. Canada, 28(11):1757-1761.

Church, W. 1963a. Red salmon spawning ground surveys in the Nushagak and Togiak districts, Bristol Bay, 1960. Alaska Department of Fish and Game, Informational Leaflet No. 29, 14 pp.

Church, W. 1963b. Red salmon spawning ground surveys in the Nushagak and Togiak districts, Bristol Bay, 1961. Alaska Department of Fish and Game, Informational Leaflet No. 30, 23 pp.

Church, W. and M. Nelson. 1963. Red salmon spawning ground surveys in the Nushagak and Togiak districts - Bristol Bay, 1962. Alaska Department of Fish and Game, Informational Leaflet No. 34, 11 pp.

Clutter, R.I. and L.E. Whitesel. 1956. Collection and Interpretation of sockeye salmon scales. Int. Pac. Fish. Comm., Bull. 9:1-159.

Cook, R.C. 1982. Estimating the mixing proportion of salmonids with scale pattern recognition applied to sockeye salmon *(Oncorhynchus nerka)* in and around the Japanese landbased driftnet fishery. Ph.D. Dissertation, Univ. of Washington, Seattle. 264 pp.

Cook, R.C. and G. Lord. 1978. Identification of stocks of Bristol Bay sockeye salmon by evaluating scale patterns with a polynomial discriminant method. Fish. Bull. 76(2):415-423.

Cousens, N.B.F., G.A. Thomas, C.G. Swan, and M.C. Healey. 1982. A review of salmon escapement estimation techniques. Canadian Technical Report of Fisheries and Aquatic Sciences, 1108. 122 pp.

Cross, B.A., S.L. Marshall, T.L. Robertson, G.T. Oliver, and S. Sharr. 1981. Origins of sockeye salmon in the upper Cook Inlet fishery of 1979 based on scale pattern analysis. Alaska Department of Fish and Game. Tech. Data Report No. 58, 76 pp.

Dark, T.A. and B.J. Landrum. 1964. Analysis of 1961 red salmon morphological data. Int. North Pac. Fish. Comm., Annual Rep. 1962:110-115.

DeLacey, A.C., L.R. Donaldson, and E.L. Brannon. 1969. Homing behavior of chinook salmon. Contributions Univ. Washington Coll. Fish. 300:59-60.

Fisher, R.A. 1936. The use of multiple measurements in taxonomic problems. Ann. Eugen. 7:179-188.

Foerster, R.E. 1968. The sockeye salmon, *Oncorhynchus nerka*. Bull. Fish. Res. Board Canada, 162-422 pp.

Fukuhara, F.M., S. Murai, J.J. Lalanne, and A. Sribhibhadh. 1962. Continental origin of red salmon as determined from morphological characters. Int. North Pac. Fish. Comm., Bull. 8:15-109.

Gilbert, E.H. and W.H. Rich. 1927. Second experiment in tagging salmon in the Alaska Peninsula fisheries reservation, summer 1923. Bull. U.S. Bur. of Fisheries, 42:27-75.

Gilbert, J.R. 1968. Surveys of sockeye salmon spawning populations in the Nushagak district, Bristol Bay, Alaska, 1946-1958. Pages 111-138 in R.L. Burgner, editor. Further Studies of Alaska Sockeye Salmon. University of Washington Publications in Fisheries New Series, Vol. III, 267 pp.

Hasler, A.D. 1966. Underwater Guideposts - Homing of Salmon. Univ. Wis. Press, Madison, 155 pp.

Hasler, A.D. and A.T. Scholz. 1983. Olfactory imprinting and homing in salmon. Springer-Verlag, New York, 134 pp.

Hasler, A.D. and W.J. Wisby. 1951. Discrimination of stream odors by fish and relation to parent stream behavior. Am. Nat. 85:223-238.

Hara, T.J. 1970. An electrophysiological basic for olfactory discrimination in homing salmon: a review. J. Fish. Res. Bd. Canada, 29:569-586.

Harden-Jones, F.R. 1968. Fish migration. Arnold Press, London. 325 pp.

International North Pacific Fisheries Commission. 1963. Annual Report. 1961: 167 pp.

Johnson, R.A. and D.W. Wichern. 1982. Applied multivariate statistical analysis. Prentice-Hall, Englewood Cliffs, New Jersey. 594 pp.

Jones, J.D. and G. Thomason. 1984. U.S./Canada salmon stock interception research southern Southeastern Alaska pink salmon *(Oncorhynchus gorbuscha)* tagging study, 1982. Alaska Department of Fish and Game, Informational Leaflet No. 231. 12 pp.

Kleerekoper, H. 1969. Olfaction in fishes. Indiana Univ. Press, Bloomington. 222 pp.

Konovalof, S.M. 1975. Differentiation of local populations of sockeye salmon *Oncorhynchus nerka* (Walbaum). (Translated from Russian by Leda V. Sagen.) Univ. Wash. Publ. Fish., New Ser. 6. 290 pp.

Krasnowski, P.V. and M.L. Bethe. 1978. Stock separation studies of Alaskan salmon based on scale pattern analysis. Alaska Department of Fish and Game, Informational Leaflet No. 175, 37 pp.

Major, R.L. and D.R. Craddock. 1962. Marking sockeye salmon scales by short periods of starvation. U.S. Fish and Wildlife Serv., Special Scientific Report -- Fisheries No. 416, 12 pp.

Major, R.L., S. Murai, and J. Lyons. 1975. Scale studies to identify Asian and western Alaska chinook salmon. Int. North Pac. Fish. Comm., Annual Rep. 1973:80-91.

Marshall, S.L., G.T. Oliver, D.R. Bernard, and S.A. McPherson. 1984. Accuracy of scale pattern analysis in separating major stocks of sockeye salmon *(Oncorhynchus nerka)* from southern Southeastern Alaska and northern British Columbia. Alaska Department of Fish and Game, Informational Leaflet No. 230, 28 pp.

Mason, J.E. 1966. Sockeye salmon scale studies. Int. North Pac. Fish. Comm., Annual Rep. 1964:117-118.

Mathisen, O.A., R.L. Burgner, and T.S.Y. Koo. 1963. Statistical records and computations on red salmon *(Oncorhynchus nerka)* runs in the Nushagak District, Bristol Bay, Alaska, 1946-59. U.S. Fish and Wildlife Service, Special Scientific Report - Fisheries No. 468, 32 pp.

McBride, D.N. 1978. Igushik River inside test fishing, 1976-1978. Division of Commercial Fisheries, Alaska Department of Fish and Game, Bristol Bay Data Report No. 67, 45 pp.

McBride, D.N. and S.L. Marshall. 1983. Feasibility of scale pattern analysis to identify the origins of chinook salmon *(Oncorhynchus tshawytscha* Walbaum*)* in the lower Yukon River commercial gillnet fishery, 1980-1981. Alaska Department of Fish and Game, Informational Leaflet No. 208, 64 pp.

McGregor, A.J., S.A. McPherson, and S.L. Marshall. 1983. Feasibility of determining the origin of sockeye salmon *(Oncorhynchus nerka)* in the Taku-Snettisham gillnet fishery using scale pattern analysis, 1981-1982. Alaska Department of Fish and Game, Informational Leaflet No. 219, 23 pp.

McGregor, A.J. and S.L. Marshall. 1982. Origins of chum salmon *(Oncorhynchus keta)* in the Excursion Inlet purse seine fishery 1981 based on scale pattern analysis. Alaska Department of Fish and Game, Informational Leaflet No. 201, 34 pp.

Metsker, H. 1967. Red salmon spawning ground surveys in the Nushagak and Togiak districts, Bristol Bay, 1964. Alaska Department of Fish and Game, Informational Leaflet No. 108, 37 pp.

Middleton, K.R. 1983. Bristol Bay salmon and herring fisheries status report through 1982. Alaska Department of Fish and Game, Informational Leaflet No. 211, 81 pp.

Mosher, K.H. 1972. Scale features of sockeye salmon from Asian and North American coastal regions. Fish. Bull. 70(1):141-183.

Nelson, M. 1964. Spawning ground survey of red salmon eggs and larvae in Bristol Bay, 1963. Alaska Department of Fish and Game, Informational Leaflet No. 40, 7 pp.

Nelson, M. 1966. Red salmon spawning ground surveys in the Nushagak and Togiak districts, Bristol Bay, 1965. Alaska Department of Fish and Game, Informational Leaflet No. 84, 40 pp.

Nelson, M. 1967. Red salmon spawning ground surveys in the Nushagak and Togiak districts, Bristol Bay, 1966. Alaska Department of Fish and Game, Informational Leaflet No. 96, 28 pp.

Nie, N.H., et al. 1978. Statistical package for the social sciences. McGraw Hill.

Pella, J.J. and T.L. Robertson. 1979. Assessment of composition of stock mixtures. Fish. Bull. 77(2):387-398.

Pennoyer, S. 1967. Bristol Bay red salmon *(Oncorhynchus nerka)*, 1966 - A compilation of catch and escapement data. Alaska Department of Fish and Game, Informational Leaflet No. 94, 97 pp.

Randall, R. and H. Yuen. 1978. Bristol Bay sockeye salmon *(Oncorhynchus nerka)* 1975 - A compilation of catch and escapement data. Alaska Department of Fish and Game, Technical Data Report No. 40, 71 pp.

Ricker, W.E. 1972. Hereditary and environmental factors affecting certain salmonid populations. Pages 19-160 in Simon and P.A. Larkin, editors. The stock concept in Pacific salmon. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver, B.C. 231 pp.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Bd. Canada No. 191. 382 pp.

Ricker, W.E. and A. Robertson. 1935. Observations on the behavior of adult sockeye salmon during the spawning migration. The Canadian Field Naturalist, 49(8):132-134.

Scarnecchia, D.L. 1979. Variation of scale characters of coho salmon with sampling locations on the body. Prog. Fish-Cult. 41(3):132-135.

Seibel, M.C. 1967. The use of expanded ten-minute counts as estimates of hourly salmon migration past counting towers on Alaskan rivers. Alaska Department of Fish and Game, Informational Leaflet No. 101, 35 pp.

Sharr, S. 1983. Separating major runs in the Copper River-Bering River sockeye salmon *(Oncorhynchus nerka)* fishery with scale pattern analysis. Alaska Department of Fish and Game, Informational Leaflet No. 218, 23 pp.

Straty, R.R. 1960. Methods of enumerating salmon in Alaska. Pages 286-296 in Transactions of the Twenty-Fifth North American Wildlife Conference. Wildlife Management Institute, Washington.

Tanaka, S., M.P. Shepard, and H.T. Bilton. 1969. Origins of chum salmon *(Oncorhynchus keta)* in offshore waters of the North Pacific in 1956-1957 as determined from scale studies. Int. N. Pac. Fish. Comm. Bull. 26:115-156.

Thompson, W.F. 1962. The research program of the Fisheries Research Institute in Bristol Bay, 1945-1958. Pages 247-314 in T.S.Y. Koo, editor. Studies of the Alaskan Red Salmon. University of Washington Press. Seattle, Washington. 472 pp.

U.S. Army Corps of Engineers. 1957. Harbors and rivers of southwestern Alaska. U.S. Government Printing Office, Washington. (84th Congress, Second Session. House Document No. 390). 89 pp.

Van Alen, B.W. 1981. 1980 Nushagak Bay offshore test fishing. Pages 64-73 in H.H. Yuen, editor. 1980 Bristol Bay Salmon Test Fishing Projects, Alaska Department of Fish and Game, Technical Data Report No. 65, 73 pp.

Wilcock, J.A. and D.N. McBride. 1983. Origins of chinook salmon *(Oncorhynchus tshawytscha* Walbaum*)* in the Yukon River fisheries, 1982. Alaska Department of Fish and Game, Informational Leaflet No. 226, 36 pp.

Worlund, D.D. and R.A. Fredin. 1962. Differentiation of stocks. Pages 143-153 in N.J. Wilimovsky, editor. Symposium on pink salmon. H.R. MacMillan Lectures in Fisheries, Univ. Bristish Columbia, Vancouver.

Yuen, H.J. and M.L. Nelson. 1983. Bristol Bay *(Oncorhynchus* sp.*)* - 1978. A compilation of catch and escapement data. Alaska Department of Fish and Game, Technical Data Report No. 88, 119 pp.

APPENDIX A

The following is an overall outline of the generalized scale pattern analysis methodology. A flow diagram is also included to demonstrate the dynamics of the process.

1. A random unbiased scale sample is collected from known numbers of each stock which might possibly occur in the mixed population. These samples are designated as known samples.

2. The scale samples are aged and the age composition of each stock is calculated. Because scale characteristics vary between age classes, only samples of the dominate age class taken across all stocks, are used for the remainder of the analysis.

3. One or more scale characteristics are measured from each remaining sample. The group membership and each scale characteristic measurement is recorded as a variable, thus establishing a data case for each fish, a data group for each stock, and a data set for the entire population.

4. Descriptive statistics are calculated for each variable across each data group and the entire data set. Upon review of these statistics, the researcher may wish to modify the data set in one of the following ways:

   A. Transformations; modifying variables to reduce the variance or improve conformity to normality.

      (1) Scaling

      (2) Weighting

   B. Reductions; selecting only the best variables.

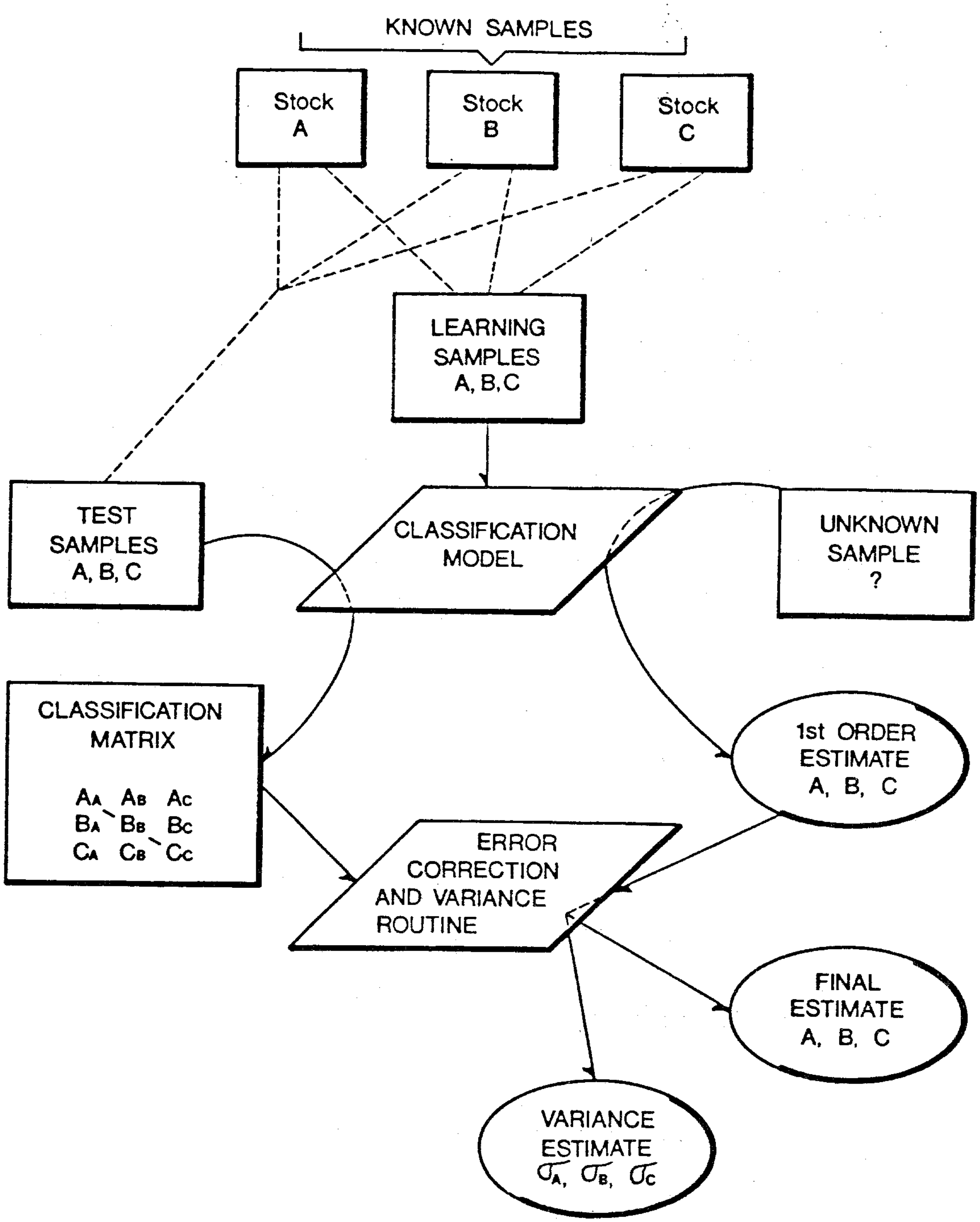
   C. Combinations; combining variables to create new ones.

5. Each data group is then randomly divided into two subgroups. One subgroup is designated as a learning sample and the other is designated as a test sample.

6. The learning samples are used to create a classification model. This model is some set of mathematical rules which then applied to a data case, predict the most probable group (stock) origin. Techniques for creating these rules include discriminant function analysis, Bayesian classification, and nearest neighbor classification.

7. The accuracy of the model is then tested by classifying the test samples. Thus, a classification matrix, an unbiased estimation of classification errors, is calculated for the model.

8. If the accuracy of the model is sufficient to reliably distinguish between the stocks, the stock composition of an unknown sample, obtained from a population of mixed stocks, may be calculated.



Flow chart of stock identification methods.

9. The unknown sample is collected and processed exactly as described in steps 1 through 4 above thus creating an unknown data group.

10. A first order estimate of stock composition is created by classifying the unknown data group with the classification model.

11. A second order estimate of stock composition is then calculated by correcting the first order estimate by the estimate of classification errors (classification matrix).

12. Estimates of the variance and confidence intervals of the second order estimates may also be calculated.

A few limitations of this technique should be noted. Each data case may only be classified to one of the groups which were included within the model. If an unknown sample contains scales from salmon of stocks which aren't included in the known samples, an erroneous stock composition estimation will be calculated. If the percentage of external samples within an unknown data group is small, the resulting error will also be small. The total contribution of minor stocks and stocks from other geographical areas must be considered when designing a stock identification program.

The accuracy of this technique and thus its reliability is directly related to the number of groups represented in the classification model. As the number of groups represented in the model increases, the number of possible errors in classification also increases. If everything else is equal, a model containing two groups will classify more accurately than a model containing three or more groups.

Once a stock composition estimate is calculated for an uknown sample based upon all possible stocks, it is possible to eliminate from the model the groups which either aren't present in the estimate or are present at very low frequencies, the model may then be recalculated. The revised estimate will contain a small bias due to the minor occurrence of external groups but the composition estimates of the remaining groups will be more precise. In most cases, this is an acceptable trade-off because management decisions are usually based on the stocks which are most abundant in a mixed stock population. However, this procedure is not advisable if the researcher is interested in an accurate estimation of the percentage of a stock which occurs at a low frequency in the mixed stock population.