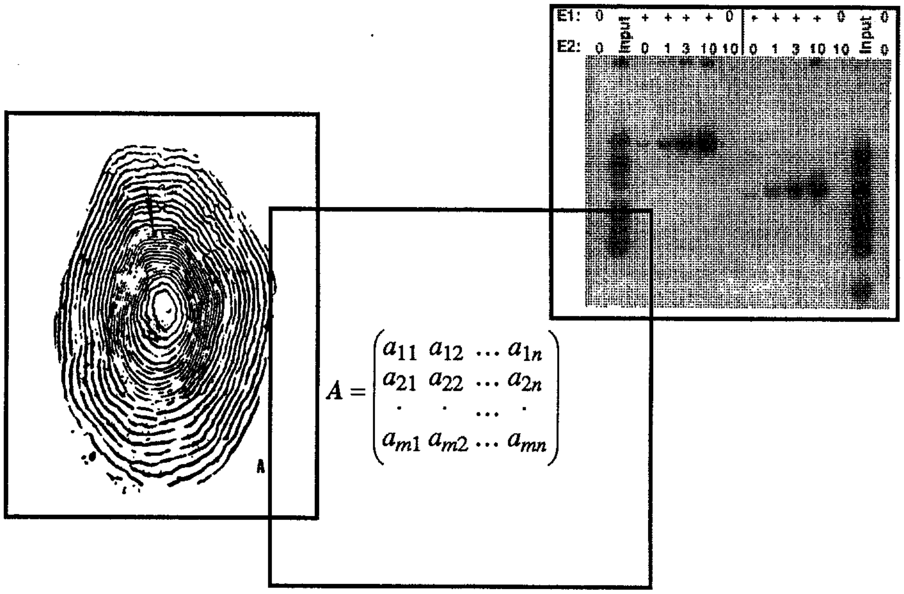
PROCEEDINGS OF
THE 1990 ALASKA STOCK SEPARATION WORKSHOP

Anchorage, Alaska
February 14-16, 1990



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Edited by

Harold J. Geiger

and

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Special Fisheries Report No. 2

Alaska Department of Fish and Game
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Kathleen Jensen and Ken Tarbox both independently suggested that this meeting should be held. Norma Jean Sands and Ben Van Alen provided support and help with planning. We especially thank Jerome Pella, Anthony Gharrett, Adam Moles, Eric Volk, Tim Mulligan, Lee Blankenship, Curt Knudsen, Dick Wilmont, Trey Walker, and Matt Cronin, and the speakers from within ADF&G for their presentations. We are also grateful to the late Hooter Rowell, an Alaskan stock separation pioneer.

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FOREWORD

In the late 1970s the Alaska Department of Fish and Game (ADF&G), Division of Commercial Fisheries, instituted a statewide stock separation project under the auspices of the office of the Chief Fisheries Scientist. Later called the Statewide Stock Biology Group, this group operated separately from the rest of the research structure the division and was responsible for great improvements in data collection and reporting. After a number of initial successes, and some failures, the stock project was decentralized in 1987. While the new decentralized structure has had some advantages, it has lessened the interchange between stock separation researchers around the state.

On February 14-16 1990, a workshop on stock separation methods was convened in Anchorage. The majority of the talks were given by ADF&G managers and researchers; speakers were also invited from outside the department representing the National Marine Fisheries Service's Auke Bay Laboratory, the University of the Alaska, the U.S. Fish and Wildlife Service, the Washington Department of Fisheries, the University of Washington's Fisheries Research Institute, and the Canadian Department of Fisheries and Oceans Laboratory at Nanaimo. The invited speakers included Lee Blankenship, Anthony Gharrett, Curt Knudsen, Adam Moles, Tim Mulligan, Jerome Pella, Eric Volk, Dick Wilmont, and Trey Walker.

The meeting opened with a review of research and fisheries issues related to stock separation problems in Alaska. This part of the meeting consumed the first day. On the second day, which ran well into the evening, talks covered ongoing work and new techniques. Many attending reported the high point of the meeting was when Adam Moles's slides on intestinal parasites of sockeye salmon coincided with the arrival of pizza during the evening talks—both turned out to be good. The final day included a discussion of scale pattern analysis and an informal discussion of unmet needs and directions for future growth in stock separation programs. The discussion of unmet needs and future directions led to the development of three work groups: a group working on statistical sampling, a group working on otolith marking of hatchery salmon, and a group working on model building. The products of the work groups' efforts are included in this report.

The sampling work group's report summarizes the historic development of sampling rationale in ADF&G'S fisheries research in support of salmon management. Mel Seibel and Dave Bernard made notable contributions to this effort. Steve Thompson's work on sample size determination is summarized, and the work group makes recommendations on sample size determination based on Thompson's work. This group recommends that the common practice of assuming that samples are simple random samples when they often clearly are not should be discouraged. A practice that has been called "pulse sampling," is the procedure of taking a grab sample from a population that is accessed over time, in a single cluster compressed in time. This group recommended that this practice also be abandoned for general use in place of sampling that is more representative and closer to a random sample. An obvious example of this is the sampling of salmon scales to characterize the age composition of an escapement stratum that covers several weeks. Rather than a single sample of 600 scales collected over two days, the sampling work group recommends collecting these scales over the entire several weeks, with each days sampling effort approximately proportional to the number of fish in the escapement on that day. The sampling work group also recommends greater quality control effort for the aging of scales.

The model building work group did not produce a report, as such, on model building, but rather provided an extensive bibliography. One valuable feature of this bibliography is that it is filled with many examples of successful stock separation projects, as well as theoretical works. The bibliography includes the often cited articles on theory and methods, including Cook and Lord (1978) and Millar (1985); these describe the theoretical basis for ADF&G's current work on scale patterns.

The work group on otolith marking produced a report which included twelve concerns and recommended actions. As one of these recommended actions, the work group recommends against using otolith marks in new mass marking projects until a processing system is in place and rules established for their use. The work group does point out that fish have already been marked with otolith marks at the Snettisham Central Incubation Facility (sockeye salmon), at the Auke Creek Hatchery (pink salmon), and at the Solomon Gulch Hatchery (pink salmon). This group calls for a single statewide, cross-divisional, entity to coordinate the development of the mass marking technique, although it remains to be seen who this entity is.

At the workshop it was revealed that mass marking techniques could involve sample size requirements orders of magnitude lower than current requirements. To estimate the proportional contribution of hatchery stocks, it may be that only 100 fish would need to be sampled out of thousands or hundreds of thousands of fish captured in a fishery if these 100 fish were from a truly random sample. This means that mass marking provides new challenges to implement the sampling theory discussed by the sampling work group, and that tremendous cost savings as well as improved accuracy could result from research into the practical aspects of drawing a random sample of fish moving into processing channels.

Lee Blankenship was asked to provide an outsiders perspective on ADF&G's stock separation program. Blankenship found some familiar aspects of our program and some unfamiliar. In the end, he was struck by our non-use of genetic stock identification methods, which he reports have been used successfully in Oregon and Washington. He feels that we have become too attached to scale pattern analysis and coded-wire tagging.

Hal Geiger
Workshop Organizer

SECTION I

REPORT FROM THE WORK GROUP ON SAMPLING

REPORT FROM THE WORK GROUP ON SAMPLING

By Harold J. Geiger (chair), John E. Clark,
Bev Cross, and Scott McPherson.

An Overview of the Development of Scientific Sampling

Today the notion of a random sample is ubiquitous in the sciences, technology, and engineering. Even so, the notion is almost universally misunderstood, incorrectly implemented, or both. Often in fisheries research, as well as many other kinds of research, the term *random* is gratuitously added to the word sample, regardless of how the sample was collected. In their book on statistical methods Steel and Torrie (1960) describe the process of *probability sampling*:

1. Each sampling unit has or is assigned a known probability of being in the sample.

2. There is a random selection at some stage of the sampling procedure, and it is directly related to the known probabilities. Random selection will involve a *mechanical procedure* for choosing the units to be included in the sample.

3. The method for computing any estimate of a mean is clearly stated and will lead to a single value of the estimate.

Later Steel and Torrie go on to define a *simple random sample* as a probability sample in which each sample has the same probability of being selected.

As late as the 1920s many respected scientists professed that sampling for mean characteristics of a population should be done by selecting groups that seem representative of the population (Jensen 1926). This method was thus named *purposive* sampling. The arguments by R.A. Fisher and his followers, such as William Cochran, eventually drove out this ideology and replaced it with the ideology of the *principle of randomization* which was applied to both experimental science and to sampling. The ideology of randomization eventually dominated partly because of the ascendancy of the study of variation. Fisher (1970) described the new thinking in his landmark book, which originally appeared in 1925:

> The conception of statistics as the study of variation is the natural outcome of viewing the subject as the study of populations . . . To speak of statistics as the study of variation also serves to emphasize the contrast between the aims of modern statisticians and the predecessors. For until comparatively recent times, the vast majority of workers in this field appear to have had no other aim than to ascertain aggregate, or average values. Variation itself was not an object of study, but was recognized rather as a troublesome circumstance which detracted form the value of the average.

We now know that a sample that was selected so that each unit in the population had an equal chance of selection will have two important properties: first, the sample is *guaranteed* to be representative, on average. More importantly, the sample will contain an internal means of assessing the degree of error in the representation. With random selection the sample will have approximately captured the same variation between units that exists in the population. That approximation will be within random sampling error. We now know how to transform this variation between units in a random sample into measures of precision. These measures of precision are conventionally expressed as *confidence intervals* (Fisher 1970; Steel and Torrie 1960).

Random sampling is not always appropriate. For example, to determine what is causing an epizootic, sick and moribund animals should be purposefully collected and examined. Even though purposive selection of sick animals is essential to establish the cause of the illness, this kind of sample will be of absolutely no use in determining what the incidence of the disease is in the affected population once the causative agent has been identified.

By the late 1940s the proponents of random sampling were in complete control of the scientific ideological mainstream, if not in control of the actual practice. In a report on the state of biometrics at the time Cochran (1950) wrote about the state of sampling: "So far as the *use* of these methods in biological research is concerned, my impression is that the situation is less than satisfactory, in that there is often a tendency to ignore the sampling problem."

In 1950, at the request of the National Research Council, the American Statistical Association appointed a committee of prominent statisticians to review the Kinsey Report (*Sexual Behavior in the Human Male*, W.B. Saunders and Co, 1948). The statisticians were William Cochran, Frederick Mosteller, and John Tukey. This committee reported their findings and eventually produced several publications on the current state of sampling practices (Cochran et al. 1953). In a paper that was part of that series (Cochran et al. 1954), the committee wrote:

> In the early years of the present century it was not uncommon to measure the claws and carapaces of 1000 crabs, or to count the number of veins in each of 1000 leaves, and then attach to the results the "probable error" which would have been appropriate had the 1000 crabs or the 1000 leaves been drawn at random from the population of interest. Such actions were unwarranted shotgun marriages between the quantitatively unsophisticated idea of sample as "what you get by grabbing a handful" and the mathematical precise notion of a "simple random sample." In the years between we have learned caution by bitter experience.

In the closing decade of this century "grab sampling", the same practice that the committee felt was out of date at the time of their writing, is still very common in Alaskan fisheries research. We frequently, for example, sample fish processed on the first day of a week and treat this sample as if it were a random sample of all fish caught throughout the week, even though during the week there were openings, closures, or the fishing fleet experienced changes in deployments or stock exploitation rates. In other instances the randomization is introduced but not in the selection of the basic elements of the population. For example, perhaps a day of the week is chosen at random, and then a non-random sample of anglers fishing on that day is selected. The sample might then be incorrectly reported as a random sample of anglers that fished in that week. The authors of this 1954 report go on to point out the obvious: that estimates of variability from grab samples tend to grossly *underestimate* the variability in the population of interest when the sample is treated as a random sample for purposes of variance calculation. It is not uncommon for tedious discussions of the computational aspects of assigning confidence intervals or selection a sample size to rage on, while the most basic assumption of all, that of the random sample, goes unchallenged and unnoticed.

It is obviously not practical, or even desirable, to achieve the perfect idea of a simple random sample in every sample that is examined in fisheries research in Alaska. However, when a grab sampling approach is employed, the sophisticated investigator will need to realize that assessing the error in the resulting estimates will involve more than a simple mechanical calculation. Often, the sampling procedure will allow no valid estimate of precision, and any resulting confidence intervals are simply wrong.

The basic principles of sampling, as we now know it, are laid down in Cochran's (1977) book. This book includes the topics of simple random sampling, stratified random sampling, cluster sampling, and systematic sampling, which collectively cover most idealized sampling situations in fisheries research.

Random Sampling and Its Variations

Simple Random Sampling

In this sampling situation each unit in the population is somehow identified and numbered *before* the sampling is conducted. In the jargon of sampling, each item in the population of interest is called a sampling unit. Then, through the cast of a die, by a pseudo-random number generator in a computer, or through some other strict probability mechanism, n of these numbers are selected one at a time without replacing the selected numbers before each subsequent selection. If each unit in the population has the same probability of selection in the random selection, then the units in the population associated with the selected numbers constitute the *simple random sample*. A population accessed any other way will not result in a simple random sample.

Stratified Random Sampling

In this case the population of interest is simply divided into smaller groupings called strata, and a simple random sample is collected in each stratum. As originally envisioned, similar sampling units are grouped into the same strata. This sampling scheme results in variation between strata being "removed" from the estimated population mean. The variance of the estimated population mean will become smaller the more dissimilar the strata means are from each other. At some point of dissimilarity between strata, the stratified random sampling will be more precise than simple random sampling. An important but unobvious result is that stratified random sampling will be less precise than random sampling if the strata are not dissimilar. For a more formal and precise description of what is meant by similar, dissimilar, and removing between strata variation, see Cochran (1977).

A population, such as a catch of fish in an entire season, is often stratified by time and fishing district. In Alaskan Fisheries research, this is done to more nearly meet the assumption of random sampling. For example, when the catch of fish occurs over a wide are, fish from one sub-area may be very different. If fish from different sub-areas tend to be sampled at different processors, then the sampling rate in the different sub-areas will be determined by the staffing levels and industriousness of the samplers at the different processors. Unless the catch is stratified by sub-areas or processors, the sampling rate will determine the influence that each sub-area will have on eventual estimates.

Multistage sampling or subsampling

In this case each unit in the population is grouped into an aggregation. These aggregations then themselves form a population of aggregations. In the first stage of sampling, a random sample of aggregations is selected. In the next stage of the sampling, units within aggregations are randomly selected. This processes can be generalized to more than two stages. The process of selecting a sample within an aggregation is called subsampling, and the second stage sample is called a subsample. For example, to determine the age composition of a catch, five length groups might be defined. Then a sample of 500 fish might be drawn from the entire catch and each fish measured for length. Finally, scales might be subsampled for age determination: i.e., only scales from 20 randomly selected fish in each length group would be read. These 20 fish in each of the five length groups would then be called the second stage sample, or the subsample.

Cluster sampling

Cluster sampling is an idea closely related to multistage sampling. In this case units in the population are thought to fall into groups of units or clusters. Often the units in the clusters cannot be selected individually by a random process, but the cluster itself can. Usually the measurements within the cluster are correlated (either positively or negatively); the intercluster correlation is an important measure of this and is used to determine appropriate sample sizes. In Alaskan fisheries, this kind of sample comes up naturally in hydroaccustic surveys of fish density. Here a transect may be selected at random. As the sonar passes over the transect, the echoes within the transect constitute a cluster.

Other Sampling Methods

Systematic Sampling

In this situation the population is placed in some kind of order, then every i^{th} unit in the population is selected by a single serial pass through the population. Often this method will have greater precision than simple random sampling, although no valid general means exist to estimate the precision in a systematic sample. However, if the sample can be broken into several systematic samples of smaller size then the precision can be estimated. In those situations each of several systematic samples are started at random, then each sample is a replicate, and the variation between replicates provides a valid means of computing the precision.

Grab or Haphazard Sampling

In this situation the sample is collected without a strict randomization protocol. Needless to say, this seems to be the most common sampling procedure in the world, if not in Alaskan fisheries research. In some cases, the population of interest is nearly in random order; if so, grab sampling is nearly indistinguishable from random sampling. If not, grab sampling will be far from representative of the population. Often, if not usually, grab samples will lead to greater bias in the estimates of precision than in estimates of central tendency, although estimates of both are almost always biased with grab samples.

Pulse or Snapshot Sampling

In this case, a population is passing through some access point over time. A sample is then selected in a small time interval. For example, fish caught in some fishery may be sampled on the Wednesday of the week, and that sample is then used to characterize the catch of the entire week. Or perhaps scales from the first half of the escapement of a salmon run are collected on a single day. This is actually a type of grab sample, but it can also be thought of as a cluster sample, where the cluster was not chosen at random, and only one cluster is selected from the population. It should be noted that if a population is changing through time, two pulse samples spread widely apart will provide greater power for detecting that change than will a random sample, a systematic sample, or two grab samples spread closely in time.

Purposive Sampling

In this situation the sampler goes to the population and selects units purposefully selects units that seem representative of the population. Originally, this term was used to mean something nearer to the selection of clusters that were thought to be similar to the overall population. As mentioned above, in the last century it was usually believed that when sampling for population characteristics, that "typical" units should be purposefully selected.

In trying to follow the development of the current state of sampling in ADF&G, most would regard the modern era as beginning in the early 1980s. Mel Seibel made contributions to sampling in Bristol Bay prior to that period, although the documentation of much of his specific work is now lost. As a result of Seibel's work, sample size requirements in Bristol Bay in the 1970s (McCurdy and Paulus 1972) were explained as follows:

> Statistical analysis of the absolute error incurred in the estimation of the proportion of a given age class in a population indicates that a minimum sample size of 150-200 fish per time period is required. Since considerable differences exists between the age composition of male and female sockeye salmon, sampling requirements are set separately for the two sexes. Taking into account imbalances in sex ratios, and illegible scales, a sample size requirement of 600 fish per time period was set. The time periods were set as a fishing period for commercial catch and three days for the escapement.

Experience seems to have shown that the sample size of 600 scales per strata is a good robust rule of thumb.

In 1982 and 1983, in several in-house memoranda prepared by David Bernard, a basic framework for sample sizes determination for age composition was developed. In 1982 Bernard reviewed sample size requirements to estimate age proportions in a catch or escapement at various levels of precision. Bernard's work was based the binomial distribution and a worst-case scenario of one age group containing 50% of the population. The equation he used to estimate required sample sizes was based on an inverted t-test for large sample sizes ($n > 30$) where n is the size of the sample from a population of size N. Let p_i be the true age proportion for age class i ($i = 1, 2, \ldots k$), d be the deviation from the true level that is to be controlled with sample size, t be a Student's t-distributed variate, and z be a standard normal variate. Then from the sampling properties of the binomial distribution, the following approximation is nearly correct:

$$t=\frac{\hat{p}_i-p_i}{s(\hat{p}_i)}=\frac{d\,n^{1/2}}{[p_i(1-p_i)]^{1/2}}.$$

To control the size of d with probability approximately no smaller than $1-\alpha/2$, t is replaced with the appropriate cumulate of the normal distribution, denoted z^*. Rearranging, solving for n, and letting the normal distribution approximate the Student's t-distribution the approximate sample size is then given by:

$$n=\frac{z^{*2}p_i(1-p_i)}{d^2}.$$

Bernard used the results of Goodman (1965) to establish correct probability levels for the z variate and for the simultaneous estimation for several age groups using Bonferroni's inequality. This involved setting the overall α equal to the sum of α_i, for i extending over all age classes. That is, if $1-\alpha$ is the overall confidence level, and $1-\alpha_i$ is the confidence level for the estimate of the i^{th} age class, then Bonferroni's inequality states

$$\alpha \geq \sum \alpha_i,$$

or alternatively,

$$1-\alpha \leq 1-\sum \alpha_i.$$

For example, for a catch in which there are three age classes, and given that we want to be 90% sure that all of the estimated proportions of catch belonging to each of the 3 age groups are within some distance from the true age proportion, the cumulative standard normal percentage is 96.67%. This is found from Bonferroni's inequality by noting that 1-3(1-0.9667) is approximately equal to 0.90.

Based on these equations Bernard developed and distributed tables of sample sizes needed for different precision and accuracy levels based on the number of age categories and the percentage comprised by the dominant age group.

After reviewing the sample sizes required for various precision levels and considering manpower requirements, John H. Clark, at that time the Chief Fisheries Scientist for the division, decided to set Cochran's α and d at α=0.10 and d=0.05. To attain these precision levels and account for unusable scales, sample sizes were generally set as follows: 600-640 per strata for sockeye and chinook salmon, and 500-560 per strata for chum and coho salmon. Coho and chinook salmon had to be sampled at the rate of 3 or 4 scales per fish to obtain the desired number of usable scales.

During the period of Bernard's work with catch and escapement sampling design, the number and length of sample periods were developed on a fishery-by-fishery basis and differed greatly among fisheries. In general, the number of strata and the length of each strata depended on how fast the age composition changed over time and the duration of the fishery or escapement. To determine sampling strata, historic age composition data was reviewed for changes through time. For short intense fisheries (e.g., Bristol Bay and Cook Inlet) the catch was stratified by fishing period, each usually lasting 12-24 hours. Similarly, for escapements which occurred over a relatively short time span, 2-4 weeks, strata were defined to be fish caught in 3-5 days. Where historical age data showed that the age composition did not change through time, the main part of the season was divided into 3 strata (early, middle, and late). For the first year of the new sampling schemes, the time and area strata were numerous. Results from the first years sampling were reviewed, and generally the number of time and area strata were reduced.

Bernard suggested that sampling within a strata occur over a short period. For example, if an escapement strata covered a period of 3 days, then a single sample day was chosen, and the desired sample size (e.g., 600) for that stratum was all taken during that day. This was done to ensure a relatively precise estimate of the age composition for that instantaneous sampling event. The reasoning was that if the age composition changed gradually through time and if the sample was collected throughout the strata, then differences in age composition between strata would be diluted by within strata variation and might not be detectable.

In an April 1983 memorandum Steve Pennoyer summarizes the response to the Statewide Stock Separation's new thinking on sampling: "[The response] has been everything from appreciation that someone has finally committed these requirements to paper, to statements that we will only do it if it doesn't cost any more money or take any more time." Elsewhere in the memorandum Pennoyer committed the Division of Commercial Fisheries to collect basic data, publish it, and to use it to forecast future population size and model the basic population biology of the herring and salmon and to evaluate management's affect on these resources.

In 1987 Phil Mundy, then Chief Fisheries Scientist, developed a policy statement on sampling for age composition, lengths, etc., for salmon. Mundy pointed out that sampling strategies must be based on the ultimate use of the data, and named these uses as "forecasts, apportionment of catch to system of origin to develop broodtables and so forth." He went on to explain that Cochran's α and d should both be set at 0.05; this required larger sample sizes than had previously been called for by John H. Clark. Equally importantly, Mundy mentioned that "it is always assumed that the projects provide representative samples." There have been few, if any, shifts in policy relating Cochran's α and d from 1987 to the present.

One requirement for determining a sample size for age determination based on the methods of Bernard was either some estimates of the proportional values or, at least, knowledge of the number of age classes in the sample. If the underlying age composition of the catch was unknown, a worst case scenario was assumed where the worst case was previously thought to involve one age class composed 50% of the catch. Sample sizes were determined for this worst case.

Thompson (1987) improved our understanding of sample size by applying Bonferroni's inequality and the normal approximation for a binomial proportion. He mathematically proved that the worst case proportion is not 0.50, which had been used by Bernard and many others, but instead $1/m$, where m is the number of age classes in the catch. This meant that for simple random samples, much of the previous work called for slightly larger samples than was actually required by the stated α and d levels. Thus, for three age classes, p should be set to 1/3 or 0.3333 to solve for n; for four age classes p should be set to 1/4 or 0.250, etc. Thompson also presented a table which gave sample sizes for simultaneously estimating the parameters of a multinomial population within a given distance (d) of the true values at given levels of significance when the number of age classes is unknown (worst case scenario for number of age classes). For a distance of d = 0.05, the sampling sizes and worst case values of m are shown in Table 1.

Table 1. Sample sizes (n) for Simultaneously Estimating the Parameters of a Multinomial Distribution within Distance d of true values with confidence 1-α, with unknown number of categories, m (from Thompson 1987).

Alpha	n	m
0.20	299	3
0.10	403	3
0.05	510	3
0.02	664	2
0.01	788	2

Exact estimates of the precision associated with a given sample size can be calculated, but this involves calculating the probabilities associated with those outcomes which result in an age distribution within the given error distance of the true population age distribution. For example, for a catch which has three age classes present in equal proportion (p = 0.333 for each age), and a fixed sample size of 300, the probability of selecting a random sample which estimates the proportion without error (100 of age 1, 100 of age 2, and 100 of age 3) is 0.00275. The probability of selecting such a sample that results in estimates an error of 0.01 or less for the proportion in each age class is 0.09684. By continuing to add the probabilities of selecting a random sample of 300 fish with all estimates of age distribution within a given interval about the true estimate results in the exact value of sample size required for the worst case where p_i=$1/m$ (Thomson 1987).

Although this method yields exact estimates of (1) precision and confidence and (2) sample sizes required to achieve simultaneous confidence limits about proportions, it is extremely computer-intensive and time consuming, requiring millions of calculations to evaluate even simple sampling programs.

Table 2 summarizes the sampling levels calculated by these three methods for a maximum distance of 0.05 from worst case true proportions.

Table 2. Sample sizes for the worst-case of $p_i = 1/m$, given for selected values of m and α using the approach of Thompson (1987), the approach of Bernard (after Goodman), and by the exact solution.

	Number of Age Classes				
	3	4	5	6	7
Based on Thompson					
α=0.10	403	377	347	319	294
α=0.05	510	468	425	387	355
Based on Goodman					
α=0.10	454	502	543	572	601
α=0.05	572	625	664	695	724
Computer generated exact numerical solution					
α=0.10	360	340	na	na	na
α=0.05	480	440	na	na	na

In summary, the value of 600 scales per stratum seems to be a reasonable answer to the question "How many scales should we take?" in the absence of more detailed information about how the age class information will be used.

Recommendations and Discussion

After discussing the deficiencies in our past sampling program the group developed the following recommendations which will improve statistical sampling in Alaskan fisheries.

1. More attention needs to be paid to the process by which samples are collected.

2. Precision estimates that are appropriate for random samples should not be gratuitously applied to grab samples.

3. When sampling to estimate the attribute of a population that is passing by the sampler in time (e.g., a salmon escapement) samplers should strive to keep the sampling rate constant throughout time within a stratum so as to approximate a random sample. Sampling should not be clustered in time without a specific reason. Samples that are clustered in time are of relatively less value for characterizing the population than samples that are spread more nearly evenly through time.

4. Whenever possible, a strict protocol of randomization is preferred to grab sampling methods. Often cluster sampling methods can be applied to situations where strict random sampling is not possible. Research into confidence interval and precision estimation should include the cluster-sample aspects of the actual sample selection when possible.

5. Samples from the catch and escapement by stock and age are the baseline data from which all catch allocations, spawner-return relationships, optimum escapement goals, and forecasts are made. As such we recommend more formal and rigorous methods be applied to quality control on all aspects of catch sampling and analysis, including catch sample selection, basic data collection, scale aging, and digitizing.

While this report is obviously not the final word on sampling, it does attempt to provide some guidance based on recent thinking in sampling, especially as it relates to sampling for salmon length, weight, and age attributes in Alaskan fisheries management. We have also attempted to reinforce correct sampling terminology and stimulate some thought about the first principles of sampling. Phrasing like ". . . a random sample of the first 20 fish through the weir . . ." is still occasionally found in memoranda and reports. This represents either a misuse of the terminology, a lack of understanding of the principles, or both.

We mention quality control as an important but overlooked aspect of sampling. This aspect of the sampling program does not come from something as simple as an equation or table, but rather comes from technical judgement and experience. One element, for example, in the overall quality control program in the Bristol Bay area is that scales not aged by individuals from the stock identification group are routinely re-examined for aging interpretation differences. The procedure used is as follows: 1) approximately 500 scales or 10% of the sample, which ever is less, are randomly selected for re-aging, 2) the scales are re-aged by two scale readers from within the stock identification group without their knowing the ages assigned initially, 3) the total age composition of the 500 randomly selected scales are summarized for each reader, 4) the total age compositions for all three readers are compared, 5) if there are significant differences (> 5-8%) between the ages of the initial reader and the ages of the stock identification readers, then the entire sample is re-aged. We recommend that similar quality control measures be used in every instance where critical management information is generated.

Data collection in Alaskan fisheries is a complex and difficult business. It is not possible to provide an inflexible set of rules on sampling that must be followed in all cases. Project leaders must make pragmatic decisions based on their unique situation. Hopefully our observations and recommendations will be of some help in making those decisions.

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Goodman, L. A. 1965. On simultaneous confidence intervals for multinomial proportions. Technometrics 7(2):247-254.

Jenson, A. 1926. Report on the representative method in statistics. Bulletin of the International Statistics Institute 22:259-377.

McCurdy, M. and R. Paulus. 1972. Bristol Bay sockeye salmon (*Oncorhynchus nerka*) 1968 a compilation of catch and escapement data. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 1, Juneau.

Steel, R.G.D, and J.H. Torrie. 1960. Principles and procedures of statistics, with special reference to the biological sciences. McGraw-Hill, New York.

Thompson, S.K. 1987. Sample size for estimating multinomial proportions. The American Statistician 41(1):42-45.

SECTION II

REPORT FROM THE WORK GROUP ON SCALE PATTERN ANALYSIS MODEL BUILDING

REPORT FROM THE WORK GROUP ON SCALE PATTERN ANALYSIS MODEL BUILDING

By Ben Van Alen (chair), Brian Bue, Kathleen Jensen,
Curt Knudsen, Charlie Swanton, and Dave Waltemyer.

We present a partial annotated bibliography of formal and "gray" literature related to the methods and applications of scale pattern analysis-based stock identification research. Emphasis is given to referencing manuscripts which describe discriminant models and aid our application of these models for the stock identification of salmon. In particular, we sought to reference articles that describe the methods behind scale pattern analysis: model construction, variable selection, evaluation of model accuracy and variance estimation. Most of the manuscripts that describe the results of stock identification studies involve salmon originating from the Pacific Coast of North America. We have referenced manuscripts on genetic stock identification only if they specifically relate to scale pattern-based stock identification work. Additionally, the reader is referred to Mundy (1984) for any references to the use of historical migratory timing data for stock identification.

This bibliography is sorted alphabetically. As an aid in locating manuscripts of interest, we have identified, in bold print, the principal topic or topics covered in each manuscript. These topics are: *Reference Text, Scale Interpretation, Method Selection, Model Building, Variance Estimation, Applied Research,* and *Software.* Following the topic(s), we have for some publications provided short descriptions or key words. We hope this bibliography will be a useful reference to researchers seeking to advance the methods of scale pattern analysis or apply scale pattern analysis to mixed-stock fishery problems.

ANNOTATED BIBLIOGRAPHY

Albrecht, G.H. 1980. Multivariate analysis and the study of form, with special reference to canonical variate analysis. American Zoologist 20:679-693.

• **Method Selection.** An excellent article presenting an intuitive introduction to multivariate analysis using simple bivariate examples with emphasis on canonical variate analysis.

Anas, R.E. 1964. Sockeye salmon scale studies. Pages 158-162 in International North Pacific Fisheries Commission Annual Report 1963.

• **Model Building.** A evaluation of variability of scale characters used in identifying continental origins of sockeye salmon in the North Pacific Ocean and Bering Sea.

Anas, R.E., and Murai S. 1969. Use of scale characters and a discriminant function for classifying sockeye salmon (*Oncorhynchus nerka*) by continent of origin. International North Pacific Fisheries Commission, Bulletin 26:157-192.

• **Applied Research.** Good overview of the application of scale pattern analysis in a linear discriminant function (a frequently cited article).

Beacham, T.D. 1987. Analysis of Yukon River chinook salmon scale characters. Presented at the Pacific Salmon Commission, Yukon River Joint Technical Committee meeting March 18, 1987 in Anchorage, Alaska. Canadian Department of Fisheries and Oceans, Fisheries Research Branch, Pacific Biological Station, Nanaimo, British Columbia, Canada.

• **Method Selection, Applied Research.** Application of analysis of variance to evaluate variation in scale characters.

Beamish, R.J., and G.A. McFarlane. 1983. The forgotten requirement for age validation in fisheries biology. Transactions of the American Fisheries Society 112:735-857.

• **Scale Interpretation.**

Bernard, D.R. 1983. Variance and bias of catch allocations that use the age compositions of escapements. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 227, Juneau.

• **Method Selection.**

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, Division of Commercial Fisheries, Informational Leaflet 180, Juneau.

• **Applied Research.**

Bethe, M.L., P.V. Krasnowski, and S. Marshall. 1980. Origins of sockeye salmon in the upper Cook Inlet fishery of 1978 based on scale pattern analysis. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 186, Juneau.

• **Applied Research.**

Bilton, H.T. 1975. Factors influencing the formation of scale characters. North Pacific Fisheries Commission, Bulletin 32:102-108.

• **Scale Interpretation.** This comparison of scale patterns with environmental factors (starvation, feeding and light period) is recommended reading for scale agers and scale digitizers.

Bilton H.T., and D.W. Jenkinson. 1977. The scale characters of jack and adult coho salmon (*Oncorhynchus kisutch*) which returned from three releases made at Rosewall Creek in April, May and June 1973. Fisheries and Environment Canada, Fisheries and Marine Service Technical Report 715, Naniamo, British Columbia, Canada.

• **Scale Interpretation.** Recommended reading for scale agers and scale digitizers.

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. International North Pacific Fisheries Commission, Bulletin 32:109-129.

• **Applied Research.** A good article on the application of scale pattern analysis to a broad regional stock identification investigation.

Bohn, B.R., and H.E. Jensen. 1971. Investigation of scale patterns as a means of identifying races of spring chinook salmon in the Columbia River. Fish Commission of Oregon, Research Report Volume 3, Portland.

• **Scale Interpretation, Applied Research.** A feasibility study focusing on selection of discriminating scale characters.

Bugaev, V.F. 1984. Method for identification of sockeye salmon, *Oncorhynchus nerka* (Salmonidae), of different spawning populations in the Kamchatka River Basin. Journal of Ichthyology 24(2):47-53.

• **Method Selection, Applied Research.** Proportion of age-0. sockeye salmon used to discriminate spawning populations.

Clutter, R.I., and L.E. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. International Pacific Salmon Fisheries Commission Bulletin 9.

• **Scale Interpretation, Applied Research.** Recommended reading for scale agers and scale digitizers.

Cochran, W.G. 1964. On the performance of the linear discriminant function. Technometrics 6(2):179-190.

• **Method Selection, Model Building.** Good article for variable selection concerns, particularly selection of positive versus negatively correlated variables.

Conrad, R.H. 1982. Separation of the 1981 Chignik sockeye salmon stocks by scale patterns and a linear discriminant function. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 76, Juneau.

• **Applied Research.**

Conrad, R.H. 1984. Management applications of scale pattern analysis methods for the sockeye salmon runs to Chignik, Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 233, Juneau.

• **Applied Research.**

Conrad, R.H. 1984. Scale pattern analysis as a method for identifying the origins of sockeye salmon (*Oncorhynchus nerka*) in the waters surrounding the Kodiak Archipelago. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 241, Juneau.

• **Applied Research.**

Conrad, R.H. 1984. Stock composition of the 1983 sockeye salmon (*Oncorhynchus nerka*) run to the Chignik Lakes estimated using scale patterns and linear discriminant functions. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 112, Juneau.

• **Applied Research.**

Conrad, R.H. 1985. Programs for performing a linear discriminant function analysis of scale patterns data from species with marine growth only (chum and pink salmon). Alaska Department of Fish and Game, Division of Commercial Fisheries (unpublished report), Anchorage.

• **Software.** This documentation for Bob Conrad's variable selection, linear discriminant function, classification programs is useful, even if you do not have the programs.

Conrad, R.H. 1985. Programs for performing a linear discriminant function analysis of scale patterns data from species with freshwater growth (sockeye, chinook, and coho salmon). Unpublished Report. Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage.

• **Software.** This documentation for Bob Conrad's variable selection, linear discriminant function, classification programs is useful - even if you don't have the programs.

Conrad, R.H. 1985. Conventions for scale patterns analysis reports. Alaska Department of Fish and Game, Division of Commercial Fisheries, unpublished memorandum dated March 18, 1985, Anchorage.

• A short memorandum which established some in-house reporting conventions for scale pattern(s) analysis reports.

Conrad, R.H. 1988. Maximum likelihood alternative for the classification matrix correction procedure. Alaska Department of Fish and Game, Division of Commercial Fisheries, unpublished memorandum dated September 27, 1988, Anchorage.

• **Model Building, Variance Estimation.** An alternate to the Cook and Lord (1978) classification matrix correction procedure which yields estimates constrained between 0.0 and 1.0.

Conrad, R.H., and G.T. Ruggerone. 1985. Stock composition of the 1984 sockeye salmon (*Oncorhynchus nerka*) run to the Chignik Lakes estimated using scale patterns and linear discriminant functions. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 151, Juneau.

• **Applied Research.**

Cook, R.C. 1982. Stock identification of sockeye salmon (*Oncorhynchus nerka*) with scale pattern recognition. Canadian Journal of Fisheries and Aquatic Science 39:611-617.

• **Method Selection, Model Building.** Application of a leaving-one-out approach in a non-parametric polynomial discriminant function.

Cook, R.C. 1983. Simulation and application of stock composition estimators. Canadian Journal of Fisheries and Aquatic Science 40:2113-2118.

• **Model Building, Variance Estimation.** Presentation of a classification matrix correction procedure which is constrained so that estimates fall between zero and one.

Cook, R.C., and G.E. Lord. 1978. Identification of stocks of Bristol Bay sockeye salmon, *Oncorhynchus nerka*, by evaluating scale patterns with a polynomial discriminant method. Fishery Bulletin 76:415-423.

• **Model Building, Variance Estimation.** Presentation of the frequently cited classification matrix correction procedure (unconstrained) and a review of linear, quadratic, and polynomial discriminant function methods.

Cross, B., and W.E. Goshert. 1988. Origins of sockeye salmon in the fisheries of Upper Cook Inlet in 1985 based on analysis of scale patterns. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Fishery Report 88-07, Juneau.

• **Applied Research.**

Cross, B.A., W.E. Goshert, and D.L. Hicks. 1986. Origins of sockeye salmon in the fisheries of Upper Cook Inlet, 1983. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 181, Juneau.

• **Applied Research.**

Cross, B.A., W.E. Goshert, and D.L. Hicks. 1987. Origins of sockeye salmon in the fisheries of Upper Cook Inlet in 1984 based on analysis of scale patterns. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Fishery Report 87-01, Juneau.

• **Applied Research.**

Cross, B.A., D.L. Hicks, and W.E. Goshert. 1985. Origins of sockeye salmon in the fisheries of Upper Cook Inlet in 1982. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 139, Juneau.

• **Applied Research.**

Cross, B.A., S.L. Marshall, G.T. Oliver, and D.L. Hicks. 1983. Origins of sockeye salmon in the Upper Cook Inlet fishery of 1981 based on scale pattern analysis. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 83, Juneau.

• **Applied Research.**

Cross, B.A., S.L. Marshall, G.T. Oliver, and S. Sharr. 1982. Origins of sockeye salmon in the Upper Cook Inlet fishery of 1980 based on scale pattern analysis. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 68, Juneau.

• **Applied Research.**

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, Division of Commercial Fisheries, Technical Data Report 58, Juneau.

• **Applied Research.**

Cross, B.A., and B.L. Stratton. 1989. Origins of sockeye salmon in east side Bristol Bay fisheries in 1987 based on linear discriminant function analysis of scale patterns. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Fishery Report 88-13, Juneau.

• **Applied Research.**

Daudin, J.J. 1986. Selection of variables in mixed-variable discriminant analysis. Biometrics 42:473-481.

• **Model Building.** Presentation of a MANOVA-log-linear location model for discriminant analysis using mixtures of continuous and categorical variables.

Davis, N.D. 1987. Variable selection and performance of variable subsets in scale pattern analysis. (Document submitted to annual meeting of the International North Pacific Fisheries Commission 1987). Fisheries Research Institute, University of Washington, Report FRI-UW-8713, Seattle.

• **Model Building.** The Wilks' Lambda and Mahalanobis distance variable selection procedures are compared, and the number of variables to include in a discriminant model is evaluated. The Wilk's Lambda selection criteria and use of a reduced sub-set of variables is recommended.

Davis, N.D., K.W. Myers, R.V. Walker, and C.K. Harris. 1989. The Fisheries Research Institute's high seas salmonid tagging program and methodology for scale pattern analysis. American Fisheries Society Proceedings of the International and Educational Workshop on Fish Marking Techniques, 27 June - 1 July, 1988, Seattle, Wa.

• **Applied Research.**

Diaconis, P., and B. Efron. 1983. Computer-intensive methods in statistics. Scientific American 248:116-130.

• **Model Building, Reference Text.** Reference for bootstrapping.

Dixon, W.J., and M.B. Brown, editors. 1979. BMDP-79, biomedical computer programs P-Series. University of California Press, Berkeley.

• **Software.** The program documentation provides a good review of discriminant analysis methodology.

Efron, B. 1979. The 1977 Rietz lecture. Bootstrap methods: another look at the jackknife. The Annals of Statistics 7(1):1-26.

• **Model Building, Variance Estimation.** Bootstrap methods are preferred over the jackknife method for estimation of the bias and variance of a statistic. The jackknife is considered a linear approximation method for the bootstrap. KEY WORDS: Jackknife, bootstrap, resampling, subsample values, nonparametric variance estimation, error rate estimation, discriminant analysis, nonlinear regression.

Efron, B. 1981. Nonparametric estimates of standard error: the jackknife, the bootstrap and other methods. Biometrika 68(3):589-599.

• **Model Building, Variance Estimation.** Discussion of nonparametric methods for estimating standard error for a point estimate. KEY WORDS: balanced repeated replications, bootstrap, Delta method, half-sampling, jackknife, infinitesimal jackknife, influence function.

Efron, B., and G. Gong. 1983. A leisurely look at the bootstrap, the jackknife, and cross-validation. The American Statistician 37:36-48.

• **Model Building, Variance Estimation.** Evaluation of the bias and standard error of an estimator written at a "relaxed mathematical level". KEY WORDS: bias estimation, variance estimation, nonparametric confidence intervals, error rate prediction.

Eggers, D.M. 1989. An overview of the application of stock identification methods in the management of Alaskan salmon fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 5J89-08, Juneau.

• **Applied Research.**

Eggers, D.E., L.K. Brannian, B.A. Cross, H.J. Geiger, K.A. Jensen, S.L.Marshall, A.J. McGregor, S.A. McPherson, and C.O. Swanton. 1990. An overview of the application of stock identification methods in the management of Alaskan salmon fisheries. Alaska Department of Fish and Game, Division of commercial Fisheries, Professional Publication No. 021, Juneau (In press) *in* Proceedings International Symposium on Problems of Pacific Salmon, September 11 - 15, 1989, Yuzhno-Sakhalinsk, U.S.S.R.

• **Applied Research.** Reviews current application of scale pattern analysis to several Alaskan fisheries.

Enslein, K., A. Ralston, and H.S. Wilf. 1977. Statistical methods for digital computers. John Wiley and Sons, Inc. New York.

• **Model Building.** Reference to the method of variable selection for a linear discriminant function model using the partial F-statistic as the criterion for variable entry/removal from the model.

Fisher, R.A. 1936. The use of multiple measurements in taxonomic problems. Annals of Eugenics 7:179-86.

• **Method Selection.** The reference document for linear discriminant function analysis.

Flury, B., and H. Riedwyl. 1985. T^2 tests, the linear two-group discriminant function, and their computation by linear regression. The American Statistician 39(1):20-25.

• **Method Selection.** Evaluation of the relationship between regression and discriminant analysis in a multivariate linear model. KEY WORDS: Mahalanobis distance, multivariate location test, partial F, redundancy of variables, variable selection, conditional mean difference.

Flury, B.K., and H. Riedwyl. 1986. Standard distance in univariate and multivariate analysis. The American Statistician 40(3):249-251.

• **Method Selection.** Article proposes a "standard distance" way to compare sample means. KEY WORDS: Mahalanobis distance, Euclidean distance, *t* test, mean difference, projection.

Fournier, D.A., T.D. Beacham, B.E. Riddell, and C.A. Busack. 1984. Estimating stock composition in mixed stock fisheries using morphometric, meristic, and electrophoretic characteristics. Canadian Journal of Fisheries and Aquatic Science 41:400-408.

• **Method Selection, Model Building.** Use of discrete or continuous characters in a conditional maximum likelihood procedure to estimate stock compositions in mixed stock fisheries.

Garner, L.A. 1983. An analysis of stock separation in the pink shrimp, *Pandalus borealis*. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 214, Juneau.

• **Applied Research.**

Geiger, H.J. 1989. A stock identification study in the northern Alaska Peninsula sockeye salmon fishery, from Harbor Point to Strogonoff Point. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Reports 5J89-11, Juneau.

• **Applied Research.**

Gilbert, E.S. 1968. On discrimination using qualitative variables. American Statistical Association Journal, December 63(324):1399-1413.

• **Model Building.** Use of dichotomous variables in linear discriminant functions.

Glick, N. 1973. Sample-based multinomial classification. Biometrics 29:241-256.

• **Model Building.** Use of qualitative (discrete) variables having multinomial distributions in discriminant analysis.

Gunstrom, G, editor. 1987. S.E. Alaska inter-divisional sockeye salmon program review. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J87-1, Juneau.

• **Applied Research.**

Habbema, J.D.F, and J. Hermans. 1977. Selection of variables in discriminant analysis by F-statistic and error rate. Technometrics 19(4):487-493.

• **Model Building.** Comparison of the performance of five variable selection procedures - DISCRIM, BMDP07M, ALLOC-1, BMDP7M, and SPSS.

Henry, K.A. 1961. Racial identification of Fraser River sockeye salmon by means of scales and its applications to salmon management. International Pacific Salmon Fisheries Commission, Bulletin 12, New Westminister, British Columbia, Canada.

• **Applied Research.**

Hill, M.O. 1974. Correspondence analysis: a neglected multivariate method. Applied Statistics 23(3):340-354.

• **Method Selection.** Review of correspondence analysis, a method analogous to principal components analysis which is appropriate for discrete data. KEY WORDS: categorical data, contingency table, multi-dimensional scaling, principal components analysis.

Horton, I.F., J.S. Russell, and A.W. Moore. 1968. Multivariate-covariance and canonical analysis: a method for selecting the most effective discriminators in a multivariate situation. Biometrics 24:845-858.

• **Model Building.**

International North Pacific Fisheries Commission. 1963. Annual Report - 1961.
• **Scale, Interpretation, Applied Research.** A good reference for selection of the "preferred scale".

Jensen, K.A., and I.S. Frank, 1988. Stock compositions of sockeye salmon catches in Southeast Alaska's Districts 106 and 108 and in the Stikine River, 1987, estimated with scale pattern analysis. Alaska Department of Fish and Game. Division of Commercial Fisheries, Technical Fishery Report 88-13, Juneau.

• **Applied Research.**

Jensen, K.A., and I.S. Frank. 1989. Stock compositions of sockeye salmon catches in Southeast Alaska's Districts 106 & 108 and in the Stikine River, 1988, estimated with scale pattern analysis. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J89-44, Juneau.

• **Applied Research.**

Jensen, K.A., I.S. Frank, and G.T. Oliver. 1989. Stock compositions of sockeye salmon catches in Southeast Alaska's Districts 106 and 108 and the Stikine River, 1986, estimated with scale pattern analysis. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Fishery Report 88-02, Juneau.

• **Applied Research.**

Johnson, R.A., and D.W. Wichern. Applied multivariate statistical analysis. 2nd edition. Prentice Hall, Englewood Cliffs, New Jersey.

• **Reference Text.**

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, Division of Commercial Fisheries, Informational Leaflet 231, Juneau.

• **Applied Research.**

Kleinbaum, D.G., and L.L. Kupper. 1978. Applied regression analysis and other multivariate methods. Duxbury Press, North Scituate, Mass.

• **Reference Text.** Good review of stepwise regression.

Koo, T.S.Y. 1955. Biology of the red salmon, *Oncorhynchus nerka* (Walbaum), of Bristol Bay, Alaska, as revealed by a study of their scales. Doctoral dissertation, University of Washington, Seattle.

• **Applied Research.** Good reference article for evaluation of scale patterns.

Koo, T.S.Y. 1962. Age designation in salmon. Pages 39 to 48 *in* T.S.Y. Koo, editor. Studies of Alaska red salmon. University of Washington Press, Seattle.

• **Scale Interpretation.**

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, Division of Commercial Fisheries, Informational Leaflet 175, Juneau.

• **Applied Research.**

Krzanowski, W.J. 1975. Discrimination and classification using both binary and continuous variables. Journal of the American Statistical Association 70(352):782-790.

• **Method Selection, Model Building.** Evaluation of the likelihood ratio classification rule using both binary and continuous variables.

Krzanowski, W.J. 1977. The performance of Fisher's linear discriminant function under non-optimal conditions. Technometrics 19(2):191-200.

• **Method Selection.** Evaluation of the performance of linear discriminant function when the underlying assumptions are not met.

Krzanowski, W.J. 1979. Some linear transformations for mixtures of binary and continuous variables, with particular reference to linear discriminant analysis. Biometrika 66(1):33-39.

• **Model Building.** This article proposes some linear transformations for mixtures of continuous and binary variables that make this data more suitable for analysis such as linear discriminant function analysis. KEY WORDS: between-group analysis, latent root and vector, linear transformation, location model.

Krzanowski, W.J. 1989. On confidence regions in canonical variate analysis. Biometrica 76(1):107-116.

• **Variance Estimation** KEY WORDS: Asymptotic distribution of latent roots and vectors, canonical variate mean, central limit theorem, informal inference, tolerance region.

Lachenbruch, P.A. 1967. An almost unbiased method of obtaining confidence intervals for the probability of misclassification in discriminant analysis. Biometrics 23(4):639-645.

• **Variance Estimation.** Presentation of the leaving-one-out procedure.

Lachenbruch, P.A. 1975. Discriminant analysis, Hafner Press, N.Y.

• **Reference Text.**

Lachenbruch, P.A. and M. Goldstein. 1979. Discriminant analysis. Biometrics 35:69-85.

• **Reference Text, Method Selection, Model Building, Variance Estimation.**

Lechner, J. 1969. Identification of red salmon stocks taken in the Cape Kumlik-Aniakchak Bay fishery, Chignik area, 1967. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 133, Juneau.

• **Applied Research.**

Major, R.L., S. Murai, and J. Lyons. 1973. Scale studies to identify Asian and western Alaskan chinook salmon. International North Pacific Fisheries Commission Annual Report 1973:80-97.

• **Applied Research.**

Marshall, S.L., F. Bergander, and S. Sharr. 1982. Origins of sockeye salmon (*Oncorhynchus nerka*) in the Lynn Canal drift gillnet fishery of 1981 based on scale pattern analysis. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Reports, Leaflet 75, Juneau.

• **Applied Research.**

Marshall, S., D. Bernard, R. Conrad, B. Cross, D. McBride, A. McGregor, S. McPherson, G. Oliver, S. Sharr, and B. Van Alen. 1987. Application of scale patterns analysis to the management of Alaska's sockeye salmon (*Oncorhynchus nerka*) fisheries. Pages 307-326 *in* H.D. Smith, L. Margolis, and C.C. Wood., editors. Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Canadian Special Publications of Fisheries and Aquatic Sciences 96.

• **Applied Research.**

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, Division of Commercial Fisheries, Informational Leaflet 230, Juneau.

• **Applied Research.** Includes sensitivity analysis for representativeness of the standards.

Marshall, S.L., and S.S. Parker. 1982. Pattern identification in the microstructure of sockeye salmon (*Oncorhynchus nerka*) otoliths. Canadian Journal of Fisheries and Aquatic Science 39:542-547.

• **Scale (Otolith) Interpretation, Method Selection.** Article shows potential for stock identification based on otolith pattern analysis. KEY WORDS: otoliths, daily rings, sockeye salmon, environmental factors.

McBride, D.N., R.D. Harding, B.A. Cross, and R.H. Conrad. 1985. Origins of chinook salmon (*Oncorhynchus tshawytscha*) in the commercial catches from the Central District eastside set gillnet fishery in Upper Cook Inlet, 1984. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 251, Juneau.

• **Applied Research.**

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, Division of Commercial Fisheries, Informational Leaflet 208, Juneau.

• **Applied Research.**

McGregor, A.J. 1983. A biochemical genetic analysis of pink salmon (*Oncorhynchus gorbuscha*) from selected streams in northern Southeast Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 213, Juneau.

• **Method Selection, Applied Research.**

McGregor, A.J. 1985. Origins of sockeye salmon (*Oncorhynchus nerka* Walbaum) in the Taku-Snettisham drift gillnet fishery of 1983 based on scale pattern analysis. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 246, Juneau.

• **Applied Research.**

McGregor, A.J. 1986. Origins of sockeye salmon (*Oncorhynchus nerka* Walbaum) in the Taku-Snettisham drift gillnet fishery of 1984 based on scale pattern analysis. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 174, Juneau.

• **Applied Research.**

McGregor, A.J. 1989. Taku River and Port Snettisham sockeye salmon stock proportions in 1988 Southeast Alaska and Canadian Fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J89-43, Juneau.

• **Applied Research.**

McGregor, A.J., and E.L. Jones. 1989. Taku River and Port Snettisham sockeye salmon stock proportions in 1987 Southeast Alaska and Canadian fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Fishery Report 88-15, Juneau.

• **Applied Research.**

McGregor, A.J., and S.L. Marshall. 1982. Origins of chum salmon (*Oncorhynchus keta*) in the Excursion Inlet purse seine fishery of 1981 based on scale pattern analysis. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 201, Juneau.

• **Applied Research.**

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, Division of Commercial Fisheries, Informational Leaflet 219, Juneau.

• **Applied Research.**

McGregor, A.J. and S.L. Walls. 1987. Separation of principal Taku River and Port Snettisham sockeye salmon (*Oncorhynchus nerka*) stocks in southeastern Alaska and Canadian fisheries of 1986 based on scale pattern analysis. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 213, Juneau.

• **Applied Research.**

McLachlan, G.J. 1980. On the relationship between the *F* test and the overall error rate for variable selection in two-group discriminant analysis. Biometrics 36:501-510.

• **Model Building.** Evaluation of the F-test variable selection procedure. KEY WORDS: linear discriminant function, variable selection, overall error rate, adequate discriminant sets, simultaneous procedure.

McLachlan, G.J., and K.E. Basford. 1988. Mixture models - inference and applications to clustering. Marcel Dekker, Inc., New York.

• **Reference Text.**

McPherson, S.A. 1987. Contribution, exploitation, and migratory timing of returns of sockeye salmon (*Oncorhynchus nerka*) stocks to Lynn Canal in 1985 based on analysis of scale patterns. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 217, Juneau.

• **Applied Research.**

McPherson, S.A. 1987. Contribution, exploitation, and migratory timing of Chilkat and Chilkoot River runs of sockeye salmon (*Oncorhynchus nerka* Walbaum) in the Lynn Canal drift gillnet fishery of 1984. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 198, Juneau.

• **Applied Research.**

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• **Applied Research.**

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SECTION III

REPORT FROM THE WORK GROUP ON THERMAL INDUCTION OF BANDING PATTERNS IN SALMONID OTOLITHS

REPORT FROM THE WORK GROUP ON THERMAL INDUCTION OF BANDING PATTERNS IN SALMONID OTOLITHS

By Karen Crandall (Chair), Carol Coyle,
Andy McGregor, and John Wilcock.

What Is a Mass Mark?

A *mass mark* is any mark, either artificially induced or naturally occurring, unique to a specific group of fish. Naturally occurring marks, including genetic markers, naturally occurring parasites and unique scale patterns, are considered as mass marks if they can be used to differentiate all individuals in a population from other stocks. Unfortunately stock-specific characteristics are rare in the natural environment.

Several presentations were given at the workshop about developing technologies which would artificially induce a mark on all fish from a particular hatchery group of interest. Induced thermal marking of otoliths, parasite marks, genetic markers, and elemental analysis were discussed. An induced mass mark must be (1) easily and cheaply applied to all fish in a release group, (2) recognizable throughout the life of the fish, and (3) capable of being processed quickly and reliably. The technique that appears to offer the most promise for the near future is thermal banding of otoliths.

Thermally Induced Otolith Banding

Thermally induced otolith banding is performed by using planned cycles of differing water temperatures to induce discrete banding patterns on the otolith. This banding can begin sometime after the otolith has been formed in the salmon embryo. The otolith is composed of calcium carbonate and proteinaceous otolin. A drop in temperature disrupts deposition of calcium carbonate (aragonite), so more proteinaceous otolin remains. This creates a distinct dark band on the otolith when viewed under transmitted light. Otoliths generally begin development just after eyeing has occurred in salmon embryos. Marking can be performed on eyed eggs prior to hatching or when the fish are alevins. According Eric Volk, who spoke at the stock separation workshop, water temperatures should differ a minimum of 2°C for clear thermal marks. As long as fish receive a 2°C difference eggs and alevins incubated in warm water can be marked with cold water and eggs and alevins incubated with cold water can be marked with warm water. It is the drop from warm to cold that creates the mark. These marks persist throughout the life of the salmon and can be found when sectioning the primordial core of the adult otoliths.

Operational costs of thermally induced otolith banding are less than the costs of coded-wire tagging, the current standard for Alaskan hatcheries. The most cost efficient hatchery situation occurs where water sources with differing temperatures already exist, such as a hatchery with a dual lake intake. Another example would be a hatchery with water supplied by several sources: e.g., creeks, lakes, wells or power plant effluents. When only one source of extremely cold water is available, heating that water substantially increases marking costs.

Some normal hatchery occurrences can potentially interfere with the inducement of marks or their readability. Examples of phenomena that might produce marks on otoliths are supersaturated water, addition of some chemicals to the water, substantial fluctuations of ambient water temperature, power outages, and possibly low dissolved oxygen.

Constraints to the success of a thermal otolith marking program are imposed by the biology and physiological stages of salmon. These include:

1) Temperature must be within the physiological limits (0.2°-15.0°C) of the species.

2) Low temperatures result in slow otolith development and may result in slow changes in otolith banding; this can be compensated for in the banding design (i.e., longer cycles).

3) Hatching and other developmental changes may naturally produce check marks on otoliths which could be mistaken for induced otolith bands. Marks induced by temperature manipulations prior to hatching may be more definitive than patterns induced after hatching. Best induced marking results after hatching are achieved from longer exposures to chilled or heated water. Marking should be completed prior to swim-up to reduce possible interference from swim-up and photoperiod. Marking fish in raceways has not been successful because of the practical problem of providing very large quantities of heated or chilled water.

Within the constraints of salmon biology, budgets, and standard hatchery practices, large scale thermal marking of otoliths is possible. Hatcheries will be limited to the amount of dual temperature water they have or are willing to procure. Application of this technology is site and objective specific.

Mass Processing of Thermally Marked Otoliths

While mass marking of otoliths is both feasible and reasonable, mass processing of marked otoliths is currently much less of a reality. Eric Volk continues to work on and perfect a method to dissect large numbers of otoliths and section for pattern recognition.

Currently, two sets of otoliths are removed from each fish and placed in ethanol until processed. Single otoliths or groups of otoliths are mounted in a mold of fiberglass resin, heated until hardened, and sectioned using a lapidary saw. Unlike sectioning a mineral sample where it does not matter where the section is made, in sectioning an otolith there is a small target area, the primordial core, which the section must pass through. This requires alternately sawing, polishing and observing work through a microscope. Mounting similar size otoliths in the same mount may permit a skilled technician to process more than one otolith at a time. *Lapilli* is a specific otolith bone with a smaller and more uniform size. For that reason it is probably the otolith of choice for sectioning work. Volk continues to work on the process, reducing the time required to process each otolith without sacrificing samples or quality. The process does require a high degree of skill. Processing of coded-wire tags pales in comparison to the more labor intensive and precise work otolith preparation requires. Although a skilled crew of two at Washington's otolith lab can process over 200 samples a day, it is really unknown how long it will take to process otoliths on a production-level basis.
The need for in-season processing and data analysis adds to the complexity of otolith processing. Otoliths can be processed by either making a half section or a thin section. Very distinct banding patterns can be discerned and read using a half section of the lapilli otolith. More complex induced patterns or naturally occurring

banding patterns require the more time consuming thin- section method. If banding patterns are very distinct and if the number of marks are few, then it may be possible to process otoliths on an in-season basis. The more complex the objectives, and accordingly the more complex the banding patterns, the less likely this tool can be used for rapid in-season analysis. If the objectives are to provide fishery managers with the proportion of the catch attributable to a marked hatchery stock, then a half section could be performed, and the otolith could be deciphered as "hatchery" or "not hatchery". This level of processing could be accomplished in-season. The problem compounds as multiple, complex marks must be classified. Half sections could be thin sectioned at a later date for more detailed analysis. Optical pattern recognition (OPR) computer packages may prove to be a quick and accurate way to process large numbers of otoliths with complex banding patterns.

Specific Fishery Problems Requiring Mass Marking Solutions

Several specific situations in which Alaska Department of Fish and Game managers believe there is a need to mass mark salmon hatchery production include: (1) Snettisham Central Incubation Facility (CIF) sockeye production targetted for transboundary river enhancement, (2) production of pink salmon in Southeast Alaska, and, (3) hatchery pink salmon produced in Prince William Sound (PWS). Below we discuss these specific cases in detail. Other hatcheries and projects across the state have recently expressed interest in the application of an induced mass marks to identify hatchery stocks.

Snettisham CIF Production of Sockeye for Transboundary River Enhancement Projects

A reliable method of identifying production of sockeye salmon from Canadian transboundary and local U.S. enhancement projects is essential for three reasons: (1) to assess the success of these projects in producing fish, (2) to give managers feedback on management strategies designed to selectively target on enhanced returns, and, (3) to provide a method for accounting for catches of transboundary river fish by the U.S. and Canada, which is necessary for monitoring harvest sharing agreements between the two nations as outlined in the Pacific Salmon Treaty.

Scale pattern analysis of sockeye salmon catches in Alaskan fishing districts of interest (Districts 106, 108, and 111) is currently used to estimate the U.S. harvest of Stikine and Taku river fish. Stocking new lakes or enhancing existing runs to their full potential may alter scale growth patterns and reduce the effectiveness of this method. The Transboundary Technical Committee to the Pacific Salmon Commission has identified thermal marking of otoliths as the mark of choice for enhanced transboundary river sockeye stocks. The committee concluded that no other reliable marking technique was available for marking all fish released.

The only other technology currently available to provide direct estimation of enhanced production is coded-wire tagging. This technique is unacceptable for use in this situation because the sheer size of the tagging and recovery efforts would be prohibitive. Because the coded-wire tag could only be applied to a sample of the enhanced populations of fish, there would necessarily be a large number of untagged enhanced fish whose scale patterns would be confounded with untagged naturally occurring wild fish from the Taku and Stikine Rivers and Port Snettisham. Thus, coded-wire tagging would compromise the ongoing scale pattern analysis work.

Hatchery Production of Pink Salmon in Southeast Alaska

Large-scale releases of hatchery pink salmon in Southeast Alaska presently occurs from Gastineau Channel and Burnett Inlet Hatcheries. These (and an other future Southeast Alaskan pink salmon produced by hatcheries) present complicated allocation and conservation problems for commercial fishery managers in the region. Gastineau Channel and Burnett Inlet pinks are mixed with numerous wild pink salmon stocks in traditional fishing areas. These fisheries have historically been managed based on wild stock abundance under an objective of maximizing catches and distributing adequate escapements among the contributing stocks. When large returns of unmarked enhanced stocks are present along with the wild stocks, managers are forced to act conservatively to ensure wild stock escapements when stock composition data is not available. This will generally result in foregoing harvesting opportunities or in the overharvest of some stocks. Thus, marking enhanced fish is mandatory for project assessment and rational management. Poor returns to Gastineau Channel Hatchery, operated by Douglas Island Pink and Chum, Inc. (DIPAC), from unmarked releases in recent years have lead to serious conflicts between hatchery operators, user-groups, and resource managers. Unfortunately, because fish were not tagged, definitive information that would allow assessment of why returns were poor (e.g., poor survival of juveniles, overfishing) is unavailable.

In 1990 both Gastineau Channel and Burnett Inlet hatcheries coded-wire tagged a portion of their pink salmon releases to help provide fishery managers with a needed stock identification tool. While this technique is expensive, requiring large annual manpower commitments at tagging, sampling, and tag processing stages, it is capable of providing the stock composition data necessary for fishery managers.

Hatchery Pink Salmon Produced in Prince William Sound

In 1988 four hatcheries in Prince William Sound released 532 million pink salmon. A.F. Koernig, Cannery Creek, and Wally Noerenberg Hatcheries operated by Prince William Sound Aquaculture Association (PWSAC) and Solomon Gulch hatchery operated by Valdez Fisheries Development Association (VFDA) coded-wire tagged 894,000 of these released fish. Intensive tagging and tag recovery programs were instituted in PWS to provide fishery managers with information needed to manage fisheries complicated by this massive influx of hatchery-produced pink salmon. PWS fishery managers have multiple responsibilities to (1) ensure adequate escapement to wild stock systems, (2) to permit adequate fishing opportunity on both wild and hatchery produced fish, and (3) to ensure that brood stock and cost recovery needs of each hatchery are met. Hatchery releases in PWS in 1989 totaled 494 million pink salmon of which 1.3 million were coded-wire tagged. Also in 1989, 4.0 million pink salmon were examined for the presence of coded-wire tags. The fishery will again be intensively sampled in 1990 to look for coded-wire tagged fish from 1989 releases. In addition to stock composition information needed for management of the fishery, coded-wire tag recovery data will be used to measure the impact of the March 1989 Exxon Valdez oil spill on the survival of juvenile fish released from hatcheries during the spring of 1989. Although this tagging and recovery program has been relatively successful, the large numbers of very small fish that must be tagged in a very short period and the large numbers of fish that must be scanned from the commercial fishery to locate marks, make this program expensive and labor intensive. If successful production-level mass marking techniques can be developed, mass marking all hatchery-produced pink salmon in PWS could conceivably reduce the costs of tagging and recovery while improving the accuracy and precision of hatchery contribution estimates.

Status of Current Otolith Mark Projects

Washington Department of Fisheries

Eric Volk has marked experimental groups of chum, coho and chinook salmon with thermal banding in the state of Washington. He thermally marked both eyed eggs and alevin chum salmon. Other experiments of his included inducing otolith banding patterns by alternately feeding and starving fingerling chinook salmon. Volk has worked with various banding patterns and temperature changes. The minimum change in temperature that created a mark was 1.7°C, and the maximum temperature change he used was 5.3°C. Volk also thermally marked small production lots of 350,000 coho salmon (both embryos and alevins) and 95,000 chum salmon (embryos and alevins). These marks have been deciphered successfully in jacks and adults from these species. Three entire production lots, each 2.2 million (spring) chinook salmon, were also successfully marked.

Alaska Department of Fish and Game (ADF&G), Snettisham Central Incubation Facility

In response to fishery managers who need to positively identify enhanced sockeye stocks released by Snettisham CIF, FRED regional sockeye marking team worked to (1) determine if sockeye could be thermally marked with a variety of different banding patterns, and (2) to check stocked lake emigrants to be sure marks were retained. The 1988 and 1989 brood years were marked with thermally induced otolith banding patterns. All marks were readily distinguishable in emergent fry. In the future ADF&G plans to mark a minimum 25 million pre-emergent sockeye at Snettisham CIF using electric water heaters with heat exchangers in the proposed permanent facility.

In 1988 two groups of eyed sockeye salmon eggs were marked with two distinct thermal marks at Snettisham CIF using planned cycles of electrically heated water. These marked fry were planted into Speel Lake in June 1989. Snettisham CIF routinely delays the development of their sockeye salmon by using chilled water (2-3°C) to time emergence to ice-out in high elevation lakes in June. During this trial two distinct marks: (1) five optically dense bands (induced by five cycles, each at 48 h at 5.0°C water and 48 h at 2.0°C water), and; (2) three optically dense bands (induced by 3 cycles at 72 h at 5.0°C water and 72 h at 2.0°C water). These two patterns were induced on 82,000 and 160,000 sockeye, respectively. FRED Division installed a smolt weir at the outlet of Speel Lake in the spring of 1990 to establish age structure, smolt size and timing of emigrating smolts.

Also during 1988 Snettisham CIF staff developed an algorithm for sockeye egg, alevin, and fry development to help design banding pattern inducement. Snettisham staff performed two power outage simulations to observe the effects of ambient water interruptions on induced banding patterns. An experimental group of alevin were marked with four broader optically dense bands (its thermal shift cycle was 144 h at 5.0°C and 144 h at 2.0°C) to induce a more dramatic visible mark on the otolith. Marking cannot commence until otolith formation begins. To determine when marking can begin, Snettisham staff developed a technique to stain, clear, and dissect eye-eggs to establish otolith presence. Snettisham staff are attempting to estimate the relationship between celsius thermal unit (CTU) and otolith development to eliminate the time consuming task of dissecting eyed eggs to establish otolith presence.

In 1989 Snettisham CIF staff expanded the marking program to mark 5.4 million sockeye eggs from three stocks with three different patterns: (1) Crescent stock was marked with six optically dense bands (48 h each), (2) Speel/Sweetheart stocks were marked with 8 optically dense bands (thermal shift cycles of 48 h each), and (3) Tahltan stock was marked with four optically dense bands (thermal shift cycles of 72 h each). These marks were induced over a two month period using 90 gpm of water heated with propane from 3.5°C to 5.5°C. Repeated minor interruptions of hot water cycles were due to coagulation of propane at cold air temperatures. The addition of methane to the lines should alleviate this problem in the future. Otoliths were checked to document the impacts of heated water disruptions on otolith banding patterns. Precise water temperature records were automatically recorded. These records were correlated to banding patterns observed in otoliths.

Auke Creek Pink Salmon

A thermal marking feasibility study was initiated at Auke Creek on pink salmon in the fall of 1989. The University of Alaska, National Marine Fisheries Service, and Alaska Department of Fish and Game are cooperatively conducting the study. Several lots of approximately 20,000 pink salmon eggs were incubated at Auke Creek Hatchery. At the eyed egg stage of development, some of the groups were treated with five thermal shift cycles of 24 h of chilled water followed by 48 h of ambient water temperatures. Changes in water temperatures were generally at least 4°C. Banding patterns on the otoliths of the eggs plainly showed these marks, and control groups did not. Resulting fry will be released in the spring of 1991 after fin clipping of the different release groups to facilitate identification upon return. This project was initiated not only to test the utility of this marking technique on pink salmon but also to provide known marked and unmarked adult samples in 1991. From this we can begin to develop adult otolith processing methodology several years prior to large-scale returns of marked transboundary river sockeye.

Prince William Sound Pink Salmon at the VFDA Hatchery

A small scale thermally induced marking project was conducted at Solomon Gulch Hatchery by Valdez Fishery Development Association on 1988 brood pink salmon. These thermally marked fish were also coded-wire tagged. Otoliths from preserved fry have not yet been checked to see if a distinguishable mark was induced. Adults from that test will be returning to the hatchery in the summer of 1990.

Concerns and Action Required

1. Thermally inducing unique banding patterns on salmonid otoliths is a promising technology that is still being developed. Managers and researchers should be made aware of the potential utility of this tool but must realize that this technique is still being developed and tested and is not yet ready for production application.

2. Marking an entire salmon stock is possible but translating that feasibility into reality is site and objective specific. Success of a marking program requires close coordination between fishery managers and hatchery staff. Hatchery staff, including maintenance people, must be included in program design to determine what really can be achieved within the constraints of the facility design, water temperature manipulation capabilities, the biology of the fish, cultural procedures, budgets, etc. In short, mass marking requires precise manipulation of water temperature and attention to details.

3. It is imperative that fishery managers clearly define their objectives and requirements. Objectives must be defined well in advance of egg takes so that plumbing, temperature regimes, etc. can be refined to facilitate marking eyed eggs, after otolith appearance but before hatching.

4. While overall policies need to be established, every stock and fishery situation presents different problems. For example, while it is necessary for transboundary enhanced sockeye to bear unique thermal marks because of multiple projects being operated and the existence of international harvest sharing agreements, this does not appear to be a requirement (at least currently) for DIPAC pink salmon releases.

5. If objectives include the need for in-season data for fishery management, clearly distinct marks must be planned and induced.

6. A systematic approach to cataloging marks needs to be developed. This is critical if multiple marking projects are implemented on the same species in the same area. Without coordination, it would be possible for two facilities to induce the same banding patterns. Without an optical pattern recognition system in place, similar marks from two different facilities could easily be misidentified. The coordination and assignment of unique banding patterns will require communication among affected researchers, managers, and hatchery operators. Rules similar to those governing the use of fin marks and coded-wire tags will need to be developed.

7. We have to develop knowledge of patterns exhibited by wild stocks. Perhaps wild stock variation is substantial and will have a bearing on the types of marks (number of bands, thickness of bands) we will need to use in specific situations. Experience will guide us as to the level of annual variation we'll see in the baseline and whether annual collections are necessary. We have anticipated this concern for the transboundary rivers; ADF&G personnel have collected some baseline otolith samples from wild juveniles from Taku River and Port Snettisham sockeye salmon.

8. The best use of this developing technique may be to mass mark hatchery populations creating a "hatchery mark" for instances where other tools do not provide fishery managers and researchers with the information they require. At least early in the development of this technology, the probability of success will be higher the more distinct the mark, the fewer the number of marks used, and the more restricted the objectives. Current technology to mark, process, and read otoliths coupled with biological and cultural constraints limit the number of distinct marks that can be induced and deciphered in adults. For these reasons this mass marking technique is not a panacea for all stock identification problems. The coded-wire tag, with its large number of unique codes, and other stock identification tools will continue to be used for many purposes.

9. Until a mass processing system and rules for use of marks are formulated, project staff should not be encouraged to conduct new mass marking programs.

10. Project-by-project review of all proposed marking programs should be conducted so that the best stock identification tool, including mass marking, is selected to suit the objectives and situation.

11. Unfortunately when we discuss in-season needs, the season we speak of is the relatively short commercial salmon season. True in-season processing of scales, coded-wire tags, GSI samples or otoliths often requires large short-term seasonal staff. If the work load were dispersed throughout the year, fewer people would need to be hired and trained. According to Eric Volk, it will take several months for a technician to become skilled at otolith preparation. By the time technicians became skilled at the process, the short sockeye or pink salmon fishery in districts of interest, would be over. There would be some year-long work deciphering and cataloging wild stock or hatchery juvenile otolith samples, but probably there is not enough work to keep technicians employed at many different

locations throughout the state. The efficiencies of one statewide processing lab seem especially compelling in the development phases, when there are more things unknown than known.

12. There appears to be a need for some entity to coordinate statewide: (1) development of the marking technology, (2) mass otolith preparation and processing, (3) development of in-season processing capabilities, and (4) the evaluation and/or development of optical pattern recognition software and hardware. It seems as if many entities within the department and within the state are working to develop these technologies. If some coordination were to take place, appropriate entities could be focused in directions which best suit their roles in fishery research, fisheries management, hatchery management, and applied technology development. Limited resources of all interested agencies should be pooled and used to their best advantage. Recent developments in this area are:

a) ADF&G has submitted a budget through the US/Canada budget process to develop thermal marking of otoliths and mass processing of these samples. The Transboundary Technical Committee to the Pacific Salmon Commission has identified thermal marking of otoliths as the mark of choice for enhanced transboundary river sockeye stocks. A budget to develop a program including the marking of transboundary river sockeye salmon, sampling fisheries, and opening an otolith processing laboratory was submitted.

b) The ADF&G Coded-Wire Tag Lab purchased equipment to process otoliths and to develop mass processing techniques and systems, as recommended by Eric Volk. The lab has also requested funds to move to a larger location to accommodate current staff and additional staff who will process marks other than coded-wire tags. In coordination with the tag lab, the FRED Division's Limnology Laboratory purchased OPR equipment. The primary purpose of this equipment is to increase their efficiency in zooplankton analysis and secondarily to develop pattern recognition on otoliths from juvenile sockeye salmon from lakes. This use of this OPR system from Biosonics is a cooperative effort between the USFWS, OSIAR, and FRED Division. Eric Volk has been approached to provide training for personnel in both the OPR system for otolith pattern recognition and in the preparation, processing, and pattern analysis of otoliths.

c) The University of Alaska, Southeast has submitted a proposal to various entities including ADF&G, NMFS, PWSAC and VFDA to evaluate the feasibility of a thermal induced mark as a mass-mark in pink salmon hatcheries in Alaska. The proposed budget will cover the purchase of equipment similar to that recently purchased by FRED Division.

Coordination of these projects and others being planned or conducted in similar directions by other agencies needs to be achieved to optimize the use of limited funds, personnel, and expertise.

Summary

Eyed eggs from all five species of salmon can be marked with a banding pattern induced by planned temperature changes. Although adult pink and sockeye salmon have not yet returned from marking experiments it is expected that the otolith banding patterns will be retained and will be readily discernable. The presence of retained banding patterns have been confirmed in adult chum, chinook, and coho salmon. The ability of hatcheries to mark all fish at their facility with a unique "hatchery mark" is site-specific. Superficially it appears that this stock separation tool is very easy to induce and inexpensive to perform. In reality, its use will require a great deal of planning and coordination. It may involve a large capital expenditure to acquire equipment and re-plumb incubators and could require yearly operational expenditures to heat or chill water. It will require planning, detailed record keeping, and labor and commitment by each hatchery operator. Mass processing and pattern deciphering of recovered otoliths is not yet a reality. The cost of developing a technology that will meet in-season fishery management criteria is unknown. If discussed concerns are addressed and if mass processing of otoliths becomes a reality, this stock separation tool could be used to address a wide variety of present-day and future biological and resource management concerns.

SECTION IV

AN OUTSIDE PERSPECTIVE ON SALMON STOCK IDENTIFICATION IN ALASKA

AN OUTSIDE PERSPECTIVE ON SALMON STOCK IDENTIFICATION IN ALASKA

By Lee Blankenship
Washington Department of Fisheries

Scale pattern analysis (SPA) and the coded-wire tag (CWT) are well established as salmon stock separation/evaluation tools in Alaska. Although, individually they are probably the most efficient tools in many cases (i.e., SPA for sockeye and CWT for coho), their use appears to have been extended to their marginal limits in at least some cases presented at this workshop (i.e., SPA for Yukon chinook, CWT for emergent pink and chum fry).

SPA and CWTs helped revolutionize salmon fishery science and management in the 1970s. But with increased enhancement emphasis and expanded needs to define and allocate the catch more accurately for all species, the individual capabilities of SPA and CWTs for supporting resource management to help manage these problems have been exceeded. We have a common tendency to continue to try to meet new needs or challenges with existing tools with which we are familiar.

Contrary to this generalization, I am encouraged by the interest in utilizing otolith marking for pink (in Prince William Sound) and sockeye salmon. Using any stock identification technique for in-season management can be difficult. When coupled with the magnitude of the Prince William Sound fishery, a real challenge exists. If in-season needs can be addressed with relatively few marks that can be easily recognized and quickly distinguished from each other, otolith marks should prove to be a real asset.

Generally, otolith marking is a mass marking tool that is inexpensive to apply in an incubation/rearing type facility. Because the marks can be applied prior to hatching, it is especially suited for groups that are to be released as fry. Recovery of the marks is most efficient in fisheries where the marked/unmarked ratio is high, such as in terminal areas.

The tool that seems the least utilized for addressing Alaskan stock identification problems is genetic stock identification (GSI). GSI is being used outside of Alaskan waters with increasing frequency and success for chum, pink, and chinook salmon. The recent expansion in use is a direct result of improved baselines containing increased numbers of variable loci and alleles (chum -22 loci; pink - 24 loci; and chinook - 35 loci). Such improved baselines provide increased information about the characteristics and differentiation of spawning stocks and thereby increase the power of GSI for analyzing mixed-stock fisheries.

Much of the recent GSI work has been financed with Pacific Salmon Treaty funds to address interception rates. This work has proven valuable for all three species in providing accurate estimates of stock contribution and interception rates in southern fisheries. In contrast, the expansion of GSI for Alaskan spawning stocks and mixed-stock fisheries has been relatively limited.

A good example (presented at this workshop) where GSI should prove valuable to ADF&G is the problem of separating upper and lower river chinook stocks on the Yukon River. There is little doubt in my mind that GSI would separate these stocks with a very high degree of accuracy. I base this judgement on the demonstrated power of GSI to distinguish chinook stocks within other major river systems, such as the Columbia and Fraser Rivers. GSI looks like an appropriate analytical technique for several other mixed stock fisheries (both in the ocean and in transboundary rivers) that were discussed informally at the workshop.

I realize that collecting baseline stocks for GSI can be costly and time consuming due to logistical problems for many Alaska stocks (although not really much more so than scales for SPA). I strongly believe, however, that it is not an unreasonable task to accomplish since it should be a one-time collection. Baseline tissues can be archived for future use in discovering new variable loci and alleles which may enhance the separability of certain stocks, thus eliminating the need for repeated baseline collections.

Washington Department of Fisheries (WDF) has made a major commitment to GSI. This GSI operation started four and one-half years ago with emphasis on chinook. Two years later, the original staff of four and the laboratory facilities were doubled in size to their present levels to increase emphasis for chum and pink.

During the last 12-month period, this group analyzed 29,000 fish for stock contributions from seven major Washington chum and chinook salmon fisheries and for several pink salmon fisheries in Southeast Alaska, British Columbia, and Washington (under contract to Pacific Salmon Commission). They also processed GSI baseline data for 45 individual stocks (approximately 4,500 fish) of these species from Oregon, Washington, and British Columbia.

In addition to using GSI for in-season and postseason management needs, WDF uses this tool to evaluate and monitor hatchery operations and enhancement/supplementation activities to help ensure the conservation of existing genetic resources.

There are presently two GSI laboratories in Alaska. One is in Anchorage with USFWS under Dr. Wilmot and the other is with NMFS at Auke Bay under Dr. Gharrett (University of Alaska - Juneau). While both groups are federally funded (one with U.S./Canada funds), their priorities (Arctic char evaluation) and lack of output for U.S./Canada interception problems, in terms of baseline data or fishery evaluations, does not seem to be timely or in line with ADF&G's current management needs.

I recommend that ADF&G seek to establish a strong working relationship with one or possibly both of these groups to develop collaborative projects to address ADF&G's stock identification needs via GSI. If ADF&G is unsuccessful in establishing such arrangements with either of these local laboratories, I suggest that it explore other options to obtain the likely benefits of responsive GSI for analyzing spawning stocks and mixed-stock fisheries. Similar circumstances developed with WDF. From 1981 to 1985, the NMFS GSI laboratory at Manchester, Washington worked cooperatively and directly under contract with WDF to provide stock composition estimates in the chinook troll fishery. In 1985 WDF decided to develop its own GSI laboratory because an expanded use of GSI was foreseen, and it was not reasonable to assume NMFS's priorities or focus would continue to be the same as WDF.

Another technique that has not been fully used by most west coast fishery agencies is the approach of combining several stock identification tools. By using single tools one may fail to obtain adequate separation whereas by combining a number of methods (i.e., sockeye SPA, GSI, and parasites), the chances are much greater that adequate resolution can be obtained.

In summary, I think ADF&G has limited its stock identification vision by becoming too dependent upon SPA and the CWT. Development of a more complete arsenal of stock identification tools from which to choose a single method or combination of methods seems more appropriate. In some cases I think the use of new tools will be more cost efficient and provide better estimates than those currently provided. I believe that in most cases the use of a range of stock identification methods will be cost efficient in terms of the value of the fisheries and the optimization of harvests.

SECTION V

INVITED SPEAKERS

EFFECTS ON SURVIVAL OF TRAPPING AND CODED-WIRE TAGGING COHO SALMON SMOLTS

By

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and

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ABSTRACT

The effects of trapping and tagging on the survival of migrating coho salmon smolts (*Oncorhynchus kisutch*) was tested. Fish were trapped utilizing a temporary "V" shaped weir of small-mesh screened panels which channeled migrating smolts into live boxes. Captured smolts were tagged with coded-wire tags. The effects were measured over three brood years using hatchery-reared coho salmon which were planted above the weir for the test group and below the weir for the control group. Over three brood years, survival of the test groups averaged 84% of the control groups.

GENETICS APPLICATIONS TO FISHERIES PROBLEMS: PRESENT AND FUTURE

By

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Protein electrophoresis is at present the most powerful of the several stock separation techniques available. Six laboratories on the Pacific Coast representing six different agencies are presently applying protein electrophoresis to various salmon management problems. In the last several years research from these labs has nearly doubled the number of useful electrophoretic characters (loci) available and extended eastern Pacific baselines for chum, pink, sockeye, and chinook salmon substantially. Nevertheless, even when electrophoresis is used in combination with other methods, there are still stock separation problems that can not be solved and which may not, indeed, have a practical solution.

The basis for applying protein electrophoresis is the genetic differences that often develop among geographically or temporally separated reproductive units of fish. Such differences develop over time as a result of random genetic drift, natural selection, or both. Clearly, genetic methods will work only if detectable differences exist. However, the differences do not have to be qualitative (black or white); they may be quantitative (shades of grey). Qualitative traits are often referred to as diagnostic. Traits that are not diagnostic cannot be used to determine the origin of a particular fish. Rather, the traits are used to estimate the composition of mixtures; as for all statistical estimates, the precision depends largely on the sample size.

Accuracy and resolution of stock identification and separation increases as the number of loci reflecting differences among stock units increases. Clearly, resolution is also greater if the loci used show relatively large differences among units; that is, the loci approach being qualitative or diagnostic. The recent improvements in the power of applications of protein electrophoresis to salmon stock questions have mostly resulted from increasing the number of discriminating loci, not from discovering loci that are more diagnostic. There is clearly a practical limit to the number of electrophoresis characters that can be either screened in a baseline or applied to a specific question.

An important limitation of all stock separation techniques (genetic characters, parasite incidence, scale pattern, etc.), is that baseline information must be available for each character and, in theory, for all potentially contributing populations. This means that a new baseline must be developed for each new character that is added to the battery. Sometimes this can be done with archived samples. Other times it means resampling all the units (stocks, populations, etc.) of interest.

Available methodology can successfully address many of our present problems and, when baselines are completed, will be able to resolve many others. However, the techniques as a whole are approaching their maximum capabilities, and many problems remain. Resolution beyond present limitations will probably require new technology. Therefore, some effort should be placed on developing that technology. It would be foolish, however, to scrap methods that do work and stop extension of baselines with hopes of the success of unproven techniques. If and when new methods prove more effective, it will take time to develop appropriate baselines.

Having posted the appropriate warning, let's consider one of the areas that shows great promise for development into a more discriminating stock separation method: DNA technology. DNA manipulation techniques have developed remarkably in the last decade or so. Biochemical tools are now available that enable geneticists to routinely determine actual nucleotide sequences in the DNA; that is, read the actual instructions for constructing a particular trait. In addition, a gene can be transferred from one organism to another (most commonly to a bacterium) and be made to function in the recipient.

The various tools that are used to manipulate genetic material can be used to resolve genetic differences in fish. The rationale for using these DNA sequence differences for stock separation is exactly the same as was described above the protein electrophoresis. The difference is a matter of resolution. There are a limited number of proteins that can be readily resolved electrophoretically. In contrast, a change in DNA sequence underlies each protein variant, DNA tools permit examination of a tremendous number of other potentially variable sequences.

There are several approaches that can be used to detect DNA sequence differences. These approaches can be separated into the particular technique used to study the DNA and the kind of DNA actually studied. The two techniques are restriction endonuclease analysis, which produces restriction fragments for restriction fragment length polymorphism (RFLP) data, and DNA sequencing. These techniques vary in resolution and ease of application. It is possible to determine the exact nucleotide sequence of a particular stretch of DNA. This is the "ultimate" in resolution, but it is only practical to examine small (several hundred base pairs) sequences at a time. In addition, without automated sequencing machinery (which is presently quite expensive), it can not be used to analyze the large number of samples required for stock separation analyses. Restriction endonucleases identify and cut very short sequences of DNA. Although their resolution is not as powerful as actual sequencing, it is not as tedious, is practical to apply to much larger pieces of DNA, and has much more resolution than protein electrophoresis. Still, there are limitations on the number of samples that it is presently practical to analyze.

In fish, two subcellular structures carry DNA, the nucleus and the mitochondrion. DNA in these two structures are inherited separately and appear to evolve relatively independently. Nuclear DNA (nDNA) is diploid, the two copies segregate during gamete formation (meiosis). Both parents contribute essentially equal complements of DNA to the diploid offspring. Nuclear DNA has an enormous number of genes ($>10^5$), as well as a large number of sequences that are not used at all. The huge number of sequences present in the nDNA provide nearly an infinite potential for discovering sequences that will enable differentiation of stocks. In addition, there should be substantial variation in unexpressed sequences because there are no selective pressures on them.

Mitochondrial DNA (mtDNA) is haploid and duplicated before the mitochondrion divides; mitochondria replicate autonomously, independently of the nucleus. Each cell has numerous mitochondria. Further, mitochondria are inherited predominantly, if not entirely, from the female parent. MtDNA is quite small and includes only about 31 genes and nearly all of it is important for the function of the mitochondrion. MtDNA sequence changes appear to accumulate faster than changes in many nDNA sequences; that is, mtDNA appears to evolve faster. The compact size, simple analysis, and general expectation of more sequence diversity are the advantages of studying mtDNA.

At this point, the technology is available to develop stock separation methods using either mtDNA or nDNA, and the DNA sequences can be examined either using restriction endonucleases or direct sequencing. Because DNA techniques are still much slower than protein electrophoresis, it is essential to find genetic differences (sequence differences) that are unique or nearly unique for each unit (population, stock, etc.) that is to be discerned. That is, to be of practical use, DNA sequence differences among units must be much more qualitative than the traits used for protein electrophoresis. It is always possible that the population structure and relatively recent colonization of salmonid populations will not produce such unit specific differences. However, since the information carried in the DNA is the "bottom line" as far as genetic resolution is concerned, at least we will know that line of inquiry has been exhausted.

It is not at all clear at this time which approach to resolving variability in DNA sequences will prove most fruitful for salmon stock identification. Several laboratories in North America, including mine and other labs in Alaska, are attempting to develop the methodology for salmonids. The fact that there are six commercially important North American species of *Oncorhynchus* makes the task more complex. Although we hope that a technique that works for one species will also work for others, that has not necessarily been our experience for methods now in use. Moreover, when a method has been developed, additional time will be required before an adequate baseline can be completed that will enable broad application of the method.

Enormous amounts of information are carried in the DNA of a fish. It is very likely that some of those sequences will provide useful stock-specific variability. Undoubtedly, DNA methods will eventually supplant other stock separation methods. If that is to happen in the foreseeable future, effort must be made to develop those techniques now because it will take time to discover which approach(es) work best and more time to procure a baseline that is adequate for other than very simple questions. Until DNA methods and baselines have been fully developed, we must still rely on available methods such as protein electrophoresis. Protein electrophoresis data will also be very useful for calibrating the resolution of the DNA techniques.

ELEMENTAL MARKING OF SALMON

By

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ABSTRACT

Mass marking salmon by feeding diets enriched in selected elements is being studied as a potential management tool. Marked fish are distinguished from unmarked fish by chemical analysis of their scales. Because scales grow concentrically, the marked and unmarked areas form distinct bands. Once the dietary treatment ends, the measured concentration of the mark element decreases as the fish grow. This decrease is not caused by a change in concentration of the mark within the marking region, but is due to the addition of new scale material that has a lower concentration of the marking element. Micro analysis of individual scales may provide a way to avoid this decrease in the measured concentration of the marking element. By analyzing only a small portion of a single scale, the concentration of the marking element, at the mark location on the scale, can be determined. In addition, micro analysis may permit the use of more than one marking region per scale. The use of multiple marking regions greatly increases the potential number of unique marks that can be obtained from a given number of elements.

Preliminary results from micro analysis of individual scales show that the marking region can be detected. It appears that once elements are incorporated into the scale, they remain there at the same concentration until that portion of the scale is reabsorbed. There is no evidence for exchange of elements from the scales to the soft tissues until scale reabsorption begins.

BIAS AND VARIATION IN STOCK COMPOSITION ESTIMATES DUE TO SCALE REGENERATION

By

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ABSTRACT

Scale samples collected from adult coho salmon (*Oncorhynchus kisutch*) showed between population differences in rates of scale regeneration that were as great as 41%. Increasing the number of scales collected per fish from one to six decreased the average difference between-population regeneration rates from 18 to 10% and doubled the average proportion of usable fish for scale pattern analysis. In six of ten populations, scale samples showed significant dependence among adjacent scales in the probability of scale regeneration. Therefore, scale sampling should be spread out over as large an area of a fish's body as possible within a region of consistent scale patterns. Results from two-stock simulations showed that bias in estimates of stock contribution declined from 23 to 11%, and the average number of fish included in simulated mixture samples nearly doubled when the number of scales collected per fish was increased from one to six. Variation in stock composition estimates due to scale regeneration declined, as well. Increasing the number of scales collected per fish reduces classification bias when regeneration rates differ between stocks, increases precision in stock composition estimates when regeneration rates are greater than zero, and makes more efficient use of sampling effort by increasing the proportion of usable fish within a sample.

RECENT WORK ON MIXTURE PROBLEMS

By

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Much effort under the Pacific Salmon Treaty has been expended in attempting to estimate stock composition of catches. Tagging of sockeye and pink salmon was used initially in the northern boundary area, but the cost makes this approach impractical for routine use. Scales have been used to provide estimates of stock composition of Southeast Alaska sockeye salmon catches since the early 1980s. However, scales are not believed useful in stock identification for some of the other species, such as pink and chum salmon. Even for sockeye salmon, the baseline set of stocks omits numerous small Alaskan and Canadian stocks which potentially contribute to fisheries; the reason for the omission is again cost. The omission of these minor stocks probably does not introduce significant disturbance in estimation of Canadian and Alaskan stock contributions in fisheries. Canada apparently agrees the estimates are useful and has based their evaluation of interceptions for equity concerns, in part, on the Alaska Department of Fish and Game estimates of stock composition from scales. Despite the successes of scale characters for sockeye salmon, other means of determining stock composition will be needed to respond to assess stock composition of salmon catches generally.

An effort to find other characters for use in stock identification was begun by the National Marine Fisheries Service and Canadian Department of Fisheries and Oceans. This research was concurrent with Alaska Department of Fish and Game's scale work and also was directed initially at sockeye salmon. Characters with greater temporal stability than scales were sought because they were less influenced by the variation in the environment. The goal was to find a sufficient number of such characters to assess stock composition of sockeye catches ideally with greater stock detail than by scales. The cost of collection of the baseline samples required stable characters so that resampling of the stocks would not be required annually. Omitting the details of the search, five characters are presently available for 54 sockeye salmon stocks of Alaskan and Canadian origin; these characters are of some use in identifying Alaskan and Canadian stock contributions where comingling occurs. Three of the characters are genetic, and are assayed for by electrophoresis of proteins: PGM-1, PGM-2, and LDH-4. Presence or absence of the parasite, *Myxobolus neurobius*, is a fourth character. Freshwater age composition is the last character.

Application of maximum likelihood estimation to samples of sockeye salmon taken from the Noyes Island fishery in 1986 and management district 106 in 1987 produced plausible estimates of fair precision for some stock groupings. Unfortunately, certain of the groups consist of stocks from both Canada and Alaska. Our main concern in assessing stock composition with these characters is the potential for bias in estimates of stock proportions. Several additional genetic characters have been discovered by the genetics group of the Auke Bay Laboratory which may alleviate this problem.

My role in this research has been in the mathematical modeling and estimation of stock composition of mixtures. The issue of bias is an area in which we are presently active. We illustrate some aspects of estimation of precision and bias by returning to a special case: the adjustment of stock composition estimates from the classification approach.

Analysts of stock mixtures who use the classification approach commonly adjust estimates of stock composition to account for misclassification. The method is commonly referred to as the "Cook and Lord" adjustment, although the approach is far older. The method is commonly attributed with the ability to correct for bias, which in a vernacular sense, is true. However, when the method is appropriately viewed as a special case of maximum likelihood estimation of stock composition of mixtures, another bias, statistical bias, remains.

In part, statistical bias occurs because stock composition estimates are constrained to be non-negative. Constrained estimates must be biased, at least when stocks purportedly in the mixture are actually rare or absent. The estimates of stock proportion for a stock absent from the mixture would vary among possible samples of the mixture and of the purported contributing stocks. The average of such estimates must be greater than zero, and so the estimate of its proportion is biased high. The contribution of an abundant stock in the mixture, which is easily confused with the rare stock, is correspondingly biased low.

The statistical bias, as well as precision of the estimates of stock proportions, depends on the actual stock composition of the mixture, the sample sizes of the mixture and stocks, and on the confusion matrix. Precision and bias can be evaluated by bootstrap and simulation methods, techniques first applied in the context of maximum likelihood estimation of stock composition from general characters.

DISTRIBUTION OF THE BRAIN PARASITE *MYXOBOLUS* AS A POSSIBLE STOCK MARKER IN SOCKEYE SALMON OF CENTRAL ALASKA

By

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SUMMARY

The brain parasite, *Myxobolus*, was present in sockeye salmon in only 15 of 64 sampling locations in northern Alaska. These systems represent the major sockeye producing systems of the state. The parasite was present in 13 locations near the Copper River, one in the Kodiak area and one on the Alaska Peninsula. The species may be different from *M. neurobius* found in sockeye in Southeast Alaska. The parasite may prove useful for separating coastal from interior stocks in the Copper River District. In conjunction with other parasite markers, it offers intriguing possibilities for separating other stocks.

INTRODUCTION

Based on studies of the distribution of the parasite *Myxobolus* in the brains of sockeye salmon in Southeast Alaska and British Columbia, Dr. Leo Margolis (Pacific Biological Station, Canadian Department of Fisheries and Oceans) proposed that *Myxobolus* held promise as a stock marker for those areas (Pacific Salmon Commission 1987). Subsequent studies by the Canadian Department of Fisheries and Oceans and the Auke Bay Laboratory showed that *Myxobolus* was present in nearly every lake in Southeast Alaska (Moles et al. in press) but largely absent from both interior Canadian lakes and from the transboundary rivers (Pacific Salmon Commission 1987). Use of the parasite proved successful in separating sockeye salmon stocks in the common fishery in both 1983 and 1984 (Moles et al. in press).

Subsequent interest in identifying continent of origin of salmon caught in high seas fisheries led to an expansion of the distribution work to other regions in Alaska. The pioneering work of Margolis had already found two metazoan parasites useful in separating eastern and western Pacific stocks of sockeye salmon (Margolis 1963). The possibility that *Myxobolus* distribution might add to the existing baseline of parasite markers was thought to be worth exploring.

Through a series of cooperative efforts, we were able to obtain samples from 64 systems in central Alaska. These systems represented the major sockeye producing systems (with a few notable exceptions). Few sockeye of commercial importance are generated by streams north of the Kuskokwim.

RESULTS AND DISCUSSION

The bulk of the systems which were positive for the parasite *Myxobolus* were in the Copper River district near Prince William Sound. Of the 16 areas examined, 7 locations had a high prevalence of the parasite (>82%). These were the coastal lakes which are shallow and productive. The rivers and sloughs had a lower incidence (<18%) as did the main body of the Chitina River (<10%). This corresponds closely to the results of previous studies in SE Alaska and Canada. The samples were analyzed by Scott Jordan of the Alaska Department of Fish and Game, who indicated that quite a few of the parasites did not have the distinctive teardrop shape of *Myxobolus*.

The samples from western Prince William Sound and from the Copper River showed only a slight incidence of the parasite. In contrast, the coastal lakes showed a high prevalence. While the coverage of the contributing coastal systems was very comprehensive, the Copper River itself was only sampled near the mouth and on the Chitina tributary. More samples will be taken from the Copper River itself to determine how useful the parasite will be for separating coastal from interior salmon.

In Bristol Bay the parasite appears to be entirely absent from all 24 systems examined. These systems represent all the major sockeye river drainages in Bristol Bay. *Myxobolus* was also absent from seven contributing tributaries of Tustamena Lake in Cook Inlet. On the Alaska Peninsula only Hoodoo Lake (Nelson Lagoon system) showed evidence of the parasite (100%). The systems examined from these three areas represent over 80% of the sockeye salmon production of Alaska.

Myxobolus has been reported for a few systems in Kamchatka. No baseline of *Myxobolus* currently exists for the Asian side of the Pacific, but the presence in some Asian samples and the absence in the major contributing systems in Alaska suggest that *Myxobolus* might prove useful in separating stocks of sockeye salmon in high seas fisheries.

The one Kodiak sample showed an 85% prevalence of the parasite. Most of the contributing streams on Kodiak and Afognak Islands are of the shallow, productive lake variety common in Southeast Alaska and Prince William Sound. Many of the parasites from this sample were also different from *M. neurobius*. They were circular in shape rather than having the distinctive teardrop morphology of *M. neurobius*. While the possible presence of two species suggests an additional discriminator, it adds the need for additional biological and distribution information. Next year, we anticipate concentrating our efforts on a more complete survey of the Kodiak stocks.

The Prince William Sound collectors also noticed a high incidence of *Philonema*, a body cavity nematode. Margolis had previously noted a high prevalence of *Philonema* in Bristol Bay sockeye (personal communication). The presence or absence of the two parasites might offer stock biologists the ability to separate a number of stocks of sockeye salmon in the mixed stock fisheries.

ACKNOWLEDGMENTS

The samples for Prince William Sound were gathered and analyzed by Scott Jordan of the Alaska Department of Fish and Game under a cooperative project between the ADF&G Stock Biology Program of Cordova (Sam

Sharr, project leader) and the Auke Bay Laboratory.

Samples for Bristol Bay, Kuskokwim and Cook Inlet were gathered by the U.S. Fish and Wildlife Service in conjunction with their stock separation program (Becky Everett, project leader).

Samples for the Alaska Peninsula were gathered by the Alaska Department of Fish and Game, Commercial Fisheries Division (Jim McCullough, project leader).

The idea that *Myxobolus* held promise as a stock marker was evolved by Dr. Leo Margolis of the Canadian Department of Fisheries and Oceans and his staff at the Pacific Biological Station following distribution studies in S.E. Alaska and British Columbia. The authors acknowledge the debt they owe Dr. Margolis and his staff for training, insights, advice and encouragement.

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PREVALENCE OF *MYXOBOLUS* INFECTION IN SOCKEYE SALMON IN ALASKA - 1989

BRISTOL BAY

Ugashik Drainage	
Ugashik Narrows	0/50
Ugashik Creek	0/50
Ugashik Lake	0/50
Deer Creek	0/50
Blade Creek	0/50
Iliamna Drainage	
Copper Creek	0/50
Gibralter Creek	0/50
Iliamna River	0/50
Belinda Creek	0/50
Battle Creek	0/50
Kvichak River	0/50
Egegik Drainage	
Becharof Lake	0/50
Featherly Creek	0/50
Naknek Drainage	
Naknek Lake	0/50
Brooks Lake	0/50
Margot Creek	0/50
Lake Clark Drainage	
Kijik River	0/50
Tonzamina Creek	0/50
Nushagak Drainage	
Wood River	0/50
Nushagak River	0/50
Kulik Lake	0/50
Nushagak Lake	0/50
Igushik River	0/50
Togiak River	0/50

KUSKOKWIM

Goodnews River, near fork	0/50
Goodnews River, main fork	0/50
Kagati Lake	0/50
Telquana Lake	0/50

COOK INLET

Lake Tustamena	
Nikolai Creek	0/50
Bear Creek	0/50
Glacier Flats	0/50
Moose Creek	0/50
Crystal Creek	0/50
Clear Creek	0/50
Seepage Creek	0/50

ALASKA PENINSULA

Meshik River	0/50
Ilnik River	0/50
Chignik Lake	0/32
Sandy River	0/50
Bear Lake	0/50
Thin River	0/50
Nelson Lagoon	28/50
Hoodoo Lake	50/50

PRINCE WILLIAM SOUND

27 Mile Slough	7/50
Martin River Slough	12/50
Ragged Point	9/50
Bering River	50/50
39 Mile Slough	2/50
Martin Lake	41/50
McKinley Lake	45/50
Little Martin Lake	47/50
Kushtaka Lake	49/50
Tokun Lake	50/50
Eyak Lake	49/50
Eshamy Weir	0/50
Main Bay (jacks)	0/50
Chitina River	3/50
Chitina River	5/50
Chitina River	0/50

GULF OF ALASKA

Paul's Bay, Afognak Island	22/26

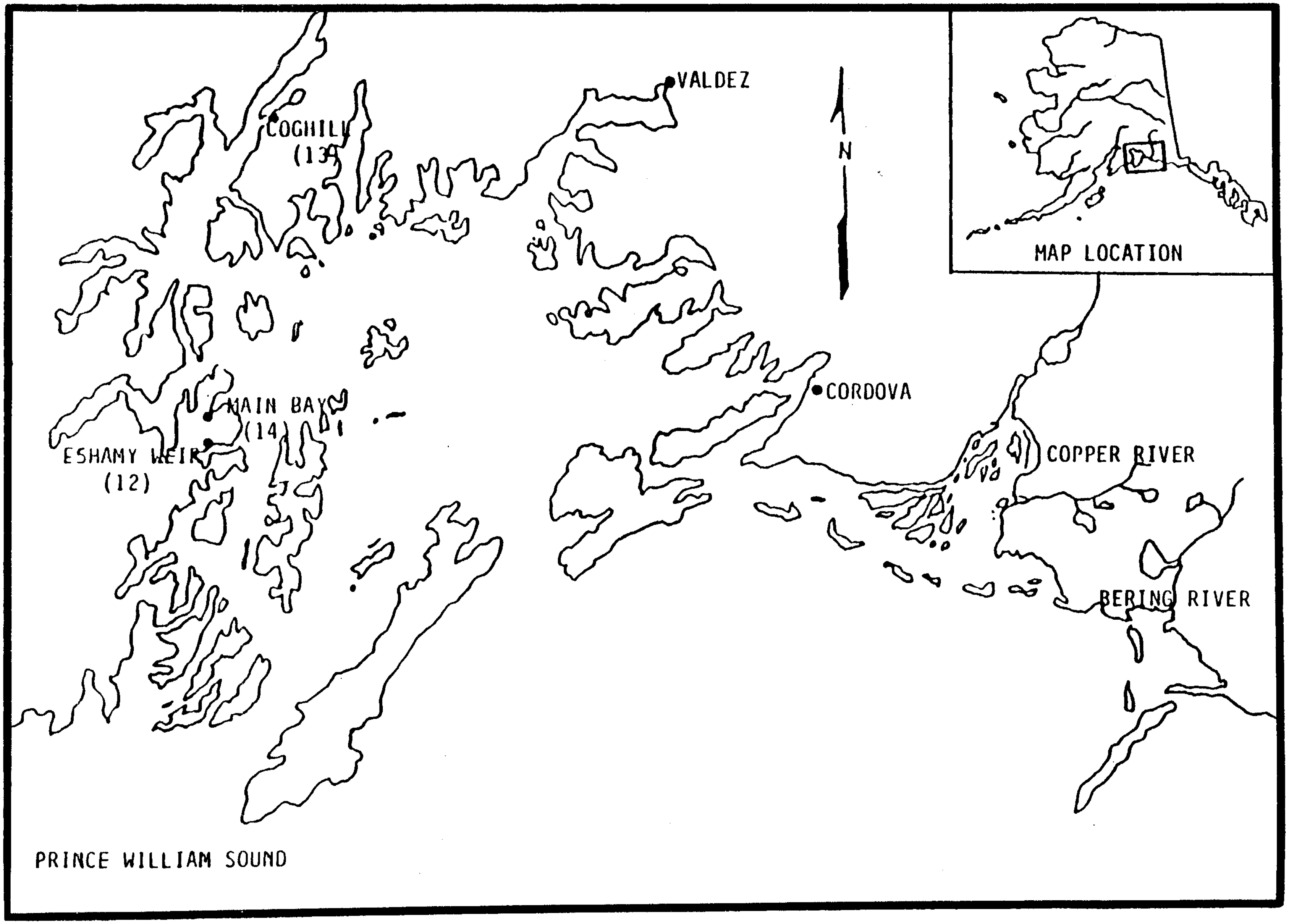

Figure 1. Map of Prince William Sound showing different sample areas.

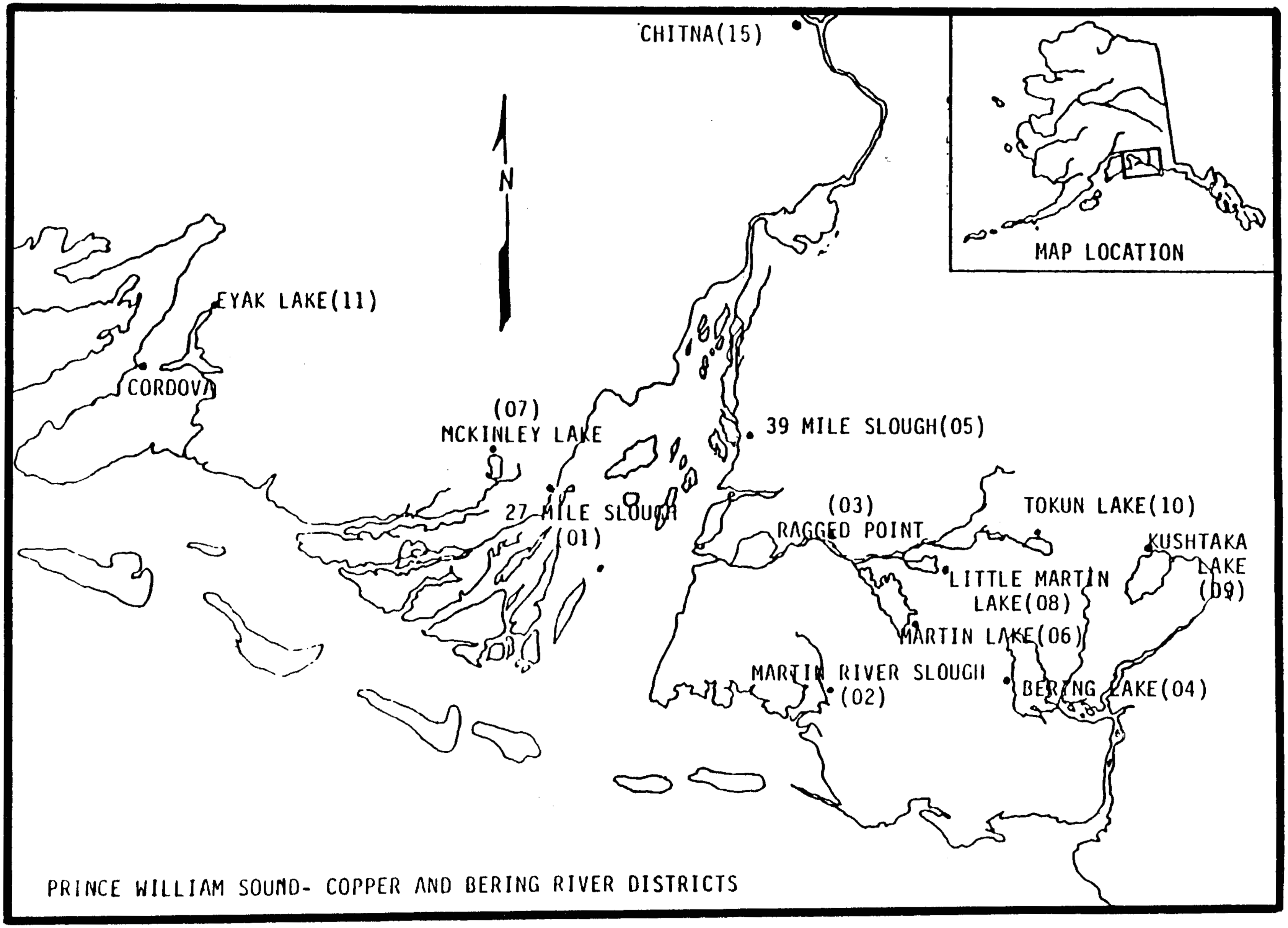

Figure 2. Map of the Copper/Bering River Districts and key sampling sites.

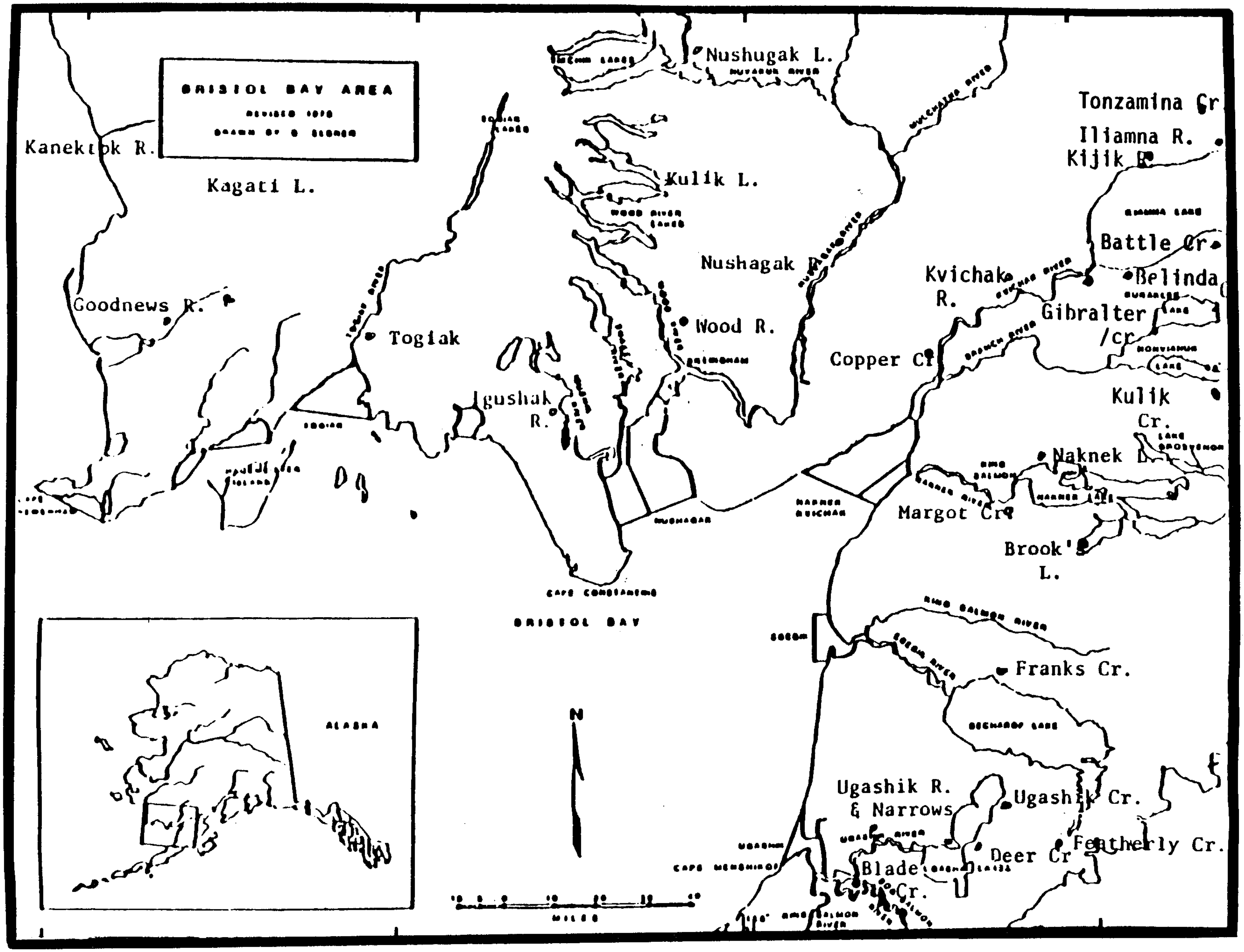

Figure 3. Bristol Bay major river systems and commercial fishing districts.

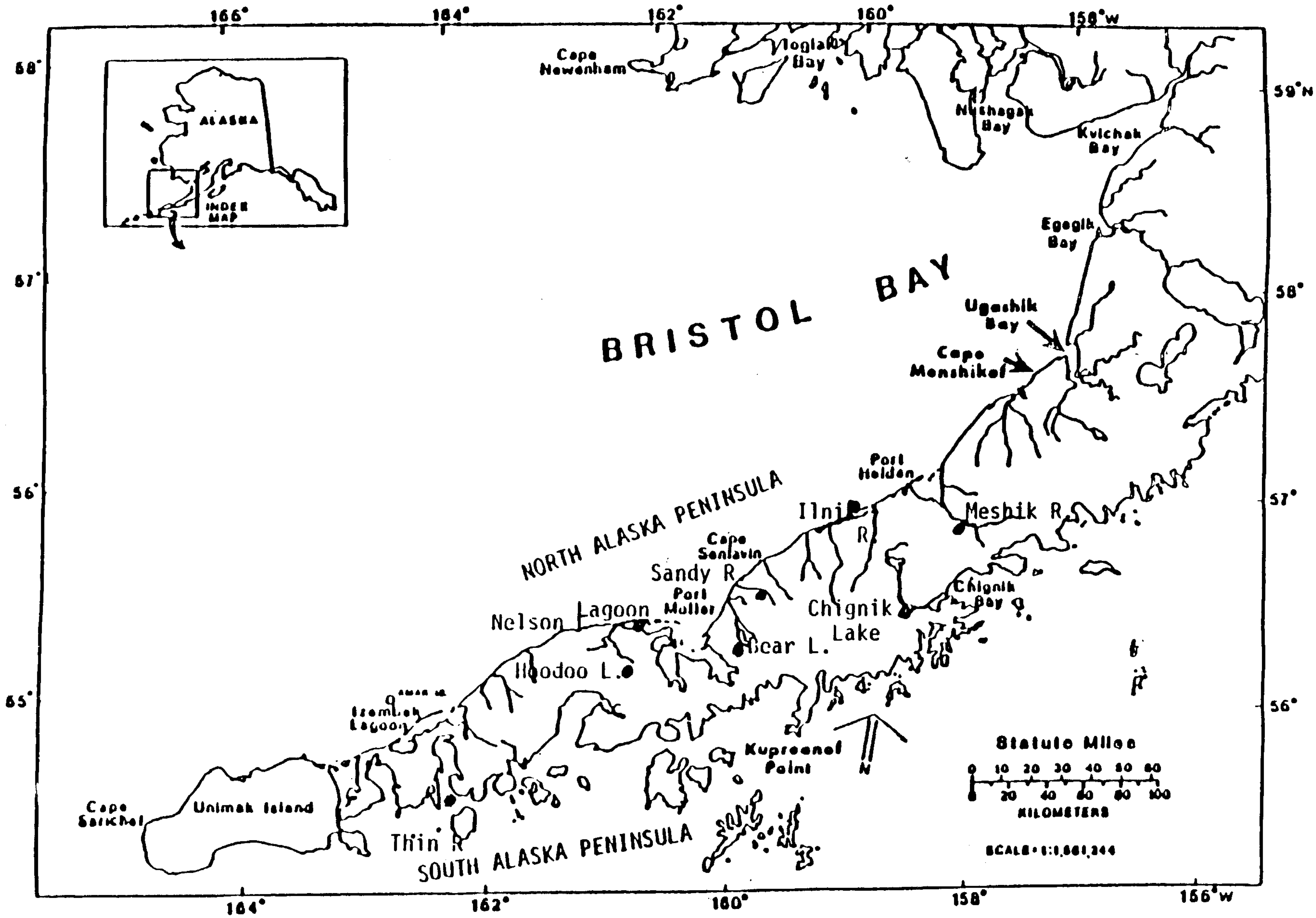

Figure 4. Map of the Alaska Peninsula from Kvichak Bay to Unimak Island.

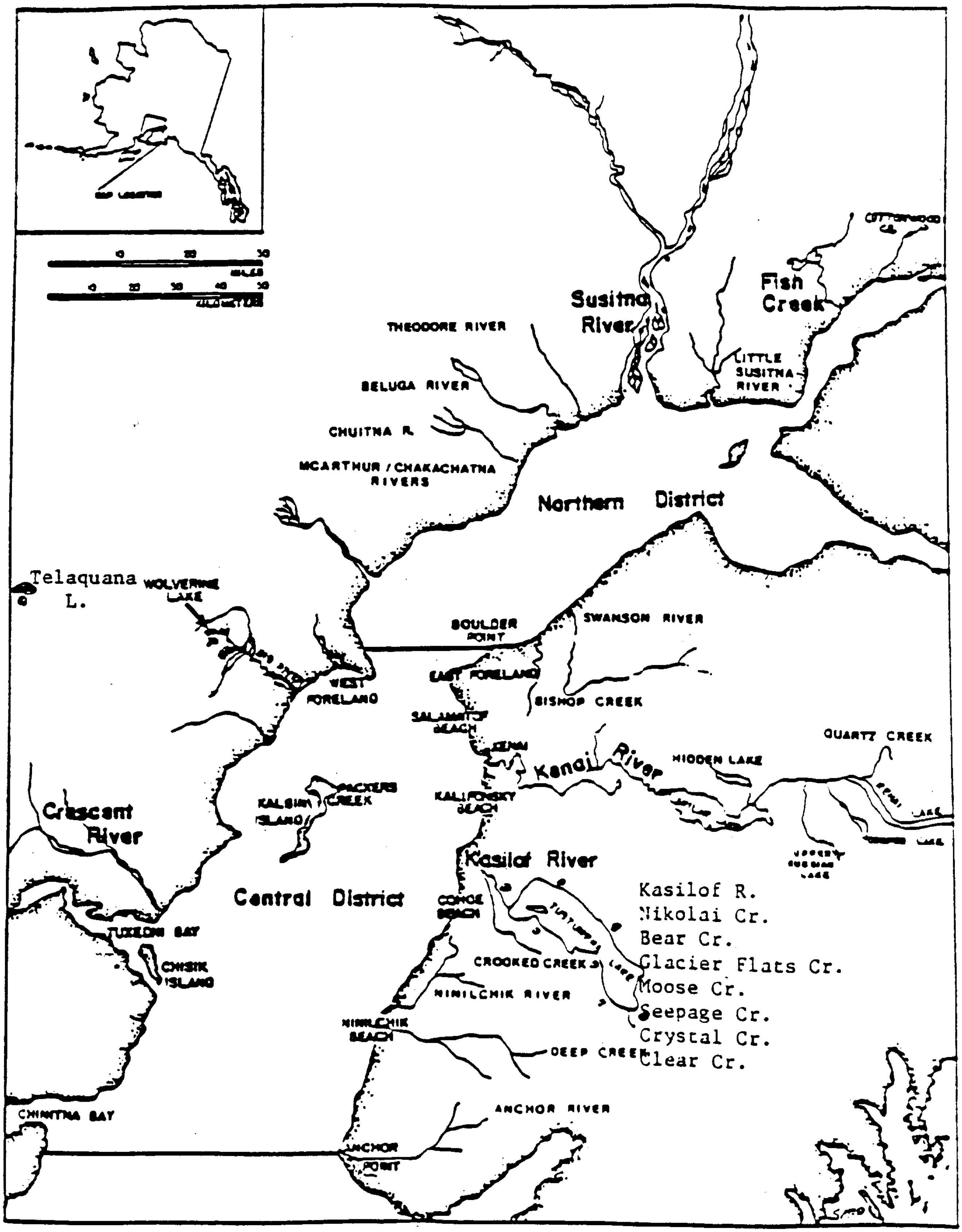

Figure 5. Upper Cook Inlet area showing the commercial fishing districts and major sockeye salmon spawning river systems.

CURRENT HIGH SEAS SCALE PATTERN STUDIES AT FRI

By

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As part of the 1986 renegotiation of International North Pacific Fisheries Commission (INPFC) areas for the Japanese high seas salmon fleets, there was a Memorandum of Understanding on Research, which includes intensified scale pattern studies by member nations, with particular emphasis on salmon in the area of the landbased drift gill net fishery south of 46°N. Results of these studies will be used in 1991 reconsideration of the eastern boundary line for that fishery, drawn at 174°E in 1986. At Fisheries Research Institute we are in the middle of studies of sockeye (age 1.2, 2.2, 1.3, and 2.3 matures and 1.2 and 2.2 immatures returning in 1986 and 1987), chinook (age 1.2 immatures returning in 1986, 1987, and 1988), and coho (age 2.1 returning in 1986 and 1987, and age 1.1 returning in 1986).

Our methods generally follow recommendations made by INPFC in 1987 for use of standardized scale pattern analysis methodology by member nations. These recommendations include (1) continued efforts to obtain improved scale samples from the U.S.S.R., (2) use of image analysis system, profile projector, or digitizing system for collection of data; (3) use of either maximum likelihood or classification (with correction) as statistical procedures for estimating the stock composition of fishery samples; and (4) basing stock composition estimates for any stratum on unknown-origin samples of 100 or more scales. Strata are recommended to be month by 5°-longitude sub-area or finer.

Improvements of samples over previous studies include better coverage of Alaskan and USSR stocks, and improved quality of USSR samples. Samples from the fishery areas continue to be deficient; mothership samples are of poor quality, and research vessel samples from the landbased area are not numerous enough for valid analyses of chinook and sockeye.

Samples are measured on a BioSonics OPRS image analysis system. The Fisheries Agency of Japan (FAJ) and TINRO in the U.S.S.R. have also acquired OPRS systems; there is the potential for future exchange of scale measurement data between agencies rather than exchange of scale impressions. Measurements are taken in each circulus in the first year of marine growth; circulus measurements are not taken in the freshwater zone because this is difficult to do under the magnification we use and because information from this zone is of less use in the large regional stock separation studies that we do.

A large number of scales (60) were measured from each sample in the first year of study, for exploratory analysis of stock groupings and methodology; fewer scales were measured for subsequent years. In general, fisheries samples were used rather than escapement samples for chinook and coho. For sockeye, where stocks are fewer and better known, escapement samples were used.

We use linear discriminant function analysis results as one tool for grouping stocks. LDF results are used rather than cluster analysis because the algorithm for distinguishing between the stocks in clustering is different from that which will be used in the final LDF analysis to separate stock groupings and classify fishery samples. BMDP output for LDF includes a table of canonical variable values at the group means. These values are coordinates in a space whose dimensions are determined by the number of canonical variables. A Pythagorean-type formula can be used to determine the distances between all pairs of group means. Stocks which are close to one another form groupings with similar variable values which we can use as regional standards. Fortunately, many geographically close stocks form clusters. Similarity between south central Alaskan stocks and Asian stocks continues to be our largest problem. Because we are grouping similar stocks together and because actual run sizes are not always well known, we have been using roughly equal sample sizes for each stock, with little or no weighting based on stock size. We are also using weighted, geographical standards in the sockeye analyses to compare current results with a study of 1972-76 sockeye done earlier at FRI, and we plan to do simulation studies to examine the effects on classification results of combinations of differing numbers from each stock in our standards.

Since LDF classification results and accuracies are generally similar to those obtained from maximum likelihood methods, we have continued to use BMDP LDF for classification. We also plan to use Fortran programs, written for us by Russell Millar, which include both classification and maximum likelihood procedures. We continue to use Fortran programs to obtain variance estimates, based on Pella and Robertson's estimator, for classification results. A recent variance estimator for maximum likelihood results which includes variance due to both the standards and unknowns has been developed by FAJ; however, it has not been well-tested yet. Bootstrapping is also available for maximum likelihood approaches.

Preliminary results of the 1986 age-2.1 coho analysis confirm indications from tagging that Asian fish predominate in the high seas fisheries areas. However, western Alaskan fish are present in appreciable numbers (approximately 30%) and are more abundant in the eastern areas of the fisheries than in the western areas.

GENETIC STOCK IDENTIFICATION IN ALASKA

By

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The Genetic Stock Identification procedure is based on resolving genetic variability in fish using the method of protein electrophoresis. Tissue samples are taken from fish in their natal areas (the baseline) and screened for variability over numerous genetic loci. The frequency of each variable enzyme is determined in each baseline population. Samples are taken from a mixed stock (the mixture) and the genetic makeup of each individual fish determined. Using a computer program based on a maximum likelihood estimator, combinations of baseline populations that statistically best fit the mixture are determined. The accuracy of the estimates are calculated by repeated bootstrap resamplings of the baseline at percentages of each population varying from 0% to 100% in the simulation. The method is currently being used in California, Washington, British Columbia, Southeast Alaska, Bristol Bay, and the Yukon River. A test in Bristol Bay shows great immediate promise for stock identification in chum salmon, but a great deal of work remains to make the procedure work for sockeye salmon.

EFFECTS ON SURVIVAL OF TRAPPING AND CODED-WIRE TAGGING COHO SALMON SMOLTS

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ABSTRACT

The effects of trapping and tagging on the survival of migrating coho salmon *Oncorynchus kisutch* smolts were tested. Fish were trapped utilizing a temporary "V" shaped weir of small-mesh screened panels which channeled migrating smolts into live boxes. Captured fish were tagged with coded-sire tags. The effects were measured over three brood years using hatchery-reared coho salmon that were planted above a weir for the test group and below a weir for the control group. Overall survival of the test groups averaged 84% of the control groups.

RECENT WORK ON MASS MARKING OF SALMONID OTOLITHS BY ENVIRONMENTAL MANIPULATION

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ABSTRACT

Research in our laboratory has shown that simple environmental manipulations during incubation and rearing periods can produce specific banding patterns in the otolith microstructure of juvenile salmonids. In embryonic and alevin chum (*Oncorynchus keta*), coho (*O. kisutch*), chinook (*O. tschawytsha*) and sockeye (*O. nerka*), brief exposures between relatively cool and warm water or alternating exposures between relatively cool and warm water sources produced distinctive, optically dense bands or zones in their otoliths. By exposing salmonid embryos or alevins to regularly repeating thermal cycles, we are able to induce specific and uniquely identifiable patterns into the otoliths based on the specific thermal cycle they are exposed to. Because the otolith carries this pattern unaltered for the life of the fish, this technique serves as an economical way to mass-mark salmonids. While the technical problem of otolith mark application and recovery have largely been solved, several complex issues still surround its practical application to fisheries management.

SECTION VI

ALASKA DEPARTMENT OF FISH AND GAME SPEAKERS

OVERVIEW OF STOCK SEPARATION RESEARCH IN THE ARCTIC-YUKON-KUSKOKWIM REGION

By

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Stock separation research in the Arctic-Yukon-Kuskokwim (AYK) Region by the Division of Commercial Fisheries has consisted of tag and recapture, radio telemetry, and scale pattern analysis (SPA) studies. Other agencies have conducted studies based upon protein electrophoresis and parasite methodologies.

Tag and recapture studies have been conducted for stock separation of (1) lower Kuskokwim River chinook and chum salmon in the 1960s; (2) lower Yukon River chinook and chum salmon in the 1960s; (3) upper Yukon and Tanana River fall chum salmon for 1976 through 1983; (4) Norton Sound salmon for 1978 through 1979; and (5) Kotzebue Sound chum salmon for 1966 through 1968 and 1981 through 1982. Radio telemetry tagging was applied to Tanana River fall chum salmon in 1988 and 1989. Early tagging studies on the Yukon and Kuskokwim Rivers were primarily designed for estimating population sizes, and only small numbers of recoveries were made from spawning stocks. The upper Yukon River tagging study indicated that fall chums moving along the north bank of the Yukon River in the Galena area were primarily bound for upper Yukon and Porcupine drainage spawning areas, while those moving along the south bank were primarily bound for the Tanana River drainage. The Norton Sound study indicated that some chinook and chum salmon tagged in the Skaktoolik and Unalakleet Subdistricts were recovered in the Yukon River. Kotzebue Sound tagging studies indicated Kobuk drainage chum salmon stocks returned earlier than Noatak River stocks. Tanana River fall chum salmon radio telemetry largely confirmed previously suspected spawning distributions.

SPA studies have been conducted for (1) Norton Sound chum salmon in 1978; (2) Yukon River chum salmon in 1974, 1976, and 1986; and (3) Yukon River chinook salmon from 1980 to 1989. In addition, herring stock standards were collected from fishing districts in AYK during the 1989 season as part of a larger Bering Sea herring bycatch study conducted by Central Region staff. The Norton Sound chum salmon feasibility study indicated that SPA appeared to provide reasonable separation, although full implementation has never been funded. The Yukon River chum salmon feasibility studies indicated that separation was not sufficient to warrant application, except as an accessory factor in combination with other stock separation methods. Yukon River chinook salmon, on the other hand, are assigned to three broad regions of origin (lower, middle, and upper river) on an annual basis for run reconstruction and post-season fisheries management assessment. The herring bycatch study is still in progress.

Other agencies have in the past or are currently conducting stock separation research in the AYK Region. These include (1) USFWS electrophoresis studies on Yukon River chinook and chum salmon since 1987; (2) Canadian Department of Fisheries and Oceans (DFO) electrophoresis studies on Yukon River chum salmon in 1985 and 1986; and (3) DFO parasite studies on Yukon River chinook salmon since 1988. In addition, samples have been provided by the Commercial Fisheries Division in recent years for INPFC high seas stock separation research using SPA and parasite methods.

Looking ahead, the top priority for future stock separation research in the AYK Region will continue to be Yukon River chinook and chum salmon because of the US/Canada treaty negotiation process. Management of the Yukon River under an international treaty regime would require timely estimates of Canadian origin fish in Alaska fishery harvests.

MODEL BUILDING IN BRISTOL BAY

By

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Linear discriminant function (LDF) analysis of scale patterns has been used to estimate the stock composition of sockeye catches within east side Bristol Bay districts since 1986. Catch by stock and age is combined with escapement data to estimate total return by individual river system. In this paper I will summarize the steps taken to build linear discriminant functions in Bristol Bay, give examples of some of the problems we've encountered, and list longstanding questions.

Model Construction

The procedures used to build classification models in Bristol Bay are commonly used by stock identification projects throughout the Alaska Department of Fish and Game. Within the east side of Bristol Bay, stock groupings are relatively simple because they are based on the four major rivers contributing to the catch (Kvichak, Naknek, Egegik, and Ugashik Rivers). The East Side of Bristol Bay is divided into three management districts located at the mouths of these four rivers. Each river has a specific escapement goal, and the adjacent fishery is regulated for achievement of its river's goal. When building models in Bristol Bay, we generally do not pool across river systems, although in 1986 we pooled Kvichak and Naknek Rivers samples because we could not differentiate between their scale patterns.

The first step in model construction is to determine which age groups to measure. In general, we digitize an age group if it comprises >15% of a district catch. We measure 200 scales per age group per river each year. Escapement scales are collected with beach seines at counting towers located near the mouths of rearing lakes. The 200 escapement samples are weighted through time based on daily tower counts. Measurements taken from scales include the number and distance between circuli along a linear axis for all freshwater annuli, plus growth, and first marine annulus. Number and distance measurements are converted to 79 or 108 variables, depending on the number of freshwater annuli, using a program called REFORMW (written by Robert Conrad, Alaska Department of Fish and Game, Anchorage).

A set of variables for inclusion in the linear discriminant analysis is selected with the aid of two programs, FSTATFW and VARSELFW (written by Robert Conrad, Alaska Department of Fish and Game, Anchorage). Descriptive statistics (mean, standard error, range) and a group F-statistic for each variable is calculated by the program FSTATFW. An initial set of variables is chosen by the operator using the following criteria: variables with the highest F-statistics for a group of related variables, variables for which >95% of the observations for a group have the particular variable, variables which are negatively correlated with variables having high F-statistics. The initial set of variables are submitted to the program VARSELFW which selects a subset of variables for a linear discriminant function analysis by a stepwise procedure using partial F-statistics as the criteria for variable entry/removal to the model (Enslein et al. 1977).

Linear discriminant function analysis (Fisher 1936) is performed using a set of scale variables defined by the operator with the program LDF-FW (written by Robert Conrad, Alaska Department of Fish and Game, Anchorage). Groups in the analysis are assumed to have an equal prior probabilities. An estimate of the accuracy of each classification model in assigning observations to the correct group is provided by the LDF-FW using a leaving-one-out procedure (Lachenbruch 1967). Samples from mixed stocks, catch samples, are assigned to a stock with the program CLASSFW written by Robert Conrad. Estimates of stock composition for the catch are adjusted for misclassification by the model with a procedure described by Cook and Lord (1978). Variances of the catch composition estimates are calculated using a procedure documented by Pella and Robertson (1979).

Analysis Assumptions

After linear discriminant models are built, we review the data to check that the basic assumptions of the analysis are met. The major assumptions underlying linear discriminant analysis are (1) the stocks being investigated are discrete and identifiable, (2) the variables used in the analysis have a multivariate normal distribution in each population, (3) the variance-covariance matrices for the population are equal. The assumption of equal variance-covariance matrices is tested in the program LDF-FW using the F-statistic in a procedure described by (Box 1949). However, we find that the F-statistic is always significant. Therefore, we try to get an idea how well this criteria is being met by reviewing the data graphically. An xy plot of the two most important variables is constructed and a contour around 90% of the points is drawn, assuming bivariate normal distribution. Equality of group covariances is judged by comparing the shapes and the angles of the group contours. We have found no efficient method of testing the multivariate distribution of the variables in the analysis. In general, we review the distribution of the variables graphically with either simple univariate line graphs or Box and Whisker plots.

Model Sensitivity

During our investigations there have been several occasions when it was important to test the sensitivity of the classification model to pooling, variable selection, and differing run strengths.

During the 1988 analysis model accuracy of assigning Naknek River samples correctly was very low unless the size of the first marine zone was included. The problem with using size of first marine growth as a variable was that plots indicated the size of first marine growth for Naknek River samples was bimodally distributed. If only freshwater scale variables were included in the analysis, Naknek River samples frequently misclassified to Kvichak River, thus samples from these rivers would have to be pooled. To test how sensitive the model was to the non-normality of this variable, we ran some simulations. We constructed three different models for the simulation (1) 4-way model with freshwater and marine variables, (2) 3-way model (Kvichak and Naknek pooled with equal weight) with freshwater variables only, (3) 3-way model (Kvichak and Naknek pooled with samples weighted based on escapement counts) with freshwater variables only.

The three models were used to classify independent sets of known escapement scales and correct classifications by the models were compared. There were differences in correct classification among the models depending on the stock. The 4-way model was most accurate in classifying Naknek and Ugashik Rivers samples, while the 3-way, equal-weight, pooled model was the most accurate for Kvichak and Egegik Rivers samples. The three models were also used to classify all the catch samples, and differences among the models were compared. The differences in the overall catch classification by the three models were not great. The largest difference (3%) in estimates of Kvichak and Naknek Rivers contribution existed between the 4-way model and the 3-way, equal-weight, pooled model. The largest difference (1%) in estimates of Egegik River contribution existed between the 3-way, equal-weight, pooled model and the 3-way, escapement- weighted, pooled model. Finally, the largest difference (4%) in estimates of Ugashik Rivers contribution existed between the 4-way model and the 3-way, equal- weight pooled model. After running these simulations, we decided to use the 4-way model because catch classification results were similar whether marine variables were included or excluded.

During the 1989 analysis, the estimate of the Ugashik River contribution to the Naknek/Kvichak catch was unusually high compared to past years. We questioned whether the high estimates of the Ugashik River contribution were real or caused by misclassification by the model of Naknek and Ugashik River stocks. To get a better understanding of how the model was classifying these two stocks, given different run strengths, we used a resampling program developed by Brian Bue (Alaska Department of Fish and Game, Anchorage, personal communication) to test the model. The model was held constant, and we constructed five independent test sets of 100 scales. The independent test sets included scales not used to construct the model. Each of the five test sets included 70 scales from Kvichak River, and each differed from each other in the numbers of Naknek River versus Ugashik River samples. The number of Naknek and Ugashik River scales included in the five test sets were (1) 0 Naknek and 30 Ugashik, (2) 10 Naknek and 20 Ugashik, (3) 15 Naknek and 15 Ugashik, (4) 20 Naknek and 10 Ugashik, and (5) 30 Naknek and 0 Ugashik. We then constructed 500 replicates of each test set with the resampling program and classified all the replicates with the model. The mean proportion correctly classified of the 500 replicates was compared to the actual run proportions for Naknek and Ugashik samples. Without adjustments for model misclassification (Cook and Lord 1978), estimates for Naknek River were slightly high at low true Naknek proportions and slightly low at high true Naknek proportions. After Cook and Lord adjustments were applied, estimates for Naknek River were equal to the true Naknek proportions. Unadjusted estimates for Ugashik River showed a trend similar to the Naknek River estimates. However, for Ugashik River, the Cook and Lord adjustment procedure did not completely correct the estimates to the true Ugashik proportions. Instead, Ugashik River adjusted estimates were lower than true proportions at all run strengths.

Questions

The following six questions are continuously asked during each Bristol Bay scale pattern analysis. (1) What is the best method to select scale samples to represent your known groups: randomly through time or weighted through time based on abundance indices? (2) What procedures should be used to screen variables to assure the best set for stock discrimination while meeting the assumption of multivariate normal? (3) Should equal prior probabilities be used for all groups even when historic data indicates that all stocks do not have equal probability of being caught, and how does the adjustment of prior probabilities interact with the Cook and Lord adjustment? (4) How important is a balance matrix - is it more important to have the diagonal or off-diagonals balanced, and what procedures should be used for balancing? (5) How sensitive is linear discriminant function analysis to unequal variance-covariance matrices? (6) Are there other procedures for adjusting estimates for model misclassification which are better than the Cook and Lord procedure because they are constrained between 0 and 1?

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APPLICATION OF SCALE PATTERN ANALYSIS IN THE MANAGEMENT OF SOCKEYE SALMON FISHERIES IN BRISTOL BAY

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The Bristol Bay sockeye salmon fishery is the largest in the world, with runs averaging 38 million annually since 1980. Sockeye salmon returning to nine river systems are harvested in five terminal fishing districts. Fishing districts and sections are located near the mouths of spawning streams to minimize problems associated with mixed stock fisheries. Sockeye fisheries in Bristol Bay are managed for fixed escapement goals by regulating fishing times and area openings.

Extensive stock assessment programs have been conducted in Bristol Bay since the early 1950s (e.g., enumeration and age-length-weight sampling of catches and escapements). Total return by brood year is available for each of the nine river systems. In the past, it was assumed that fish caught in each fishing district originated from rivers terminating within the respective district. However, in recent years concerns over the degree of interceptions occurring among the three east side districts (Naknek/Kvichak, Egegik, and Ugashik) have surfaced due to changes in catch and production trends. Catches in the Naknek/Kvichak District have declined in recent years, while those in Egegik and Ugashik Districts have increased. In addition, return-per-spawner ratios are consistently higher for Egegik and Ugashik Rivers than for Kvichak and Naknek Rivers. Is the high production due to more favorable rearing conditions in Egegik and Ugashik Rivers, or are Kvichak and Naknek Rivers fish being intercepted in the more southern districts and erroneously assigned to the Egegik and Ugashik Rivers? Past tagging studies (Straty 1975) suggested that stock mixing does occur to some degree within districts located on the east side of Bristol Bay.

In response to these concerns about interceptions, the Alaska Department of Fish and Game initiated studies in 1985 (Fried and Yuen 1985) to evaluate the usefulness of scale pattern analysis in estimating catch composition within east side Bristol Bay fishing districts. From 1986 to 1989 sampling programs and data analyses were expanded and the contribution by stock to Naknek-Kvichak, Egegik, and Ugashik Districts sockeye catches were estimated (Bue et al. 1986, Cross and Stratton 1989, *In press*, Cross et al. 1990). A brief summary of the results from these studies are presented in this paper.

Estimates of Catch Composition

Most sockeye salmon harvested in each fishing district originated from rivers within the district, although there was interception of outside stocks in every area. In general, interception of sockeye salmon stocks from other districts was least for Naknek-Kvichak District and greatest for Egegik District.

Naknek-Kvichak District

There were no significant trends through time in stock percentages for sockeye salmon catches in Naknek-Kvichak District. Sockeye salmon originating within the District (Kvichak and Naknek Rivers) accounted for ≥85.0% of the total district catch from 1986 to 1989. The percent contribution of Naknek River sockeye salmon to the total District catch decreased from 82.7% in 1986 to 14.6% in 1988 and then increased to 18.3% in 1989. Conversely, the contribution of Kvichak River sockeye salmon to the district catch increased from 7.3% in 1986 to 82.1% in 1988 and then decreased to 66.5% in 1989. Percent contribution of Egegik sockeye salmon to Naknek-Kvichak District catch ranged from 2.7% in 1987 and 1988 to 6.9% in 1986. Percent contribution of Ugashik River sockeye salmon to Naknek-Kvichak District catch was 3.1% in 1986, 8.1% in 1987, 0.7% in 1988, and 10.8% in 1989.

Egegik District

Egegik District stock contribution to the total Egegik District sockeye salmon catch decreased each year from 1986 to 1989. The percentages of Egegik River fish in the District catch were 83.1% in 1986, 74.6% in 1987, 68.4% in 1988, and 60.4% in 1989. Kvichak sockeye salmon comprised an increasing percentage of Egegik District catch with contributions ranging from 2.9% in 1986 to 16.4% in 1989. The percentage of Naknek River sockeye salmon in Egegik District catch was fairly stable from 1986 to 1988, ranging from 5% in 1987 to 7.7% in 1986. In 1989 the percentage Naknek River sockeye salmon comprised of the Egegik District catch increased to 13%. Ugashik River stock contribution to the Egegik District sockeye salmon catch was 6.3% in 1986, 11.7% in 1987, 9.9% in 1988, and 10.2% in 1989.

Ugashik District

There were trends through time in stock contributions to sockeye salmon catches in Ugashik District during 1986 to 1989. Samples taken in 1986, 1988, and 1989 showed that most sockeye salmon harvested in Ugashik District prior to 23 June were from other districts. In general, the percent contribution of Ugashik sockeye salmon to Ugashik District catch increased through time, while the percent contribution of Egegik sockeye salmon decreased through time.

The contribution of Ugashik River sockeye salmon to the Ugashik District annual catch increased from 63.8% in 1986 to 87.1% in 1989. Kvichak River sockeye salmon consistently made up 2% to 4% of the Ugashik District catch during 1986 to 1989, while the Naknek River sockeye salmon contribution decreased from 16.4% in 1986 to 1% in 1989. The percent contribution of Egegik sockeye salmon to the Ugashik District catch ranged from 5.3% in 1987 to 17% in 1986. In 1986, the year with the greatest amount of fishing time and effort of the four years studied, the Ugashik District catch was comprised of the largest percent of non-Ugashik River sockeye salmon. During 1987 to 1989, when fishing time was limited early in the season and effort levels were lower, the percent contribution of non-Ugashik sockeye salmon decreased.

Runs by River System

Interception of a river's sockeye run outside its district of origin is important to consider when determining spawner-return relationships, setting optimum spawning escapement goals, and implementing stock specific regulations. The percent of the total run to a river harvested outside its district of origin is a good measure of the effect of interception on a sockeye salmon stock, and to what degree a manager can regulate fisheries for stock specific goals.

Kvichak River

The percent of the Kvichak River total run harvested outside Naknek-Kvichak District varied from a high of 16.8% in 1986 to a low 5.4% in 1987. The highest percent of outside harvest occurred in 1986 which was also the smallest Kvichak River sockeye salmon total run during 1986 to 1989. In fact, the percent of the Kvichak

River total run caught outside (16.8%) the District in 1986 was greater than the percent caught within (12.6%) the District.

Naknek River

The percent of the Naknek River total run caught outside Naknek-Kvichak District was fairly consistent for all years: 21.5% in 1986, 17.4% in 1987, 26.6% in 1988, and 23.9% in 1989. In 1988 the percent of the Naknek River total run harvested outside (26.6%) the district was slightly greater than that harvested inside (24.4%) the district.

Egegik River

The percent of the Egegik River total run caught outside Egegik District was greater in 1986 (16.4%) than in either 1987 (4.5%) or 1988 (3.8%) and similar to that in 1989 (11.3%). The within-district catch comprised a similar percent of the Egegik River sockeye salmon total run in all years: 65.5% in 1986, 72.5% in 1987, 70.3% in 1988, and 67.9% in 1989.

Ugashik River

The percent of the Ugashik River sockeye salmon total run caught outside Ugashik District was much lower in 1986 (8.9%) than during 1987 to 1989: 30.1% in 1987, 26.4% in 1988, and 35% in 1989. Conversely, the percent of the Ugashik River total run caught inside the District decreased from 69.1% in 1986 to 40.5% in 1989.

Conclusions

Of the three fishing districts on the east side of Bristol Bay, Egegik District generally had the greatest interception of sockeye salmon destined for other districts during 1986 to 1989. In addition, the interception of non-Egegik sockeye salmon in Egegik District increased each year from 1986 to 1989. Naknek-Kvichak District had the least interception of outside stocks during 1986 to 1989. The percent (36.1%) of the Ugashik District catch made up of sockeye salmon from other districts was greatest in 1986, exceeding the interception rate in Egegik District (16.9%) for the same year. The decrease in interception found in Ugashik District for 1987 to 1989 was coincident with reductions in fishing time and effort early in the season.

Of the four major sockeye salmon stocks returning to east side Bristol Bay river systems, Naknek and Ugashik Rivers had the largest portions of their total runs harvested outside their district of origin. Conversely, Egegik River had the smallest portion of its sockeye salmon total run caught outside its natal district. The percent interception of sockeye salmon returning to Kvichak River was greatest in 1986 when total abundance was low.

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A COMPARISON OF STOCK COMPOSITION ESTIMATIONS

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Analysis of scale patterns has been used to estimated contributions of U.S., Canadian, and transboundary river sockeye salmon stock groups to net fisheries in Southeast Alaska since 1982. Stock groups are separated based on measured differences in growth patterns in the freshwater and first marine scale zones. This study compares four stock composition estimators to determine which method most accurately identifies the proportion of each of five stock groups found in Southeast Alaska Districts 106 and 108 mixed stock fisheries. Mixed stock catches are simulated by combining scales sampled from five stock groups, including one from British Columbia, two from Southeast Alaska, and two from the transboundary Stikine River.

A total of 200 scales from age-1.3 fish was available for each stock group. A data set was created by systematically selecting every tenth scale from each stock group to form a test data set and using the remainder to develop a classification model data set. Ten data sets were made where each had a test data set that had no scales common to any other test set but had a model data set with many scales common to other model sets. Thus, each test data set consisted of 100 samples, 20 from each of 5 stock groups, and each model data set was composed of 900 samples, 180 from each of 5 stocks. The sample sizes were chosen to mimic the sample sizes currently used in scale pattern analysis of Districts 106 and 108 catches where age-specific models are developed from samples of 200 fish from each of 5 stock groups and stock compositions are estimated from samples of 100 scales.

The stock composition of the simulated catches were estimated with linear discriminant function (LDF), quadratic discriminant function (QDF), nearest neighbor analysis (NN), and a maximum likelihood estimator (MLE). Two different algorithms were tested for the LDF, a fortran program written by Robert Conrad (Linear #1) and the SAS LDF program (Linear #2). The QDF and NN were also run on SAS, and the MLE was run with a fortran program written by Russell Millar.

The first estimates of classification accuracy are indicated by the confusion matrices. The classification accuracies of the model data sets were lower for the NN than for the LDFs and QDF (Figure 1). The on-diagonal balance was better for the LDFs than for the QDF. The total number of fish assigned to a stock was farther from the actual number for the NN than for the other analyses (Figure 2). This value is a function of the balance of the matrix (both off and on-diagonal) and of the sample size of each component group (in this case, all are equal).

Another method of estimating classification accuracy is to classify test data sets where the stock compositions of the test sets are known. The percent of samples correctly classified was lowest for NN and roughly equal for the LDF #2 and the QDF (this data was not available for LDF #1) (Figure 3). The balance in the LDF was adequate, with all stocks classifying at least 50% correctly in all but two data sets. The balance in the QDF was poor, the Alaska I group classified less than 30% correctly in half of the data sets, while the Alaska II and Nass/Skeena groups generally classified more than 70% correctly. The initial classification estimate (total number of fish assigned to a stock) was poorer for the QDF than for the other analyses (Figure 4). The final, or adjusted classification estimate (initial estimate adjusted with a classification matrix adjustment procedure, was lower for the QDF than for the other analyses (Figure 5). The MLE estimates were similar to the LDF and NN estimates. The individual stock classifications were very poor for some stocks in some test sets and the relative classification accuracy of a stock was not consistent among analyses.

The mean classification accuracies indicated that LDF was often the most accurate estimator, however, for some data sets NN was better and in final classification estimate the MLE was often the most accurate (Figure 6). The mean classification accuracy of each stock from the 10 data sets was usually poorest for the QDF and highest for the LDF, although NN was nearly as high for some stocks (Figure 7). In the final classification of the test data the LDF and MLE were well balanced and classified all stocks equally well.

The grand mean classification accuracy (the mean classification accuracy of all stocks in all data sets) was highest for the LDF and lowest for the NN (Figures 8 and 9). The grand mean classification for the final test data was the same for the MLE and the LDF.

The initial estimates of stock composition of the test data were more accurate than the adjusted estimates for all data sets. This could be due to a combination of errors in the confusion matrix and in the test data due to sample size (Table 1). Because several of the values in the confusion matrix are small, the matrix is sensitive to slight shifts in the data used to build it. Also, because 900 samples were used to build the confusion matrix and only 100 samples are classified in the test sets, it is nearly impossible for the classification matrix of the test set to mirror that of the confusion matrix. Due to the within group variance, a set of 20 samples will likely not have the same multidimensional distribution as the 180 samples used to build the model. The combination of similar stock-specific classification accuracies among stocks in the test set, model balance, and equal numbers of each stock in the test sets results in very high initial classification rates. Thus, any errors in the matrices result in an adjusted estimate which is less accurate than the initial estimate. Theoretically, the adjusted estimate would become more accurate than the initial estimate the more stock composition varied from equal numbers or if models were less balanced.

In most instances the stock compositions estimated with the LDF were closer to the actual compositions than were those estimated with other methods. The MLE worked as well as the LDF for the final test data. Therefore, it appears that LDF or MLE would be the most appropriate estimators to use in analysis of mixed stock fishery catches in Districts 106 and 108.

Table 1. Matrix comparison for two data sets.

Classified Stock or Origin						Classified Stock of Origin					
1	2	3	4	5	Total	1	2	3	4	5	Total
Confusion Matrix											
111	28	2	5	34	180	109	28	4	5	34	180
15	120	5	7	33	180	15	120	6	7	32	180
7	11	112	29	21	180	6	9	114	33	18	180
7	14	30	125	4	180	7	16	31	123	3	180
17	27	16	17	103	180	19	24	14	16	107	180
157	200	165	183	195	900	156	197	169	184	194	900
Test Data Set											
10	2	2	1	5	20	11	2	0	1	6	20
2	12	2	0	4	20	0	15	1	1	3	20
0	1	15	3	1	20	1	2	10	3	4	20
0	2	6	12	0	20	0	2	1	17	0	20
5	0	3	0	12	20	2	3	1	3	11	20
17	17	28	16	22	100	14	24	13	25	24	100
Confusion Matrix * .111											
12	3	0	1	4	20	12	3	0	1	4	20
2	13	1	1	4	20	2	13	1	1	4	20
1	1	12	3	2	20	1	1	13	4	2	20
1	2	3	14	0	20	1	2	3	14	0	20
2	3	2	2	11	20	2	3	2	2	12	20
17	22	18	20	22	100	17	22	19	20	22	100
Adjusted Stock Composition Estimate											
Test Data											
20	12	39	10	20		13	23	8	29	27	
Confusion Matrix * .111											
19	20	20	20	21		19	20	21	19	21	

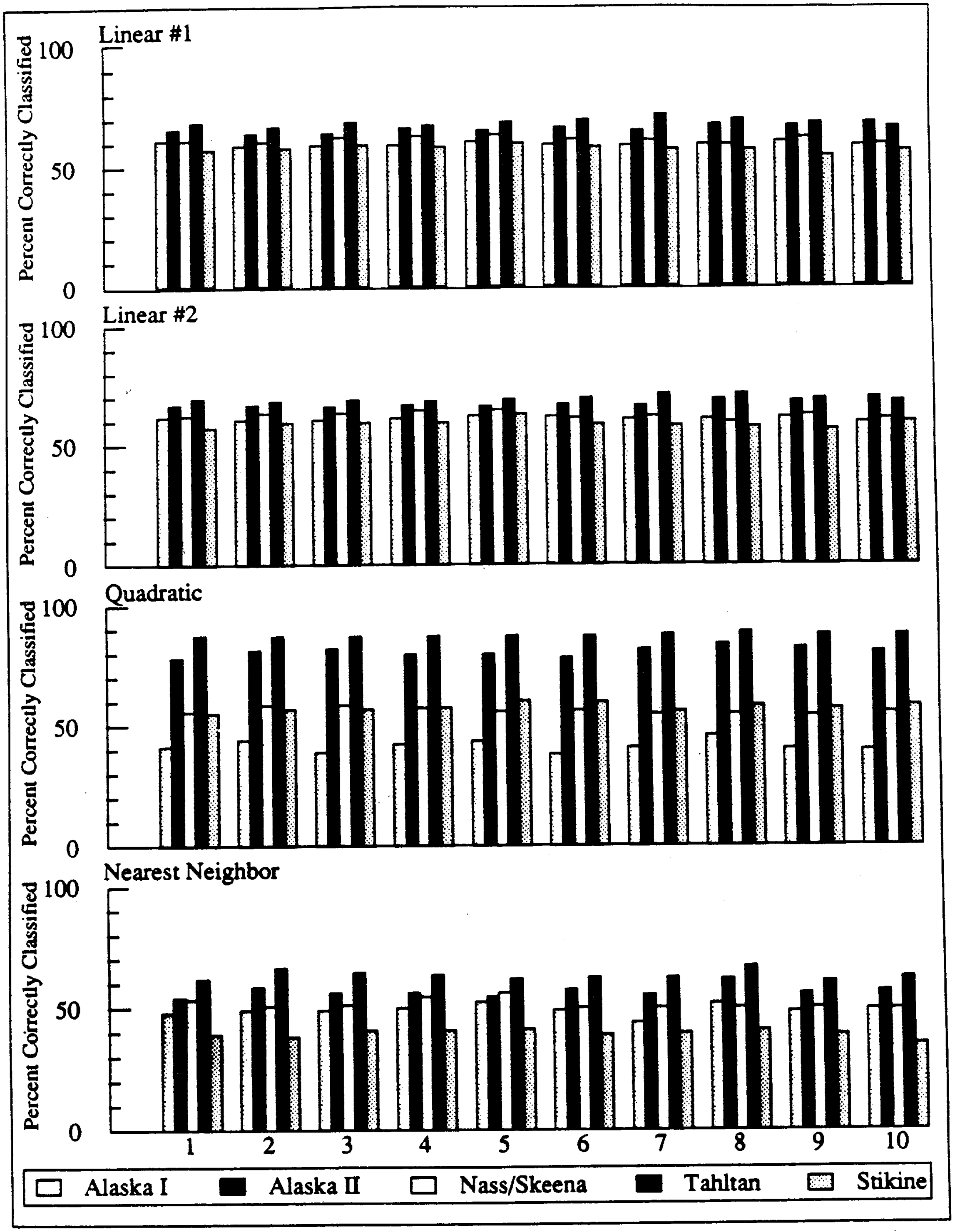

Figure 1. Classification accuracies; estimates from the confusion matrix.

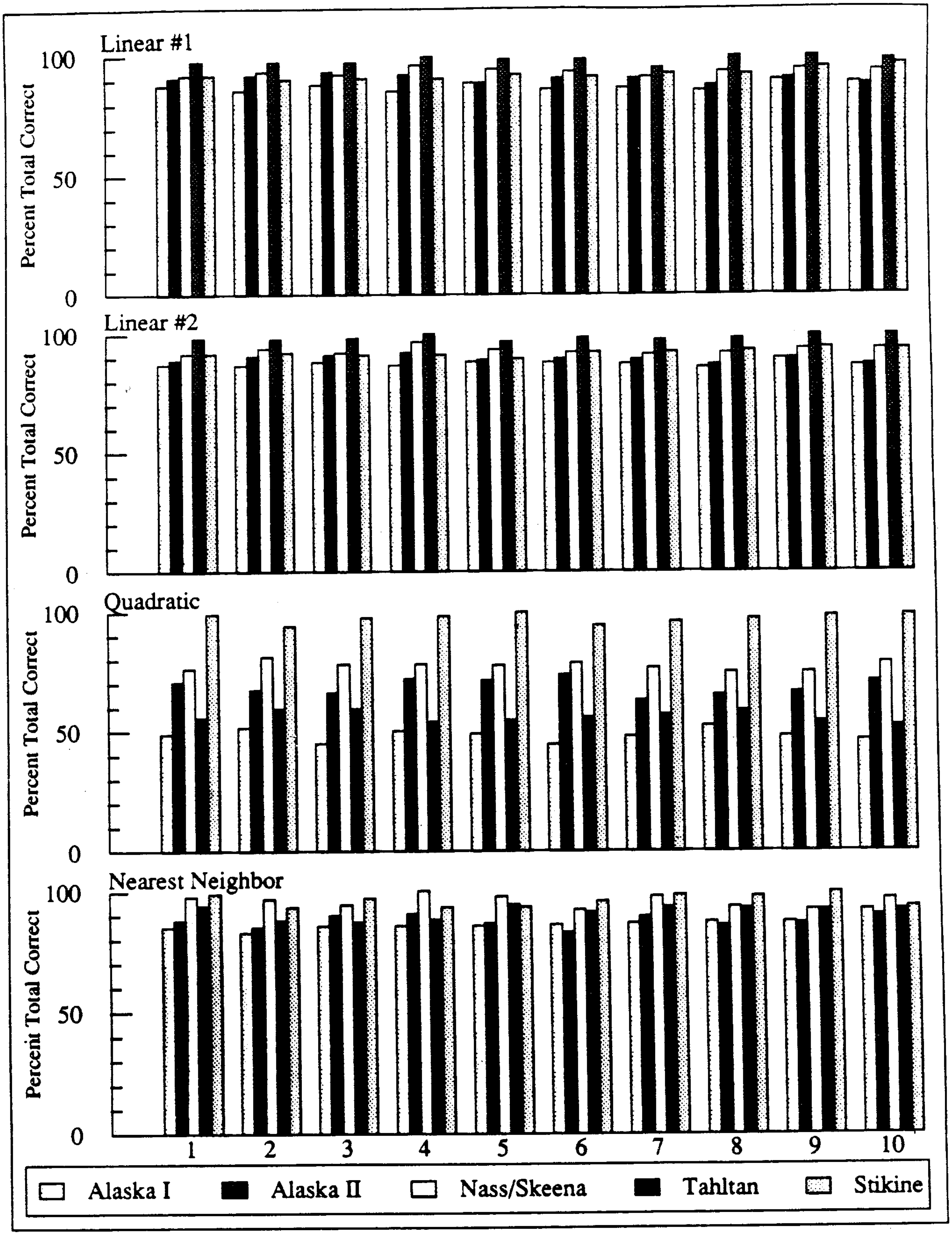

Figure 2. Total number of fish assigned a stock as a function of the actual number present; estimates from the confusion matrix.

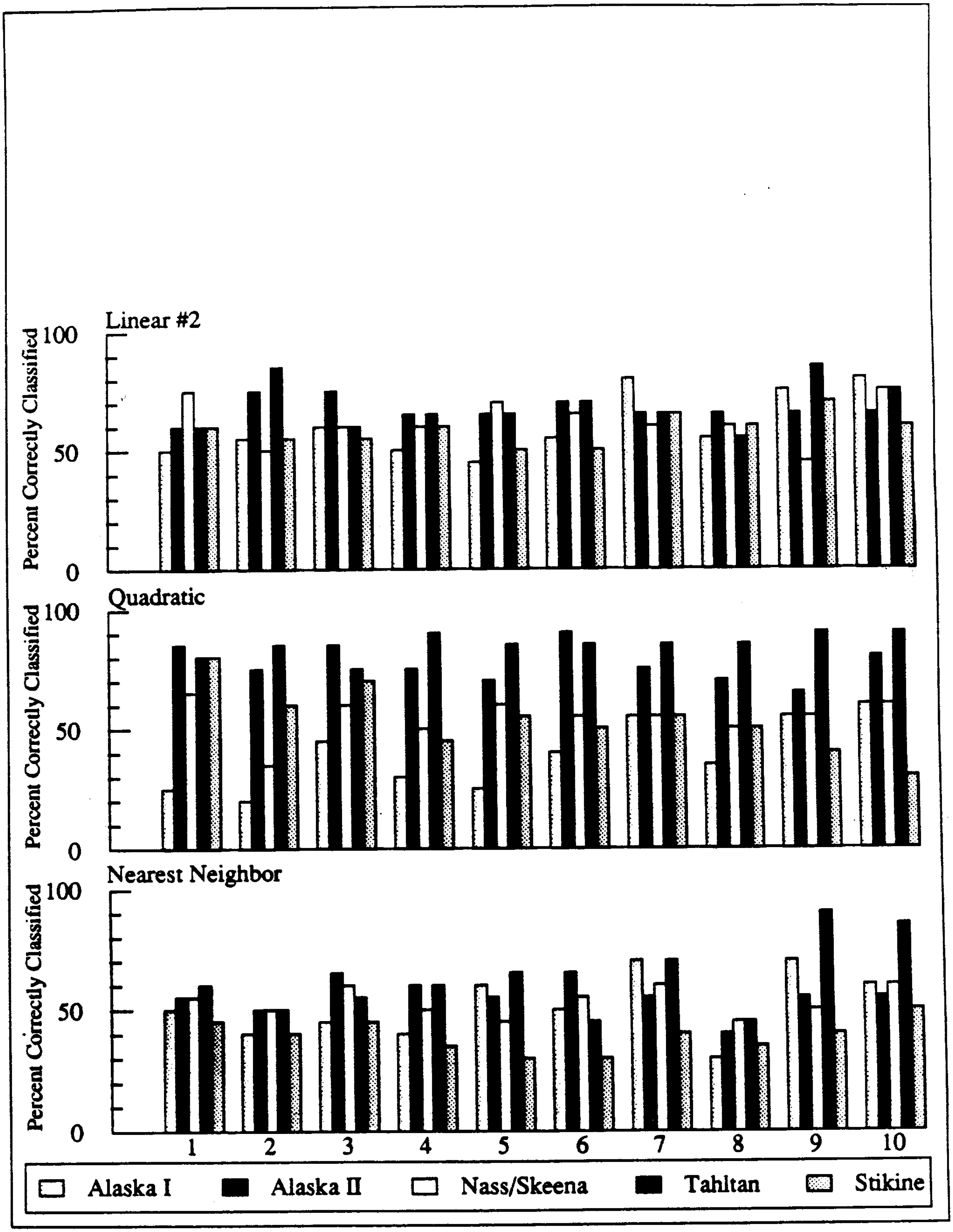

Figure 3. Classification accuracies; estimates from test data.

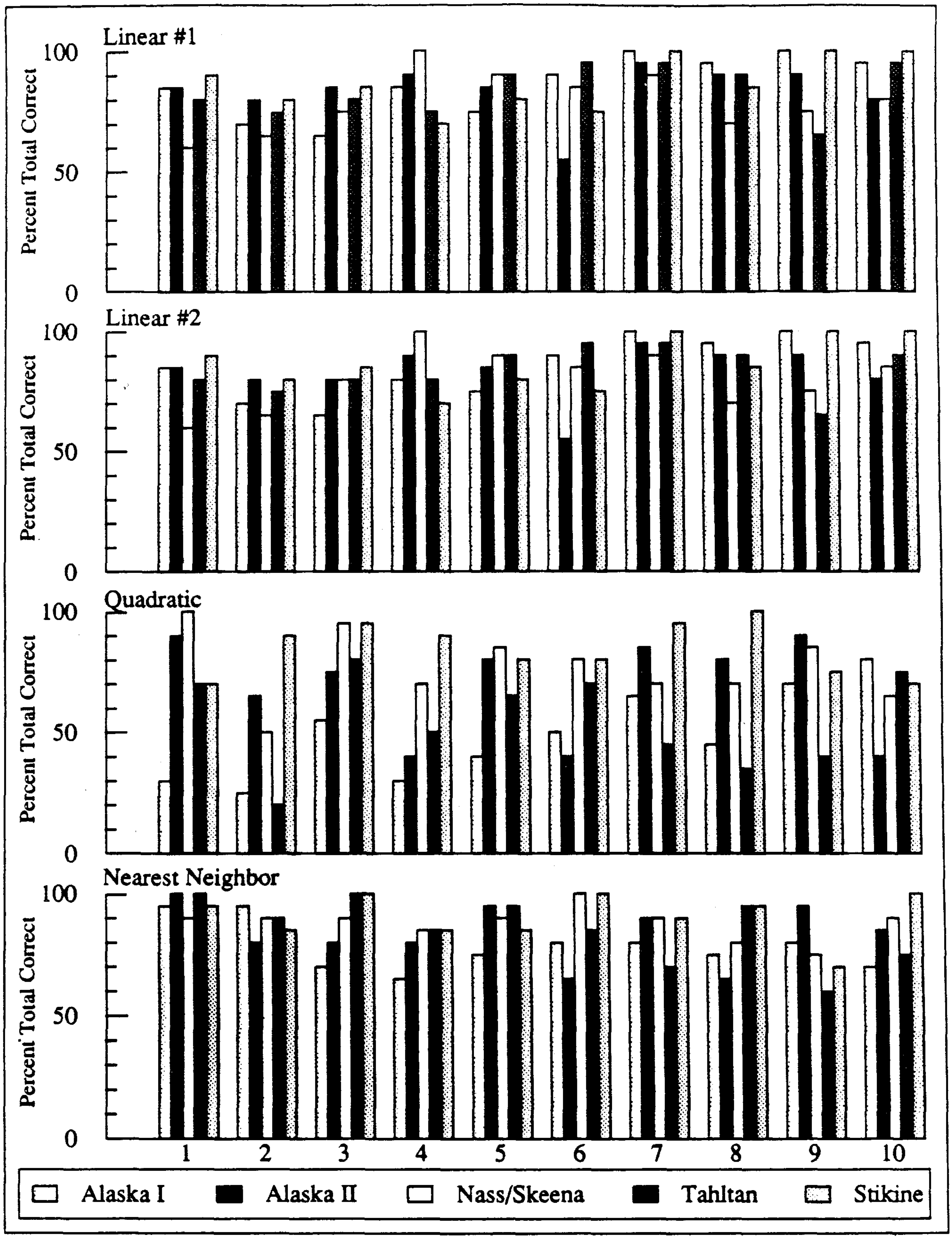

Figure 4. Total number of fish assigned a stock as a function of the actual number present; estimates from the test data.

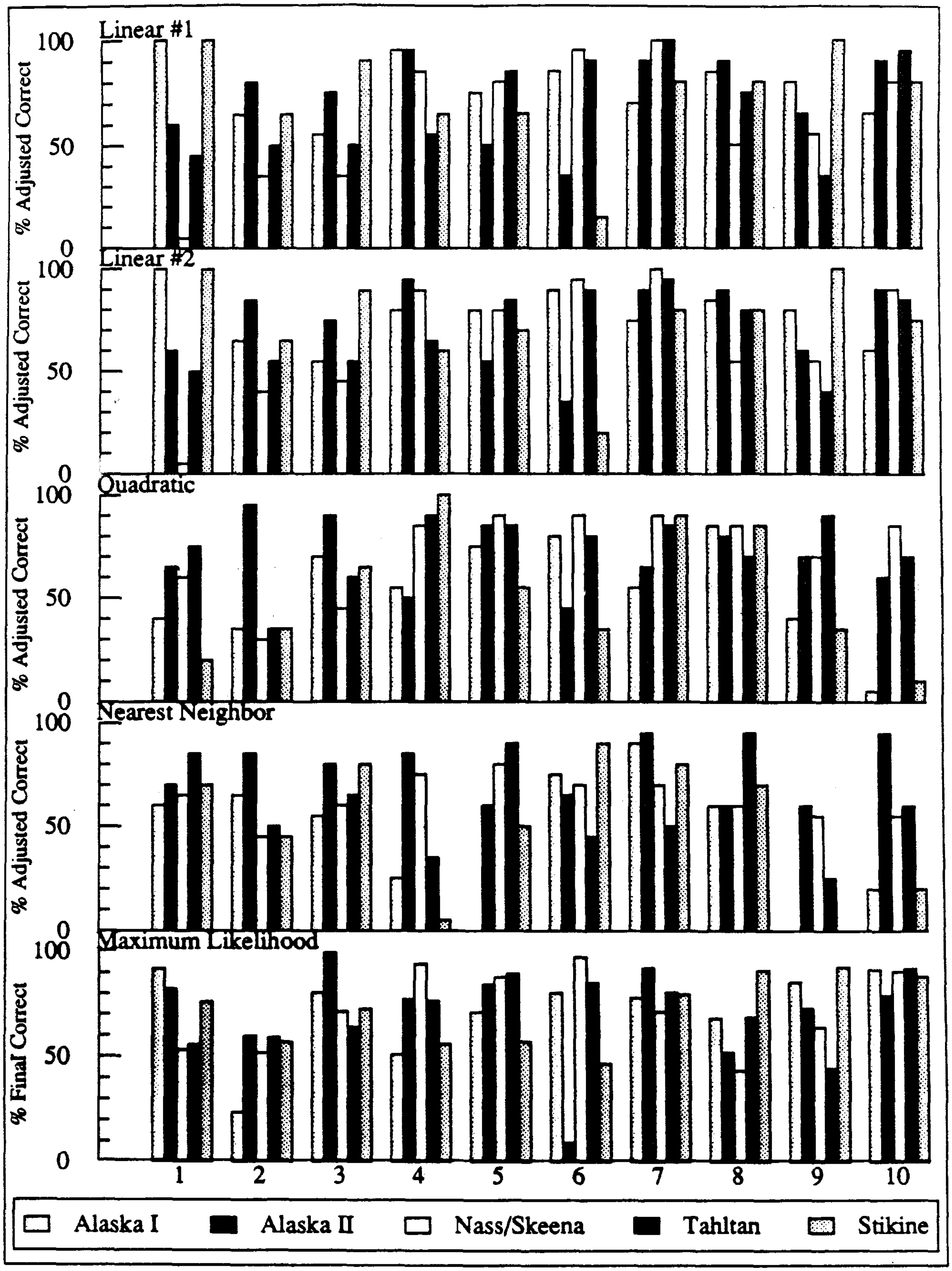

Figure 5. Total number of fish assigned a stock as a function of the actual number present; estimates from test data adjusted by confusion matrix.

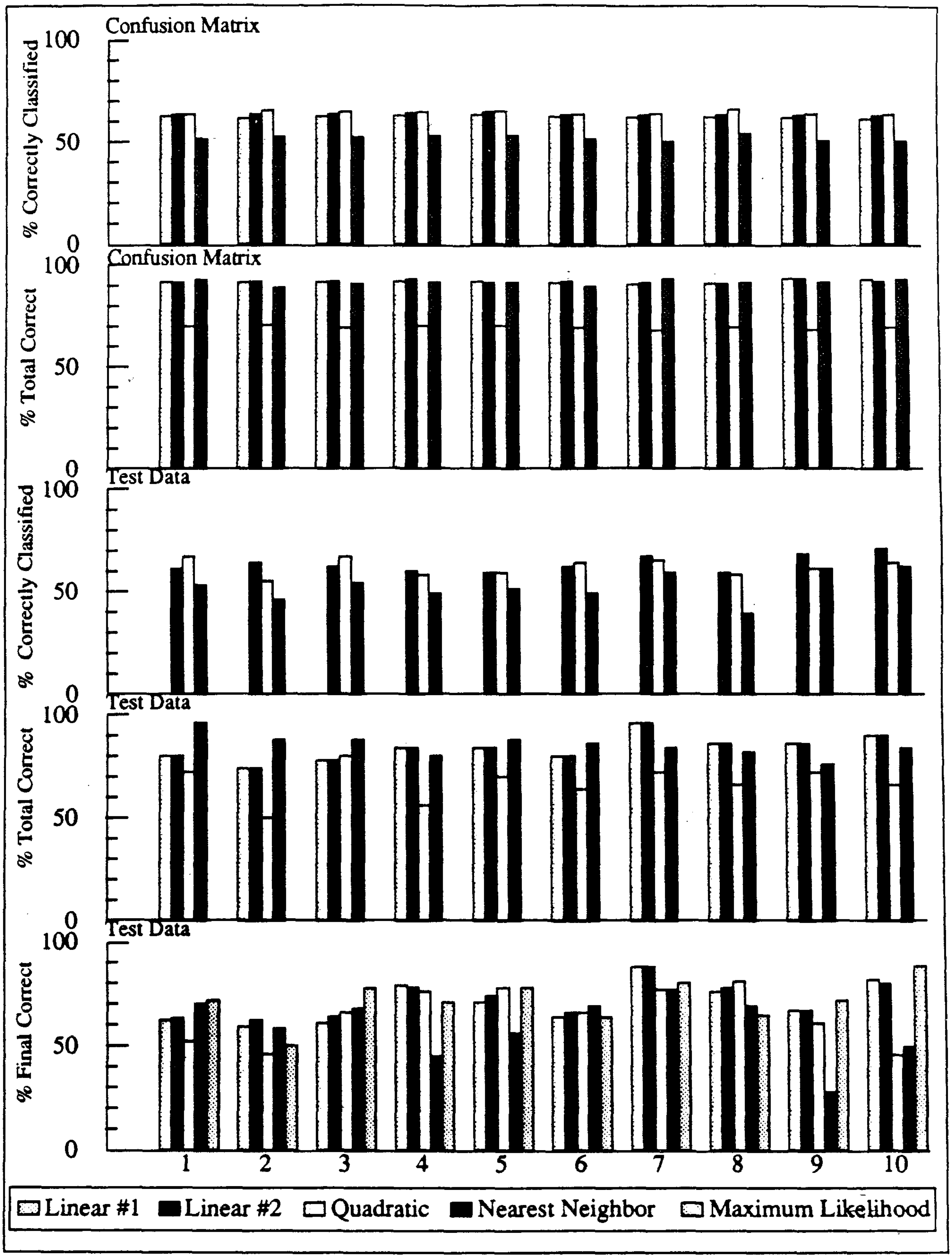

Figure 6. Mean classification accuracy of 5 stocks, 10 data sets.

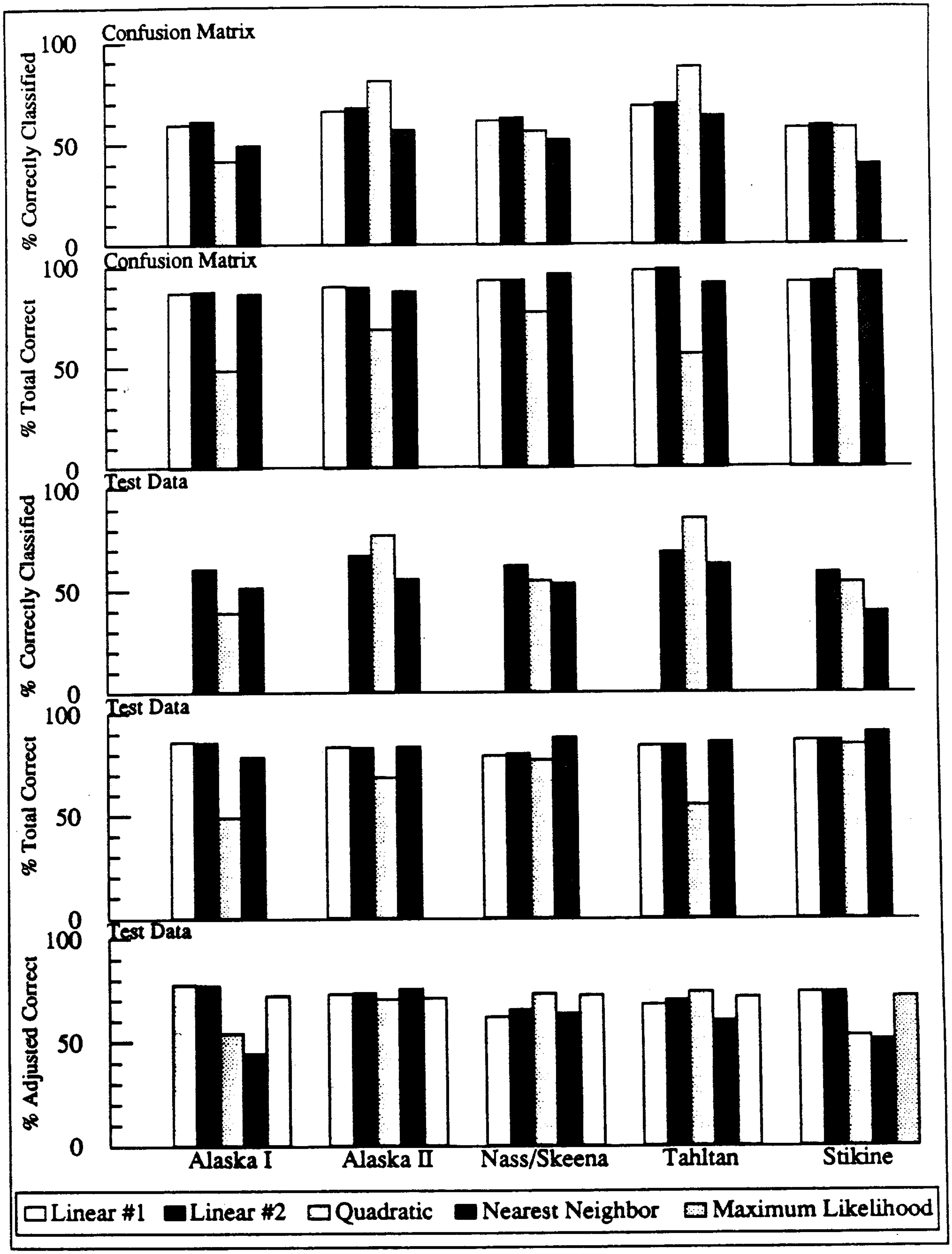

Figure 7. Mean classification accuracy of 10 data sets, 5 stocks.

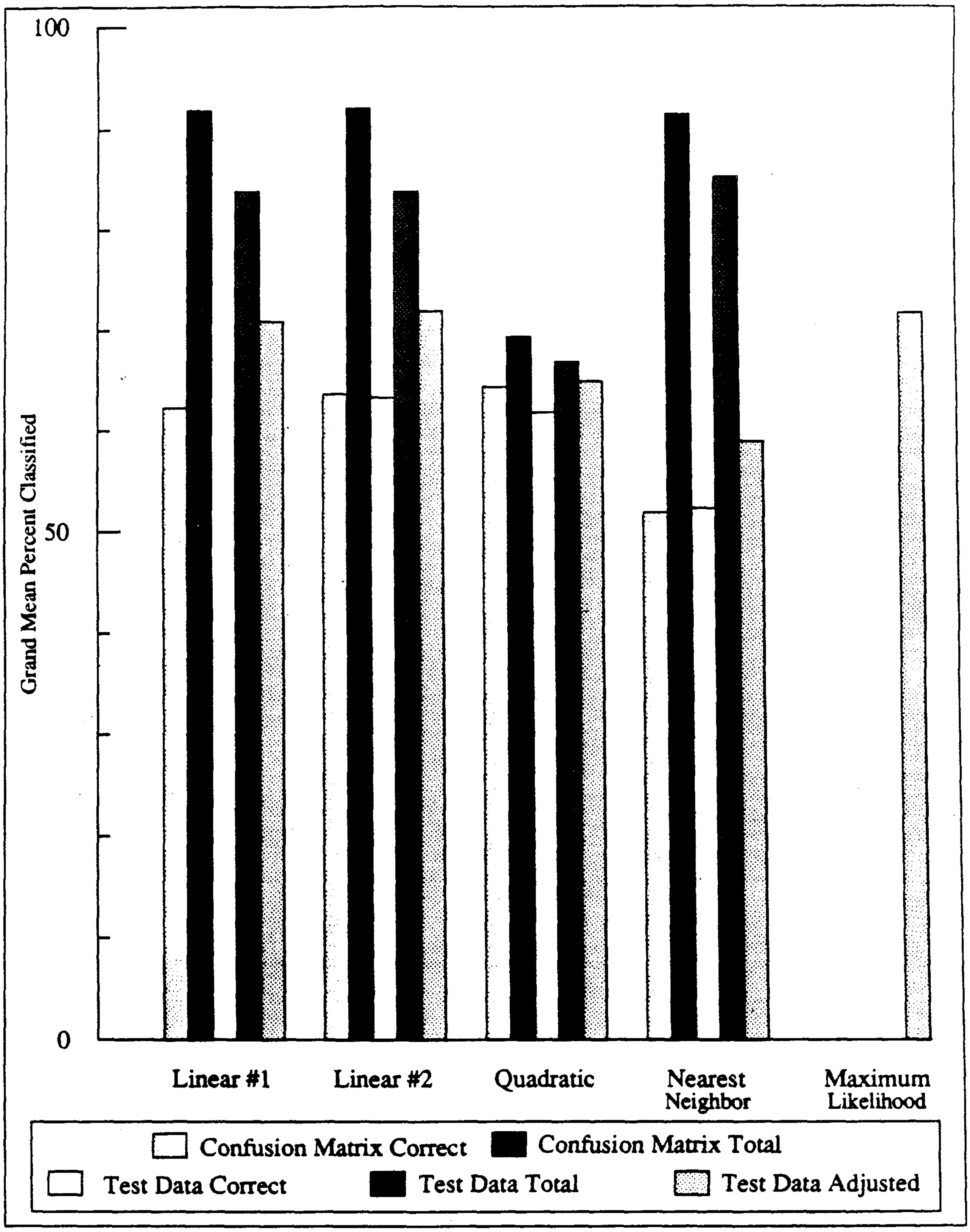

Figure 8. Grand mean classification accuracy of 5 stocks, 10 data sets.

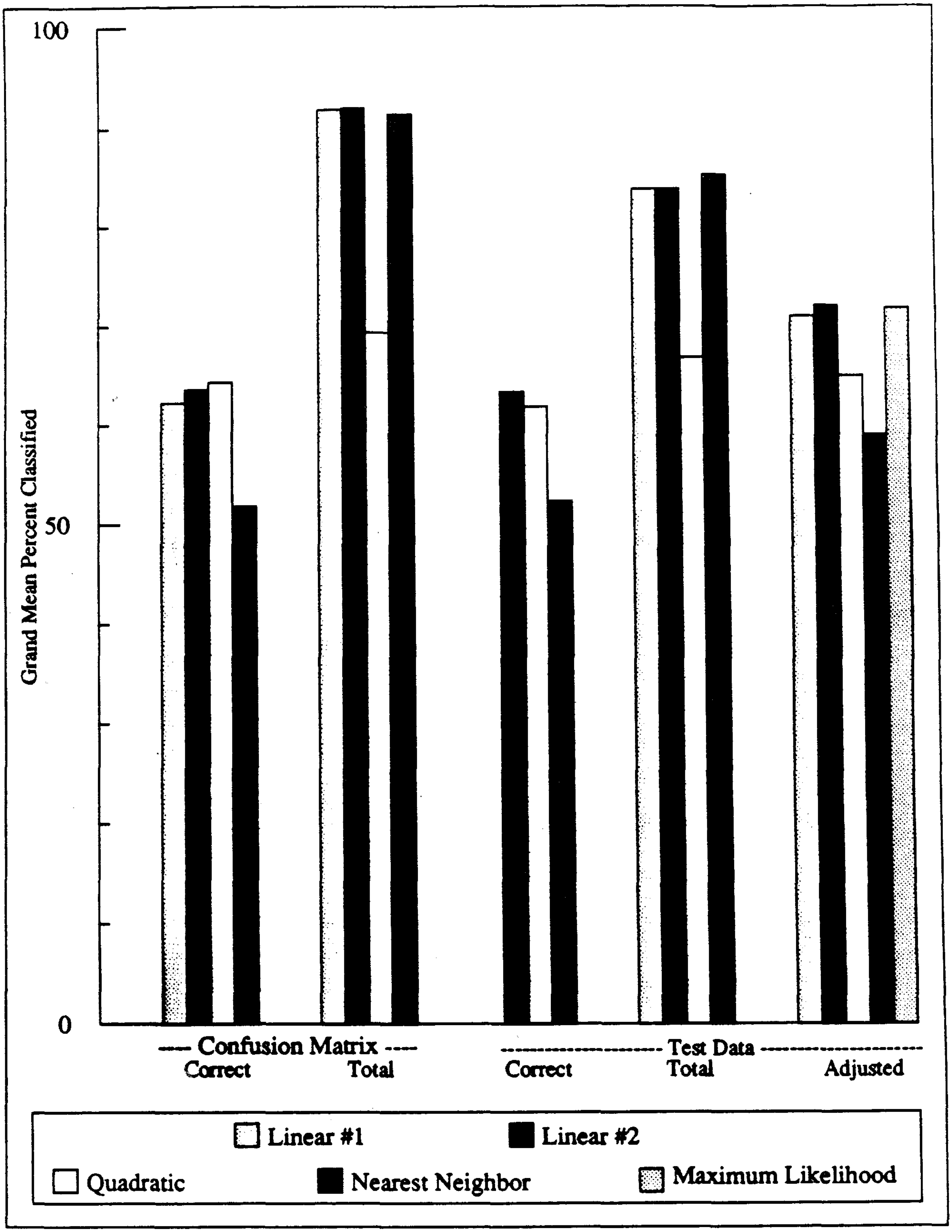

Figure 9. Grand mean classification accuracy of 5 stocks, 10 data

MODEL BUILDING IN SOUTHEAST ALASKA

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In 1982, a study was undertaken to determine if scale pattern analysis would be a useful tool in estimating the origin of sockeye salmon harvested in mixed stock fisheries in southern Southeast Alaska (Marshall et al. 1984). Knowledge of the stock compositions of sockeye catches in southern Southeast Alaska was gained from marine tagging studies. Tag recoveries indicated that Southeast Alaska lake systems and the Canadian Nass and Skeena Rivers were the dominant components in the Districts 101 to 104 fisheries and that these groups, plus Stikine River fish, were present in District 106.

A model with samples from age-1.3 fish from the Nass, Skeena, and Stikine Rivers and from 24 central and southern Southeast Alaska lake systems was run to show which populations of fish spawning in Alaska had scale patterns similar to those which spawn in Canadian or transboundary rivers and vice versa. The leaving one out classification estimator indicated that few of the Canadian or transboundary fish classified as U.S. and only two of the U.S. stocks had a significant portion of scales which misclassified to Canada.

Age-specific models were tested along with pooled-age models where freshwater ages were combined (1.2, 1.3 and 2.2, 2.3) and where all four age-groups were combined. The mean accuracies of the pooled-age models were less than those of the age-specific models; however, because differences were small, it appeared that intergroup differences were greater than interyear differences and that historical models could be used to estimate stock compositions in-season.

The final component of the study was to determine the best way to build the composite stock groups. Four model building strategies were tested: (1) equal probability where N scales were desired, a random sample of N/24 scales were selected from each of 24 Alaskan systems for the U.S. standard and N/3 from each of the Nass, Skeena, and Stikine Rivers for the Canadian standard; (2) geographical probability where N/7 scales were selected at random from each of the 7 Alaskan systems from which tagged fish had been observed subsequent to the marine tagging in 1982 and N/2 scales were selected from Nass and from the Skeena Rivers; (3) escapement probability where scales were selected from the same systems as for the geographical probability, but the number of scales from each of the seven systems was based on the magnitude of the escapements, and (4) tag probability where the same seven systems were sampled, but samples were weighted by the contribution to the catch as estimated from the 1982 tagging study. The four models were used to classify three groups of test scales taken from escapements in the following proportions: 90% U.S. and 10% Canada, 50% U&.S. and 50% Canada, and 10% U.S. and 90% Canada. There were no significant differences in the ability of each of the four models to separate test scales according to their origin.

Models used in scale pattern analysis in Southeast Alaska have been refined since the original work was done. Scale patterns of some stocks have changed, probably as a result of climatic changes, changes in rearing densities of the juveniles, introduction of lake fertilization or fry planting, or other mechanisms. Some of the stock groupings used in the original models no longer worked, and in other cases more stock specific models were needed.

The original model used for Districts 101 through 104 consisted of a U.S. composite (included samples from 28 systems) and a Canada composite (included samples from two Canadian systems). An additional standard, the Stikine River, was added to the model used in District 106. In 1983 a south migrating component consisting of scales sampled from catches in Johnstone Strait was added to the Canada composite, and the Stikine standard used in District 106 was split into the Tahltan Lake group and the non-Tahltan or mainstem group. Further model refinements were required in 1986 when it became apparent that Alaska fish were misclassifying to the non-Tahltan Stikine group. Two separate Alaska standards were created, and five-standard (Alaska I, Alaska II, Nass/Skeena, Tahltan, Stikine) model was used to classify the District 106 and 108 catches. In Districts 101 through 104, the Canada composite was split into the Nass River and the Skeena River groups, and a four-standard (Alaska I, Alaska II, Nass, Skeena) model was used to classify catches.

The models used to classify the sockeye catch in District 111 have also changed since 1982. Two composite stock groups were used in the original model; the Taku group consisted of samples collected from fish wheel catches in the Taku River, and the Snettisham group consisted of samples collected from the Crescent and Speel Lake weirs. The scale patterns of Taku River fish changed through the migration, and it became evident that early migrating stocks had different patterns than late migrating stocks. The next step in model building was to stratify samples through time. Taku standards were made from samples collected at Canyon Island during three sequential periods. The models from the first and last periods had greater classification accuracies than did the middle period model. The weekly catch in District 111 was classified with the appropriate model with an assumed one-week lag between the district and Canyon Island. In 1986 results from a sockeye salmon radio tagging program indicated that the principle spawning locations in the Taku River. Scale samples were collected from the major spawning grounds. The lake systems tended to have identifiable pattern types. However, the small tributaries and mainstem samples had similar means and high variances. Therefore, the best combination of Taku stocks and stock groups was found to be one standard for each of three lake systems and one composite group standard that included small tributaries and mainstem spawners. At this time the Snettisham group was split into the Crescent and Speel stocks. The model currently used in District 111 consists of six stocks or stock groups.

One of the challenges in model building is deciding which stocks to include in composite stocks. Stocks are combined or separated based on the similarities or differences in the values of variables used most commonly in model building. We can get a general idea of stock similarity from running the F-stat program or plotting frequency distributions of the important variables. We then group the stocks to form two or more composites. Classification variables are selected, and the LDF program is run. The classification matrix yields some information on the appropriateness of our composites. The final test is to classify a set of scales of known origin and find which stocks tend to classify to other composite groups. The stocks which misclassified are reassigned to the appropriate composite.

Although the original 1982 study indicated that there was little difference between models built with different component weighting procedures, additional studies, simulating mixed stocks in other fisheries, have shown that this is not always the case. For the District 106 and 108 models, the number of fish in each of the individual stocks of a composite are weighted by a combination of estimated run size and geographic proximity to the fishery of interest. This method has higher accuracy than models built with equal numbers of fish from each stock. The most southern sockeye stocks in Southeast Alaska tend to have larger freshwater growth zones than stocks in central Southeast; therefore, southern stocks more closely resemble stocks in Northern British Columbia than do central Southeast stocks. Results from marine tagging of sockeye salmon indicate that southern Southeast stocks, particularly those on the outer coast, do not contribute heavily to fisheries in Districts 106 and 108. Therefore, reducing the number of Southeast stocks in the Alaska model(s) benefits model accuracy.

Variable selection has evolved along the model building. Typically, the f-stat program is run to check for abnormalities in the data, changes in mean values from prior years, and general separability of the stock groups. A fixed set of 40 variables is input into the varsel program. The fixed set was chosen as a time saving procedure since many variables were never selected in the process, and others were not desired. Two variables never included in District 106 and 108 models are the number of plus-growth circuli and the width of the plus growth zone. These two variables can differ greatly between years for a given stock. Because the models are used for in-season analysis, plus growth is not a desired variable. Inclusion of plus growth (and certain other variables) also violates the normality assumption for LDF.

Variables not selected by the varsel program are frequently added to or substituted for chosen variables to increase model accuracy. In a situation where stocks A, B, and C tend to misclassify as each other and stocks D and E misclassify as each other, varsels are run on each of the groups. The variables selected for each group are combined and the LDF program is run to estimate the model accuracy. Sometimes the variables selected from the A, B, and C group alone result in a more accurate model than the original A, B, C, D, and E variables did. Other variables may be added or substituted to increase the classification accuracy of a single group or to improve the balance of the classification matrix. Often four or five models are tested before one is developed that has a satisfactory combination of accuracy and balance.

The models developed for the postseason analysis are used to classify the catches in-season during the following year. We attempted to develop a historical model with 5 years of escapements but were unsuccessful. At various stages of the LDF program, all the samples in one stock would misclassify to another stock. The stock which dropped out and the step at which it did so varied with the variables selected and the stocks included in the model. Unfortunately, we were unable to ascertain why the model bombed and did not have time to devote to further study. It is possible that the within group variances simply became too large to allow separation of groups.

In most years the prior year models have worked well for stock composition estimation; however, adjustments have occasionally been needed. In 1986 in District 106 the first weeks of in-season analysis indicated that the non-Tahltan Stikine group was contributing more than 25% of the commercial catch. Because this group has a late migratory timing and had never before seen more than a minor catch component, it was plausible that there was a problem with the in-season models. In prior years, even when the non-Tahltan stocks were more abundant than the Tahltan stocks in the Stikine River commercial catch, they were less abundant than the Tahltan stocks in the District 106 catches in weeks when both stocks were present. In 1985 the ratio of Tahltan sockeye salmon over all Stikine River sockeye salmon in commercial catches in District 106 was mirrored in the Canadian inriver catch 1 week later, with generally less than a 10% difference through mid-July. Therefore, an adjusted in-season stock composition estimate was made by applying a ratio of the Tahltan to non-Tahltan stocks in the inriver Stikine fishery to the estimated proportion of Tahltan fish in the District 106 catch by

$$N_{dt} = \frac{N_{r(t+1)}}{T_{r(t+1)}} * T_{dt}$$

where: N_d = adjusted estimated proportion of non-Tahltan Stikine fish in Alaska's district d catch in week t,

$N_{r(t+1)}$ = proportion of non-Tahltan Stikine fish in the Canadian commercial catch in week 3t+1,

$T_{r(t+1)}$ = proportion of Tahltan fish in the Canadian commercial catch in week t+1, and

T_{dt} = proportion of Tahltan fish in Alaska's district d catch of week t.

Postseason analysis indicated that an Alaskan stock was misclassifying as the non-Tahltan Stikine group. The stock had a small freshwater growth zone, similar to the non-Tahltan Stikine fish but had a large first marine zone, similar to the other Alaskan stocks. To reduce misclassifications, a new stock group (Alaska II) was added to the District 106 and 108 models.

A different problem became apparent a couple years later when the in-season analysis indicated a substantial number of Nass/Skeena fish in the District 108 sockeye catch. Historically, the Tahltan and non-Tahltan Stikine stocks had dominated the catch in District 108 and the Nass/Skeena stocks had contributed little or nothing to the catch. Because the Tahltan and Nass/Skeena stocks tend to misclassify as each other it seemed likely that the fish that classified to the later group were really of Tahltan origin. A second analysis was run with a model without the Nass/Skeena group, and the former Nass/Skeena fish were classified as Tahltan fish. A further test was made by classifying the inriver catch with the full, five-group model. A substantial portion of the catch was classified to the Nass/Skeena group. We therefore concluded that the in-season model was incorrectly classifying Tahltan fish in District 108 as Nass/Skeena fish. The postseason model verified that was indeed the situation.

In other cases, when the in-season models yield results different from those in previous years, additional information has been used to determine if the model is accurate. The age composition of the commercial catch can function as a method of verification in some districts. In the District 106, 108, and 111 fisheries, a strong component of age-0. sockeye is indicative of a strong run of mainstem transboundary river fish. A substantial number of age-2. sockeye salmon in the District 101-104 catches generally indicates the presence of a large number of Canadian fish. Migratory timing, catches in terminal area fisheries, and individual fish lengths can also provide insight into possible model accuracy in in-season analysis.

In Southeast Alaska model complexity has grown as the need for more and more detailed stock composition estimation has become apparent. Simple, two-stock models no longer provide sufficient information to manage mixed stock fisheries. In several fisheries harvest estimates for individual stocks are required in order to reconstruct runs or comply with the Pacific Salmon Treaty.

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THE ALASKA PENINSULA SALMON FISHERIES

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ABSTRACT

The Alaska Peninsula fisheries are a complex mixture of terminal, mixed local stocks, and stocks migrating to other management areas and continents. Management plans have been developed and approved by the Board of Fisheries to harvest targeted species while minimizing the harvest of incidental species. Management plans, district boundaries, forecasts, and escapement goals are continuing to evolve as information becomes available on stock status of the fisheries. Tagging studies have occurred from 1922 to 1987 mostly on sockeye and chum stocks during June in the South Unimak and Shumagin Islands Section fisheries. Scale pattern analysis (SPA) has been used to separate chum stocks in the June South Unimak fishery and sockeye stocks in the Ilnik Section of the North Peninsula. SPA of coho stocks may be useful in distinguishing major stock groupings for future allocation issues in the Shumagin Islands Section and South Unimak. Biological markers such as parasite infestation, age class composition of sockeye stocks, and genetic analysis may also be useful for distinguishing stocks. With increased stock composition data inseason management decisions could be based not only on preseason management plans and aerial assessment of local stocks but could also involve time and area closures if conservation or allocation concerns between competing user groups are an issue. Problems associated with stock analysis include budgetary concerns, purchasing restrictions, and trained personnel available to digitize, develop models, and analyze the results.

THE USE OF SCALE PATTERN ANALYSIS IN MANAGING TRANSBOUNDARY AND BOUNDARY AREA FISHERIES OF SOUTHEAST ALASKA

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The development of scale pattern based stock identification programs in Southeast Alaska has been driven by the need to address issues related to the Pacific Salmon Treaty between the Unites States and Canada. Negotiations between the two nations continued over twenty years before a pact was signed in 1985 covering the harvest sharing and conservation of west coast salmon stocks. The lack of stock identification data for large interception fisheries of both nations presented serious problems for negotiators and fishery managers.

To address these problems the Stock Biology Group of the Alaska Department of Fish and Game (ADF&G) initiated scale pattern analysis (SPA) studies in the early 1980s in most of the Southeast Alaskan sockeye salmon fisheries relevant to the Treaty negotiations. In this paper I provide a brief summary of the programs ADF&G has developed for transboundary and boundary area fisheries and discuss their evolution, current status, and possible future orientation.

The Alsek, Taku, and Stikine Rivers are the three principle transboundary rivers in Southeast Alaska. They flow from headwaters in the Yukon Territory and northwestern British Columbia through Southeast Alaska into the Pacific Ocean. Large runs of sockeye salmon spawn in these rivers, primarily in Canada. The United States has conducted commercial gill net fisheries at the mouth of each river since the late 1800s, while Canada developed commercial fisheries in the Stikine and Taku Rivers in the late 1970s. With the addition of these new Canadian fisheries and our almost complete lack of knowledge of the interceptions, run sizes, and population dynamics of the sockeye salmon resources of the Taku and Stikine Rivers, it became obvious that runs would be rapidly depleted without the development of comprehensive stock assessment programs and cooperative international fishing agreements.

Taku River sockeye salmon are taken in the District 111 gill net fishery just south of Juneau. The Taku run is comprised of stocks originating from lake systems such as Kuthai, Little Trapper and Tatsamenie Lakes and from numerous stocks that spawn in sloughs along the mainstem of the river and in various tributaries. In District 111 they are mixed with U.S. sockeye stocks from Port Snettisham (Speel and Crescent Lakes).

Annex IV of the Pacific Salmon Treaty covers the transboundary rivers and dictates an 82% U.S. to 18% Canada sharing arrangement of the total allowable catch (TAC) of Taku River sockeye salmon for the years 1988 to 1992. The TAC represents the amount of fish available in excess of the mutually-agreed escapement goal of 71,000 to 80,000 fish. Harvest sharing agreements for both the Taku and Stikine Rivers are linked to the development of joint sockeye salmon enhancement programs designed to produce annual returns of an additional 100,000 adults to each river. In-season stock assessment programs are required to regulate for both the escapement goal and harvest sharing. ADF&G now operates both in-season escapement estimation (McGregor and Clark 1989) and marine stock identification (McGregor and Walls 1987) programs to provide this information for the Taku River.

An SPA program was instituted for District 111 in 1983. Linear discriminant function (LDF) analysis was used, together with age composition data, during the first few years to simply separate Taku River stocks from Snettisham stocks. The analysis was done strictly on a postseason basis for catch accounting purposes.

A large amount of scale pattern variation was apparent within the Taku River run, so more stock-specific models were developed beginning in 1986. Currently, LDF analysis is used to distinguish among four Taku (Kuthai, Trapper, Tatsamenie, and mainstem Taku) and two Snettisham (Crescent and Speel) stock groups and is used on an in-season basis to estimate stock compositions in District 111. Samples from prior years are used to develop age-specific standards for in-season use. Scales are sampled from the catch and stock composition estimates are generated within 24 to 48 hours. Postseason analysis of the data is accomplished by updating the models with current year data and then reclassifying the catches. In addition, LDF is used to provide postseason stock composition estimates for the Canadian inriver fishery.

SPA studies have revealed differential run timing among Taku River sockeye stocks as well as differences in stock composition between subdistricts in District 111, suggesting that potential exists for developing more stock-specific management systems for the District 111 and inriver fisheries. Another interesting result has been the newly realized importance of the mainstem Taku River stock group. This conglomeration of river and slough spawning stocks represents the major contributor in both the District 111 and inriver fisheries.

Stikine River sockeye salmon are taken in the highly mixed stock U.S. fishery in District 106 and in a more terminal fishery near the Stikine River delta in District 108. Canadian commercial inriver fisheries are operated near the international boundary and upriver near Telegraph Creek. A small Canadian food fishery is located upriver as well. The Stikine River sockeye run differs from that of the Taku in that one lake system (Tahltan Lake) produces a large proportion of the catch, and a weir has been operated on that system since 1959. Other production comes from mainstem stocks and glacial lake systems.

Harvest sharing of Stikine River sockeye salmon is more complicated than for the Taku River. Currently, the Canadian TAC is dependent on run size, varying from a minimum of 4,000 fish to a maximum of 30,000 fish, with the remainder of the TAC available to the U.S. fleet in Districts 106 and 108. Beginning in 1993, when enhanced fish will first return to the Stikine River, the U.S. and Canada will share the harvest of Stikine River sockeye salmon equally.

In-season stock assessment programs are needed to monitor compliance with Annex provisions. In-season forecasts of run size and TAC are generated using a joint U.S.-Canada management model (Transboundary Technical Committee 1988); results are used to recommend weekly fishing times for each nation's fisheries. The model requires that stock compositions of marine and inriver fisheries be estimated during the season.

ADF&G began stock identification work on the Stikine River in the early 1980s. The program started modestly, using circuli counts to discriminate between Tahltan and non-Tahltan (mainstem Stikine) stocks in the Canadian lower river commercial fishery. Total escapement to the Stikine River was estimated by expanding the total Tahltan Lake run (inriver catch plus weir count) using the estimated proportion of mainstem Stikine to Tahltan fish in the lower river fishery. The program has been expanded to U.S. marine fisheries, where LDF analysis of scale patterns is now used to separate five stock groups; two Alaskan groups (called Alaska 1 and Alaska 2 and created from samples from up to 24 small coastal island lake systems), Tahltan Lake, Stikine River, and Canadian Nass/Skeena River stocks (Jensen and Frank 1989). Currently, in-season stock composition estimates of Subdistricts 106-30 (Sumner Strait), 106-41 (Clarence Strait), and District 108 catches are generated each week of the fishing season using SPA.

Differences in egg diameter are now used by Canada to provide in-season estimates of the inriver stock composition. Analysis of genetic and parasite traits of lower river commercial and test fishery catches together with Tahltan weir counts is used by Canada to develop total drainage escapement estimation.

SPA studies have shown that the run timing of the Tahltan Lake stock is earlier than that of the mainstem Stikine stocks, which should allow the fishing fleets of both nations to selectively target on enhanced returns of the Tahltan stock without overharvesting mainstem stocks. SPA has also shown that while Stikine sockeye stocks comprise the majority of the District 108 sockeye salmon harvest, catches in District 106 are predominantly of coastal Alaskan and Nass/Skeena origin. Additionally, it is important to note that differences in the in- and postseason estimates of stock composition in Districts 106 and 108 have generally been small, indicating that the interannual variation in scale patterns is small compared.to differences among stock groups.

Further south toward the border between Alaska and British Columbia, Southeast Alaskan fisheries harvest extremely mixed stocks of sockeye salmon. U.S. fisheries off the outer coast of Prince of Wales Island in District 104 and near the mouth of the Nass River in District 101 are some of the largest in Southeast Alaska. Stocks present in these areas include those from Southeast Alaskan island systems, the Stikine River, the large Canadian mainland Nass and Skeena Rivers, and in some years the Fraser River and other 'southerly migrating' stocks. ADF&G has used SPA to generate postseason stock composition estimates for all boundary area fisheries (Districts 101-105) since 1982 (Oliver and Farrington 1989).

SPA models originally simply identified Alaskan from Canadian stocks, relying on the extremely large differences in scale patterns resulting from differing rearing conditions in the large and productive Canadian interior lakes and the small coastal Alaskan lakes. More stock-specific models have been developed as management needs have arisen, including separating the Nass and Skeena stocks and including south migrating stocks (Fraser) during years of peak abundance for these stocks. Extensive testing of model construction has been done, including sensitivity tests to measure the effects of building standards in different ways (Marshall et al. 1984). Model accuracy was shown to be very robust to the manner in which the Alaskan and Canadian standards were constructed. Age-class pooled models were also developed. Accuracies of these models were only slightly lower than for age-specific models, indicating that scale variation between years is not large and historical models can be used for in-season analyses.

Among the interesting results generated by this program are total estimates of the contribution of Alaskan and Canadian stocks to fisheries in southern Southeast Alaska. In most years Canadian stocks comprise the majority of the catch, followed by Alaskan stocks and very small numbers of Canadian Stikine River fish.

The future of transboundary and boundary area scale pattern programs may involve some dramatic changes. On the transboundary rivers it will be necessary to document new production from joint U.S.-Canada enhancement projects. Stocking new lakes or enhancing existing runs to their full potentials may alter scale growth patterns. New stock identification methods will be necessary to distinguish enhanced production from existing wild runs. The Transboundary Technical Committee has identified thermal marking of otoliths as the mark of choice for enhanced transboundary river sockeye stocks. In the boundary-area fisheries, more stock-specific models are needed to aid in refining management systems for particular Alaskan stocks. Additionally, stock composition estimates are needed from northern British Columbia fisheries because Canada does not currently operate the necessary stock assessment programs to provide this data.

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LYNN CANAL SOCKEYE MANAGEMENT SYSTEM IMPROVEMENTS FROM SCALE PATTERN DATA

By

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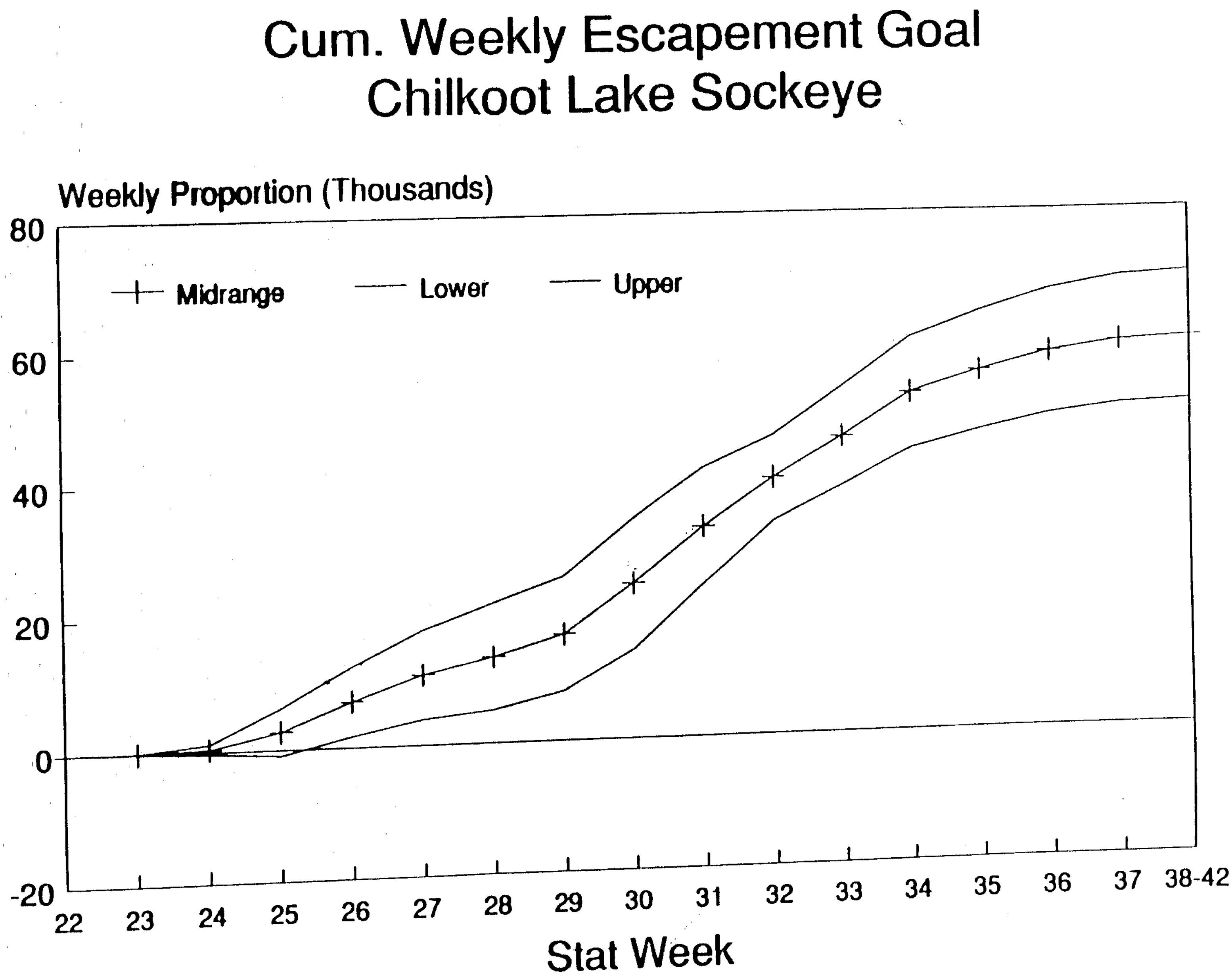
ABSTRACT

The objective of this presentation is to show how results of scale patterns analyzed are used to improve management of sockeye salmon in Lynn Canal, Southeast Alaska. Scales have provided precise estimates of catch and escapement by age for Lynn Canal sockeye runs for approximately 14 years. These estimates form a time series which has been used to improve the information available to the manager in-season. The Lynn Canal sockeye salmon population is composed almost entirely of fish from the two runs to Chilkat Lake and Chilkoot Lake, and the primary goal of management is to achieve the escapement objectives for each lake. The pieces that have been added to the in-season information system from the historic data base are a preseason forecast, in-season total run forecasts, escapement objectives, and a timely escapement forecast for Chilkat Lake. The preseason forecast is a multiple regression using parent abundance, siblings, size, and growth in fresh water. The in-season total run forecasts rely on historical migratory timing densities and curve fitting. The escapement objectives are set from spawner-recruit analysis and are bound by the variance around optimum escapement. The timely escapement forecast for Chilkat Lake relies on current year stock ID, escapement, and incoming run strength data. Implementation of the in-season management algorithm is centered around tracking of escapements and knowing how much season abundance remains. The preseason forecast serves as the primary abundance forecast briefly at the start of the season and is soon phased out by the in-season abundance forecasts. Weekly escapement objectives are designed to ensure adequate distribution over all spawning segments; if outside acceptable bounds more or less conservative, openings are indicated.

Stock contributions to the catch are estimated using visual classification of scales. Advantages of this system for Lynn Canal sockeye are (1) ability to classify every age class, (2) high classification accuracy, (3) precise estimates of contribution by age, (4) variance estimate around entire catch, and (5) low cost. This method is compared to linear discriminant function analysis for one age class in one year's data.


Cum. Weekly Escapement Goal
Chilkoot Lake Sockeye
Weekly Proportion (Thousands)
Midrange
Lower
Upper
80
60
40
20
0
-20
22
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WILD COHO SALMON TAGGING STUDIES IN SOUTHEAST ALASKA

By

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Juvenile marking studies have been employed in research on Southeast Alaska coho salmon stocks since 1972. Fluorescent pigment was used in earlier studies but was replaced by coded-wire tags in 1976. To date, wild coho salmon have been marked in 29 systems throughout Southeast Alaska and Yakutat. The focus of earlier research was to estimate harvest rates and time/area/gear type distributions in the fisheries for individual stocks. Tagging and recovering fish in systems throughout the region has provided an understanding of the migratory patterns of different stock groupings and the impacts of the fisheries on adult returns.

Since 1985, the coded-wire tagging program has been directed toward long-term monitoring of selected coho salmon populations or "indicator stocks," of which there are six distributed throughout Southeast Alaska. For each indicator stock annual estimates are made of total stock size, escapement, harvest by area, time and gear type, harvest rates (total and by fishery), age composition, juvenile or smolt population size, and juvenile or smolt to adult survival rates. Over time, monitoring of these populations is expected to provide estimates of stock-recruitment relationships and a better understanding of the magnitude and underlying causes of fluctuations in adult abundance. In addition, monitoring of harvest rates provides a basis for evaluating the effect of changes in fishing patterns as management strategies change and as the fisheries evolve over time.

Of the six established wild indicator stocks, five reside in lake systems, while none are located in small stream systems. This presents a problem in applying information on the population dynamics from these indicator stocks to management of the overall mix of stocks in Southeast Alaska. Lake systems provide a more stable environment for rearing fish and lake stocks tend to be represented by more freshwater age classes compared with stocks in non-lake systems. Lake systems have been emphasized for logistical reasons; i.e., it is very difficult to maintain weirs on small Southeast Alaska streams without lakes because of extreme fluctuations in flow during the fall months when adult coho salmon return to spawn. In addition, it is difficult to tag a sufficient number of fish from small stream populations for statistical reliability. Large river systems also present problems because the progeny of adults that spawn in different tributaries appear to intermix, which complicates accounting for tag returns. Therefore, a system-wide approach of tagging and escapement estimation may be the only alternative for assessing populations and estimating harvest rates in most large rivers. Development of research techniques to study coho salmon populations in non-lake systems in Southeast Alaska will continue to be a challenge.

Coded-wire tagging can provide relatively high resolution estimates of the contribution of tagged stocks. However, until recently it was not considered applicable to large-scale stock composition problems because it is typically not feasible to tag all contributing stocks. The utility of coded-wire tagging in identifying individual stocks, combined with new information demands presented by the US/Canada Pacific Salmon Treaty, have prompted researchers to look for ways of using coded-wire tags to estimate stock compositions. One approach has been to estimate "production factors" for tag groups by expanding tag recoveries in more mixed stock fisheries by the inverse of the proportion tagged in more terminal fisheries. This method has been used in Southeast Alaska to develop contribution estimates for some of the transboundary rivers and the combined river systems in Lynn Canal. However, it is limited by the fact that production factors cannot be estimated for many stocks for which there are no terminal fisheries.

Another more promising technique for estimating the stock composition of multiple mixed stock fisheries using coded-wire tag data is under development. It requires catch data and coded-wire tag estimates of the fishery distributions of most contributing stock groups. This information is available or can be acquired with limited additional tagging for most coho salmon stock groups from northern California to Southeast Alaska. Currently, two estimation procedures, linear programming and a non-linear method, are being evaluated for solving coded-wire tag stock composition models. The US/Canada Coho Technical Committee is using a linear programming model to estimate stock compositions for fisheries from northern California to central British Columbia. Coded-wire tag data may be used to estimate the stock composition of catches in Southeast Alaska and northern British Columbia after the different estimation procedures are further evaluated to determine their reliability in solving stock composition problems.

Coded-wire tagging has been the stock technique of choice for most coho salmon stock ID studies throughout the coast. Survival rates of tagged fish are usually high, averaging approximately 6.5% for rearing juveniles and 12% for smolts in Southeast Alaska. Well-organized catch sampling programs have been in place for most fisheries from Southeast Alaska south for several years. In addition, low success rates in developing other stock ID techniques for this species has made coded-wire tagging attractive.

SALMON STOCK IDENTIFICATION AND MANAGEMENT APPLICATIONS IN CHIGNIK, ALASKA

By

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For many years stock identification has played an important role in the management of the Chignik salmon fisheries. Early stock identification work involved tagging salmon from both outside and within the Chignik Management Area. Some of the information obtained from these studies is still used to manage and allocate Chignik salmon resources today. Chignik-bound sockeye are intercepted in both the Kodiak and Alaska Peninsula Management Areas. These interceptions have created perennial disputes between the competing user groups. Tagging studies have shown that a large portion (approximately 80%) of the fish harvested in the Cape Igvak Section of the Kodiak Management Area and the Southeast District mainland fishery of the Alaska Peninsula Management Area are destined for Chignik. Management plans based on several years of tagging now allow specific allocation of the resource in these controversial areas. Since the 1960s, an average time of entry curve, based on several years of tag/recapture data, has been used to separate the early and late runs of sockeye salmon entering the Chignik Lakes system. Beginning in 1979, scale pattern analysis (SPA) has been used to set the average time of entry curve for inseason management. SPA is also used to determine the final sockeye allocations for the early and late runs.

SUBSAMPLING FOR MEAN LENGTH SALMON

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I evaluated sample size requirements for estimating the mean length at age of chinook, coho, sockeye, and chum salmon in Southeast Alaska. A need to streamline the Southeast Region's salmon catch and escapement sampling program without adversely compromising the usefulness of this length data provided the stimulus for this study. With our funding constraints we could neither afford the inefficiency of over-sampling nor collection of useless data.

The question posed is: what number of measurements is needed to derive an estimate of mean length that is within a prescribed level of relative precision (*r*) with probability (*p*)? To answer this, I looked at the variability by species, gear, and district of mean length estimates reported for Southeast Alaska fisheries in 1985 (Figure 1) and used a modification of an equation in Cochran (1977; equation 4.5 on p. 77) to compute sample size requirements.

Cochran's formula for estimation of the sample size for the calculation of the mean of continuous data given a desired confidence level and relative precision is:

$$n_o = [\frac{t * S}{r * \bar{Y}}]^2 \qquad (1)$$

where,

n_0	=	desired sample size
t	=	t-value (two tailed)
S	=	standard deviation
r	=	relative precision as proportion of mean
$\bar{Y}$	=	mean (length in our case)

Since the terms "S" and "$\bar{Y}$" are related to the size of the fish, I modified this equation to replace these relative measures with an absolute measure of variability: the coefficient of variation (CV), where $CV = S/Y$. This yielded the following equation:

$$n_o = [\frac{t * CV}{r}]^2 \qquad (2)$$

Using equation (2), I then calculated the number of samples needed for different levels of probability (p = 0.90, 0.95, 0.98, and 0.99) and coefficient of variation (CV = 0.05 to 0.30 incremented by 0.01) while holding the level of relative precision (r) constant at 0.05 (Table 1).

The calculation of sample sizes involved in iterative procedure. I first calculated the sample size using an assumed t-value, then recalculated the sample size using the t-value ($n-1$) for the calculated sampled size. This procedure was repeated until the sample size estimates stabilized. To apply these calculations to the determination of sample sizes needed to estimate mean lengths of salmon sampled from Southeast Alaska fisheries, I established three criteria:

(1) We desire estimates of mean length by age class that 95% of the time are precise to within $\pm$5% of the estimated mean length for that species-gear-area-time strata.

(2) We need to calculate desired sample size using a CV that at least 95% of our historical data falls at or below. In our case (Figure 1)

CV	=	0.14 for chinook,
	=	0.14 for coho,
	=	0.08 for sockeye, and
	=	0.09 for chum.

(3) We want to estimate mean lengths at such a level of relative precision for only those age classes that comprise more than the following percentages of the sample (catch):

Chinook	-	20%
Coho	-	30%
Sockeye	-	10%
Chum	-	15%

These percentages are based on looking at historical age composition data (Figure 2) and the realization that we would be unable to obtain precise mean length estimates for minor age classes even if we measured all the fish we sampled scales from.

Based on the above criteria we need to measure at least 164 chinook, 109 coho, 130 sockeye, and 100 chum per sample strata (Table 2, Figure 3). If we further assume that 15% of the fish we sample have unagable scales then we need to sample at least 189 chinook, 126 coho, 150 sockeye, and 115 chum per strata. Under sampling goals of 600 scales per strata this equates to measuring lengths from approximately 30% of the chinook, 25% of the sockeye, and 20% of the coho and chum. Note that these sample sizes are not intended to yield precise estimates of mean length by sex or stock within each strata but will likely yield acceptably precise estimates for pooled periods and/or area totals. This general procedure could be applied to evaluation of the means of other continuous data sets.

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Table 1. Sample size needed for estimating the mean of continuous data within a desired level of relative precision (r = .05) and probability (p = 0.90, 0.95, 0.98, and 0.99) at a predetermined coefficient of variation.

	Sample Size Needed			
Coefficient of Variation	r = 0.05 p = 0.90	0.05 0.95	0.05 0.98	0.05 0.99
0.05	5	7	9	11
0.06	6	9	11	14
0.07	8	11	14	17
0.08	9	13	17	21
0.09	11	15	22	26
0.10	13	18	26	31
0.11	15	22	30	36
0.12	18	25	35	42
0.13	20	29	40	49
0.14	23	33	46	56
0.15	26	37	52	64
0.16	30	42	59	72
0.17	33	47	66	81
0.18	37	52	74	90
0.19	41	58	82	100
0.20	45	64	90	110
0.21	50	70	99	121
0.22	54	77	108	132
0.23	59	84	118	145
0.24	64	91	128	158
0.25	70	99	139	171
0.26	75	106	150	185
0.27	81	115	162	200
0.28	87	123	174	215
0.29	93	132	187	230
0.30	99	141	200	246

Table 2. Minimum number of measurements needed to estimate the mean of continuous data within a relative precision (r) of 0.05 and a probability (p) of 0.95 for all groups comprising more than a certain percentage of a sample.

Coefficient of Variation	Percent							
	5%	10%	15%	20%	25%	30%	35%	40%
0.05	140	70	47	35	28	23	20	18
0.06	180	90	60	45	36	30	26	23
0.07	220	110	73	55	44	37	31	28
0.08	260	130	87	65	52	43	37	33
0.09	300	150	100	75	60	50	43	38
0.10	368	184	123	92	74	61	53	46
0.11	431	215	144	108	86	72	62	54
0.12	498	249	166	125	100	83	71	62
0.13	576	288	192	144	115	96	82	72
0.14	656	328	219	164	131	109	94	82
0.15	745	373	248	186	149	124	106	93
0.16	839	419	280	210	168	140	120	105
0.17	941	470	314	235	188	157	134	118
0.18	1,048	524	349	262	210	175	150	131
0.19	1,161	580	387	290	232	193	166	145
0.20	1,280	640	427	320	256	213	183	160
0.21	1,407	703	469	352	281	234	201	176
0.22	1,538	769	513	384	308	256	220	192
0.23	1,676	838	559	419	335	279	239	209
0.24	1,821	911	607	455	364	304	260	228
0.25	1,972	986	657	493	394	329	282	247
0.26	2,129	1,064	710	532	426	355	304	266
0.27	2,291	1,145	764	573	458	382	327	286
0.28	2,461	1,231	820	615	492	410	352	308
0.29	2,635	1,317	878	659	527	439	376	329
0.30	2,820	1,410	940	705	564	470	403	352

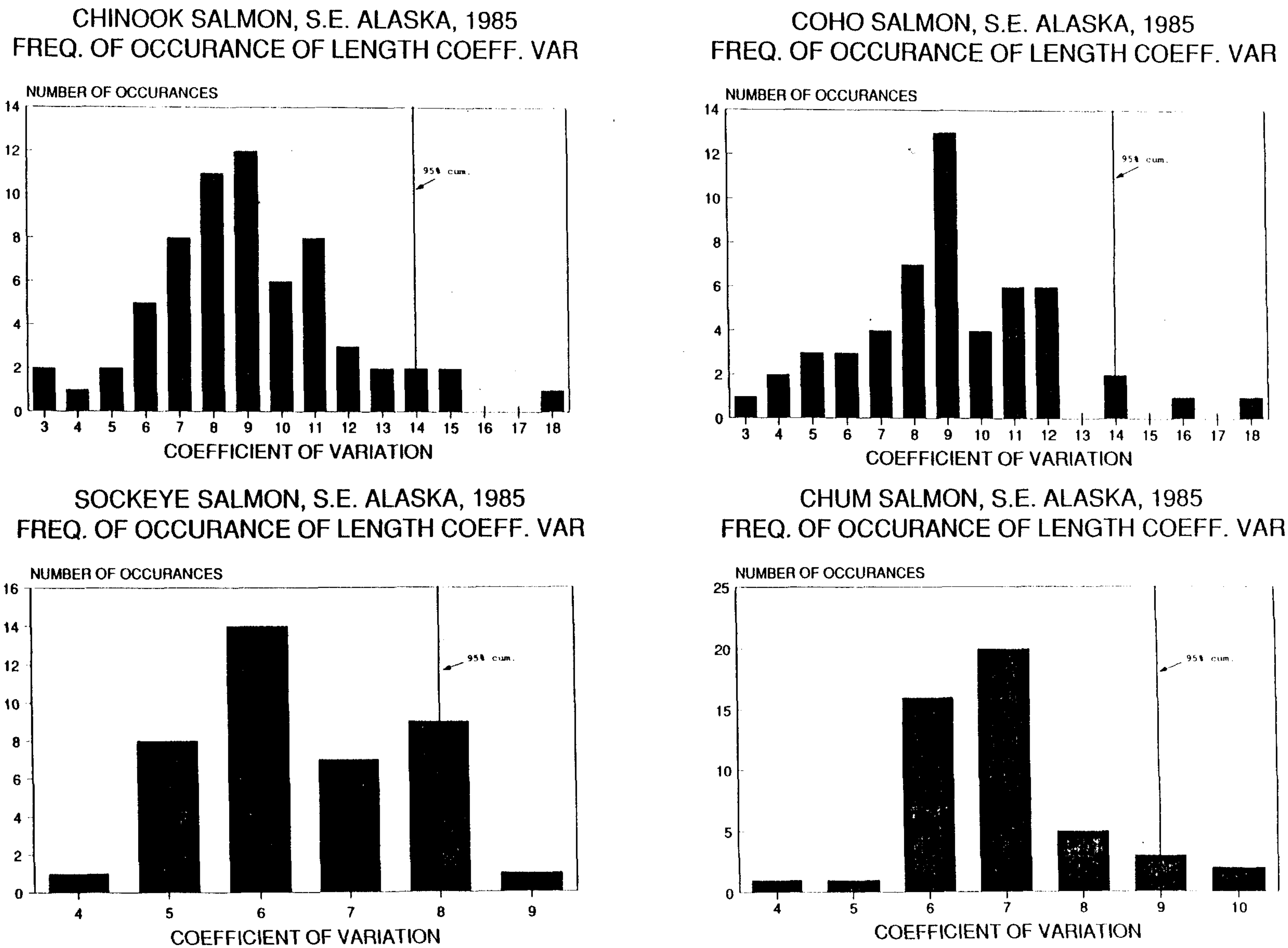

Figure 1. Coefficient of variation (in percent) of length measurements, at age, of chinook, coho, sockeye, and chum salmon sampled from the principle Southeast Alaska troll, seine, and gill net fisheries, 1985.

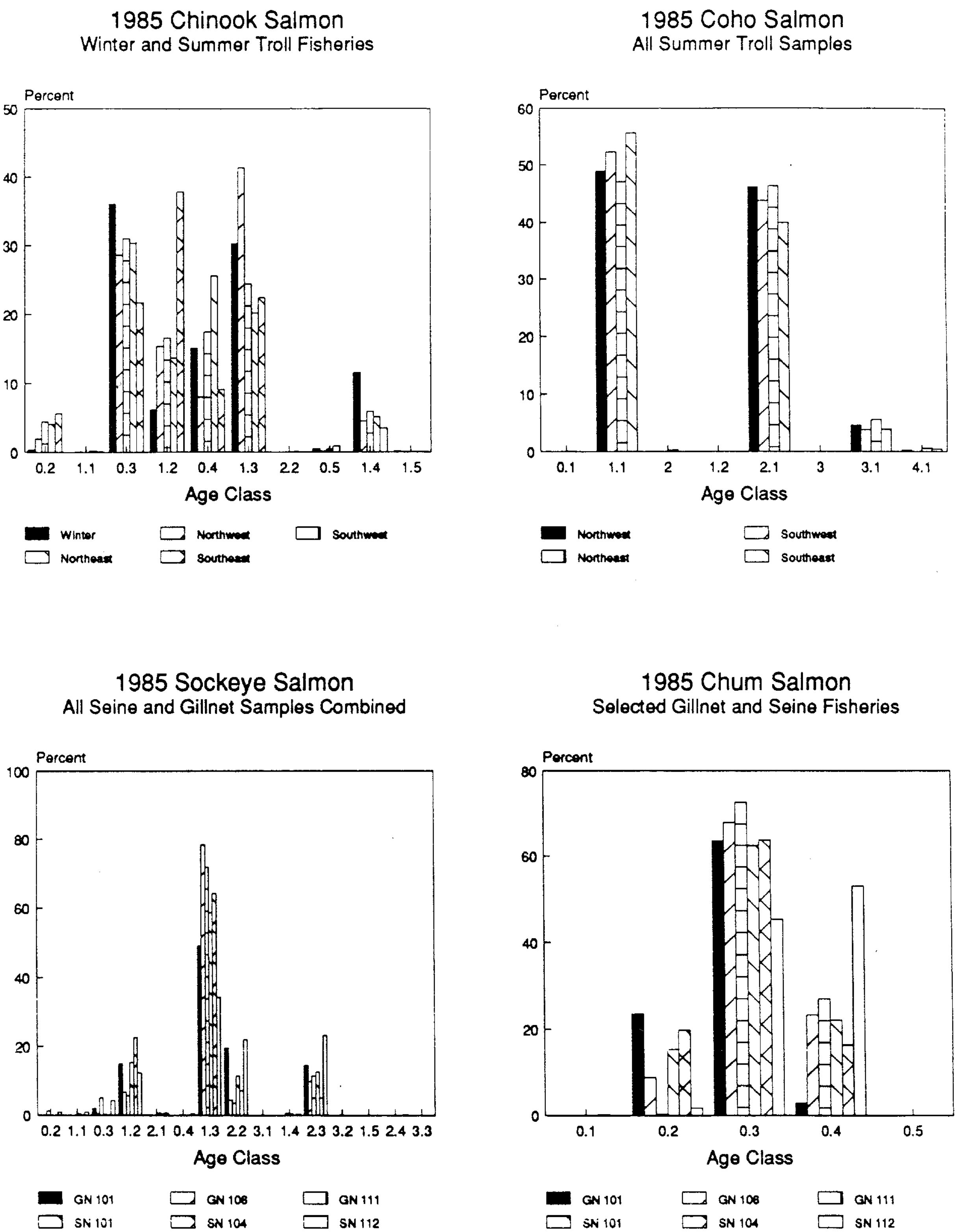

Figure 2. Age composition of chinook, coho, sockeye, and chum salmon harvested in Southeast Alaska troll, seine, and gill net fisheries, 1985.

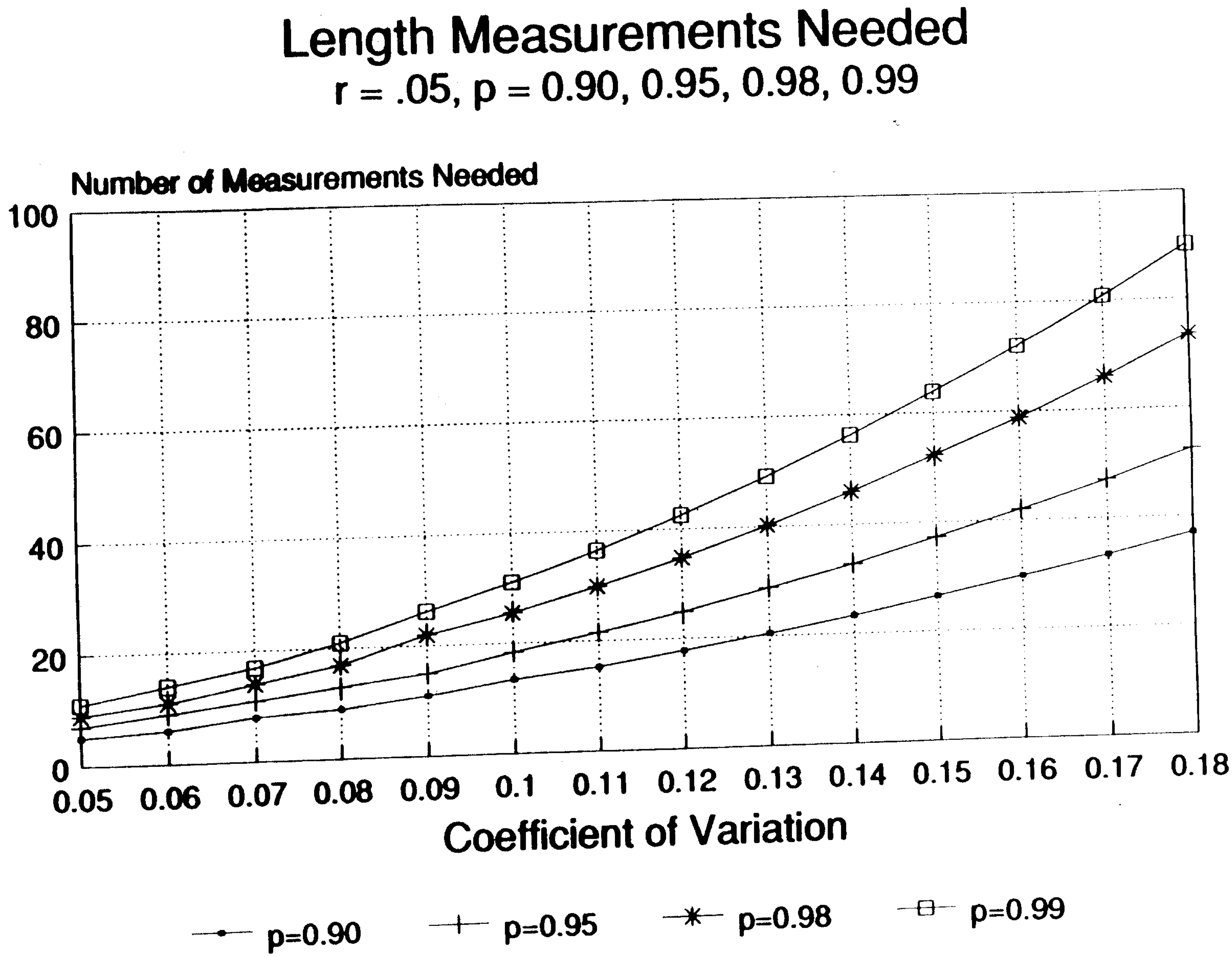

Figure 3. Sample size needed for estimating the mean of continuous data within a desired level of relative precision (r = .05) and probability (p = 0.90, 0.95, 0.98, and 0.99) at a predetermined coefficient of variation.

THE PROPORTIONATE CUTPOINT DISCRIMINATION METHOD

By

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SUMMARY OF PRESENTATION

We introduce a non-parametric, two-group, one- or two-variable, classification procedure, termed Proportionate Cutpoint Discrimination (PCD) and demonstrate its use in scale pattern-based stock identification of wild and hatchery coho salmon in Southeast Alaska. This PCD procedure is relatively simple to apply, highly adaptable to in- or postseason two-group stock identification applications, and superior to Linear Discriminant Function (LDF) with respect to accuracy and bias of classifications.

The classification procedure is applied against the empirical (frequency distribution of variable(s). In its simplest form, a two-group/one-variable model, the decision rule (point in this case) for determining group classification is where there is an equal proportion of each group on either side of the decision rule (i.e., the middle [M] for both groups combined). In contrast, the particular LDF classification rule is half-way between the means.

In a more advanced form, again for a one-variable model, we use two decision points such that the proportion of $Group_A$ on the left of the decision rule [A] is equal to the proportion of $Group_B$ on the right of decision rule [A']. In this model, unknown individuals are classified to $Group_A$ if the measurement is less than cutpoint [A] and to $Group_B$ if greater than cutpoint [A']. The individuals not directly classified, those within this [A] - [A'] interval, are assigned a stock of origin based on the posterior probabilities of those directly classified. In other words, the model directly classifies individuals whose measurements are most dissimilar and uses this information to assign those whose measurements are most similar. Classification accuracies increase linearly up to the point where 100% of $Group_B$ lies to the right of cutpoint [A] and, similarly, 100% of $Group_A$ lies to the left of cutpoint [A'].

The PCD procedure can incorporate a second variable by classifying individuals depending on where the measurement for $Variable_1$ falls in relation to the pooled-group median for $Variables_1$ [M_1] <u>and</u> where the measurement for $Variable_2$ falls in relation to the pooled-group median for $Variable_2$ [M_2]. For example, assuming the two variables are positively correlated, individuals are classified to $Group_A$ if $Variable_1$ and $Variable_2$ measurements are less than [M_1] and less than [M_2] or to $Group_B$ if these respective measurements are greater than [M_1] and [M_2]. Those individuals whose measurements are not consistently less than, or greater than, the two cutpoints are assigned based on the posterior probabilities of those directly classified. A fixed, model-specific, adjustment is also used to account for the independence of the two variables. For negatively correlated variables, group assignment would be based on greater than one cutpoint and less than the other.

A conditional two-variable PCD method was developed which enabled efficient, accurate, and quantifiable stock identification of wild versus hatchery coho salmon when scales were examined on a microfiche viewer at time of aging. Hatchery coho had, on the average, larger freshwater growth zones and more freshwater circuli than the wild fish. Fish were assigned (recorded on the mark-sense AWL form) to either wild, hatchery, or "unclassified" groups according to where the size of the freshwater and, for a calculated proportion of the fish, plus growth zones fell in relation to "cutpoints" etched on a template (acetate card) held up to the scale image. Different PCD models were used for different fisheries because we were able to use catch distribution information from coded micro-wire tagging studies to evaluate the appropriate stock groupings. The basic all-group standard consisted of scales from 716 wild and 352 hatchery age-1.1 coho salmon sampled in 1987. The scales were digitized following standard ADF&G methods. We used Conrad's PLOTFW program to extract these measurements from the digitized records and LOTUS to determine frequency distributions, build the PCD model, and determine the cutpoints. Self classification accuracies for the two-variable PCD models were high, ranging between 91.2% and 95.8%, depending on the model used. For comparison, the best LDF model, which included six variables after seven steps, had an average classification accuracy of 93.1% and was biased (as evidenced by off-diagonal imbalance in the classification matrix) due to non-compliance with one or more of the underlying assumptions related to normally distributed data. Our PCD models were not tested for bias of self classification. However, prior experience with using the leaving-one-out procedure (Lachenbruch 1967) with linear discriminant function models having high accuracies (>90%) and large sample sizes (>300 observations per group) suggests that we would have a negligible (<1%) drop in accuracy using this method to evaluate model accuracies.

The non-parametric PCD classification criteria yields the highest possible classification accuracies for each group. Only the assumptions common among all classification methods are needed: that there are measurable differences between groups and that standards are representative of the groups. The first assumption can be evaluated with classification accuracy and the second only with sensitivity testing of the weighting given to the sub-groups which comprise each standard. A historical PCD model might even be used to classify fish in-season and correct post-season without reexamination of the scales. Established procedures for corrections of misclassification errors (Cook and Lord 1978) and estimation of confidence intervals (Pella and Robertson 1979) can be used. Variations of this PCD procedure are being successfully used for stock identification of sockeye salmon in southern Southeast Alaska and Lynn Canal fisheries. A maximum likelihood procedure is also being examined for its use in classifying the "unclassified" fish. Application of this PCD methodology for multi-variable, multi-group classifications is also being evaluated.

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