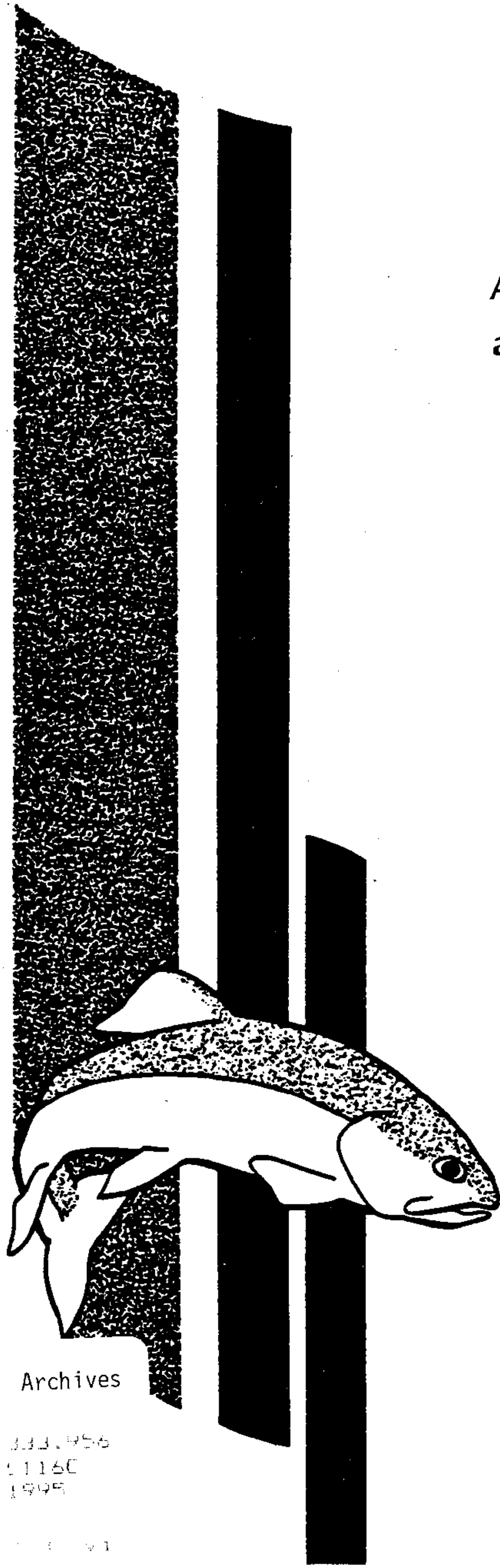

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Fisheries Progress Report No. 44
1995

Province of British Columbia
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by

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Fisheries Progress Report No. 44

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Labelle, M., S. Pollard, R. Frith, and K. English. 1995. Skeena River steelhead stock assessment program: 1994 catch and escapement monitoring plan. Prov. B.C. Fish. Prog. Rep. No. 44. 50 p.

ABSTRACT

During 1994, a large scale stock-assessment program was implemented to determine the status of steelhead and coho populations in the Skeena River. Catches in commercial fisheries were to be monitored by means of a fishery observer program. Escapements were to be estimated primarily by fence counts combined with radio-tagging and tracking operations. This report describes (i) the rationale for the approach selected, (ii) the procedures used to determine the distribution of observer, tagging, and survey effort levels required, and (iii) the features of the model used to estimate escapements to each major tributary. Planning studies suggested that 20-30 observers-days per week would be required to provide estimates of steelhead catches that are within $\pm 32\%$ of the actual value. Approx. 250 steelhead and 350 coho should be radio-tagged to estimate escapements. This objective could be met by having two seiners operate in the mouth of the river for 4 $d \cdot wk^{-1}$ each, from the second week of July to the last week in September. Fifteen radio-tracking devices installed upstream of the fishery, and at the confluence of each major tributary should be operated until the following spring to monitor movement patterns, tag loss and tag escapements. Escapement enumerations and stream surveys should be conducted at index sites throughout the system to determine tagged proportions and estimate escapements to non-index sites. Bio-samples collected in each tributary and during the tagging-tracking operations will be analyzed to identify genetic markers and estimate genetic variation. The plan recommends that the monitoring program be continued for two or more years to assess the level of annual variations. After this period, the information obtained should allow scientists to design a more cost-effective and logistically simpler method to provide catch and escapement estimates on an annual basis.

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1.0 INTRODUCTION

The Skeena River is the second largest watershed in British Columbia. The river flows southwest for 400 km from the Skeena Mountains to Chatham Sound on the north Coast of British Columbia (Fig. 1.0). The Skeena River is used by large populations of Pacific salmon (*Oncorhynchus sp.*) that support established fisheries and their associated infrastructures. This river also contains populations of summer run steelhead trout (*Oncorhynchus mykiss*) that are highly prized by anglers (Billings 1989). Salmon and trout populations are subject to exploitation mainly during the summer on their return to the spawning grounds. The commercial net fisheries target the more abundant species of sockeye and pink salmon. Due to their overlap in return timing, less abundant stocks of chinook, coho and steelhead are incidentally intercepted as they migrate through the fisheries at the river mouth. Although the annual catch and escapement of these species is not know with certainty, various indices suggest that some Skeena River steelhead populations are over-exploited and are below the carrying capacity of their natal stream (Tautz et al. 1992; Ward et al. 1993).

During November 1991, the Fisheries Minister of the Government of Canada committed to selectively reducing steelhead harvest rates in net fisheries by 50% within three years. This implied that the Area 4 gill-net harvest needed to be reduced from approx. 36% (mean, 1985-91) to 18% by the end of 1994. Fishery scientists from the Canadian Department of Fisheries & Oceans (DFO) and the BC Ministry of Environment, Lands and Parks (MELP) were then asked to formulate management plans for this purpose. The initial plans were designed to allow fishery managers to maintain high harvest rates on sockeye while reducing those on coho and steelhead stocks through the combined use of selective harvest methods, time and area closures, and gear restrictions.

The impacts of various fishing plans were assessed by numerical simulations using the available information on run timing, harvest rates, stock productivity, and stream carrying capacity (Tautz et al. 1992; Ward et al. 1993; Cox-Rogers 1994). Given the uncertainty on the demographic traits of various stocks and the dynamics of the fisheries, the numerical simulations relied on several assumptions regarding stock-recruit relations, habitat capacity, relative catchabilities, migration patterns, and gear effectiveness. This assessment highlighted the need for empirical studies to provide more background information. Since managers were concerned about excessive harvest rates, it follows that monitoring efforts should be geared to provide more reliable estimates of catch and escapement.

Catch and effort statistics for the Canadian commercial gill-net and seine fleets are compiled by DFO from hail surveys, over-flights and sales slip records. Sockeye catch statistics are considered reliable because of thorough sales records. In contrast, steelhead catch statistics are less reliable due, in part, to their non-commercial status (e.g., suspected under-reporting, non-representative sampling, etc.). Better estimates of steelhead catches may be obtained by observers interspersed throughout the fishery to monitor catch rates and composition. The mean steelhead catch within a vessel category, expanded for corresponding fleet size, would provide an estimate of the total commercial catch. Alternatively, the steelhead:sockeye catch ratio, stratified by time, area, and gear type, may be multiplied by the corresponding sockeye catch to provide an estimate of total steelhead catch.

An estimate of catch directly from catch rates based on observer records amounts to a conventional stratified estimation procedure. However, this approach requires extensive adjustments to observer records to account for differences in catch rates for various net types and fishing periods within each stratum, involves making assumptions about the catch-to-effort relation, and requires considerable resources to monitor sufficient vessels in each stratum. In contrast, estimating steelhead catches based on the mean steelhead:sockeye ratio may be technically easier and less costly. Plans to develop a reliable estimate of catch based on this ratio are described in this report.

Salmon escapements to the Skeena River are estimated by DFO staff from spawning ground surveys, counts at fish traps, and test fishery indices. Escapement records vary in reliability because few traps are used for enumeration, spawning ground surveys are not conducted in all tributaries, and the test fishery intercepts a variable fraction of the runs passing Tyee (Fig. 1.0) each year (Cox-Rogers and Jantz 1993). Therefore, escapement estimates of coho and steelhead are uncertain, and must be improved if reliable estimates of harvest rates on the major stocks are desired.

One of the traditional procedures of escapement estimation consists of a two-stage process involving adult enumeration and mark-recapture operations (Cousens et al. 1982). Mark-recapture models were developed specifically for such procedures (Schwarz et al. 1993; Labelle 1994). Use of this approach to estimate escapement in all of the major Skeena River tributaries would be prohibitively expensive and impractical. Inferences drawn by reference to an 'indicator, or index' stock (Symons, and Waldichuk 1984) is an appealing concept. But a recent study indicated that one stock is not always representative of trends in neighboring ones (Labelle 1990). Nevertheless, it seems reasonable to assume that an assemblage of stocks could be used as an indicator of total escapement to the Skeena River. For steelhead, this assemblage could include stocks from the Babine, Sustut and Bulkley rivers, which are thought to represent approx. 40% of the total Skeena River steelhead population (Tautz et al. 1992). Existing fish traps on some tributaries could be used to determine escapements to 'index streams'. A large-scale radio-telemetry program (e.g., Eiler et al. 1990; Koski et al. 1993, 1994) could provide data on the distribution of steelhead adults within the Skeena River. Data on tagged proportions in index streams could then be used in conjunction with the distribution of tagged fish to derive escapement estimates for the major Skeena River tributaries.

The above catch-and-escapement monitoring program could provide stock-specific harvest rates if stock contributions to the total catch can be estimated. For many salmon species, this has been determined from juvenile coded-wire tagging (Jefferts et al. 1963; Jewell and Hager 1972), and sampling of the catch. However, steelhead juveniles rear in natal streams, then may move into the mainstem where representative sampling and tagging is difficult. An alternative method of stock identification in the adult catch is thus required. Recently, DNA fingerprinting methods (Bentzen et al. 1993) have been used to show differences between steelhead stocks from the Skeena River (Dr. E. Taylor, UBC, pers. comm.). Stock identities could be estimated by this method using tissue samples of spawners from various tributaries and fish subjected to radio-tagging and tracked to their destination. Complementary scale sampling could provide information on age structure, which is required to estimate year-class strength within the catch, and overall harvest rates of a cohort and stock.

Accordingly, a large-scale catch-and-escapement monitoring program for the Skeena River was designed during 1993-94, and implemented during the 1994 fishing season. It was hoped that this program would evolve into a long term, cost-effective program for steelhead stock monitoring. Because of the public concerns expressed in 1993 about the status of coho stocks, the program was designed to provide information on these stocks as well. This report describes the key features of this coho and steelhead monitoring program, and the scientific basis for the approach selected. It should be emphasized that the lack of detailed information on the attributes of certain stocks and fisheries dictated that numerous assumptions be made to derive the estimates required to design the program. These assumptions were clearly identified in this report; their validity should be assessed whenever possible to improve the reliability of the estimates.

2.0 HISTORICAL DATA SOURCES

2.1 Catch

Catch statistics for the Canadian commercial fleets are obtained from hail surveys and sales slip records. Hail surveys are conducted by fisheries officers while monitoring the commercial fishing fleet. Catch statistics are verbally requested as fishing occurs. Sales slip records are fish sale receipts provided by buyers and processing plants. Hail surveys serve to estimate daily catch by sub-area, while sales slip records provide estimates of annual catches by area.

The 1982-92 hail survey and sales slip records for Statistical Area 4 (Fig. 2.1) were compiled according to gear, sub-area, and year to determine trends in catch and effort. Sub-area Y (Fig. 2.2) was not identified separately in the DFO database for 1982-83; the associated summaries could not be generated. Gill-net effort (boat·days) varied from 14,279 in 1988, to 5,113 in 1983 (Table 2.1), while the number of seine days never exceeded 941 (Table 2.2). Commercial catches in Area 4 are mainly comprised of sockeye and pink salmon (Table 2.3) that are taken predominantly by the gill-net fleet (Table 2.4).

During 1982-92, seine fishing was conducted mainly in sub-areas W and X. Seiners operated in sub-area Y during three seasons, and never in the River/Gap/Slough region (sub-area Z). During 1990-92, about 53% of all seine fishing was conducted in sub-area W, 21% in sub-area X, and 26% in sub-area Y (Table 2.5). The corresponding gill-net figures were 21%, 17%, 32%, with 31% for sub-area Z (Table 2.6). Total gill-net and seine effort during 1990-92 averaged 10,786 and 145 vessel·days, respectively. Over 90% of the 1990-92 catch for sockeye, coho, chinook and steelhead was landed by gill-net vessels.

Gill-net fishing effort is concentrated in statistical weeks 7-2 to 8-1 (month-week, i.e., second week of July and first week of August) within sub-areas W, X and Y, and in weeks 7-2 to 8-2 within sub-area Z. Seine fishing effort is concentrated in sub-areas W and X, and is more variable in time across years. Seine fishing occurs mainly between weeks 7-4 and 8-2. Since 1988, gill-net fishing in all sub-areas began in June-July, and continued until week 8-3. On average, more gill-net vessels operate in sub-areas Y and Z, even though the sockeye catch per vessel·day (CPUE) has been consistently greater in sub-area Z (Table 2.7).

From 1982 to 1992, the seine CPUE generally exceeded gill-net CPUE for all species, with maximum averages of 549 sockeye (in 1988) for seine vessels, and 177 (1985) for gill-net vessels (Tables 2.7, 2.8). The CPUE for coho and steelhead were considerably lower than for sockeye, in both vessel types. The maximum average CPUE for coho and steelhead in Area 4 were 98 and 7 for seine vessels, and 6 and 3 for gill-net vessels. The steelhead CPUE declined after 1986. Thomas (1991, 1992, 1993) suggested that fishers under-reported steelhead catches after this period in response to the imposition of unpopular conservation measures. Relatively low steelhead CPUE values were also noted before 1984, when steelhead catches were not consistently monitored.

Estimates of average weekly gill-net CPUE were greatest in sub-area Z and the River/Gap/Slough for all species except coho. The coho CPUE was greatest in sub-area X, the North Porcher area. From 1990 to 1992, the average CPUE was lowest for steelhead, with the mean steelhead:sockeye ratio being <0.01, or 3 to 5 steelhead for every 1,000 sockeye caught (Table 2.9). The mean weekly seine CPUE were greatest in sub-area W for all species except steelhead which had higher CPUE in sub-area X. The steelhead:sockeye ratio in seine catches was lower than for gill-net catches in sub-area W, but similar in sub-area X (Table 2.9).

2.2 Run Timing

Test fishing has been conducted at Tyee in the lower Skeena River since 1950 to provide indices of escapement past the commercial fishery. The test fishery begins in the first week of June and usually ends in early September. The test fishing period covers the entire runs of sockeye, pink, steelhead and chinook, but coho immigrants which enter later are not intercepted. Catch in the test fishery presumably represented a constant portion of the runs passing Tyee each day, although recent studies suggest that sockeye catchability can vary considerably among years (Cox-Rogers and Jantz 1993).

Estimation of the timing of salmon and trout returns are routinely based on commercial and test-fishing catches, spawning ground surveys, and hypothesized migration rates. Ward et al. (1993) reconstructed the sockeye run timing in Area 4 from test fishery and hail catch records. They assumed the run timing curve was normally distributed, and that sockeye required 1 d to move across each of the four sub-areas. The mean of the standard deviations of run timing curves for the period from 1980 to 1990 was estimated to be 12.5 days. The catch statistics for other species are less reliable, but the run timing curves of coho, steelhead and chinook have also been assessed, and some were quite similar to sockeye (Ward et al. 1993). For this assessment, the dates of peak run timing for coho, chinook and steelhead were set to the day on which 50% of the cumulative test fishing catches were attained each year. The mean run timing curves were assumed to have standard deviations of 12.5 d, as for sockeye (Fig. 2.3). A review of the 1989 to 1992 CWT recovery patterns indicated that the standard deviation of the run timing of tagged steelhead stocks was about 11.2 d, which is sufficiently similar to that of sockeye to support the approach used here.

Ward et al. (1993) examined the test fishing records for the June 1 to Sept. 15 periods of 1956 to 1990, and noted that the peak timing of sockeye and steelhead differed, from 2 to 33 d (mean, 16.5 d), with sockeye always first. The test fishing records for the period 1980 to 1992 (DFO files) also indicated that peak timing varied from July 1 to July 10 for chinook (median = July 5), Aug. 1 to Aug. 20 for steelhead (median = Aug. 4), and Aug. 6 to Sept. 2 for coho (median = Aug. 11). Thus, steelhead run timing in 1994 could differ substantially from the pattern in Fig. 2.3.

2.3 Historical escapement levels

Salmonid escapements are monitored through a combination of test fishery indices, fence counts and spawning ground surveys. Few fences are used for enumeration purposes so escapement estimates are largely based on surveys of selected streams by fishery officers during peak spawning periods of salmon. The maximum spawning counts are used as the estimated escapements in most cases. Due to variation in survey timing and incomplete coverage of spawning grounds, stream surveys provide only crude estimates of escapement. Estimates for coho are less reliable than for other species (Labelle 1994). For early-run coho, DFO escapement estimates are derived mainly from test fishery data (Kadowaki 1988).

There has been no system to monitor steelhead escapements throughout the Skeena River, so historical trends were computed from test fishery catches and sockeye escapements. Over 90% of the Skeena sockeye escapement is enumerated at the Babine River fence. Since sockeye catch statistics are fairly accurate, sockeye harvest rates were considered to be reliable. Steelhead harvest rates were considered similar to those of sockeye (Ward et al. 1993). Ruggerone et al. (1990) noted that steelhead seem to migrate closer to the surface than sockeye, but insufficient data were available to test this hypothesis and reject the assumption of equal catchability. Therefore, the steelhead harvest rates were based on sockeye harvest rates after making adjustments for slight differences in run timing (Table 2.10). The 1984-86 hail records were considered reliable (D. Peacock, DFO, Prince Rupert, pers. comm.), so the corresponding steelhead escapements were based on hail statistics and sockeye harvest rates (method 1):

$$\hat{E}_{st,yr,1} = \frac{\hat{C}_{st,yr}}{\hat{H}_{sk,yr} \cdot R} - \hat{C}_{st,yr} \quad (1)$$

where:

$\hat{E}_{st,yr,1}$ = Estimated escapement of steelhead (*st*), in year (*yr*), method 1

$\hat{C}_{st,yr}$ = Estimated steelhead catch (or sockeye *sk*) in Area 4 from hail surveys

$\hat{H}_{sk,yr}$ = Estimated harvest rate for sockeye (*sk*)

R = Steelhead/sockeye harvest ratio (0.93 minimum from Ward et al. 1993)

For 1982-83 and 1987-92, steelhead escapements were based on the steelhead:sockeye ratio in test fishery catches, and sockeye escapements estimated from sale slip records and the Babine River fence counts (method 2):

(2)
$$\hat{E}_{st,yr,2} = \frac{I_{st,yr}}{I_{sk,yr}} \cdot \hat{E}_{sk,yr}$$

where:

$I_{sh,yr}$ = Test fishery catch index for steelhead (or sockeye *sk*) in a given year

$\hat{E}_{sk,yr}$ = Estimated sockeye escapement in a given year

Estimates obtained by means of Eq. 2 were found to 65-81% larger than those based on Eq. 1 when both were applied to the 1984-86 data. It was hypothesized that steelhead were more susceptible to capture by gill nets than sockeye, which accounted for the differences observed. On this basis, the 1982-83 and 1987-92 steelhead escapement estimates obtained with Eq. 2 were adjusted to account for suspected differences in vulnerability based on the ratio of escapement estimates for 1984-86:

(3)
$$\hat{F}_{yr} = \frac{1}{3} \sum_{yr=84}^{86} \frac{\hat{E}_{st,yr,1}}{\hat{E}_{st,yr,2}}$$

(4)
$$\hat{E}^{*}_{st,yr,2} = \hat{E}_{st,yr,2} \cdot \hat{F}_{yr}$$

For coho, Eq. 1 was used to estimate the 1982-92 escapements because the associated hail survey records were considered reliable. Coho harvest rates (Table 2.10) were based on those of sockeye after (i) making some adjustments for the early-run component, and (ii) accounting for the contribution of non-Skeena coho to the Area 4 catch or about 80% until week 7-4, and 50% until week 8-3 (Kadowaki et al. 1992). Estimates of coho escapements (Table 2.11) were comparable to those reported by Kadowaki et al. (1992), based on modified test fishery indices for sockeye.

2.4 Stock contributions to escapements

Since coho escapements are monitored during stream surveys, contributions of individual stocks to the total escapement can be estimated directly (Table 2.12). For steelhead, contributions were considered based on total escapement estimates and distribution of tagged fish to terminal sport fisheries in the 1992-93 tagging program (Ward et al. 1993). Alternative estimates have been derived from scale pattern analysis (Cox-Rogers 1986), but were not available for all years, and were not used here to maintain consistency across all years.

3.0 COMMERCIAL CATCH ESTIMATION

3.1 Monitoring effort requirements

Previous coded-wire-tagging (CWT) programs revealed that the District 101 gillnet and 104 seine fisheries in Alaska intercept coho and steelhead stocks from northern B.C. These fisheries account for 99% of the steelhead catch from southeast Alaska, and 22% of the total steelhead catch in northern boundary fisheries (Table 3.1). The Canadian seine and gill-net fleets in Statistical Areas 3 and 4 account for 21% and 73% of the Canadian commercial steelhead catch in northern B.C. The catch records do not include the suspected under-reporting and sampling deficiencies in commercial fisheries, but were nevertheless used in the design of the monitoring program presented here.

Interviews with commercial fishers, conducted by J.O. Thomas & Assoc., provided data records which were used to determine the relation between the observer effort and the precision of gill-net catch estimates for Area 4. Only the 1992 records were used here, since they were the most complete set. A 'test data set' was generated by duplicating each of the 1992 records to provide 70 observer records per week. The amount of observer effort required was then estimated as follows:

i) set the initial sample size was set at 10 observer·days per week,
ii) randomly select records from week 7-1,
iii) estimate the average steelhead:sockeye ratio$(\hat{R}_i)$ for week *I* from:

(5)
$$\hat{R}_{i,j} = \frac{\sum_{j=1}^{n} st_{i,j}}{\sum_{j=1}^{n} sk_{i,j}}$$

where:

st_{ij} = number of steelhead (or sockeye *sk*) in week *i*, sample *j*
n = total number of samples collected in a given week;

iv) estimate the steelhead catch for week *i* (ratio times reported sockeye catch),
v) repeat steps 2-3 for weeks 7-1 through 8-1,
vi) estimate the annual steelhead catch (sum of the weekly catch estimates),
vii) repeat steps ii to vi 100 times and save the weekly and annual catch estimates,
viii) estimate the mean and standard error from the 100 estimates of weekly and annual catches;
ix) repeat steps ii to viii using sample sizes of 20, 30, 40, 50, 60, and 70.

The accuracy achieved for a given sample size was assessed by comparing the actual catch (based on all samples) and the estimated mean catch from 100 iterations. The relative discrepancy between the known catch value used in the simulation (C) and the estimated mean catch ($\hat{\bar{C}}$) will be termed bias $\{=(C-\hat{\bar{C}})\cdot C^{-1}\}$.

The precision of steelhead and coho catch estimates varied as a function of time and sampling effort (Fig. 3.1, 3.2). When relatively few steelhead were present (weeks 7-1, 7-2) catch estimates were less precise than during peak catch periods (week 8-1) for given sampling effort levels. The precision of steelhead catch estimates improved rapidly as sampling rates increased to 30 per week, and more slowly with further increases in effort. Similar patterns were observed for coho, although greater precision could be achieved with lower sampling effort because of their greater abundance.

When sample sizes exceed 20 per week, the bias associated with the annual steelhead catch estimate was negligible (<1%), and the mean weekly CPUE estimates for peak catch periods tended to be normally distributed (Fig. 3.3). This indicates that unbiased catch estimates could be obtained by surveying at least 20 boats each week. There were not sufficient data to repeat the above analysis for the Area 4 purse seine fleet. Seine vessels tend to have larger daily catches, so less observer effort should be required to provide catch estimates with comparable levels of accuracy. It was thus assumed that unbiased estimates of seine catches could be obtained with about half the gill-net monitoring effort. For steelhead catch estimation, the incremental benefits obtained by using >30 observer.days per week were relatively small, so this level of sampling effort was judged to be the most cost-effective and accepted as the 1994 target.

If the 1994 run strengths and fleet sizes are comparable to those of 1992, the steelhead and coho catch estimates for the Area 4 fisheries should have a 95% probability of being within ±32% of the actual value. This level of accuracy was judged to be sufficient to meet the statistical requirements of the present study.

3.2 Allocation of sampling effort

When stratified sampling designs are used, sampling effort should be allocated in proportion to the variation of the variable being measured (Cochran 1977). In the present case, this is the steelhead:sockeye ratio. Given the uncertainty about the expected distribution of catches and the feasibility of allocating observer effort on short notice, it was reasoned that proportional sampling was probably not possible, and observers should simply be interspersed throughout the fleets during each fishery. This approach was judged to be acceptable since interspersing sampling effort generally serves the same purpose as its randomization (Hurlbert 1984).

Based on pre-season assessments, DFO officials tentatively established that the 1994 gill-net fishery openings could occur on June 27, July 4-5, 11-12, 15-16, 18-19, 21, 23, 26-27, and Aug. 3, 5, 8, 15, 22, Sept. 11 and 18. The 1994 seine fishery openings were tentatively set for July 16, 21, 26 and Aug. 3, 8, and 15. For the weeks with 1 d gill-net fishery opening, at least 30 observers should be available to provide the sampling effort required each week. Fewer observers could be used during extensive fishery openings since each observer could monitor activities on successive fishing days.

3.3 Catch Estimation for Statistical Area 3 and Alaskan Fisheries

During an average season, the combined catch of steelhead from the Area 3, District 101 and District 104 fisheries typically accounts for about 40% of the reported harvest for the northern boundary area. Steelhead harvested in these fisheries usually include smaller portions of Skeena stocks, but daily catch records in these fisheries were not available for further assessment. Therefore, efforts should be made to monitor Area 3 catches of steelhead whenever possible. For US catches, the Alaska Department of Fish and Game (ADF&G) proposed to monitor the commercial harvest of steelhead in their District 101 and 104 fisheries during 1988 (Doug Jones, ADF&G, Douglas, Alaska, pers. comm.). The ADF&G proposal recommended that eight technicians and one biologist be employed for 2-3 months for this purpose. This program was never implemented, but efforts should be made to involve ADF&G in the monitoring program to quantify catch rates and stock composition in S.E Alaska fisheries.

4.0 MODIFIED GILL-NET MONITORING

As a substitute for the traditional time, area, and gear closures, selective harvest methods can be used to minimize the harvest of weak stocks. One of the techniques proposed by North Coast fishers consists of suspending modified gill-nets 1 m below the surface. In theory, suspending nets by means of 'weed-lines' allows greater escapement of steelhead since these fish tend to swim near the surface. The effectiveness of 'modified gill-nets' in reducing interception has been assessed during 'experimental surveys' conducted in rivers and marine environments (Anon. 1993). The tests indicated that standard gill-nets caught about 3 times as many steelhead as modified gill-nets for similar soak times over relatively deep, brackish waters. Within rivers, modified gill-nets were less effective, as standard gill-nets caught only twice as many steelhead for similar soak times (Anon. 1993).

The above tests were conducted under ideal conditions where paired comparisons are made without interference from other vessels. During a typical fishery opening, migrating steelhead would most likely encounter several gill-nets. The catching power of modified gill-nets could be influenced by the fish movement patterns through the fleet, the number of nets encountered, and their response following contacts. There are not sufficient data on the effects of such influences to predict the harvest reduction resulting from the fleet-wide use of modified gill-nets. The potential harvest reduction could be investigated by monitoring steelhead tagged with sonic devices as they move through the fleet, but tagging and tracking many steelhead during the fishery would be logistically difficult and expensive. An alternative approach would be to intersperse modified gill-nets throughout the fishing area. By contrasting the catch rates between gill-net types, differences in selectively could be quantified under actual fishing conditions. The later approach was opted for in this study, so efforts were made to determine the statistical requirements of such a monitoring program.

4.1 Measures of Variance

A statistical comparison of mean catch rates from observer records can be conducted using (1) random samples from each vessel type, or (2) a paired sampling design involving adjacent vessels of different types. The latter option provides greater statistical power, but given the associated logistic difficulties, the former was preferred. The power of this test is the minimum difference between means that can be statistically detected (Zar 1984), and is dependent on the sample size and the catch variance among vessels in each category. Interview data from a previous observer program (Thomas 1992) were used to determine the among-boat variance for traditional gill-nets.

Catch rates of steelhead were estimated using a similar procedure as described in Section 3.0. For each simulation, 100 random samples of specific sizes (5-120) were selected with replacement from all interview records obtained during the peak fishing period (week 8-1). For each sample, the mean and variance of the catch were estimated. The variance of the means was considered as a measure of precision, and was used to estimate the error statistic used to determine the minimum detectable differences between the two catch rates for given sample sizes. The among-boat variance in steelhead CPUE decreased with increasing sample size (Table 4.1, top). The results indicated that >30 boats would have to be sampled to detect differences of less than 100% of the mean.

The catch records used for the above analysis were from standard gill-nets. For modified gill-nets, the catch records from the experimental fishing were used to estimate catch rate variances and means, although the following limitations were acknowledged:

(1) Tests were conducted on days when the commercial fishery was closed.
(2) Three net types were used during the experimental surveys: 60 mesh mono-filament, 60 mesh multi-filament and 90 mesh mono-filament. Only the 60 mesh multi-filament nets were to be allowed in the commercial fishery.
(3) Fishing times were controlled to ensure catch data between net types were comparable. Thus, the variation in catch rates in the test data set is less than would be observed under actual conditions.
(4) Only one boat fished with a modified gill-net each week so there was no measure of among boat variance available. Thus, the variation is less than would be observed during a typical fishery.

Estimates of catch variance for modified and standard gill-nets were derived from the test data for the peak-run weeks, and from survey records for weeks with substantial fishing effort. Modified gill-nets had a lower mean catch rate than standard gill-nets (Table 4.2). Modified multi-filament 60 panel nets showed a 38% reduction in mean steelhead catch compared to the standard nets of the same size (Table 4.2). On average, the standard deviations for modified gill-net catches were lower than those of standard nets. Typically, standard gill-net catches exhibited variances proportional to the means ($r=0.99$). Therefore, the regression of variances against means from commercial records was considered to be indicative of the actual variances of the means for the modified gill-nets.

4.2 Estimation of monitoring effort

The minimum detectable difference of mean steelhead catches between the two net types was estimated by means of a traditional t-test as described in Zar (1984):

(6)
$$S_p^2 = \frac{s_1^2 + s_2^2}{n_1 + n_2 - 2}$$

(7)
$$\delta = \sqrt{2\frac{S_p^2}{n}}\left(t_{\alpha,v} + t_{\beta(1),v}\right.$$

where:

s_1^2	= between boat catch variance for modified (or standard S_2) gill-nets
S_p^2	= pooled catch variance for both net types
$n\_$	= number of boats sampled by category
$t_{\_,v}$	= critical values for α at 0.05 and β at 0.10, for n-2 degrees of freedom
δ	= minimum detectable difference in steelhead catch rates

The testing procedure involves first estimating δ for sample sizes of 5-120 where each sample is the daily boat catch. The among-boat variance in steelhead catch for given sample sizes was estimated by sub-sampling survey records for week 8-1 (middle of the steelhead run, the first week of August). The result of the random sampling procedure is a mean and variance for 100 randomly sampled means over a sample size range of 5-120.

The mean steelhead catch and variance from random sampling and commercial catch data from week 8-1 were used to estimate δ. In the first assessment, catch variances were considered equal for both net types (Table 4.1, top). The minimum detectable difference expressed as a percent of the mean standard net catch declines to $\leq$100% when sample sizes are $\geq$30. Sample sizes of $\geq$70 are needed to detect a minimum difference of $\leq$50%. The mean catch difference between the two net types in tests was 38% for multi-filament 60 gill-nets, so $\geq$80 samples would be required to detect this difference. However, the assumption of equal variance may over-estimate sample size requirements. The influence of reduced variance for modified net catches was examined under the assumption that the mean catch was half that of standard nets (Table 4.1, bottom). For modified net catches with variance in the 0.85 to 0.90 range, a 50% reduction in mean catch and a 37% reduction in variance yields only a small reduction in minimal detectable difference. A 50% difference in mean catch still requires >70 samples.

Variance may be over-estimated for other reasons. Under-reporting is a probable source of added variance because inconsistent under-reporting increases the catch variance. Also, the variance for week 8-1 was the highest in 1992, which may over-estimate the variance during an average week. These factors are not apt to have a large effect on minimum detectable difference, so samples of 50 would rarely detect a 50% difference.

The experimental design and variance analysis conducted above relied on a single statistical week (week 8-1). The daily catch data used to estimate variance are mainly for one day catches within that week. Therefore, the estimated effort for detecting differences between net catches is the resolution that can be realized within one statistical week. Differences in catch rates among days are possible due to weather, depletion of fish from previous fishing, and changes in fleet size. Steelhead catch variance estimates include the among-day variance when sampling occurs over four days. Due to the common occurrence of at least a 50% difference between weekly means and variances for steelhead catches in 1992, sampling strata for comparisons of mean catches should be restricted to one week intervals. Amalgamating samples from a two-week interval will result in larger variances and poor statistical resolution. Therefore, to detect a 50% difference between means, at least 70 weed-line boats should be sampled within a week. The number of observers will depend on the number of days the fishery is open within a week. For one day openings, 70 observers would be required.

A superior approach is to use a paired design, since the statistical power is greater and variation in catch rates among days does not influence the variance estimate for the test statistic. Assuming a weed-line and non-weed-line vessel pair, both with observers, and both fishing in the same general vicinity, the 70 samples could be spread out over the four-week interval when fishing effort is high and steelhead are running at strength, i.e., during statistical weeks 7-5 to 8-3. A maximum of 18 observers on weed-line vessels would be required to detect a 50% difference in mean steelhead catch. Fewer observers would be required for openings exceeding two days per week. This latter option requires the construction of fewer weed-line nets, involves a more attractive work period for observers, and samples a larger and more representative portion of the steelhead and sockeye run.

5.0 RADIO TELEMETRY OPERATIONS

Radio telemetry has been used to estimate patterns of run timing, distribution and escapement of chinook salmon in the Nass and Taku rivers (Eiler et al. 1990; Koski et al. 1993, 1994), and migration rates of steelhead in the Skeena River (Beere 1991; Spence 1989). In these studies, a high fraction of the tagged groups were tracked to destination (Table 5.1). The results of these studies were used to determine the tagging, tracking and recovery efforts required to provide basin-wide escapements of coho and steelhead in the Skeena River.

5.1 Tagging objectives

5.1.1 General considerations

Mark-recapture estimates of escapement can be influenced by the demographic traits of the fish, tag loss through mortality and migration, and the spatial and temporal distribution of tagging and recovery efforts. Radio-tags should be applied in proportion to abundance throughout the run to ensure that tagged fish represent all segments of the population. At a minimum, sufficient tagging and recovery efforts should be made to ensure that ≥4 tags are detected in each tributary of interest so that the 95% confidence intervals of the recoveries do not overlap with zero (see Ricker 1975). During the Nass River radio-tagging program, about 2% of the escapement was tagged and 14% of it was examined for tags each year. This allowed the crews to recover 3% of the tags applied, enough to estimate escapements to the major tributaries. Given recent Skeena River escapement levels (Tables 5.2), tagging 1-2% of the escapement would mean tagging 220-440 steelhead and 300-600 coho. For steelhead stocks representing 10-35% of a total escapement of 22,000 fish, some 7-23% of their escapement should be sampled to obtain 500 fish. Efforts should be made to inspect as many fish as possible at each fish fence to improve the reliability of the estimates derived, and to obtain appropriate biological information.

5.1.2 Tag attrition

Loss of radio-tagged fish may be caused by natural mortality (predation), regurgitation, battery failures, removals due to fishing, and emigration. Natural mortality losses can be accentuated when inappropriate capture and handling methods are used. Beere (1991) obtained survival rates of 15% for steelhead captured and tagged from gill-net vessels operating in brackish waters. By contrast, approx. 60% of steelhead tagged from seine vessels in marine waters were subsequently detected in the lower sections of the river (Spence and Hooton 1992). In the Nass River (Koski et al. 1994), about 40% of the steelhead tagged at fish wheels were tracked to their spawning grounds several months later, despite some losses due to fishing. Preliminary analysis of the Nass River results indicated that 3% of the tags applied were regurgitated, 14% of the tags could not be tracked due to tag or battery failure, and 35% of the steelhead did not enter the tributaries as expected (perhaps an abnormal behaviour due to tagging). Eiler et al. (1990) reported that 67% of the coho tagged at fish wheels in the Taku River were tracked. Based on these data, it was estimated that approx. 60% of the fish tagged near the Skeena River mouth could be tracked to their destination if seine vessels were used in the capture and tagging in marine waters, efforts were made to minimize handling stress, and there were no losses due to fishing or emigration after release.

It is unlikely that there would be no losses due to emigration and fishing during the 1994 Skeena River tagging program. Non-Skeena stocks may account for up to 50% of the coho caught by seiners in Area 4. This fraction is thought to be negligible for steelhead. Mainstem harvest rates for coho have averaged 8% from 1982 to1991 (Kadowaki et al. 1992). Steelhead harvest due to native food fisheries, and mortality associated with catch-and-release regulations could also amount to the same. As a result, one could expect that approx. 30% of the coho and 50% of the steelhead tagged could be successfully tracked to the spawning grounds.

5.1.3 Capture and tagging methods

Previous radio-tagging programs on the Skeena River indicated that it was preferable to capture steelhead by seining in marine waters than with gill-nets in brackish waters (Beere 1991). Seiners should be used to capture and tag steelhead and coho in 1994. The level of effort required to achieve the tagging objectives is a function of the daily catch rates for seine vessels in the study area. Catch rates of seine vessels in areas 4Y and 4Z are difficult to predict because seiners operate mainly in outside areas. Therefore, effort requirements were crudely estimated based on historical catch records, and advice obtained from biologists, fishery managers and local fishers.

Reported seine catches in Area 4X for 1982-92 were used to predict mean daily catches of coho and steelhead in Area 4Z where tagging would most likely take place. Peak catch in Area 4X during 1982-92 was 7 per seine·day for steelhead, and 60 for coho. These catch rates were assumed to be comparable to those of recent years given their similarity to those in outside waters during 1990-92. Predicted coho CPUE in Area 4Z was then set to half of the Area 4X index to account for non-Skeena stocks in the catch. Predicted steelhead CPUE in Area 4Z was set to twice the Area 4X index to account for suspected under-reporting. Predicted mean daily catch ranged form 1.3 to 13.7 for steelhead, and 4.6 to 30.2 for coho (Table 5.3). These figures were considered reasonable since Spence (1989) caught on average 9 steelhead per set in 1988 while fishing inside of Area 4.

Assuming that >90% of the fish caught are suitable for tagging, the above figures suggest that 90 seine·days would be required to catch and tag 350 steelhead, but only 30 would be required for coho. Since coho have a more protracted run, the tagging objective could be met with 3.5 vessel·days per week, but 10 vessel·days per week would be required for steelhead. Fishing should take place when most of the run (or 80%) move through Area 4Y and 4Z. Judging from the patterns in Fig. 2.3, coho should be tagged during weeks 7-4 to 9-4 (end of July to end September), and steelhead tagged mainly during weeks 7-2 to 9-1 (early July to early September).

It may be difficult to catch 350 steelhead if the steelhead run is below average in number. Furthermore, sufficient funds may not be available for 700 radio-tags and extensive tagging operations. Objectives for tagging 250 steelhead and 350 coho would be more realistic. This target could be met if two seine vessels fished 4 days per week, from the second week of July to the last week of September, within or upstream of Area 4Z. Efforts should be made to apply constant fishing and tagging efforts over the duration of the coho and steelhead runs to minimize differences in tagged proportions among the stocks, and within each population.

5.2 Tracking of tagged fish

To determine the optimal tag monitoring effort, the number of tagged coho and steelhead that could potentially escape to various tributaries was estimated based on the figures provided previously (Table 5.5). The predicted escapement patterns indicated that the desired objectives for minimum tag recovery within individual tributaries will be difficult to achieve unless tracking efforts cover both the migration period and the distribution of coho and steelhead.

Stationary receivers should be installed at every major confluence to monitor the movements of all tagged fish during their period of stream residency (Table 5.4). Mobile receivers should be used periodically to track the movements of tagged fish that do not exhibit a normal migration pattern, (i.e., extensive downstream movement), to ascertain whether or not a tag has been regurgitated (extensive stationary position), and verify tag losses due to fishing or predation (lost between two fixed stations).

Given the expected escapement and migration patterns, at least 15 stationary receivers should be used to monitor coho and steelhead escapements. These receivers should be placed at the confluence of major tributaries to monitor movement past or into each tributary. An additional station should be placed upstream of tidal influence to determine the actual escapement of tagged coho and steelhead. Additional stations should also be installed at sites where adult enumeration is conducted to provide information on tagged proportions. Ideal sites would be near the Moricetown fishway, and the counting fences on the Babine River, Toboggan Creek and Sustut River. Stationary receivers placed in the lower sections of the Skeena River should be operational by the last week of July. Steelhead tracking stations should be operational by the second week of July. All stations should be maintained until freeze-up, and those which detected steelhead should be kept in operation until the following spring to determine post-winter movement patterns, and to estimate over wintering mortality and straying rates.

5.3 Estimation of tagged proportions

To provide reliable escapement estimates and assess the validity of various assumptions, tagged proportions should be estimated in as many tributaries as possible, through fish fence and fishway counts, dead-pitch operations, broodstock collection, beach-seining operations, snorkel and angler surveys, and food-fishery monitoring activities. Field surveys will be required primarily for coho escapement estimation, since the majority of coho are expected to escape to the lower Skeena River tributaries where no fish fences are used.

6.0 ESCAPEMENT ESTIMATION

Even if radio-tags are applied to coho and steelhead after capture in seine vessels, and in proportion to their abundance, and the subsequent distribution of tagged fish throughout the Skeena River is determined by telemetry, the tagged proportions within each tributary will not be known unless sufficiently large samples are obtained from stream surveys. Even if surveys are conducted, traditional mark-recapture models as described by Ricker (1975) and Seber (1982) would not be suitable for escapement estimation. For this reason, a mark-recapture model was specifically designed to estimate escapements, based on previous stream survey data and estimates of tagged proportions expected in the 'indicator' streams, where escapement shall be provided by fish trap fences.

6.1 Model parameters and definitions

i = index used to distinguish each stream (i = 1, . . ., I)
z_i = number of radio-tags detected in a stream i
z = vector of the radio-tag recovery values
Z = total number of radio-tags detected in the entire watershed ($Z = \sum z_i$)
p = proportion of all fish escaping that are radio-tagged
p_i = proportion of fish in stream i that are radio-tagged
Pr = probability of an observation or event
e_i = escapement to stream i.
E = escapement to the entire Skeena River ($E = \sum e_i$)
q_i = proportion of the escapement going to stream i ($q_i = e_i / E$)

6.2 Model structure

Consider the case involving one indicator stream and three target streams (I = 4). A complete enumeration is conducted at the fence on the indicator stream, so that the number of spawners and their tagged status is known with certainty. The escapement of tagged fish to each target stream is known, and some data on the tagged proportions is available from complementary surveys. Thus, each salmon escaping to the Skeena River can potentially be classified into one of eight categories (four streams x two tagged groups), and the tag recovery pattern can be viewed as an outcome from a series of multinomial experiments, with the probability of an outcome in any category given by:

(8) $$\Pr(z_1, z_2, z_3, z_4) = \frac{Z!}{\prod_i z_i!} \prod_i p_i^{z_i}$$

In the above model, p_i is the probability of tagging fish of a specific stream, which we would like to estimate given Z and z_i. If tags are applied in proportion to abundance throughout the run, tagged proportions can be assumed to be similar across all streams (the null hypothesis), which eliminates the need for subscript p. If the number of tags recovered is not sufficiently large, the estimates of p may not be accurate, so data on the all tagged and untagged fish sampled should be used to estimate the probability of the observations. If the probability of being tagged and escaping to stream *i* are independent, the probability of this event is pq_i while that of being untagged in stream *i* is $(1-p)q_i$. The probability of the observations can now be considered as the product of two multinomial experiments:

$$\Pr(z_1,..,z_4,e_1-z_1,..,e_4-z_4)=\frac{Z!}{\prod_i z_i!\,(e_i-z_i)!}\prod_i pq_i^{\,z_i}\,((1-p)q_i)^{(e_i-z_i)} \tag{9}$$

For a system with *i* rivers, there are $3i+1$ parameters in Eq. 9 that are not independent because of the $2i$ constraints ($z_i = p \cdot e_i$, $e_i = E \cdot q_i$). Eq. 9 can be solved for all the parameters if there are $i+1$ relations or known parameter values. Since escapements of tagged and untagged fish to target streams are known, Eq. 9 can be solved by estimating the remaining parameters (e_1, e_2, e_3). The log-likelihood of the hypothesized escapement to each of the three target streams given the field observations becomes:

$$\ell(e_1,e_2,e_3|e_4,\mathbf{z})=\ln(Z)-\sum_i \ln(z_i!)-\sum_i \ln((e_i-z_i)!)+\sum_i z_i\ln(pq_i)+\sum_i (e_i-z_i)\ln((1-p)q_i) \tag{10}$$

In theory, Eq. 10 could be solved with non-linear function minimization routines after setting *p* to *Z/E*. The IMSL function minimization routine BCPOL (Simplex algorithm, IMSL 1989) was used to estimate the parameters (subject to bounds since $z_i \le e_i$) given a hypothetical data set consisting of 'known' parameter values (Table 6.1). An initial test revealed that the overall escapement estimate was close to the actual value (148.9 and 150.0 respectively), but the discrepancy between the estimated and actual escapements to certain streams {relative error $= \left|(\mathrm{e_i}-\hat{e}_i)\cdot \mathrm{e_i}^{-1}\right|$} was substantial (20.6% for stream 2). Dr. David Fournier (Nanaimo, B.C., pers. comm.) noted that perhaps Eq. 10 was not numerically well determined, and suggested an alternative model structure to facilitate convergence:

$$\ell(e_1,e_2,e_3|e_4,\mathbf{z})=\sum_i \ln\left(\frac{z_i}{pq_iZ}\right)^2+\ln\left(\frac{e_i-z_i}{(1-p)q_iZ}\right)^2 \tag{11}$$

Maximizing Eq. 11 (or minimizing the negative of Eq. 11) is akin to finding the parameter values which minimize the sums of squares of deviations from the expected values for the tagged and untagged components of each stream population. Escapements to the target streams were estimated by solving Eq. 11 (Table 6.1). The relative error of the escapement estimates were negligible, and the overall escapement was nearly identical to the "actual" escapement. Thus, Eq. 11 was considered sufficient for estimating escapements under relatively 'ideal' conditions, namely; (*i*) all fish have the same probability of being captured, tagged and recaptured, (*ii*) tagging does not significantly affect the catchability, behaviour or survival of the fish after release, (*iii*) fish do not lose their tags prior to recovery (or tag loss is quantified), (*iv*) all tag escapements are detected, and (*v*) escapements to the indicator streams are known. Under field conditions, such assumptions may be violated to some extent, even when precautions are taken to reduce this risk. The robustness of this estimator to departures from the underlying assumptions is therefore of interest. For the purposes of this plan, only a simplistic assessment of the performance of the model was conducted.

6.3 Model testing

The performance of this estimator (Eq. 11) was assessed under hypothetical conditions possible during 1994. When two of eight tributaries were used as indicators, and tagged proportions were identical across all stocks, the relative error of the overall escapement estimate was $<1\%$, and those of the tributary escapements ranged from 0.0 to 0.2% (Table 6.2). This confirmed that the model could provide accurate escapement estimates under 'ideal conditions', if the planned field operations produced the expected number of tag recoveries.

Even when a complete enumeration is conducted with a fence, one might expect that the escapements to indicator streams would be in error to some extent due to the undetected passage of some fish through the fence and deficiencies in the survey procedures. To assess sensitivity of the model, the target stream escapements were estimated based on some indicator stream escapements subject to error. When both indicator stream escapements were in error by +10%, the relative error of the each target stream escapement estimate was about 10% (Table 6.3). The relative error of the target stream escapement estimates closely matched the error of the indicator stream escapements when the later two were in error by +20% or -20%. When the indicator streams escapements were in error by +20% and -20% respectively, the relative error of the target stream escapement estimates were negligible or about 2%. If only one indicator stream escapement was in error by 20%, the relative error of the target stream escapement estimates were at intermediate levels or about 10%. These results highlight the need to determine the indicator stream escapements with certainty. They also suggest that two or more indicator stocks should be used to derive escapement estimates for the target streams since this would reduce the influence of a single target stream escapement that could potentially be in error.

Another potentially important source of error that would most likely operate under actual field conditions is the differential recovery rate of tagged fish. It is doubtful that an equal fraction of the tagged fish from each stock will escape to their respective streams because a variable number from each stock might be intercepted by fishing, die of natural causes along the way, reject their tags, etc. Furthermore, one might expect that the tag escapement records for the target streams might be less reliable than those of the indicator streams since the constant monitoring activities in the later streams should allow field crews to better maintain the stations and test and monitor the telemetry devices for anomalies.

To assess the effects of tag escapement errors, the target stream escapements were estimated based on some tag escapement to target streams that were subject to error. When tag recovery rates to the target streams were 10% lower than those of the indicator streams, the relative error of the target stream escapements estimates were not constant across streams (perhaps owing to rounding errors), and ranged from 0-10% (Table 6.4). The target stream escapement estimates were always lower than the actual values.

When tag recovery rates to the target streams were 10% higher than those of the indicator streams, the target stream escapement estimates exceeded the actual values by 8-10%. When tag recovery rates to the target streams were a mixture of either +10% or -10% of the indicator streams recovery rates, the target stream escapement estimates were above or below the actual values by 8-10%. Interestingly, the escapement estimates that exceeded the actual values were not always those which had relatively higher tag recovery rates. However, when tag recovery rates to the target streams were a mixture of either +30% or -30% of the indicator streams recovery rates, the target stream escapement estimates were consistently above or below the actual values by about 30%, and target streams escapements which exceeded the actual values were those for which the tag recovery rates were relatively higher.

6.4 Further refinements

The results presented indicate that under certain conditions, one can obtain accurate estimates of escapements to the target streams by reference to the distribution of radio-tags throughout the Skeena River and information on tagged proportions from various sources. The simulations conducted provided some insight into the performance of the model when some of the basic assumptions are not met. It was beyond the scope of this report to assess the performance of the model under the whole spectrum of scenarios that one can encounter in the field. However, further model testing and development should be conducted before the final escapement estimates are generated. The model should also be structured to incorporate ancillary data from all surveys conducted in the target streams. These data could be used to set further constraints on the parameter estimates, and determine if the underlying assumptions are met. One of the key assumptions is that radio-tags are applied proportionally throughout the run. Cass et al. (1995) used test-fishing data to approximate the proportion of pink salmon tagged at release. The model could be modified to allow tagged proportions to vary during the season based on trends in test fishing CPUE and tagging rates. The model could also be modified to account for the uncertainty associated with escapement estimates from mark-recapture operations conducted in certain tributaries.

7.0 GENETIC METHODS OF STOCK IDENTIFICATION

Several genetic techniques are available for steelhead stock discrimination. The strengths and limitations of each technique are discussed, and the results of previous studies are summarized briefly. Based on the results of these studies, recommendations are outlined for further work on stock identification using genetic techniques.

7.1 Summary of techniques and previous studies

7.1.1 Allozyme electrophoresis

This is the most common genetic tool used in stock assessment to date. This technique has been applied to numerous investigations on stock discrimination, population structure and conservation requirements. It is the cheapest and least labour-intensive method of genetic screening, particularly where large-scale population sampling is required. Inheritance studies on salmonids have found allozymes to be inherited in a Mendelian fashion, reflecting the contributions from both parents. Levels of heterozygosity and inbreeding can be determined, and discriminating between complex inheritance models can be done with reasonable confidence. The biggest advantage in using allozymes is the vast data base already in existence. Ninety independent allozyme markers have been developed for steelhead, 30-60 of which are found to be variable on a regular basis (Phelps et al. 1994).

Allozyme electrophoresis is based not directly on DNA sequence variation, but on phenotypic expression of nuclear DNA variation. Most of the variation occurring at the DNA level (>99%, Park and Moran 1994) is not observed using this technique, so the levels of measurable variation and heterozygosity detected is lower than for techniques that directly measure DNA variation. Since allozymes are tissue-specific, invasive or lethal sampling of organ tissues is usually required to screen certain enzyme loci, which may not be tolerated in some instances.

Several allozyme studies have focused on Canadian and U.S. steelhead stocks (Parkinson 1984; Reisenbichler and Phelps 1989; Reisenbichler et al. 1992; Phelps et al. 1994). The ability to discriminate populations varied among studies. Most studies utilized fewer than 10 loci, thus limiting the ability to resolve populations. Differences were noted between adjacent streams, among drainages and between sample years but these differences were not consistent (Parkinson 1984; Reisenbichler and Phelps 1989; Reisenbichler 1992). In a large-scale study applying 60 independent allozyme markers, Phelps et al. (1994) noted that stocks were fairly distinct genetically although among-tributary differences within drainages were not studied in detail.

7.1.2 Mitochondrial DNA Restriction Fragment Length Polymorphisms

Mitochondrial DNA is a relatively small, circular piece of DNA that is maternally inherited and does not undergo recombination. Its rapid mutation rate makes it a sensitive indicator of maternal genetic history. Because it is more sensitive to evolutionary processes and has an effective population size (Ne) smaller than that for allozymes, there is a greater probability of fixation for different mt DNA clones or haplotypes compared to allozymes (Ferguson 1994). Mitochondrial DNA can detect recent genetic bottlenecks that allozyme analysis cannot. Any tissue can be used in the analysis so non-invasive sampling is possible. With the advent of Polymerase Chain Reaction (PCR), mt DNA analysis can now be carried out on fresh, frozen or alcohol-stored tissue.

The mt DNA RFLP (restriction fragment length polymorphism) technique involves various restriction enzymes that recognize restriction (or cut) sites (usually 4-6 nucleotides long) in the mt DNA. At every such site the mt DNA is cut (or restricted) by the enzyme. If a mutation occurs, the restriction enzyme no longer recognizes the site. The resulting fragments are electrophoresed, and banding patterns result according to the length of the DNA fragments. Because mt DNA RFLP analysis deals directly with sequence variation, it is said to have a higher resolving power than allozymes. It also covers the mt DNA extensively, and markers are considered random and neutral. Populations with discrete mt DNA haplotypes can easily be discriminated.

Mitochondrial DNA RFLP analysis gives no indication of male contribution. Inbreeding and heterozygosity values (important in considering the genetic condition of a population) cannot be estimated. Because mt DNA is strictly maternally inherited (with no recombination), it is considered as a single character (Ward and Grewe 1994). Finally, while the use of PCR can eliminate the requirement for large amounts of tissue, it limits the amount of mt DNA that can be assessed, and different sections or genes must be amplified to cover the entire mt DNA molecule.

A preliminary study on 100 samples of Skeena steelhead was conducted by LGL Ltd. to determine the viability of using mt DNA RFLP analysis to discriminate Skeena steelhead stocks (LGL 1994). Blood samples were taken from approximately equal-sized adult groups from each of the 5 tributaries; Babine River (N=20), Copper River (N=21), Kispiox River (N=20), Morice River (N=20) and Sustut River (N=19). Two regions of mt DNA, Cytochrome b gene (750 base pairs) and the NADH-1 gene (690 base pairs), were amplified using PCR and sequenced for one fish from each tributary (N=5).

Sequencing of these regions identified two haplotypes 'a' and 'b' based on restriction enzyme analysis using restriction enzymes *MnlII* and *DpnII*. The distribution of the two mt DNA haplotypes varied according to tributary but both were present in all but the Copper River stock where only 'b' was present (Fig. 7.1, Table 7.1). Monte Carlo chi-square randomization procedure (Roff and Bentzen 1989) was used to compare the distributions of haplotypes. This revealed highly significant differences among tributaries ($p<0.0001$). The study suggested a slight clinal distribution of the haplotypes with 'a' increasing in frequency in the upstream tributaries. However, the individual stocks could not be discriminated based on the results obtained so far.

Oncorhynchus sp. demonstrate considerable variation at the mt DNA level (L. Bernatchez, R. Danzmann, per. comm.). The addition of more restriction enzymes would likely increase the discriminating power of this analysis considerably. However, relative levels of heterozygosity cannot be compared among populations using mt DNA analyses so parallel nuclear DNA analysis would be required.

7.1.3 Nuclear VNTR DNA Markers: Single-locus minisatellites and microsatellites

The use of DNA "fingerprints" has only recently been considered for stock analysis. Nuclear DNA contains hyper variable regions randomly dispersed throughout the genome. These regions are treated as loci and are often associated with many alleles (fingerprints) and high levels of heterozygosity (Hallerman and Beckmann 1988). Methods to detect a particular locus bearing variable numbers of tandem repeats (VNTR) have been developed. These methods simplify the interpretation of the banding patterns, making it possible to assign bands to individual loci.

VNTR loci are generally considered to be non-coding (Stevens et al. 1993) and assumed to be neutral. Selective pressures should not influence variation. Any tissue can be used, eliminating the need for lethal sampling. Since patterns are assumed to be Mendelian and codominant in expression, heterozygosity and inbreeding can be estimated. The greater resolution of these techniques compared to allozymes results in much higher levels of variation and heterozygosity. This in turn results in a greater potential to discriminate among different populations. VNTR variation may be useful where allozyme electrophoresis has failed to detect variation among populations.

VNTR locus analysis is relatively new, and various aspects of the technique need further refinement. The high degree of variation observed at some VNTR loci may actually prove to be too sensitive to discriminate stocks. This problem can be minimized by selecting loci that express the amount of variation appropriate for the study. Secondly, available mixture models developed for mixed-stock analysis depend on relatively few variable states (i.e. alleles) with distributions that are polynomial or at least predictable. The distribution of VNTR allelic variation within populations is not fully understood. However, it is generally felt that VNTR loci are suitable for stock discrimination and population structure analyses and that the methodology can be tailored to address specific issues.

Pilot studies on Skeena River steelhead were conducted using two classes of VNTR loci, minisatellites and microsatellites. Minisatellites include DNA sequences made up of repeating units of 9-64 base pairs, with a total length of 0.1 to 7.0 kilobases (Jeffreys et al. 1985).

The viability of this technique was initially tested using samples of adult steelhead collected in winter 1992 from two tributaries, Copper River (N=24) and Kispiox River (N=20), and genomic DNA from blood was probed with two minisatellite probes Ssa1 and T34 (Taylor 1994b). This study complemented a previous one using samples from three other tributaries; Morice (N=23), Sustut (N=19) and Babine (N=28); and five other populations from the north Pacific (Taylor 1994a). For the most recent study, additional samples from Babine (N=17) and Morice (N=30) were also taken during the spring of 1992 to test for temporal stability of genetic variation. Two minisatellite loci Ssa1 and T34 were probed.

The results indicated that allelic variation among the populations was highly significant for Ssa1 and T34 (Monte Carlo chi-square randomization test, $p<0.0001$). These loci both had a high degree of polymorphism indicated by the number of alleles segregating at each locus and the level of heterozygosity observed within populations (Table 7.2). For Ssa1, the total number of alleles was 18 with heterozygosity values ranging from 0.32 to 0.74. For T34, an assumed tetrasomically-inherited locus, the total number of alleles observed was 26 with heterozygosity values ranging from 0.72 to 0.87. While all populations shared the most common allele for both loci, several other alleles for each locus varied considerably in frequency. Genotype frequencies within each of the populations generally did not deviate from Hardy-Weinberg equilibrium, indicating that the breeding system is random and that no within-sample genetic groupings exist. The results indicated that the samples from Babine and Morice Rivers were temporally stable. The numbers of segregating alleles and levels of heterozygosity detected are substantially greater than those detected by allozyme studies. Thus, greater ability to resolve genetically distinct populations is expected.

Microsatellite sequences include tandem repeats of 1-5 base pairs with a total length of usually less than 0.2 kilobases. A preliminary study was conducted by Hologene Genetic Technologies Ltd. (1994) using samples from 99 adult steelhead from the Skeena River in 1993. Five main tributaries were sampled; Copper River (N=21), Babine River (N=20), Kispiox River (N=20), Morice River (N=20) and Sustut River (N=18). Five microsatellite single-locus probes (designated as Omy002, Omy027, Omy038, Omy077, and Omy105) were used to detect variation.

All 5 loci were found to be highly heterozygous with the number of segregating alleles at each locus ranging from 5 to 26, and mean heterozygosity (per locus) ranging from 0.707 to 0.804. Genotype distribution per locus within each of the populations generally did not deviate from Hardy-Weinberg equilibrium, indicating that the breeding system is random and that no within-sample genetic groupings exist. The allelic frequencies were significantly different among populations for 4 out of the 5 loci (Table 7.3). Based on a discriminant function analysis which predicted population assignment, the success rate was 74% compared to 20% due purely to chance.

7.2 Recommended approach for stock identification

Based on preliminary studies, mini- and microsatellite single-locus markers appear to be equally superior to mt DNA RFLP and allozyme analyses. These two techniques give similar, significant levels of genetic differentiation among tested Skeena tributaries. Mini- and microsatellite loci are randomly dispersed throughout the entire nuclear genome and assumed to be neutral markers not subject to selective pressures. These disomically inherited loci reflect high and varying degrees of variation, both in the number of segregating alleles per locus and in overall heterozygosity. The potential to detect variation among populations is high. In terms of cost-effectiveness, PCR greatly reduces the amount of tissue required initially in microsatellite analysis. Compared to mini satellites, fewer steps are involved, more samples can be run in the same time, and the initial set-up cost is lower (Dr. E. Taylor, UBC, per. comm.). Based on this review, microsatellite analysis was thought to be the most appropriate candidate for the Skeena River stock identification program.

The goal of a mixed-stock analysis (MSA) is to assign steelhead of unknown origin to a particular population with an acceptable level of certainty. This requires a reliable data base representing all populations potentially contributing to the mixed-stock fishery of concern. Major biases develop in MSA models when contributing groups are missing (Pella and Milner 1987). The data base must incorporate substantial sample sizes of fish taken from the baseline populations to maximize the probability of sampling all allelic variation present (Wood et al. 1987). Based on the preliminary surveys, it was estimated that at least 50 samples should be obtained from each population contributing to mixed stock fisheries in Area 3-4. These are currently thought to include (*i*) Skeena River stocks from the Bulkley, Babine, Sustut, Zymoetz, and Kispiox rivers, (*ii*) Nass River stocks from the Damdochax, Cranberry, Tseax, Seaskinnish, Bell-Irving, Meziadin and Kwinageese rivers, (iii) and perhaps stocks from more distant streams in the Kitimat and Dean rivers. To minimize sampling biases, adults should be sampled throughout the run and spawning season, and collections should be randomized temporally and/or spatially.

A number of statistical methods and computer packages will be applied to the genetic data obtained. BIOSYS (Swofford and Selander 1981) estimates a number of genetic values (e.g. heterozygosity levels, inbreeding coefficients, distribution of variation) and tests several assumptions (e.g. Hardy-Weinberg expectations, heterozygosity deficiencies). A maximum likelihood procedure for estimating stock composition should be developed using mixture models similar to those described in the past (Fournier et al. 1984, Pella and Milner 1987, Wood et al. 1987). Robustness of discriminatory data should be tested using bootstrapping analyses such as those available in the PHYLIP genetic analysis program (Felsenstein 1990).

The ultimate goal is to characterize each distinct steelhead stock of the Skeena River system using genetic markers. This evidence will be substantiated with scale-ageing data and radio telemetry. Once this database is established, any netted individuals may be assigned with an acceptable level of certainty to a particular population. From this information, the relative contributions of the different Skeena stocks to the fishing industry by-catch can be determined. Furthermore, effective genetic population size (Ne) or broodstock size (Nb; Waples and Teel 1990) can be estimated. Eventually, escapement numbers adequate to maintain the population for conservation purposes will be estimated based on demographic and genetic data.

8.0 SUMMARY AND DISCUSSION

To provide reliable estimates of catch and escapement of Skeena River steelhead and coho, plans were made to implement fishery observer and radio-tagging programs in 1994. Observers would be interspersed in the seine and gill-net fleets to monitor fishing effort, determine catch composition, and conduct some bio-sampling. At least 30 observer·days per week would be used to monitor gill-net catches, with another 15 observer·days per week for seine catches. The effectiveness of modified gill-nets would also be assessed under actual fishing conditions through comparison of observer records collected on board standard and modified gill-net vessels during the four-week period, centred over the peak steelhead migration period.

Uninjured steelhead captured during fishing operations would be tagged and released to provide information on migration patterns and validate the stock identification methods. External tags would be applied by observers on commercial fishing vessels, and radio-tags would be applied near the river mouth from chartered seine vessels. Seine vessels would be chartered to catch and tag a total of 250 steelhead, and 350 coho. Seine vessels would fish for 4 $d \cdot wk^{-1}$ each, from the second week of July to the last week of September, within or upstream of Area 4Z. Efforts would be made to apply constant fishing and tagging efforts over the duration of the coho and steelhead runs to minimize differences in tagged proportions among stocks within each population.

The number of radio-tagged fish escaping to various Skeena River tributaries would be determined by radio-telemetry. A stationary receiver would be installed along the Skeena River mainstem above tidal influence to determine the escapement of tagged fish. Additional receivers would be placed at the confluence of 15 tributaries. Aerial and ground mobile tracking would also be conducted periodically to provide additional information on the factors accounting for tag attrition. All receivers would be maintained until spring to provide information on the post-winter movements patterns, straying rates and over-winter mortality of steelhead.

Adult enumeration would be conducted at certain index streams where fence counts can be made. Surveys would be conducted whenever possible in non-index streams and at the Moricetown fishway to determine tagged proportions. Escapements to various tributaries would be estimated from escapements to index streams, the distribution of radio-tagged fish throughout the system, and ancillary data from complementary field surveys. A maximum likelihood model was developed to provide tributary specific estimates of escapement based on the above data. Efforts should be made to improve the model so that it can incorporate information from the Tyee test fishery, and provide robust estimates of escapement when the underlying assumptions are not fully met.

Scale samples of all steelhead handled should be used for ageing purposes. DNA probes will be used to characterize steelhead of each stock in terms of genetic traits. Once the appropriate probes have been identified, all bio-samples collected in the fishery, in various tributaries, and in adjacent rivers will be processed. Whenever possible, radio-tag information will be used to validate the stock identities. Efforts should be made to develop an appropriate model to categorize individuals based on their genetic profiles. Once the stock ID method has been tested and shown to be effective, estimates of stock contributions to commercial fisheries, harvest rates and conservation requirements will be generated

It is recommended that radio-tagging continue for 2 or more years. It was hoped that after this start-up phase, suitable stock identification methods will have been developed and validated. Estimates of stock contributions and harvest rates should also be available, and could be used to assess the performance of the model of stock and fishery dynamics, which will be used to assess fishery management plans. However, even if the fishery management model is shown to be fairly accurate, information on stock status will undoubtedly be needed to confirm the model predictions under new management scenarios, and to ensure that the stock conservation initiatives are successful. It is unlikely that sufficient funds can be obtained each year to monitor stock status through a combination of observer programs, radio-tagging operations and genetic monitoring. Therefore, more cost-effective and logistically simpler methods will have to be developed to estimate catch and escapement estimates on an annual basis. If efforts are made to reduce the harvest of steelhead, monitoring efforts should focus on escapement levels to ensure that minimum spawning requirements for stock conservation purposes are met. Ideally, passive sampling devices like fish wheels should be used for this purpose since they can provide indices of escapement in a cost-effective fashion. Fish wheels installed at the Kitselas Canyon could be used to conduct tagging, sampling and escapement monitoring each year. Tagged proportions in steelhead escaping to the upper Skeena River and Bulkley River could then be monitored through fishways counts at Moricetown, and with another wheel at Four Mile Canyon. This tagging/sampling design could provide indices of overall escapement to each section of the Skeena River, which might be sufficient for management purposes. Therefore, it is recommended that further efforts be made during the next three years to develop and test the use of selective harvest methods such as fish wheels and traps.

9.0 ACKNOWLEDGEMENTS

The authors wish to acknowledge the valuable contributions of several scientists to this investigation: Dave Narver, Al Martin, Art Tautz, Bruce Ward, Mark Beere, Colin Spence, Dave Peacock, Less Jantz, Steve Cox-Rogers, William Koski, Richard Alexander, Robert Bocking, David Fournier, Eric Taylor, Doug Jones, and Vic Lewynsky. We hope this manuscript will help highlight the substantial efforts made to understand the complexity of the Skeena River fishery, and the life history attributes of its fish populations.

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Table 2.1. Hail catch and effort data for the Area 4 gill-net fishery. Effort figures represent the number of boat·days of fishing activity (Source: DFO records).

Sub-Area	Year	Effort	Sockeye	Pink	Coho	Chinook	Steelhead
W	82	1380	176414	9053	3276	1145	1035
W	83	1007	64216	146214	6385	518	745
W	84	1558	94813	149381	9404	549	4070
W	85	2981	385383	254798	27471	1440	5719
W	86	932	55694	124261	8663	359	1460
W	87	985	70791	210311	5230	553	943
W	88	2438	173858	66760	7569	941	1590
W	89	1440	108405	76188	9312	747	273
W	90	1455	132346	56575	6499	599	665
W	91	2192	231899	151612	15322	1370	596
W	92	3036	324029	127553	7891	853	1042
X	82	3243	435673	23604	7848	2563	2590
X	83	1772	122853	249787	11276	964	1356
X	84	1204	84652	56918	5897	834	3215
X	85	2669	332660	117533	13967	1961	4629
X	86	1296	95091	166644	9601	550	3252
X	87	862	67683	145149	1785	471	920
X	88	2644	209679	74235	4066	1335	1973
X	89	1265	80021	84981	3906	1433	368
X	90	1509	92305	83309	13217	1147	439
X	91	1831	147231	165723	14741	1036	294
X	92	2135	155790	101624	5855	1178	489
Y	84	2143	190826	129969	6066	1354	6512
Y	85	2994	405115	144947	6938	2904	5305
Y	86	1309	123994	156367	6219	1117	4118
Y	87	1291	123309	206049	1909	1100	1562
Y	88	3852	445297	103676	2794	4436	4985
Y	89	1866	136871	103401	2412	1969	931
Y	90	3511	245761	129548	10983	2191	2185
Y	91	3491	266172	333008	8459	3235	1299
Y	92	3288	372876	150795	5237	3429	944
Z	82	3015	426628	26937	7783	2204	2720
Z	83	2334	139079	360297	14524	1088	2103
Z	84	2251	302164	199571	7451	2620	8488
Z	85	3866	682966	606454	7301	6698	10596
Z	86	2564	198388	752954	14723	3939	10171
Z	87	2665	197605	1045912	3850	1854	4427
Z	88	5345	785469	242129	5483	13598	8221
Z	89	2999	262173	403236	5920	6932	1944
Z	90	3671	307817	527712	16874	5888	2346
Z	91	3407	397444	783711	7671	7825	1686
Z	92	2832	354884	473286	5555	7449	1638
Combined	82	7638	1038715	59594	18907	5912	6345
Combined	83	5113	326148	756298	32185	2570	4204
Combined	84	7156	672455	535839	28818	5357	22285
Combined	85	12510	1806124	1123732	55677	13003	26249
Combined	86	6101	473167	1200226	39206	5965	19001
Combined	87	5803	459388	1607421	12774	3978	7852
Combined	88	14279	1614303	486800	19912	20310	16769
Combined	89	7570	587470	667806	21550	11081	3516
Combined	90	10146	778229	797144	47573	9825	5635
Combined	91	10921	1042746	1434054	46193	13466	3875
Combined	92	11291	1207579	853258	24538	12909	4113

Table 2.2. Hail catch and effort data for the Area 4 seine fishery. Effort figures represent the number of boat·days of fishing activity (Source: DFO records).

Sub-Area	Year	Effort	Sockeye	Pink	Coho	Chinook	Steelhead
W	82	581	253686	69976	12500	2014	602
W	84	464	217490	408760	6558	2514	3635
W	85	388	190687	378853	6415	2998	1138
W	86	54	14699	266948	6186	986	376
W	87	96	22892	248280	1342	823	267
W	88	115	63105	76976	735	455	491
W	89	4	840	30720	0	0	0
W	90	31	4538	51335	1261	143	9
W	91	15	3641	65930	23	3	0
W	92	128	63428	253005	2143	509	31
X	82	360	173989	38848	7474	1318	315
X	84	250	96700	85200	3160	1446	1246
X	85	431	209505	343157	6346	4631	1504
X	86	40	8969	103937	3049	195	231
X	87	119	27865	165119	1349	912	197
X	88	104	56899	65562	606	565	562
X	89	32	5514	241291	247	16	12
X	90	17	1352	26966	555	56	10
X	91	31	6036	139829	755	53	0
X	92	69	28356	112438	82	5	32
Y	89	41	935	116686	32	2	1
Y	90	12	1473	28951	0	0	0
Y	91	132	35602	644830	0	35	0
Combined	82	941	427675	108824	19974	3332	917
Combined	84	714	314190	493960	9718	3960	4881
Combined	85	819	400191	722009	12761	7628	2642
Combined	86	94	23668	370885	9235	1181	607
Combined	87	215	50757	413399	2691	1735	464
Combined	88	219	120004	142538	1341	1020	1053
Combined	89	77	7289	388697	279	18	13
Combined	90	60	7363	107252	1816	199	19
Combined	91	178	45279	850589	778	91	0
Combined	92	197	91784	365443	2225	514	63

Table 2.3. Commercial catch and effort in Area 4. Effort figures represent the number of boat-days of fishing for gill-net (GN) and seine (SN) vessels (Source: DFO records).

Gear	Year	Effort	Sockeye	Pink	Coho	Chinook	Steelhead
GN + SN	82	8579	1466390	168418	38881	9244	7262
GN + SN	83	5113	326148	756298	32185	2570	4204
GN + SN	84	7870	986645	1029799	38536	9317	27166
GN + SN	85	13329	2206315	1845741	68438	20631	28891
GN + SN	86	6195	496835	1571111	48441	7146	19608
GN + SN	87	6018	510145	2020820	15465	5713	8316
GN + SN	88	14498	1734307	629338	21253	21330	17822
GN + SN	89	7647	594759	1056503	21829	11099	3529
GN + SN	90	10206	785592	904396	49389	10024	5654
GN + SN	91	11099	1088025	2284643	46971	13557	3875
GN + SN	92	11488	1299363	1218701	26763	13423	4176

Table 2.4. Area 4 catch and effort as a percent of annual catches and the number of boat-days of fishing activity in the year (Source: DFO hail records).

Gear	Year	Effort	Sockeye	Pink	Coho	Chinook	Steelhead
Gill-net	82	89.0	70.8	35.4	48.6	63.9	87.4
Gill-net	83	100.0	100.0	100.0	100.0	100.0	100.0
Gill-net	84	90.9	68.2	52.0	74.8	57.5	82.0
Gill-net	85	93.9	81.9	60.9	81.3	63.0	90.9
Gill-net	86	98.5	95.2	76.4	80.9	83.5	96.9
Gill-net	87	96.4	90.0	79.5	82.6	69.6	94.4
Gill-net	88	98.5	93.1	77.3	93.7	95.2	94.1
Gill-net	89	99.0	98.8	63.2	98.7	99.8	99.6
Gill-net	90	99.4	99.1	88.1	96.3	98.0	99.7
Gill-net	91	98.4	95.8	62.8	98.3	99.3	100.0
Gill-net	92	98.3	92.9	70.0	91.7	96.2	98.5
Seine	82	11.0	29.2	64.6	51.4	36.0	12.6
Seine	83	0.0	0.0	0.0	0.0	0.0	0.0
Seine	84	9.1	31.8	48.0	25.2	42.5	18.0
Seine	85	6.1	18.1	39.1	18.7	37.0	9.1
Seine	86	1.5	4.8	23.6	19.1	16.5	3.1
Seine	87	3.6	9.9	20.5	17.4	30.4	5.6
Seine	88	1.5	6.9	22.7	6.3	4.8	5.9
Seine	89	1.0	1.2	36.9	1.3	0.2	0.4
Seine	90	0.6	0.9	11.9	3.7	2.0	0.3
Seine	91	1.6	4.2	37.2	1.7	0.7	0.0
Seine	92	1.7	7.1	30.0	8.3	3.8	1.5

Table 2.5. Distribution of seine effort (boat·days) in Area 4 by year, sub-area, and statistical week (Source: DFO hail survey records).

Year 19_	Sub-area	6-4	7-1	7-2	7-3	7-4	7-5	8-1	8-2	8-3	8-4	9-1	9-2	Total
82	W				123	88	53							264
83	W													0
84	W					118	120							238
85	W					66	31		18					115
86	W						23			9	6			38
87	W					32			9	11				52
88	W				25	52	8	30						115
89	W							2	2					4
90	W							14	9					23
91	W							6	5					11
92	W					8	20	15	10					53
	$\bar{x}$ =				74	61	43	13	9	10	6			83
82	X				68	112								180
83	X													0
84	X					90	30							120
85	X					87	45		17					149
86	X						9			3	2			14
87	X					40			25	13				78
88	X				12	20	19	53						104
89	X							5	10					15
90	X							9	2		1	1		13
91	X							4	10	3				17
92	X					1	14	11	6					32
	$\bar{x}$ =				40	58	23	16	12	6	2	1		66
82	Y													0
83	Y													0
84	Y													0
85	Y													0
86	Y													0
87	Y													0
88	Y													0
89	Y									14	5			19
90	Y									12				12
91	Y							46	60					106
92	Y													0
	$\bar{x}$ =							46	60	13	5			12

Table 2.6. Distribution of gill-net effort (boat·days) in Area 4 by year, sub-area, and statistical week.

Year 19_	Sub-area	6-4	7-1	7-2	7-3	7-4	7-5	8-1	8-2	8-3	8-4	9-1	9-2	Total
82	W		144	144	140	116	72							616
83	W			115	112	110	92	78	78	32				617
84	W			47	175	176	130	88	53					669
85	W		97	163	165	204	105	111	131	49				1025
86	W			97	102	81	87	71	45	31	18	22		554
87	W			72	76	102	87	73	44	58				512
88	W	67	116	149	275	275	73	100	87	40				1182
89	W	46	73	212	167	29	27	41	28	7				630
90	W	44	86	81	112	175	79	68	44	13				702
91	W		58	127	189	154	167	60	43	38	4			840
92	W		81	162	225	199	188	122	48	31				1056
	$\bar{x}$ =	52	94	124	158	147	101	81	60	33	11	22		764
82	X		262	267	305	271	234							1339
83	X			209	196	307	208	100	100	57				1177
84	X			81	151	125	100	67	17					541
85	X		91	158	246	118	145	70	84	38				950
86	X			39	56	175	130	71	40	40	27	19		597
87	X			50	80	100	115	90	15	25				475
88	X	200	215	149	185	140	150	260	44	31				1374
89	X	68	186	104	187	42	33	27	33	3				683
90	X	78	36	50	89	150	168	81	20	10	4	11		697
91	X		78	36	50	89	150	168	81	20	10	4	11	697
92	X		73	87	112	172	165	94	65	29				797
	$\bar{x}$ =	115	134	112	151	154	145	103	50	28	14	11	11	848
84	Y			54	175	200	140	153	58					780
85	Y		128	250	224	200	143	149	63	30				1187
86	Y			67	90	174	138	89	42	30	26	7		663
87	Y			62	221	202	128	70	50	44	22			799
88	Y	263	210	205	230	195	346	180	101	34				1764
89	Y	65	169	176	192	84	19	78	49	17	17			866
90	Y	181	184	156	196	298	403	159	51	24	13	10	16	1691
91	Y		207	256	276	238	200	48	74	34	25			1358
92	Y		127	196	320	181	250	140	55	51	66			1386
	$\bar{x}$ =	170	171	158	214	197	196	118	60	33	28	9	16	1166
82	Z		158	167	274	369	369							1337
83	Z			119	302	174	195	148	148	133				1219
84	Z			97	153	238	138	196	124					946
85	Z		44	55	159	257	218	190	190	112				1225
86	Z			66	140	200	179	182	140	107	100	37		1151
87	Z			91	47	181	234	213	155	175	103			1199
88	Z	120	162	214	348	240	260	315	270	200				2129
89	Z	171	215	253	359	104	39	143	132	33	30			1479
90	Z	89	146	169	279	300	245	288	164	56	30	11	13	1790
91	Z		56	139	189	275	205	161	106	77	28			1236
92	Z		35	53	224	210	159	135	137	126	42			1121
	$\bar{x}$ =	127	117	129	225	232	204	197	157	113	56	24	13	1348

Table 2.7. Average catch per boat-day for the Area 4 gill-net fleet (Source: DFO hail survey records).

Year	Sub-area	Sockeye	Pink	Coho	Chinook	Steelhead
1982	W	128	7	2	1	1
1983	W	64	145	6	1	1
1984	W	61	96	6	0	3
1985	W	129	85	9	0	2
1986	W	60	133	9	0	2
1987	W	72	214	5	1	1
1988	W	71	27	3	0	1
1989	W	75	53	6	1	0
1990	W	91	39	4	0	0
1991	W	106	69	7	1	0
1992	W	107	42	3	0	0
1982	X	134	7	2	1	1
1983	X	69	141	6	1	1
1984	X	70	47	5	1	3
1985	X	125	44	5	1	2
1986	X	73	129	7	0	3
1987	X	79	168	2	1	1
1988	X	79	28	2	1	1
1989	X	63	67	3	1	0
1990	X	61	55	9	1	0
1991	X	80	91	8	1	0
1992	X	73	48	3	1	0
1984	Y	89	61	3	1	3
1985	Y	135	48	2	1	2
1986	Y	95	119	5	1	3
1987	Y	96	160	1	1	1
1988	Y	116	27	1	1	1
1989	Y	73	55	1	1	0
1990	Y	70	37	3	1	1
1991	Y	76	95	2	1	0
1992	Y	113	46	2	1	0
1982	Z	142	9	3	1	1
1983	Z	60	154	6	0	1
1984	Z	134	89	3	1	4
1985	Z	177	157	2	2	3
1986	Z	77	294	6	2	4
1987	Z	74	392	1	1	2
1988	Z	147	45	1	3	2
1989	Z	87	134	2	2	1
1990	Z	84	144	5	2	1
1991	Z	117	230	2	2	0
1992	Z	125	167	2	3	1
1982	Combined	136	8	2	1	1
1983	Combined	64	148	6	1	1
1984	Combined	94	75	4	1	3
1985	Combined	144	90	4	1	2
1986	Combined	78	197	6	1	3
1987	Combined	79	277	2	1	1
1988	Combined	113	34	1	1	1
1989	Combined	78	88	3	1	0
1990	Combined	77	79	5	1	1
1991	Combined	95	131	4	1	0
1992	Combined	107	76	2	1	0

Table 2.8. Average catch per boat·day in the Area 4 seine fleet (Source: DFO hail survey records).

Year	Sub-area	Sockeye	Pink	Coho	Chinook	Steelhead
1982	W	437	120	22	3	1
1984	W	469	881	14	5	8
1985	W	491	976	17	8	3
1986	W	272	4936	114	18	7
1987	W	238	2586	14	9	3
1988	W	549	669	6	4	4
1989	W	210	7680	0	0	0
1990	W	146	1656	41	5	0
1991	W	243	4395	2	0	0
1992	W	496	1977	17	4	0
1982	X	483	108	21	4	1
1984	X	387	341	13	6	5
1985	X	486	796	15	11	3
1986	X	225	2604	76	5	6
1987	X	234	1388	11	8	2
1988	X	547	630	6	5	5
1989	X	172	7540	8	1	0
1990	X	80	1586	33	3	1
1991	X	195	4511	24	2	0
1992	X	411	1630	1	0	0
1989	Y	23	2846	1	0	0
1990	Y	123	2413	0	0	0
1991	Y	270	4885	0	0	0
1982	Combined	454	116	21	4	1
1984	Combined	440	692	14	6	7
1985	Combined	489	882	16	9	3
1986	Combined	252	3946	98	13	6
1987	Combined	236	1923	13	8	2
1988	Combined	548	651	6	5	5
1989	Combined	95	5048	4	0	0
1990	Combined	123	1788	30	3	0
1991	Combined	254	4779	4	1	0
1992	Combined	466	1855	11	3	0

Table 2.9. Average CPUE for Area 4 during 1990-92 based on gear, sub-area, and species. The last column label indicates the mean steelhead:sockeye catch ratio (Source: Unpublished DFO hail records).

Gear type	Sub-Area	Boat days monitored	Sockeye	Pink	Coho	Chinook	Steelhead	St:Sk
Gill-net	W	2228	101.2	50.0	4.7	0.4	0.4	0.0036
Gill-net	X	1825	71.5	64.4	6.5	0.6	0.2	0.0033
Gill-net	Y	3430	86.6	59.4	2.4	0.9	0.4	0.0054
Gill-net	Z	3303						
Seine	W	99	294.9	2676.0	19.6	2.9	0.2	0.0008
Seine	X	39	228.4	2575.5	19.4	1.7	0.3	0.0028
Seine	Y	48	130.8	2432.6	0.0	0.1	0.00	0.0000

Table 2.10. Estimates of coho, steelhead and sockeye harvest rates based on run-timing patterns and sockeye harvest rates (adapted from Ward et al. 1993).

	Sockeye	Steelhead		Coho		Sockeye	
Week	H.R.	Run[1]	H.R.[2]	Run[1]	H.R.[2]	Run[1]	H.R.[2]
6-2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6-3	0.00	0.00	0.00	0.00	0.00	0.01	0.00
6-4	0.16	0.00	0.00	0.00	0.00	0.02	0.00
7-1	0.23	0.00	0.00	0.00	0.00	0.04	0.01
7-2	0.37	0.02	0.01	0.00	0.00	0.11	0.04
7-3	0.38	0.06	0.02	0.01	0.01	0.20	0.08
7-4	0.52	0.14	0.07	0.05	0.03	0.22	0.11
7-5	0.47	0.23	0.11	0.13	0.06	0.18	0.08
8-1	0.37	0.25	0.09	0.22	0.08	0.12	0.04
8-2	0.30	0.18	0.05	0.25	0.08	0.07	0.02
8-3	0.16	0.09	0.01	0.19	0.03	0.03	0.00
8-4	0.01	0.03	0.00	0.10	0.00	0.01	0.00
9-1	0.00	0.01	0.00	0.04	0.00	0.00	0.00
9-2	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Total			0.37		0.28		0.40

1. Proportion of run occurring in each statistical week.
2. Fraction of total harvest by week (sockeye harvest rate x fraction of total run)

Table 2.11. Steelhead and coho escapements as estimated by methods 1-2 (see section 2.3), and by Kadowaki et al. (1992) based on modified test fishery indices for sockeye (last column).

Year	Steelhead	Coho	Sockeye
1982	25870	27701	33916
1983	9741	70320	33650
1984	43249	39427	38542
1985	35744	42649	24592
1986	34463	41786	27530
1987	31942	36684	16133
1988	47951	17314	12690
1989	23032	36947	42864
1990	28217	48910	41317
1991	13401	38824	30060
1992	24291	27794	n/a

Table 2.12. Contributions (%) of Skeena River stocks to total escapements. The categories L.Skeena and M.Skeena account for various streams in the lower and middle sections of Skeena River.

		Sustut	Bulkley		Kispiox	Zymoetz	Babine	Morice
Steelhead		10	35		10	10	25	10
	Coastal	Lakelse	L. Skeena	Kitsumkalum	Kispiox	M. Skeena	Babine	Morice
Coho	13	26	16	12	11	7	9	6
	Coastal	Bear	L. Skeena	Kitsumkalum	Kispiox	Skeena	Babine	Morice
Chinook	7	26	2	33	7	4	3	20

Table 3.1. Steelhead commercial catch statistics for fisheries in the northern boundary area. Canadian statistics are from the DFO sale slips database. Districts 101-104 catch statistics consist of sale records, and represent minimum catch estimates (source: Doug Jones, ADF&G).

B.C.	Area 1-2	Area 3			Area 4			Area 5	Total
Year		X, Y	Z	Total	Seine	Gill-net	Total		
1982	392	1946	1502	3448	956	11420	12376	239	16455
1983	425	2948	1219	4167	0	4704	4704	168	9464
1984	474	4618	1484	6102	2067	19356	21423	817	28816
1985	1754	1350	4488	5838	1765	23584	25349	968	33909
1986	600	2789	2048	4837	204	18803	19007	1365	25809
1987	612	1280	798	2078	209	7935	8144	609	11443
1988	377	1651	110	1761	503	12940	13443	261	15842
1989	347	1199	93	1292	109	3095	3204	176	5019
1990	374	894	24	918	41	6661	6702	202	8196
1991	228	1489	362	1851	70	3188	3258	137	5474
1992	250	785	546	1331	108	1459	1567	66	3214
$\bar{x}$ =	530	1904	1152	3057	548	10286	10834	455	14876
% Total	4	13	8	21	4	69	73	3	100

Alaska	Districts				Alaska	BC+AK	Alaska	Area 3	Area 4
Year	101	102	103	104	Total	Total	(%)	(%)	(%)
1982	787	8	1	330	1126	17581	6	20	70
1983	1582	24	11	1847	3464	12928	27	32	36
1984	2061	93	7	2042	4203	33019	13	18	65
1985	5156	0	19	1379	6554	40463	16	14	63
1986	4339	193	21	5180	9733	35542	27	14	53
1987	2359	25	5	319	2708	14151	19	15	58
1988	1517	38	13	1625	3193	19035	17	9	71
1989	1474	8	5	788	2275	7294	31	18	44
1990	942	20	17	776	1755	9951	18	9	67
1991	716	11	5	351	1083	6557	17	28	50
1992	2392	21	0	1147	3560	6774	53	20	23
$\bar{x}$ =	2120	40	9	1435	3605	18481	22	18	55
% Total	59	1	0	40	100				

Table 4.1. Minimum detectable difference in estimated steelhead catch for week 8-1 data when variances are assumed equal (top), or assumed to be 37% different to reflect a 50% difference in mean catch (bottom).

Sample Size	Variance of mean CPUE	Variance CPUE	Pooled Variances	Critical *t*-values α = 0.05	Critical *t*-values α = 0.10	Minimum detectable difference	Difference as % of the mean
5	0.880	0.276	1.379	2.776	1.533	3.200	364
10	0.867	0.114	1.141	2.262	1.383	1.741	201
20	0.907	0.065	1.296	2.093	1.328	1.232	136
30	0.871	0.033	0.984	2.045	1.311	0.860	99
40	0.850	0.027	1.068	2.023	1.304	0.769	90
50	0.852	0.015	0.755	2.010	1.299	0.575	67
60	0.853	0.010	0.624	2.000	1.296	0.475	56
70	0.851	0.007	0.516	1.995	1.294	0.399	47
80	0.856	0.005	0.362	1.991	1.292	0.312	37
90	0.849	0.005	0.450	1.987	1.291	0.328	39
100	0.857	0.004	0.400	1.984	1.290	0.293	34
110	0.850	0.003	0.330	1.982	1.289	0.253	30
120	0.848	0.003	0.360	1.980	1.289	0.253	30

5	0.889	0.276	1.123	2.776	2.132	3.290	370
10	0.886	0.114	0.930	2.262	1.833	1.766	199
20	0.885	0.065	1.056	2.093	1.729	1.242	140
30	0.863	0.033	0.802	2.045	1.699	0.866	100
40	0.849	0.027	0.870	2.023	1.685	0.774	91
50	0.846	0.015	0.615	2.010	1.677	0.578	68
60	0.851	0.010	0.509	2.000	1.672	0.478	56
70	0.856	0.007	0.420	1.995	1.668	0.401	47
80	0.860	0.005	0.295	1.991	1.665	0.314	37
90	0.849	0.005	0.367	1.987	1.291	0.296	35
100	0.857	0.004	0.326	1.984	1.290	0.264	31
110	0.850	0.003	0.269	1.982	1.289	0.229	27
120	0.848	0.003	0.293	1.980	1.289	0.229	27

Table 4.2. Daily steelhead catch for standard and modified gill-nets (V. Lewynsky unpubl. data). S.D. = standard deviation, C.V. = coefficient of variation.

Gear	Net type	Sample size	Mean	S.D.	C.V.
multi-60	standard	15	1.60	0.755	0.47
	modified	15	1.00	0.625	0.63
mono-60	standard	15	1.20	0.705	0.59
	modified	14	0.93	0.526	0.57
mono-90	standard	15	2.27	0.816	0.36
	modified	14	0.57	0.486	0.85

Table 4.3. Minimum detectable difference in mean steelhead catch for modified and standard gill-nets as a function of daily monitoring effort (left). Effects of sampling period and daily sample size on total sample size for paired design (right).

Boats monitored	$\delta/\bar{x}$ (%)	Boats monitored	$\delta/\bar{x}$ (%)	Boats per day	Monitoring Period 1 week	2 weeks	3 weeks	4 weeks
0	-	60	56	5	10	20	30	40
5	370	70	47	10	20	40	60	80
10	199	80	37	20	40	80	120	
20	140	90	35	30	60	120		
30	100	100	31	40	80			
40	91	110	27	50	100			
50	68	120	27	60	120			

Table 5.1. Outcome of chinook radio-tagging programs conducted in the Nass and Taku rivers in 1989, 1992, and 1993.

	Nass River[1]		Taku River[2]
Variable	1992	1993	1989
Number of fish tagged	360	350	429
Attrition due to mortality regurgitation and emigration	32	10	47
Number of fish lost for other reasons	5	9	6
Number of fish caught in fisheries	32	95	21
Number of fish tracked to destination	291	236	355
Percent of tagged group tracked to destination	81	67	83
Terminal harvest rate[3]	9	27	5

1. Koski et al. 1993 Koski et al. 1994
2. Eiler et al. 1990
3. From commercial fishery on the Taku and native and sport fisheries on the Nass.

Table 5.2. Estimated escapement and harvest of Skeena River coho, 1982-91 (Kadowaki et al. 1992).

Year	Estimated spawners	Native harvest	Sport harvest	Terminal run size	Harvest rate (%)
1982	33916	2400	1000	37316	9.1
1983	33650	2550	1000	37200	9.5
1984	38542	2480	1000	42022	8.3
1985	24592	1060	1000	26652	7.7
1986	27530	2060	1000	30590	10.0
1987	16133	1820	1000	18953	14.9
1988	12690	263	1000	13953	9.1
1989	42864	650	1000	44514	3.7
1990	41317	2021	1000	44338	6.8
1991	30060	1363	1000	32423	7.3
$\bar{x}$ =	30129	1667	1000	32796	8.1

Table 5.3. Predicted mean daily seine catch of Skeena River coho and steelhead in Area 4Y. All figures based on historical catch records adjusted for non-Skeena stock components, and hypothesized under-reporting.

	Steelhead			Coho		
Statistical Week	Area 4X gill-net CPUE index	Area 4X seine $CPUE_1$ index	Predicted Area 4Z seine $CPUE_2$	Area 4X gill-net CPUE index	Area 4X seine $CPUE_3$ index	Predicted Area 4Z seine $CPUE_4$
7-1	0.37	0.74	1.48			
7-2	0.37	0.74	1.47			
7-3	0.66	0.67	1.34			
7-4	0.80	1.98	3.96	4.23	12.69	6.35
7-5	1.52	6.85	13.71	5.21	17.91	8.96
8-1	1.33	3.33	6.66	6.70	10.36	5.18
8-2	1.91	1.95	3.90	7.78	9.18	4.59
8-3	2.01	1.08	2.15	8.76	36.85	18.42
8-4	2.32	4.67	9.34	16.39	43.85	21.92
9-1	0.76	1.54	3.07	22.60	60.44	30.22
9-2				16.39	43.83	21.92
9-3				8.76	23.43	11.71
9-4				7.78	20.81	10.40

1. CPUE values for weeks 7-1 7-2 8-4 9-1 based on gill-net to seine ratio for weeks 7-3 to 8-3.
2. Assumed a 50% under-reporting bias for Area 4X.
3. CPUE values for weeks 8-4 to 9-4 based on gill-net to seine ratio for weeks 7-4 to 8-3.
4. Assumed that 50% of the Area 4X catch is from non-Skeena stocks.

Table 5.4. Time of spawning of coho salmon in the Skeena River watershed (from Jantz et al. 1989).

Skeena River regions	Start	Peak	End
Coastal	Late Sep.	End Oct. - Late Oct.	Late Nov.
Lakelse	End Oct.	Mid Oct. - Late Nov.	End Dec.
Kitsumkalum	Late Sep.	Mid Oct. - Late Nov.	End Dec.
Other Lower Skeena	Late Sep.	End Oct. - Late Nov.	End Dec.
Kispiox	Mid Sept.	End Oct. - End Nov.	Late Nov.
Bulkley/Morice	Late Aug.	Mid Sep. - Mid Nov.	Late Jan.
Other Mid-Skeena	Late Sep.	End Oct. - Mid Nov.	End Dec.
Babine	Mid Aug.	Mid Sep. - End Nov.	End Dec.
Bear	Late Aug.	Mid Sep. - Late Nov.	End Dec.

Table 5.5. Predicted radio-tag returns for steelhead (top) and coho (bottom) in the major Skeena River areas.

		Predicted tag escapement							
Tags applied	% Tracked to tributary	Bulkley	Morice	Kispiox	Babine	Sustut	Zymoetz		
150	50%	26	19	8	8	8	8		
200	50%	35	25	10	10	10	10		
250	50%	44	31	13	13	13	13		
300	50%	53	38	15	15	15	15		
350	50%	61	44	18	18	18	18		
400	50%	70	50	20	20	20	20		
450	50%	79	56	23	23	23	23		
500	50%	88	63	25	25	25	25		
		Coastal[1]	Lakelse	Kitsumkalum	Lower Skeena	Kispiox[2]	Bulkley/ Morice[2]	Middle Skeena[2]	Babine[2]
150	30%	6	12	6	7	5	3	3	4
200	30%	8	15	7	9	7	4	4	6
250	30%	10	20	9	12	8	4	5	7
300	30%	12	23	11	14	10	6	6	8
350	30%	14	27	13	17	12	6	7	10
400	30%	16	31	14	19	13	7	8	11
450	30%	18	35	16	22	15	8	10	12
500	30%	20	39	18	24	16	9	10	14

1. Mostly Ecstall River stock (96%).
2. Tag returns would increase in these Upper Skeena stocks if most of the tags applied in August.

Table 6.1. Hypothetical escapement data set used for model testing. Figures in bold are known parameter values from field surveys. Estimates in the top and lower sections were obtained by minimizing Eq. 10 and 11 respectively. See text for label description.

Stream number (i)	Stream category	Actual escap. (e_i)	Radio-tag detected (z_i)	Actual tagged (p)	Actual. contr. (q_i)	Estimated escap. ($\hat{e}_i$)	Estimated tagged ($\hat{z}_i$)	Estimated contr. ($\hat{q}_i$)
1	target	10	**2**	0.2	6.7	7.60	26.3	5.1
2	target	30	**6**	0.2	20.0	23.80	25.2	15.9
3	target	50	**10**	0.2	33.3	57.50	17.4	38.3
4	indicator	**60**	**12**	**0.2**	40.0	-	-	-
Total[1]		150	**30**			148.90		
1	target	10	**2**	0.2	6.7	9.99	20.0	6.7
2	target	30	**6**	0.2	20.0	29.98	20.0	20.0
3	target	50	**10**	0.2	33.3	49.97	20.0	33.3
4	indicator	**60**	**12**	**0.2**	40.0	-	-	-
Total[1]		150	**30**			149.96		

1. Total includes the known escapement to the indicator stream.

Table 6.2. Hypothetical escapement data set used for model testing. Figures in bold are the known parameter values from field surveys. Streams 7-8 are indicators. All estimates were obtained by minimizing Eq. 11. See text for label description.

Stream number (i)	Tributary name	Actual escap.[2] (e_i)	Radio-tag detected (z_i)	Actual tagged (p)	Actual. contr. (q_i)	Estimated escap.[3] ($\hat{e}_i$)	Estimated tagged ($\hat{z}_i$)	Estimated contr. ($\hat{q}_i$)
1	Coastal	3934	**24**	0.61	12.8	3939	0.61	12.8
2	Lakelse	8033	**49**	0.61	26.1	8047	0.61	26.1
3	Kalum	3770	**23**	0.61	12.2	3770	0.61	12.2
4	L. Skeena	4918	**30**	0.61	16.0	4918	0.61	16.0
5	Kispiox	3443	**21**	0.61	11.1	3446	0.61	11.2
6	Bulkley	2131	**13**	0.61	6.9	2133	0.61	6.9
7	M.Skeena	**1803**	**11**	**0.61**	5.9	-	-	-
8	Babine	**2787**	**17**	**0.61**	9.0	-	-	-
Total[1]		30820	**188**			30843		

1. Total includes the known escapements to the indicator streams.
2. DFO estimates averaged over the 1980-88 period and adjusted so that the fraction tagged = 0.61.
3. Figures rounded to the nearest integer.

Table 6.3. Relative error of escapement estimates to target streams for given levels of error associated with the indicator stream escapements. Streams 7-8 are indicators. Figures in bold are the known parameter values from field surveys. All estimates were obtained by minimizing Eq. 11.

Stream number (i)	Tributary name	Actual escap.[1] (e_i)	Radio-tag detected (z_i)	Rel. error of $\hat{e}_i$ for e_7 + 10% e_8 + 10%	Rel. error of $\hat{e}_i$ for e_7 + 20% e_8 + 20%	Rel. error of $\hat{e}_i$ for e_7 - 20% e_8 - 20%	Rel. error of $\hat{e}_i$ for e_7 + 20% e_8 - 20%	Rel. error of $\hat{e}_i$ for e_7 + 0% e_8 - 20%
1	Coastal	3934	**24**	9.99	19.98	20.03	1.86	10.45
2	Lakelse	8033	**49**	10.00	19.98	20.02	1.59	10.27
3	Kalum	3770	**23**	10.00	20.00	20.00	1.88	10.45
4	L. Skeena	4918	**30**	9.96	19.99	20.01	1.83	10.43
5	Kispiox	3443	**21**	9.99	19.95	20.04	1.92	10.51
6	Bulkley	2131	**13**	10.00	19.99	20.04	1.97	10.56
7	M.Skeena	**1803 ±x**	**11**	-	-	-	-	-
8	Babine	**2787 ±x**	**17**	-	-	-	-	-
Total		30820	**188**					

1. DFO estimates averaged over 1980-88 and adjusted so tagged portions of 0.61.

Table 6.4. Relative error of escapement estimates to target streams for given levels of error associated with the tag recovery data. Streams 7-8 are indicators. Figures in bold are the known parameter values from field surveys. Estimates were obtained by minimizing Eq.11.

Stream number (i)	Tributary name	Actual escap.[1] (e_i)	Radio-tag detected (z_i)	Rel. error of $\hat{e}_i$ for z_1 to z_6 - 10%	Rel. error of $\hat{e}_i$ for z_1 to z_6 + 10%	Rel. error of $\hat{e}_i$ for $z_{1,3,5}$ -10% $z_{2,4,6}$ +10%	Rel. error of $\hat{e}_i$ for $z_{1,3,5}$ -30% $z_{2,4,6}$ +30%
1	Coastal	3934	**24 ± x**	8.31	8.34	8.31	33.35
2	Lakelse	8033	**49 ± x**	10.22	10.18	10.22	32.67
3	Kalum	3770	**23 ± x**	8.70	8.70	8.67	30.42
4	L. Skeena	4918	**30 ± x**	10.02	10.00	10.02	33.35
5	Kispiox	3443	**21 ± x**	0.03	9.47	9.53	33.31
6	Bulkley	2131	**13 ± x**	7.70	7.65	7.70	30.78
7	M.Skeena	**1803**	**11 ± x**	-	-	-	-
8	Babine	**2787**	**17 ± x**	-	-	-	-
Total		30820	**188**				

1. DFO estimates averaged over 1980-88 and adjusted so tagged portions of 0.61.

Table 7.1. Frequencies of mitochondrial DNA haplotypes "a" and "b" in steelhead from various Skeena River tributaries as detected by the restriction enzymes *Dpn*II and *Mnl*I (LGL 1994).

Tributary name	Sample size	Haplotype "a"	Haplotype "b"
Morice River	20	0.45	0.55
Morice River	20	0.20	0.80
Sustut River	19	0.47	0.53
Zymoetz River	21	0.00	1.00
Kispiox River	20	0.25	0.75

Table 7.2. Allelic frequencies for minisatellite loci *Ssa*1 and *T*34 in the five populations of steelhead from the Skeena River. Variation at each locus consists of data for six alleles; "O" represents all rare alleles with pooled frequency of < 5%.

Tributary/Year	Sample size	*Ssa*1 alleles A	B	C	E	F	O	*T*34 alleles O	D	E	F	J	G
Babine River 1992	18	.161	.482	.143	.089	.036	.079	.167	.210	.320	.240	.036	.027
Babine River 1993	28	.188	.520	.094	.031	.063	.094	.121	.200	.360	.270	.016	.030
Morice River 1992	30	.000	.750	.136	.068	.000	.045	.148	.114	.386	.193	.114	.045
Morice River 1993	23	.017	.803	.050	.050	.017	.063	.155	.110	.380	.200	.075	.080
Sustut River	19	.158	.421	.000	.026	.211	.184	.034	.184	.340	.130	.220	.092
Zymoetz River	24	.000	.687	.125	.146	.021	.021	.153	.251	.327	.231	.000	.038
Kispiox River	20	.000	.650	.050	.200	.000	.100	.068	.227	.341	.341	.000	.023

Table 7.3. Chi-square analysis of allelic differences among Skeena River tributaries (Hologene Genetic Technologies, 1994).

Locus	Number of alleles	Chi-square	*P*
Omy077	12	68.090	.01140
Omy038	25	156.925	.00009
Omy105	26	147.909	.00132
Omy105	24	110.224	.09473
Omy027	5	46.954	.00007
Total		530.101	.00000

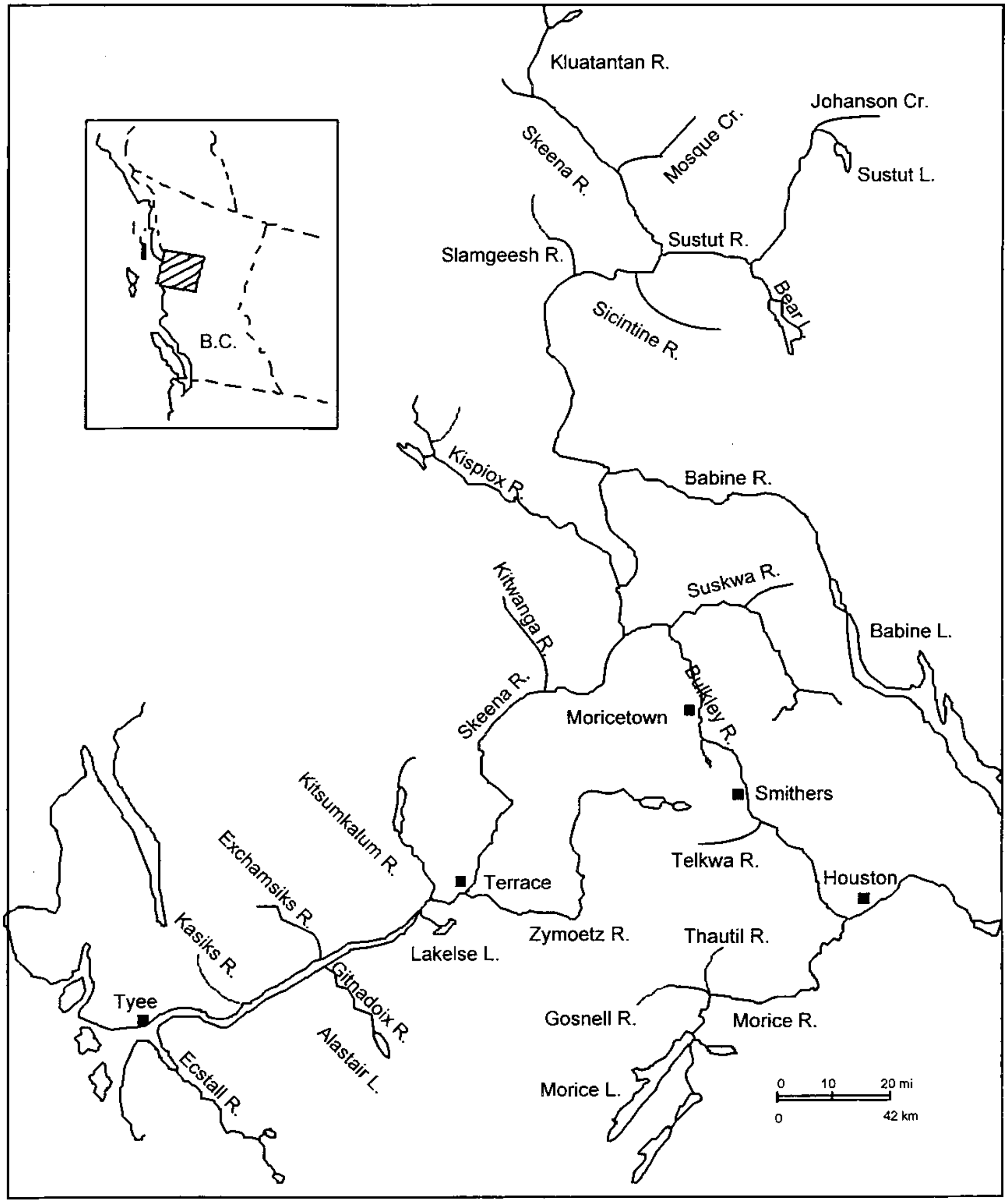

Figure 1.0. Map of the Skeena River watershed, showing major tributaries and towns.

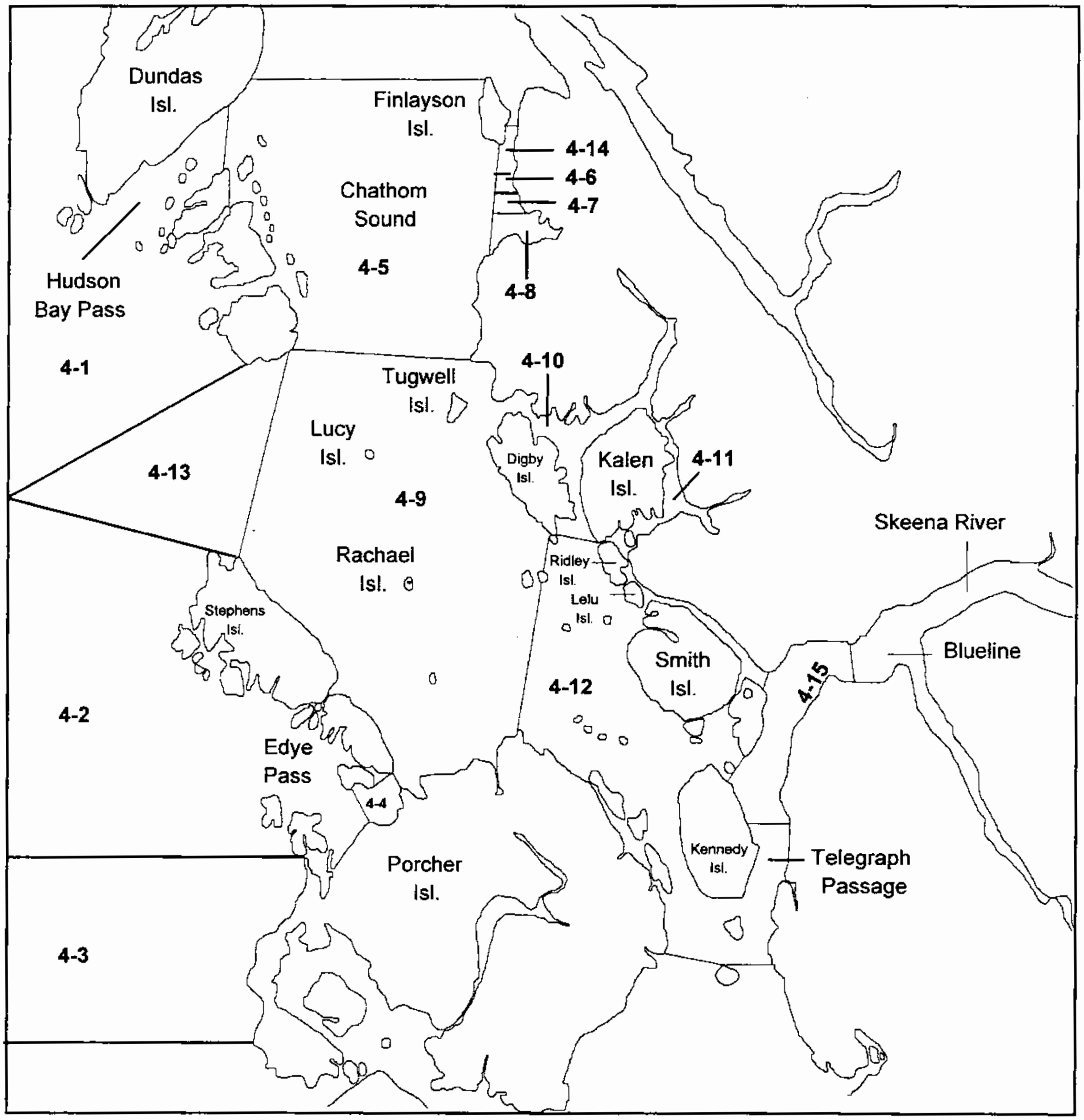

Figure 2.1. Major geographical features and management zones of Statistical Area 4 at the entrance to the Skeena River. Statistical Area 3 lies further to the south.

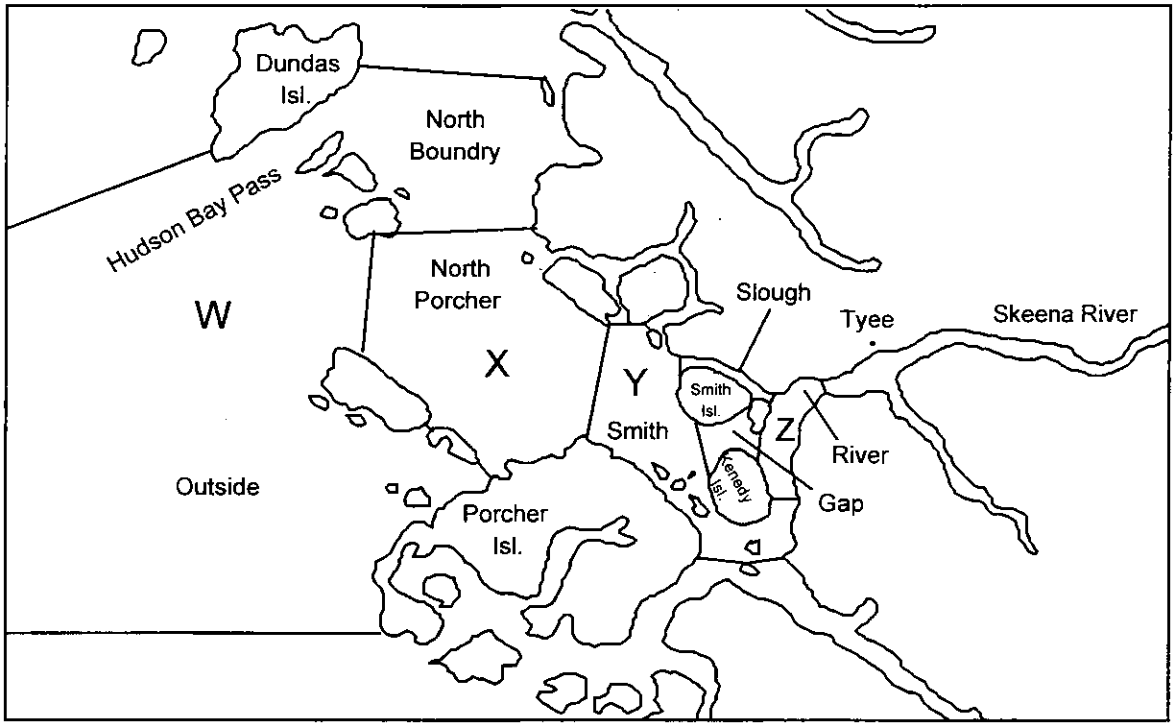

Figure 2.2. Boundaries of sub-areas for Statistical Area 4 near Prince Rupert, BC. The sub-area boundary labels W, X, Y, Z correspond to the DFO fishery management areas designated as Outside, Sound, Smith and River/Gap/Slough, respectively.

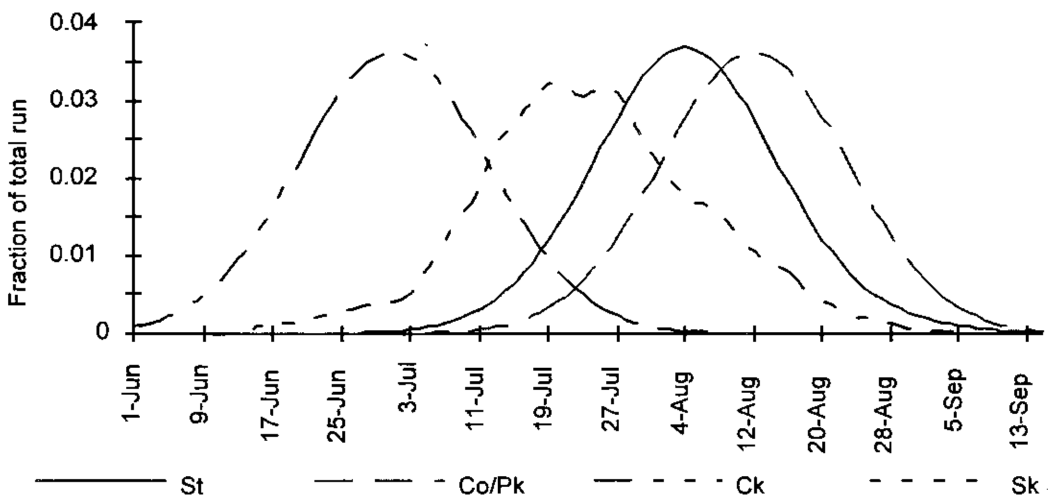

Figure 2.3. Average run timing as detected by the Tyee test fishery. The distributions were based on a composite of the reconstructed runs over 1980-90. The species and codes are steelhead (St), coho (Co), pink (Pk), chinook (Ck) and sockeye (Sk).

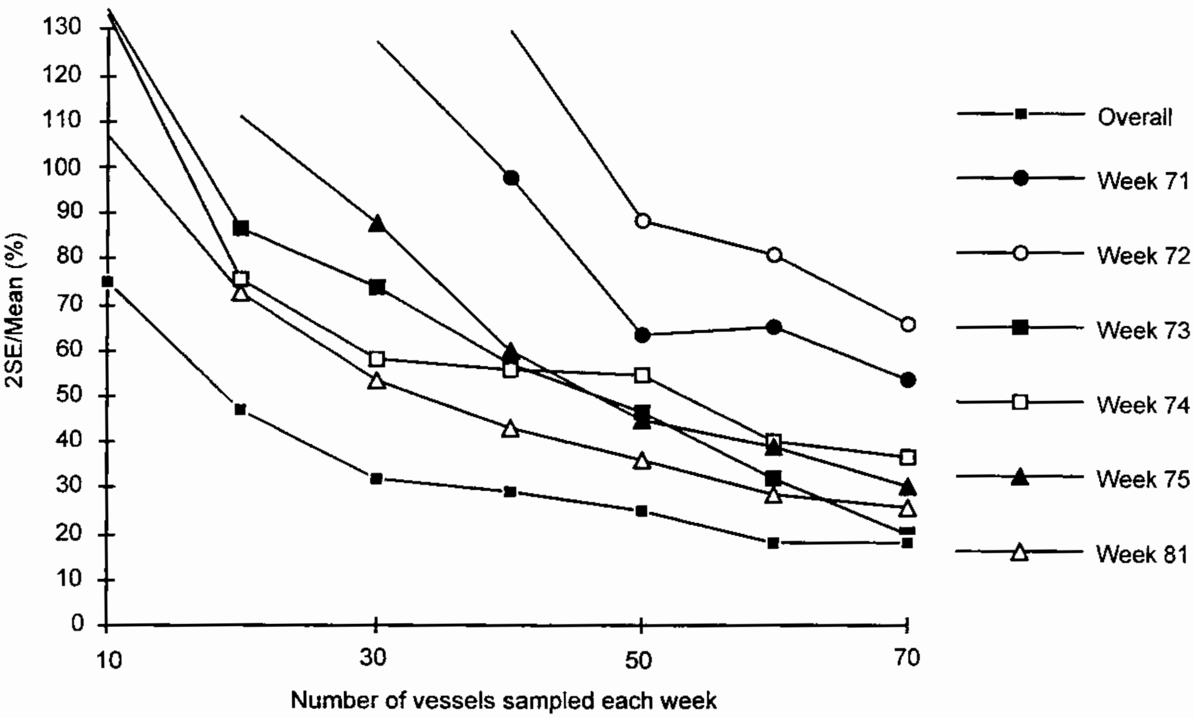

Figure 3.1. Sample size against the precision of steelhead catch estimates. The ordinate scale indicates half of the 95% confidence interval (CI) of the catch estimate (i.e. mean ± x%). Week 71 = month 7, week 1.

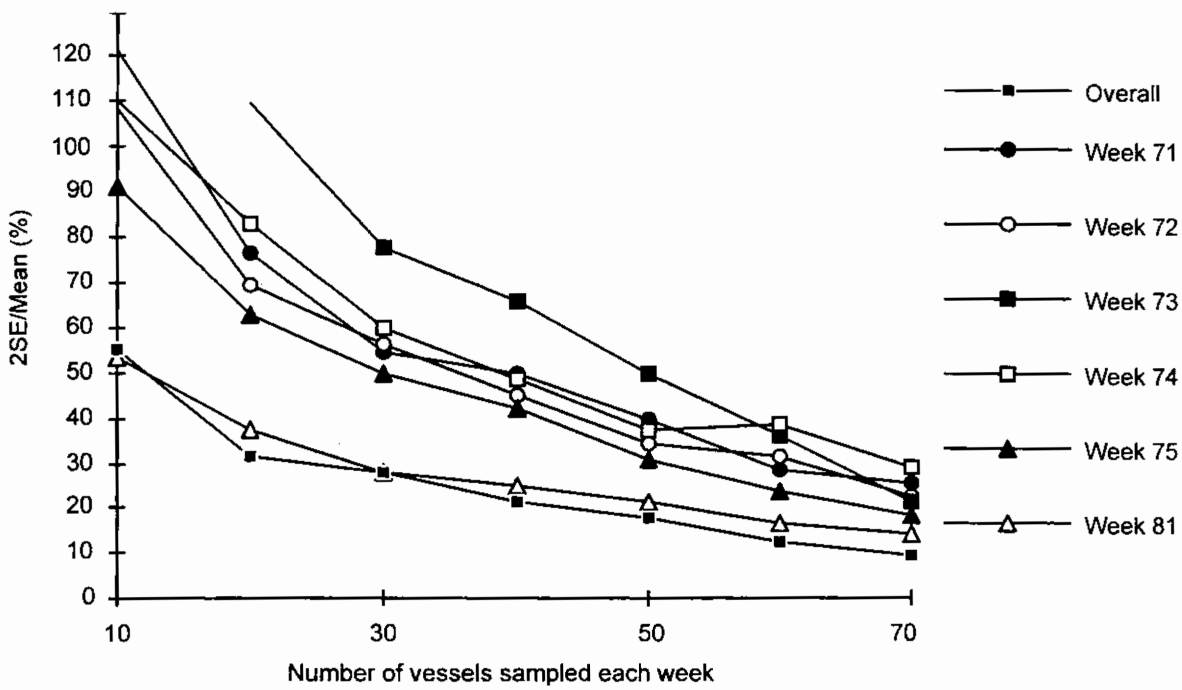

Figure 3.2. Sample size and the precision of coho catch estimates. The ordinate scale indicates half of the 95% confidence interval of the catch estimate (i.e. mean ± x%).

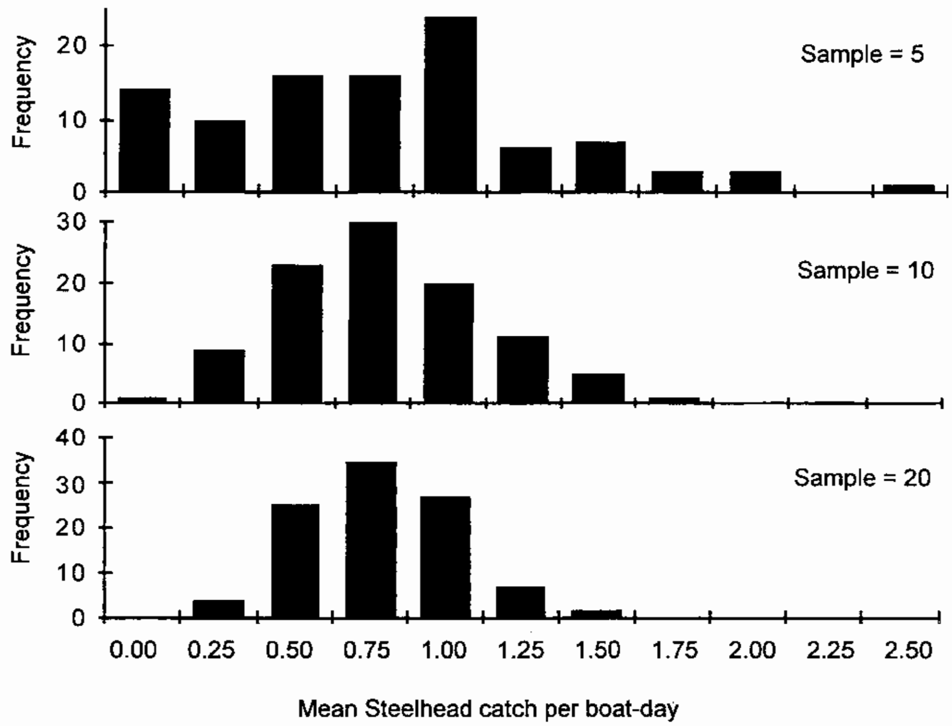

Figure 3.3. Distribution of mean steelhead catches per gill-net boat·day for week 8-1 in relation to the number of boats monitored.